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Working Group on Methods of Fish Stock Assessment

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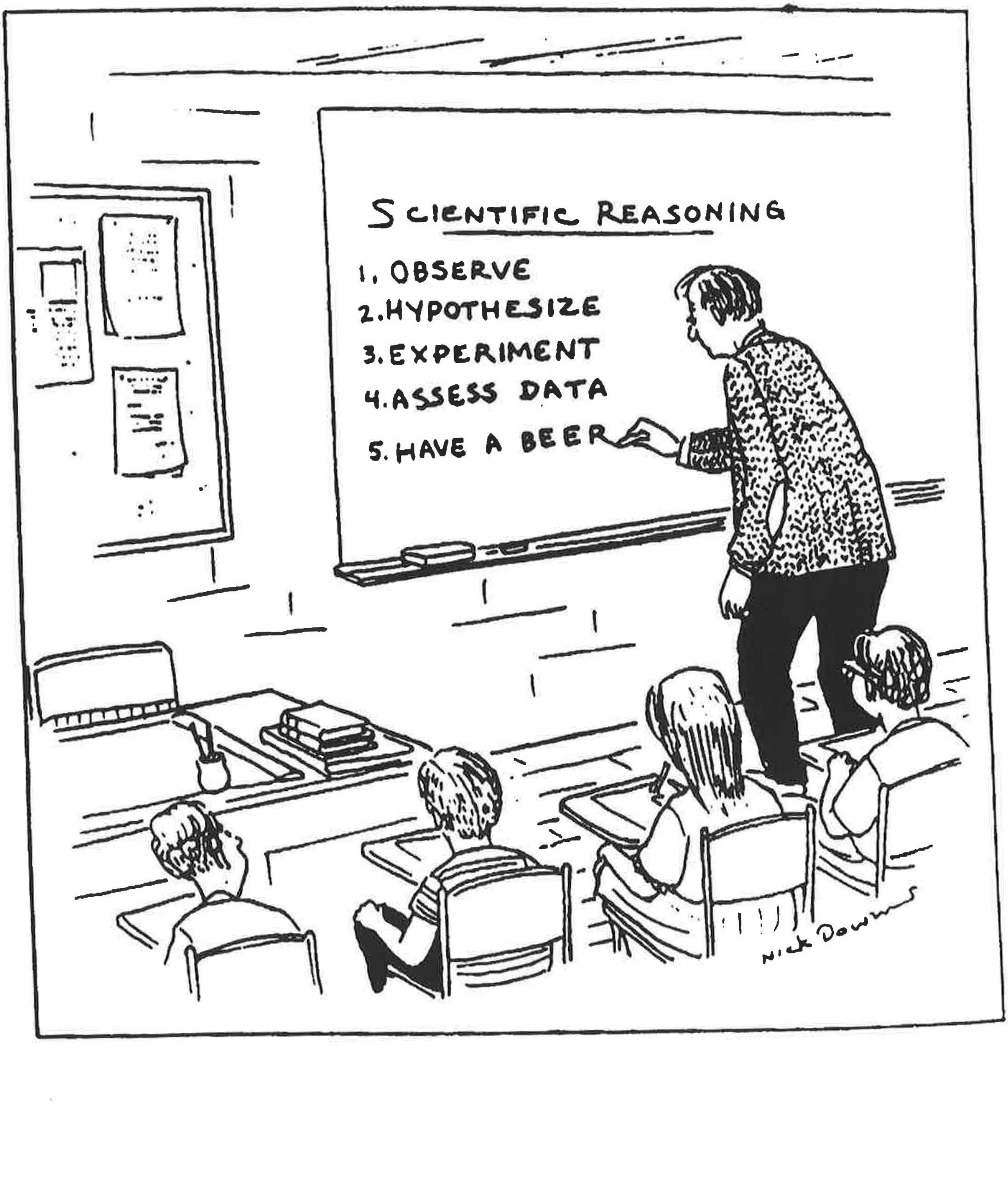

SCIENTIFIC REASONING
1. OBSERVE
2. HYPOTHESIZE
3. EXPERIMENT
4. ASSESS DATA
5. HAVE A BEER
Nick Downes

Working Group on Methods of Fish Stock Assessment - Reports of 1993 and 1995 Meetings

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Report of 1993 Meeting

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Report of the Working Group on Methods of Fish Stock Assessment, 1993

1 Short-lived species

1.1 Introduction

Examples of problems raised in this context did not all appear to be related to life-span *per se*, as some of the species mentioned (e.g., sandeels, sardine) were harvested over age ranges extending beyond 5 years of age. Rather, the essential difficulty seems to relate to the provision of the short-term projections required for management purposes. This is frustrated, either because of the large contribution which the recruitment of the forthcoming year will make to the biomass of a genuinely short-lived species, or because of evaluation difficulties which arise for longer-lived species because of inadequacy or absence of certain data (such as recruit surveys).

The first of these situations occurs typically in anchovy fisheries, where the stock consists of a few year classes only. Even if regular surveys take place, much of the annual catch can have been taken before projections can be adjusted to take account of the results of the most recent survey. This is, therefore, as much a management as an assessment problem. The Working Group considered examples of two such stocks — South African anchovy and Icelandic capelin — for which "management procedures" (see Section 4.4) have been adopted to address such problems. These examples are summarised briefly below, followed by a description of how this approach might be applied to the anchovy stock in ICES Sub-area VIII. Examples given in Anon. (1992a) show that uncertainties about the level of F, M and recruitment lead to a 1/4 to 2-fold uncertainty about the current size of this resource in relation to the most recent spawning stock biomass estimate by egg survey.

For the second set of situations, there are usually sufficient data in principle to perform a full age-structured (VPA) (Gulland, 1965) assessment, but this is unsatisfactory for a number of reasons. A number of alternative approaches, which may prove helpful in such circumstances, are discussed below.

1.2 Examples of "management procedures" for short-lived species

1.2.1 Management of the South African anchovy resource

The South African anchovy is a short-lived species, with only three age classes contributing to the spawning stock. The TACs for the fishery are set on the basis of hydro-acoustic survey estimates of spawning biomass and recruitment (Butterworth and Bergh, in press). A particular complication is that the bulk of the catch is taken from the recruits of the year, and much of this component of the catch may already have been landed by the time the recruitment survey estimate for the year becomes available.

TACs are set directly from the survey estimates by means of very simple formulae, which correspond roughly to a constant proportional harvesting strategy. The initial TAC set at the start of the season is based on the results of the spawning biomass survey, and assumes that the recruitment for the forthcoming year will be equal to its historic average level. However, only a proportion (some 70%) of this TAC may be taken before it is revised later in the season in the light of the result of the subsequent recruitment survey. This is to guard against the possibility of below average recruitment, which might otherwise result in the revised TACs desired falling below catch levels already achieved.

The control parameters of the harvesting strategy (e.g. the proportion of biomass to be harvested) are chosen on the basis of the results of simulations projecting the stock forward for a period of 20 years under the proposed strategy for setting TACs, and the associated survey programme which provides the estimates from which these TACs are calculated. These simulations are conditioned on a recent assessment of the resource, and take the imprecision of the estimates of population dynamics parameters into account. The control parameter value choices are based on a consideration of factors such as the anticipated average annual catch, the extent to which catches will vary from one year to the next, and the trade-offs between these and other measures of performance.

Essentially, the problem of catches being taken from the recruits of the year before a survey estimate of the recruitment strength becomes available, is addressed by consideration of the assessed distribution of historic recruitments; this allows the probability that the initial TAC is set higher than turns out to be appropriate to be kept low. TACs are also subject to constraints intended to facilitate the smooth operation of the industry; e.g. the maximum decrease in TAC allowed from one year to the next is 25%, with account being taken of such constraints in the 20-year projection calculations.

Naturally, the whole process of choosing this "management procedure" (see Section 4.4) relies on the assumption that the TACs indicated will be adopted and enforced each year. In general, simulation tests of management procedures need to include tests of actual catches exceeding the TACs if this is a problem.

1.2.2 Management of the fishery on capelin in the Iceland-Greenland-Jan Mayen area

The capelin stock in the Iceland-Greenland-Jan Mayen area is a short-lived stock, maturing at ages 2-3 in the autumn and spawning in March (at ages 3-4). The spawning mortality is believed to be almost 100%.

The 2-3 group generally feeds in the northern part of the region, between Jan Mayen and Iceland, and starts on a return spawning migration in early autumn, appearing at the northern coast of Iceland in September-October. From there, the spawning migration to the south and southwest coast of Iceland begins in December-January. Most of the fishing takes place during the months October-March and is concentrated on the mature part of the population (ICES. 1993a). A part of the fishery takes place earlier, mainly in August, but this is also aimed at the 2-3 group.

Since the capelin is a migratory species, management is in accordance with international agreements which are binding to the parties involved. The management system is based on an aim to leave a minimum of 400,000 t spawning biomass at the end of the season.

When the maturing capelin migrates up to the northern coast, it sometimes mixes with juveniles. This leads to problems since the juveniles are recorded on the acoustic equipment of fishing vessels, but escape through the purse-seine. The effect of capture and escape in terms of mortality is completely unknown, but may potentially become high when repeated catches are made at the same location. Local management in Iceland, therefore, uses closed areas and time periods in order to reduce the catches of juveniles.

The stock estimate is obtained using acoustic surveys which usually take place in October and January. These surveys have proved to be internally consistent in most cases, with deviations of less than 5% (in numbers) between the January survey and the predicted January estimate based on the October survey. Any exceptions to this seem to correspond to years when the autumn survey was an underestimate and noted as such in survey reports. In general, the January survey thus seems to be the most reliable estimate available, but of course this is in the latter part of the season. The following management system has, therefore, been adopted. The system is based on the assumption that the acoustic estimates of maturing capelin are absolute stock estimates.

For a given season, August-March, a precautionary TAC needs to be set in order to enable an opening of the fishery in those years when capelin are abundant. This is done using a simple regression method connecting the acoustic estimates in one year to the estimates of the corresponding year classes from the year before, accounting for processes in the intervening period. The regression thus provides a way of obtaining estimates of the TAC which can be taken from the stock, leaving 400,000 t to spawn.

Since the prediction is quite variable, the precautionary TAC is reduced by roughly 30% from the predicted value. This corresponds to the maximum historical deviation between the predicted value and the final stock estimate.

Having obtained a precautionary TAC, the fishery can be opened in August. The October acoustic survey then yields a stock estimate which is usually satisfactory as a basis for the TAC for the entire season. In some circumstances weather or ice prevent completion of a satisfactory survey, in which case a repeat survey is needed. In any case, various pressures usually necessitate a second survey in January. This usually confirms the former estimate.

1.3 The anchovy fishery in Sub-area VIII

The proportions of the annual catch taken from this resource are roughly as follows:

Jan - Mar	10% juveniles and mature fish.
Apr - June	60% mature fish (spawning takes place during this period).
July - Sept	20% mature fish.
Oct - Dec	10% juveniles and mature fish.

An acoustic survey takes place each April just before spawning, followed by an egg survey in June.

The key problem is that any TAC set at the start of the year cannot take account of the size of recruitment the previous year, because the forthcoming April hydroacoustic survey provides the first estimate of that recruitment (ICES. 1992a).

A management scheme similar to that for the two fisheries described above seems possible for this case. An initial TAC would be set (conservatively) in January based on the previous year's survey results and the catch taken subsequent to these surveys. This would be updated as soon as the results of the April hydroacoustic survey become available. Clearly, the efficacy of such an approach depends critically upon associated administrative procedures. Unless TAC revisions can be adopted and announced quite soon after the survey results become available, the initial TACs have to be set rather conservatively. The values of the parameters of the equations linking the survey results to the TACs to be set would be evaluated by conducting simulations of the application of such management procedures to the resource over a certain time frame, and considering the anticipated results. These projections would need to be based on a recent assessment of the resource: a key aspect of this assessment exercise would be the estimation of summary statistics of the distribution of historic recruitment levels. They would also need to take account of the anticipated level of precision of future surveys.

1.4 Some possible alternatives to a full age-structured (VPA) assessment

Annual catch or even catch-at-age data are generally insufficient to allow a satisfactory assessment of the stock in the absence of additional information. Essentially, a time series of an index of relative abundance (at least) is a pre-requisite, although some inferences can be drawn given only a simple estimate of abundance provided that this is available in absolute terms. For example, Beddington and Cooke (1983) provide tables which relate an initial catch level to such a survey estimate, as a function of biological and technological parameter values (natural mortality, growth rate and age at first capture). Their calculations take account of recruitment variability, and their results are expressed in relation to the probability of (unintentionally) reducing the stock below a specified threshold within a certain period.

In circumstances where catch-at-age data are not available, or their level of precision is such that VPA methods are unable to perform adequately, some variant of a "dynamic" (or "non-equilibrium") production model may provide a superior alternative. Some discussion on such models may be found in the report of the 1987 meeting of this group (ICES. 1993c). The simplest versions of such models use a single variable only to categorise the state of the stock (usually taken to be the recruited biomass, B) and have the form:

$$B_{y+1} = B_y + g(B_y) - C_y + e_y \qquad (1)$$
$$U_y = qB_y + \mu_y \qquad (2)$$

where

- $g(B_y)$ is the surplus production in year y (typically a function with two parameters to be estimated or a recruitment index),
- C_y is the total catch (by weight) in year y,
- e_y is the "process" error,
- U_y is the relative index of abundance for year y (e.g. CPUE, or the result of a survey),
- q is the catchability (a parameter that can be estimated), and
- μ_y is the observation error.

Estimates of the model parameters (q and two parameters for the surplus production function) are usually obtained by means of an "observation error" estimator, e.g., minimize $\Sigma\mu_y^2$ assuming $e_y = 0$. This approach may prove unsatisfactory, however, if recruitment fluctuations (represented by the e_y) are of comparable magnitude to the biomass B_y. Typically a longish time series (and some data "contrast" - see, e.g., Walters, 1986) of the relative abundance index is required to allow adequate estimation of the three parameters. This process can be facilitated if the U_y are measures of absolute abundance, in which case the catchability parameter q must be near to 1. Packages are available which implement such assessment models, e.g., "PC-BA" (Punt, 1992).

Reservations about such simpler forms of these models are that they fail to make any allowance for the age-structured nature of the stock (and the implications thereof for its dynamics), or changes in the exploitation pattern over time. These can be addressed by extending the production model to an "age-structured production model" (e.g., de la Mare, 1989; Punt and Butterworth, 1992; Hilborn, 1990). Equation (1) above is then replaced by equations incorporating the full age structure of the stock, and allowance is made for the age structure of the catch by means of a selectivity function (which may change in time) to disaggregate annual total catches by age, or directly if age-breakdowns of annual catches are available. Parameters are estimated in a similar manner to that described above, though now certain further information (e.g., recruit surveys) can be incorporated more naturally into this process. The parameters of the surplus production function are replaced by those of the stock-recruitment relationship assumed. Thus, in comparison to VPA, this approach replaces estimation of the recruitment for every year by estimation of stock-recruitment function parameters. However, bias may be a concern if recruitment fluctuations are of comparable magnitude to the total biomass. Further extensions of this approach allow some account to be taken of process errors (the e_y) - e.g., Francis *et al.*(1992); Punt and Butterworth (1992); Punt and Japp (in press) - but have a level of complexity which probably renders them inappropriate as potential "off-the-shelf" assessment tools. Few examples exist where these methods have been shown to be better than the full age-based methods. Stock-recruitment functions and process error models have been included in age-based assessment methods such as Cagean (Deriso *et al.*, 1985).

Another set of methods which can take partial account of age structure are extensions of the de Lury approach (Rosenberg *et al.*, 1990; Conser, 1991). For short-lived species these rely on the availability of an index of abundance during the course of the season such as commercial CPUE, which enables the size of the resource to be assessed from an estimate of the rate of decline in the index induced by the fishery. Under a real-time management system, the fishery may then be closed when the stock size is estimated to have fallen below a threshold level.

1.5 Conclusions

Although conventional catch-at-age analysis such as VPA may not be the best assessment method for short-lived species, it may nevertheless be of some use in the absence of better techniques. A variety of problems may make such analyses poorly suited for an annual TAC management regime for short-lived species. This may include the lack of recruitment indices, the need for in-season management, etc. It would be desirable, therefore, to pursue actively some of the alternative methods discussed above to develop an assessment methodology which could be more readily applied in a revised management system.

In particular, the Working Group recommends that:

1. Catch-at-age analysis should continue until replaced by alternative assessment methods.

2. Working Groups such as the Norway Pout and Sandeel Working Group should examine all available data, especially monthly or quarterly CPUE data in order to determine, e.g., relationships between CPUE and abundance which would enable alternative management methods to be applied. Procedures and programs corresponding to various models for the analysis of CPUE and survey data exist and should be investigated.

Finally, many of the problems noted for short-lived species arise mainly under a system of control by TACs and are much less severe under alternative management regimes such as effort control, which may be more appropriate in such cases.

2 Assessment methodology

2.1 Shrinkage

2.1.1 Theoretical concepts

In classical statistics, shrinkage pertains to prediction in multiple regression (Copas, 1983). Predictions made by regressing on some explanatory variables can often be `improved' by shrinking them towards the mean of previous observations. Essentially, this can be thought of as obtaining a satisfactory compromise between an estimator with potentially high variance and low bias (that based on the multiple regression) and one with low variance and potentially high bias (the mean).

Many other estimation problems also present the choice between one estimator with high variance and low bias and another with low variance but potentially high bias. Again, taking a suitably weighted average of these estimators can provide a satisfactory compromise between bias and variance and has generally become known as `shrinkage'.

Fryer *et al.* (WP 7) illustrate the compromise between bias and variance in the following simple example. Suppose a random variable Y is related to an explanatory variable X by

$$y = \alpha + \beta x + \epsilon,$$

where α, β are (unknown) parameters and ϵ is a normally distributed error term with zero mean and constant variance σ^2. Given n observations (x_i, y_i), $i = 1...n$, we wish to predict the expected value of Y at $X = x'$; namely

$$y' = \alpha + \beta x'.$$

Two possible estimators of y' are

$$y_{LS} = \hat{\alpha} + \hat{\beta} x',$$

where $\hat{\alpha}$ and $\hat{\beta}$ are the least squares estimates of α, β, and

$$y_{AM} = \frac{1}{n}\sum_{i=1}^{n} y_i$$

the arithmetic mean of the y_i. The estimator y_{LS} is unbiased, whereas y_{AM} is generally biased. However, y_{LS} has a larger variance than y_{AM}.

One way of combining bias and variance is to consider the mean square error. Now

$$\text{MSE}[y_{AM}] \le \text{MSE}[y_{LS}] \text{ if } \tau^2 \le 1$$
$$\text{MSE}[y_{AM}] \ge \text{MSE}[y_{LS}] \text{ otherwise}$$

where

$$\tau^2 = \frac{\beta^2 S_{xx}}{\sigma^2}$$

and

$$S_{xx} = \sum_{i=1}^{n} (x_i - \bar{x})^2.$$

It is convenient to think of τ^2 as the signal-to-noise ratio of the regression of y on x. Thus, to minimise mean square error, we should use y_{AM} if $\tau^2 \le 1$ and y_{LS} otherwise. It is important to note that neither estimator is optimal for all values of τ^2. (Of course, a practical consideration is that the true value of τ^2 is unknown).

A third estimator - the `shrinkage' estimator - is a weighted average of y_{AM} and y_{LS},

$$y_{SH} = (1 - \theta)y_{AM} + \theta y_{LS}$$

where $0 \le \theta \le 1$. This estimator includes y_{AM} and y_{LS} as the special cases $\theta = 0$ and $\theta = 1$ respectively.

Taking

$$\theta = \frac{\tau^2}{1 + \tau^2}$$

minimises the mean square error of y_{SH}, and is such that

$$\text{MSE}[y_{SH}] \le \min\{\text{MSE}[y_{AM}], \text{MSE}[y_{LS}]\}$$

for all values of τ^2. Note that
• when τ^2 is large - i.e. large signal-to-noise ratio - θ is close to 1 and y_{SH} is close to y_{LS},

• when τ^2 is small - i.e. small signal-to-noise ratio - θ is close to 0 and y_{SH} is close to y_{AM}.

The mean square errors of the three estimators can be written as

$$MSE[y_{LS}] = \sigma^2 \left(\frac{1}{n} + \frac{(x' - \bar{x})^2}{S_{xx}} \right)$$

$$MSE[y_{AM}] = \sigma^2 \left(\frac{1}{n} + \frac{(x' - \bar{x})^2}{S_{xx}} \tau^2 \right)$$

$$MSE[y_{SH}] = \sigma^2 \left(\frac{1}{n} + \frac{(x' - \bar{x})^2}{S_{xx}} \frac{\tau^2}{1 + \tau^2} \right)$$

and are shown in Figure 2.1.1 as a function of τ^2.

In practice, θ must be estimated from the data, and this causes some problems. In particular, the mean square error of y_{SH} is inflated, because it now includes some extra variability due to the estimation of θ. Consequently, y_{SH} is rarely the optimal estimator of y' for a particular value of τ^2. However, y_{SH} is generally 'close' to optimal for all values of τ^2, whereas y_{AM} and y_{LS} are sometimes 'far' from optimal.

In the example above, θ does not depend on the value of x' (ie the value of x used to predict Y). However, this is not always the case. For example, if there are errors in the explanatory variables, then the optimal value of θ decreases (ie more shrinkage than if there are no errors in the explanatory variables) and the appropriate value of θ depends on x'.

It is important to note that shrinkage estimators provide a compromise between bias and variance - ie bias not too big, variance not too big. However, the method of application will depend on the problem under consideration. Further, determining the level of shrinkage will depend on the quality and type of data available.

Of course, it is always possible to take a weighted average of two estimators, regardless of their biases and variances. Assuming the weights are not a function of the data, the resulting estimator has a bias that is a weighted average of the original biases and a variance that is less than or equal to the maximum of the two original variances. Whether this is a sensible thing to do depends on the problem in question.

During the meeting, the theory developed by Fryer *et al.* (WP 7) was extended to the case of Laurec-Shepherd tuning with one effort series. Although the results are extremely tentative, approximate CVs were estimated for age 3, 4, 5 Western Channel Sole for a retrospective analysis running from 1979 to 1989. These 'theoretical' CVs (Table 2.1.1) were generally between 0.3 and 0.4 for ages 3 and 4 and between 0.2 and 0.3 for age 5, and were similar to the 'optimal' CVs found by the retrospective analyses described in Section 2.5.

The results suggest that optimal CVs will vary with stock, age and effort in the most recent year. Further, the amount of shrinking is likely to increase with both errors in effort data and errors in catch at age data, particularly if the estimates of effort and catch in the most recent year are poor.

2.1.2 Shrinkage in VPA tuning

The CPUE data from a fleet can be related to the VPA results by

$$u_{ay} = q_a + c_{ay} - f_{ay} + \epsilon_{ay}$$

where the small letters denote log-values of the respective variable.

The values of f_{ay} are obtained from VPA and treated as exact. The catchabilities are estimated from the observed values for y=1,2,...,t-1. By inserting the estimated value of q_a the fishing mortality rates in the last year are obtained from the observed values as

$$f_{at} = q_a + c_{at} - u_{at}.$$

A simple model of the fishing mortality rates is

$$f_{ay} = f_{a0} + \delta_{ay}$$

where f_{a0} is a constant value and δ_{ay} residual. The values of f_{a0} can be estimated and a weighted average of f_{a0} and the estimate obtained from the observed values in the last year has a lower mean square error than the estimate from the observed values alone. The optimal weights depend upon the ratio between the variance of the residuals ϵ_{ay} and δ_{ay}, respectively (Gudmundsson, WP 8).

The variance associated with CPUE data is often high so shrinkage could potentially improve the estimation of terminal Fs considerably. Shrinkage can also improve the estimates if more than one set of fleet data is included or if more sophisticated methods are applied such as the extended survivors analysis. However, as the influence of measurement errors in the final year is reduced, the optimal weight of the estimated average would be lower.

Misspecification of models leads to systematic errors in estimates derived from them. With the CPUE data the main risk is usually that catchabilities change systematically over time. The introduction of shrinkage reduces the effect of such misspecifications.

On the other hand, shrinkage produces systematic errors if the assumption of a constant mean of the fishing mortality rates is wrong. In the time series method this assumption is tested against more general models and is in fact rejected for a large proportion of actual stocks (Gudmundsson, 1987; in press). This does not imply that shrinkage should be abandoned, but that the mean values of the fishing mortality rates should be estimated only from values in the most recent past. As a result of this it is difficult to estimate the variance from the data, but the problem is examined empirically in Section 2.5.

Notice that in the statistical literature the word shrinkage is applied to prediction of future values of the dependent variable (corresponding to u_{ay} above), but it also has the effect of moving the value predicted by straightforward application of the regression towards an estimated mean value. In this context shrinkage is rarely useful with less than three independent variables whereas the optimal weight attached to an estimated mean of the fishing mortality rate would generally be reduced by adding a new set of CPUE data.

2.1.3 Shrinkage and time series analysis

In the time series method, the catch-at-age values are treated as dependent variables and the equation

$$C_{ay} = [F_{ay}/Z_{ay}][1 - \exp(-Z_{ay})]N_{ay}\exp(-Z_{ay}) + \epsilon_{ay}$$

is combined with a time series model of $\log F_{ay}$ which does not assume a constant mean value.

The catch at age observations contain information about changes in fishing mortality rates, even in the last year. There is a "shrinkage" effect similar to that described for the VPA tuning methods. In the time series method it weighs the indication of changes in the last year from the catch at age data against predictions of the Fs from the time series model. The time series predictions are conservative, but usually they are not as simple as the "same as last year" or the "same as the average in the past". CPUE data can be included in the analysis, but they are not indispensable for detecting changes in the last year. The parameters of the time series model are estimated from the data. (Gudmundsson, 1987; in press).

As an example of the ability of the time series method to estimate sharp changes of fishing mortality in the last year the Working Group used a simulated data-set with very large changes with time, jointly for all ages, copied from a simulated data-set from Fournier and Archibald (1982). Random variations with standard deviation 0.1 were added to the log Fs and the standard deviations of the catches were also 0.1 for the best observed ages and higher for the oldest fish. The results are presented in Figure 2.1.2. For comparison, untuned Xsa4 was run with shrinkage and the retrospective results are given in Figure 2.1.3. (This is an exceptionally unfavourable data-set for that method.) Note that only the last two years for each retrospective assessment are given for the time series method.

2.2 Recruitment estimation

To complement the theoretical investigations on methods for combining several recruitment indices (Rosenberg *et al.*, 1992, Gudmundsson, WP9), and on whether shrinkage should be used (Fryer *et al.*, WP 7), an empirical evaluation of the various regression methods and options available to working groups for recruitment estimation has been carried out on actual data. This was made in the form of a retrospective analysis of how year-class strengths predicted by the RCT3 program compare with the VPA estimates obtained in the most recent assessments, i.e. using a similar approach to that used for retrospective evaluation of tuning methods.

2.2.1 Retrospective analysis

The RCT3 program has been run on a selection of data-sets known to have been somewhat problematic, using each of the three regression methods available in that software, viz., calibration, predictive and functional regression (the latter is implemented but not explicitly proposed to the user), with or without shrinkage. The other options proposed by the program were adopted consistently across runs for each stock and generally were the proposed defaults, such as a CV of 0.2 of the VPA mean for shrinkage, minimum of 3 points in regressions, no exclusion of surveys with small variance, etc. However, most of the time series used in this comparison were rather short and, except for the Northeast Arctic cod data, no time taper was considered.

Whichever regression method is used, the RCT3 software performs a log-transformation on both the VPA and the recruitment indices, i.e. it fits a power rather than a linear relationship, in which the power (called "slope" in the outputs) is expected to be close to one. An important point to notice is that the recruitment indices taken from the relevant working group reports sometimes had to be rescaled in order to become significantly larger than the constant 1.0 added to them by the program prior to log-transformation. One should not be surprised that the data and results here may differ from those in the reports.

The closeness/discrepancy between RCT3 and VPA estimates for each method can be examined graphically (albeit with difficulty) and has also been measured by the root mean square logarithm of the ratios (RCT / VPA) over the years in which both VPA and RCT estimates are available; these "scores" are given in the bottom row of the tables of results. The smaller the figure, the better the RCT estimates by the method considered match, on average, the recruitments eventually obtained by VPA.

Due to a limitation of the spreadsheet software used for plotting the results, only 5 options could be graphed in addition to VPA. Thus, results from the predictive regression with shrinkage had to be omitted from the figures and are only given in the tables.

Western English Channel sole (Division VIIe)

Six series of indices from 4 surveys are available for the period 1978-1991, and VPA estimates of 1-year-olds are thought to be sufficiently converged prior to 1989 (Table 2.2.1). Since survey indices are scarce in the earlier years, valid comparisons can only be made for the 1984-1988 year classes, but it was felt of interest to include the VPA estimate of the apparently strong 1989 year class in the comparison. Note, however, that RCT3 did not use that estimate in fitting the regressions. The results are given in Table 2.2.2 and Figure2.2.1.

Over this short time series, all methods track the changes in recruitment rather well and, although they all have a slight tendency to overestimate recruitment, one cannot conclude that there is a systematic effect. The most extreme results are given by the calibration method without shrinkage, but the lowest score is obtained by the predictive regression with shrinkage which cannot deal with the abrupt changes observed in that stock, for reasons discussed below. The best score is for the functional regression without shrinkage. The differences between the shrinkage and no-shrinkage options are largely attributable to the fact that the surveys are poorly correlated with recruitment (one actually takes place in the northeast part of the Channel), so the mean is often given a predominant weight in the final estimation.

Irish Sea plaice (Division VIIa)

Eight series of indices from 4 surveys are available for the 1974-1991 year classes, and VPA estimates of 1-year-olds up to the 1988 year class are used in the regressions (Table 2.2.3). Several of the surveys used are rather poor indicators of recruitment as indicated by their very small r-squares and, when the shrinkage option is turned on, the mean usually receives the largest weight.

The 1980-1988 year classes are considered in the comparison tests (Table 2.2.4 and Figure 2.2.2). Here again, the calibration method without shrinkage gives the most extreme variations, although it performs slightly better in terms of root mean square log-ratio than both methods using predictive regressions. The best scores are obtained by the calibration with shrinkage and the functional regression without shrinkage. It is noteworthy, however, that most methods overestimated recruitment of the 1984-1988 year classes, although they all detected the drop in 1986-1988. Surprisingly, the calibration with shrinkage does better in that respect than the predictive regression without shrinkage.

Icelandic cod

Recruitment data are available from commercial CPUEs of age-3 fish from 1983-1991, and for ages 1-4 from surveys carried out since 1984 (Table 2.2.5). Sufficiently converged VPA estimates of 3-year-olds are available for the 1980-1987 year classes and, to allow for a minimum number of points in the regressions, comparisons can only be made for the 1984-1987 year classes. Caution is warranted in interpreting such a small set.

The results (Table 2.2.6 and Figure 2.2.3) conform with expectation, namely: the methods involving shrinkage respond to variations in recruitment but with some delay (particularly for 1984-1985), and the calibration without shrinkage exaggerates the fluctuations. For the 1987-1990 year classes, all methods are fairly consistent but, for the 1991 year class, the "shrunk" methods predict recruitment to be about average whereas the other methods indicate a sharp decrease. The scores probably do not make much sense here. They indicate, however, that the functional regression without shrinkage performs best, followed by the predictive regression without shrinkage. If there has been a problem with the recruitment estimation for this stock, it may have arisen because all indices used by the Working Group were small compared to the constant "1" added by the program, resulting in a very weak signal on the log scale.

North Sea herring

During its 1991 and 1992 meetings, the Herring Assessment Working Group for the Area South of 62°N experienced some problems with recruitment forecasts, particularly due to differences in regressions using raw or log-transformed survey indices. The problem was further addressed by the Workshop on the Analysis of Trawl Survey Data (ICES. 1992d), but the emphasis at that meeting was on the comparison of the standard IYFS index with various elaborations of this index, and all the evaluations were made on log-transformed data. As stated above, the RCT3 program systematically performs a log-transformation of data on both axes, so the current exercise is of little relevance to the issue as it emerged initially.

Nevertheless, a data-set (Table 2.2.7) was compiled for 1-ring (read: 2-group) herring using the IYFS indices (means of all rectangle means) and VPA estimates for the 1980-1990 year classes given in the report of the 1992 Herring Working Group (ICES. 1992e) (n.b.: the index for the 1990 year class in that report differs from the figure used by the Trawl Survey Workshop, but this has no importance for the present purpose). The year classes prior to 1980 were not included since the survey procedures were not completely standardized at that time.

The "herring problem" is clearly reflected in the results (Table 2.2.8 and Figure 2.2.4) which show a rather large discrepancy among methods and with VPA. All methods fail adequately to match the drop in abundance of the 1985-1987 year classes and the upsurge of the 1988 year class shown by VPA, although the estimate of the latter is still uncertain due to poor convergence of the VPA (*cum* $F < 0.6$). Moreover, the methods involving shrinkage missed the large 1985 year class, and it is no surprise that their scores in terms of root mean square log ratios are the poorest overall. The methods without shrinkage have similar scores.

Northeast Arctic cod

As documented in the report of the relevant working group, recruitment indices for this stock are available from a number of surveys carried out over a variable range of years during the period 1955-1992 (Table 2.2.9; note the rescaling). These were regressed against VPA estimates of the 3-year-olds from the 1957-1986 year classes, and comparisons were made with RCT3 predictions for the 1972-1991 year classes (Table 2.2.10 and Figure 2.2.5).

Although they sometimes depart from the VPA estimates, all methods give fairly consistent estimates of recruitment over the period. This is reflected in their scores which are all similar and can be taken to be sensible with such a long time series, in contrast with the previous examples. It can be noted, however, that the methods involving predictive regression perform slightly worse than the others.

2.2.2 Summary and conclusions

It appears quite difficult to draw any firm conclusion from these comparisons since the way in which the various methods perform depends not only on their intrinsic properties, but also on specific features of the data to which they are applied. Thus, no method seems to come out as universally better than the others. A tentative way of summarising the results is to tabulate the ranks, in terms of increasing root mean square log ratios, that each method achieved in each of the cases examined, as presented in the text-table below:

Stock/ Method	CAL+ SH	CAL- SH	FUN+ SH	FUN- SH	PRE+ SH	PRE- SH
VIIe Sole	4	3	5	1	6	2
VIIa Plaice	1	4	3	2	5	6
Icelandic Cod	4	3	5	1	6	2
North Sea Herring	5	2	4	1	6	3
NE Arctic Cod	1	4	2	3	6	5
Overall	15	16	19	8	29	18

Great caution should be exercised in interpreting this table, since differences in rank may be disproportionate in comparison with differences in absolute values of the scores. In addition, all applications of shrinkage used a single common value (0.2) of the CV of the VPA mean, and the methods might rank differently if an appropriate value was used in each case. It is thus advisable to refer to the specific assumptions each regression method makes about the error structures in the variables.

- The calibration mode of regression assumes that the errors in the VPA estimates are negligible compared to the errors in the survey indices. This is often the case in recruitment estimation, in view of the generally large variance of survey results, unless VPA is badly affected by errors in the catch-at-age data due to poor sampling, aging errors or occasional misreporting, for example. Despite its reasonably good score, the calibration without shrinkage often produces rather extreme variations, and the results confirm that shrinkage is necessary when using calibration regression. It is noteworthy that calibration with shrinkage performed best in both cases where the data series were long enough to make the comparisons of some significance.

- The functional regression is relevant when both variables are subject to error, but one has to provide an estimate of the ratio of the respective error variances, which is not an easy problem. As currently implemented, RCT3 assumes that variances in log-VPA and log-indices are of similar magnitude. This is a very specific option in the large family of functional regressions, and its relevance for general application is questionable.

- The predictive mode of regression is the one which is most commonly used in other contexts. It assumes that most of the errors apply to the 'predicted' variable compared to errors on the explanatory variable. As mentioned earlier, this is probably not valid for the present problem in most circumstances. The OLS model does not deal explicitly with errors on the explanatory variable and, if these exist, they result in bias on the estimates of the slope, the effect of which is similar to that of shrinkage. Moreover, when several indices are used in that way, some shrinkage applies to the predictions inferred from each index and, when these are eventually combined, the mean contributes several times to the final estimate. It is, therefore, no surprise that in these examples the predictive regression with shrinkage performed worst, as the sort of "two-stage shrinkage" makes it unable to match sudden changes in recruitment.

Obviously, this exercise has been based on a very restricted set of cases and some caution is called for. However, the results are consistent with previous conclusions from this Working Group in 1987 and by Rosenberg *et al.* (1992), that calibration with shrinkage is the preferred method among the class of regression estimators. It is recommended that working groups routinely evaluate the performance of their recruitment estimations using the retrospective analyses facility which has always been available in RCRTINX2 and RCT3, just as they do for retrospective evaluations of VPA tuning.

2.3 Integration of recruitment estimation and VPA

At present most ICES working groups use VPA for the estimation of current population size for all age groups except a few of the youngest, and a separate regression method for estimating the abundances of the youngest, recruiting age groups. The regression estimates are generally used in preference to the VPA estimates for the recruits because the latter are usually based on poorly sampled catch-at-age data which are known to be unreliable. Nevertheless, in some cases the VPA-based estimates may have some utility, and it would be preferable to include them in the estimation procedure with a weight appropriate to their precision, rather than to ignore them completely. This is especially true for intermediate ages where both estimates may have comparable precision. Whilst it is possible to deduce usable variance estimates from the standard program outputs, and carry out the combination calculation manually, this is rarely done, and a less labour-intensive method would be desirable.

There is no difference in principle between the methods used for tuning the VPA and recruit index analysis, as both are based on a calibration regression model: the procedure for the adult ages simply assumes a log slope of one (constant catchability) for the older ages, whilst the slope is estimated for the recruits, allowing catchability to vary with stock size in a density dependent manner. The problem of combination is thus handled gracefully by more recent methods such as XSA and ADAPT, which allow the incorporation of recruit index and survey data, and permit the appropriate model to be used for the different age groups. This ensures that all data are used once only (avoiding possible duplication which may otherwise occur), and eliminates the combination problem since all the estimates are made and used together in a consistent manner (Shepherd, 1991a).

The Working Group considers that the use of such a combined estimation is far preferable to maintaining the tradition of separate VPA and recruit index estimation, and to developing more elaborate methods of *post hoc* combinations. The Working Group, therefore, recommends that assessment working groups investigate the XSA option in the VPA tuning package for this purpose.

It is, however, very important that working groups continue to scrutinise the analysis of the data, especially for the recruiting ages, very carefully. Further enhancements to the XSA output are in hand to assist this process. It may also be instructive to continue to use RCT3 for diagnostics. It should also be noted that in order to allow all available data for pre-recruit ages to be included, working groups may have to extend the age range of the data file to include all the youngest ages, inserting zero catches in the catch number file as necessary. Natural mortality estimates for these youngest ages will also be required. Since these only provide an appropriate re-scaling of the estimates, however, this need not be the cause of too much grief.

2.4 Updating VPA with recent survey data

At present the estimation of the current state of the stock is normally done with a tuned VPA procedure of some sort (i.e. including XSA and ADAPT). The VPA algorithm depends on the availability of catch-at-age data, so this procedure of calibration and estimation can only produce estimates of stock size up to and including the end of the last year for which catch data are available. Survey data which became available after that can only be used in an *ad hoc* way to update the assessment. In some cases this can mean that survey data cannot be utilised properly for up to a year after they become available, which is clearly undesirable, especially as the recent evolution of the stock is often a matter of considerable interest and debate. Some procedure for making proper and efficient use of recent survey data is, therefore, highly desirable.

Some methods based on direct maximum likelihood or least squares estimation such as CAGEAN (Deriso *et al.*, 1985), ADAPT (Gavaris, 1988), and ITCOTIO (Pope and Stokes, 1989) can, if necessary, be augmented to include the missing catch-at-age data as additional parameters, and thus be used in this way without much practical difficulty. It is not obvious that this is the best way to proceed, however, because it may simply lead to catches being computed which are consistent with the log-catch ratios from the most recent surveys. The recent fishing mortality estimates are thus wholly determined by the recent surveys, which might, therefore, just as well have been used directly. Any previous information on population size and fishing mortality has effectively been ignored. This is not quite what is wanted and, in the spirit of Bayesian priors and Kalman filters, one may well wish for something a little more refined.

In effect this means

a) using information on recent F-at-age values as a basis for prior estimates along with the new estimates,

b) using forward projections of the previous survivors at currently estimated rates of F along with the new estimates.

This may be done by the inclusion of extra terms in the maximum likelihood methods to represent these prior expectations. The procedure required, however, is very similar to that involved in applying shrinkage to estimates of mean F in VPA tuning. There should in fact be no difficulty in extending the tuning procedures to allow for the incorporation of more recent survey data in this way. The user would need to supply expected F-multipliers (varying with age if a mesh change had taken place) for the most recent years. These would be used to bring forward all available estimates in time, and thus to generate estimates of survivors in the usual way. Any discrepancies between the assumed Fs and those implied by the surveys would be apparent in the residual tables.

2.5 Retrospective testing of tuning methods

At the 1991 meeting of the Working Group on Methods of Fish Stock Assessment (ICES. 1991) it was discovered that shrinking the predicted terminal fishing mortality towards the mean was quite effective in reducing the retrospective bias problem in the stocks on which it was tried, and that it also seemed to be useful in reducing random variation in the predicted F values. A theoretical explanation of the latter property is now available (Section 2.1) but the application of shrinkage to reduce retrospective bias is still an *ad hoc* procedure.

The Working Group was asked to investigate the appropriate use of shrinkage in tuning and advise how it should be implemented for the use of working groups. To address this question, retrospective analysis was carried out on two stocks which had proved troublesome at the 1991 meeting (Western Channel, Division VIIe sole, and NAFO Division 4VsW Cod) (ICES. 1991), and for the simulated data-set No. 5 from the Reykjavik meeting (ICES. 1993c). This was done using Laurec-Shepherd tuning and several variants of XSA, including that now implemented as part of the standard VPA tuning package as well as the time series-based method (TSER) (for the simulated data-set only). The VPA analyses were carried out with no shrinkage, and with the "cv" parameter (the log standard error specified to be attached to the mean F) ranging from 0.1 to 0.5 in steps of 0.1. It should be noted that low values of this parameter imply strong, and high values weak, shrinkage.

In all, more than fifty retrospective analyses were carried out for each stock, and the results for each run were summarized by a page of figures and one of tabulated results, as at the 1991 meeting (ICES. 1991). These results are too voluminous to include in the report, but examples are given in Tables 2.5.1 to 2.5.10 and Figures 2.5.1-2.5.10 of the unshrunk, overshrunk, and optimally shrunk results for each stock. The full set of results are summarized in Tables 2.5.11 to 2.5.16. These show the percentage of estimates at each age which appear to be in error by a log ratio of more than 0.5 ("outliers"), the mean log ratio ("bias") and the root mean square log ratio (i.e., r.m.s. prediction error, "s.e."). The latter estimates are as usual multiplied by 100 and may be regarded as percentage errors. The comparison for the real data-set is with the final run of the series, whilst for the simulated data-set it is with the "truth".

In the "basic" version of shrinkage implemented for the Laurec-Shepherd x XSA2 procedures, a CV for mean F is specified by the user. This may be referred to as "hard" shrinkage. Clearly, if the variability of F (at any age) is larger than that assumed, it would be appropriate to use the higher observed CV (and, therefore, to shrink less). This is here referred to as "soft" shrinkage.

Further, shrinkage has hitherto been applied only to the terminal F estimates (i.e., those for the last year and the oldest age). However, it is known that separable VPA, which determines terminal F and year class strength from estimates of catch at age and smoothed (separable) fishing mortalities over the whole cohort, is a relatively robust method of analysis, especially when the survey/CPUE data are of poor quality. This is effectively the logical conclusion of the shrinkage process (ignoring the tuning data and using just catch at age and some smooth model for fishing mortality). It is, therefore, possible to explore another "universal" flavour of shrinkage, in which population at age is estimated from catch at age and a smoothed (running mean) estimate of F for all ages and years, and these are included in the analysis in the usual way (i.e., as though they were estimates from surveys). This is easily done in the XSA method (but is not possible for the standard tuning methods). It could be regarded as taking a solution similar to that from separable VPA as a prior, and modifying it in the light of information from survey and/or CPUE data.

A summary of shrinkage terminology used in this report is given below:

strong:	giving much weight to the mean, by specifying a small CV value.
weak:	giving little weight to the mean, by specifying a large CV value.
hard:	using the specified CV value only to determine the strength of shrinkage.
soft:	using the observed CV (when higher than that specified) to determine the strength of shrinkage.
marginal:	using shrinkage only on the terminal F values, at the margins of the catch-at-age array.
universal:	using shrinkage to the mean F throughout the catch-at-age array, thus biassing the solution towards one with a slowly changing exploitation pattern.

The methods used were:

L/S:	standard Laurec-Shepherd tuning.
XSA2:	extended survivors, as previously tested at the Reykjavik (ICES. 1993c) and St. John's (ICES. 1991) meetings.
XSA4:	the XSA4 variant of extended survivors analysis (not generally available) which shrinks to an exponentially weighted running mean F, and allows for hard or soft, and marginal or universal shrinkage options (HM, HM and SU options were tested, as hard universal shrinkage was already known to give extremely variable results on poor quality data).

The results indicate that weak shrinkage (CV ≈ 0.5) is not only adequate but preferable. Strong shrinkage (CV ≈ 0.1) can easily create a biased retrospective pattern in which the direction of bias is reversed. This is not at all surprising for stocks in which quite rapid changes of fishing mortality have taken place.

The conclusion and message for working groups is that weak shrinkage should be preferred, that a CV of 0.5 may be a sensible starting value, and that the version implemented in the standard tuning package is adequate. Although shrinkage is sometimes very effective in reducing both bias and variance, as perceived by a retrospective analysis, this cannot be guaranteed. Routine retrospective testing with several values of CV is desirable and has now been provided as a "push button" option in the VPA tuning package, for both L/S and XSA2 procedures. Files which can be read directly by the SAS tabulation and plotting routines now provided at ICES may be produced automatically. Working groups are urged to make use of these facilities, and explore the effect of shrinkage on their assessments, before making a choice. It is expected that weak shrinkage will be sufficient and preferred in most cases.

It should be stressed that shrinkage is a recognised procedure for reducing the variance of predictions. Where a retrospective pattern shows bias, shrinkage may still help, for example if the bias is in the terminal estimates. However, if it is the converged VPA estimates which are biased, shrinkage can make the situation worse. Thus, if shrinkage is used to "cure" retrospective patterns (as opposed to variability), the sources of bias should be investigated zealously to avoid aggravating an already serious problem.

These results confirm the conclusion of the Reykjavik Workshop (ICES. 1993c) that the simulated data-set No. 5 is not so "badly behaved" as many real data-sets. With methods now available this data-set can be analyzed with little difficulty to a high precision. The Working Group reiterates that new or improved methods should, as a minimum, be tested on this data-set, and should be discarded or amended if they do not perform well. More difficult standard simulated data-sets are required for future use.

2.6 Conclusions

The Working Group concluded that future work should emphasize development and testing of integrated methods for the entire assessment process, which include the years and age groups traditionally used in assessments along with younger ages (pre-recruits) and also the year following the last catch data year, if surveys exist for that year.

A low level of shrinkage in VPA tuning is found to be beneficial in most cases and rarely (if ever) detrimental. The effect of various options can now easily be tested retrospectively using programs (VPA and SAS) available at ICES.

3 Stock-recruitment relationships and MBALS

3.1 Stock-recruitment, general

Several questions on the relationship between stock and recruitment were analysed using the databases compiled by Myers and co-workers (Myers *et al.*, WP 10) and P. Mace (unpubl.). These databases consist of estimates of spawning stock biomass, recruitment, catch, fully recruited fishing mortality, taxonomic information, life-history parameters, and some basic parameters relevant to fisheries management. Also included are units and the source and reference in an ASCII format that is readable by any programming language or statistical package. The data have been read into an Splus object for easy access. For the purposes of this meeting, the 72 stocks with at least 20 years of concurrent stock and recruitment data were used in the analysis. When the Myers database is finished in a few months, it will be freely available over Internet to all interested users. A summary and analysis of the database will soon be published as a technical report.

The Working Group agreed that it is very useful to have estimates of spawning stock biomass, recruitment and associated variables together in one database. The Working Group suggested that the data-sets should be provided to the various working groups for quality control. It was also suggested that the working groups provide comments on the reliability of each series. It is recommended that the results from assessments be kept in a standard format, and that a stock and recruitment database be kept up to date. It is suggested that an updated database be kept at ICES (see Section 3.7).

Several preliminary conclusions from the analysis were presented from work soon to be published by Myers and co-workers. These conclusions are:

A relationship between stock and recruitment commonly occurs

In general, there is a surprising amount of evidence for a relationship between stock and recruitment. A simple chi-square test (Table 3.1.1) indicates a significant relationship for a number of these stocks (20% of the stocks at the 5% significance level). This is a very weak test, and an examination of the parametric fits indicates much stronger evidence (Myers, in prep.).

Depensation is undetectable in most stock and recruitment data

The hypothesis was examined that fish populations can exhibit multiple stable states, and that they may collapse suddenly because of depensatory recruitment, i.e. increased mortality or lower *per capita* reproductive output at low stock sizes. Of the 105 populations examined, only one, Icelandic spring-spawning herring, showed statistically significant evidence of depensation; however, it was the only population studied that became commercially extinct. Previous empirical claims of the existence of depensation lacked a firm statistical basis, and this analysis indicates that such depensation is undetectable in the data on a large number of stocks. This result calls into question the theoretical claims that the collapse of fish stocks can be attributed to depensatory recruitment.

Overcompensation and stability

The hypothesis was examined that fish populations exhibit overcompensation, i.e. that recruitment is a decreasing function of spawning stock biomass at larger stock sizes and that the equilibrium population would be stable. To test overcompensation, the fit of the Shepherd (1982) stock recruitment model was estimated:

$$R = \frac{\alpha S}{1 + \left(\frac{S}{K}\right)^{\gamma}}$$

The model was re-estimated with the overcompensation parameter, gamma, constrained to be 1. A likelihood ratio test was used in a significance test. 105 stocks from the Myers *et al.* (WP 10) compilation of stock and recruitment data were used in the analysis. Thirteen of these showed statistically significant overcompensation.

Clear evidence of overcompensation of recruitment is apparent in the data; however, it does not appear to be generally a very important phenomenon for most marine fish within the stock levels that were observed. Overcompensation appears to be most common among species in which cannibalism of young can be an important source of mortality. However, it can also occur in species in which cannibalism appears to be rare and not important, e.g. herring.

The most serious difficulty in the estimation of the stock-recruitment function is due to the time series bias in the parameters caused by the dependence of the stock on earlier recruitment, i.e. large recruitment usually leads to large stock sizes (Hilborn and Walters, 1992). This type of bias is most important when there is little contrast in stock size; in these cases the estimates of stock and recruitment parameters must be treated with caution. This bias would tend to make overcompensation appear to occur more often than it actually does and would make populations appear more unstable than they actually are.

There is another bias in the estimation of the replacement line, i.e. the spawning stock biomass that would result from any level of recruitment at zero fishing mortality. It has been assumed that there is no density-dependent growth or mortality after recruitment to the fishery has occurred. This is clearly false for many populations (Millar and Myers, 1990), and would have the effect of making the replacement line curve upwards, i.e. one in which the first and second derivatives are positive. This would tend to make the population dynamics around the equilibrium point less stable.

3.2 Stock and recruitment: biological reference points for fishing mortality

Biological reference points such as F_{high} and F_{med} which are based on percentiles of the observations are liable to depend on the range of stock sizes which have been observed. Indeed, as pointed out by T. Jakobsen (pers. comm.), if all the observations relate to low stock sizes (among those stock sizes attainable by the stock), F_{med} may well be a better estimate of the fishing mortality which will lead to collapse, than of one which is sustainable. Similarly, if recruitment is very variable at low stock size, the estimate of F_{high} may be inflated above that which corresponds to eventual collapse (Sissenwine and Shepherd, 1987).

Thus, whilst these percentile-based estimates are easily derived and better than no estimate at all, it would be very desirable to deduce more rigorously-based estimates of dangerous and safe levels of fishing mortality. Ideally, the estimate of F at which collapse is to be expected, hereby denoted by F_{ult}, following the suggestion of Pope (WP. 6), should be deduced from the slope at the origin of a fitted stock-recruitment relationship. A comprehensive set of such estimates has been reported by Myers *et al.* (WP. 10). However, they find that dubiously high values of this slope are regularly produced when Beverton and Holt and Shepherd-type relationships are fitted, although the problem is less acute for fitted Ricker relationships.

Pope (WP.6) has suggested that there is merit in working with plots of the reciprocals of recruitment and SSB, especially if the values are normalised by estimates of the maximum (average) recruitment attainable (by the unfished stock) and the SSB corresponding to this recruitment with no fishing (the virgin biomass). On such plots the Beverton and Holt relationship is a straight line, passing through a predetermined intercept at (1,1). Only the slope of this line remains to be determined, and it yields directly an estimate of the maximum sustainable ratio by which biomass-per-recruit may be reduced (for which 20% has been suggested as a reasonably safe lower limit). The plot also emphasises and gives enhanced influence to points arising near the origin of the stock-recruitment plot, which is entirely appropriate. It may, however, do strange things to the error distributions associated with the observations so that robust procedures for fitting the stock-recruitment relationship are really needed. Finally, this presentation has the merit that data for different stocks are reduced to a common scale, and may be superimposed legitimately. Thus, if there is any common behaviour among species or families, it may be detected by such a presentation of the data. An example of this figure from Pope (WP. 6) is given as Figure 3.2.1. Pope further suggests that one half of F_{ult} would be an appropriate target for sustainable management, as he shows that it is guaranteed to yield at least half the maximum number of recruits (under either the Ricker or Beverton and Holt model). Thus, F_{ult} may provide a superior replacement for F_{high}, and $F_{ult}/2$ a replacement for F_{med}. These estimates should be relatively insensitive to the range of stock sizes observed in the historic data.

Finally, Pope suggests that in seeking threshold values like F_{ult}, it would be appropriate to determine values which apply to the worst run of years on record, and cites a biblical precedent for examining seven-year running means. This considerably reduces the scatter on the reciprocal plot, and his suggestion implies an appropriate non-parametric method for fitting the S/R line, since one may set it to pass through the least favourable point. In practice, the worst 90 percentile would probably be preferable.

3.3 Stock and recruitment analysis without VPA, and the stability of F_{med} and related reference points

In WP5 Pope investigates the observation (T. Jakobsen, pers. comm.) that the F_{med} biological reference point is more stable than might have been expected under changes of natural mortality (cf. previous discussion by the Working Group on the stability of reference points in ICES. (1985). To do so he derives a method for deducing indices of SSB and recruitment from CPUE or survey data only (i.e. without total catch or catch-at-age data). A similar procedure was used by Sparholt (1992) in a Working Paper to ACFM in 1992. These estimates are correctly dimensioned, but the scaling depends on an undetermined ratio of the catchabilities of recruits to that of mature fish. Furthermore, Pope shows that similarly scaled estimates of steady-state SSB-per-recruit may be derived from the same data, for any level of fishing effort represented in the data-set, including the current level. The techniques involve log-catch ratios and are closely related to those used by Shepherd and Nicholson (1991) for multiplicative modelling of such data.

In this way it is possible to determine whether current effort is higher or lower than that required to reach F_{med} (or any related measure deducible directly from the stock-recruitment plot in terms of SSB-per-recruit, including F_{ult} as defined above). This provides the essential signal required by managers, i.e. should effort be decreased, or may it be increased, together with a **very** rough estimate of the magnitude of the change, if it is legitimate to assume that SSB/R is roughly inversely proportional to effort over a small range.

The estimate of the reduction factor may be considerably refined if catch-at-age and effort data are available, still without performing VPA, and thus without requiring an estimate of M, and it is also possible to compute yield-per-recruit in the same way (and subject to the same scaling) over the range of effort data observed. Thus, potentially, the effort corresponding to F_{max} may also be determined if it lies within the range of effort observed.

Pope then shows that, although these estimates are constructed without adopting any value for M, changes in the perceived trend of F and recruitment at different levels of fishing mortality would cause errors in these estimates. These errors are analogous to those induced by a wrong choice of M. The F_{med}-type estimates are, however, relatively robust under a change of M because a cancellation occurs, whilst those for F_{max} do not benefit from such a cancellation and are much more sensitive to M.

This explains the observations of T. Jakobsen (pers. comm.), but does not of course remove the difficulty mentioned above of sensitivity to the ranges of biomass observed. Nevertheless, this work does show that it is possible to go much further than has hitherto been realized in providing conventional management advice even where much of the data normally required is lacking. These methods may be particularly useful where it is possible to carry out research surveys, but difficult or impossible to obtain accurate statistics from the commercial fishery.

3.4 MBALs (Minimum Biologically Acceptable Levels)

Myers *et al.* (WP 10) examine stock and recruitment data from 72 stocks (Myers, in prep.) and spawning stock biomass per recruit data (Mace, in prep.) to develop procedures for estimating critical spawning biomass thresholds. The selected data-sets each contained at least 20 data points. Eight methods for estimating the critical spawning biomass level were tried. Six of the methods relied on fitted stock-recruitment relationships, where the parameters were estimated using maximum likelihood assuming lognormal errors. Of these, two estimated the point where recruitment was 50% of its maximum value on the fitted Ricker and Beverton and Holt relationships, respectively. The other four estimated the critical point as 20% of the estimated virgin biomass obtained from the intersection of fitted stock-recruitment relationships or mean recruitment with the replacement line at $F = 0$. Two further methods based on the work of Serebryakov (1991) as detailed by Shepherd (1991b), were examined. One estimate was from the spawning stock biomass at the point where the 90th percentile of the survival ratio (R/S) intersected the 90th percentile of recruitment in each data-set and the other was the spawning biomass at the intersection of the 90th percentile of the survival ratio with mean recruitment.

In general, there will be no best method for estimating critical spawning levels for all stocks. However, a number of simple criteria can be used to determine if the estimated critical point is sensible. An important indicator is the linear slope of the log-transformed points (or preferably the linear slope assuming log-normal errors) above and below the estimated critical point. A simple decision diagram (Figure 3.4.1) has been developed to interpret these slopes. If the slope above the estimated critical biomass is positive, and the slope below is also positive, the critical point estimate is sensible if the slope above is less than the slope below. If the slope above is greater, the critical point is probably at too low a spawning stock biomass. If both slopes are negative, the estimated critical point is too conservative. Finally, if the slope above the estimate is positive and the slope below is negative, the data are pathological and the estimate is not sensible. Using these measures, the Serebryakov method using 90th percentiles often gives a sensible result, but can be very variable. Several of the other methods perform nearly as well and on a case by case basis may be better at times.

Another criterion is that recruitment below the estimated critical point should be on average lower than above the critical point. In other words, there should be an expected impact of allowing spawning stock biomass to drop below the critical level. The two methods based on the fitted stock-recruitment relationships and the associated point where recruitment is 50% of the expected maximum both do well with respect to this criterion when sensible estimates have been made based on the slope criteria. The results on this criterion for the other methods are more variable.

The ability of any of the methods to estimate a reasonable critical level is closely related to the range of observed spawning biomass. If the only observations are all near the origin, with little information on the level of maximum recruitment, then the critical level should probably be near or above the highest observed spawning biomass. On the other hand, if the slope of all the points is negative, and the range of data only covers high biomasses, then a reasonable critical level may be near or below the lowest observed spawning biomass. It is important to check the range of the data and, to put it on a common scale, it can be plotted as a proportion of the estimated virgin biomass.

Many of the methods are extremely sensitive to the range of the data observed. For example, the Serebryakov methods will give very different answers for the same stock if only the data corresponding to the lower half of the observed biomass range is used in the estimation. This is an undesirable property since it implies that the threshold level decreases as the average level of exploitation increases. On the other hand, the methods using the 50% of maximum recruitment point on fitted curves do not have this problem, but are often unable to obtain reasonable estimates.

Suggested Procedure for the Analysis

The comparative study provides some general guidance on procedures for estimating MBALs, but the analysis for any particular stock may result in one estimation method being preferred over another. Based on the comparative study there are a series of recommended steps which should be followed for the analysis of a given stock. Two example diagnostic sheets were prepared by the Working Group to illustrate the methods (Figures 3.4.2 and 3.4.3).

1) Shepherd, Ricker and Beverton and Holt stock-recruitment relationships should be fitted (using maximum likelihood or other statistical approach).

2) A replacement line at F = 0 should be calculated from the spawning biomass per recruit curve using growth, maturation and selectivity data. The replacement line is a line through the origin whose slope is given by the inverse of the spawning biomass per recruit at F = 0. Note that this replacement line assumes that growth and maturation schedules are constant over the entire range of spawning stock biomass including the "virgin" biomass level and usually requires extrapolation beyond the observed spawning stock biomass levels. These estimates of virgin biomass should be regarded as tentative and may only be appropriate for scaling the data.

3) The following MBAL estimates should be plotted on the stock-recruitment graph.

   a) the SSB at 50% of maximum recruitment on the fitted stock-recruitment relationship,

   b) the Serebryakov level using the 90th percentile of survival and the 90th percentile of recruitment,

   c) 20% of the virgin biomass estimated from the intersection of the replacement line and the fitted stock-recruitment relationship,

   d) 20% of the virgin biomass estimated from the intersection of the replacement line and mean recruitment.

4) Tabulate for each of these estimates the ratio of mean recruitment above and below MBAL. Estimation methods which show a clear reduction in recruitment below the MBAL are preferable. Graph the probability of recruitment in the upper and lower quartiles of the data over the range of observed spawning biomass.

5) Calculate the range of the data as a proportion of virgin biomass (using estimate d). A wider range of data provides a better basis for estimating MBAL. Note, however, that the estimate of virgin biomass should be viewed with caution because of the assumed stationarity in life history parameters extrapolated to higher stock biomass (see point 2 above).

6) Calculate and tabulate the linear slope of the data above and below each MBAL estimate assuming lognormal errors. Discard any slope estimates which include less than five data points. These slopes help one to judge whether the MBAL estimates are sensible as in Myers *et al.* (WP10). In general, if the slope below the MBAL estimate is positive and if the slope above is less than the slope below, the estimate is sensible. If the slope above is greater than the slope below, it is risky and if both slopes are negative it is over-conservative (Figure 3.4.1). The calculation of these slopes can be done over the range of observed biomass to indicate the most appropriate MBAL (Figures 3.4.2 and 3.4.3).

7) In general, if the slope over the entire range of data is negative, MBAL should be estimated at or slightly below the lowest observed spawning biomass. This should be interpreted in the light of the range of the data observed. In this circumstance it is expected that

only relatively high biomasses with respect to the estimated virgin level have been observed.

8) If the slope over the entire range of data is positive and only relatively low spawning biomass levels have been observed then MBAL should be above the highest observed spawning biomass.

9) MBAL estimates should be chosen only if they are sensible with respect to point (6) above using the slopes of the data either side of the estimates. The estimate should be at a point below which recruitment declines or the probability of good recruitment declines using the calculations in point (4) above. The MBAL estimate should be considered tentative if only a small range of spawning biomass has been observed.

10) If the fitted stock-recruitment relationship(s) are reasonable, i.e. do not result in extremely high slopes at the origin or predict maximum recruitment well outside the range observed, the estimate as in (a) above is to be preferred because it will not be so dependent on changing data and because it has the best theoretical underpinning. Note that the (a) estimate should still be compared to tests 7-9.

11) If the (a) estimate is judged to be unacceptable, the choice between b - d should be made using the criteria listed above.

3.5 Caveats

Stock-recruitment relationships are almost always very noisy and, therefore, long-time series are required in order to detect such relationships. For this reason assessment working groups should regularly run a final VPA as far backwards in time as possible (although such long-time series should not be used for tuning purposes).

One consequence of the use of such long-time series is that important environmental changes may have taken place during the period. For example, the Icelandic cod data include data from before, during and after the period 1965-1970. That particular period was one of severe ice conditions which are likely to have had major effects on the ecosystem from plankton upwards.

Such effects must be kept in mind when stock-recruitment data are analysed.

3.6 Future work

The estimation of stock-recruitment relationships is an important area for future work. The Working Group noted that inclusion of prior information to facilitate estimation of the slope at the origin is a particularly promising line of attack and should be considered in the near future. Some work along these lines done during the meeting gave promising results.

Some of the methods suggested in this section can easily be implemented using a ruler and a hand calculator. In order to implement maximum likelihood estimation of parameters within assessment working groups, programs need to be made available. A SAS program to estimate the parameters assuming lognormal errors in recruitment (i.e. using non-linear least squares on log R) would be adequate for this purpose.

3.7 Conclusions (stock and recruitment)

The analysis of stock and recruitment data carried out at the meeting showed that several of the novel methods tried out seem to be quite promising. In particular, the profiles of the probability of good and poor recruitment seem to capture many of the essential features, and may often assist in determining MBALs. The fitting of several stock-recruitment relationships paying proper attention to the error structure is also often informative.

The Working Group recommends that assessment working groups should regularly re-analyse stock and recruitment data and an example of a set of analyses which are likely to be useful are given in Figures 3.4.1 and 3.4.2. These analyses are commended to stock analysts as worth trying.

The Working Group wishes to record that the rather extensive analysis of these data would not have been possible without access to the database assembled and made available by R.A. Myers. The Working Group recommends that such data from ICES stocks be routinely collected and maintained in a standard format accessible on the Internet. The Working Group further recommends that the format be standardised with that used by other collection agencies and that data from as many other sources as possible (notably North America) also be kept in the ICES system.

4 Management advice

4.1 Risk analysis: generalities and indistinct terminology

In the last few years there has been considerable interest in extending scientific advice for fisheries management to take proper account of the uncertainty inherent in assessments of the state of the stocks and uncertainty about their future course (e.g., because of unknown future recruitment). These uncertainties mean that the effects of various management options and procedures can only be determined in terms of probabilities. The presentation to managers of the probability of various outcomes in terms of the state of the fishery and the resource for different management scenarios has been generally referred to as risk analysis, and several recent scientific meetings have been devoted to this subject (NAFO, 1991; Canadian Department of Fisheries and Oceans, 1992; Alaska Sea Grant, 1992). In the U.S., the National Marine Fisheries Service has set up a Risk Assessment Working Group to pursue the topic, and a Theme Session will be devoted to risk analysis at the 1993 ICES Statutory Meeting.

Several contributors to the Methods Working Group and to its e-mail conference prior to the meeting had pointed out that there is a substantial literature on decision theory and risk analysis which defines "risk" as the expected loss for a specified loss function. A loss (or conversely a utility) function quantitatively expresses the value a manager gives to different attributes. In a fishery context, a loss function may include the yield foregone compared to some reference level, spawning biomass or recruitment foregone compared to a reference level or economic measures of fishery performance over specified time scales. In decision theory, "risk" can only be evaluated when a loss or utility function has been chosen or, in other words, after the relative importance of attributes of the fishery and resource have been quantified.

In contrast to the decision theory approach, the term "risk" has been used more loosely in fisheries to mean "the probability of something bad happening" (Francis, 1991). Risk analysis under this usage would consist of the calculation of probabilities associated with stock abundance falling below a specified level within a given time period, for example. In other words, risk is the probability of an adverse event or a mishap resulting from management action (or inaction). The calculation of the probability of a mishap is, of course, conditional upon the type of variability included in the calculation and the risk is conditional upon the unspecified importance a decision maker (manager or scientist) attaches to the mishap.

The Working Group supports the need to avoid confusion in terminology, and in general agrees that it would be desirable for scientific advice for managers to go beyond simple calculation of the probability of a mishap in developing risk analyses in future. In some circumstances, it may be possible to conduct a formal analysis of expected loss with a specified loss (utility) function or functions or for a number of likely loss functions. This is to be encouraged. However, in other cases, it may only be feasible to present the probabilities of mishaps with respect to a number of measures of fishery and resource status without specifying tradeoff between them. It is quite clear that no rigid terminology for "risk" and "risk assessment" is likely to be widely accepted and fishery scientists in ICES will continue to use these terms to mean the probability of a mishap. As long as the advice given continues to evolve in such a way that methods are developed for incorporating uncertainty in the advice in a useful way that is interpretable by decision makers, the strict terminology is of secondary importance.

The Working Group found it convenient to refer to diagrams of probabilities of mishaps and benefits as "probability profiles" and recommends this usage. When presenting such diagrams, the conditional nature of the probabilities should be clearly stated; also, what time scale they apply over, what sources of variability have been included and what assumptions have been made. There are usually five types of uncertainty to be considered:

1) uncertainty in the parameters defining the current state of the stock.

2) uncertainty in the future values of relevant quantities such as recruitment.

3) uncertainty in specification of the models and their parameters defining the population dynamics (natural mortality rate, growth rate, etc.).

4) uncertainty in future assessments of the state of the stock.

5) uncertainty arising from imprecise management controls (TACs being exceeded for example).

In principle, it is desirable that all of these should be taken into account in a risk assessment, but it is still useful to perform the analysis on a subset in many cases. At present, few analyses include all sources of uncertainty, but many are available which describe only measurement error (1) or recruitment (2) uncertainty. These should be regarded as an important step forward and are to be encouraged rather than criticized for leaving some factors out.

Another important point is that assessments of the probabilities of mishaps, and the losses associated with them, are important in their own right. While a logical next step may be to minimize expected losses to determine a "risk averse" strategy in a decision theoretic approach, it may be more useful in giving scientific advice to managers to evaluate the contributions to overall loss (or utility) separately or, in other words, to produce probability profiles of important attributes. The Working Group considers that a major effort is required to implement methods for probability profiling as a regular component of stock assessments.

Probability profile studies can take two forms because there is a concern both for the short-term possible outcomes of management measures and the long-term robustness of management strategies.

4.2 The short-term possible outcomes of management measures

It is well recognized that the results from fisheries assessment methods suffer from three sources of uncertainty. There is imprecision in the data, uncertainty in the model assumptions and variability in the estimates (the model predictions do not match the data precisely). Probability profiles can show the effects of this uncertainty on the distribution of parameter estimates. For example, the distribution of projected catch values reflects the probability that the fishing mortality resulting from a given total catch will be greater than the target fishing mortality.

The calculation of probability profiles can be done in many ways. Analytical methods calculate the distribution of the parameter estimates by assuming a distribution shape for the errors in the input data and calculating an approximation of the resulting non-linear estimation variance and covariance. Parametric resampling methods (Monte-Carlo) also assume a distribution for the variability in the input data but get the distribution of the estimated parameters by generating random realizations from the assumed distribution of the input data. Non-parametric re-sampling methods produce new random input data by adding to the corresponding predicted value an error selected randomly from the original empirical distribution of the residuals. Many combinations of these methods are possible (Restrepo *et al.*, 1992).

4.2.1 Sensitivity analysis

Sensitivity analysis is not directly related to the question of estimating probability profiles but is relevant in so far as it considers the effect of uncertainty in model input (the parameters) on model output (or state variables). Calculating the probability profile of projected catch, for example, can be thought of as estimating how much the effect of uncertainty in the current population affects the predicted catch (the state variable). A particular method, the Fourier Amplitude Sensitivity Test (FAST) (Cukier *et al*, 1978) seems appropriate in this context. The analysis requires that for each parameter (eg fishing mortality or population size) a range of uncertainty be defined. The method then chooses sets of parameter values from the uncertainty ranges according to specific criteria so that a full range of combinations of parameter values is sampled. The choice of parameter sets is such that the amount of variability in the state variable can be partitioned analytically into the contribution from each parameter. Thus it is possible to determine which parameters contribute most to the variability in the state variable. By choosing uncertainty ranges which correspond to the variances of the parameters the method will also give estimates of the variance of the state variable. This variance could be used to plot a probability profile provided the frequency distribution of the input parameters is realistic.

FAST is not strictly an appropriate technique for calculating probability profiles but it may be useful in determining a suitable formulation for doing so. By performing FAST first, it may be possible to simplify a simulation study by eliminating those parameters which contribute very little to the state variable. As can be seen in the example in Section 4.2.5 below, if it can be shown that only a few parameters contribute to the variability of projected catch then the estimation of variance of unimportant parameters may be unnecessary.

4.2.2 Covariance matrix from statistical analysis of catch-at-age data

The covariance approach is a very simple three step procedure that requires the fitting of a statistical model to the data. The steps are:

STEP 1: Carry out an assessment using the chosen statistical model.

STEP 2: Calculate the parameter covariance matrix. This can usually be done directly from the Hessian matrix which forms part of the minimization procedure (e.g. see Seber and Wild, 1989).

STEP 3: Translate the parameter covariance matrix into the variance of the desired quantity. This can often be done using a linear approximation method such as a delta method (a finite difference approximation).

Many analyses of catch-at-age data involve the fitting of a statistical model with an explicit objective function. The assumptions about the error structure of the data and the fitting procedure generally permit the estimation of the parameter covariance matrix. Examples of existing methods in which this is in principle possible are ADAPT (Gavaris, 1988), CAGEAN (Deriso *et al.*, 1985), Time series analysis (Gudmundson, WP8) and XSA (Shepherd, 1991a). Given this matrix it is possible to estimate the variance of any quantity derived from the parameters using, for example, a delta method. Thus, in the case of ADAPT, for example, the variances of the survivors can be used directly to compute the variance of the predicted yield given an estimate of recruitment and its variance.

One of the main advantages of this approach is that of speed, since alternative methods using bootstrapping or simulation can take considerable computational time. However, considering only the variability in the estimated parameters can result in underestimation of all the uncertainty contributing to the variability of the calculated quantity. Natural mortality, for example, is seldom estimated from catch-at-age analysis but must certainly contribute to the variability of projected populations and yield. Covariance matrices calculated from non-linear minimization may also be poor estimators of the true distributions.

4.2.3 Uncertainty estimates from Monte Carlo simulation of the assessment process

Monte Carlo simulation is a generalized method for obtaining uncertainty estimates from any model. Restrepo et al. (1992) describe the use of such simulations in quantitative stock assessments and their application in obtaining probability profiles for management recommendations. The basic Monte Carlo procedure is as follows:

STEP 1: Quantify the uncertainty in the inputs used for the assessment. This can often be achieved from statistical analyses of the raw data. For instance, variances can be estimated for the catch estimates and for the abundance survey estimates that go into the VPAs. In some cases, however, uncertainty in the inputs cannot be estimated statistically. For example, natural mortality is often input as an assumed quantity, not an estimated one, and thus the uncertainty associated with it must also be assumed. In addition to obtaining the variance estimates for the inputs, Monte Carlo simulation requires an idea about the shape of the input error distributions. Often these follow from statistical theory (e.g. the catch compositions at age are sometimes assumed to follow a multinominal distribution, and the abundance indices may be lognormally distributed). In other cases, the shapes of these probability density functions (pdf's) must be assumed (e.g. the uncertainty in M may be uniformly distributed, implying that all values within a range are equally likely).

STEP 2: Repeat the assessment process numerous times drawing random sets of inputs. The objective of this is to generate a large number (e.g. 1000) of plausible data-sets by drawing values at random from all the input pdf's. Then, for each data-set, the entire assessment is carried out with the model being used (e.g. Separable VPA, XSA, ADAPT, etc.). The end result of this step is the production of a large number of plausible assessment results.

STEP 3: Repeat all additional analyses and projections for each set of assessment results. Additional results may include the computation of the current status of the fishery with respect to common reference points (e.g. what is the ratio of current F to $F_{0.1}$?). The current F is available from each set of results in step 2; the reference point can also be estimated for each set by using the set-specific values of the variables required. For instance, to compute $F_{0.1}$ one would need the set-specific values of M, the current selectivity pattern and the weight-at-age vector. For each set one would then compute the ratio $F_{status\ quo}/F_{0.1}$ and the distribution of these values would describe the uncertainty in the ratio. The same process is followed for the projections upon which scientific advice will be based. The projections are carried out in the same manner as for the point estimates, once for each data-set obtained in step 2. Here it is again important to keep track of set-specific values that affect the outcomes (e.g. M). Recruitment forecasts used for the projections should also be associated with a variance. The simplest way to do this with few assumptions is to pick randomly one of the recruitment values estimated in the assessment process. Alternatively, one could fit a stochastic stock-recruitment relationship to the estimated time series in each data-set, and generate recruitment forecasts from that model.

A main advantage of Monte Carlo simulation in this context is that it is a very flexible way to account for possible departures from model assumptions. Another advantage is that it is a method to obtain uncertainty estimates for models that do not have an explicit objective function in a statistical minimization framework (e.g. *ad hoc* tuning). The main disadvantages of Monte Carlo simulation for use in working groups are that a) many decisions and analyses must be made in preparing the information about input uncertainty distributions and b) they are very intensive computationally, with a single run requiring several hours on a fast PC.

4.2.4 Uncertainty estimates from bootstraps

Bootstrapping (Efron, 1982) is related to Monte Carlo simulation but requires many fewer assumptions. Estimates of the uncertainty in the assessment are obtained from the model fit to the data rather than being dependent on the specification of uncertainties for all inputs. The basic bootstrap procedure is as follows:

STEP 1: Carry out the base assessment. Obtain the initial model fit and compute the residuals (e_{ij}).

STEP 2: Generate numerous data-sets by resampling the residuals. The non-parametric way of doing this is to generate new observations from

$$y_{obs_{ij}} = y_{pred_{ij}} + e_{ik} \qquad (1)$$

In this case y_{ij} may refer to the jth value of the ith available index of abundance. The new *y* observations are thus obtained by adding the predicted *y* and a residual chosen at random from the set estimated in step 1. The parametric way of doing this is to assume a distribution type for the residuals in step 1 (e.g. lognormal) and estimate the mean and variance for their distribution. The resampling would then be carried out by randomly
choosing residuals drawn from this distribution rather than from the limited set of observations in step 1.

STEP 3: Repeat the assessment process for each data-set.

STEP 4: Repeat all additional analyses and projections for each set of assessment results. This and the preceding step are identical to the last two in the Monte Carlo procedure. Note, however, that many of the variables (e.g. M and all other data considered to be fixed) will not change in value from data-set to data-set.

The bootstrap procedure, like Monte Carlo simulations, can be used for methods without an explicit statistical objective function. The bootstrap is less flexible in the sense that it is still conditional on most inputs being known precisely; in this sense it is very similar to the method in Section 4.2.2. However, the bootstrap can be used with very few assumptions, especially if non-parametric resampling is carried out as in step 2 above. In terms of speed, bootstraps are computationally intensive like Monte Carlo simulations.

4.2.5 Examples of probability profiles for North Sea cod

In order to exemplify the methods described in the previous sections, probability profiles were calculated for a simulated projected catch of North Sea cod in 1992 given catch at age data and research vessel survey data for 1982-1991 from ICES. (1993b). The software available at the meeting was such that it was necessary to limit the analysis to ages 3-10 so as to achieve some comparability between methods. Thus, this simulation does not correspond to the accepted forecast for this stock but simply illustrates the methodology.

For the covariance method recruitment in 1992 at age 3 was taken as the geometric mean recruitment estimated for the previous ten years and the sample variance used for an estimate of its uncertainty. For the Monte Carlo and bootstrap methods recruitment was selected at random from the ten previous recruitment values. In a second set of runs recruitment was selected as the geometric mean of the last ten estimated recruitment values in the Monte Carlo and bootstrap methods, and a variance equivalent to this procedure used on the covariance method. This simulated recruitment was estimated with high precision. The probability profile plotted was the cumulative probability distribution of the projected catch at *status quo* fishing mortality. It is equivalent to the probability that the fishing mortality in 1992 will be greater than the fishing mortality in 1991. This is because the probability of a given catch from the distribution is equal to the probability that F=F*status quo*.

The analysis of the cod data is for illustration only and is not intended for any other purpose.

Fast Analysis: Uncertainties in the input parameters are given in Table 4.2.1. These give an uncertainty range of plus or minus two standard deviations. Results of the sensitivity analyses are shown in Figure 4.2.5.1. The results show that for high recruitment variance, the variability in the catch is due almost entirely to recruitment. When recruitment variance is low, the uncertainty in the population estimate at age 3 becomes important. This means, in the case of high recruitment variance, that all the methods are likely to perform similarly since they all made a similar assumption about recruitment.

Covariance method:As an example, a particular statistical model has been used here to estimate the covariance matrix using the methodology described in Cook *et al.* (1991). It assumes that all the errors are in the catches. Briefly, the model is based on the assumption that fishing mortality F is a product of a year effect, f, and an age effect, s, so that;

$$F_{ay}=s_a f_y \qquad (2)$$

where *a* and *y* are subscripts for age and year respectively. It is then possible to write down the catch, C_{ay} in terms of F_{ay} and recruitment, R, in year *y-a+1*, ie

$$C_{ay}=g(s_a f_y, R_{y-a+1}) \qquad (3)$$

Subject to certain constraints the parameters can be estimated by minimizing the sum of squares;

$$\sum_a \sum_y [\log(\overline{C_{ay}})-\log(C_{ay})]^2 \qquad (4)$$

This model has many parameters so the covariance matrix is very large. For reasons of space, only the CVs of the Fs and populations in 1991 are given in Table 4.2.2. It is important to understand that the estimated CVs are conditional on the model assumptions and constraints. These are elaborated in Cook *et al.* (1991).

Bootstrap and Monte Carlo methods: The bootstrap and Monte Carlo methods repeated an ADAPT assessment with varying inputs. The parameters estimated were the 1992 populations at ages 4 to 7 and the age-specific catchability for all indices. The fishing mortality for ages 7 to 10 in 1991 were constrained to be the same as for age 6. Within each iteration the recruitment for catch projections at *status quo* fishing mortality was chosen at random from the estimated recruitment of previous years.

For the Monte Carlo simulations the natural mortality was chosen uniformly at random between 0.14 and 0.28, the catches were assumed to be distributed lognormally with CVs between 3 and 10 percent and the abundance indices were also assumed to be lognormal with CVs of 40 percent.

The resulting CVs in the terminal year are given in Table 4.2.2.

The estimated probability profiles from the methods are shown in Figures 4.2.2 and 4.2.3. When recruitment has high variance, the profiles are all very similar both in their location and slope. For the bootstrap and Monte Carlo methods, the profiles show inflexions. This is due to the fact that, as applied here, these methods draw on an empirical frequency distribution for recruitment taken from the estimated recruitment in the VPA (see Figure 4.2.4). Only ten values were used in the data-set which is unlikely to give a smooth frequency distribution. In the covariance method, recruitment was assumed to be lognormal. The principal reason for the similarity of the profiles is the fact that the recruiting age group dominates the catch in this example. Hence its variability dominates the calculations as adumbrated in the sensitivity analysis.

When recruitment variability is low (Figure 4.2.3) the bootstrap and Monte Carlo methods still agree very closely and, not surprisingly, give a much steeper profile. The covariance method is still similar but has a noticeably lower slope. This is due to the fact that the particular model used in the covariance method only uses the catch data and so there is very little information in the data on the youngest age in the most recent year. This age group, therefore, has a high estimated variance. Since it makes an important contribution to the projection (Figure 4.2.1) it makes a large contribution in the probability profile.

Despite important differences in the methods applied here, the estimated profiles are very similar which is encouraging. It does not mean, however, that this would be generally true. The covariance approach would be a desirable tool to use in working group environments because of the speed of computation. However, the use of such a method should be supported by more thorough studies involving Monte Carlo and bootstrap studies where a more comprehensive investigation of uncertainty can be made.

4.3 Medium-term projection and advice

4.3.1 Methods for medium-term simulations

Management strategies can be very complex, and can involve many regimes, exceptions and complex interactions. The only way to assess the long-term performance of management strategies on such systems is via simulation. Detailed simulations will require the modelling of fish stock dynamics, management measures and the resulting exploitation behaviour. This exercise may help to identify more precisely the consequences of a particular strategy.

Medium-term simulations should be stochastic and explicitly include variability in (a) the current status of the stock, and (b) the likely trajectory of future recruitment. Uncertainty in current stock status can be estimated with any of the methods in Section 4.2. Owing to the dangers involved when assuming that recruitment is independent of stock size, the simulated future recruitment should be drawn from a stochastic stock-recruitment relationship. Such a relationship can be obtained by fitting a relationship to the data and estimating the variance around the fitted relationship (see Section 3) or using kernel methods (Evans and Rice, 1988; Skagen, 1991; Cook and Forbes, WP2). The projections should be made so that each stock size trajectory will differ from the others due to random outcomes.

In their simplest form, these simulations can be used to examine the medium-term performance of simple management strategies. For instance, one can estimate the probability that the stock will go below a threshold level at least once during a 20-year period, given that it continues to be fished at F*status quo*. Such projections would be carried out in a manner analogous to Step 1 of Section 4.2.3.

More complicated simulations are required to evaluate the medium- and long-term performance of management strategies under more realistic situations. It is likely that the management measures taken from year to year over a medium-term horizon will vary, depending on the perceived status of the stock every few years. Thus, it is important that the future assessments of the stock be simulated as well. There are many ways to simulate this interaction between future stock status and future management measures and only two are provided in the paragraph below. Note that other components of the simulation (uncertainty in current status, stock-recruitment) should be taken into consideration as explained at the beginning of this section.

(A) **Without actual assessment updates.** At any point in time in the simulations, the status of the stock will be known (i.e., the software should keep track of all state variables of interest such as abundance, catches, age structure, etc.). The perceived stock status at that point in time can be generated by drawing from a distribution of possible estimates. For instance, if the fishing mortality for a given trajectory in year 2000 is F = 1.2, one could randomly draw an estimated F from, say, a lognormal distribution with mean 1.2 and CV = 0.2. This estimate of F would be used in place of an assessment. Then, given the known catch, one could estimate the corresponding stock size. Depending on that perceived outcome, the management regulation for the following simulation year would be decided.

(B) **With actual assessment updates.** This would be similar to (A) above, except that the simulated data would be used as input to an assessment model. Since uncertainty should play an important role, these inputs should be subjected to measurement error (e.g. the catch or relative abundance would be sampled from distributions centred around the simulated value). The assessment results would then provide a perceived estimate of stock status which would in turn affect the following year's management advice.

A particular advantage of method (B) over method (A) is that the former can more easily track the benefits of an increasingly longer time series of data in terms of reducing assessment uncertainty. In this sense, method (B) can more realistically simulate flexible management control laws (Section 4.4).

4.3.2 Assessment working group advice

In the light of the current state of most fish stocks assessed by ICES, it is clear that simple short-term advice does not cover all aspects of the problem. Short-term advice captures the fact that many stocks are overexploited according to any reasonable definition of the term. However, this form of advice does not capture the fact that a fairly large number of stocks show a stock-recruitment relationship. Thus, higher yields would be expected at higher stock sizes. The effect of such relationships would be expected to appear within a few years of a build-up of the stock. Medium-term advice should, therefore, be considered a regular part of the work done by assessment working groups.

In order to implement medium-term advice, it will be necessary to make software available to do the relevant computations. The Methods Working Group noted that software already exists for this purpose (see Section 4.3.1), but this software needs to be modified and adapted to the specific output recommended in this report (see Section 4.3.3).

The Methods Working Group, therefore, recommends that an *ad hoc* study group led by R. Cook (Aberdeen) be set up to develop the medium-term prediction and simulation software as indicated in this report in order that the assessment working groups may be able to make use of it as a regular part of the assessments.

Output from the software should include (but not be restricted to) expected annual yields and spawning stock sizes for the time period in question along with fractiles of the distribution of these estimates.

4.3.3 Presentation of medium-term management advice

The Working Group considers that the medium-term consequences of the various management options are not very clear in the present form of the advice of ACFM, and suggests that some improvements could be made. The present section commencing "Continued fishing at current levels of fishing mortality" often simply repeats in words information already presented in the option table, and could be replaced by a new section on the medium-term "consequences". In the immediate future this could simply contain text setting out the expected consequences along the following lines.

"Medium-term Projections"

> Over the next five/ten/fifteen years the consequences of these management options are likely to be:
>
> A: Gradual recovery of SSB to levels above the MBAL after three or four years provided recruitment improves from the current low level.
>
> B: SSB remains close to the MBAL for the foreseeable future.
>
> C: Continued decline of SSB to levels well below the MBAL with increased risk of recruitment failure."

These statements have been framed making reference to MBAL, but this concept needs to be critically reviewed (see Section 3).

In some cases sufficient information already exists in the Working Group reports for this to be done in the near future. In other cases ACFM would need to request the assessment working groups to prepare and present the necessary catch forecasts. The use of deterministic forecasts for this purpose is, however, really rather unsatisfactory, as they often (but not always) depend crucially on unknown future recruitment. As described above and in Section 4.2, methods for preparing appropriate stochastic forecasts are now available, and the Working Group recommends that ACFM should encourage assessment working groups to adopt and use these methods as soon as possible (see Section 4.3.2).

It should be stressed that these forecasts need to take account of the uncertainty of recruitment, by Monte Carlo methods, and should incorporate the information on the probability distribution of recruitment at the appropriate stock levels as described in Section 3, thus taking due account of any stock-recruitment relationship indicated by the data.

When the results of such forecasts become available, it would be possible to expand the section in the ACFM report on medium-term projections considerably.

A suggested presentation of the results of such calculations is given in Figures 4.3.1-4.3.5. These give the trajectories of medium-term yield and SSB under various selected management options, with the uncertainty indicated by the appropriate upper and lower percentiles, e.g. quartiles. In addition to this it is suggested that estimates of the inter-annual variability of yield (as percentage change), and the cumulative yield over the selected time horizon should be given for each option. This would provide a much firmer basis for the textual advice proposed above, which should probably be retained.

The Working Group recognises that this could expand the ACFM report by around half a page or a full page for each stock for which it is done, but considers that this would not be inappropriate if it assists in conveying an important message which is currently not reaching managers at all clearly.

4.4 Management procedures

The development of "management procedures" for the management of fish stocks recognizes that this process involves more than assessment exercises. Esséntially four steps are involved in the actual overall process:

i) the stock "generates" data each year (e.g. catch-at-age data, CPUE, survey results);

ii) these data are input to an assessment process which estimates *(inter alia)* the size and productivity of the resource;

iii) the results of the assessment process are used to formulate a control measure, such as a TAC (through a "catch control law") or a fishing effort level;

iv) the control measure impacts the dynamics of the stock, and hence the results of i - iii when the whole procedure is repeated each following year.

The management procedure approach argues that all these steps have to be considered, and in combination rather than separately. This is both because of the interaction between the steps, and because the anticipated consequences of certain management measures can sensibly be considered only in terms of their application and updating over a period of time rather than for a single year only.

Alternative candidate management procedures are evaluated by means of computer simulation (e.g. ICES. 1990), which mimics steps i) - iv) above. Thus:

a) a computer model of the stock and fishery is developed, which each "year" generates data of the form available for the actual fishery - thus, for example, survey results are output, which incorporate typical measurement errors;

b) an updated assessment of the stock is calculated each simulated "year" from the data generated and those data only (the "assessor" does not know the true state of the stock) - by means of VPA, for example;

c) the control measure is calculated each "year" from the results of b) - an $F_{0.1}$ TAC for example;

d) the TAC, say, is fed back to the computer model of the stock, where this information is used in updating the numbers at age for the following year.

Steps a) - d) are repeated for a number of years chosen to be appropriate for the time-scale of the stock's dynamics: 10-20 years would be appropriate for most fish species. At the end of this simulation period, the computer model of the stock provides information on its true status to allow statistics of the anticipated performance of the management procedure to be developed. Typical such statistics might include the spawning stock biomass at the end of the period, the total catch taken during the period, and the extent to which the catch taken (or fishing effort applied) has varied from one year to the next.

Eventually, managers have to select between different candidate procedures on the basis of the trade-offs which they exhibit between such attributes. The simulations need to be repeated a number of times because of stochastic effects - recruitment variation and measurement errors, for example - so that performance statistics are expressed as parameters (means or percentiles) of the resultant distributions of values for chosen attributes.

This evaluation process provides a framework to take explicit account of the inevitable uncertainties in the state of knowledge of a resource. Although primary calculations to choose a procedure make use of a computer model of the stock which is based on the current "best" assessment of the resource, it is essential that they be repeated for plausible variations of this assessment. The purpose of such "robustness tests" is to determine whether the procedure under consideration provides performance statistics which are reasonably insensitive to such variations (which should reflect the degree of uncertainty - both structural and as regards the imprecision of parameter estimates - in the current "best" model of the resource).

The Working Group noted that there has recently been increased interest in the possibility of using defined management procedures within the ICES area (Horwood and Griffith, 1992). It was noted that techniques now exist for the evaluation of candidate management strategies according to multiple criteria as discussed above. The Working Group considers that the development of longer-term management strategies is possible and much needed, and recommends that within ICES the subject should be carried forward by the Working Group on Long-Term Management Measures.

5 Report review

5.1 Earlier reports of the Working Group on Methods of Fish Stock Assessment

The results in this report demonstrate that the statement in the report of the 1989 meeting (ICES. 1993c) that methods such as TSA which do not use CPUE/survey data "have no chance of detecting sharp changes of fishing mortality in the last year" is incorrect: TSA1 in particular detects such changes with remarkable accuracy. Clearly such methods have considerable practical potential, and the Working Group would strongly support work to produce a version of this method which could be used operationally.

5.2 Report of the Planning Group for the Development of Multispecies, Multi-fleet, Assessment Tools

The Planning Group had basically two questions to address:

a) The dissemination of multi-species tools to area-based working groups and,

b) The definition of fleets, data formats and analytical software for area-based working groups.

It became clear at an early stage of the Planning Group meeting that the terms of reference could not be dealt with as they stood because of resource implications in national institutes and in the ICES Secretariat. In the case of multi-species software, for example, only one institute had the expertise and resources for development and much of this was being funded externally. It was not felt that other institutes could commit resources to the project. Furthermore, the most commonly used multi-species tools are very data demanding and presently only exist for the North Sea and Baltic areas. This means that only two assessment working groups would be able to benefit from new software. Thus, it did not appear to be a priority to devote international resources to this type of development.

So far as analytical software was concerned the Planning Group pointed out that the main needs are in short-term prediction and long-term analysis. Forecasting programs need to be better interfaced with other analytical software. Long-term (multi-species) analysis is required but should be developed under the umbrella of the Working Group on Long-Term Management Measures.

In the case of fleet definitions and data formats for area-based groups, it became clear that the existing data storage format within IFAP was not suitable for the development of a fleet-based data structure. The design of a new data structure has substantial implications for IFAP. The Planning Group did not feel able to pursue this issue since the IFAP steering group would need to be involved. In view of the development of an SAS-based data management system by the Danish Institute for Fisheries and Marine Research (DIFMAR), which is to be fleet-based, it appeared prudent to await the completion of that package before subjecting IFAP to substantial re-development. This package should be completed by the end of 1993 as part of an EC-AIR contract. In the meantime it would be better to concentrate resources on optimising the performance of the present IFAP system. The Planning Group suggested that area-based working groups should also consider a simplified STCF exchange format as a basis for the exchange of their own data.

The Methods Working Group generally endorsed the conclusions of the report.

5.3 Report of the Workshop on the Analysis of Trawl Survey Data

Aspects of the work carried out by the Trawl Survey Workshop have been discussed under Section 2.2. The Working Group recommends that the report, edited by G. Stefánsson, should be published in the Cooperative Research Report series.

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WP1. Cook, R. M., and Reeves, S. A. An assessment of North Sea industrial fish stocks with incomplete catch-at-age data.

WP2. Cook, R. M., and Forbes, S. T. Unsafe biological limits for North Sea cod.

WP3. Beek, van, F. SPLIR, a risk analysis model to assist in finding appropriate long term levels of fishing mortality.

WP4. Butterworth, D. Current initiatives in the management of the S.A. anchovy and Antarctic krill resources.

WP5. Pope, J. G. Thoughts on the stability of estimates of F_{med}/F_{low} and F_{max}/F_{now} relative to changes in natural mortality.

WP6. Pope, J. G. A consideration of ways of introducing stock recruitment constraints into pragmatic fisheries management.

WP7. Fryer, R., Cook, R., and L. Hastie. The B Team talk about shrinkage.

WP8. Gudmundsson, G. Time series analysis of catch at age data without effort measurement.

WP9. Gudmundsson, G. Applications of recruitment indices.

WP10. Myers, R.A., Rosenberg, A. A., Mace, P., Barrowman, N., and Restrepo, V. In search of recruit ment overfishing thresholds.

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Table 2.1.1 'Theoretical' CVs for Western Channel Sole

	Age 3	Age 4	Age 5
1978	0.05	0.14	0.01
1979	0.14	0.12	0.08
1980	0.21	0.19	0.19
1981	0.25	0.22	0.26
1982	0.38	0.33	0.29
1983	0.41	0.39	0.24
1984	0.33	0.33	0.18
1985	0.39	0.38	0.22
1986	0.34	0.34	0.19
1987	0.05	0.05	0.02
1988	0.16	0.15	0.08
1989	0.37	0.36	0.20

Table 2.2.1 Western Channel Sole RCT data.

```
"Western Channel sole recruits"
6,14,2  ,"(no. surveys, no. years, vpa col no.)"
1978, 4924, -11, -11, -11 ,   11, -11  , -11,
1979, 8441, -11, -11, 272,  135, -11  , -11,
1980, 4773, -11, -11, 107,   77, -11  ,  408,
1981, 3873, -11,  50, 200,    3,  260,  127,
1982, 6034,  41,  69,  46,    2,  331,  204,
1983, 6580,  45, 122,  38, -11 , 1386,  376,
1984, 3368,  21,  49, -11 , -11 ,  220,   90,
1985, 5251,  30,  57, -11 , -11 ,  497,  141,
1986, 3080,  17,  44, -11 ,    4,  420,   96,
1987, 2968,  20,  25,  36,    8,  823,  180,
1988, 2168,  17,  27,   2,    8,  290,   82,
1989,-11,    79, -11, 777,   25,  530,  229,
1990,-11,   -11, -11,  25,   21,  447,  450,
1991,-11,   -11, -11,  46, -11 ,  170, -11,
UK7e2
UK7e3
Fr7d0
Fr7d1
UK7d0
UK7d1
```

Table 2.2.2 Western Channel Sole (VIIe). RCT3 Retrospective Analysis.

Year-Cl	VPA	CAL +SH	CAL NSH	FUN +SH	FUN NSH	PRED +SH	PRED NSH
1984	3368	5222	2368	5109	3334	5220	4045
1985	5251	4566	4257	4575	4348	4615	4420
1986	3080	3598	3284	3770	3540	3914	3718
1987	2968	3744	3533	3877	3727	4006	3886
1988	2168	2933	2675	3073	2881	3275	3116
1989	7631	8728	10494	7513	8325	6829	7358
1990		5289	6193	4955	5208	4692	4802
1991		3913	3071	3790	3303	4007	3755
RMSLR 84-89		0.258	0.241	0.267	0.180	0.300	0.225

Table 2.2.3 Irish Sea Plaice RCT data.

```
"Irish sea plaice recruits"
6,18,2  ,"(no. surveys, no. years, vpa col no.)"
1974,11180,-11,-11,-11,352,473,-11,-11,-11,
1975,17254,-11,308,726,1775,1711,8.18,-11,-11,
1976,19167,78,877,190,1648,650,14.56,-11,-11,
1977,23226,32,641,1110,1744,3018,6.06,-11,-11,
1978,20768,237,348,4046,5588,1161,19.09,-11,-11,
1979,15585,757,3003,2330,1925,1897,3.37,-11,-11,
1980,8497,17,98,323,940,844,3.4,-11,-11,
1981,21525,18,585,3125,1371,1538,12.9,-11,-11,
1982,21330,1250,1195,4061,1796,2358,22.18,-11,-11,
1983,22422,262,1983,2995,2208,1683,-11,-11,-11,
1984,16235,508,2635,2649,2281,970,17.9,-11,-11,
1985,18995,430,2520,2246,1959,2145,19.71,-11,-11,
1986,20025,1033,2074,4886,4264,2945,29.71,-11,29776,
1987,10945,173,2624,4053,2961,914,38.78,12727,11168,
1988,5797,397,506,553,610,134,14.01,5998,6985,
1989,-11,31,438,271,480,-11,9.65,24855,14079,
1990,-11,216,873,-11,-11,-11,8.31,11052,-11,
1991,-11,-11,-11,-11,-11,-11,40.37,-11,-11,
"ssoct0"
"ssjun1"
"ssoct1"
"ssjun2"
"ssoct2"
"irmay1"
```

Table 3.2.4 Irish Sea plaice. RCT3 Retrospective Analysis.

Year-Cl	VPA	CAL +SH	CAL NSH	FUN +SH	FUN NSH	PRED +SH	PRED NSH
1980	8497	16403	15694	15712	15160	17566	17604
1981	21525	17343	18797	17172	17700	16746	17032
1982	21330	22490	29080	21434	23430	19234	20047
1983	22422	21001	25207	20230	21477	18875	19424
1984	16235	21207	23609	20420	21217	19264	19643
1985	18995	22060	25680	20853	21826	19331	19743
1986	20025	26646	35072	23842	25770	20944	21692
1987	10945	21173	23577	20228	20867	19170	19455
1988	5797	10753	5287	13125	12058	15017	14613
1989		9738	4166	10886	9382	13584	13046
1990		15360	11361	15198	14740	15798	15798
1991		16723	1186595	18626	30174	16378	17402
RMSLR 80-88		0.405	0.428	0.418	0.407	0.457	0.452

Table 3.2.5 Icelandic cod RCT data.

Icelandic COD. Predicting 3-group.
5 12 2

'Ycl'	'VPA'	'CPUE'	'SUR4'	'SUR3'	'SUR2'	'SUR1'
1980	229	30	-11	-11	-11	-11
1981	141	170	50	-11	-11	-11
1982	145	210	29	38	-11	-11
1983	336	1620	79	96	46	-11
1984	299	760	95	111	53	180
1985	175	60	55	82	31	160
1986	86	30	16	27	11	50
1987	159	20	34	26	27	40
1988	-11	70	28	30	17	70
1989	-11	-11	-11	46	23	90
1990	-11	-11	-11	-11	25	60
1991	-11	-11	-11	-11	-11	20

Table 2.2.6 Icelandic Cod. RCT Retrospective Analysis.

Year-Cl	VPA	CAL +SH	CAL NSH	FUN + SH	FUN NSH	PRED +SH	PRED NSH
1984	299	222	426	225	314	217	263
1985	175	228	234	225	228	227	231
1986	86	126	66	132	90	143	109
1987	159	138	132	139	134	143	138
1988		123	117	128	123	131	127
1989		156	152	158	154	159	155
1990		163	159	163	160	164	161
1991		157	44	153	63	157	82
RMSLR 84-87		0.285	0.280	0.294	0.161	0.332	0.206

Table 2.2.7 North Sea Herring RCT data.

```
Herring in North Sea +IIIa - 1 ringers
1 11  2
1980   85610  1293
1981  169767  1797
1982  153421  2663
1983  158214  3416
1984  275885  3667
1985  335217  5717
1986  278343  4192
1987  152919  3468
1988  176851  2146
1989  119454  2433
1990    -11   2339
IYFS-1rg
```

Table 2.2.8 North Sea herring – 1 ring/IYFS RCT3 Retrospective Analysis.

Year-Cl	VPA	CAL +SH	CAL NSH	FUN +SH	FUN NSH	PRED +SH	PRED NSH
1984	275885	150186	238354	151264	203725	148333	182057
1985	335217	208865	437840	209553	358699	201346	305523
1986	278343	231465	273946	228463	261098	223223	250201
1987	152919	214288	226356	212860	222430	210781	218959
1988	176851	149344	129066	151434	135955	155202	142145
1989	119454	165441	153458	166725	158045	169026	162000
1990		155304	141456	156801	146984	159555	151717
RMSLR 84-89		0.382	0.261	0.380	0.254	0.395	0.278

Table 2.2.9 Northeast Arctic Cod RCT data.

NORTHEAST ARCTIC COD : recruits as 3 year-olds (inc. data for ages 0, 1, 2 & 3)
16, 35, 2 (No. of surveys, No. of years, VPA Column No.)

YEAR	EFFORT	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1957	791	-11	-11	-11	-11	120	160	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11
1958	919	-11	-11	-11	-11	160	240	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11
1959	730	-11	-11	-11	-11	180	140	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11
1960	473	-11	-11	-11	-11	90	190	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11
1961	339	-11	-11	-11	-11	20	20	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11
1962	778	-11	-11	-11	-11	70	40	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11
1963	1583	-11	-11	-11	-11	210	1200	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11
1964	1293	-11	-11	-11	-11	490	450	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11
1965	170	-11	-11	-11	-11	10	10	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11
1966	112	-11	-11	-11	-11	20	10	20	-11	-11	-11	-11	-11	-11	-11	-11	-11
1967	197	-11	-11	-11	-11	10	10	40	-11	-11	-11	-11	-11	-11	-11	-11	-11
1968	405	-11	-11	-11	-11	70	10	20	-11	-11	-11	-11	-11	-11	-11	-11	-11
1969	1016	-11	-11	-11	-11	110	60	250	-11	-11	-11	-11	-11	-11	-11	-11	-11
1970	1818	230	640	600	420	700	850	2510	-11	-11	-11	-11	-11	-11	-11	-11	-11
1971	525	70	90	60	30	370	240	770	-11	-11	-11	-11	-11	-11	-11	-11	-11
1972	622	50	40	340	150	540	170	520	-11	-11	-11	-11	-11	-11	-11	-11	-11
1973	614	160	50	150	20	700	50	1480	-11	-11	-11	-11	-11	-11	-11	-11	-11
1974	348	10	10	40	10	60	10	290	-11	-11	-11	-11	-11	-11	-11	-11	104
1975	639	600	10	440	10	930	40	900	-11	-11	-11	-11	-11	-11	-11	8820	797
1976	199	10	10	10	10	40	10	130	-11	-11	-11	-11	-11	-11	450	2350	109
1977	140	10	10	20	10	20	10	490	-11	-11	-11	-11	-11	-11	280	140	-11
1978	158	10	20	10	10	10	30	220	-11	-11	-11	-11	-11	-11	160	-11	58
1979	158	10	10	10	10	10	80	400	-11	-11	-11	-11	-11	-11	-11	730	71
1980	169	10	10	10	10	10	80	130	-11	-11	232	-11	-11	107	30	40	17
1981	386	10	10	10	10	40	40	100	-11	177	1220	-11	268	73	10	150	174
1982	508	10	80	80	130	80	100	590	2590	3660	1620	1450	1130	991	-11	5060	550
1983	894	40	90	110	70	450	410	1690	21700	6470	6790	4990	4520	2970	23820	8780	1246
1984	282	10	10	20	80	70	150	1550	390	4030	2330	2390	1810	1410	690	5780	126
1985	230	30	100	20	30	40	60	2460	5620	3870	1800	409	1080	332	6250	470	79
1986	216	10	20	10	10	20	50	1370	253	635	379	415	166	154	10	230	31
1987	-11	10	10	10	10	10	10	170	38	127	258	31	27	82	10	90	32
1988	-11	10	10	10	10	70	10	330	71	489	370	36	83	288	-11	580	145
1989	-11	10	10	40	10	70	100	380	1220	2127	1704	615	1009	-11	1450	4840	490
1990	-11	60	10	40	40	-11	-11	1230	3567	4822	-11	1316	-11	-11	2770	10040	-11
1991	-11	30	60	-11	-11	-11	-11	2300	997	-11	-11	-11	-11	-11	2500	-11	-11

R-1-1 USSR Bottom trawl index, area I, age 1
R-2B-1 USSR " " " " IIb, age 1
R-1-2 USSR " " " " I, age 2
R-2B-2 USSR " " " " IIb, age 2
R-1-3 USSR " " " " I, age 3
R-2B-3 USSR " " " " IIb, age 3
INTOGP International 0-group survey
N-BST1 Norwegian Barents Sea, Bottom trawl survey, age 1
N-BST2 Norwegian " " " " " age 2
N-BST3 Norwegian " " " " " age 3
N-SVT1 Norwegian Svalbard area " " " age 1
N-SVT2 Norwegian " " " " " age 2
N-SVT3 Norwegian " " " " " age 3
N-BSA1 Norwegian Barents Sea, Acoustic survey, age 1
N-BSA2 Norwegian " " " " age 2
N-BSA3 Norwegian " " " " age 3

Table 2.2.10 Northeast Arctic Cod. RCT3 Retrospective Analysis.

Year-Cl	VPA	CAL +SH	CAL NSH	FUN +SH	FUN NSH	PRED +SH	PRED NSH
1972	622	1076	1256	993	1107	913	996
1973	614	818	867	793	828	764	792
1974	348	288	262	322	304	357	341
1975	639	567	571	580	584	571	574
1976	199	279	257	320	306	365	354
1977	140	263	245	294	282	325	315
1978	158	215	198	244	232	270	260
1979	158	202	190	224	216	242	235
1980	169	142	131	162	154	180	173
1981	386	198	191	202	197	214	210
1982	508	490	511	455	465	414	420
1983	894	819	865	765	798	635	654
1984	282	481	485	467	470	457	460
1985	230	423	427	413	415	404	406
1986	216	167	158	193	188	217	213
1987		136	128	158	153	186	182
1988		230	225	237	235	257	255
1989		377	385	355	359	348	351
1990		428	473	395	412	359	368
1991		389	538	381	426	334	349
RMSLR 72-86		0.392	0.409	0.404	0.407	0.433	0.429

Table 2.5.1 Western Channel Sole. XSA2 unshrunk.

	Age								Age groups		
	2	3	4	5	6	7	8	All	Recruits	Partial recruits	Fully recruited
F ratio											
70 < p	5	2	1	1	2	3	5	19	5	2	12
50 < p <= 70	1	2	4	6	4	5	4	26	1	2	23
30 < p <= 50	1	4	4	2	3	1	1	16	1	4	11
10 < p <= 30	0	1	0	1	1	2	2	7	0	1	6
-10 < p <= 10	3	3	4	3	3	2	1	19	3	3	13
-30 < p <= -10	2	1	0	0	0	0	0	3	2	1	0
-50 < p <= -30	0	0	0	0	0	0	0	0	0	0	0
-70 < p <= -50	1	0	0	0	0	0	0	1	1	0	0
p <= -70	0	0	0	0	0	0	0	0	0	0	0
Outliers											
|p| > 50	7	4	5	7	6	8	9	46	7	4	35
|p| < 50	6	9	8	6	7	5	4	45	6	9	30
Total	13	13	13	13	13	13	13	91	13	13	65
Mean	44	39	37	37	43	51	58	44	44	39	45
Std.	67	35	28	26	30	31	35	38	67	35	30

Table 2.5.2 Western Channel Sole. XSA2 shrinkage CV=0.1.

	Age								Age groups		
	2	3	4	5	6	7	8	All	Recruits	Partial recruits	Fully recruited
F ratio											
70 < p	0	0	0	0	0	0	1	1	0	0	1
50 < p <= 70	0	1	0	1	0	1	0	3	0	1	2
30 < p <= 50	0	0	1	1	3	1	1	7	0	0	7
10 < p <= 30	2	1	2	1	0	1	3	10	2	1	7
-10 < p <= 10	2	3	3	4	3	2	2	19	2	3	14
-30 < p <= -10	1	2	1	0	0	2	0	6	1	2	3
-50 < p <= -30	2	0	0	0	1	0	0	3	2	0	1
-70 < p <= -50	2	3	2	0	1	1	1	10	2	3	5
p <= -70	4	3	4	6	5	5	5	32	4	3	25
Outliers											
|p| > 50	6	7	6	7	6	7	7	46	6	7	33
|p| < 50	7	6	7	6	7	6	6	45	7	6	32
Total	13	13	13	13	13	13	13	91	13	13	65
Mean	-69	-61	-68	-71	-76	-80	-81	-72	-69	-61	-75
Std.	98	103	118	139	134	149	157	126	98	103	136

Table 2.5.3 Western Channel Sole. XAS2 shrinkage CV=0.5

	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	All	Age groups: Recruits	Partial recruits	Fully recruited
F ratio											
70 < p	2	0	0	1	0	0	1	4	2	0	2
50 < p <= 70	1	1	0	0	1	1	0	4	1	1	2
30 < p <= 50	2	2	2	1	2	1	2	12	2	2	8
10 < p <= 30	1	3	5	3	2	5	2	21	1	3	17
-10 < p <= 10	1	4	5	6	6	3	6	31	1	4	26
-30 < p <= -10	2	3	0	1	1	2	1	10	2	3	5
-50 < p <= -30	4	0	1	1	1	1	0	8	4	0	4
-70 < p <= -50	0	0	0	0	0	0	1	1	0	0	1
p <= -70	0	0	0	0	0	0	0	0	0	0	0
Outliers											
|p| > 50	3	1	0	1	1	1	2	9	3	1	5
|p| < 50	10	12	13	12	12	12	11	82	10	12	60
Total	13	13	13	13	13	13	13	91	13	13	65
Mean	10	11	9	9	10	10	12	10	10	11	10
Std.	48	26	22	28	28	27	36	31	48	26	28

Table 2.5.4 4VSW Cod. XSA2 unshrunk.

	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	All	Age groups: Recruits	Partial recruits	Fully recruited
F ratio											
70 < p	0	1	0	0	0	0	0	1	0	1	0
50 < p <= 70	1	0	1	0	0	0	0	2	1	1	0
30 < p <= 50	0	0	0	0	0	0	0	0	0	0	0
10 < p <= 30	1	0	1	1	1	1	0	5	1	2	2
-10 < p <= 10	4	3	1	3	1	2	2	16	4	7	5
-30 < p <= -10	0	2	1	1	1	0	2	7	0	4	3
-50 < p <= -30	0	0	2	0	3	2	2	9	0	2	7
-70 < p <= -50	1	1	1	2	0	1	1	7	1	4	2
p <= -70	2	2	2	2	3	3	2	16	2	6	8
Outliers											
|p| > 50	4	4	4	4	3	4	3	26	4	12	10
|p| < 50	5	5	5	5	6	5	6	37	5	15	17
Total	9	9	9	9	9	9	9	63	9	27	27
Mean	-29	-34	-35	-38	-45	-45	-39	-38	-29	-36	-43
Std.	81	76	62	46	43	44	37	55	81	60	40

Table 2.5.5 4VSW Cod. XSA2 shrinkage CV=0.1.

	Age							All	Age groups		
	3	4	5	6	7	8	9		Recruits	Partial recruits	Fully recruited
F ratio											
70 < p	5	2	0	0	0	0	0	7	5	2	0
50 < p <= 70	0	1	0	0	0	0	0	1	0	1	0
30 < p <= 50	0	1	2	0	1	0	0	4	0	3	1
10 < p <= 30	0	1	2	2	1	2	2	10	0	5	5
-10 < p <= 10	2	2	4	6	4	3	1	22	2	12	8
-30 < p <= -10	1	1	1	1	1	2	3	10	1	3	6
-50 < p <= -30	1	1	0	0	2	2	1	7	1	1	5
-70 < p <= -50	0	0	0	0	0	0	2	2	0	0	2
p <= -70	0	0	0	0	0	0	0	0	0	0	0
Outliers											
|p| > 50	5	3	0	0	0	0	2	10	5	3	2
|p| < 50	4	6	9	9	9	9	7	53	4	24	25
Total	9	9	9	9	9	9	9	63	9	27	27
Mean	101	31	12	3	-6	-9	-20	16	101	15	-11
Std.	128	48	20	12	26	26	30	65	128	32	27

Table 2.5.6 4VSW Cod. XSA2 shrinkage CV=0.4.

	Age							All	Age groups		
	3	4	5	6	7	8	9		Recruits	Partial recruits	Fully recruited
F ratio											
70 < p	4	0	0	0	0	0	0	4	4	0	0
50 < p <= 70	1	1	0	0	0	0	0	2	1	1	0
30 < p <= 50	0	0	0	0	1	0	0	1	0	0	1
10 < p <= 30	0	2	1	1	0	2	2	8	0	4	4
-10 < p <= 10	2	3	5	3	3	3	1	20	2	11	7
-30 < p <= -10	1	2	2	3	2	1	3	14	1	7	6
-50 < p <= -30	0	1	1	2	3	3	3	13	0	4	9
-70 < p <= -50	0	0	0	0	0	0	0	0	0	0	0
p <= -70	1	0	0	0	0	0	0	1	1	0	0
Outliers											
|p| > 50	6	1	0	0	0	0	0	7	6	1	0
|p| < 50	3	8	9	9	9	9	9	56	3	26	27
Total	9	9	9	9	9	9	9	63	9	27	27
Mean	58	5	-8	-11	-13	-12	-16	0	58	-4	-14
Std.	89	26	16	21	25	24	22	45	89	22	23

Table 2.5.7 Reykjavik Simulation 5. XSA2 unshrunk.

	Age 3	4	5	6	7	8	9	10	All	Age groups: Recruits	Partial recruits	Fully recruited
F ratio												
70 < p	0	0	0	0	0	0	0	0	0	0	0	0
50 < p <= 70	0	0	0	0	0	0	0	0	0	0	0	0
30 < p <= 50	1	0	0	0	0	0	0	0	1	1	0	0
10 < p <= 30	1	1	0	0	0	0	0	0	2	1	1	0
-10 < p <= 10	8	7	7	4	2	6	4	4	42	8	14	20
-30 < p <= -10	3	6	6	9	11	5	5	3	48	3	12	33
-50 < p <= -30	1	1	2	2	2	3	4	4	19	1	3	15
-70 < p <= -50	0	0	0	0	0	1	2	4	7	0	0	7
p <= -70	1	0	0	0	0	0	0	0	1	1	0	0
Outliers												
|p| > 50	1	0	0	0	0	1	2	4	8	1	0	7
|p| < 50	14	15	15	15	15	14	13	11	112	14	30	68
Total	15	15	15	15	15	15	15	15	120	15	30	75
Mean	-9	-9	-15	-15	-18	-20	-25	-31	-18	-9	-12	-22
Std.	27	14	13	11	11	17	19	20	18	27	14	17

Table 2.5.8 Reykjavik Simulation 5. XSA2 shrinkage CV=0.1.

	Age 3	4	5	6	7	8	9	10	All	Age groups: Recruits	Partial recruits	Fully recruited
F ratio												
70 < p	0	0	0	0	0	0	0	0	0	0	0	0
50 < p <= 70	1	0	0	0	0	0	0	2	3	1	0	2
30 < p <= 50	3	0	0	0	0	2	2	2	9	3	0	6
10 < p <= 30	3	2	2	3	3	2	2	2	19	3	4	12
-10 < p <= 10	4	8	6	7	7	3	4	2	41	4	14	23
-30 < p <= -10	2	5	6	5	4	7	3	2	34	2	11	21
-50 < p <= -30	0	0	1	0	1	1	4	4	11	0	1	10
-70 < p <= -50	2	0	0	0	0	0	0	1	3	2	0	1
p <= -70	0	0	0	0	0	0	0	0	0	0	0	0
Outliers												
|p| > 50	3	0	0	0	0	0	0	3	6	3	0	3
|p| < 50	12	15	15	15	15	15	15	12	114	12	30	72
Total	15	15	15	15	15	15	15	15	120	15	30	75
Mean	5	-2	-7	-3	-5	-1	-5	-2	-2	5	-5	-3
Std.	34	13	15	13	14	26	26	40	24	34	14	25

Table 2.5.9 Reykjavik Simulation 5. XSA2 shrinkage CV=0.5.

	Age									Age groups		
	3	4	5	6	7	8	9	10	All	Recruits	Partial recruits	Fully recruited
F ratio												
70 < p	0	0	0	0	0	0	0	0	0	0	0	0
50 < p <= 70	0	0	0	0	0	0	0	0	0	0	0	0
30 < p <= 50	1	0	0	0	0	0	0	0	1	1	0	0
10 < p <= 30	4	2	1	1	1	1	1	1	12	4	3	5
-10 < p <= 10	3	6	6	4	7	7	3	4	40	3	12	25
-30 < p <= -10	4	7	7	9	5	4	7	4	47	4	14	29
-50 < p <= -30	3	0	1	1	2	2	4	5	18	3	1	14
-70 < p <= -50	0	0	0	0	0	1	0	1	2	0	0	2
p <= -70	0	0	0	0	0	0	0	0	0	0	0	0
Outliers												
|p| > 50	0	0	0	0	0	1	0	1	2	0	0	2
|p| < 50	15	15	15	15	15	14	15	14	118	15	30	73
Total	15	15	15	15	15	15	15	15	120	15	30	75
Mean	-5	-6	-12	-11	-13	-14	-19	-21	-13	-5	-9	-16
Std.	24	12	13	12	14	19	16	20	17	24	13	16

Table 2.5.10 Reykjavik Simulation 5. TSA.

	Age									Age groups		
	3	4	5	6	7	8	9	10	All	Recruits	Partial recruits	Fully recruited
F ratio												
70 < p	0	0	0	0	0	0	0	0	0	0	0	0
50 < p <= 70	0	0	0	0	0	0	0	0	0	0	0	0
30 < p <= 50	0	0	0	0	0	0	0	0	0	0	0	0
10 < p <= 30	1	4	2	3	2	7	4	5	28	1	6	21
-10 < p <= 10	8	6	8	7	8	3	6	5	51	8	14	29
-30 < p <= -10	1	0	0	0	0	0	0	0	1	1	0	0
-50 < p <= -30	0	0	0	0	0	0	0	0	0	0	0	0
-70 < p <= -50	0	0	0	0	0	0	0	0	0	0	0	0
p <= -70	0	0	0	0	0	0	0	0	0	0	0	0
Outliers												
|p| > 50	0	0	0	0	0	0	0	0	0	0	0	0
|p| < 50	10	10	10	10	10	10	10	10	80	10	20	50
Total	10	10	10	10	10	10	10	10	80	10	20	50
Mean	3	6	4	6	7	11	11	11	7	3	5	9
Std.	9	6	8	6	4	5	7	7	7	9	7	6

Table 2.5.11 The percentage of terminal F estimates (all ages) which are in error by a log ratio of more than 0.5, them mean log ratio and r.m.s log ratio (s.e).

Western Channel (VIIe) Sole

OUTLIERS	SHRINKAGE CV 0.1	0.2	0.3	0.4	0.5	unshrunk
L/S	45	21	19	16	14	15
XSA2	51	38	23	15	10	51
XSA4 HM	44	23	14	12	19	51
XSA4 SM	18	15	14	15	19	51
XSA4 SU	7	7	10	8		51

BIAS	SHRINKAGE CV 0.1	0.2	0.3	0.4	0.5	unshrunk
L/S	-50	-14	-5	3	7	18
XSA2	-72	-42	-12	4	10	44
XSA4 HM	-41	-12	9	19	23	44
XSA4 SM	22	18	20	22	23	44
XSA4 SU	4	-1	-2	0		44

SE	SHRINKAGE CV 0.1	0.2	0.3	0.4	0.5	unshrunk
L/S	106	42	36	32	32	36
XSA2	126	85	49	33	31	38
XSA4 HM	60	43	31	29	30	38
XSA4 SM	30	31	30	30	30	38
XSA4 SU	25	27	28	29		38

Table 2.5.12 The percentage of terminal population estimates (all ages) which are in error by a log ratio of more than 0.5, the mean log ratio and r.m.s. ratio (s.e).

Western Channel (VIIe) Sole

OUTLIERS	SHRINKAGE CV 0.1	0.2	0.3	0.4	0.5	unshrunk
L/S	37	21	20	15	11	12
XSA2	39	41	26	15	10	39
XSA4 HM	43	23	14	10	12	38
XSA4 SM	14	12	13	14	12	38
XSA4 SU	4	7	8	9		38

BIAS	SHRINKAGE CV 0.1	0.2	0.3	0.4	0.5	unshrunk
L/S	46	13	5	-1	-5	-14
XSA2	70	42	13	-3	-9	-41
XSA4 HM	40	14	-6	-16	-21	-41
XSA4 SM	-20	-16	-18	-20	-21	-41
XSA4 SU	-2	3	4	2		-41

SE	SHRINKAGE CV 0.1	0.2	0.3	0.4	0.5	unshrunk
L/S	108	44	38	33	32	33
XSA2	126	90	53	36	32	38
XSA4 HM	65	46	32	28	29	34
XSA4 SM	29	30	28	28	29	34
XSA4 SU	24	27	28	28		34

Table 2.5.13 The percentage of terminal F estimates (all ages) which are in error by a log ratio of more than 0.5, the mean log ratio and RMS log ratio (s.e)

4Vs W Cod

OUTLIERS	SHRINKAGE CV 0.1	0.2	0.3	0.4	0.5	unshrunk
L/S	25	29	29	32	36	55
XSA2	16	14	13	11	14	41
XSA4 HM	25	21	16	16	24	40
XSA4 SM	24	24	24	24	24	40
XSA4 SU	22	22	22	19	19	40

BIAS	SHRINKAGE CV 0.1	0.2	0.3	0.4	0.5	unshrunk
L/S	-4	-11	-18	-26	-32	-54
XSA2	16	13	7	0	-5	-38
XSA4 HM	43	34	23	11	3	-38
XSA4 SM	-19	-18	-17	-17	-19	-38
XSA4 SU	3	3	4	2	1	-38

SE	SHRINKAGE CV 0.1	0.2	0.3	0.4	0.5	unshrunk
L/S	68	65	61	59	57	51
XSA2	65	59	51	45	39	55
XSA4 HM	76	71	66	60	55	55
XSA4 SM	50	47	46	46	46	55
XSA4 SU	50	48	46	44	44	55

Table 2.5.14 The percentage of terminal population estimates (all ages) which are in error by a log ratio of more than 0.5, the mean log ratio and RMS log ratio (s.e) for all ages.

4Vs W Cod

OUTLIERS	SHRINKAGE CV 0.1	0.2	0.3	0.4	0.5	unshrunk
L/S	25	22	21	24	29	48
XSA2	21	16	14	14	12	32
XSA4 HM	20	17	14	12	15	32
XSA4 SM	15	17	17	16	16	32
XSA4 SU	12	12	12	12	10	32

BIAS	SHRINKAGE CV 0.1	0.2	0.3	0.4	0.5	unshrunk
L/S	2	7	12	28	22	38
XSA2	-14	-11	-8	-4	0	33
XSA4 HM	-31	-25	-17	-9	-1	33
XSA4 SM	13	13	13	13	14	33
XSA4 SU	0	-1	-1	-1	1	33

SE	SHRINKAGE CV 0.1	0.2	0.3	0.4	0.5	unshrunk
L/S	66	62	58	50	54	60
XSA2	56	51	44	38	34	67
XSA4 HM	70	66	61	56	51	65
XSA4 SM	57	56	56	57	59	65
XSA4 SU	58	58	56	57	59	65

Table 2.5.15 The percentage of terminal F estimates (all ages) which are in error by a log ratio of more than 0.5, the mean log ratio and r.m.s log ratio (s.e).

Reykjavik simulated data set 5.

OUTLIERS	SHRINKAGE CV 0.1	0.2	0.3	0.4	0.5	unshrunk
L/S	12	6	6	8	8	9
XSA2	5	2	1	1	2	7
XSA4 HM	3	1	1	1	2	7
XSA4 SM	3	3	2	1	2	7
XSA4 SU	2	2	1	0	0	7

BIAS	SHRINKAGE CV 0.1	0.2	0.3	0.4	0.5	unshrunk
L/S	-7	-8	-9	-10	-10	-11
XSA2	-2	-9	-12	-13	-13	-18
XSA4 HM	-5	-12	-14	-14	-13	-17
XSA4 SM	-13	-14	-14	-14	-13	-17
XSA4 SU	-9	-11	-12	-12	-12	-17

SE	SHRINKAGE CV 0.1	0.2	0.3	0.4	0.5	unshrunk
L/S	35	28	26	26	26	27
XSA2	24	19	17	17	17	18
XSA4 HM	19	17	16	17	17	18
XSA4 SM	17	17	17	17	17	18
XSA4 SU	15	15	15	16	17	18

Table 2.5.16 The percentage of terminal population estimates (all ages) which are in error by a log ratio of more than 0.5, the mean log ratio and r.m.s log ratio (s.e).

Reykjavik simulated data set 5.

OUTLIERS	SHRINKAGE CV 0.1	0.2	0.3	0.4	0.5	unshrunk
L/S	16	12	11	9	9	10
XSA2	11	6	6	6	5	8
XSA4 HM	6	5	6	4	4	8
XSA4 SM	6	6	6	4	4	8
XSA4 SU	6	5	5	4	4	8

BIAS	SHRINKAGE CV 0.1	0.2	0.3	0.4	0.5	unshrunk
L/S	5	5	6	5	6	7
XSA2	1	7	10	11	11	16
XSA4 HM	3	10	12	12	11	16
XSA4 SM	11	12	13	12	11	16
XSA4 SU	8	9	10	10	10	16

SE	SHRINKAGE CV 0.1	0.2	0.3	0.4	0.5	unshrunk
L/S	49	43	40	38	38	30
XSA2	39	36	35	35	35	35
XSA4 HM	35	34	35	35	35	36
XSA4 SM	35	35	35	35	35	36
XSA4 SU	33	33	34	34	34	36

Table 3.1.1 Chi square evaluation of 72 stocks from Myers et al. (1993) stock and recruitment database. Note that the p-values for the chi-square p-value uses Yates' continuity correction, so the p if all cells have the same entry will not be 0, e.g. hake from South Africa.

	below median SSB	above median SSB
above median Recruitment	a	b
below median Recruitment	c	d

If the relationship between Recruitment and SSB is positive then the p-value of the Chi square test is signed positive.

ID	Stock	a	b	c	d	p-value
ANCHOCAL	Northern anchovy California	7	5	6	7	- 0.835
BWHITNA	Blue whiting Northern ICES	6	4	4	6	- 0.655
COD1	Cod NAFO 1	5	10	11	5	+ 0.107
COD2J3KL	Cod NAFO 2J3KL	5	8	9	5	+ 0.339
COD3NO	Cod NAFO 3NO	5	9	9	5	+ 0.257
COD3Ps	Cod NAFO 3Ps	6	7	7	6	+ 1
COD4TVn	Cod NAFO 4TVn	8	10	11	8	+ 0.625
COD4VsW	Cod NAFO 4VsW	7	8	9	7	+ 0.862
COD4X	Cod NAFO 4X	11	9	10	11	+ 0.873
CODBA2224	Cod Baltic Areas 22 and 24	3	7	7	3	+ 0.18
CODCS	Cod Celtic Sea	3	7	7	3	+ 0.18
CODFAPL	Cod Faroe Plateau	9	5	5	9	- 0.257
CODICE	Cod Iceland	7	10	10	7	- 0.493
CODIS	Cod Irish Sea	8	3	3	8	- 0.0881
CODNEAR	Cod North East Arctic	6	13	13	6	+ 0.0516
CODNS	Cod North Sea	7	6	7	7	- 0.853
POLLVI	Pollock or saithe IVES VI	7	3	4	6	- 0.369
SAHAKE	Hake South Africa 1.6	5	5	5	5	0.655
SAPILCH	Southern African pilchard South Africa	5	10	11	5	+ 0.107
SARDCAL	Pacific sardine California	1	14	15	1	+ 7.16e-06
CHAKE5Ze	Silver hake NAFO 5Ze	4	12	13	4	+ 0.0091
SHAKEMAB	Silver hake Mid Atlantic Bight	4	12	13	4	+ 0.0091
SOCKADAM	Sockeye salmon Adams Complex, B.C., Canada	1	18	18	1	+ 2.09e-07
SOCKBIRK	Sockeye salmon Birkenhead River, B.C., Canada	8	10	11	8	+ 0.625
SOCKCHIK	Sockeye salmon Chilko River, B.C., Canada	3	16	16	3	+ 9.89e-05
SOCKHFLY	Sockeye salmon Horsefly River, B.C., Canada	1	18	18	1	+ 2.09e-07
SOCKRINL	Sockeye salmon Rivers Inlet, B.C., Canada	8	8	10	10	0.737
SOCKSKEE	Sockeye salmon Skeena River, B.C., Canada	8	14	15	8	+ 0.102
SOCKSTEL	Sockeye salmon Stellako River, B.C. Canada	2	17	17	2	5.57e-06
SOCKSTUA	Sockeye salmon Early Stuart Complex, B.C. Canada	5	14	14	5	+ 0.00944
SOLEIS	Soke Irish Sea	7	3	3	7	- 0.18
SOLENS	Sole North Sea	11	6	6	11	- 0.17
SOLEVIIe	Sole ICES VIIe	2	9	9	2	+ 0.0105
WHITNS	Whiting North Sea	6	7	7	6	+ 1
WHITVIa	Whiting ICES VIa	8	4	5	8	- 0.313
WPOLLEBS	Walleye pollock E. Bering Sea	6	5	6	7	1
WPOLLGA	Walleye pollock Gulf of Alaska	7	3	4	7	- 0.27

Table 4.2.1 Uncertainties used in FAST analysis.

Age	Terminal Fs	Terminal Ns
3	1.18	1.42
4	1.17	1.61
5	1.17	1.80
6	1.18	1.93
7	1.21	2.08
8	1.14	2.23
9	1.45	2.32
10	1.76	2.55

Table 5.2.2 Coefficients of variation (CVs) used in the various methods for calculating probability profiles.

				Terminal Fs				
Method/Age	3	4	5	6	7	8	9	10
cov/SepVPA	.09	.09	.09	.09	.10	.07	.23	.38
Boot/ADAPT	.26	.18	.14	.24	.24	.24	.24	.24
Monte/ADAPT	.20	.20	.18	.25	.25	.25	.25	.25
				Terminal Populations				
cov/SepVPA	.21	.30	.40	.47	.54	.62	.66	.78
Boot/ADAPT	.18	.12	.06	.11	.11	.11	.11	.11
Monte/ADAPT	.13	.13	.09	.13	.14	.16	.16	.17

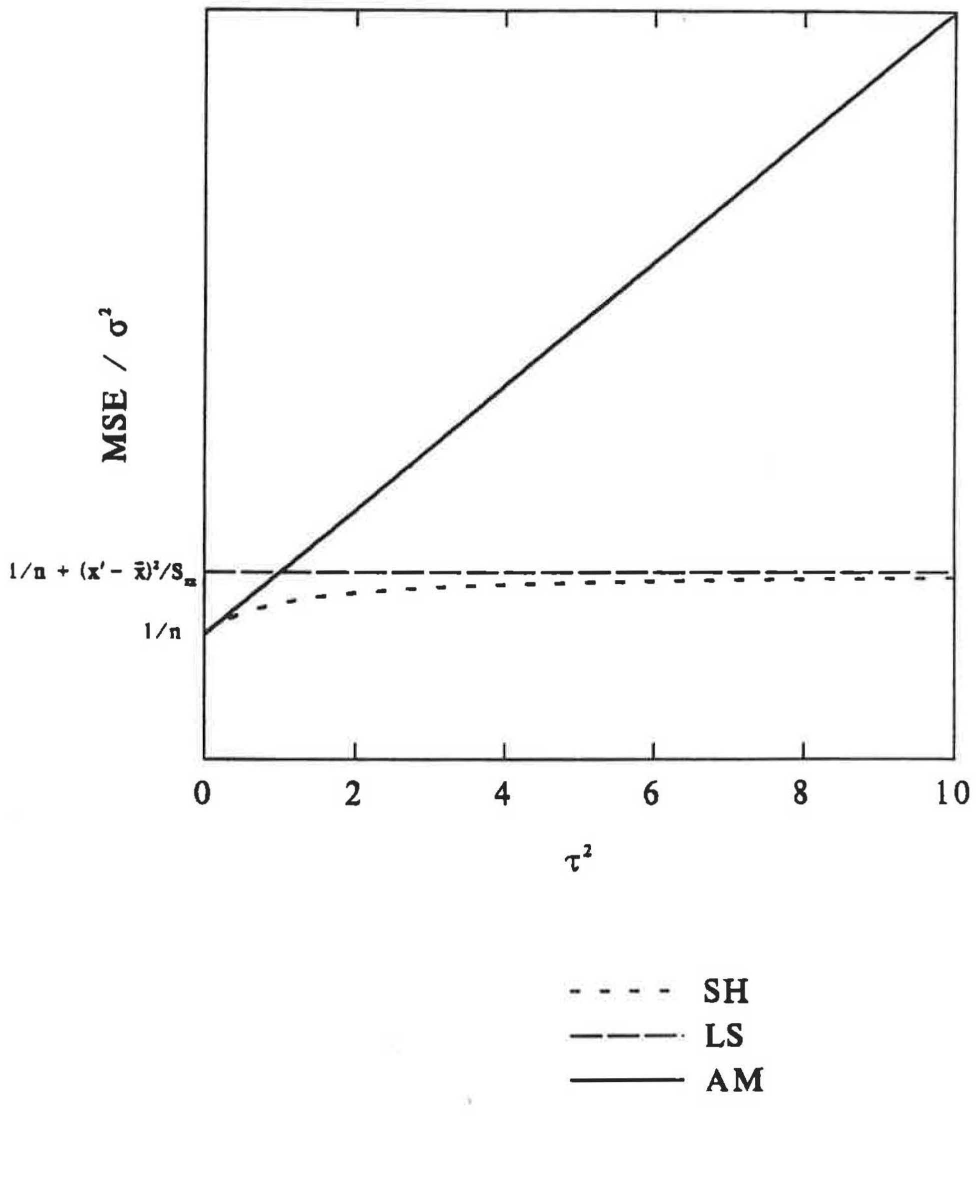


Figure 2.1.1 Mean square errors of three estimators of random variable y' as a function of τ^2 (SH- shrinkage; LS - Laurec-Shepherd; AM - arithmetic mean).

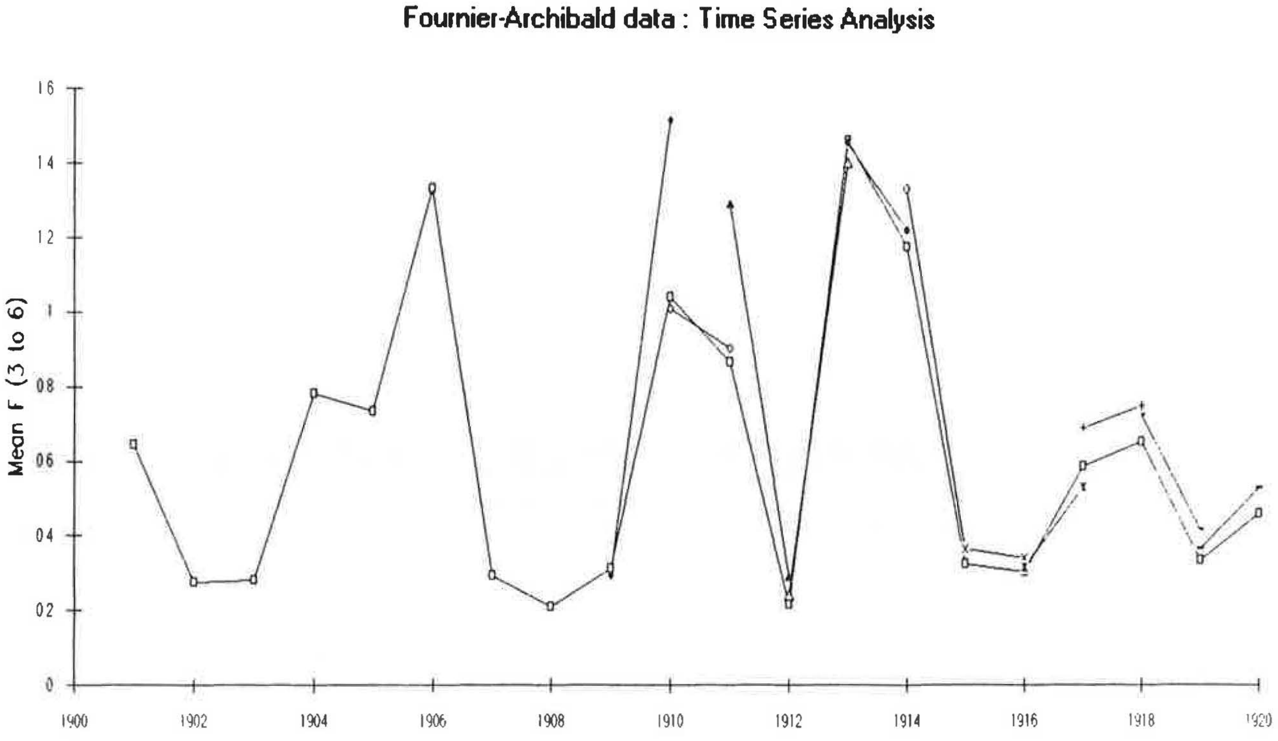


Figure 2.1.2 Fournier-Archibald data: Time Series Analysis.

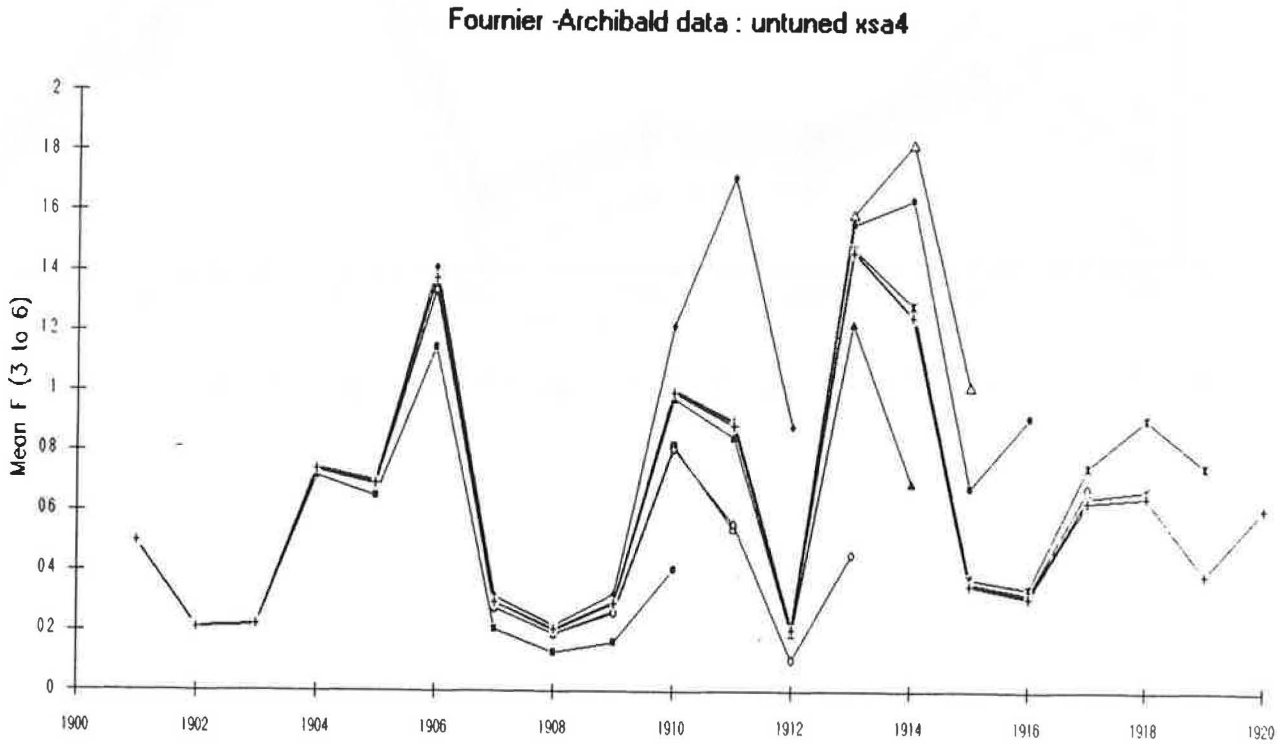


Figure 2.1.3 Fournier-Archibald data: untuned XSA4.

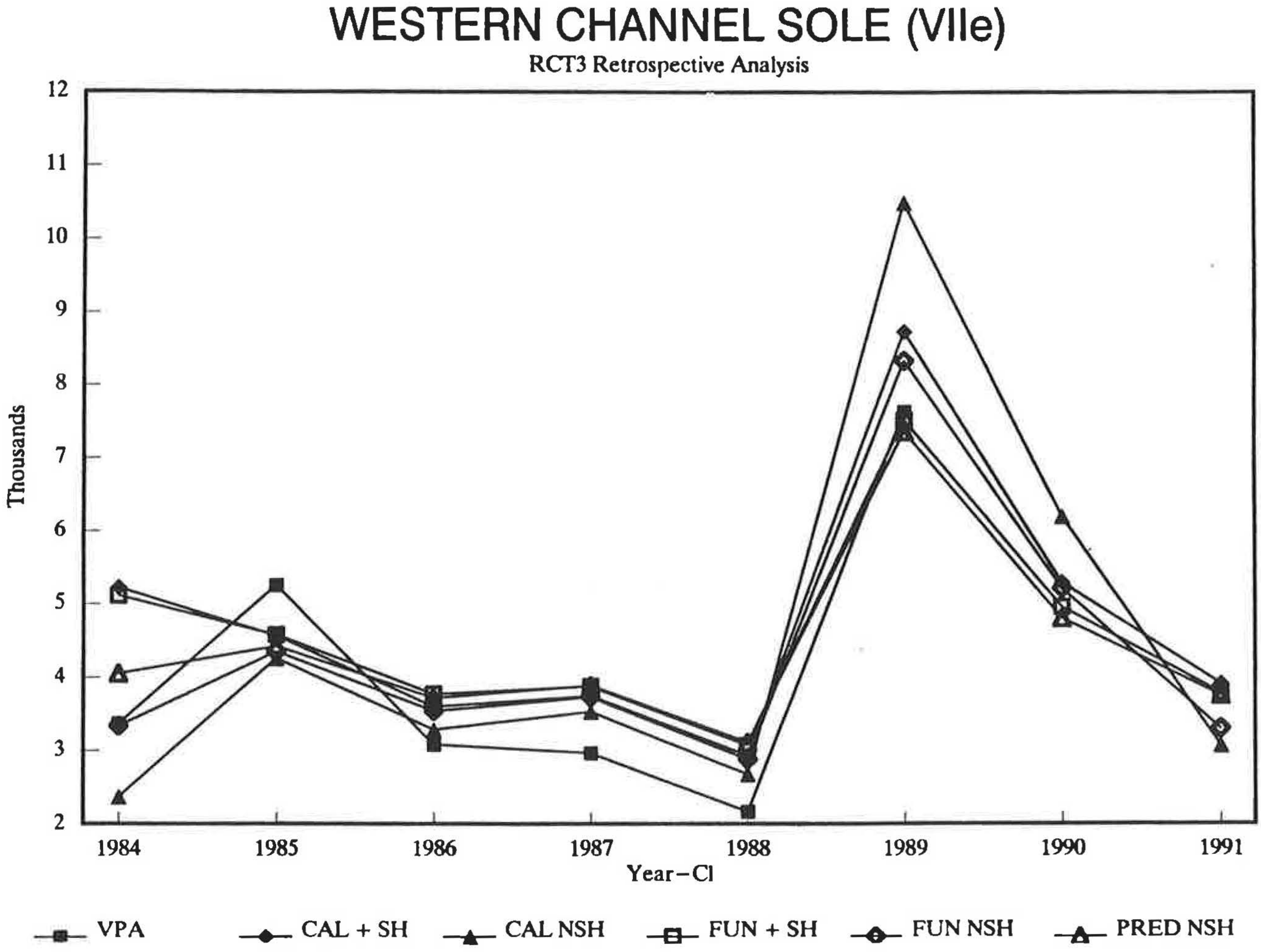


Figure 2.2.1 Western Channel Sole (VIIe). RCT3 Retrospective Analysis.

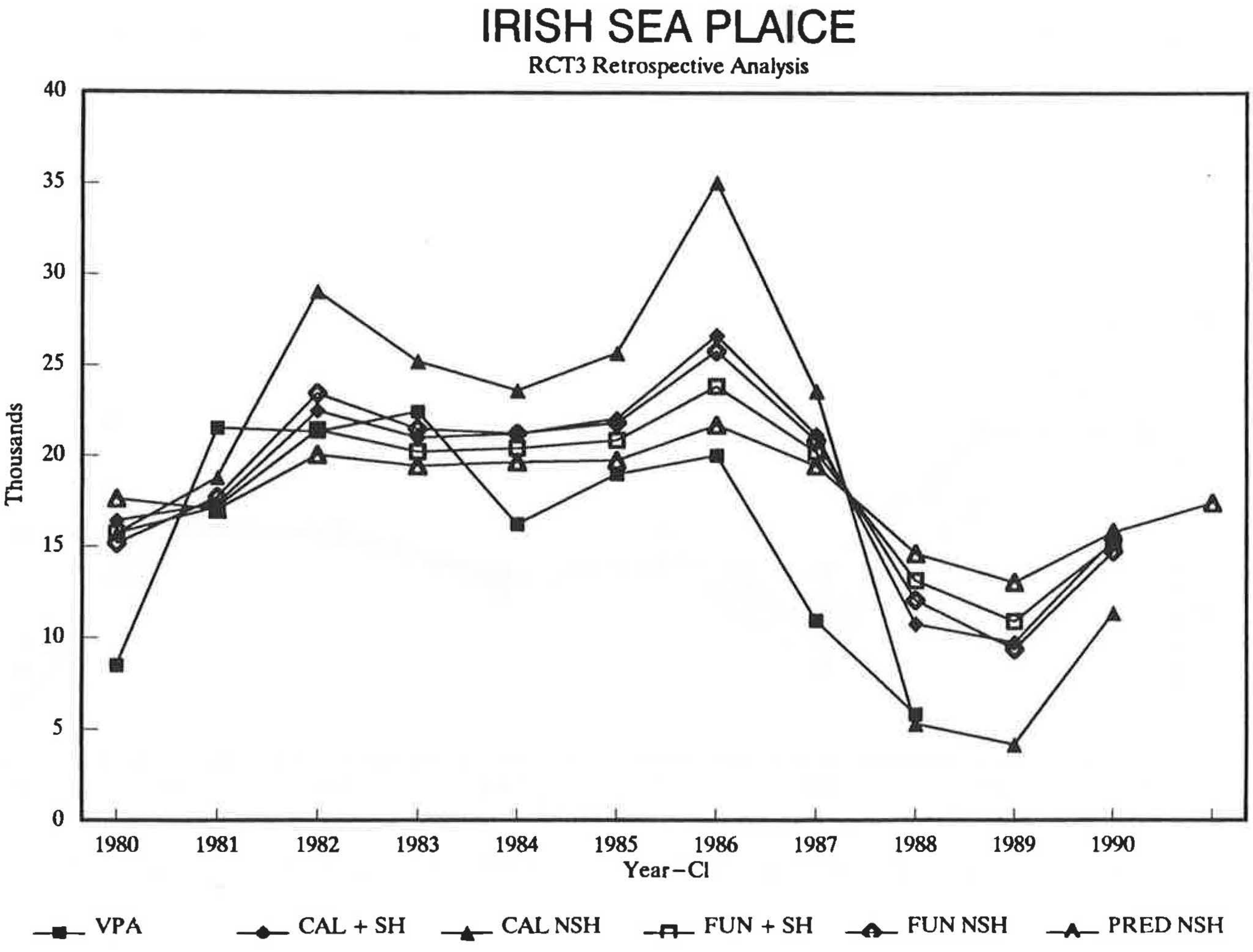


Figure 2.2.2 Irish Sea Plaice. RCT3 Retrospective Analysis.

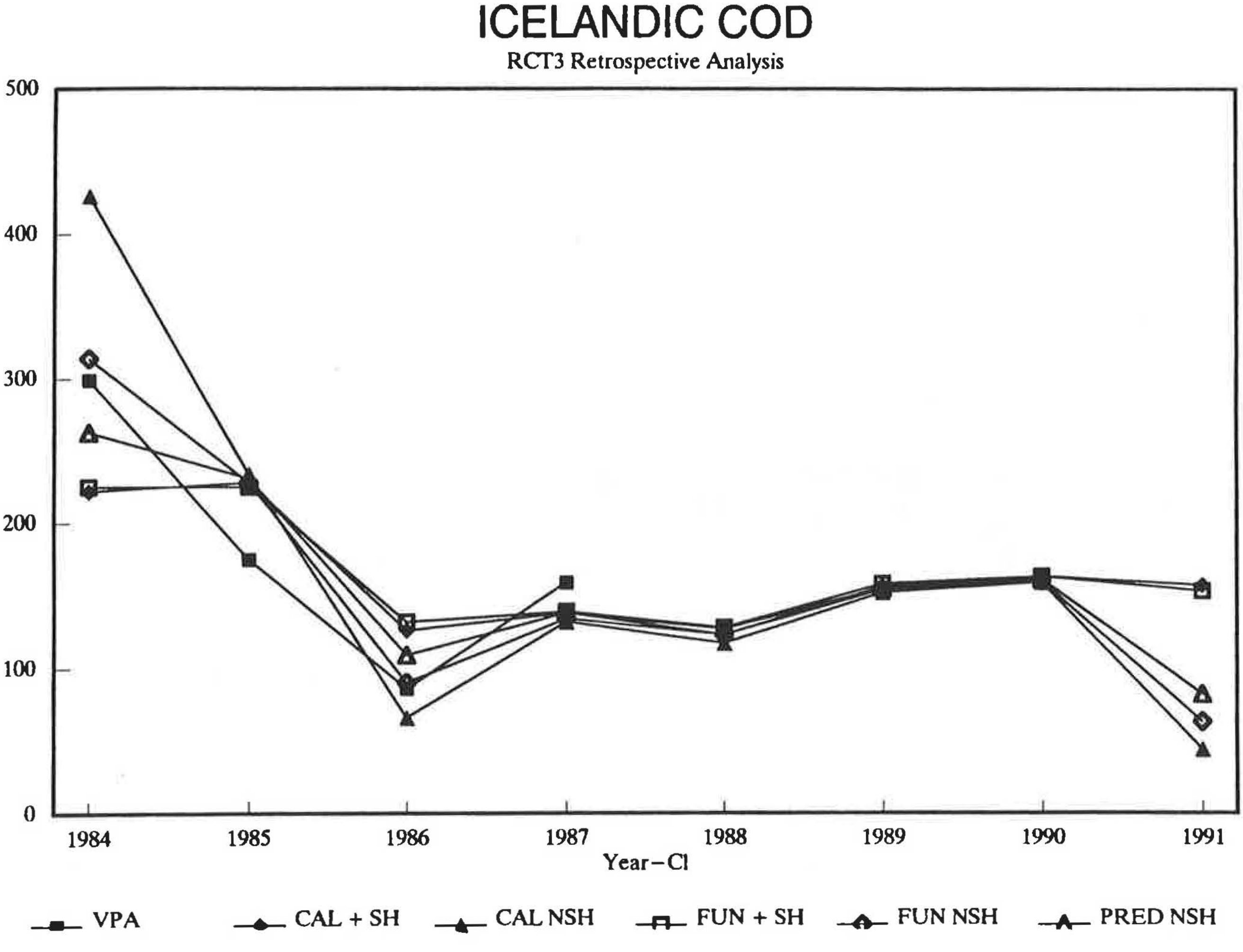


Figure 2.2.3 Icelandic Cod. RCT3 Retrospective Analysis.

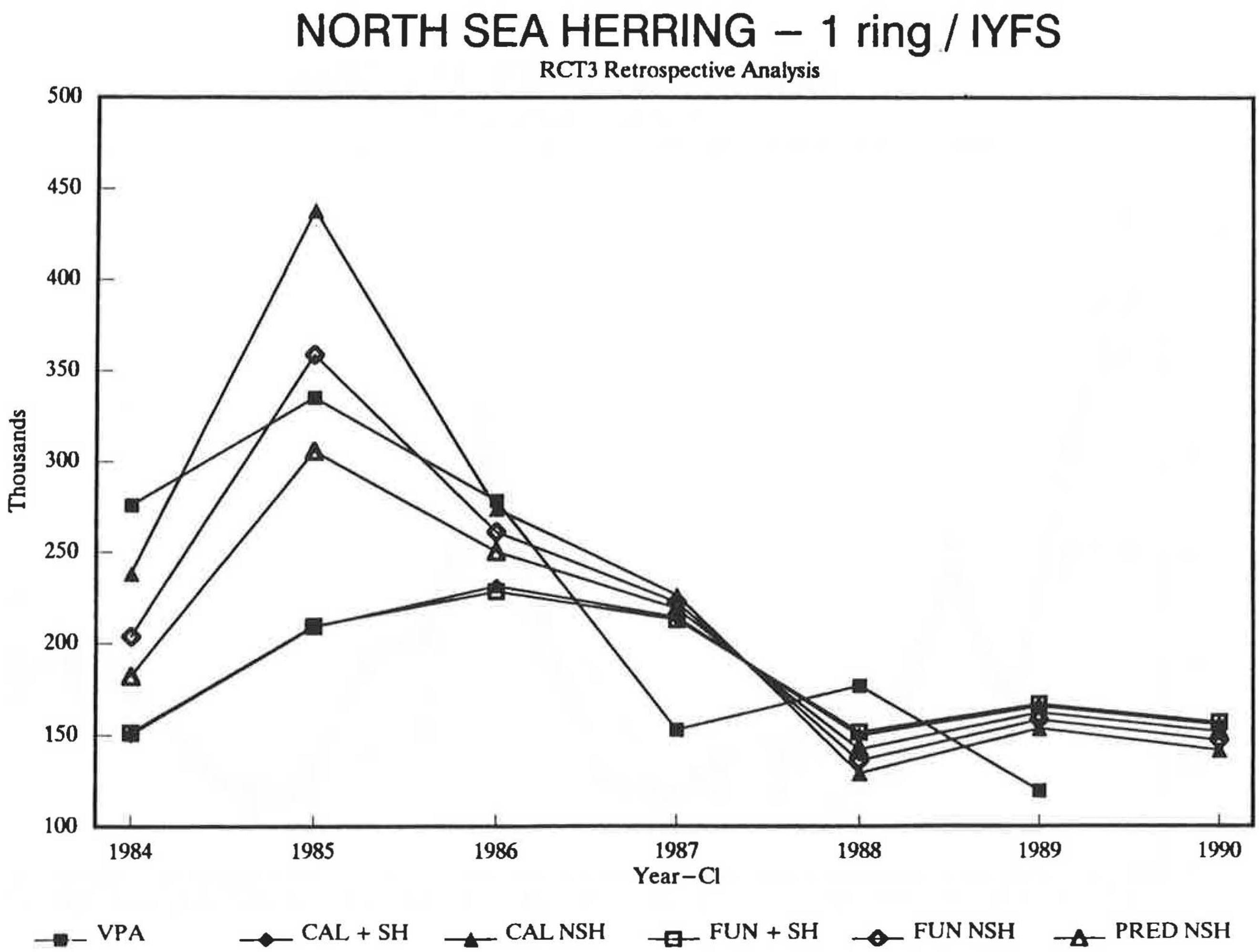


Figure 2.2.4 North Sea Herring - 1 ring/IYFS.

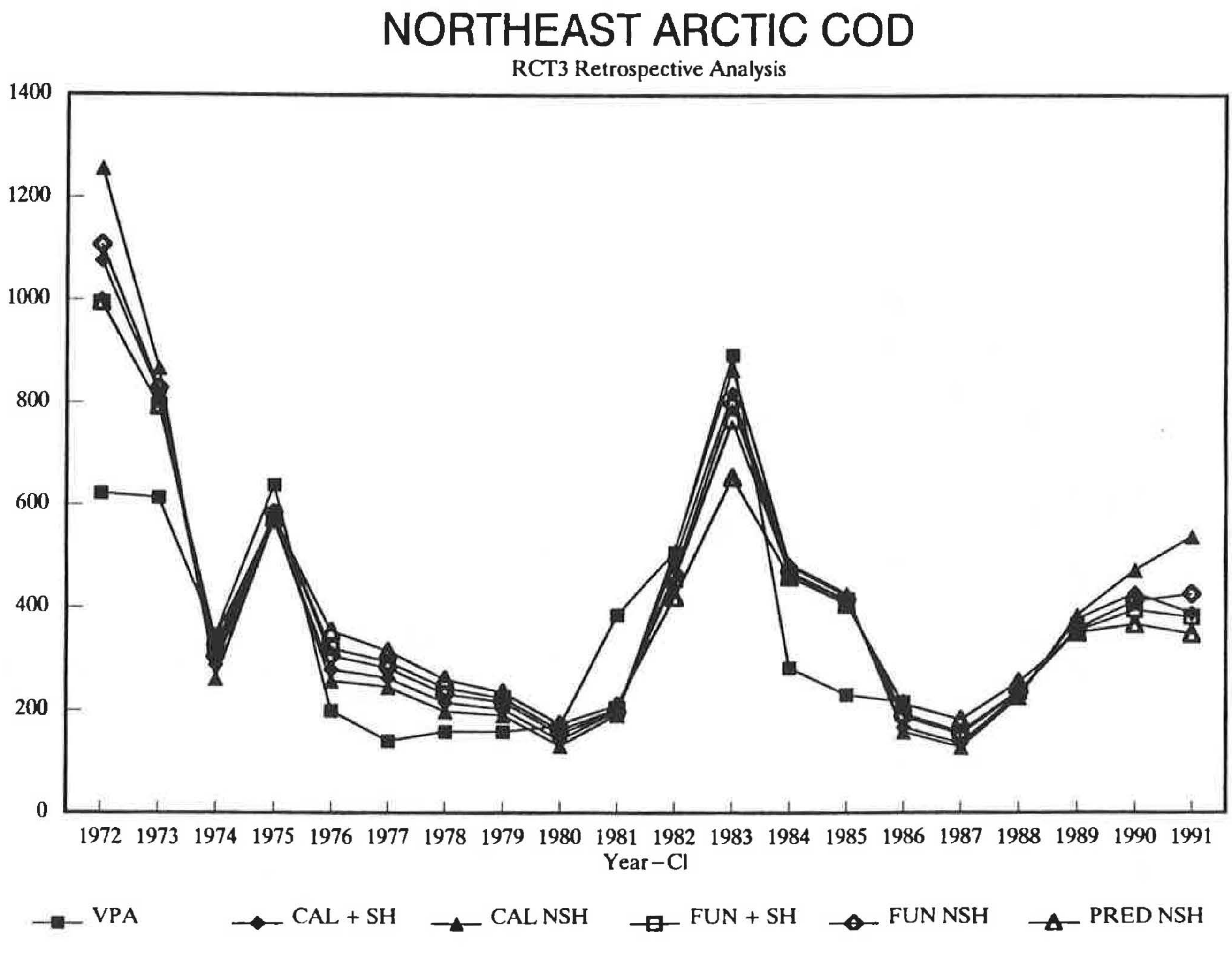


Figure 2.2.5 Northeast Arctic Cod. RCT3 Retrospective Analysis.

Stock: Western Channel Sole
Procedure: XSA2 Unshrunk

Retrospective analysis
s7exsa2.s0

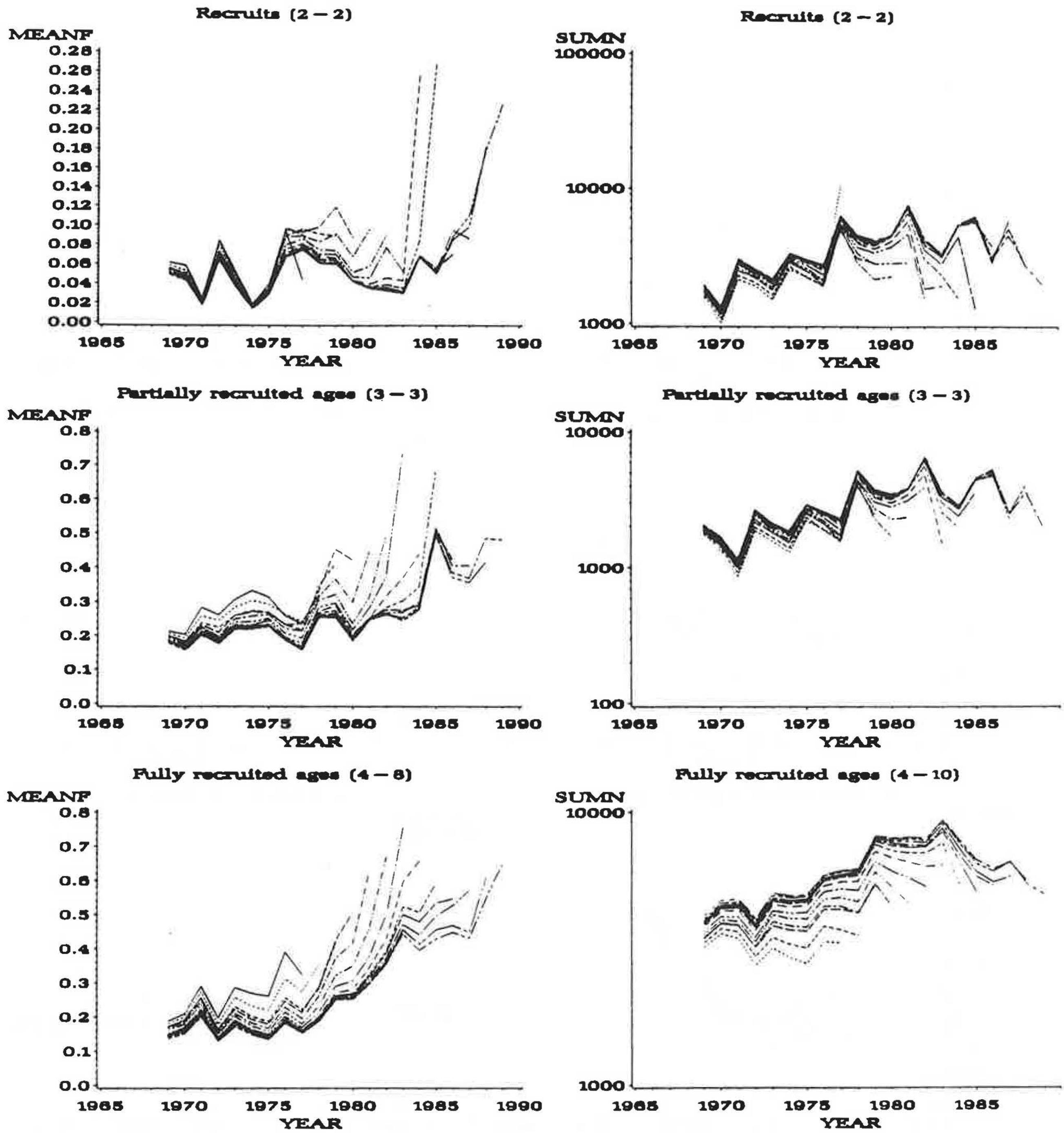


Figure 2.5.1 Western Channel Sole. XSA2 shrinkage CV=0.1.

Stock: Western Channel Sole
Procedure: XSA2 Shrinkage CV = 0.1

Retrospective analysis
s7exsa2.s1

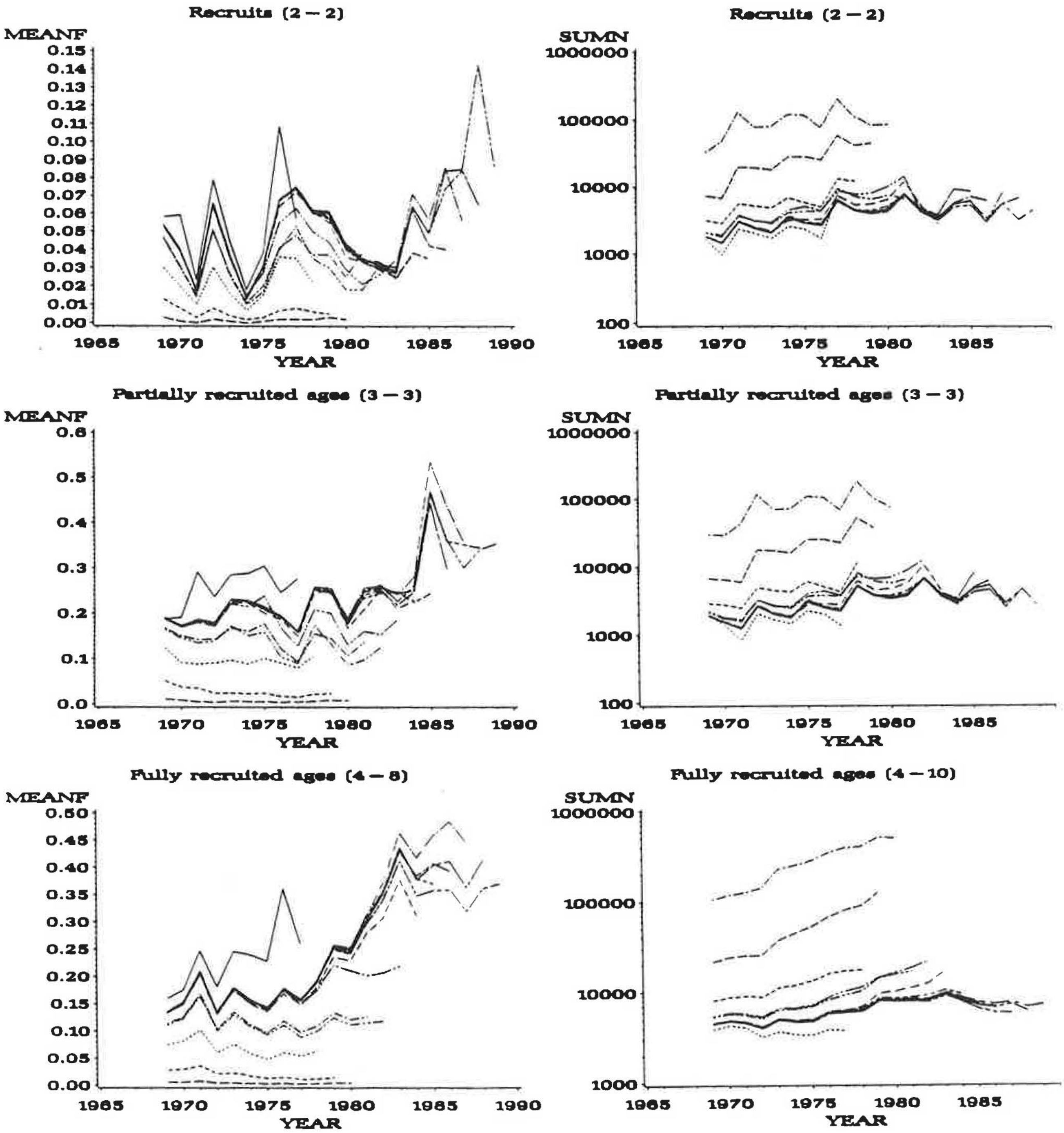


Figure 2.5.2 Western Channel Sole XSA2 shrinkage CV= 0.1.

Stock: Western Channel Sole

Procedure: XSA2 Shrinkage CV = 0.5

Retrospective analysis
s7exsa2.s5

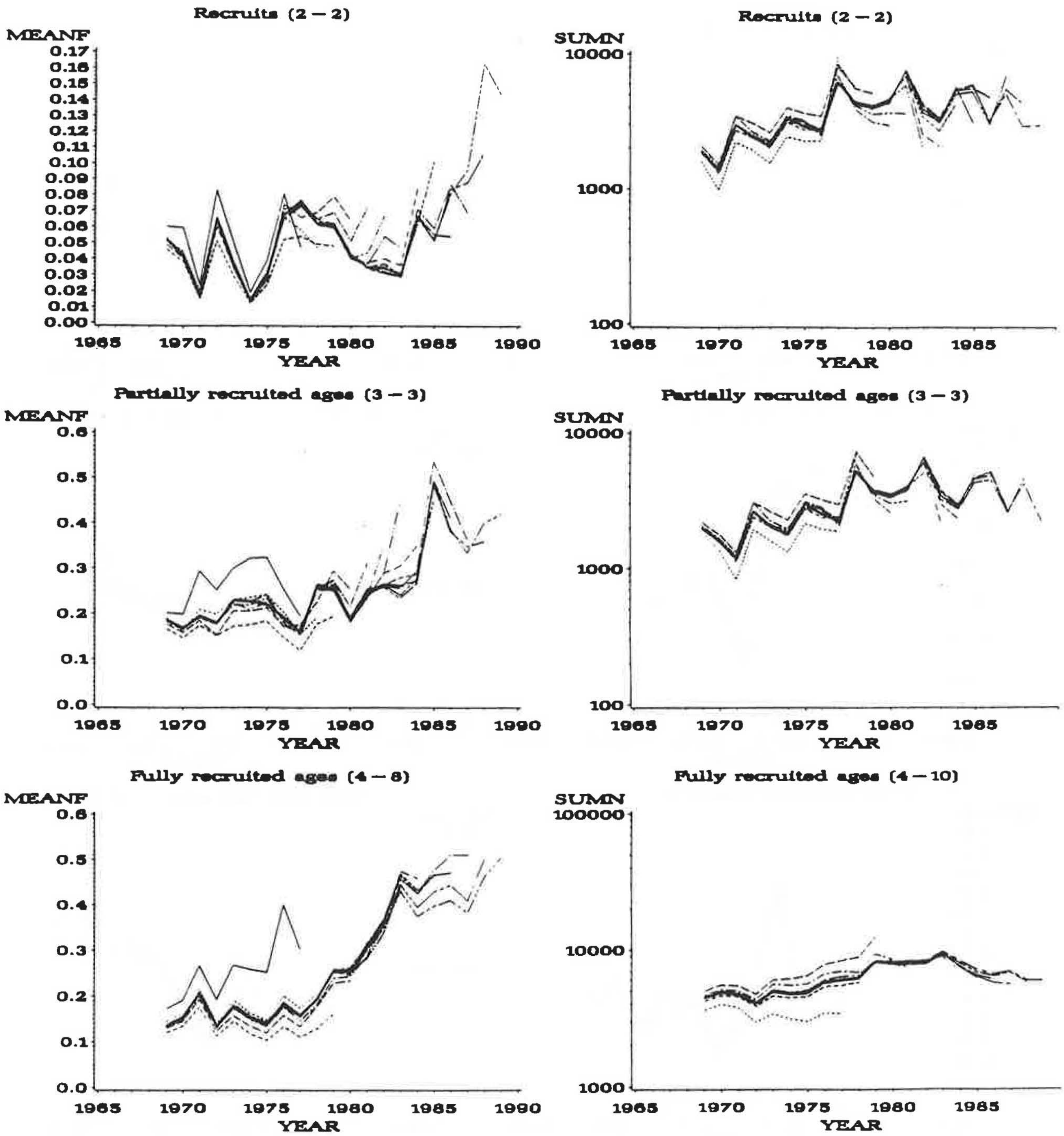


Figure 2.5.3 Western Channel Sole. XSA2 shrinkage CV= 0.5.

Stock: 4Vs W Cod
Procedure: XSA2 Unshrunk

Retrospective analysis
c4vxsa2.s0

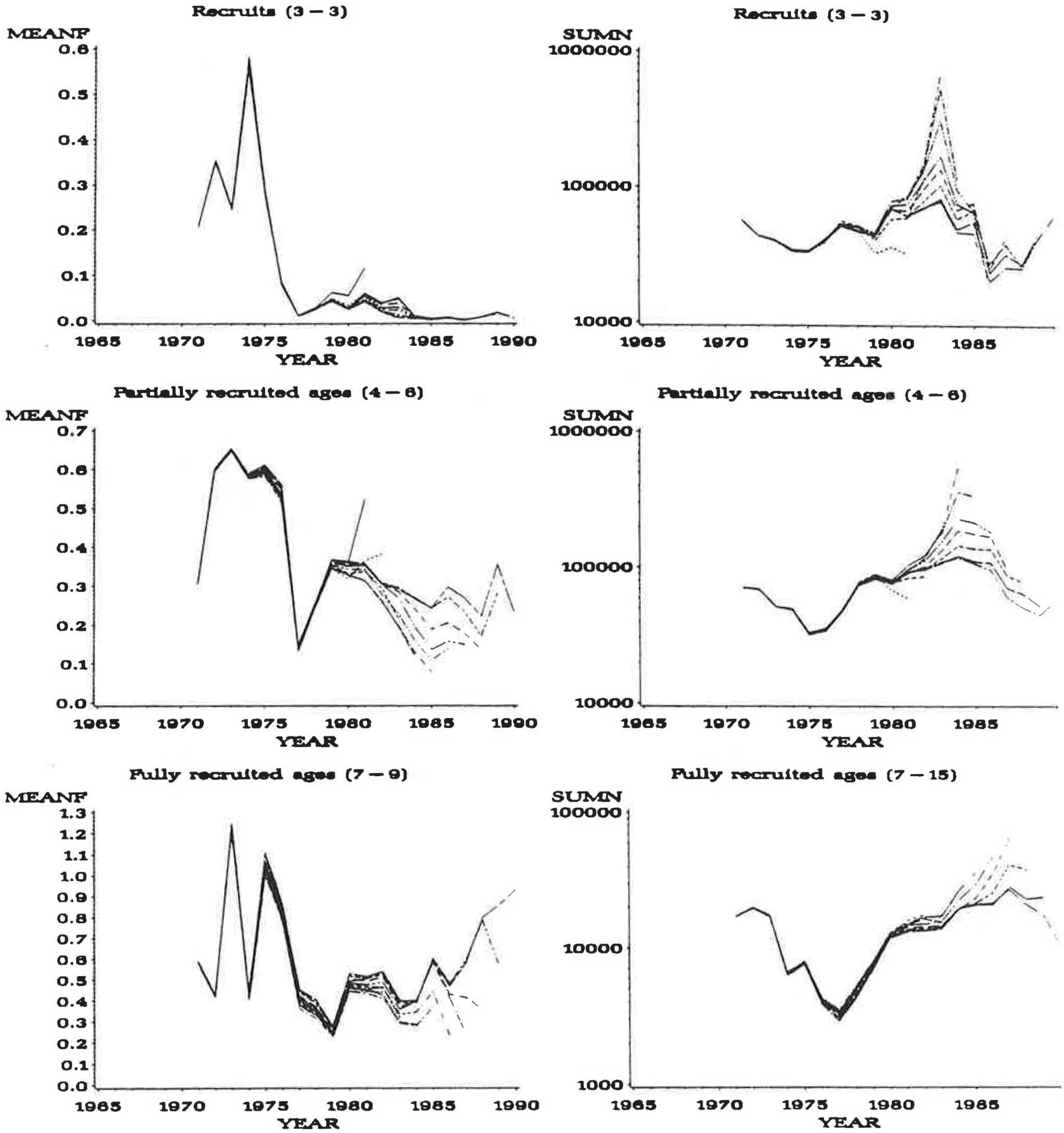


Figure 2.5.4 4Vs W Cod. XSA2 unshrunk.

Stock: 4Vs W Cod
Procedure: XSA2 Shrinkage CV=0.1

Retrospective analysis
c4vxsa2.s1

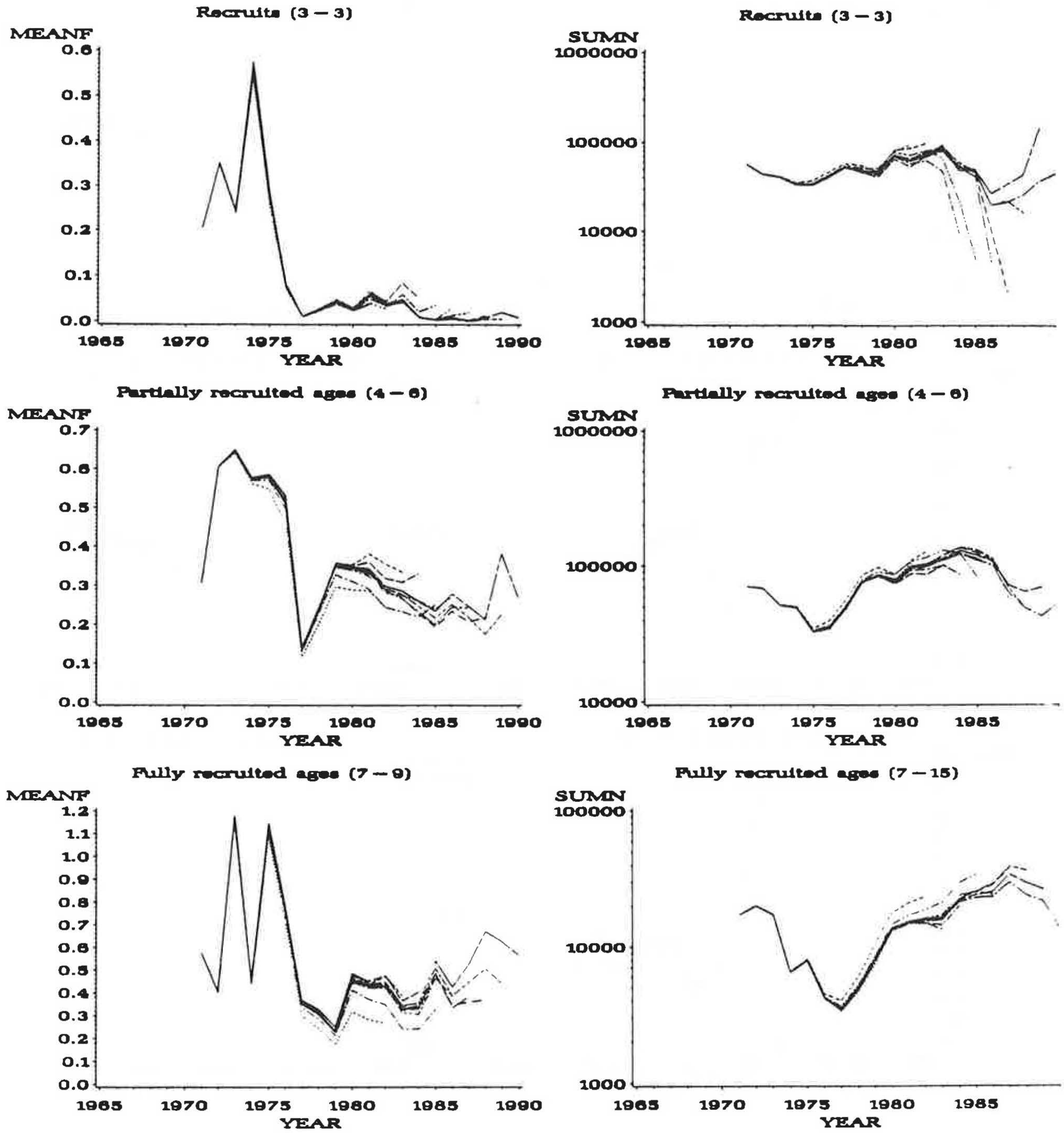


Figure 2.5.5 4Vs W Cod. XSA2 shrinkage CV=0.1.

Stock: 4Vs W Cod
Procedure: XSA2 Shrinkage CV=0.4

Retrospective analysis
c4vxsa2.s4

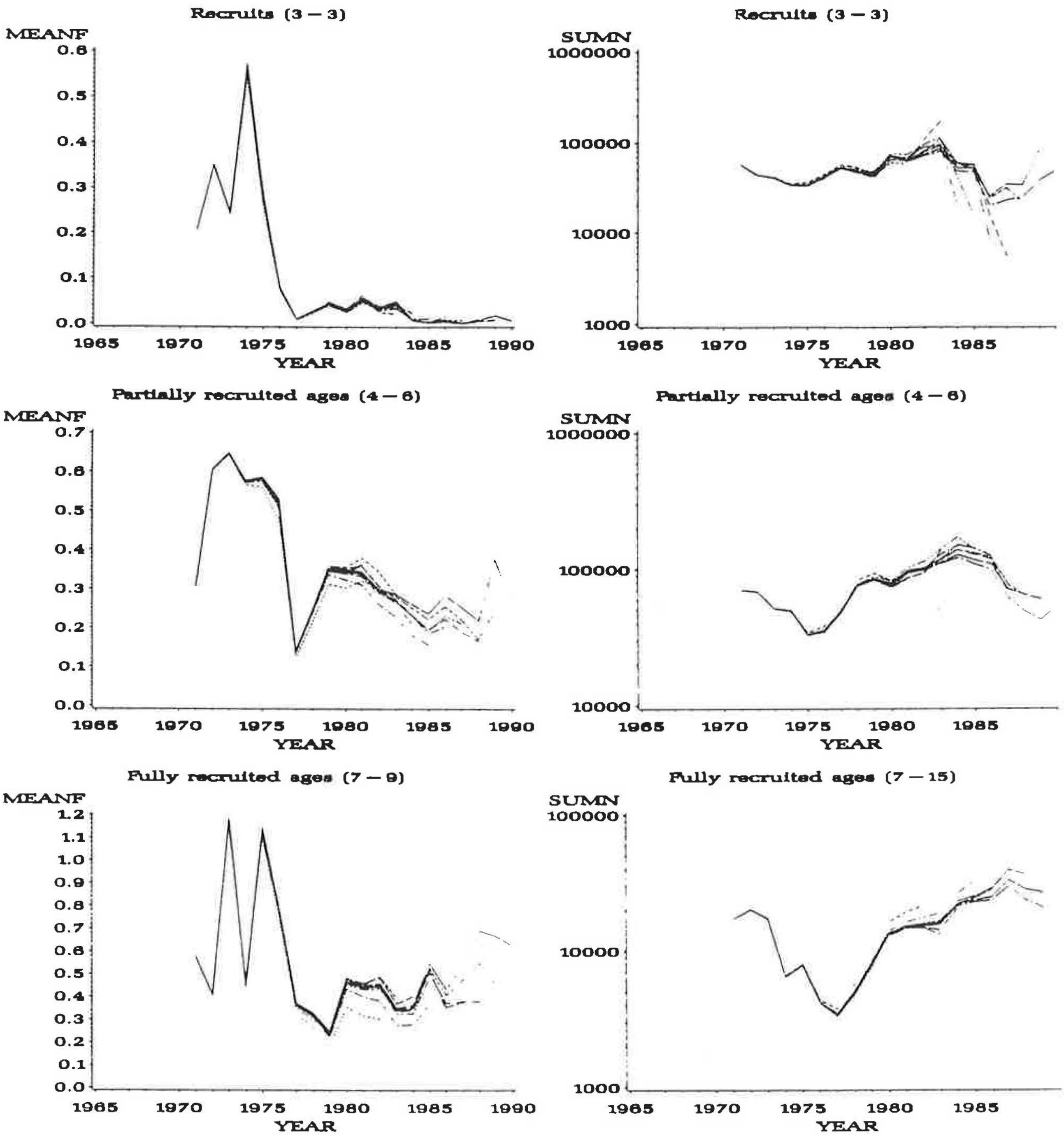


Figure 2.5.6 4Vs W Cod. XSA2 shrinkage CV=0.4.

Stock: Reykjavik Simulation 5
Procedure: XSA2 Unshrunk

Retrospective analysis
sim5xsa2.s0

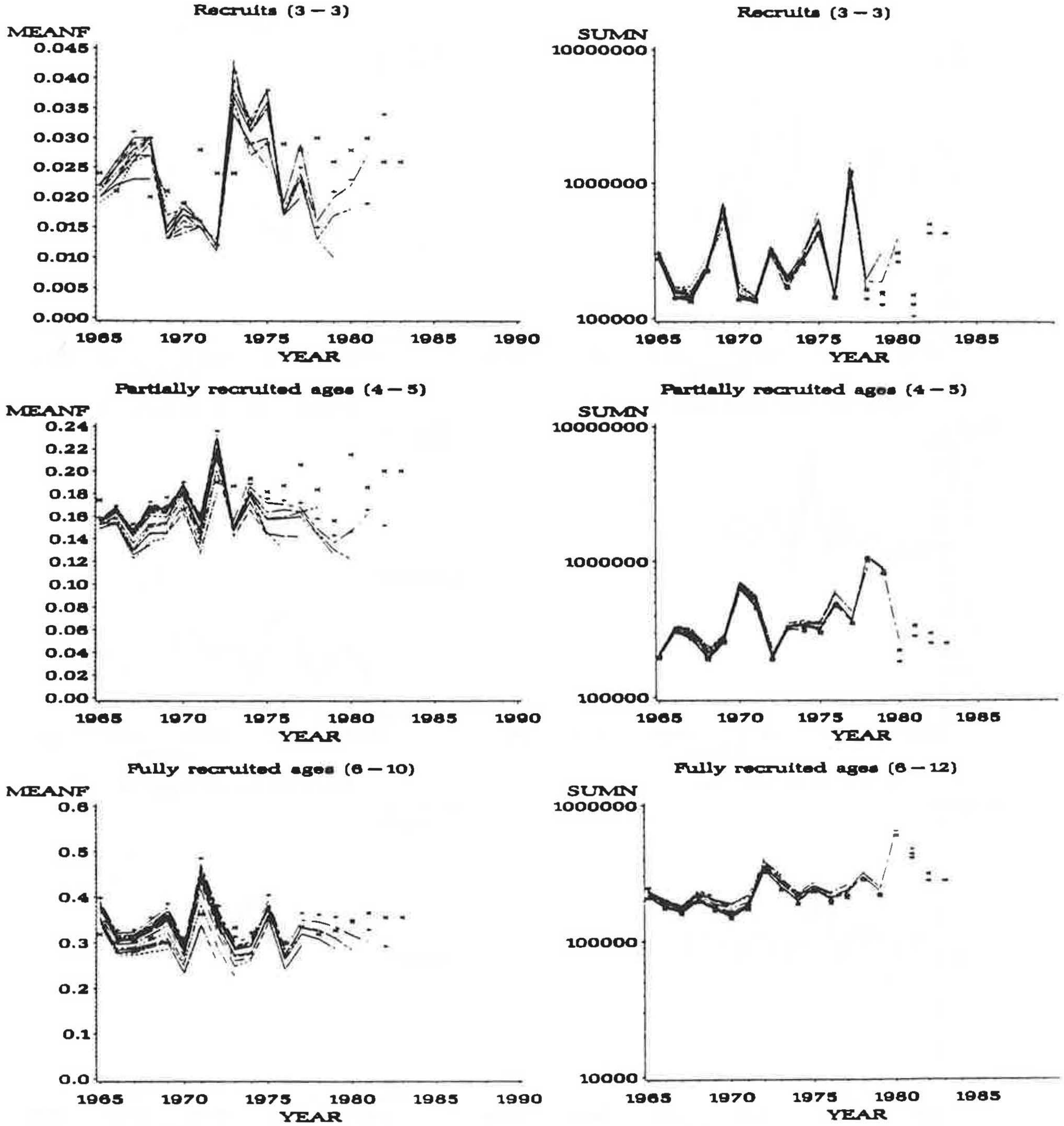


Figure 2.5.7 Reykjavik simulation 5. XSA2 unshrunk.

Stock: Reykjavik Simulation 5
Procedure: XSA2 Shrinkage CV=0.1

Retrospective analysis
sim5xsa2.s1

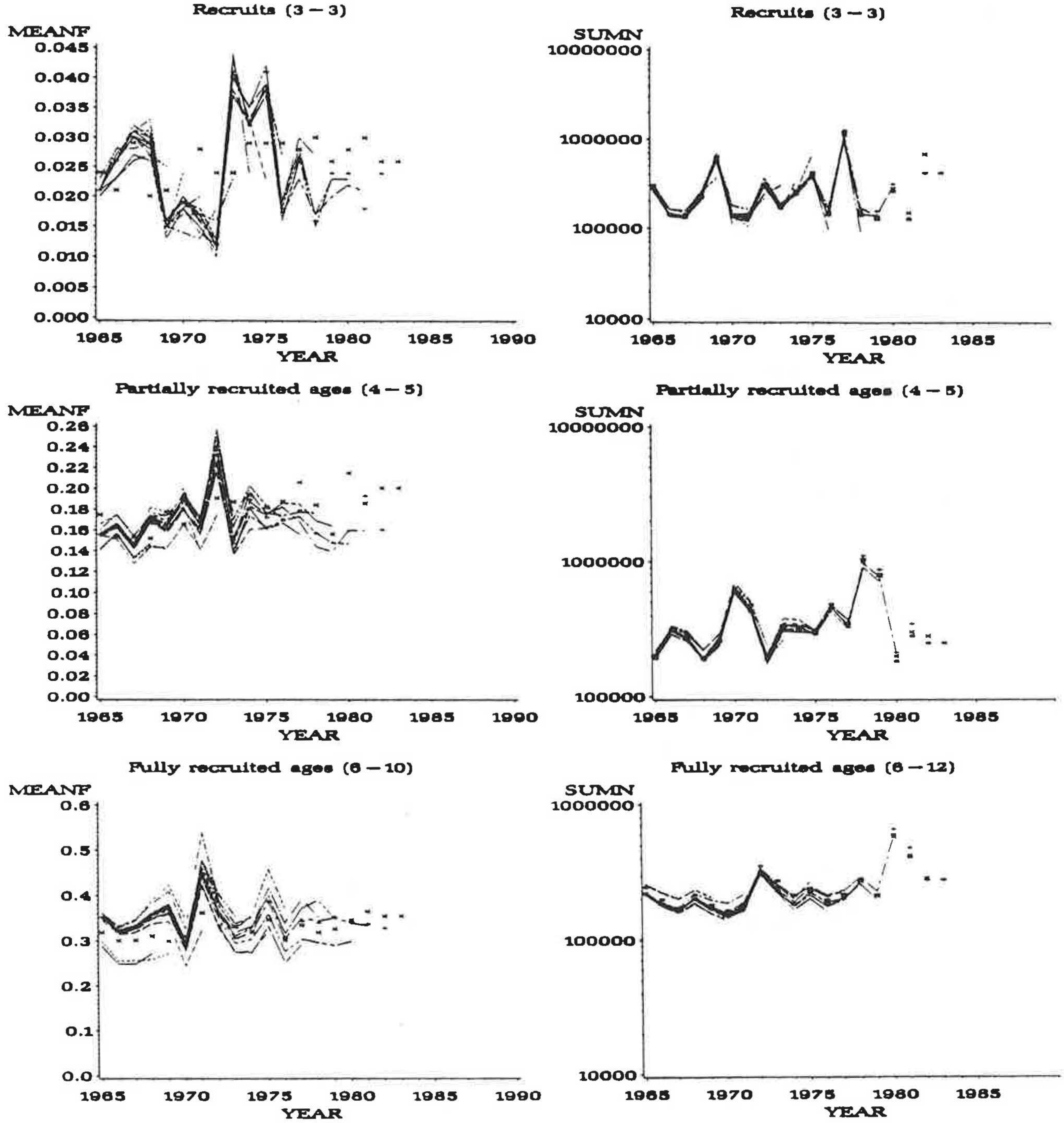


Figure 2.5.8 Reykjavik simulation 5. XSA2 shrinkage CV=0.1.

Stock: Reykjavik Simulation 5
Procedure: XSA2 Shrinkage CV=0.5

Retrospective analysis
sim5xsa2.s5

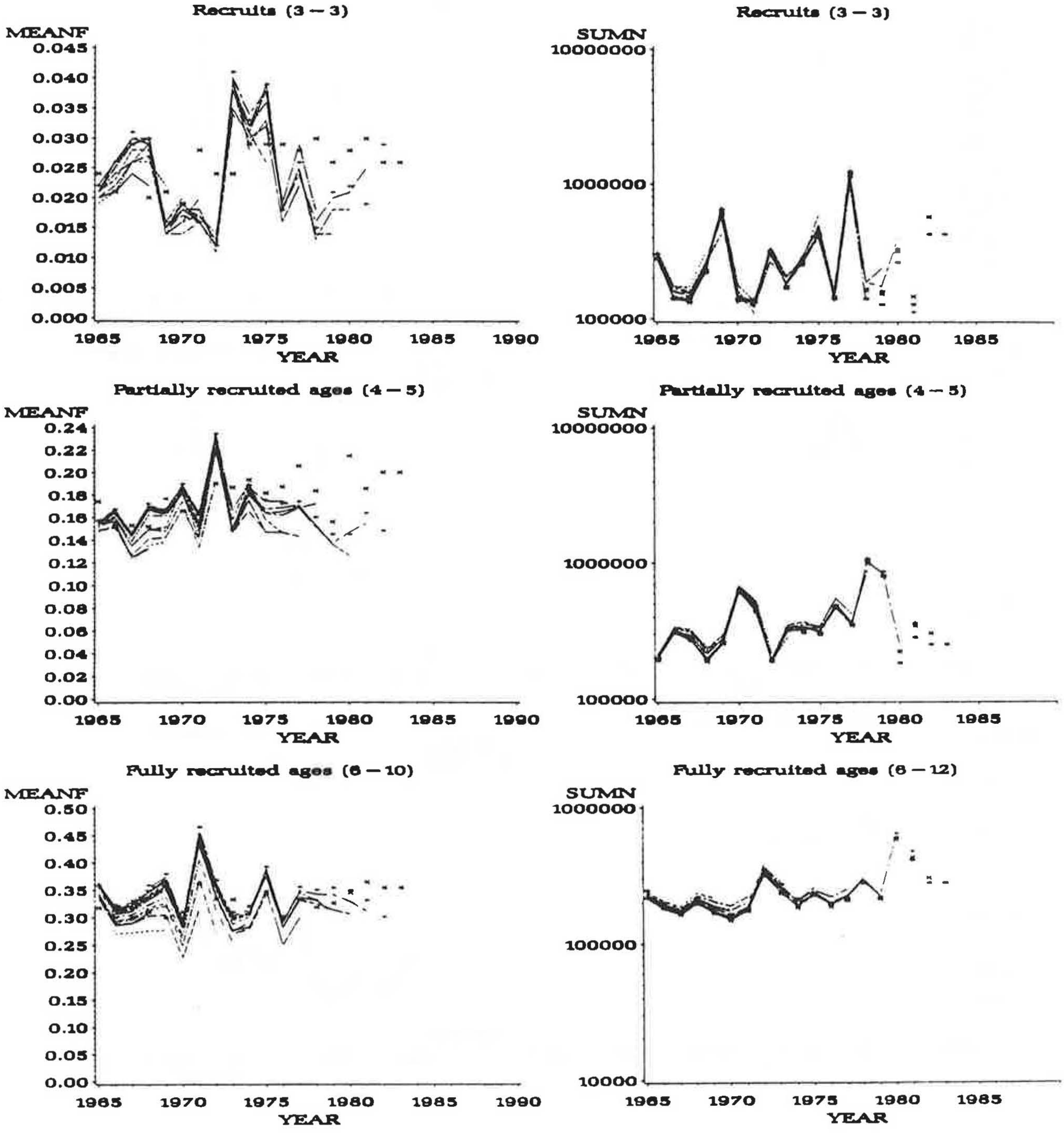


Figure 2.5.9 Reykjavik simulation 5. XSA2 shrinkage CV=0.5.

Stock: Reykjavik Simulation 5
Procedure: TSA

Retrospective analysis
simul.txt

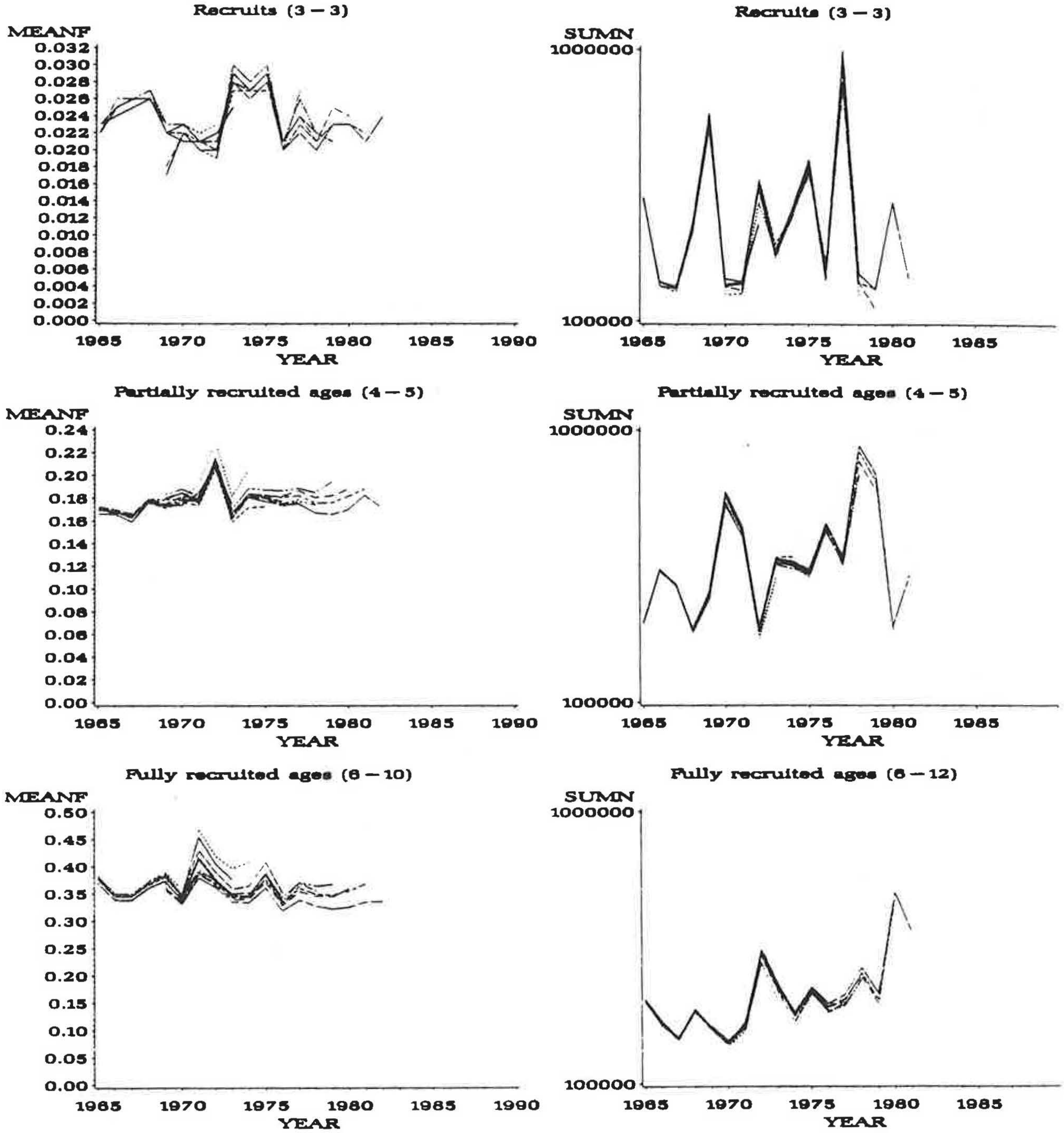


Figure 2.5.10 Reykjavik simulation 5. TSA.

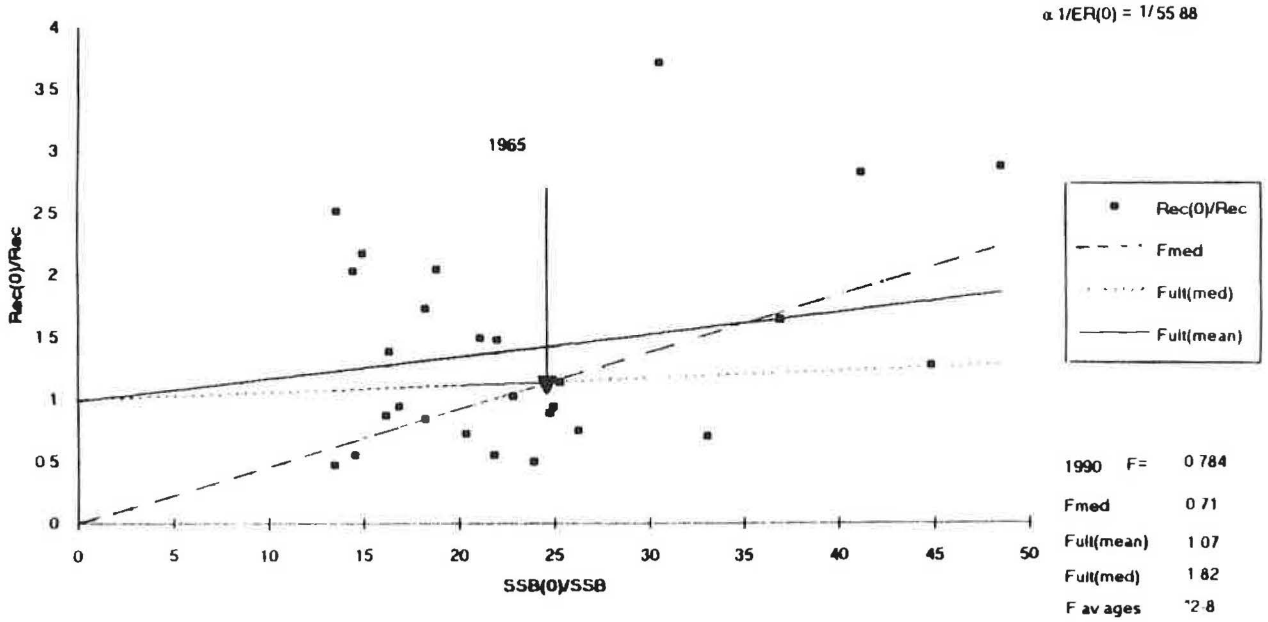


Figure 3.2.1 Example of a plot of the reciprocal of recruitment against the reciprocal of spawning stock biomass showing derivation of biological reference points (from Pope WP 6).

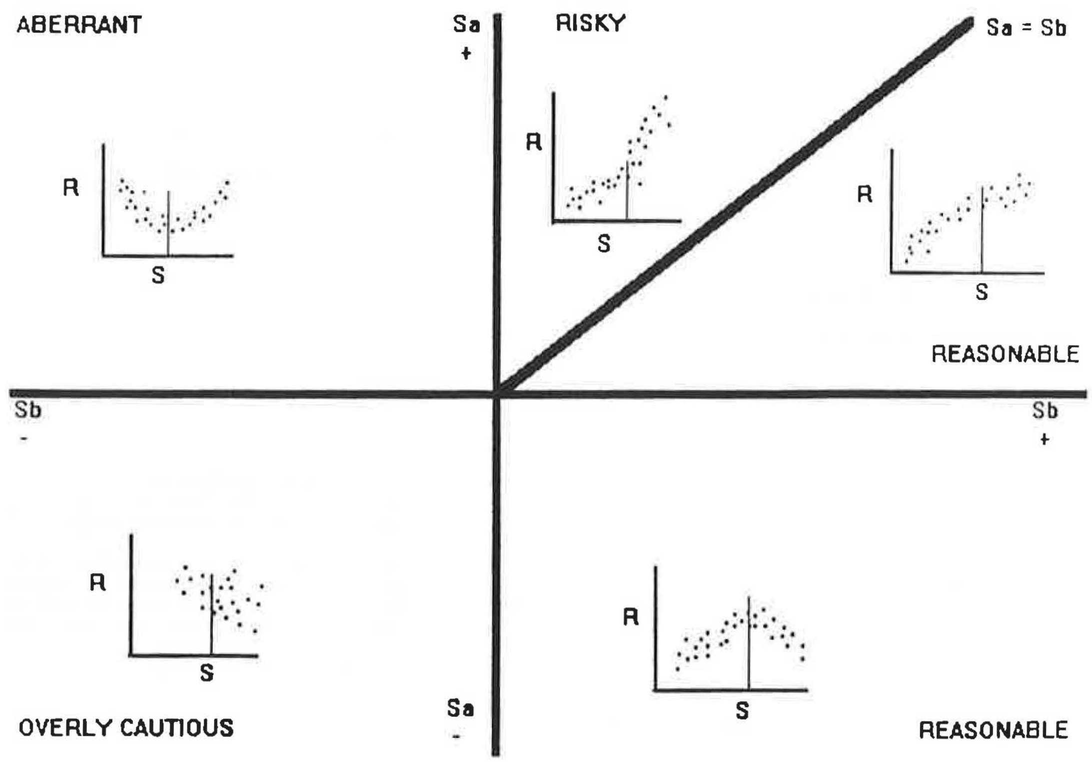
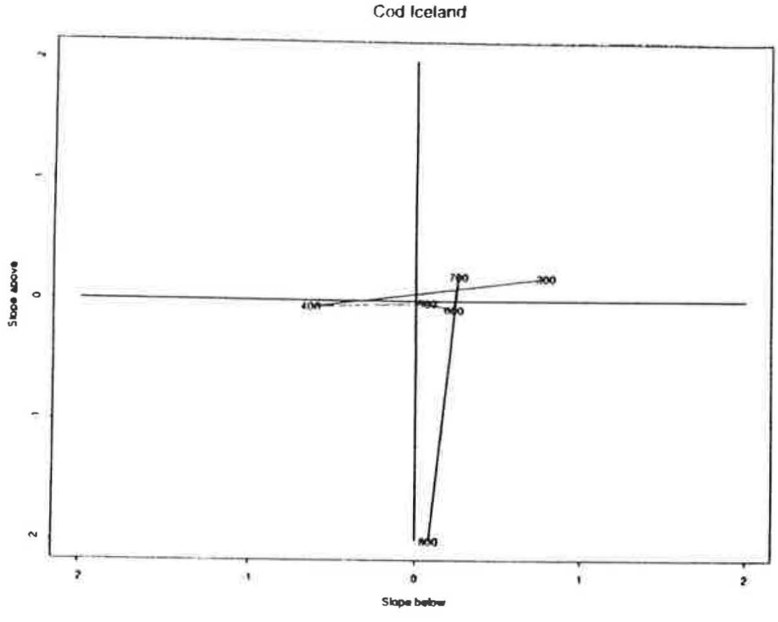
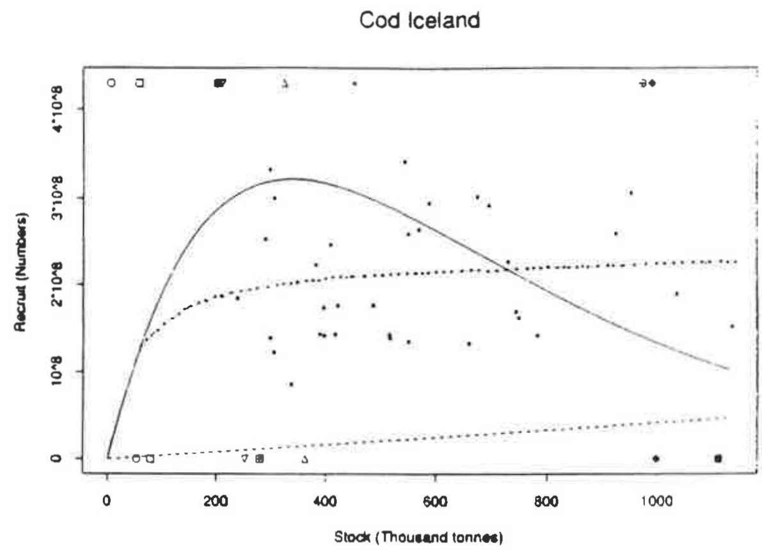
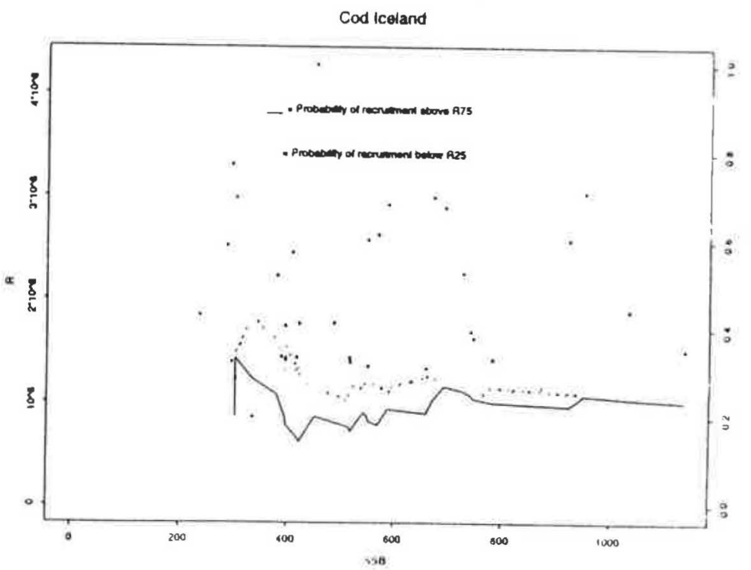


Figure 3.4.1 Decision diagram for slope above and below threshold biomass.





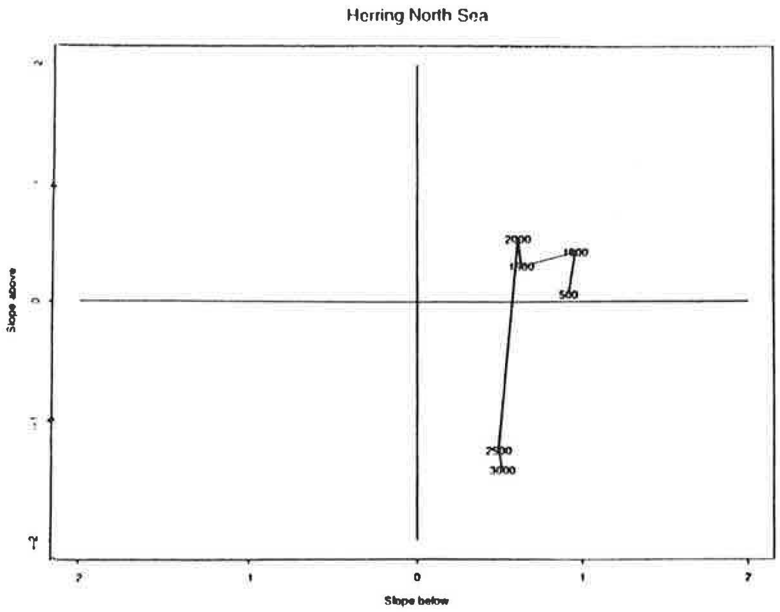


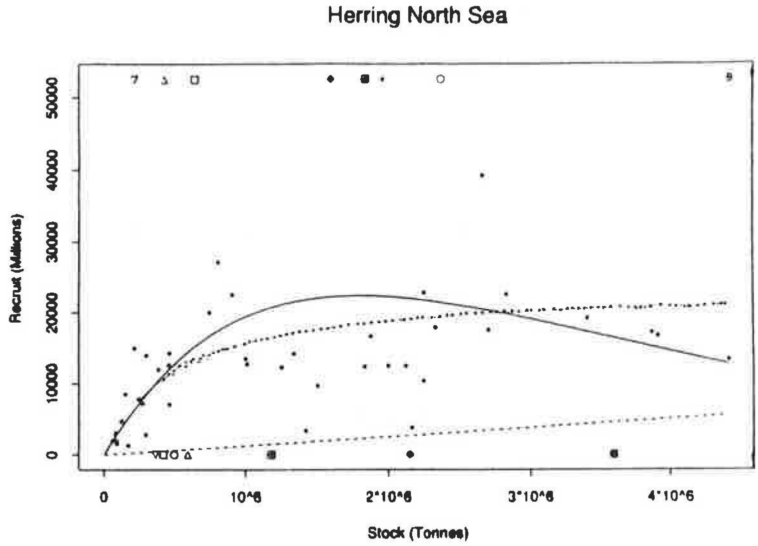
Virgin biomass from the Rmnv method	4988
Minimum observed SSB as proportion of virgin	0.0475
Maximum observed SSB as proportion of virgin	0.2281

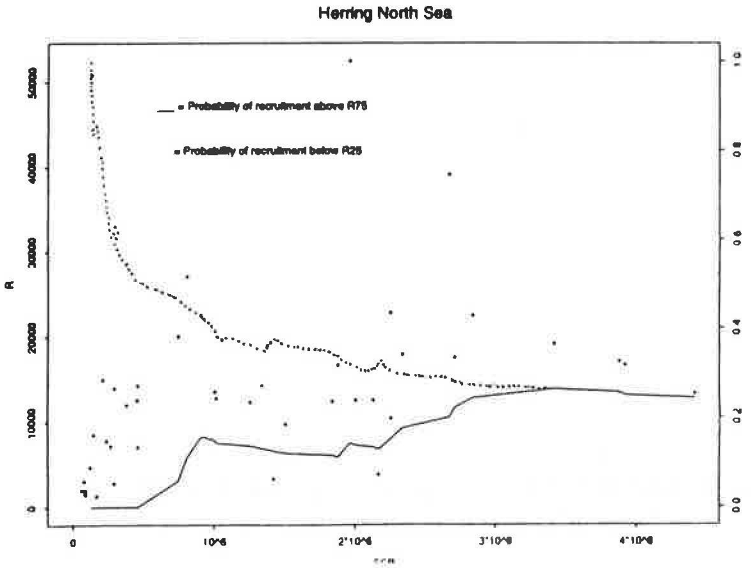
Sbv:	361.77	ratio of mean above & below	1.054
BH50:	52.40	ratio of mean above & below	Cannot be estimated
RK50:	78.37	ratio of mean above & below	Cannot be estimated
Rmnv:	997.759	ratio of mean above & below	0.7993

Slope of replacement line: 41684.03

Figure 3.4.2 Icelandic Cod - diagnostic sheet for estimating MBAL.







Virgin biomass from the Rmnv method		10751649	
Minimum observed SSB as proportion of virgin		0.0053	
Maximum observed SSB as proportion of virgin		0.4107	
Sbv:	591787	ratio of mean above & below	2.44
BH50:	493716	ratio of mean above & below	2.44
RK50:	415862	ratio of mean above & below	2.70
Rmnv:	2150329	ratio of mean above & below	1.52

Slope of replacement line: 0.0012658

Figure 3.4.3 North Sea Herring - diagnostic sheet for estimating MBAL.

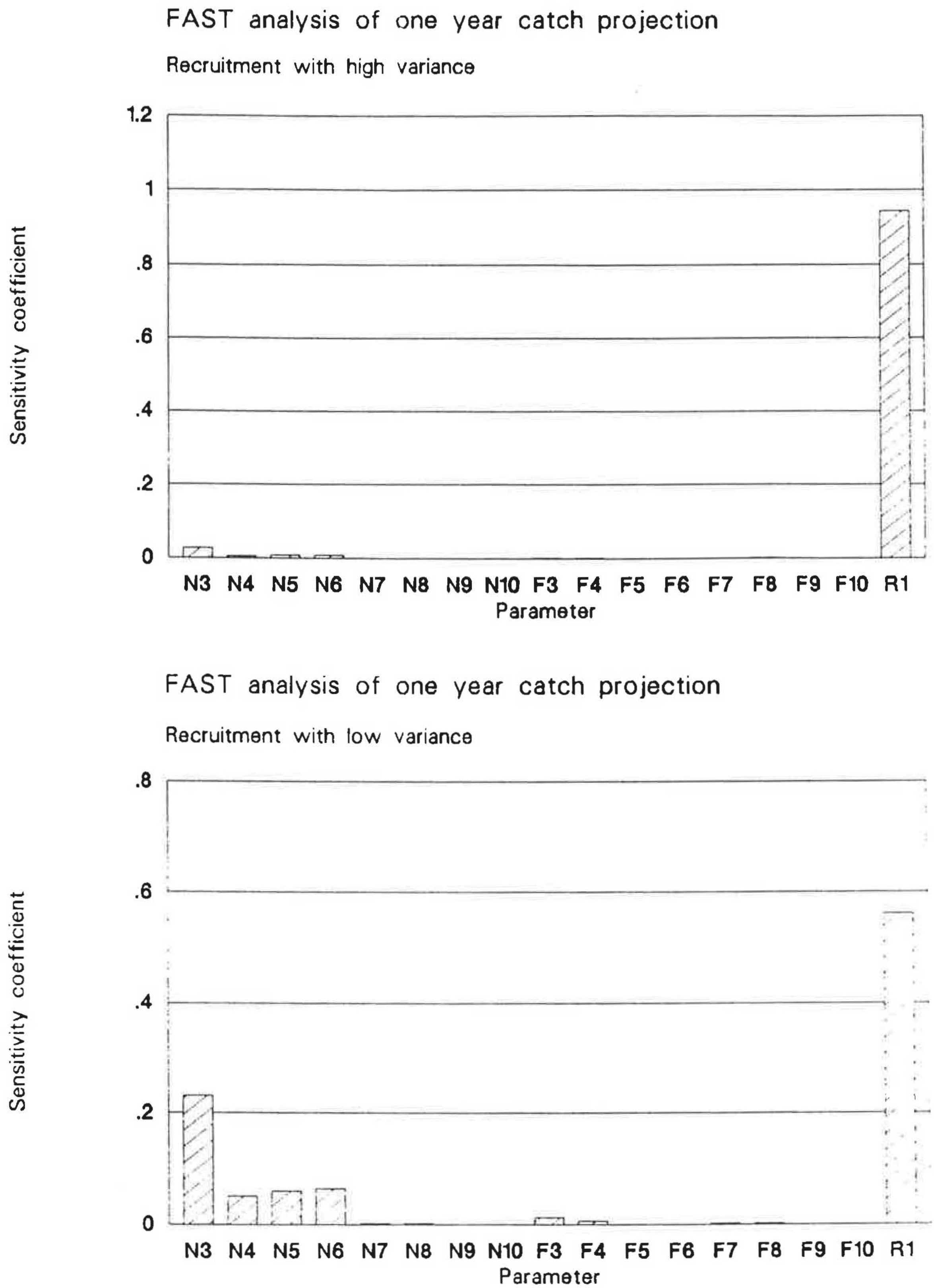


Figure 4.2.1 Output from sensitivity analysis. Ns refer to terminal populations indexed by age and Fs to terminal Fs at the sage ages. R1 is recruitment at age 3 in 1992.

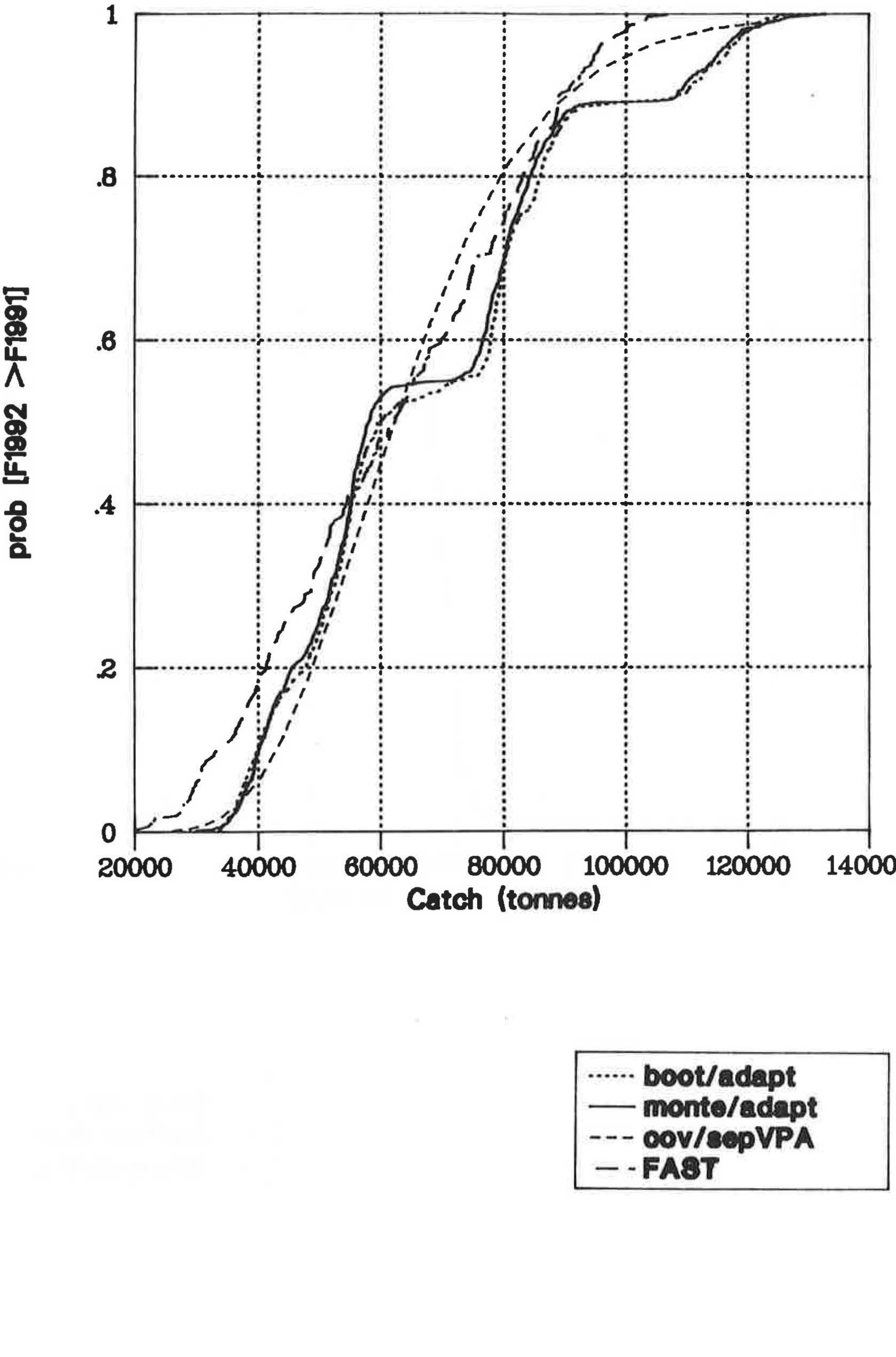


Figure 4.2.2 Probability profile for the simulated cod forecast example when recruitment variability is high in the recruiting year class. The profile is illustrative only.

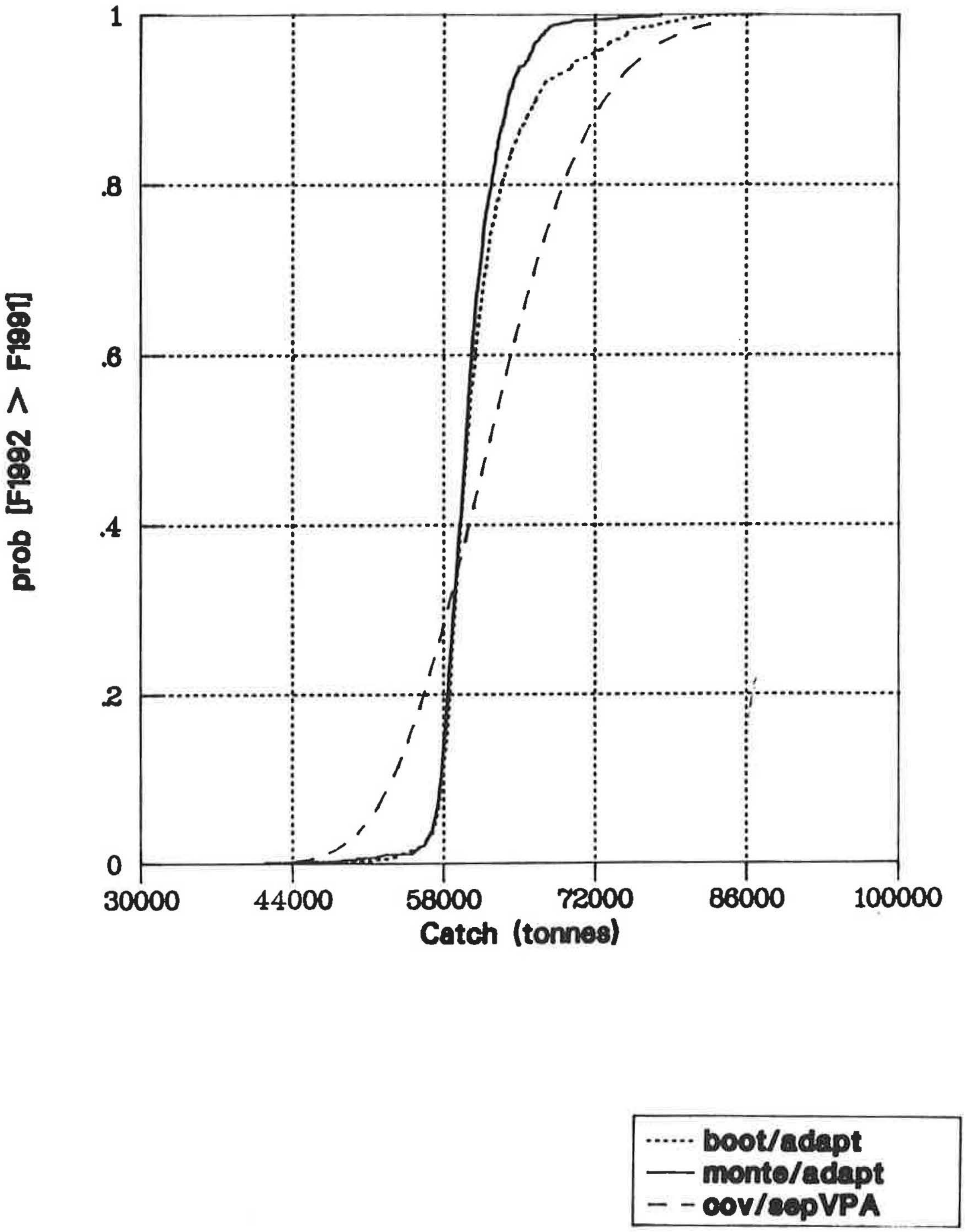


Figure 4.2.3 Probability profile for the simulated cod forecast example when recruitment variability is low on the recruiting year class. The profile is illustrative only.

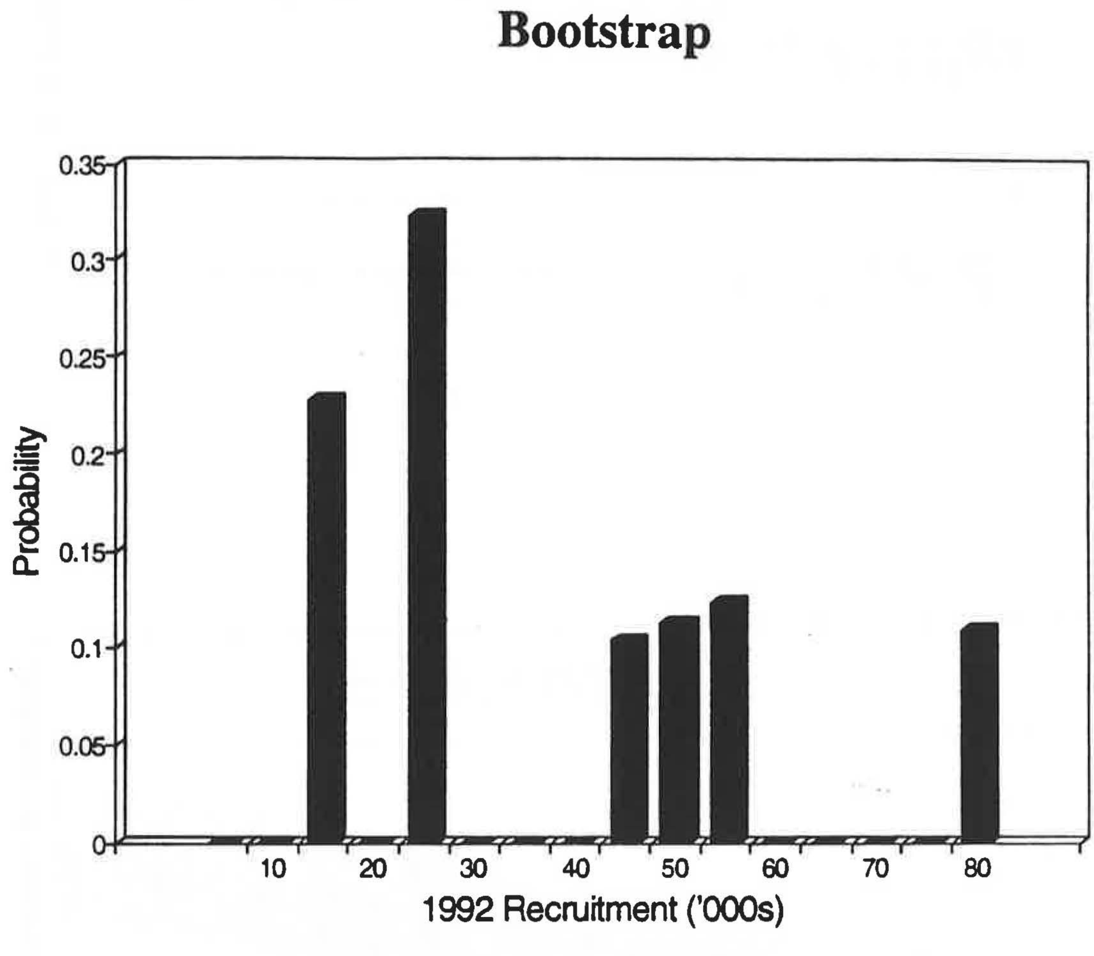


Figure 4.2.4 Observed distribution of recruitment estimates used in bootstrap technique.

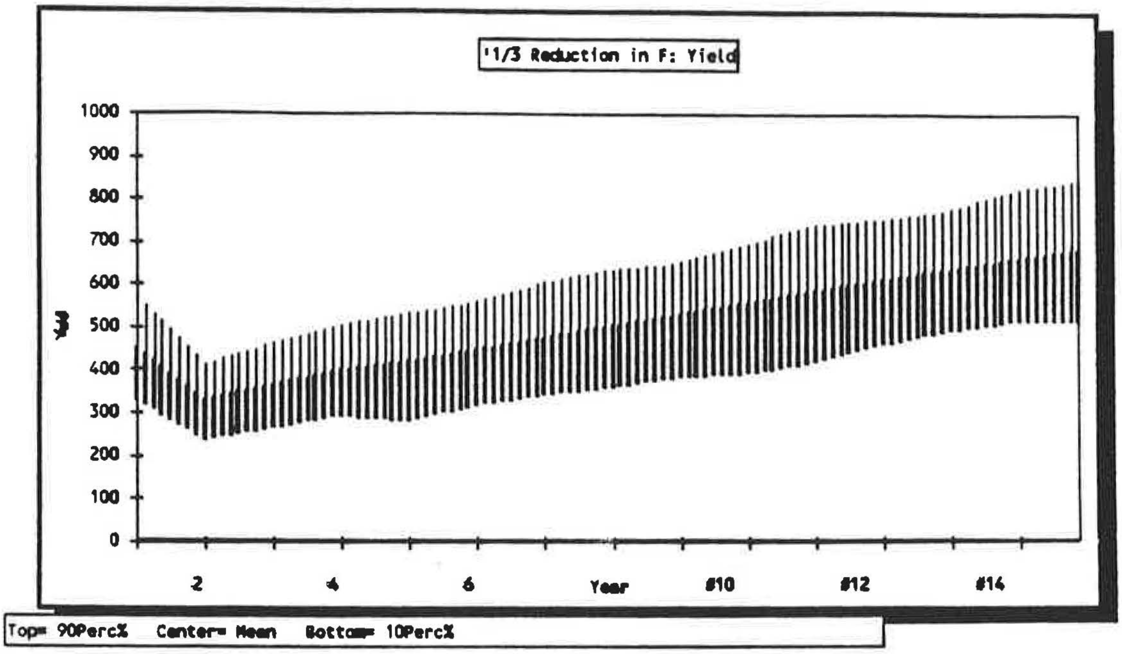


Figure 4.3.1 Medium-term (15 y ear)prediction of yield with upper and lower 90% confidence bars.

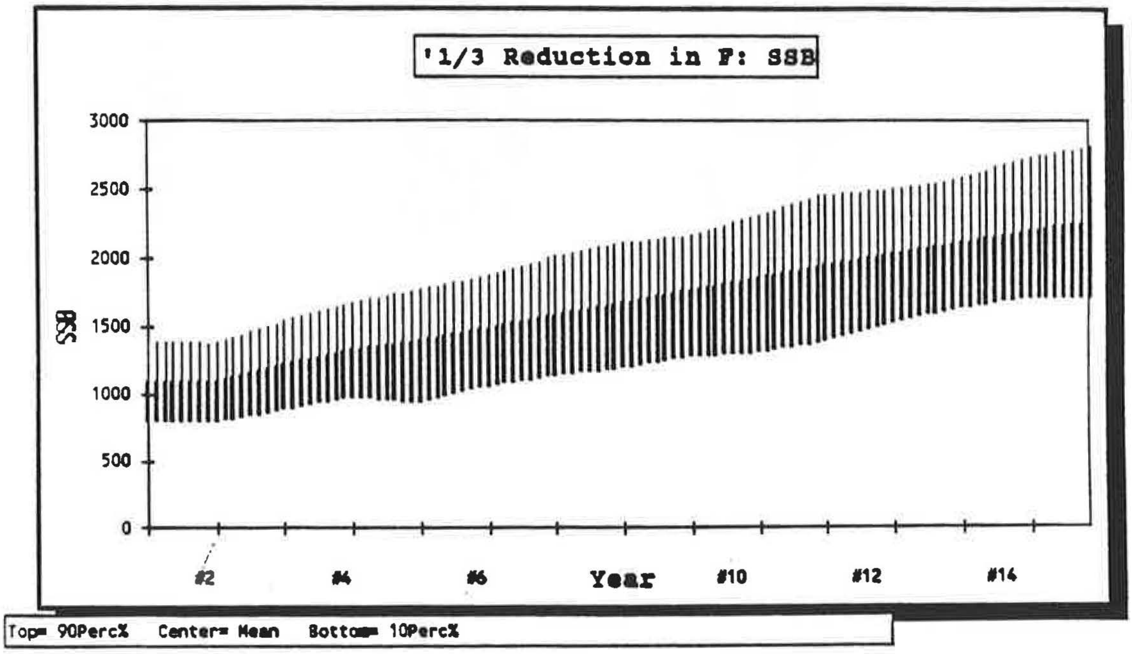


Figure 4.3.2 Medium-term (15 year) prediction of SSB with upper and lower 90% confidence bars.

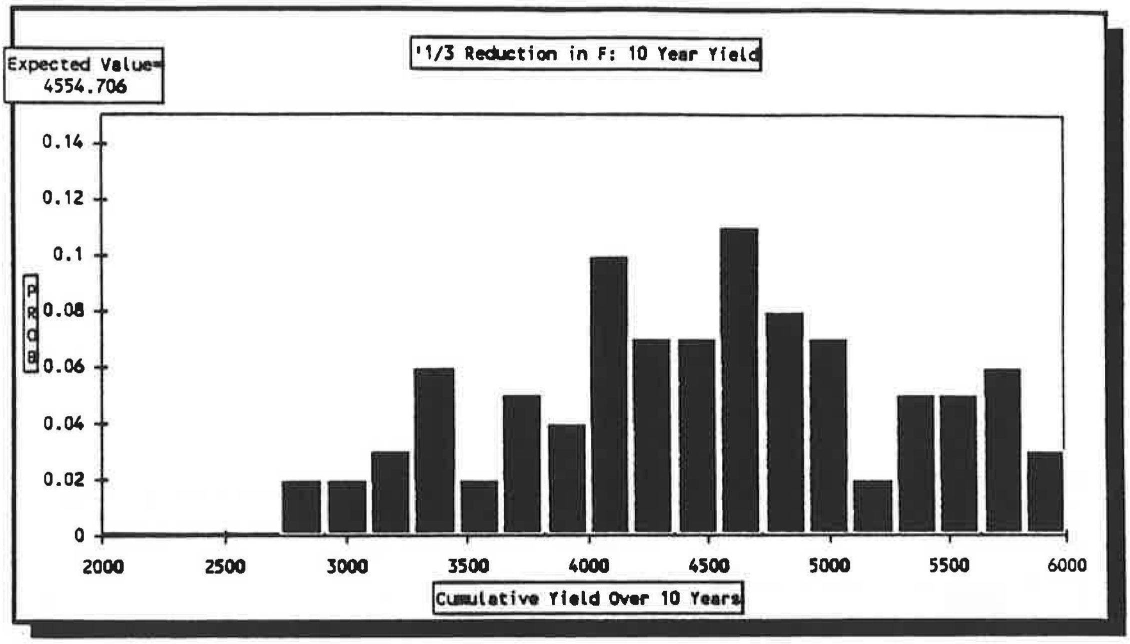


Figure 4.3.3 Histogram of simulated total yields over a 10 year period.

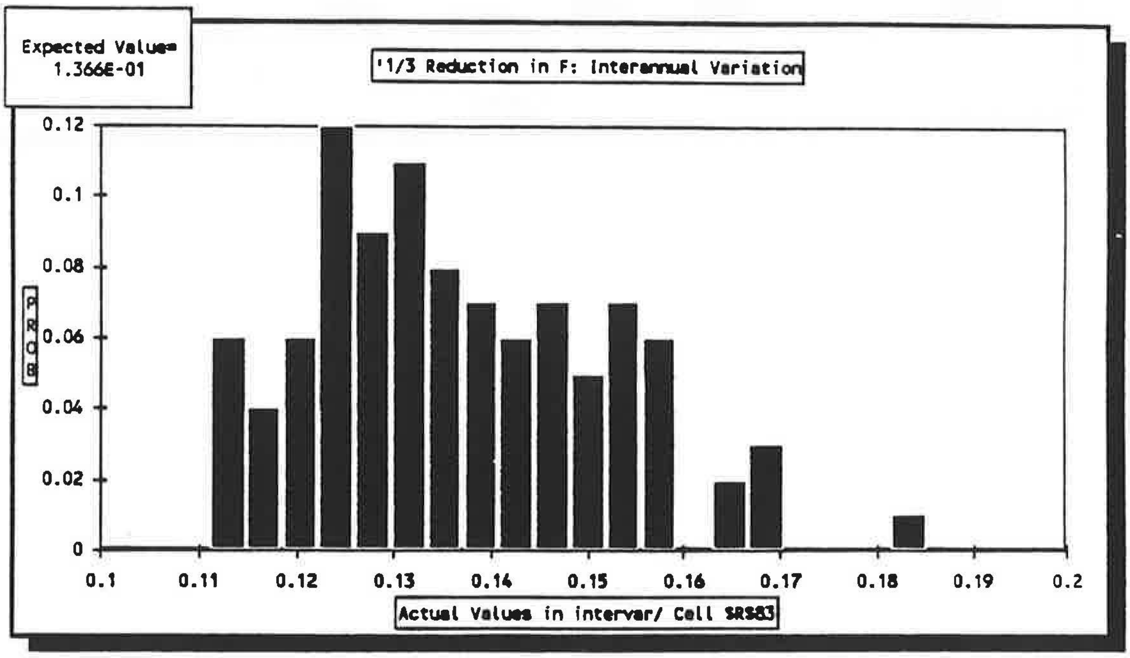


Figure 4.3.4 Histogram of simulated interannual variations.

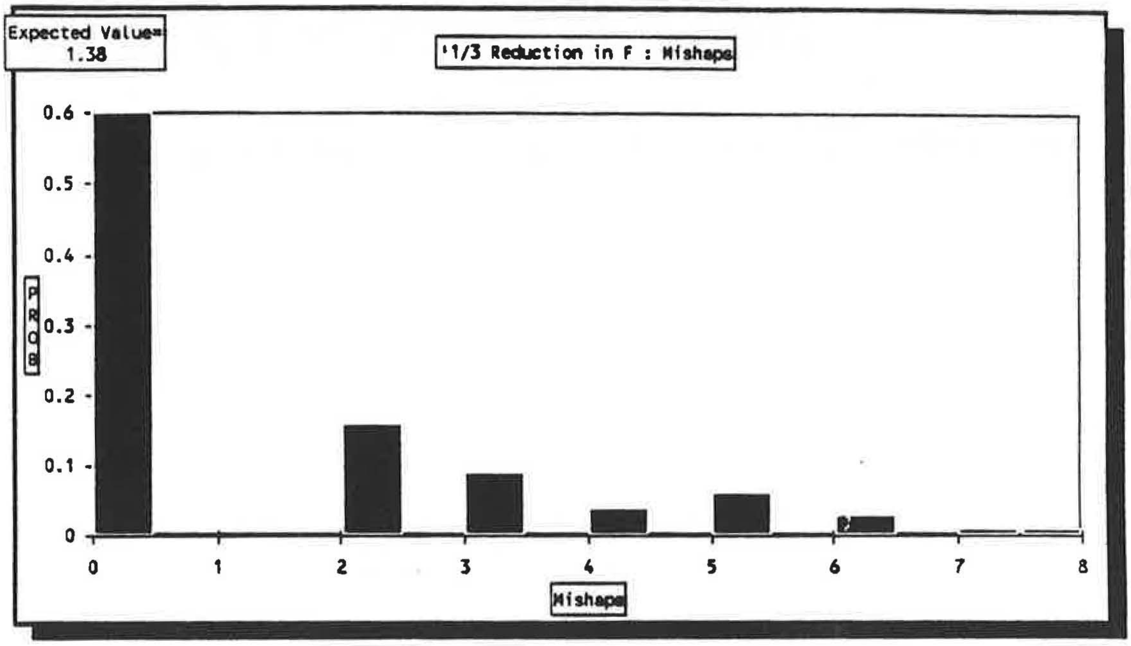


Figure 4.3.5 Probability distribution of the number of mishaps.

Appendix A: Notation

NOTE: This standard (and largely mnemonic) notation is followed sofar as possible, but not slavishly. Other usages and variations may be defined in the text. Array elements are denoted by means of either indices or suffices, whichever is more convenient. The same character may be used as both an index or a variable, if no confusion is likely.

Suffices and Indices

y indicates year		
f	"	fleet
a	"	age
t	"	last (terminal) year
g	"	oldest (greatest) age group
l	"	length
k	"	year class
$	"	summation over all possible value of index (usually fleets)
#	"	summation over fleets having effort data
@	"	an average (usually over years)
*	"	a reference value

Quantities (all may have as many, and whatever, suffices are appropriate).

C(y,f,a) Catch in numbers (including discards)
E(y,f) Fishing effort
F(y,f,a) Fishing mortality
F (y,f) Separable estimate of overall fishing mortality
s

q	Catchability coefficient (as in F=qE)
Y	Yield in weight
W	Weight of an individual fish in the catch
W	Weight of an individual fish in the (spawning) stock
S	
B	Biomass
P	Population number (also fishing power)
E	Fishing effort
U	Yield or landings per unit of effort
C	Catch in weight of fish (including discards)
W	
N	Stock in numbers of fish
F	Instantaneuos fishing mortality rate
M	Instantaneuos natural mortality rate
Z	Instantaneuos total mortality rate
S	Selection coefficient defined as the relative fishing mortality (over age)
R	Recruitment
f	Relative F (e.g., F/F*)
y	Relative yield (e.g., Y/Y*)
d	Fraction discarded
b	Fraction retained (b=1-d)
h	Hang-over factor
G	Instantaneous growth rate (in weight)
L	Landings in numbers (excludes discards)

l	Length
l_∞	Von Bertalanffy asymptotic length
K	Von Bertalanffy "growth rate"
r	Recruit index
MSY	Maximum sustainable yield
Fmsy	Fishing mortality associated with MSY
Emsy	Fishing effort associated with MSY
Bmax	Pristine stock biomass
m	Shape parameter for various surplus production models

Appendix B

Summary of Reports of Ices Working Group on the Methods of Fish Stock Assessment (And Associated Meetings)[1]

Summary of topics

Topic	1981	1983	1984	1985	1987	1988	1989	1991	1992	1993
1 Application of separable VPA	-	M	r	-	-	-	-	m	-	-
2 Simpler methods of assessment	-	-	M	M	i	-	-	i	-	m
3 Measures of overall fishing mortality	-	-	-	-	-	-	-	i	-	-
4 Use of CPUE effort and survey data in assessments	M	M	r	r	M	M	m	i	-	i
5 Need for two-sex assessment	-	-	-	-	-	-	-	-	-	-
6 Computation and use of yield per recruit	-	M	m	i	-	-	-	-	-	-
7 Inclusion of discards in assessments	-	-	-	-	-	-	-	-	-	-
8 Methods for estimation of recruitment	-	-	M	r	M	-	-	-	-	M
9 Density dependence growth, mortality, etc.)	-	-	-	-	-	-	-	-	-	-
10 Linear regression in assessments	-	-	M	-	m	-	-	-	-	-
11 Effect of age-dependent natural mortality	-	-	-	M	-	-	-	-	-	-
12 Stock-production models	-	-	-	-	M	-	-	-	-	-
13 Utilization of research survey data	-	-	-	-	M	M	m	i	M	m
14 Use of less reliable fishery statistics	-	-	-	-	m	-	i	i	-	i
15 Construction of survey and CPUE indices from disaggregated data	-	-	-	-	-	-	M	i	-	-
16 Implications of timing of WG meetings	-	-	-	-	-	-	m	-	-	
-										
17 Testing of age-balanced methods of analysis	-	-	-	-	-	M	m	M	-	-
18 Effects of management measures on CPUE	-	-	-	-	-	-	-	m	-	-
19 Evaluation and development of diagnostics	-	-	-	-	-	-	-	M	-	-
20 Application of length-based methods	-	-	-	-	-	-	-	m	-	-
21 Extension of time series of stock and recruitment	-	-	-	-	-	-	-	m	-	-
22 Problems with weight-at-age	-	-	-	-	-	-	-	-	-	-
23 Evaluation of uncertainty and risk	-	-	-	-	-	-	-	-	-	M
24 Shrinkage	-	-	-	-	-	-	-	-	-	M
25 Stock-recruitment relationships	-	-	-	-	-	-	-	-	-	M
26 Retrospective analysis	-	-	-	-	-	-	-	-	-	m
27 Minium Biologically Acceptable Levels (MBALs)	-	-	-	-	-	-	-	-	-	M

[1]See List of Meetings on page 71.

M: Major topic; m = minor topic; r = reprise;
i: incidentally considered

Dates, Locations and reports of previous meetings of the ICES Working Group on Methods of Fish Stock Assessment (and Associated Meetings)

Date	Place	Report Title	Citation CM Paper	Cooperative Research Report
1981	Copenhagen	ICES Ad Hoc WG on the Use of Effort Data in Assessments	1981/G:5	129 (1984), 1-66
1983	Copenhagen	ICES WG on Methods of Fish Stock Assessment	1983/Assess:17	129 (1984), 67-134
1984	Copenhagen	ICES WG on Methods of Fish Stock Assessment	1984/Assess:19	133 (1985), 1-56
1985	Copenhagen	ICES WG on Methods of Fish Stock Assessment	1986/Assess:10	157 (1988), 1-92
1987	Copenhagen	ICES WG on Methods of Fish Stock Assessment	1987/Assess:24	191 (1993), 1-77
1988	Reykjavik	ICES Workshop on Methods of Fish Stock Assessment	1988/Assess:26	191 (1993), 78-172
1989	Nantes	ICES WG on Methods of Fish Stock Assessment	1990/Assess:15	191 (1993), 173-249
1991	St John's	ICES WG on Methods of Fish Stock Assessment	1991/Assess:25	
1992	Woods Hole	ICES Workshop on the Analysis of Trawl Survey Data	1992/D:6	
1993	Copenhagen	ICES WG on Methods of Fish Stock Assessment	1993/Assess:12	

Report of Working Group on Methods of Fish Stock Assessments, 1995

1 Estimating quantities from uninformative, missing or misleading data

If information about ages were not satisfactory, one approach would be to renounce any attempt to estimate the fine detail of a stock and concentrate on getting good estimates of total numbers or biomass. Methods that take this approach are referred to as aggregated methods. Another approach would be to do the best possible job of resolving more detail of the stock - say the numbers at length or at age - but to recognize that it may not be a very good job and be prepared to evaluate just how bad it is. Methods that take this approach are called disaggregated methods.

A particular worry is that the data may not be simply inadequate to resolve all the detail desired, but actually misleading - for example if there are large numbers of deaths due to fishing that are not reported in catch statistics. It is in general not possible to detect misleading data unless the way it is misleading changes with time. The meeting considered methods for at least detecting, and possibly correcting, changes along with methods, which avoid using, catch data.

1.1 Issues in aggregated methods

Aggregated (lumped) methods estimate the history of fishable numbers and/or biomass. In what circumstances do disaggregated (sliced - either by age or by length) methods compromise ones ability to estimate lumped quantities accurately? In what circumstances do they enable more accurate estimates of lumped quantities?

By analogy with singular value decomposition, it should be possible to identify a list of quantities that are individually meaningful, and that the data can separately resolve. These quantities can then be ranked according to how well the data can resolve them. For example: total numbers; numbers at the youngest age at which fish recruit well to survey gear; numbers at successively older ages. It is no more trouble to use a method that attempts to estimate individual older ages and reports back that it cannot be done very well, than it is to use a method that gives up on the older ages from the start.

Is there a general (largely model-independent) theory of what hypotheses or estimated quantities are difficult to resolve, and what sorts of data are good at resolving them?

Is recruitment each year largely predictable from some combination of spawning stock, environmental conditions, and time trends; or must each year's recruitment be estimated separately with (almost) no prior model?

1.2 Issues in disaggregated methods

Is it better to slice by length or by age? The advantage of length is that it corresponds to the most directly available data; the advantage of age is that it permits the easiest analysis.

1. Are there intrinsic reasons for wanting to know the history of numbers at age, or is all really useful knowledge contained in a history of numbers at length? For some risk assessment purposes, one may wish to know if the stock is composed of few or many cohorts.

2. What properties make age information useful?

    a) The timescale is clear and the rate of ageing is known exactly, so that surveys from previous years can be interpreted as abundance indices for a cohort in the current year.

    b) There is a clearly identifiable starting point (oldest age), which provides a starting point from which a cohort's population history may be reconstructed.

3. To what extent does length information have similar properties?

    a) For young fish one has moderately accurate information about which fish in last year's survey would have been in a particular length group this year; for old fish the accuracy degrades quickly.

    b) There is a length that is never attained. However, whereas failure to reach an age can be explained only by death, failure to reach a length can be explained also by cessation of growth: hence there is no unambiguous starting point for reconstructing the history of a length group.

4. Many age-based data sets are derived from length-based data through an age-length key (ALK). There may therefore be advantages to working with a length-based model instead of immediately attempting to infer ages from length information.

5. What is a good model for growth? Is it age- or length-dependent, or both? What is the pattern of individual variability in growth rates (including an individual's memory of past variations)? How are growth rate parameters estimated, including correcting for length-dependent mortality, and how much of an advantage is it for age-based methods that their ALKs do not depend on this estimation? Does it matter if growth parameters are estimated from many years of data lumped together, whereas

age-length keys are typically determined for each year (or year and spatial subregion) separately?

6. What is a good numerical representation of growth? Is it necessary to use time increments more frequent than annual, to respect annual patterns in both growth and fishing activity? Should length classes be evenly spaced in length, or in time (i.e. the difference in successive mean lengths of intervals represents the average annual increment at that length)? To what extent should ease of numerical analysis influence the scientific choice about how to represent growth?

7. Age-based analysis has an advantage because it uses more information - the information that goes into the age-length key. Are there ways to use the same information directly in a length-based analysis, to make a fair comparison of the approaches?

8. Do length- and age-based methods differ only in their estimates of quantities that neither method estimates very well, or also in their estimates of "easy" quantities like total numbers or numbers at the youngest easily catchable age?

9. Are old fish mainly useful for determining lumped quantities, like total numbers by year, while young ages provide adequate information for cohort strength estimates, which information at older ages has no power to change?

1.3 Issues of diagnosing misleading data

Changes in unreported fishing deaths, in natural mortality and in (survey) catchability can all have qualitatively the same effect on VPA estimates. There is a need for diagnostic methods to detect when this has occurred. The following would all be valuable properties of a diagnostic method, although they may not be possible to attain:

a) power to detect real changes
b) independence of tuning details;
c) capability of distinguishing different kinds of changes;
d) capability of detecting actual errors and not just changes;
e) capability of quantifying errors and not just detecting them.

2 Imposing additional structure data sets

2.1 Introduction

The Working Group considered various data sets during its meeting, as listed in Tables 1.5.1-3. The data were chosen to illustrate certain important aspects related to the Terms of Reference. In addition, a selected subset was used to facilitate the comparison of as many methods as possible.

The following subsections describe the various data sets briefly, pointing out the various quirks in each set.

2.2 Gulf of Maine cod

The biology of Gulf of Maine cod is well understood. Commercial sampling has been quite extensive and research vessel surveys have been carried out on a regular basis since the mid-1960s. Growth parameters and other biological information are provided in Table 2.2.1.

Assessments are generally age-based using ADAPT. However, catch at length data (Figure 2.2.1a) and survey indices of abundance at length (e.g. Figure 2.2.1b) was assembled for methods testing and evaluation at this meeting.

The "official" results presented for this stock in Section 7 are based on an ADAPT run calibrated to the NMFS spring and fall surveys jointly. These results differ slightly in some years from the most recent Gulf of Maine assessment (Mayo 1995), which in addition to using the spring and fall surveys incorporated commercial CPUE indices and survey indices from the Massachusetts State surveys.

2.3 Icelandic cod

The biology of the Icelandic cod is quite well known and hence available data are quite extensive. The estimated basic biological parameters are given in Table 2.3.1. The growth parameters are estimated from all available age-length data and the length-weight relationship is based on a recent survey off the northern coast.

Both the catch in numbers data and survey indices have been disaggregated into the numbers in each age and length cell. Examples of these data are given in Tables 2.3.2–2.3.3.

Although the Icelandic cod is well sampled, immigration from Greenland may confound results from comparisons, both due to sudden changes in abundance and to apparent changes in growth.

2.4 Icelandic haddock

The Icelandic haddock was used as a stock which is reasonably well sampled and believed to have no major problems in terms of age determination. Growth is known to have been quite variable for this stock, however, and this may affect methods, which assume a constant growth pattern.

Overall growth parameters and coefficients in the length-weight relationship are given in Table 2.4.1.

These biological parameters are computed based on all available samples of length and age or weight.

Catch at length and abundance at length is given in Figure 2.4.1a and b.

During the meeting a problem was discovered with the data, due to the way an age-length key had been computed for the 1986 survey. The effect was minor and this problem did not affect any of the conclusions drawn.

As for the cod, the catch in numbers data and survey indices has been disaggregated into the numbers in each age and length cell. Examples of these data are given in Tables 2.4.2–2.4.3.

2.5 Simulated tuna data - noise-free

A stock projection model was developed which generates numbers at size and age. Growth from a given size and age is described by a beta function. The beta function has a finite range and is sufficiently versatile to describe a wide range of behaviour, which is controlled by two parameters (p, q). The parameters were contained to be integers and when p and q are equal, the distribution is symmetric. For all the simulations below parameter values of p = q = 3 are used. The surviving animals in a particular length-age-year cell (Nl,a,y) are distributed over lengths for the following year and age as

$$N_{.,a+1,y+1} = (N_{l,a,y} * Beta(p,q))\ exp(- F_{.,a,y} + M) \quad (2.5.1)$$

where the dot subscript denotes all values of the subscript. In the versions of the model used in this study the natural mortality is 0.2 for all ages and sizes and years and the selectivity is an explicit function of length alone which is multiplied by a fully recruited F for each year. The approximate partial recruitment was found to be 0.2 and 0.5 for ages 1 and 2 and with older ages fully recruited, thereafter.

The projections were run for 15 years with 10 age classes and 50 length classes. The catch at length is given in Figure 2.5.1 Three dimensional population numbers and catch matrices were produced. A summary size at age matrix was formed from the averages over the duration of the projection. This matrix was normalized such that the total over all length groups for a given age is 1 and this was denoted as the growth template. The size at age information in the growth template was used by each of the catch conversion routines in their own manner. The true effort data was also given so that CPUEs could be produced for tuning. The effort series began at an F of 0.1, which increased by 0.02 per year up to 0.38 in year 15. This data series (Tables 2.5.1–3) was also used by ICCAT for testing methods and there it was known as HCGM (High Contrast Good Means).

2.6 Simulated tuna data - noise in catch at length

The susceptibility of the methods under consideration to noise in the data was evaluated by adding lognormal noise to the catch length frequencies. The corrupted catch data were in turn used as indices of abundance by dividing by the true effort for each year. Sample output of the noise- corrupted (CV = 0.6) catch at length data has been generated (Figure 2.6.1). All other parameters are the same as for the clean set.

2.7 North Sea haddock

Biological sampling of the stock is generally good for both the landings and the discards. Fish discarded may account for a substantial component of the catch. The main problem with the data relates to the official catch statistics. When TACs were set at levels corresponding to a reduction in fishing mortality rate, there was an increasing tendency to misreport catches or for the catch simply to go unreported. This problem is believed to affect the data for 1991 and 1992. It is not thought to be a problem prior to this or in 1993. The data used by the Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak include a correction for mis-reporting in 1992. The data analyzed at this meeting did not include this correction to see if the methods used were able to detect and correct for it. The data used were the standard inputs to the ICES VPA program. Only the age composition data for 1992 differ from the assessment Working Group inputs and are given in Table 2.7.1.

2.8 Southern Gulf of St Lawrence cod (NAFO Division 4T, 4Vn (November to May)

Southern Gulf of St Lawrence cod is well sampled. Substantial changes in growth have occurred with high weights in the late 1970s decreasing until the mid-1980s to about half their previous value. This stock suffers from a serious retrospective pattern; misreporting and discarding are believed to have occurred. Predation may have increased as a result of increased grey seal abundance. Landings and survey estimates were available for 1982 to 1992 both at length and at age. The research survey has been conducted by three different vessels and adjustments have been made when necessary.

The stock spawns in Division 4T in early summer, feeds in Division 4T over the summer and autumn, and migrates to Division 4 Vn to overwinter from November - May.

2.9 *Sebastes marinus* (Icelandic area)

Redfish stocks are notoriously hard to assess due to problems in age reading (ACFM, 1994). It is therefore of interest to see whether stock-production models can be used for such stocks and whether analyses of length distributions can be used. Estimates of basic biological parameters are given in Table 2.9.1. The length-weight relationship is obtained from actual measurements, but the von Bertalanffy growth parameters are derived by assuming that this redfish stock grows by 2 cm per year for the first few years of life and ends up at 55 cm at a high age.

Length distributions for this stock are given for the catches and surveys in Figure 2.9.1a and b. Several things emerge from these figures:

a) This redfish stock grows by about 2–3 cm per year at an early age (1–8);
b) Recruitment is highly variable, with (roughly) the 1985, 1988 and 1990 year classes apparently large, but intermediate year classes much smaller;
c) The length distributions from the catches do not seem to have a lot of information content.

2.10 Unit 1 redfish (Gulf of St. Lawrence) *Sebastes fasciatus* and *Sebastes mentella*

As with other redfish stocks, it is difficult to determine the catch at age of Unit 1 redfish landings. The estimated biological parameters are given in Table 2.10.1. Recruitment to this stock is sporadic with 8 to 10 years separating year classes with negligible recruitment in between. The fishery started in the early 1950s and CPUE is available since 1959. Although the catch per unit effort has been standardized for season, area and size of vessel, the effects of vessel and gear changes over the period are unlikely to have been fully taken into account. Landings at length were available for 1981–1993 and survey data at length for 1990–1994.

2.11 Pacific ocean perch

Data on Pacific ocean perch *(Sebastes alutus)* were taken from the Goose Island Gully stock in Queen Charlotte Sound, British Columbia, Canada (Table 2.11.1). The fishery began in the 1950s and the stock was heavily targeted by Soviet and Japanese vessels between 1965 and 1976. Major stock depletions were believed to have occurred by the late 1970s (Archibald *et al.* 1983). The subsequent Canadian fishery has been regulated by comparatively low quotas, with annual catches ranging between 600 and 1500 t. The fishery operates by trawl at average depths of 150–300 m. The fishery is highly multi-species; not uncommonly, five or more *Sebastes* species are caught in a single trawl tow and over 20 *Sebastes* species are landed commercially from British Columbia. Historically, Pacific ocean perch was the most important species in this complex, but now accounts for only about 20% of the landed rockfish catch. In particular, misreporting and discarding of Pacific ocean perch are known problems, especially during the late 1980s and 1990s. Thus, reported catch is a minimum estimate of the true catch and recent commercial CPUE data provide a poor abundance index (Richards 1994). Relative biomass estimates from swept-volume trawl surveys are available for the period of the major fishery, but no surveys were conducted between 1985 and 1993.

Based on the break and burn method of age determination, Pacific ocean perch have been aged to 90 years. The assessment uses a value of M=0.05. For the analyses described here, assumed recruitment to the fishery occurred between ages 6–12 years and maturation occurred over ages 7–13 years. Approximate values of the von Bertalanffy growth parameters (L_∞, k, t_0) were (50, 0.08, 0) and coefficients (α,β) of the length-weight regression were (0.00001, 3).

2.12 Oceanic *Sebastes mentella*

Knowledge of Oceanic *S. mentella* in the Irminger Sea and adjacent waters is very restricted. As for *S. marinus*, it is hard to assess the stock due to age reading problems. Stock-production models and length distributions are therefore of interest.

Acoustic methods have been used to estimate the fishable stock size. Several acoustic surveys have been conducted since 1982 (first year of catch), but survey information is limited (ICES, 1991). This is mainly because none of the surveys have covered the entire distribution area. The 1994 survey, however, covered almost the whole distribution area and is considered the most reliable so far.

Length distributions from the 1983 and 1994 surveys are given in Figure 3.4.6 and an estimate from the 1994 acoustic survey of 2.2 million tonnes or 3.5 billion individuals (Magnússon, *et al.*, 1994) is used as an input for the analysis.

2.13 Eastern Scotian Shelf cod (NAFO Divisions 4VsW)

Eastern Scotian shelf cod is well sampled. Substantial changes in growth have occurred as in southern Gulf cod. Age and length information were available for landings (1971–1993) and for two research surveys, one in July (1971–1993) and the other in March (1979–1993). This stock has suffered from a serious retrospective pattern. Modelling of grey seal population trends and feeding suggest that their predation on cod may have increased in the 1980s. Misreporting, dumping and discarding is believed to have occurred in this stock.

3 Aggregate methods

3.1 Background

This Section describes approaches to modelling fish populations by emphasizing aggregate measures such as total biomass and the total weight or number of fish caught. These methods can be classified in several ways, depending on whether the population is modelled as stationary in time and whether the age structure of the population is taken into account. These stock-production models are described in Sections 3.2–3.5. In each case a likelihood function or a relative is maximized in order to obtain parameter estimates.

Length measurements may in some instances be used either to obtain recruitment indices or general extensions and alternatives to regular stock-production models. These alternatives range from apparently minor variations which merely add a length-based deviance to the likelihood to methods that are based on a considerably different concept which incorporates recruitment indices and includes both measurement and process error in the likelihood function.

3.2 Pooled, static, production models

Static, i.e. time-independent, models have commonly been used in the past. Popular examples of such models include Y=rB(Y-B) as the equilibrium yield for a given stock size. Models along these lines are described by Schaefer (1957) and Fox (1970). Although such models have a long history, they have not been included in this report since they do not account for the simplest time delays in population trends.

Annual assessments of the Cape hakes in the southeast Atlantic have, under the auspices of the International Commission for the Southeast Atlantic Fisheries (ICSEAF) traditionally been made using standard Schaefer (1957) or Fox (1970) surplus production models. These simple models were used primarily because of a lack of confidence in age-based methods such as VPA. However, it was early recognized that the standard, or static, methods had a basic flaw in that they assumed that the stocks being assessed were in a state of equilibrium. This could lead to potentially serious errors in the assessments. During the initial stages of a fishery the annual catch would be above the replacement yield (RY) so as to fish the stocks down to the level of maximum population growth or maximum sustainable yield (MSY). Consequently, by assuming an equilibrium state, the static models would overestimate the productivity of the resource and would inevitably result in overshooting the MSY level. Once a stock has been depleted beyond its MSY level, then optimal management practice would be to harvest less than the RY each year to rebuild the stock to the MSY level. In this case, the static models should theoretically underestimate the productivity, which would allow faster recovery. However, the methods require a long time series of catch and effort data, preferably from the inception of the fishery, and the data from the "mining phase" are typically more numerous than those from the "rebuilding phase". Consequently, the productivity is still overestimated.

3.3 Dynamic surplus production methods

In an attempt to address the weaknesses in the static surplus production model, a number of dynamic approaches were developed for example by Butterworth and Andrew (1984) and Schnute (1985). The Butterworth and Andrew (1984) model became the standard method applied at ICSEAF and in South Africa. This model was expanded by Punt (1991) to include multiple commercial CPUE estimates and multiple direct biomass survey estimates. Software developed by Punt (1994) was applied to the four data sets that included estimated annual effort. These were Gulf of Maine cod, Pacific ocean perch, Unit 1 redfish and *Sebastes marinus* (Icelandic area). For these stocks, the survey biomass estimates were obtained by applying the length-weight relationships to the catch-at-length data for all lengths greater than the length at 50% recruitment. The model could not fit the data for CRED and consequently the results for only three stocks are presented here.

The results for the three stocks assessed here, as given in Figures 3.3.1 to 3.3.3, show that, the model did not fit the data for any of these stocks at all well.

The estimates of population growth rate (r) and carrying capacity (K) are not at all precise for any of the stocks, as seen in Tables 3.3.1 to 3.3.3. This is because the parameters r and K are interlinked and the model cannot disentangle these two parameters without more contrast in the data. However, the composite term (rK) is estimated reasonably well, enabling a relatively good estimate of current depletion, although the individual parameters are not well estimated.

When the survey data were included in the model, both GCOD and CPOP yielded unrealistic results. These data were therefore excluded from the model fits. For both of these stocks, the global minimum of the Log-likelihood (lnL) surface was fairly robust, but lay in a trough of low values. The minimum for the fit to the IMAR data set was very sensitive to the initial values chosen for r and MSY. However, the estimate of relative depletion (B_{t+1}/K in Table 3.3.3) was between 13% and 15% for a wide range of initial parameters. Initial parameters were therefore chosen that yielded similar estimates of K to the age-based production model, so that the estimates of relative depletion could be presented.

3.4 Age-based production models

3.4.1 Background

Age-based production models are similar in concept to surplus production models (pooled dynamic production models - see Section 3.3) except that the population dynamic equations include age structure. The type of data needed to apply them is much the same as for the pooled models, that is, a (complete) catch history (landings by weight) and some time series of abundance indices (generally either CPUE or survey data). These abundance indices are assumed to measure total recruited biomass (i.e. "fishable" biomass). Information on catch at age or size is not required for these methods, though some recent implementations of these techniques are starting to incorporate such information (see below). Thus, although these methods are referred to as "age-based" production models, in general they do not require age-based input data.

Although the basic input data (catch and abundance indices) are shared between the two methods, age based models require some additional assumptions in relation to the pooled production models. In particular, they require estimates of parameters relating to recruitment, natural mortality, growth and selectivity. These parameters are generally specified as inputs rather than being estimated from fitting to the catch and abundance data. Typically, only two or three parameters are estimated from these methods. In most instances these parameters correspond to mean virgin biomass (B_0 or K), a catchability coefficient relating relative to absolute abundance (q) and, in some instances, a stock recruitment curve parameter (slope at zero biomass or r). More recent applications allow for joint fitting to several abundance indices, in which case a separate q is estimated for each index.

The strength of the age-based production models is similar to that of the pooled models in that the data requirements are minimal and they incorporate a full dynamic model for the stock, thus allowing exploration of long-term dynamics and exploration of future harvest strategies. The weakness of both methods is that they are very dependent on having sufficient contrasts in the data. To estimate two parameters (B_0 and q) requires contrasts in abundance, and to estimate an additional stock recruitment parameter requires data on stock recovery. They also require either a complete catch history, an estimate of depletion at the start of the time series or some similar measure.

3.4.2 Spreadsheet implementation

Age-based production models as described above usually include some stock-recruitment function, with one parameter to be estimated. In place of this parameter, an average recruitment level can be estimated. In this setting the initial (virgin) biomass, level is a simple function of the constant recruitment. This type of approach has been used by the North-Western Working Group (NWWG 1993) and in formulating the ACFM advice for Oceanic *Sebastes mentella* (ICES, 1994). The North-Western Working Group (NWWG) attempted to estimate the growth function and also to vary the selection pattern, using an acoustic estimate of stock size along with the length distribution on the survey.

A spreadsheet implementation of this same model along with some variations was used during the meeting to illustrate the behaviour of age-structured production models using data for *S. marinus*.

The basic assumption made is that the initial stock was in a virgin state with an equilibrium stock composed of age groups from a constant number of recruits. The virgin stock is thus computable based on knowledge of the number of recruits and the annual natural mortality. The number of ages is taken to be very large (65), so that natural and fishing mortalities define the effective age range.

A weight-based von Bertalanffy growth curve was used by the NWWG, giving weights at each age. This was changed to a regular 3-parameter length-based von Bertalanffy growth curve, which was used together with a length-weight relationship, as described in Section 2.9.

Some choice needs to be made concerning the selection pattern, which can be either taken to be constant (knife-edge) or for example, of the more general form

$$1 - e^{-k^S(a - a_o + 1)}$$

where a_o is the first age in the analysis and K^S is an assumed constant. In the base analysis, a simple knife-edge at 32 cm selection pattern is used, whereas the more general form is used for illustration purposes below.

The unknown parameters are thus the natural mortality and the constant recruitment. Projections of the stock are possible for any given value of these parameters based on the usual Baranov equations and the given catches taken from the stock in the years under consideration.

A given stock trajectory, B_y, can be used to predict the survey abundance U with qB_y, for some catchability parameter, q. Assuming lognormal errors, q can be estimated as the average of ln(U/B). For any given recruitment level, R, a sum of squares, SSE, can therefore be computed based on (lnU-ln(qB)).

Figure 3.4.1 shows the basic parameters assumed in the model. Other parameters are given in Table 2.9.1.

The resulting fitted biomass trend based on survey abundance data is given in Figure 3.4.2. This model indicates a depletion level (ratio of current to initial biomass) of 16%. The model also gives the time trend in fishing mortality, as illustrated in Figure 3.4.3.

The important differences between this particular model and the one used by the North Western Working Group (NWWG) are:

a) The stock under investigation by the NWWG was *S. mentella*, for which there is a single acoustic estimate, as opposed to a series of survey abundance indices for *S. marinus*. Thus, the present model minimizes the sums of squared deviances from the predicted survey indices whereas the NWWG forced the stock trajectory to go through the biomass estimate, treating it as absolute.

b) The NWWG estimated the growth parameters by utilizing the length distributions.

The main purpose of simple spreadsheet models such as this one is to obtain an understanding of the nature of the model, rather than for assessments. Thus, the SSE-value can be computed for various values of the curvature parameters in the selection and growth curves (k^s and k). Figure 3.4.4 shows the resulting SSE surface where recruitment is fixed throughout. It is seen that the minimum on this surface is not very well determined, for steeper selection curves, the growth parameter becomes more poorly determined and the estimates of the two parameters are confounded. This is not surprising, particularly since only the abundance series is used.

The most important lesson from these simple models based solely on survey or CPUE abundance data is that the number of estimable parameters is very low and should probably be limited to only a single parameter (initial biomass or recruitment parameter) along with catchability, which comes in as a nuisance parameter. Other parameters, such as the individual growth rate, selection or population growth rate usually need to be taken as given.

In spite of these constraints, the results in Figures 3.4.1–3.4.4 are quite promising in that these one-parameter model seem to be able to explain the data reasonably well for some stocks.

3.4.3 Variations on spreadsheet implementation

In this section there are some extensions and variations of the model in the previous section (3.4.2), with two applications.

For the case of oceanic *S. mentella*, the catch is mainly, or entirely, taken from the mature part of the stock. It was therefore considered reasonable to assume that fishing takes place with a constant selection on the mature part of the stock. Additionally, length distributions were computed rather than weight distributions, incorporating the traditional relationship between length and age (von Bertalanffy) and weight and length:

$$\bar{l}_a = L_\infty\left(1-\exp\left(-k\left(a-a_0\right)\right)\right) \text{ with } \bar{w}_a = \alpha \bar{l}_a^{\beta}$$

and proportion mature as $p_a = \dfrac{1}{1+e^{-g\left(\bar{l}_a - l_0\right)}}$

The initial stock is given in Section 3.4.2 (generated from constant recruitment and natural mortality) and fishing mortality is chosen to give the observed catch in weight:

$$C_y = \sum \bar{w}_a \left[\frac{F_y}{Z_y}\left(1-\exp\left(-Z_y\right)\right)\left(p_a N_a\right)\right]$$

Another step was to generate the full length distribution in the catches and/or stock from the model and compare them with the observed ones. This was done by taking the von Bertalanffy mean lengths at each age and using the normal distribution (with standard deviation proportional to the mean length) to generate length distributions within each age-group and scaling them in accordance with the stock/catch numbers for each age-group. The length distribution for a given year can then simply be computed by summing across age-groups.

A full set of parameters is:

Parameter:	**Explanation:**
R	Average recruitment.
L_∞	von Bertalanffy parameter.
k	von Bertalanffy parameter.
a_0	von Bertalanffy parameter.
CV	Coefficient of variation of the length distribution within each age-group.
g	Proportion mature parameter (or some other selection parameter).
l_0	Proportion mature parameter (or some other selection parameter).
M	Natural mortality.

Most of the parameters are predetermined.

For oceanic *S. mentella* there were only three parameters estimated (*R, g and* l_0). The von Bertalanffy parameters were given, the *CV* was taken as = 0.05, the length/weight relationship was known and *M* was taken to be 0.05. As in Section 3.4.2, the predicted stock trajectory was forced to go through the latest acoustic survey estimate (1994, 3.5 billion individuals). At the same time, the 1994 length distribution from the model was compared to the observed one observed on the survey. The parameters were estimated by minimising the difference between the length distributions using the Anderson-Darling statistic,

$\int_l \left(cum_{obs}(l) - cum_{pred}(l)\right)^2$, which is simply the sum-of-squares for the discrete spreadsheet model. Figures 3.4.5 and 3.4.6 show the fishable biomass, fishing mortality and length distribution for 1994.

The Unit 1 redfish from the Gulf St. Lawerance (see Section 2.4.10) has recorded landings from 1953 and length distributions from the catches from 1981; other data includes CPUE series and research vessel survey estimates. Only the length distributions in the catches were used to estimate the parameters by maximising the log-likelihood function from the multinomial distribution. The selection pattern used was:

$$s_a = \frac{1}{1+e^{-g\left(\bar{l}_a - l_0\right)}}$$

but an alternative pattern could be as in Section 3.4.2. The recruitment and the two selection pattern parameters were estimated. The results are shown in Figures 3.4.7–3.4.9. Figure 3.4.10 is a contour plot of the multinominal log-likelihood function as a function of recruitment (*R*) and a selection parameter (g_0), showing a maximum with recruitment around 230–260 million and selection parameter in the range of 23–29. It is seen that for a recruitment above 250 the selection parameter can vary widely without changing the value of the log-likelihood function very much.

The model has its pros and cons. Firstly, the proportion in each length-group is not multinominally distributed due to the intra-haul correlation (Pennington and Vølstad, 1994), but the Anderson-Darling statistic does not utilise sample size. Secondly, there is no reason to limit the recruitment to one average number; a smooth trend could be parameterized or even an extra recruitment parameter estimated for those years where high/low recruitment is believed to have happened. Thirdly, the length distributions used do not need to form a series of distributions in time (only one distribution can be used as in the case of oceanic *S. mentella*), but some abundance information (acoustic estimates, CPUE) would seem to be a good addition to the length distributions.

3.5 Bayes-based production models

3.5.1 Background

The underlying models for the Bayes-based methods are very similar to those discussed in Sections 3.3 and 3.4 above. The method differs principally in the way in which uncertainty is treated in fitting the models to the data.

In the Bayes-based methods, a prior distribution is specified for parameters (i.e. a distribution for estimates prior to fitting to the data) and a posterior distribution (a probability density function) is derived for selected parameters after fitting. These distributions are related via Bayes' theorem, which states that

P(model i|data) = P(model i) * L(data|model i) / Sum$_j$ [P(model j) * L(data|model j)]

where P(model i) is the prior probability for model i ("model i" here equates to a specific value for a particular parameter), P(model i|data) is the posterior probability we are interested in (i.e. the probability of the model given the observed data), L(data|model i) is the likelihood of the observed data given model i, and the sum in the denominator is to normalize the posterior probabilities such that they sum to one over all models. The prior for each model (parameter) can be formally derived from analysis of data extraneous to the process, or may simply represent a "best guess" as to the likely distribution for the parameter.

Once the posterior distributions have been derived, various other estimates can be derived from them, including maximum likelihood (the mode of the posterior), median, mean etc. This approach lends itself to estimating the "risk" of various outcomes (e.g. the probability of the stock being below some threshold level), and the posterior distribution for a variable or parameter (e.g. stock size) directly reflects the uncertainty in that estimate.

3.5.2 Implementation

A specific implementation of the Bayes-based approach was tested at the meeting. This implementation (Stock Reduction Analysis or SRA) is based on methods developed in New Zealand, Australia and at the University of Washington (see e.g. Francis, 1993 Mcallister *et al.*, 1994, and Punt, 1993) and similar approaches have also been developed in the scientific committee of the IWC. A description of the underlying dynamic model and likelihood equations used in SRA may be found in Working Document A2. The dynamic model is an age-structured model with stochastic recruitment about a Beverton-Holt stock recruitment relationship. It assumes constant, age-independent natural mortality, a constant selectivity over time, and von Bertalanffy growth.

In the version of SRA tested at this meeting, all parameters are fixed except B_0 (virgin biomass) and the "catchability" coefficient q for each relative abundance index. The latter are estimated via maximum likelihood within the program, so the only prior, which is specified, is on B_0. The prior on B_0 is assumed uniform over a range from Bmin to Bmax. Given this prior, the posterior for B_0 (and for other quantities of interest, such as stock size over time) is calculated in the following way (with details of the model and likelihood equations given in Working Documents:

1. Select a value for B_0 from the initial range (prior).

2. Select a time sequence of recruitment residuals to generate an initial stock size B_1 at the start of exploitation (assuming mean recruitment at B_0 levels) and to project the population forward over time for the given catch history.

3. Using the likelihood equations calculate the likelihood of the data (i.e. the relative and/or absolute abundance indices) given the population projection. If the stock crashes for the particular projection, set the likelihood to zero);.

4. Repeat steps 2 to 3 for a (large) number of random recruitment sequences and keep track of the average likelihood across simulations at the selected value of B_0.

5. Repeat steps 1 to 4 for a new value of B_0 drawn from the prior.

In practice, the initial value for B_0 is chosen at Bmin, and incremented by fixed amounts up to Bmax. Since the prior on B_0 is uniform, this procedure generates the posterior directly from the mean likelihoods at each value of B_0.

This procedure accounts for both process error (through the stock recruitment variability) and observation error (reflected through the Cvs on the observed data in the likelihood equations)

3.5.3 Results

Some results from application of SRA to Australian orange roughy data are given in Working Document A2. This method was also applied to a number of the stocks assessed in this meeting and results are presented for four of these cases. The results are presented for each case as two graphs, the first showing the mean biomass trajectory for the stock (where the mean is the likelihood weighted average over the posterior distribution for stock size) with the relative abundance data superimposed (scaled by the likelihood weighted q's). The second graph for each case shows the posterior distribution for B_0 from the analysis.

Results based on for Icelandic data for Sebastes *marinus* (stock SMAR) are given in Figures 3.5.1 and 3.5.2. There is a reasonable degree of contrast in the two abundance indices which show a similar decline from 1985 to 1993 (Figure 3.5.1) and the CVs for the fit of the model to the indices are low (20% for the survey data and 11% for CPUE). This is reflected in the relatively "tight" posterior on B_0 (Figure 3.5.2) with the mean and mode for "virgin" biomass being at about 1,000,000 t. The level of current depletion of the stock is estimated at about 20%. The stock size is projected forward for five years under a 25,000 t annual catch and shows some recovery over that period. The "risk" (=probability) of being below 20% of B_0 decreased from 0.56 in 1994 to 0.27 in 1999 under this management scenario. No attempt was made to fit to the mean length data (which were available), but the projections from the model show a slight but steady trend downwards in mean length, which is at odds with the data. The model is therefore not capturing some aspects of the dynamics of this stock.

Results for Gulf of Maine cod (stock GCOD) are given in Figures 3.5.3 and 3.5.4. Figure 3.5.3 shows that the relative abundance data are quite variable and that the trends are not well captured by the model. The CVs on the fit to the three abundance indices are all of the order of 40%. The posterior distribution on B_0 is very broad (indicating that it is poorly estimated). The absolute levels of biomass seem unrealistically high (130,000 t in 1994). Estimates of current depletion are likely to be quite unrealistic as information on exploitation prior to 1965 was not available. Biomass levels are high because the trends in relative abundance cannot be accounted for by the catches and, since the total trend over the period is slight, the method infers a large stock, which is relatively lightly fished. As with the IMAR stock, the model fails to capture the recruitment variations, which seem to be driving the changes in relative abundance.

For Gulf St Lawrence redfish (stock CRED), the model was fitted initially to a long time series of CPUE data which did not show any trend over the length of the series. Since it was felt that this time series did not represent a consistent abundance index, the model was rerun with a much shorter time series of CPUE data (1990 to 1993) which exhibited a strong downward trend (Figure 3.5.5). The model was able to fit these data quite well (CV on fit of only 13%) with an initial biomass of about 1,000,000 t and a current depletion to 20%. The posterior distribution for B_0 (Figure 3.5.6) is typical of analyses with short time series, indicating considerable uncertainty (upper stock sizes essentially unbounded).

The last stock analyzed by this method is Pacific ocean perch (stock CPOP) from the west coast of Canada. There is a long time series of CPUE data and an intermittent time series of survey indices (Figure 3.5.7). Although there is considerable variation in CPUE over the period, the lack of a clear longer-term trend again suggests a relatively low level of depletion (to only 80% of B_0) using this method. The posterior distribution for B_0 is very broad indicating large uncertainty and the CVs on the fit to the data are 40% on CPUE and 30% on the survey index. The biomass levels plotted in Figure 3.5.8 are the mode rather than the mean of the posterior distributions (i.e. maximum likelihood values).

3.5.4 Discussion

The results described above indicate that this method appears to work well in some situations, but fails rather badly to predict absolute biomass levels in others. As implemented at the moment, it also fails to pick up shorter-term trends in abundance driven by year class variability, although it is possible in principle to capture those effects with this method (by doing enough loops over recruitment variability).

The method seems likely to work reasonably well, where the abundance index used in fact measures relative abundance, and where it is measured over a period with reasonable contrasts in stock size. It appears not to work well where the early exploitation history is not available, and where changes in stock size are driven more by recruitment variability than by changes in fishing pressure. Where it produces a "reasonable" assessment of current stock status (as judged by the spread of the posterior distributions on stock size), the method is well suited to investigating the consequences of medium-term harvest strategies. Another advantage of the method is that it can incorporate a variety of types of data within a consistent statistical framework. It is also well suited to incorporating other sources of uncertainty via priors on any of the parameters.

3.6 Modified DeLury model

3.6.1 Model description

Surplus production models and age-structured models are both widely used for stock assessment. They represent data-poor and data-rich environments, respectively, under which assessments are carried out (Tables 3.6.1 and 3.6.2). Owing to data limitations and/or management requirements, many marine species fall into a middle ground - available data are not adequate for proper age-structured modelling, but much of what is known about the species of interest will not be utilized if assessments are done solely with surplus production modelling. Additionally while age-structured models provide a wealth of demographic information useful for management (e.g. age-specific population numbers and mortality rates), surplus production model output is much more limited and may not be adequate in many management situations.

A two-stage modified DeLury modelling framework (Allen 1966; Collie and Sissenwine 1983; Conser 1994) can be used to bridge the gap between the more data-intensive assessment methods (e.g. age-structured models) and those that tend to be used in data-poor situations (e.g. production models). In its simplest form, the model requires only total annual catch, a recruitment index, and an index of abundance for the fully recruited group. However, auxiliary information can be incorporated, if available, to relax some of the model assumptions. Annual stock sizes and fishing mortality rates are estimated using a nonlinear, total least squares objective function that allows both measurement and process errors. A foundation for risk-based management advice under uncertainty is provided by estimating variance, bias, and nonparametric confidence intervals for all model state variables. A suite of diagnostic procedures and visualization tools also provides the means to assess the appropriateness of the model results objectively.

3.6.1.1 Model for parameter estimation

Define a survey year as the period between the successive annual surveys used to provide indices of abundance. Then define terms:

R_{0y}	population size (in number) of the recruits at the beginning of survey year y
N_{0y}	population size (in number) of the fully-recruited age group at the beginning of survey year y
C_y	catch in number during survey year y
M	instantaneous rate of natural mortality (yr^{-1})

Then using the DeLury framework, the first order difference equation

$$N_{0,y+1} = (N_{0y} + R_{0y} - C_y)\,e^{-M} \quad (3.6.1)$$

relates the fully-recruited stock size at the beginning of a year, $N_{0,y+1}$, to the fully-recruited stock size at the beginning of the previous year, N_{0y}, plus recruitment, R_{0y}, minus the catch, C_y, all discounted for natural mortality, M. In what follows, the survey indices of abundance in numbers, n_y and r_y, are related to absolute stock sizes by catchability coefficients:

$$n_y = q_n N_{0y} \quad (3.6.2)$$

$$r_y = q_r R_{0y} \quad (3.6.3)$$

Substituting Equations (3.6.2) and (3.6.3) into (3.6.1) and introducing a process error term gives

$$n_y = \left(n_{y-1} + \frac{r_{y-1}}{s_r} - q_n C_{y-1} \right) e^{-M+\varepsilon y} \qquad (3.6.4)$$

where

$$s_r = \frac{q_r}{q_n} \qquad (3.6.5)$$

is the selectivity of the recruits relative to the fully-recruited group; and ε_y is a normally distributed random variable with mean 0 and variance σ_ε^2 representing the process error. The measured survey index of abundance for the fully-recruited animals (n') is related to the *true* index of abundance (n_y) by

$$n'_y = n_y e^{\eta_y}$$

Similarly for the recruits,

$$r'_y = r_y e^{\delta_y} \qquad (3.6.7)$$

where η_y and δ_y are normally-distributed random variables, which represent the survey measurement error. Let Y be the number of years of available data. Then there are 2Y parameters to be estimated

n_y	for all years
r_y	for all years except the last year
q_n	

and let $\hat{n}_y, \hat{r}_y$ and $\hat{q}_n$ represent the estimates of these parameters obtained by minimizing the nonlinear least squares objective function

$$S(\theta) = \lambda_\varepsilon \sum_{y=2}^{Y} \varepsilon_y^2 + \sum_{y=1}^{Y} \eta_y^2 + \lambda_\delta \sum_{y=1}^{Y-1} \delta_y^2 \qquad (3.6.8)$$

where λ_ε and λ_δ are relative weights for the process error and recruit measurement error, respectively (relative to the measurement error for indices of the fully-recruited group), and S, the sum of squares, is a function of the parameters to be estimated (θ). The objective function has 3Y-2 residual error terms. This leaves Y-2 degrees of freedom for the model.

In principle, the selectivity of the recruits, s_r, is also an estimatable parameter. However, in practice S_R is often negatively correlated with q_n and cannot be estimated simultaneously with it. Consequently it is often necessary to fix s_r using data exogenous to the model (e.g. gear experiments) or by using qualitative information regarding survey gear performance. When s_r is fixed (i.e. not estimated), it need not be constant with time, i.e. it may taken on year-specific values, s_{ry}. The model equations given in the next section allow for this year-specificity in the relative selectivity of recruits. For example, in many situations where ageing is difficult, it may still be possible to identify members of the incoming year class (e.g. with a modal analysis such as that of Fournier *et al.* 1990), and thereby define recruitment as an age-based phenomenon. If the mean length at age of the recruiting year class varies appreciably from year to year, and if selectivity is thought to be principally a function of length, then it may be advantageous to treat the selectivity as a length-based process, i.e. s_{ry} can be treated as a function of the mean length of the recruiting year class:

$$s_{ry} = \Psi\left(\mu_{r0y}\right) \qquad (3.6.9)$$

where:

μ_{r0y}	mean length of the recruiting year class at the beginning of the year
Ψ	a function relating μ_{0y} and s_{ry} that is invariant with time. Ψ may be derived, for example, from gear experiments that measure selectivity as a function of length.

Note that in this Section the term *selectivity* is used when reference is made to the survey gear, while the term *partial recruitment* will be used below when referring to the commercial fishery.

3.6.1.2 Population size and mortality rates

Given $\hat{n}_y, \hat{r}_y$ and $\hat{q}_n$ from the nonlinear least squares minimization of Equation 3.6.8, and the value(s) of s_{ry} (either estimated or fixed using exogenous information), population size and fishing mortality rates for the recruits and for the fully-recruited group are:

$$N_{0y} = \frac{\hat{n}_y}{\hat{q}_n} \quad for\ y = 1,\ldots, Y \qquad (3.6.10)$$

$$R_{0y} = \begin{cases} \dfrac{\hat{r}_y}{s_{ry}\hat{q}_n} & for\ y = 1,\ldots, Y-1 \\ \dfrac{r_{y'}}{s_{ry}\hat{q}_n} & for\ y = Y \end{cases}$$

where N_{0y} and R_{0y} represent the fully-recruited and recruit population sizes, respectively, as in Equation 3.6.1. Then

$$Z_{R+N,y} = \log_e\left(\frac{N_{0y}+R_{0y}}{N_{0,y+1}}\right) \quad for\ y = 1,\ldots,Y-1$$
$$F_{R+N,y} = Z_{R+N,y} - M \tag{3.6.12}$$

where $Z_{R+N,y}$ and $F_{R+N,y}$ are the total mortality and fishing mortality rates, respectively, during survey year y for all animals of recruitment size and larger (i.e. recruits plus the fully-recruited group). When using age-structured models, e.g. virtual population analysis (VPA), it is common practice to express the fishing mortality rate (F) for a group of ages as a weighted average of the F's on the individual components (ages) that make up the group. This analogy with VPA provides an alternative expression for $F_{R+N,y}$ (cf. Equation 3.6.12)

$$F_{R+N,y} = \frac{R_{0y}F_{Ry} + N_{0y}F_{Ny}}{R_{0y} + N_{0y}} \tag{3.6.13}$$

The fishing mortality rates of the recruits (F_{Ry}) and the fully-recruited ages (F_{Ny}) are related by

$$F_{Ry} = \overline{p}_{Ry}F_{Ny} \tag{3.6.14}$$

where $\overline{P}_{ry}$ is the average partial recruitment of the recruits (to the commercial fishery) over the course of year y, i.e.

$$\overline{p}_{Ry} = \int_0^1 \Phi_y(t)\,dt \tag{3.6.15}$$

where Φ_y is a year-specific (if needed) partial recruitment function (taking on values between 0 and 1) that gives the proportion of recruits available to the commercial gear at any time (t) during the survey year. This relationship (Φ_y) should reflect the expected growth rates of recruits during the year and the performance of the commercial gear, as well as other factors that affect partial recruitment, e.g. the effects of regulations. This functional relationship may change over years, but is assumed constant within each year. The Φ_y are not estimated in the model, but must be determined from exogenous information and/or data. Alternatively, in the special case where recruitment is an age-based process and intra-year growth follows a von Bertalanffy curve, it may be more natural to express Φ_y as a function of length (rather than time).

Substituting Equation 3.6.14 into Equation 3.6.13 and solving for F_{Ny} gives

$$F_{Ny} = \frac{F_{R+N,y}\left(R_{0y} + N_{0y}\right)}{\overline{p}_{Ry}R_{0y} + N_{0y}} \tag{3.6.16}$$

and F_{Ry} is obtained from Equation 3.6.14.

Then given annual mean weight estimates for the recruits and fully-recruited animals (generally from research survey sampling), biomass and surplus production estimates are readily available. These equations and a complete description of the bootstrap formulation are given by Conser (WP A5). Several extensions of the basic equations and implementation of a Bayesian framework for handling multiple indices of abundance are presented in Conser (WP A3).

3.6.2 Application to Gulf of Maine cod

Two research surveys are available for this stock - the USA National Marine Fisheries Service Spring and Fall Surveys. Two runs of the modified DeLury model were made, one using the Spring survey indices and another using the Fall indices. The two sets of results were then combined using the quasi-Bayesian framework described by Conser (WP A3).

Examination of commercial catch at length data relative to the survey indices at length (i.e. plots such as Figure 6.3.1) indicated that 58 cm and larger cod constituted the fully-recruited group in the Spring survey. The Fall survey occurs approximately six months earlier and data collected during the survey are used to index abundance on 1 January of the following year. Animals 55 cm and larger were used for the fully-recruited group based on the Fall survey data. In both cases, the recruit length range was defined to capture approximately one year of growth. Survey data in the length range 40–57 cm were used to index recruitment in the Spring survey run, and those in the 37–54 cm range were used in the Fall survey run. The respective indices, catches, mean weights and other model inputs are provided in Table 3.6.3. Results are given Figures 3.6.1 and 3.6.2.

The model diagnostics were generally good with one large outlier in the Fall survey run (Figure 3.6.1). The recruitment, fishing mortality, and exploited biomass estimates are compared with those attained from an age-based assessment (using ADAPT) in Section 7. The modified DeLury estimates compare well with those from ADAPT in recent years. However, the trends tend to differ resulting in divergent estimates in the early part of the time series.

3.6.3 Application to Icelandic cod

The modified DeLury model was applied to Icelandic cod using survey indices of abundance from a single research survey. Otherwise, the application paralleled that described for Gulf of Maine cod. Input data are given in Table 3.6.4, and results are provided in Figure 3.6.3. In comparison with the "official" estimates, the DeLury F's are comparable in recent years but lower in the early years. Trends in exploited biomass are similar but the DeLury estimates are consistently lower.

3.6.4 Application to Icelandic haddock

For Icelandic haddock, the application paralleled results are provided in Figure 3.6.4. In comparison with the "official" estimates, the DeLury F's are comparable over most of the time series but higher in the recent years. Trends in exploited biomass are similar but the DeLury estimates are consistently lower.

3.6.5 Application to *Sebastes marinus* (Icelandic area)

Input data for the *Sebastes marinus* application are given in Table 3.6.6. Results are provided in Figure 3.6.5. No "official" results are available for this stock. The DeLury model appears to fit the survey indices well. No diagnostic problems were apparent.

3.6.6 Application to Canadian redfish

Input data for the Canadian redfish application are given in Table 3.6.7. Results are provided in Figure 3.6.6. No "official" results are available for this stock, and the available survey time series is limited (5 years). The DeLury model appears to fit the survey indices well. No diagnostic problems were apparent.

3.7 Overview and future directions

The methods tested in this section seem to fall into two groups in terms of performance (as well as overall approach), with the variants on the surplus production model approach in one group, and the modified DeLury method in the other. A summary of the results by method is given in Table 3.7.1, from which several general conclusions arise.

First, the production model approaches only perform well for one of the stocks, that being IMAR, the Icelandic redfish. The three production models used all give very similar results, although the dynamic production model (DYNP) has large variances on estimates of virgin biomass (K). This is because this method estimates an extra productivity parameter, which is inversely correlated, with the estimate of K. However relative depletion is well estimated in this model.

All the production models perform relatively poorly for the other stocks, either due to lack of contrast in the relative abundance data, or to inconsistencies between the data and the models (inability to capture strong recruitment effects). For these stocks, the methods seem consistently to overestimate stock sizes. The modified DeLury method seems to perform well in most cases, with the possible exception of *S.marinus* (although there is no "official" assessment for this stock with which to compare the results). For the stocks where the production models generate unrealistically large stock sizes, the estimates using the DeLury method fall much closer to "official" or accepted levels. The DeLury method also seems to capture some of the age structure (recruitment) effects in the data quite well.

To summarize, the production models are worth considering as an assessment tool for several reasons including:

1. They do not require (although some can make use of) age or length based data, and therefore in some instances may be the only assessment techniques available.
2. The results in this section suggest that they may sometimes be useful, even when other data are available and they may form a useful adjunct to, or check on, age or length based methods.

It should be noted that work reported elsewhere suggests that in some instances, production models can outperform age-based assessments (tuned VPAs) when incorporated in management procedures (e.g. Punt 1993).

Turning to the modified DeLury method, it seems that this approach has greater affinity with the age and length-based methods, and is generally capable of capturing the same information from the data. It seems, therefore, to show considerable promise in cases where age data, in particular, are not available.

It is therefore concluded that the age-based production models show considerable promise. When care is taken to restrict the model parameters sufficiently, these models can usefully estimate overall biomass trends and be used to predict the effect of different catch levels in the future.

The group considered possible future directions in the development of production models and concluded that these should be explored with an emphasis on incorporating information available on a stock-by-stock basis. Notably, in many cases, length distributions are available and survey length distributions may provide important information on recent and future recruitment levels, as is clear from the *Sebastes marinus* examples in Section 4.

A growth model is usually available within an age-structured production model and thus theoretical length distributions may be constructed. Some technical problems arise, however, due to the non-uniform growth. If the population at a given age is taken in the model to be all of the same length, then the cumulative probability distribution (cdf) of lengths will tend to be reasonably smooth. However, the corresponding pointwise probability density (i.e. length distribution) will not be as smooth and aggregation into length groups will not be quite trivial unless some smoothing or spread is used.

Survey length distributions are sometimes available as samples of lengths and in other cases, they have been scaled to be population abundance indices at length.

When simple random samples are available, the log-likelihood for each year, based on a multinominal assumption, simply consists of the sum across lengths of the terms $L_l \ln p_l$, i.e. the observed frequency times the logged theoretical proportion (McCullagh and Nelder, 1989). However, the results of Pennington and V¢lstad (1994) show that the multinominal assumption is unlikely to hold. Also, in cases when the length distributions have been computed so as to be population abundance indices at length (as opposed to counts), an alternative approach needs to be taken.

One possible approach to comparing theoretical and observed length distributions is through the use of the Anderson-Darling, Cramér-von Mises or Kolmogorov-Smirnov measures of the difference between two cumulative distribution functions (described in Durbin, 1973, but see also Anderson and Darling, 1952 and 1954, Cramér, 1928, Kolmogorov 1933 and Smirnov 1939, 1941). The estimator used here is of the Cramér-von Mises type and is given by

$$\sum_l [H(l) - G(l)]^2 .$$

Where H and G are taken to be the observed and fitted cumulative distributions, respectively.

Naturally, a selection ogive has to be estimated or (more likely) assumed, for the survey length distribution in relation to the population length distribution.

For a stock such as *S. marinus*, it was concluded that a promising future line of work would be to try to estimate a "typical" recruitment level (or one-parameter stock-recruitment function) and then to estimate separately the apparently outstanding year classes seen in the length distributions.

4 Length-based methods

4.1 Introduction

The usual procedure for deriving the age compositions of catches required for VPA-based assessments involves application of age-length keys (ALK's) to the length compositions. There are several reasons why alternatives to this procedure should be investigated:

i. Since ALK's represent the proportions of age groups at each length, they reflect not only the growth pattern in the stock but also the relative strength of the year classes. An ALK sampled for a given population (i.e. year/season or area) can therefore only be applied to the length composition of that same population (otherwise the estimated age composition may be strongly biased) and ALK's have to be re-estimated routinely. In addition, fish of young and intermediate ages can grow significantly during the year, and the precision of age compositions is greatly improved when ALK's are sampled and applied on a seasonal basis. This result in considerable costs that can only be afforded for those stocks that are of major importance in each country. The prospects of budget and staff restrictions in many institutes may further decrease the number of stocks to which this approach will be applicable, leading to possible disruptions in the provision of advice based on analytical assessments.

ii. VPA requires rather long time series of catch-at-age data to provide useful results and is vulnerable to disruptions in the regular supply of catch-at-age data, e.g. due to occasional problems in age sampling that may cause major problems for several years. Methods for filling gaps in the data have not been standardized;

iii. long time series of catch-at-length data may exist for some stocks but, if the corresponding ALK's were not sampled, this information may be underutilized when VPA-based methods are considered.

Sections 4.2–4.4 present methods whereby age compositions are derived from length compositions, so as to be carried forward into usual age-based analyses. The SP-Key approach (Section 4.4) integrates the VPA into the calculation and uses the results iteratively to improve the length-to-age conversion.

Another possibility for using catch-at-length data is for direct estimation of stock sizes and fishing mortalities. This does not require estimation of catch at age, but growth must be modelled in some way. Pope (Working Document L:8) suggests a method for predicting *status quo* catches from length composition data, relying heavily on GLM's and separability. Sullivan (1992) proposes a method for catch-at-length analysis, estimating models of growth and separable fishing mortality rates by a Kalman filter. A time series analysis approach is presented in Section 4.5.

Related approaches, e.g. the Modified DeLury model, are considered in Section 3.6.

4.2 Length-to-age conversion methods

4.2.1 Numerical conversion methods

Many "indirect" methods have been developed for the resolution of length-frequency distributions into age compositions, culminating with maximum-likelihood methods that utilize sequences of length distributions and set constraints on the solutions (e.g. MULTIFAN, Fournier *et al.*, 1990). Several of these methods estimate other parameters, such as mean lengths at age, growth parameters, total mortality or even the number of component age groups. However, for many cases encountered in the ICES context, the challenge is rather to utilize existing information on distributions of sizes at age, based on results from growth studies or data from sparse age-length keys, to estimate the catch-at-age arrays required for VPA in the absence of regular ALK's.

Leaving aside the "slicing" method dealt with in the next section, this particular problem can be expressed in the form of the matrix equation:

$$\mathbf{P} = \mathbf{X} \,.\, \mathbf{Q}$$

where **P** is the known vector of size frequency distributions of the catch in a given year, **X** a known or assumed matrix of proportions p(l | a) of sizes within each age, and **Q** is the unknown vector of proportions of each age group in the catch. The matrix **X** is essentially determined by the growth pattern and, for younger fish, by the selectivity of the gears, but should remain relatively constant through time if growth and selectivity do not vary much. In contrast with ALK's, it is not dependent on the relative strength of year classes.

When age-length key data for other years are available, they can be used to set up the X matrix. However, since ALK's are often based on a fixed number of otoliths per size class, they first need to be raised (multiplied by the length composition in the corresponding year) to absolute numbers at age and length. The proportions of lengths within each age are then computed. Alternatively, when reliable results of growth studies are available, it is possible to estimate the mean and standard deviation of lengths at each age. The X matrix can then be set up by assigning proportions according to an assumed probability distribution (e.g. Normal).

The methods that have been explored to resolve the above equation fall into two categories: the least-squares (LS) methods of Clark (1981) and Shepherd (1985) on the one hand; and the iterated age-length key (IALK) methods of Kimura and Chikuni (1987) and Hoenig and Heisey (1987) on the other. Comparative trials of these methods on simulated data (Working Document. L:5) indicated that the methods of Clark (1981) and, Kimura and Chikuni (1987) performed satisfactorily when the true parameters of the X matrix, as used for the data generation, were used. The performance deteriorated significantly, however, when errors in the input parameters were assumed. Only these two methods have been used for the subsequent trials.

In the current implementation the conversion is performed for each year or season independently. The input data for each period consist of series of length compositions, one for each fleet or survey (e.g. tuning fleets), one of which must be that of the total international catch. The LS methods consider each fleet separately, but with the same X matrix, whereas the IALK methods use the information in both the X matrix and the total catch to derive an overall ALK which is subsequently applied to the length composition of each fleet. The mean weights at age are also computed. However, for the LS methods, these are approximate as they are only based on the length distributions in the X matrix. When all years' data have been processed, the results are passed to whichever VPA package is desired.

4.2.2 Tests on Icelandic haddock

The main difficulty encountered with the Icelandic haddock data was the construction of appropriate X matrices for each year. Knowing that the growth pattern of this stock is seasonal and has changed over time, it would have been necessary to adjust the mean lengths and standard deviations accordingly. This would have been facilitated if the quarterly length compositions, which were effectively used to derive the ALK-based age compositions, had been available for inspection. The average growth parameters were available to estimate mean lengths at mid-year. For intermediate ages, these corresponded well with apparent modes in the commercial length distributions in several years, except for an "unexplained" peak around 50 cm, but the SD's had to be guessed. Moreover, as shown in Tables 2.4.2 and 2.4.3, it was difficult to match the growth pattern in the survey and commercial catch. For age 1 in particular, the growth parameters give a mean length of about 30 cm, in accordance with modes in the 25–30 cm range in the spring survey, but this leaves the problem of interpreting the very distinct mode at about 15 cm in each year's survey. Forcing these fish into the 1-group vastly overestimates the abundance of that age group.

Nevertheless, as a starter, the conversion methods were applied brutally, using the same X matrix for all years. The estimated age compositions of commercial and survey catches from this first run are given in Table 4.2.1 where they are compared with the ALK-based estimates. For the commercial catches, both methods give results of similar overall magnitude, but these are well off the reference estimates. They fail to recognize the weak 1979 year class, and the good 1985 and 1989 year classes are traced during the first two years only. Because of the misreporting-specification of SD's, they cannot properly allocate the fish of older ages whose length distributions overlap widely, and this is particularly visible in the overestimation of age 10 at the expense of ages 8 and 9. The same problems are encountered with the survey data, in addition to the overestimation of the age 1 index for the reasons given above.

This attempt exemplifies precisely the conditions under which these methods are unlikely to work properly, with little knowledge of the growth pattern and availability of only annual length frequency data despite seasonal growth variability.

4.2.3 Tests on "clean" tuna data

For this trial on simulated data, information on average growth was available in the form of an array of size frequencies-at-age per 5 cm groups, from which approximate mean lengths and standard deviations could be inferred to set up an X matrix assuming normal distributions. Growth is supposed to be very fast initially, but an asymptote is reached rapidly, while standard deviations are assumed to increase regularly with age. The effect is that age components are undistinguishable from ages 6/7 on.

Results of a first run using the same X matrix for all years are given in Table 4.2.2. Apart from the trivial age 1 component, both conversion methods are able to allocate fish with reasonable accuracy up to about age 5, notably when a strong cohort is passing through. For the older age groups, they clearly have problems. As expected, this is due to the considerable overlap of the length distributions of the older fish. Another reason is that the current software only uses 1 cm grouping for the construction of the X matrix and for the conversion. With SD's of the order of 15 cm, and assuming normal distributions truncated to 3 SD's on either side of the mode, this means that columns in the X matrix for these ages are very small numbers spread over more than 100 cm. In other words, there is only a very weak signal in the X matrix to partition fish in the upper range of the length composition, and most are allocated to ages 6 and 7, the last ages for which there is a rather clear signal. In this respect, Clark's method exhibits an extreme behaviour, as it cannot find feasible solutions. This prevents using these estimates to start a VPA unless ages 7 and older are collapsed into a plus-group.

Despite their obvious deficiencies, the estimates from the Kimura and Chikuni's method were input to XSA tuning, where abundance indices are the total catch numbers at age divided by an effort index. Catchability was assumed constant from age 6 on and no shrinkage was used. The tuning diagnostics are not very significant in this artificial example, although some large residuals confirm that the abnormally low estimates of catches at older ages violate the constant catchability assumption. The VPA results are given in Table 4.2.3, and the estimated stock numbers can be compared with the true values given in Table 2.5.1.

Although the stock numbers for several ages are a poor approximation of the true data, due to the large underestimation of terminal age population, the relative strength of the cohorts is reasonably well reflected in the estimates for the younger ages (Figure 7.1.4). In usual circumstances, this information, combined with the tuning diagnostics, would be sufficient to reiterate the conversion process with refined estimates for the parameters of the X matrix applicable to each year. This is a lengthy process, which would have required more time than available at a Working Group meeting. In this respect, the more integrated SP-Key approach presented hereafter is certainly superior.

4.2.4 Provisional conclusions

Although the results of these tests look disappointing, they should not mean that the use of indirect methods of estimating age compositions is a dead end. Clearly, all these methods, whether graphical or numerical, have problems in allocating size frequencies to age groups whose length distributions overlap too extensively. One way of reducing this problem is to perform the conversion on seasonal, rather than annual, length compositions in which the components are usually clearer. Another condition is to utilize as much additional information as possible about relative year classes strengths, variation in growth, etc. The tuna example also indicates how results and diagnostics from trial VPA's can be used for this purpose.

To a large extent, the conventional ALK approach is subject to the same problems: the more ages there are at a given size, the more otoliths must be sampled to refine the allocation to ages; the use of seasonal ALK's and length compositions greatly improves the estimates of the annual age compositions.

Lastly, the test on Icelandic haddock illustrates that biological information is necessary when length frequency data are analyzed.

4.3 Slicing

A version of the familiar cohort slicing was presented in Mohn (WP L7) in which it was applied to simulated data and data from haddock and scallop stocks in Canada. The method slices the catch and abundance at length at the mid-points between the annual modes or at points defined by a growth model. Each slice represents an age and the 'aged' data are then analysed by traditional VPA techniques. This method has been shown to be relatively stable and requires no iteration or numerically intensive calculations. However, some care must be used when applying slicing or other length conversion methods that the growth model fits the data. Investigation of length distributions suggested that the Icelandic haddock would be a reasonable candidate for slicing as the modes in the survey were distinct for the first two age groups and the cohorts could be followed as they aged (Figures 2.4.1.a and b). The Gulf of Maine cod (Figures 2.2.1 a and b) was a less promising candidate because modes and cohorts were less clear. The Iceland redfish data (Figures 2.9.1a and b) were not analysed by slicing because the width of the year class length distribution was much broader than the inter-age differences in the catch. Separation into ages would have been artificial at best. The slicing routine was applied to Gulf of Maine cod data and Icelandic haddock.

Gulf of Maine cod catch at length and survey (Spring) data at length were first truncated to the 25 – 91 cm range as there were few fish greater than 91 cm in either survey or catch and as there was no catch below 30 cm. Figure 4.3.1 shows residual patterns for slicing these data. A large + in this figure denotes a large positive residual while a large circle is a large negative one. The slice estimates (Figure 4.3.2) show roughly the same biomass pattern as the official estimates but at a higher level. It should be kept in mind that the official values were fit using data from both surveys while these results are tuned only to the Spring survey. The residual pattern from fitting the sliced catch and RV estimates for Icelandic haddock shows a strong diagonal pattern (Figure 4.3.4). Figure 4.3.3 shows the slicing estimates for biomass and F(4–6) as well as official values for Icelandic haddock. Length distributions were truncated from 10–80 cm for analysis. The "slice" biomass corresponds well to the official estimates since about 1985 but overestimates biomass in the earlier years. The slicing estimates for F do not correspond well to the reference levels and show a strong trend in time.

4.4 SP-key

The name SP-Key is given to a method, which uses cohort numbers at age to weight a size at age distribution to produce an age-length key. This age-length key is then used to produce new catch and abundance indices at age, which iteratively produce new VPA estimates. The process continues until convergence, which in practice takes place in a few iterations. The procedure is started by using cohort slicing or Kimura-Chikuni to do the first conversion from lengths to ages. The same data were used in this analysis as in Section 4.3 where they are briefly described. Tables 4.4.1–4.4.2 and Figure 4.3.2 show the results of this technique. Because age-based estimates were available sum of square residuals could be produced as indices of performance. At each SP-Key iteration the sum square residual between the length-based estimates and the aged estimates are compiled (C-SSR and RV-SSR). The mean residual from the non-linear least squares (NLLS) ADAPT estimate is given in the final column. In the case of Gulf of Maine cod (Table 4.4.1 and Figure 4.3.2), the SP-Key iterations did not improve the sum square residuals of the catch or the RV series. The NLLS-MSR, which is a measure of how well the generated age data fit the ADAPT model, however, improved by almost a factor of 2 during the iterations. The SP-Key estimates follow the shape of the official estimates for Gulf of Maine cod well, and much better than the slice estimates, but are consistently biased.

The summary performance of SP-Key with Icelandic haddock data (Table 4.4.2) shows an almost twofold improvement in the C-SSR statistic and a greater than twofold improvement in RV-SSR during the SP-Key iterations. The NLLS fit did not show such a dramatic improvement. The pattern of residuals (Figure 4.3.4) shows that the strong diagonal trend seen in the slicing data fit was not significantly removed during the SP-Key iterations. The failure to remove the pattern suggests some degree of mismatch between the assumed size at age in the analysis and the data. When compared to the official age-based estimates and the Sliced estimates (Figure 4.3.3) the SP-Key results approximated the pattern better than the Sliced but were consistently biased.

Conclusions

Length-to-age based VPA methods require more parameters and more data preparation than age-based techniques. It is fussy, but naturally important, to assure that size categories and definitions of growth be coordinated to the data. The number of length and age classes has to be determined, usually by trial and error. The SP-Key method produces age-length keys from size at age data. None were available at this Working Group meeting and the distributions were approximated with normal distributions with standard deviations of 4.5 cm for Gulf of Maine cod at all ages and 3 cm for Icelandic haddock. The performance of the methods would be expected to improve were this information is available.

4.5 Time series analysis of catch-at-length data

As an alternative to estimating catch-at-age values from catch-at-length observations, stocks and fishing mortality rates can be estimated directly from the catch-at-length data without any reference to age-groups. Gudmundsson (1995 and WP L1) describes this in combination with time series modelling of the fishing mortality rates. This method was applied to three stocks during the meeting: Icelandic haddock, Gulf of Maine cod and *Sebastes marinus*.

The catch-at-length data are grouped into intervals of equal lengths, which must be so long that a negligible number of fish grow, by more than two intervals in one year. The average growth of fish in respective intervals is assumed to follow the von Bertalanffy function, defined by the maximum attainable length, L_∞, and the growth of the shortest fish included in the analysis. A third parameter determines the length distribution in the next year of survivors from a given length interval, subject to the prescribed average growth. Other parameters are similar to time series analysis of catch-at-age data and estimation is based on the extended Kalman filter (Gudmundsson, 1994).

For some stocks, there is substantial variation in growth from year to year and this can be modelled by adding noise to the growth parameter and estimating it as an unobserved time series. However, in practice it is not possible to distinguish these variations from measurement errors and transitory variations in fishing mortality rates, at least not when the analysis is only based on catch-at-length data.

The estimated fishing mortality rates at length represent the actual fishing mortality rates to which fish in the respective length and year are subject. The stock values at a given length represent the number of fish at the beginning of the year, liable to be caught at that length in the respective year. These fish are thus of that length or shorter. At the end of the year survivors of respective stocks have all reached the length with which they are associated and some are longer. As a result of this, introduction of survey data is less straightforward than in catch-at-age analysis; the survey indices do not correspond exactly to the stock concept of the catch-at-length analysis.

Estimates of stock numbers and fishing mortality rates by this method are less accurate than those obtained by time series analysis of catch-at-age data of similar quality. Because of the interaction of growth, which is represented by parameters, and stocks and fishing mortality rates which are estimated as unobserved time series, calculation of the accuracy of the time series estimates by the Kalman filter is of little value and is not reported. After estimating the last year's values by the filter, final estimates of previous values are obtained by a recursive backward procedure. In catch-at-age analysis, this greatly increases the accuracy in a similar way to that in VPA. Because of the uncertainty about the growth, less is gained by this in catch-at-length analysis.

The analysis of Gulf of Maine cod was carried out for 9 length intervals of 9 cm, centered at 44 up to 116 cm (Table 4.5.2). L_∞ was fixed at 146 cm and natural mortality rate at 0.2. The annual average growth of 44 cm long cod was estimated as 13 cm. No other information was used. Results are presented in Figure 4.5.1 and in Section 7.

The analysis of Icelandic haddock was carried out for 8 length intervals of 6 cm, from 39–44 cm to 81–86 cm (Table 4.5.1). L_∞ was fixed as 89 cm and M as 0.2. Average growth of 42 cm long haddock was estimated as 8.7 cm. Analysis without introducing any auxiliary information, apart from fixing the maximum length and M, produced unrealistic estimates. The results presented here were obtained by adding a recruitment index to the shortest lengths from the survey data, but no other use was made of them. The fishing mortality rates presented in Figure 4.5.1 show that the separable assumption is inappropriate for this stock.

The analysis of *Sabastes marinus* was carried out in length intervals of 2 cm from 32–33 cm to 52–53 cm. The natural mortality was fixed at 0.05 and L_∞ at 62.5 cm. The growth of the shortest fish, 32 cm, was estimated as 1.6 cm per year. The estimated fishing mortality rates were of the order of 0.2. The time series methods are generally less accurate with low fishing mortality rates. There was a large difference between the results obtained from the Kalman filter and the backward procedure respectively and both are included in Section 7. The results obtained directly from the Kalman filter estimation were in better agreement with prior ideas about the development of the fishery. There are survey results available which should be included in the analysis of this difficult stock, but there was not time to do that with the present method.

4.6 Canadian Unit 1 Redfish (CRED) length frequency analysis

4.6.1 Background

Long-lived species such as rockfish (e.g. *Sebastes* spp.) present particular stock assessment problems. Typically these problems stem from the inability to age these fish accurately by the usual method of otolith reading. With the complication of low natural mortality, erratic recruitment, but a potentially large number of age-classes, VPA assessments often fail. On the other hand these species offer an opportunity to attempt the use of length-based methods since fisheries for these species target fish that are characterized more by their length than their age. As with age-based methods, a complete assessment requires two fundamental types of data: 1) abundance data which measures the current state of a population, and 2) data measuring the rate of change (i.e. the dynamics) of the state such as recruitment, growth and natural and fishing mortality rates.

For the Canadian Unit 1 4RST(Jan-Dec), 3Pn(Jan-May) and 4Vn(Jan-May) *S. fasciatus* and *S. mentella* mixed fishery) only four years (1990–94) of surveyed length frequencies and abundance data are available (data provided by Mr. Bernard Morin, Maurice Lamontagne Institute, Mont-Joli, Québec, Canada), while commercial length frequencies have been available since 1981. Land effort have been measured since the early 1950's (Figure 4.6.1) With age data still somewhat limited, and the need to consider two species as one with the same growth parameters (currently thought to be a reasonable assumption), the menu of potential assessment techniques for this stock is somewhat restricted. As a first start an assessment can be undertaken by exploiting the fact that slow growing and long-lived populations like Unit 1 redfish have length frequency distributions that appear somewhat stable over time in the commercial length range. Although recruitment to the younger ages for this species can be highly variable over the years, recruitment to the preferred commercial length of about 25 cm will tend to be more regular over time when individuals undergo stochastic growth according to, for example, the von Bertalanffy growth form (Botsford *et al.,* 1994).

In the absence of an age-based analysis, or any estimates of natural mortality from numbers-at-age determined for an unfished population, a length frequency approach must exploit information on natural mortality from lengths below the length of commercial exploitation (for Unit 1 redfish about 25 cm) and assume that any trend in mortality over time for this length range can be inferred to continue for the commercial lengths. Fishing mortality can thus be estimated as the mortality unaccounted for by the natural mortality function of length extrapolated to commercial lengths.

Contemporary length frequency analysis typically consists of extracting age modes from length frequencies from which an analyst might obtain a growth curve (Schnute and Fournier 1980, Smith and McFarlane 1990) and perhaps also a mortality function of age (Fournier and Breen 1983). More recently Botsford *et al.*, (1994) and Smith *et al.*, (1998) have developed a methodology which facilitates the estimation of growth and mortality patterns from length frequency distributions lacking age patterns. Their methodology is founded on the assumption of constant recruitment. However, simulations they have done have shown that for growth dominated distributions, i.e. those of relatively long-lived species (Botsford *et al.* 1994), their method is robust to failure of this assumption when the variance in the level of recruitment over time is less than about twice the mean level of recruitment.

For the Unit 1 redfish complex, with its known slow growth and mortality rates, and consequently many age-classes within a length frequency distribution, the assumption of constant recruitment as a foundation for analysing length frequency distributions is attractive. The attractiveness of this assumption increases if you accept the notion that length frequencies for Unit 1 redfish change slowly over time and therefore combining length distributions collected in different years fortifies the assumption of constant recruitment. Annual variation in recruitment is dampened and length frequencies would be expected to tend to the form of distributions typified by constant recruitment as depicted in Botsford *et al.* (1994).

4.6.2 Analytical approach

The Unit 1 redfish survey length distributions collected from 1990–1994 were analysed with this concept in mind. Under the assumption of steady-state conditions, parameter values were estimated for natural and fishing mortality and growth variance (Botsford *et al.* 1994) using a non-linear search algorithm, conditional on estimates for von Bertalanffy's L_∞ and K parameters obtained from aging studies, and parameters for commercial selectivity estimated independently. Commercial selectivity was estimated as described below. Survey selectivity was estimated directly from the length frequency analysis.

This initial analysis was followed up by two subsequent analyses. First, the fishing mortality estimate obtained from the steady-state length frequency analysis was taken as an average for the period 1990–94. Next, the ratio of landings in year y to surveyed biomass in year y was used to calculate a relative harvest rate index. Assuming the estimated fishing mortality represents the average harvest rate over this period, then an estimate of each year's fishing mortality was obtained by prorating F by the annual harvest rate index. Second, a somewhat *ad-hoc* attempt was made to estimate natural and fishing mortality parameters from the length frequency distributions from each year's survey. These distributions showed strong year class pulses so the length frequency analysis was modified to relax the strict assumption of constant recruitment and treat year class pulses as noise around an average level of recruitment. Allowing recruitment to be noisy required that we did not attempt to estimate survey selectivity patterns. Since the proper mathematical expression of this concept has yet to be developed, it was assumed that the variance in the model fit was the sum of the multinominal variance associated with random sampling of a predicted length frequency distribution (Schnute and Fournier 1980) plus a second variance term added to the multinomial variance and which decreased exponentially over length. The distribution of numbers-at-length was then assumed to be log-normally distributed at length, with a small correction to allow observed values of zero individuals. This empirical approach to the analytical concept would at least allow a first cut at judging the utility of such a length-based approach to the assessment of Unit 1 Redfish.

The definitions of variables included in the analyses are given in the text table below, followed by two equations describing how natural mortality and recruitment variance were modelled as functions of length.

Symbols and their corresponding definitions.	
Symbol	Definition
L_∞	Von Bertalanffy's L_∞ (cm)
σ_L	SD in L_∞ (cm)
K	Von Bertalanffy's K (y^{-1})
σ_L	SD in K (y^{-1})
A	Intercept of natural mortality function (y^{-1})
B	Instantaneous coefficient of natural mortality function (l^{-1})
μ_C	Mean of commercial Gaussian selectivity (cm)
σ_C	SD of commercial Gaussian selectivity (cm)
F	Instantaneous fishing mortality (y^{-1})
μ_S	Mean of survey Gaussian selectivity (cm)
σ_S	SD of survey Gaussian selectivity (cm)
R	Coefficient of recruitment variance over length (l^{-1})
V(l)	Recruitment variance-at-length
M(l)	Natural mortality-at-length (y^{-1})
ω	Ratio scaling parameter for commercial to survey selectivity

$$\mathbf{M(l) = ae^{-bl}}$$

$$\mathbf{V(l)} = e^{-r(l-L_\infty)}$$

4.6.3 Selectivity curve

A selectivity curve was calculated by determining the ratio of commercial to surveyed abundance-at-length (Figure 4.6.2) for the years 1990–1993 for which both survey and commercial length frequencies exist. The average was obtained by scaling the (estimated population) abundance of individuals in the length frequency distribution for each year to about 1000 (the approximation is due to integer rounding error) individuals, then summing over the years (Table 4.6.1). The curve was fitted by minimising the sum of squares of the ratio of commercial abundance-at-length over survey abundance-at-length. For each length the sum of squares was weighted by the survey abundance-at-length. Estimated values for the three parameters of this cumulative Gaussian selectivity ogive were μ_C=25.4 cm, σ_C=1.1 cm with the nuisance parameter abundance ratio (ω) being estimated at 2.56. The desire by the fishery for fish only 25 cm or larger shows up clearly in the selectivity curve as an almost knife-edged selectivity at 25 cm.

4.6.4 Steady-state (SS) length frequency analysis

Figure 4.6.3 shows the effect of averaging the surveyed length frequencies collected from 1990–94. The average was obtained by scaling the (estimated population) abundance of individuals in the length frequency distribution for each year to about 1000 individuals, then summing over the years. It should be noticed that the summation dampens the effect of the strong 1988 year class and generates a bimodal length frequency distribution which Botsford *et al.* (1994) claim as representing on Bertalanffy growth with, for example, an exponentially declining natural mortality rate. The analysis of these 5000 length frequency data points (Figure 4.6.4) supports this view, with the estimates obtained showing both a and b to be significant (Analysis SS, Table 4.6.2). Note that because the exact sample sizes of the original distributions are not known, meaningful confidence bounds on the parameters estimates cannot be produced. However, all estimated values seem reasonable. The natural mortality function

$$M(l) = 10.85e^{-.245l}$$

yields values for M at lengths of 10, 20 and 30 cm of 0.86, 0.07 and .005, respectively. These are reasonable values for a long-lived species in consideration of the fact that M(l) is constrained to be exponentially declining. Arguably a hyperbolic mortality function might tend to allow M(l) to be more flat through the domain of the commercial lengths.

4.6.5 Relative F

For a long-lived species where survey abundance would be expected to change slowly over time (if it is well measured) and landings are known, then catch divided by survey abundance can be defined as an index of the relative fishing mortality F. For Unit 1 redfish these data are available for the years 1990–94. Using the estimated steady-state value of F=0.184 obtained from Analysis SS values of F in the text below were calculated for each of the years 1990–94 from the relative F shown in Figure 4.6.5.

Calculated F for years 1990–94.	
Year	Calculated F
1990	0.086
1991	0.140
1992	0.229
1993	0.281

4.6.6 Random recruitment (RR) annual length frequency analyses

As an alternative to the steady-state analysis (Analysis SS) it was tested if values of F similar to those obtained from Analysis SS and the relative F index could also be estimated by analysing independently the 1000 individuals in each of the annual length distributions. The results (Analyses RR1990-RR1994) were obtained conditionally on the previously known (from ageing data) or estimated (Analysis SS) growth parameters. Overall, the results were unsatisfactory, and in some cases natural mortality was estimated to be zero. It seems clear that this occurs because the length frequencies are dominated by the strong 1988 year class that moved toward the upper mode of the length distribution from 1990–1994 (Figure 4.6.6). Because of this strong effect it was concluded that, for the years taken individually, there is insufficient information to extract the natural mortality signal from the highly variable recruitment signal over short time periods. More information than is provided in a single year's length distribution is required to document the distribution and moments of recruitment variability over time.

4.6.7 Conclusions

In principle the application of a steady-state, constant recruitment, length frequency analysis model to Unit 1 Redfish data remains a viable option for estimating the average values of fishing and natural mortality over periods of a few years. The method tried here cannot be rejected on the basis of these preliminary trials. However, it does appear that the random recruitment approach to analysing annual frequencies seems less promising, at least until the distribution, mean and variance of the recruitment signal can be reasonably estimated. This process begins by developing the proper mathematical description of how recruitment pulses attenuate from left to right through a length frequency distribution. The appropriate likelihood function for such a process must also be developed. Such an analysis would also benefit from independent information on natural mortality in the length range where fishing occurs. For the moment, if a steady-state natural mortality function is obtainable from an analysis of length frequency distributions averaged over a few years, and von Bertalanffy growth parameters are well estimated from ageing studies, then perhaps these parameter values can be imposed upon annual analyses to estimate a contemporary F.

4.7 Summary

Length-based methods can identify relative year class sizes at younger ages, but without additional information on growth, they cannot estimate reliably the age-composition on the fully-recruited length group. To take advantage of the convergence properties of the VPA equations, it is useful to extend the age composition to as old an age as possible. However, if the precision of the age determinations is low, the VPA calculations will degrade the signal on relative year class strength. Continued and enhanced research on non-VPA based assessment methods which are not handicapped by the low precision on age-determination of older age groups is encouraged.

5 Methods tolerant of errors in catch data

5.1 Introduction

For a large number of fish stocks, the estimation of historical stock trends relies on the analysis of commercial catch-at-age data. The data themselves are derived from samples of the age compositions of the catch raised by estimates of the total catch in weight. The latter quantity is usually based on official landings data corrected, where possible, for discards, misreporting and non-reported catches. Where the correction factors can be estimated adequately a range of methods can be used to calculate historical estimates of spawning stock biomass, fishing mortality and recruitment. Unfortunately the estimation of misreporting and non-reporting can be problematic because illegal landings are made deliberately to avoid detection and hence quantification. In addition, the estimation of discards may be poor or completely lacking. This may lead to serious bias in the catch data which, if not corrected, will inevitably bias any analysis. The problem has been of some concern to ACFM (ICES, 1993).

This section considers a number of methods, which attempt to alleviate the difficulties, outlined above or to diagnose where the problems might occur. Some methods attempt to model the "hidden" component of the catch while others try to fit parameters, which quantify the degree of misreporting, compared with fishery-independent data. A third class of model simply tries to estimate historical stock trends without using catch data. The appropriate model to use will depend very much on the suspected problems in the data. Models in this section are orientated toward age-disaggregated data and depend to a large degree on survey abundance indices. Section 3.6 considers other models, which account for certain types of errors in the catches using length data.

Another class of model not considered here, but which may be of use are those which enable the treatment of suspect observations as "missing" data. The CAGEAN approach (Deriso *et al.*, 1985) is one where it is possible to do this. This was the method used for North Sea haddock by ICES, (1994) and by Cook and Reeves (1993) to estimate missing catches of North Sea industrial fish species. A version of survivors analysis (Doubleday, 1981) proposed by Skagen (WP/S4) can also be used in this way.

5.2 Separable Analysis of Research Vessel Data (RCCPUE)

5.2.1 Introduction

One potential way of avoiding the problem of bias in the catches is to analyse data which are independent of the fishery such as research vessel surveys. It is worth considering an analysis of survey data which might allow the estimation of stock trends. This section considers a simple model applicable to survey data, which appears to be useful for a number of examples.

5.2.2 Models

5.2.2.1 Single survey model

One of the major potential problems of surveys is that the sample size is generally small and hence the abundance estimates are likely to be noisy. It is, of course, possible to convert the raw abundance estimates from a survey into biomass estimates, and to estimate fishing mortality and the associated catch. These, however, are likely to be adversely affected by sampling error. To attempt to reduce this problem, a simple model is used here to try to remove some of the noise. The model used is a modification of the commonly used separable model often used in the analysis of catch-at-age data (Deriso *et al.*, 1985; Pope and Shepherd, 1982; Gudmundsson, 1986). The underlying assumption is that the fishing mortality rate, F, is the multiple of a year effect, f, and an age effect, s, i.e.: where a and y index age and year respectively. Making the usual assumption that the total mortality, Z, is the sum of the fishing mortality rate and natural mortality rate, M, and that populations decay exponentially over time, the number of fish, N, at the start of the year from a particular cohort with an initial number of recruits, R, is given by:

$$F_{a,y} = s_a f_y \qquad (5.2.1)$$

$$N_{a,a-1+y} = R_y e^{-}\sum_{i=1}^{a-1} Z_{i,i-1+y} \qquad (5.2.2)$$

Now for an abundance index, u, we may assume the following relationship:

$$u_{a,y} = q_a N_{a,y} \qquad (5.2.3)$$

Substituting 5.2.3 into 5.2.2 we obtain:

$$u_{aa1+y} = q^1{}_a u^r{}_y e - \sum_{i=1}^{a-1} z\, i, i+1+y \qquad (5.2.4)$$

where u^r is the abundance index at the age of recruitment and the quantity q'_a is the ratio:

$$q'_{a'} = \frac{q_a}{q^r} \quad (5.2.5)$$

If catchability is constant for all age groups this ratio will be unity and can be ignored. It is likely that it will not be constant for one or more of the youngest age groups. In this case estimates of the ratio will be required in order to obtain unbiased estimates of the mortality rates.

From equations 5.2.1 and 5.2.4 it can be seen that any abundance index, u, can be described in terms of the initial cohort size, u^r, the exploitation pattern, s, and the year effects, f. Now let the observed abundance index, û, be measured with log-normal error such that;

$$\hat{u} = ue^{\varepsilon}, \quad \varepsilon \sim N(0,\sigma^2) \quad (5.2.6)$$

Given A age groups and Y years of data it is now possible to estimate the parameters u^r, s, and f by minimising the sum of squares:

$$\sum_{a=1}^{A} \sum_{y=1}^{Y} [\log(\hat{u}_{a,y}) - \log(u_{a,y})]^2 \quad (5.2.7)$$

Since the year and age effects are multiplied, it is necessary to fix at least one parameter in order to scale all the others. A simple way to do this is to set $f_1 = 1$. This means that the selectivity pattern is set equal to the fishing mortality rate at age in the first year. In practice it was found that the estimates of f obtained by minimising (5.2.7) were sensitive to noise in the data. An alternative objective function was therefore used which restrained the estimates using a penalty function, i.e.;

$$\sum_{a=1}^{A} \sum_{y=1}^{Y} [\log(\hat{u}_{a,y}) - \log(u_{a,y})]^2 + \lambda \sum_{y=1}^{Y} (1 - f_y)^2 \quad (5.2.8)$$

It is also worth noting that it is only possible to estimate A-1 selectivities, s, and Y-1 year effects, f. This is because the estimates of Z are effectively obtained from the ratio;

$$Z_{a,y} = \log\left(\frac{N_{a,y}}{N_{a+1,y+1}}\right) \quad (5.2.9)$$

and for AY observations, there are only (A-1)(Y-1) equations of the form of equation (5.2.9). This equation also helps in understanding why it is not possible to estimate q' within the objective function (5.2.7). Substituting (5.2.3) into (5.2.9) gives;

$$\log\left[\frac{u_{a,y}}{u_{a+1,y+1}}\right] = \log\left[\frac{q'_a}{q'_{a+1}}\right] + s_a f_y + M_a \quad (5.2.10)$$

from which it can be seen that for constant M at age, q' is effectively a correction to M.

A more detailed description of the model with an analysis of North Sea demersal survey data is given in Cook, (1995, WP/U2).

5.2.2.2 Multiple survey separable model

The model above can be extended to incorporate several surveys conducted at different times of the year. Letting the suffix s denote survey, we have

$$u_{say} = q_{sa} N_{sa} \exp(-\delta_s Z_{ay}) \quad (5.2.11)$$

where δ is the survey time expressed as a proportion of the year.

Assuming

$$\hat{u}_{say} = u_{say} \exp(\varepsilon_{say}), \ \varepsilon_{say} \sim N(0, \sigma_s^2) \quad (5.2.12)$$

then the parameters can be estimated by maximising a "penalised" log-likelihood subject to constraints. That is by minimising the function

$$\sum_{s=1}^{S} \left(AY \log(\sigma_s^2) + \sum_{a=1}^{A} \sum_{y=1}^{Y} \frac{[\log(\hat{u}_{say}) - \log(u_{say})]^2}{\sigma_s^2} \right) + \lambda \sum_{y=1}^{Y-1} (f_y - f_{y+1})^2 \quad (5.2.13)$$

where λ is a known smoothing parameter. The constraints now follow.

$$q_{s,1} \le q_{s,2} \le q_{s,3} = q_{s,4} = \dots = q_{s,A} \quad (5.2.14)$$

but we have allowed catchabilities to vary freely between surveys. We have also assumed that the youngest age class is the least exploited

$$s_1 \le \min(s_a, a = 2 \dots A) \quad (5.2.15)$$

Finally, for identifiability and sensibility, it was assumed that

$$s_a \geq 0,\ f_y \geq 0,\ \frac{1}{Y}\sum_{y=1}^{Y} f_y = 1,\ q_{1,1} = 0$$

(5.2.16)

Clearly, there are loads of parameters hanging loose, but the idea was to impose as few fishery-based assumptions as possible, and let the survey data do the talking.

For the data sets considered below, the parameter estimates give a very flat exploitation pattern, with large differences between the catchabilities of the "young" age classes. Therefore, other solutions were explored by adding another penalty function that forced the catchabilities to be more similar:

$$\sum_{s=1}^{S}\left(AYlog(\sigma_s^2) + \sum_{a=1}^{A}\sum_{y=1}^{Y} \frac{\left[\log(\hat{u}say) - \log(u_{say})\right]^2}{\sigma_s^2} \right) + \lambda \sum_{y=1}^{Y-1} (f_y - f_{y+1})^2 + \lambda' \sum_{s=1}^{S}\sum_{a=1}^{2} (q_{s,a} - q_{s,a+1})^2$$

(5.2.17)

5.2.3 Analysis of test data sets

The models described above were used to analyse those test data sets for which survey abundance indices were available. For the single survey model all the data were analysed with the model incorporating the penalty function except the North Sea haddock data, where equation (5.2.8) was used as the objective function.

Survey data alone can only be used to estimate stock size on a relative scale. In order to compare trends from the surveys with conventional assessments, the estimated summary statistics (catch in weight, spawning stock biomass and recruitment) were scaled to the mean over a reference year range. In the case of fishing mortality rate, the survey estimates should be in the same units as conventional assessments so rescaling is not necessary.

5.2.3.1 North Sea haddock

Three surveys are available for this stock, the International Bottom Trawl Survey (IBTS), the Scottish Groundfish Survey (SGFS) and the English Groundfish Surveys (EGFS). Results are shown in Figure 5.2.1 and are compared to the ICES working group assessment from ICES (1995). All the surveys show the same trends, which are broadly similar to the VPA. There is a tendency, however, for the surveys to show greater consistency among each other than with the VPA. The estimates of mean fishing mortality rate appear to be very noisy but the overall level of F is similar to the VPA. The analysis does not suggest that changes in misreporting of catches are large enough to obscure gross trends in stock size.

Figure 5.2.2 shows the same surveys analysed with the multiple survey model for three levels of smoothing on the survey catchabilities. The highest level of smoothing gives the closest agreement with the conventional assessment.

5.2.3.2 Gulf of Maine cod

Results for the analysis of each of the two surveys separately are given in Figure 5.2.3. The trends for recruitment and spawning stock biomass agree well. For total catch, the estimated trends are similar to the reported catch except for 1982. Fishing mortality trends show little consistency either in the trend or the absolute level.

Figure 5.2.4 shows the results using the multiple survey model for three levels of smoothing on the survey catchabilities. The best agreement between the survey trends and the VPA is achieved with the highest degree of smoothing. The different level of smoothing shows the sensitivity of the trends to the shape of the estimated exploitation pattern. Greater smoothing causes the estimated exploitation pattern to shift up the age range. This means that recruits have a smaller impact on the predicted catch. In this example the effect is most noticeable where the 1987 year class enters the catch. The peak catch shifts to the right as smoothing increases.

5.2.3.3 Gulf of St Lawrence cod

Stock trends from the single survey analysis are given in Figure 5.2.5. The survey estimates reflect well the standard assessment results for recruitment and spawning stock biomass. Although the penalty function in equation (8) will tend to produce a flat trend in fishing mortality, the strong trend in F seen in the VPA is picked up by the survey model analysis. Despite this agreement, however, the predicted catches do not show much agreement with the observed values.

5.2.3.4 Icelandic haddock

Figure 5.2.6 shows the estimated historical trends. As with the other stocks, recruitment and spawning stock trends compare well with the VPA. Fishing mortality estimates are very variable but nevertheless lead to predicted catches which show similarity with the observed values.

5.2.3.5 Icelandic cod

The analysis for this stock gives the weakest agreement with the VPA (Figure 5.2.7). Only recruitment trends show any convincing similarity to the VPA. This stock is known to be affected by migration and it may be that this property results in the poor agreement.

5.2.4 Summary

VPA and the model estimate similar trends in recruitment and spawning stock biomass. This is because the method is able to exploit repeated measures of the same year class over a number of ages to remove some of the measurement error. Where there is no strong signal in the real fishing mortality rate, the model is not usually able to detect the year on year fluctuations in F. However, in the one example where F shows a strong trend the model was able to recover it reasonably well (Section 5.2.3.4). Although trends in F are not generally adequately estimated, the typical level of F is usually reproduced and may provide some corroborative evidence of the VPA estimates given the same assumptions about natural mortality. The noisiness of the fishing mortality rate estimates is translated into the predicted catches. Where the noise in the F estimates dominates, fitted catches show poor agreement with the observed values. However, if the dynamic range in the stock biomass is large compared to the noise in estimated F, predicted catches may track the observed values adequately.

5.3 A modified stage 1 ITCOTCIO model

The modified stage 1 ITCOTCIO regression is a procedure for exploring the assumption that the fishing mortality imposed by a fleet can be described by a separable model. It assumes that catches-at-age from a survey are available and provide a reference against which the fleet data can be compared. Inconsistencies between the two data sets are modeled as a bias in the catch data of the fleet. This bias can be interpreted in a number of ways, for example mis-reporting, discarding or changes in catchability and natural mortality.

5.3.1 The model

Pope and Stokes (1989) proposed a GLM approach to interpreting catch-at-age data. They assumed that fishing mortality, F(a,y,f), is separable (see Pope and Shepherd, 1982) and can be described by

$$F(a,y,f) = E(y,f)\, q(a,f) \qquad (5.3.1)$$

That is as the product of an annual fleet fishing effort, E(y,f), effective over all ages, and an age specific fleet catchability, q(a,f), constant over all years. Catch data for a fleet f, C(a,y,f), can therefore be interpreted as

$$\ln\{C(a,y,f)\} = \ln\{\tilde{E}(y,f)\} + \ln\{q(a,f)\} + \ln\{\overline{P}(y,a)\} + \varepsilon \qquad (5.3.2)$$

$$\ln\{E(y,f)\} = \ln\{\tilde{E}(y,f)\} + \eta \qquad (5.3.3)$$

where $\tilde{E}$ (y,f) denotes the expected annual effort and $\overline{P}$(y,a) the average population, aged a, in year y. Equation 5.3.3 can be considered as having the same form as 5.3.2, with η and ε having the same distributional structure and

$$\ln\{q(a,f)\} = 0 \text{ and } \ln\{\overline{P}(y,a)\} = 0 \qquad (5.3.4)$$

Interpreted in this fashion equations 5.3.2 and 5.3.3 can form the basis of a linear regression model with three first-order interaction terms (estimated without main effects). The model can be fitted using standard statistical packages such as GLIM (Baker and Nelder, 1978). The aliasing conventions of GLIM are particularly convenient if the equations are treated as equivalent by adopting the following procedure: Firstly, the dependent variables of the regression, Y(a,y,f), [i.e. ln{E(y,f)} and ln{C(a,y,f)}] are age indexed (aa) as follows. The logarithms of effort are indexed as Y(1,y,f) and the catch-at-age data indexed as Y(2,y,f) for the youngest age (a1) through to Y(a2-a1+1,y,f) for the oldest age (a2). Secondly, the y * f interaction is fitted first followed by the aa * y interaction and then by the aa * f interaction. That is, for the effort data:

$$\ln\{Y(1,y,f)\} = \alpha(y,f) + \varepsilon . \qquad (5.3.5)$$

and for the catch-at-age data:

$$\ln\{Y(\text{aa},y,f)\} = \alpha(y,f) + \beta(\text{aa},y) + \chi(\text{aa},f) + \varepsilon$$
$$\text{aa} = 2, 3, \ldots, \text{a2} - \text{a1} + 1. \qquad (5.3.6)$$

When this indexing and fitting sequence is carried out in GLIM, the first age term of the second interaction and the first age and first fleet terms of the third interaction (i.e. β(1,y), χ(1,f), χ(aa,1)) are automatically aliased and set to 0. In the case of β(1,y) and χ(1,f) this is exactly what is required to satisfy the conditions given in equation 5.3.4. The only inconvenience of this is that χ(aa,1) is set to 0 and the other χ(aa,f) are scaled to this level. In general this will mean that χ(aa,f) does not have a direct interpretation as ln{q(a,f)}.

This model forms the first stage in the Pope and Stokes (1988) ITCOTCIO technique. It can be modified to provide a means for investigating the extent to which misreporting or discarding bias in catch-at-age data can be detected.

Fleets with biased catch-at-age data, but unbiased effort data, manifest themselves in ITCOTCIO fits by either, having residuals in a systematic direction in particular years, or by creating such residuals in other fleets. Assigning higher weights to fishing and acoustic surveys and/or fleets with more reliable data, concentrates the residuals within the suspect fleets, and may reveal annual patterns.

The regression approach can then be taken a step further by applying zero weights to the years in which the catch-at-age data is considered to be corrupt, and deriving new catch-at-age values, based upon estimates of the terms in equation 5.3.6. Note that in equation 5.3.6, the effort equivalent term α(y,f) would be based upon current effort, the mean population equivalent term β(aa,y) would be based on the relative population given by reliable fleets and surveys, and the catchability equivalent term χ(aa,f) would be derived from the more reliable estimates in earlier years. Thus, to obtain new estimates would require faith in the fleets current effort and in the integrity of its catch-at-age data at some time in the past.

A second regression approach is the fitting of a second-order interaction term, to estimate the scale of the bias inherent within the catch-at-age data of suspect fleets. That is :

$$\ln\{Y(\text{aa},y,f)\} = \alpha(y,f) + \beta(\text{aa},y) + \chi(\text{aa},f) + \delta(y,f,b) + \varepsilon \quad (5.3.7)$$

and

$$\ln\{Y(1,y,f)\} = \alpha(y,f) + \varepsilon \quad (5.3.8)$$

where b is a factor with one level for the catch-at-age data from the unbiased fleets and a second level for misreporting-fleets. This model fits for general misreporting- of all ages, and allows an assessment of the significance of the misreporting-effect.

5.3.2 Assessments

Working document U5 describes the application of the modified ITCOTCIO technique to simulated data sets. The assessment was shown to be sensitive to the level of noise in the catch-at-age data from the fleets. During the meeting, the technique was applied to representative data sets. The results of the assessments are presented in Figures 5.3.1 to 5.3.5. Each Figure presents the expected bias correction factor in each year of the assessment: the extent to which the fleet catch-at-age data would have to be raised to correct for any detected bias. The vertical lines depict the approximate 95% confidence limits for each year and the horizontal line at a bias correction factor of 1 represents the case of no bias.

Gulf of Maine cod

The assessment was conducted with ages 2–6, which are present in both the survey and fleet data sets. Comparisons between the two stock surveys (Figure 5.3.1a) are consistent with no misreporting. The expected bias indicates the possibility of a trend with time. The mean value is consistently above 1, which may result from a difference in the time of year at which the surveys were carried out.

The comparison between the two stock surveys and the fleet catch-at-age data (Figure 5.3.1b) is also consistent with no misreporting. However, the expected bias may indicate the possibility of over reporting during the 1980's.

North Sea haddock

The assessment was conducted with ages 2–5, which are present in both the survey and fleet data sets. Comparisons between the two stock surveys (Figure 5.3.2a) are consistent with no misreporting. The expected bias is consistently below 1, which may result from a difference in the time of year at which the surveys were conducted.

Comparisons were made between the two stock surveys and each fleet separately. Figure 5.3.2b presents the results for a trawl fleet. The level of bias is consistent with no misreporting up until the final year. However, the catch-at-age data from this fleet are known to have a high level of noise (catchability c.v's in the range 45 – 70 %), and the separation of bias from the inherent noise is not possible. Figures 5.3.2c and 5.3.2d compare the stock surveys with a seine fleet and a light trawl fleet with lower inherent levels of noise (20 – 50%). Both assessments indicate similar, increasing, trends with time. In both cases, the expected bias was significant for the years 1990, 1991 and 1993.

The bias factor in the modified ITCOTCIO model was redefined such that the model could be applied across all fleets in a combined assessment. This allowed the estimation of a common correction factor for the catch-at-age data. Each fleet was given equal weight in the analysis. The results are presented in Figure 5.3.3. The expected bias shows a similar pattern to the individual assessments, but the combined assessment has reduced the standard errors. The combined results show that bias may also have been significant in 1986 and 1987.

Southern Gulf cod (NAFO Division 4TVn)

The assessment was conducted with ages 4–11, which are present in both the survey and fleet data sets. The comparison between the stock survey and the fleet catch-at-age data (Figure 5.3.4) is consistent with no detectable bias.

Eastern Scotian Shelf cod (NAFO Division 4VsW)

The assessment was conducted with ages 2–9, which are present in both the survey and fleet data sets. A comparison between the two stock surveys, using the modified ITCOTCIO model, gave results, which were consistent with no detectable bias.

The comparison between the two stock surveys and the fleet catch-at-age data were also consistent with no misreporting. However, an examination of the residual patterns for each age, revealed differences between the younger and older ages, with a marked change in trend over time (Figure 5.3.5). The data set was therefore separated into two age groups, 2 – 5 and 6 – 9, and assessments conducted independently for the two categories.

Figure 5.3.6 presents the results of the assessments for bias. Figure 5.3.6a indicates that for the younger ages there was an increasing trend during the early 1980's followed by a dramatic change in 1986. At these ages, the bias remained significantly high, but showed a decrease with time, over the next five years. In contrast, Figure 5.3.6b shows that for the ages 6 – 9, at the 95% level of significance, the results are consistent with no detectable bias.

Summary

The trends in bias, estimated by the modified ITCOTCIO model could be explained by trends in catchability, natural mortality, misreporting-or discarding. Against this background, the sudden increase in the bias correction factor estimated for the Eastern Scotian Shelf cod, during the mid 1980's, is consistent with the perceived patterns of under-reporting, discarding and increased predation by seals. There is also evidence for the apparent over-reporting estimated for the Gulf of Maine cod. However, the bias correction factors estimated for the North Sea Haddock are inconsistent with the perceived pattern. Misreporting-is considered to have been severe 1992 and low in 1993.

5.3.3 Sensitivity

A possible criticism of the modified stage 1 ITCOTCIO model, is that as formulated, it assumes that a fleet's effort data has been recorded correctly. In order to investigate the influence of mis-specifications in the effort, further analyses were undertaken. Three typical effort functions were replaced by their average value (Figures 5.3.7a(i), b(i), c(i)), and the effect of the substitution on the expected relative bias examined. The solid lines represent true effort over time, the dotted lines the average effort over the same period.

Figures 5.3.7a(ii), b(ii) and c(ii) show the results. In general, changing the effort function has little effect on the overall pattern of the relative bias. However, the substitution of a strong trend in effort, can induce substantial changes in the trend of the expected bias. In such cases, if effort data are considered to be recorded incorrectly, the use of a derived index of effort, based on a smoothing function may be appropriate. This requires further investigation.

5.4 Time series analysis

In a joint analysis of catch-at-age and CPUE data from a research vessel survey, total mortality was produced by three mortality rates, i.e. natural, fishing, and the hidden mortality rate H_{ay}. The natural mortality is assumed known and the fishing mortality rate is estimated by a time series model as described by Gudmundsson (1994). By assuming that no permanent changes take place in the catchability of the research vessel survey it is possible to estimate a model with a small number of parameters, representing changes in hidden mortality with time. The model used in the estimates presented here was

$H_{ay} = (y-1)[k_1 + k_2(a_m - a)] + d_y(y-y_m)[k_3 + k_4(a_m - a)]$ for $a \leq a_m$,

$H_{ay} = H_{am,y}$ for $a > a_m$.

The time interval included in the analysis is split in two halves, y_m is the first year in the second half and d_y is zero for the first half and one for the second half. a_m is an assumed age of full recruitment and k_1 - k_4 are unknown parameters.

No significant improvement of goodness of fit was obtained when hidden mortality was included in the models for catches at age for Gulf of Maine cod or Icelandic haddock. For the 4T South Gulf cod and North Sea haddock, hidden mortality was highly significant. Only the Scottish ground fish survey was used with the catch-at-age data for North Sea haddock. The estimated values of H_{ay} are presented in Table 5.4.1. and other results in Section 7.

The estimated pattern of hidden mortality rates is constrained by the estimated model, which must be fairly simple, but can easily be changed from the one used here. (A different model was used for simulated data in a working paper (Gudmundsson, 1995 and WP), but as it did not seem to be suitable for the actual data available at the meeting it was changed to the one presented above).

The present model describes linear changes in time, with a possible break in the middle of the period and different rates of change for the ages. It is meaningless to try and interpret results for each year and age with the present models. For both stocks hidden mortality rates seem to have been higher for the younger fish. The parameters k_1 and k_2 were insignificant for 4T Southern Gulf cod which indicates that the unrecorded mortality was mainly confined to the later years. These parameters were left out in the estimation of hidden mortality for this stock so that the only description possible is a linear increase at each age from 1987–1992. The likelihood function and standard deviations of the parameters show that the models fit much better than any models without hidden fishing mortality rates, but this does not guarantee that the estimated models are close approximations to the actual mortality rates.

5.5 Overview

Two of the three (ITCOTCIO and Time series) methods applied in this Section appear to be able to identify bias in the data which could be interpreted as misreporting. However, the same patterns could be generated by changes in natural mortality, in the consistency of the abundance index(es) over time or by model mispecification. If the bias indeed came from misreporting, adjustments could be made to take it into account.

The third method (RCCPUE) is an assessment method, which does not use catch estimates and is therefore not affected by misreporting. The ITCOTCIO provides confidence intervals for the estimated bias correction factor. Because the confidence intervals are large, in several cases, it is not possible statistically to conclude that the bias exists even though the bias correction factor is consistently different from 1 (e.g. Figure 5.3.2).

The methods offer potential and warrant further investigation.

Two of the methods used for investigating bias in catch-at-age data have shown that there may be an increasing trend in hidden mortality for some stocks. The use of time series tapes and shrinkage within turning procedures could increase the sensitivity of VPA results to such bias. Working Groups should establish whether time series tapes and shrinkage are appropriate for their stocks in view of this problem.

6 Diagnostic methods

6.1 Background

A large number of techniques exist to investigate problems in data sets. Specific methods for diagnosing problems in assessment data sets have been considered by this Working Group on several occasions. Many approaches are likely to detect specific problems related to misreporting or similar issues. Hence, although the methods described in this section are aimed directly at diagnosing ill-behaved data sets, many of the methods in earlier sections also provide useful diagnostics, which can be used for evaluating fisheries, data sets.

Graphical and exploratory diagnostic methods can provide insight into all levels of fisheries assessments, from

1. quality of the data,

2. consistency between data sets,

3. validity of methods/model assumptions,

4. improved interpretability and communication.

In addition to diagnosing the state of data sets, it is highly relevant to be able to evaluate the general state of a stock or fishery even in circumstances when data are very poor and this is a further potential of some of the methods described in this section.

6.2 Stock performance display

Simple data descriptions are useful for communicating complex information. Rivard (Working Paper A-1) suggests one such possible method for the display of time series data on stock performance or condition. We applied the method to Gulf of Maine cod (Figure 6.2.1). Values in a given time series were divided into quartiles representing stock conditions "much worse than average", "worse than average", "better than average", and "much better than average". Eight series were available. In addition, an overall series was created from the mean ranks of the other series. The display indicates that the stock was in "much better than average" condition at the beginning of the series and "much worse than average" condition at the end of the series.

The Working Group discussed other possible algorithms for displaying this type of information. For example, the choice of five groups is preferable to four groups so that average and extreme values can be clearly illustrated. The appropriate number of categories also depends on the length of the series. With fewer than 15 data points, three categories would be more appropriate than five categories. In addition, similar series (e.g. multiple biomass estimates) should be combined to avoid overweighting one type of information.

This approach is most useful when stock condition has varied. If biomass has been relatively constant, then the condition categories may not be biologically meaningful. Thus, the categories should not be interpreted to reflect "risk" to the stock without additional information.

6.3 Relative F

Sinclair (Working Paper L-2) describes a method for estimating a relative value of $F_{y\ \mathrm{from}}$ catch at length and survey abundance index at length data. Under the assumption that fishing patterns and the index measurement are consistent over time, the ratio C_{yl}/U_{yl} is proportional to F_{yl}. An overall value for relative F_y is then estimated as the least squares mean of the year effect in an analysis of covariance, where $\log(C_{yl}/U_{yl})$ is the dependent variable and length and year are independent variables. The model includes a cubic function of length to capture size selectivity in the catch (relative to the survey) and all three year-length interaction terms.

The model was applied to the spring survey data for Gulf of Maine cod. The shape of the size-selectivity ogive varied annually for this stock (Figure 6.3.1). Indeed, model year-length interaction terms were significant. Thus, the interpretation of relative F_y using this approach may be confounded with shifts in availability to, or selectivity by, the fishery and survey. Applications to specific stocks must consider the appropriateness of the selectivity formulation.

The general approach was considered to be most useful for exploratory analysis, conducted on Gulf of St. Lawrence cod, Icelandic cod, Icelandic haddock, Icelandic redfish and Canadian unit 1 redfish in addition to Gulf of Maine cod. In particular, annual plots of C_l/U_l against length as in Figure 6.3.1 provide an estimate of the selectivity ogive. Furthermore, a simple examination of time trends of C_{yl}/U_{yl} for selected lengths can indicate temporal shifts in availability or selectivity. For example, relative F_y for 61–72 cm Gulf of Maine cod increased slightly over the 1982–93 period, while relative F_y for 40–48 cm cod decreased (Figure 6.3.2). The pattern may be partially explained by the strong 1987 year class passing through the fishery.

6.4 Constraint-added linear models of catch/survey indices at age

Two-way arrays of catch-at-age a in year y have been modelled as

$$C_{ay} = F_y S_a R_k \text{cum}(-Z_{ay}).$$

For survey indices, $F_y S_a$ reflects the fishing effort of the survey, $R_k\text{cum}(-Z_{ay})$ measures the available stock surviving from the recruitment R_k, discounted by the cumulative mortality to year y. If this mortality is roughly constant, log (catch-at-age) can be approximated by a linear model of year class, age and year effects (Working paper U.7).

This model was applied to North Sea haddock indices from the English Groundfish Survey (EGFS) (1982–94), the Scottish Groundfish Survey (1982–1994) and the International Bottom Trawl Survey (IBST) (1983–1994). The reported age ranges were 1–8, 1–7 and 1–5 respectively.

The model appeared to fit the data reasonably well as shown in the following summary:

Survey	Total SSQ	df	Residual SSQ	df	Res. sd.	% Variation Explained
EGFS	984.2	103	30.8	66	0.68	96.9
SGFS	680.9	90	7.2	55	0.36	98.9
IBTS	230.2	59	1.5	30	0.22	99.4

Because of the relationship between the year, age and year class subscripts (y=k+a), the estimated effects are not unique, but may be distorted by an arbitrary trend; adding an appropriate, sensible constraint will remove this trend, assuming that the assumed constraint is correct. Figure 6.4.1 shows the year class, age and year effects estimated with the constraint that the first and last year effects should be equal. This implies roughly that the year effects should have no trend.

The pattern of year effects appears to fluctuate around zero, with a single large deviation in 1983 in the SGFS series. The pattern of age effects seems to be consistent between the three surveys. However, the patterns of year class effects are less consistent, although this is difficult to judge against the increasing scatter of the poorly estimated early year classes.

A formal comparison of the surveys can be made by combining the survey series, and including main-effect terms for surveys, and interaction terms between survey and each of year class, age and year. The survey main effect is simply a survey scaling factor; the interaction terms measure the extent to which, e.g. the year class effects are the same for all surveys. The following analysis of variance was obtained for the EGFS, SGFS and IBTS data:

Source	df	SSQ	EMS	F-ratio
Survey (S)	2	110.5	55.2	211
Year class (K)	19	448.2	23.6	90
Age (A)	7	1374.2	196.3	750
Year (Y)	11	8.5	0.8	2.9
SxK	33	9.6	0.3	1.1
SxA	10	4.1	0.4	1.6
SxY	21	11.2	0.5	2.0
Residual	151	39.5	0.26	

There is little evidence of any difference between the surveys except in scaling.

There is a useful diagnostic plot for examining whether the assumed constraints are appropriate. If the constraint equating the first and last year effects is incorrect, the result will be an induced trend in the effects of all of the factors. Since for all three surveys the year class effects should be the same except for scaling, then e.g.

$$\text{Year class}(k)_{EGFS} - \text{Year class}(k)_{SGFS} = \text{constant} + k(\delta_{EGFS}-\delta_{SGFS})$$

where e.g. δ_{EGFS} is the slope of the induced trend in the EGFS year classes. Therefore, any systematic changes revealed by plotting the differences between surveys in the estimated year class effects will suggest either, that there are true differences in the year class estimates or, that the assumed constraint on the year effects in one or more of the surveys is inappropriate.

Figure 6.4.2 shows (EGFS year class effect -SGFS year class effect), (EGFS-IBTS) and (SGFS-IBTS) plotted against year class respectively, banded by the standard errors of the differences. These plots show that the estimates of the earlier year class effects in the IBTS tend to be lower than those from the EGFS and the SGFS. To some extent, particularly in Figure 6.4.2, the differences change steadily over the whole sequence of year classes, suggesting that there may in fact be some small trend in the year effects in the IBTS which has erroneously been set to zero.

Similar plots could, of course, be constructed for the estimated age and year effects.

6.5 Nonlinear interaction model for survey indices

The models described in Section 5.2 use survey indices of abundance to estimate historic stock trends. Two assumptions underlying these models are:

- the catchabilities at age of the survey are constant over time,
- fishing mortality is separable.

One way of assessing these assumptions is as follows.

Consider following the log-ratio of the indices of abundance down a cohort. If the assumptions hold then, using the notation of Section 5.2,

$$\log(u_{a,y}/u_{a+1,y+1}) = \log(q_a/q_{a+1}) + s_a f_y + m_a.$$

With some algebraic manipulation, this can be expressed in the form

$$\log(u_{a,y}/u_{a+1,y+1}) = m_a + \alpha_a + f_y' + s_a' f_y', \qquad (6.5.1)$$

where

- $\Sigma\alpha_a = \Sigma s_a' = \Sigma f_y' = 0$,
- α_a is an age effect,
- f_y' is a year effect related to the fishing mortality,
- s_a' is an age effect related to the exploitation pattern.

Thus, the log-ratios can be described by main effects in year and age and an interaction term which is a function of the year main effects. This is an example of Mandels' "bundle of lines" interaction model(Mandel 1961).

A simple way of assessing the adequacy of this model is to plot the observed log-ratios against year for each age. If the model is adequate, then the series of lines for each age will go up and down together, but without necessarily being parallel (unless the exploitation pattern is flat); a stylised example is given in Figure 6.5.1.

A more complicated way of assessing the model is to compare it to one with a more general interaction term, namely:

$$\log(u_{a,y}/u_{a+1,y+1}) = m + \alpha_a + f_y' + s_a'\beta_y, \qquad (6.5.2)$$

where β_y is not necessarily related to fishing mortality. Constraints need to be placed on the β_y for identifiability: e.g. $\Sigma\beta_y = 0$, $\Sigma\beta_y^2 = 1$ and $\beta_1 > 0$. If the observations on $\log(u_{a,y})$ are independent and normally distributed with zero mean and constant variance σ^2, then the observations on log-ratios have a particular covariance structure, with

$$\mathrm{Cov}\,[\log(u_{a,y}/u_{a+1,y+1}), \log(u_{a',y'}/u_{a'+1,y'+1})] = \begin{cases} 2\sigma^2 & \text{if } a = a',\ y = y' \\ -\sigma^2 & \text{if } |a-a'| = 1,\ |y-y'| = 1 \\ 0 & \text{otherwise.} \end{cases}$$

Models (6.5.1) and (6.5.2) can be fitted by generalised non-linear least squares and compared by an F test.

These techniques were applied to haddock abundance indices from the IBTS, SGFS and EGFS. The plots of log-ratios against year are shown in Figure 6.5.1. They do not appear too unreasonable for the SGFS and EGFS. However, in the IBTS, the log-ratios between ages 1 and 2 appear to behave quite differently from the others. These findings were corroborated by the F tests:

	F	df	P
IBTS	6.11	9,18	<0.001
SGFS	3.16	10,20	<0.05
EGFS	3.01	10,20	<0.05

suggesting more serious departures from model (6.5.1) for the IBTS than for other two surveys.

6.6 Right-left twin ratio

Given the population of a cohort at some age, one can infer the population of the same cohort at a different age by accounting for the intervening deaths; and one can infer the population of a different cohort at the same age from the ratio of abundance indices. To infer the population of a different cohort at a different age requires both of these operations; and it should make no difference in which order they are performed. A right-turn inference scales the abundance index before replacing deaths; a left-turn inference replaces deaths first. The ratio of the outcomes of right- and left-turn paths to a given result.

Data sets for many stocks fail this consistency test (Evans, 1994) Failure implies a change in something over time, but (as usual) one cannot infer simply from this diagnostic whether it is the accounting for deaths or the proportionality constant of the abundance index that has changed. However, one can get more detailed information about where it may be profitable to look for causes by plotting the degree of inconsistency against various putative explanatory variables, such as difference in time between the two cohorts, or difference in their populations, or the age at which the calibrations are performed.

An implementation was developed for this ratio and it was used to detect trends in q. On simulated data in which discarding began in year 10, the ratio detected the change. Mohn (WP U4) showed that in simulations with increased discarding, the estimated q also increases. The ratio was inverted to Right/Left as it then displays the same direction of trends as qs. It should be noted that this was an *ad hoc* and incomplete implementation of the author's method. Evans (1994) reports results for a number of stocks including 4tvn cod. During the Working Group meeting, the method was applied to Gulf of Maine cod and 4VsW cod. The upper pair of plots in Figure 6.6.1 show the results for both surveys in the Gulf of Maine. The y-axes have been logged. The right left ratios (R/L) have been made relative to three reference cohorts: the first, last and middle full cohorts in the catch data. Figure 6.6.2 shows the right left ratio for 4VsW cod. The four lines are for four reference years: the first and last full cohorts in the data and two intermediate years. The results a downward trend for Gulf of Maine cod and an upward one for 4VsW, which is consistent with the results from other methods.

6.7 Q-window

Mohn (WP U4) presented diagnostics for discarding based on a two step process. As well as producing the diagnostic of a q trend the method also corrects its output for the trend. The first step was to estimate the time trend in qs at age, which was done by performing VPAs on a moving data window and estimating q in each time segment. Although this showed trends in q, it was also shown that these trends could have many causes: catch data error (discarding, misreporting, etc.), survey errors (year effects) or even model mispecification errors (unmodelled changes in particle recruitment patterns). The second step was to calculate the fishing mortality after the VPA estimates were corrected for the non-stationary q. Estimates of F from log (N/N) - M and from solving C/N iteratively are compiled. Simulated data experiments showed that the difference between these estimates reflects either a change in discarding practices or a change in natural mortality. A suite of 12 plots tracks the steps in the process. For 4VsW cod, the figures are in WP-U4. The results for Gulf of Maine cod are shown in Figures 6.7.1 and 6.7.2. In Figure 6.7.1 a retrospective pattern in biomass is seen in either the traditional display (upper left figure) or in the moving window (upper right). The pattern is somewhat unusual, however, in that the later estimates of early biomass are greater than the earlier estimates. The bottom left sub-plot shows the q trends for ages 2 to 5. Figure 6.7.2 (bottom pair) compares the VPA numbers at ages to the surveys before and after q correction, which is seen to have a considerable effect. The two estimates of F are shown in the right middle sub-plot, and show a divergence beginning in the late 1980s. Because the C/N estimates are higher than the Z-M it suggests that discarding has decreased, that hidden M has decreased or that the survey q has decreased.

6.8 Outliers

Estimation of changes in reporting rates, natural mortality, catchability, and/or discarding is difficult because one must infer an unobservable quantity by deducing an inconsistency in an observable quantity. Unless the precision of the observable quantity is high, the likelihood of detecting change will be low. The purpose of this Section is to illustrate the use of general linear models to detect evidence of misreporting and/or changes in catchability. Given such a model, detection of unreported catches can be considered analogous to the detection of statistical outliers in a residual analysis. For the purpose of this analysis, an outlier occurs when the estimated value lies below the (1-α)% prediction interval of the empirical relationship. In this report the general framework is applied to three stocks of cod (Georges Bank, Gulf of Maine, 4T-Vn Southern Gulf) and the Georges Bank stock of yellowtail flounder. Assessments of Georges Bank cod and yellowtail flounder stocks were reported in NMFS(1994). Results of those assessments are included herein to allow comparison with stocks considered by the Working Group.

Methods

Linear regression analysis was used to investigate the relationship between stock biomass (from the assessment) and a survey index. The general model can be written as

$$B_{vpa,y} = a\, U_y^b \qquad (6.8.1)$$

$$\ln(B_{vpa,y}) = \ln(a) + b \ln(U_y) \qquad (6.8.2)$$

where $\mathbf{B_{vpa}}$ is an assessment based estimate of biomass in year **y**, $\mathbf{U_y}$ is the research survey index (kg/tow) in year **y**, and **a** and **b** are parameters. Standard linear regression techniques can be applied to Eq. 6.8.2 to generate the prediction interval estimates for index data not included in the model. The prediction interval half width in the log scale is defined as

$$PI_{half} = \left|t_{1-\alpha/2,n-2}\right| \sqrt{MSE + \frac{MSE}{n} + s^2(b)(U_{y'} - \bar{U})^2} \qquad (6.8.3)$$

where **MSE** is the mean square error of the regression, $\mathbf{s^2(b)}$ is the standard error of the **b** parameter, $\mathbf{U_{y'}}$ is the survey index for a year not included in the regression.

Suppose it is hypothesised that catches in the terminal year are fully reported and the fishery- independent abundance index is available. If H_0 is false, assessment-based estimates of **B** derived from catches in year **y'** may lie outside the prediction intervals for the regression (Eq.6.8.2). The probability that an observed value of $\mathbf{B_{y'}}$, times an arbitrary multiplier δ, lies below the (1-α)% prediction interval is given by the α that satisfies-

$$\delta B_{y'} = \hat{B}(U_{y'}) - PI_{half} \qquad (6.8.4)$$

The derived value of αcan be plotted against δ to assess the relative change in $B_{y'}$ necessary to achieve a desired level of probability that $B_{y'}$ is representative of the prior underlying relationship between B_y and U_y.

Results

Linear regressions between estimated stock biomasses and the research surveys for Georges Bank yellowtail flounder, Georges Bank Cod, Gulf of Maine Cod, and 4T-Vn Southern Gulf Cod (Table 6.8.1) were all statistically significant ($P<0.05$). Residual analyses revealed no major outliers, no significant autocorrelation, and close correspondence to the underlying normality assumptions. Figure 6.8.1 depicts the linear regressions and 90% confidence intervals developed from n-1 observations (i.e. the last year is not included). The lower bound of the 90% prediction interval is shown as a dashed line. The last year's value is denoted as a triangle D. For Georges Bank yellowtail flounder (Figure 6.8.1a) the 1993 data point lies within the prediction interval, suggesting no apparent change in reporting or catchability. Results for Georges Bank and Gulf of Maine cod (Figure 6.8.1b,c) are slightly below the prediction line whereas the 1993 estimate of B for Southern Gulf cod (Figure 6.8.1d) is far below the prediction limit. Either reporting or catchability appears to have changed in 1993 for the Southern Gulf stock. Closer inspection of Figure 6.8.1d reveals an apparent temporal pattern in the relationship between B and U.

Data for the 4T-Vn cod were partitioned into three groups (1971–87, 1988–92, 1993) and analysis of covariance was used, (Figure 6.8.2) to determine if longer-term changes in the relationship between B and U had occurred. The model suggests that a major change in reporting or catchability commenced about 1988 and accelerated in 1993. The results of the ANCOVA model are in substantial agreement with findings from time series analyses of hidden mortality reported in Section 5.4 Within the fishery itself, 1988 corresponded to an implementation of minimum size limits, in 1989 ITQs were implemented and in 1993 the mesh size was increased. Some of these measures were unpopular with fishermen and may have resulted in misreporting.

Analyses of a *vs* δ for the three cod stocks (Figure 6.8.3) show a progressive increase in the potential magnitude of misreporting and/or catchability ranging from a low value for Gulf of Maine cod, and highest values for Southern Gulf cod. For example, the biomass estimate for Southern Gulf cod would have to increase by a factor of 1.7 (i.e. $\delta=1.7$) in order to be 50% certain that the estimated value was within the 90% prediction interval of the historical relationship between B_y and U_y shown in Fig 6.8.1d. If all of the change were induced by misreporting, then only about 60% (i.e., $1/\delta$) of the catches would have been reported in 1993. If non-reporting were the primary cause of the difference between B_y and its regression estimate for Georges Bank cod, then only about 86% (i.e., $1/(\delta=1.15)$) of the catch would have been reported in 1993. There is no statistical evidence of change in the Gulf of Maine cod stock.

Discussion

As previous sections of this report have noted, the simultaneous effects of changes in natural mortality, discarding, misreporting, and catchability are inseparable, a comparative approach among similar stocks may give some insight into potential causal factors. As a final note, it should be recognised that δC cannot exceed the estimated population abundance at the end of the penultimate year. This provides a logical constraint on the estimated magnitude of the under reporting. If $\delta*C > B_{y-1}$ then there may be evidence of a trend in misreporting. The regression-based method would not be useful for diagnosing longer-term trends in underreporting owing to the structural dependencies in the VPA estimation.

6.9 Relative Q

During the Working Group meeting a method was coded up which uses VPA numbers at age estimates ($N_{a,y}$), which may or may not have been tuned, and compares them to research vessel estimates ($U_{a,y}$) by considering the ratio of Na,y in any year to a reference year, yr. It is assumed that q is also a function and age and year.

$$(U_{a,y})/(U_{a,yr})=(q_{a,y}*N_{a,y})/(q_{a,y}*N_{a,yr})$$

rearranging gives:

$$(q_{a,y})/(q_{a,yr})=(U_{a,y}/U_{a,yr})/(N_{a,yr}/N_{a,yr})$$

if a reference year were not specified the GM average over all years was used for normalisation. It should be noted that the R/L ratio is referenced to a cohort while the relative q is referenced to a year or average over years. For convenience in plotting, the relative qs were logged. In Figure 6.6.1, the lower pair of sub-plots shows the relative qs for Gulf of Maine cod, spring and autumn surveys. The trends are similar to those shown for the right left turns ratios and the q-window estimates. Figure 6.6.2 shows the relative q trend for 4VsW cod and again it mirrors the estimates of the other two methods.

6.10 Overview

The eight diagnostic methods discussed in this section differ in their purpose but they are united in their aim to disentangle the morass of data, which form the basis of assessments.

The Stock Performance Display is primarily a method for communicating various stock performance indicators to a non-technical audience, but it may also be useful in summarising several different types of data to help decision making. The Relative F method was intended to indicate trends in exploitation rates, when the catchability of the abundance index has not changed over the period considered and when there is no change in hidden mortality, but it could also be a useful exploratory tool for examining selectivity ogives. The CALM, the Outlier approach and the non-linear interaction model, would be useful in examining the consistency of several indices of abundance and their relationship with the assessment model used. The Right/Left ratio and Relative q methods could identify possible changes over age or over time in the basic data, which should be taken into account in subsequent modelling. The Q-Window, inspects possible changes in apparent catchability which could result from changes in M or in reporting practices.

These methods are concerned with the details of individual data analyses and methodologies. Often simple graphical displays provide a quick way of looking at the data and either (a) confirming the validity of existing methods of analysis or (b) identifying potential trouble areas and suggesting avenues which may lead to new methods of analysis. The methods discussed appear to offer potential. In some cases they complement techniques described in this report, particularly in Section 5. Future work, which unifies some of these approaches, would be desirable.

7 Comparison of methods: a matter of choice

7.1 Time series of results

A great variety of methods have been described and applied to real data sets in the report. It was not the intention of the meeting to test methods against each other with a view to ranking methods in order of merit. Each method has been conceived and developed for a different purpose. What is important is to choose the appropriate method for the task in hand. It should also be borne in mind that there is no substitute for good data. The fact that a particular model is less data demanding than another is not an excuse for failing to collect basic data. Usually the less the data available, the less the information that can be gained about the stock which may be used for management purposes.

The results from the various test runs are summarised in Tables 7.1.1–7.1.9 and in Figures 7.1.1–7.1.9. The labels for the various lines are defined in Table 1.5.2. Where possible, for each method, a time series of recruitment, mean fishing mortality, exploitable biomass and spawning stock biomass is plotted. The plots should only be interpreted as the performance of the method against the stock, not as a comparison of method against method. In doing this great care needs to be exercised since the methods are not necessarily measuring the same quantity or using the same data. The following points should be borne in mind:

a) Length-based methods (and the modified DeLury) do not necessarily interpret recruits as a single year class, rather a group of fish of a particular size range which are entering the fishery. This class of fish will not correspond to a single year class as measured by age-based methods.
b) Each method used the available data appropriate to the technique. As a result, there are inconsistencies between methods on the reference age of recruitment, the age range used for calculating mean fishing mortality rate and the definition of exploitable biomass. Thus in the interpretation of the recruitment plots, for example, the year classes as plotted on an annual time scale do not necessarily line up. Care is needed in understanding whether like is being compared with like.

c) Given the diversity of methods and data, the time series have been plotted on a relative scale except for fishing mortality, which in general is on an absolute scale [note that the "relative F" is plotted on a relative scale, however]. Where it is of interest to examine absolute estimates of the summary statistics, such as biomass, Tables 7.1.1–7.1.9 give the values concerned.

7.2 Paired comparisons

In addition to the time series plots given in Section 7.1, a set of e.g. fishing mortality estimates from any two methods can be plotted as a paired scatter plot. Figures 7.2.1–7.2.9 show such scatter plots of the results obtained from all methods applied to the various stocks.

Each panel in a figure contains a single scatter plot of results from two methods. For example, Figure 7.2.1a. contains a comparison of all recruitment results for the Gulf of Maine cod stock. The first column contains year (YR) on the x axis. Hence each panel in the first column contains the time trend of estimates.

Care has to be used in the interpretation of these results:

1. Each panel is scaled on both axes. Thus, although both the DYNP and AGEP appear to agree with the official estimates for Pacific ocean perch (obtained by catch-age analysis), this result is misleading. The DYNP and AGEP estimates of biomass are an order of magnitude larger than the official methods, but agreement seems to be good due to scaling. Furthermore, most of the data contrast occurred in years prior to those illustrated here.

2. Similarly, some of the fishing mortality plots will contain simply a small amount of noise around a single fishing mortality. This can be seen by comparing figures in Section 7.1 and Section 7.2. For example the fishing mortality obtained for SPKE in Figure 7.1.1 varies slightly around 0.4, but in Figure 7.2.2, this appears as considerable variation.

3. Some of the recruitment plots are inevitably somewhat hard to interpret, since the definition of recruitment can not be made fully consistent across methods.

8 Summary

The results in this report indicate that there are several alternatives to classical VPA-based methods, and the use of these may be applicable or even preferable, e.g. under the following circumstances:

1. In some cases the data available will dictate specific methods, e.g. aggregate production methods, when only total abundance data is available;

2. In other cases it is possible that a specific class of methods fits the observed data well and thus should be considered at least as an alternative to "classical" methods;

3. Finally, it is always useful to consider alternative approaches to assessments and the methods given in this report can in many cases be used as useful adjuncts or diagnostics in addition to those presently used in ICES.

Moreover, in cases where VPA-based assessment is not practical (e.g., some redfish stocks) and current management advice is largely qualitatively-based, the application of one or more of these methods would be beneficial.

The Working Group concluded that several of the methods given in this report are quite generally applicable and should be included as a part of the regular assessment suite. Such methods should be tested quite extensively for the stock in question, on simulated data and for sensitive to assumptions.

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9.1 Working documents

Aggregated methods

A1 Rivard, D. Guide to stock "Performance".

A2 Smith, A. D. M., and Bax, N. J. Risk assessment for management of orange roughy (*Hoplostethus atlanticus*) in south-eastern Australia.

A3 Conser, R. J. A Bayesian framework for the modified DeLury model with application to Atlantic surfclam.

A4 Johannesson, G., and Sigurdsson, Th. Oceanic redfish in the Irminger Sea.

A5 Conser, R. J. A modified Delury modelling framework for data-limited assessments: Bridging the gap between surplus production models and age-structured models.

Length-based methods

L1 Gudmundsson, G. Time series analysis of catch-at-length data.

L2 Sinclair, A. F. Estimating fishing mortality at age and length directly from research survey and commercial catch data.

L3 Mesnil, B. Experiences with the use of some methods to estimate age comparisons from length compositions of the catches.

L5 Mesnil, B. Tests of some numerical methods of length to age conversion on simulated data.

L6 Mohn, R. Simultaneous estimation of age abundance using an iterated sequential population and age length key analyses.

Unreliable catch statistics (survey-based and diagnostic methods)

U1 Gudmundsson, G. Estimation with unrecorded fishing mortality.

U2 Cook, R. Analysis of research vessel data to estimate historical trends of three North Sea demersal stocks.

U3 Fryer, R. Combining research vessel survey data to estimate historical stock trends of North Sea haddock.

U4 Mohn, R. Another look at the retrospective problem.

U5 Darby, C. D., and Pope, J. G. Estimation of vital parameters when catch-at-age data are corrupted by misreporting or discarding.

U6 Pope, J. G., and Darby, C. D. Shall there by life without the comfort blanket of VPA?: Estimation of vital parameters where catch-at-age data are missing or corrupted.

U7 Nicholson, M., and Dawson, W. Constrained Linear Models for Analysing Catch-at-Age Data.

Supporting documents

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Table 1.5.1 Abbreviations for stock names.

GCOD:	Gulf of Maine Cod
ICOD:	Icelandic Cod
IHAD:	Icelandic Haddock
CTUN:	"Clean" simulated tuna
4HAD:	North Sea Haddock
4COD:	Southern Gulf Cod (4T-4Vn (Nov - May)
CRED:	Canadian (Unit 1) Redfish
IMAR:	Icelandic data on *S. marinus*
CPOP:	Pacific Ocean Perch

Table 1.5.2 Methods used.

C_l, C_a	Catch in numbers at length and age
U_l, U_a	Survey or CPUE indices at length and age
L_∞, K, t_0	Parameters in von Bertalanffy equation
M	Natural mortality
α, β	Coefficients in length-weight relationship

Method	Input data	Output	Use	Abbrev
Mod. de Lury	$C_l, U_l, L_\infty, K, t_0, M, \alpha, \beta$	$N_1, N_{2+}, F_1, F_{2+}, B$	A	MDLU
Static prod.	$Y_y, U_y,$	B_y	A	
Dyn. prod.	$Y_y, U_y,$	B_y	A	DYNP
Age-str prod. mod.	$Y_y, U_y, L_\infty, K, t_0, M, \alpha, \beta$	$B_y, N_1, B_0 = K$	A	AGEP
Slicing	$C_l, U_l, L_\infty, K, t_0, M, \alpha, \beta$	N_a, F_a	L	SLIC
SP-Key	$C_l, U_l, L_\infty, K, t_0, M, \alpha, \beta$	N_a, F_a	L	SPKE
L-A conversions	C_l	C_a	L	LACO
TSER for C(l)	$C_l, U_l, L_\infty, K, M, \alpha, \beta$	N_l, F_l	L	TSCL
ITCOTCIO	$[C_a], U_a$	N_a, F_a	U	ITCO
RCCPUE	U_a	N_1^{rel}, F_a	U	RCCP
TSER for C(a)	$[C_a], U_a$	H_a, N_a, F_a	U	TSCA
Rel. F	C_l, U_l	F^{rel}	D	RELF
Q-window	$[C_a], U_a$	H_a, N_a, F_a	D	QWIN
R-L diagn	C_a, U_a		D	RLDI
Outliers	N_a^{vpa}, U_a		D	OUTL
CALM	C_a		D	CALM
Nonlin. int.	Ua		D	NONL
Display	Any index	plots	D	DISP
Age-based production models				APRO
Official Base				OFFI

Usage: A=Alternative assessment method; L=Length-based method; U=underreporting detection/estimation; D=Diagnostic method. Parentheses indicate that the data are optional. Square brackets indicate that the data are being verified by the methods.

Table 1.5.3 Summary of runs.

	GCOD	ICOD	IHAD	CTUN	NTUN	4HAD	4COD	CRED	ORUF	IMAR	SMEN	VCOD	CPOP
Md de Lury	x	x								-			
Slicing	x			x	x					-			
SP-Key	x			x	x					-			
L-A conv.			x	x									
TSER - C(l)	x									-			
Age-prod	x	x						x	x	x			
Rel. F	x	x								-			
Outliers													
RCCPUE	x	x	x			x	x						
TSER-C(a)	x		x			x	x						
ITCOTCIO	x					x	x					x	
Q-window	x												
R-L diagn	x												
Abuse													
APRO										x			
Display													
Nonlin sep.						x							
Dyn pr md.	x												
Official base	AGE	AGE	AGE	N/A	N/A	AGE	?	?	BIOM	N/A	N/A		

Table 2.2.1 Biological parameters for Gulf of Maine Cod.

OTHER BIOLOGICAL DATA AND VITAL RATES

NATURAL MORTALITY RATE (assumed invariant with age and time)

M = 0.2 per yr

VON BERTALANFFY GROWTH PARAMETERS (from Penttila and Gifford 1976)
$L = L_\infty (1-\exp(-K(t-t_0)))$

L_∞ = 146.5 cm
K = 0.116 per yr
t_0 = 0.285 yr

LENGTH-WEIGHT RELATIONSHIP -- W = a*L**b
(L in cm and W in kg)

a = 0.000008104
b = 3.052

Table 2.3.1 Icelandic cod. Biological data and vital rates.

NATURAL MORTALITY RATE (assumed invariant with age and time)

M = 0.2 per yr

VON BERTALANFFY GROWTH PARAMETERS (from Penttila and Gifford 1976)
$L = L_\infty (1-\exp(-K(t-t_0)))$

L_∞ = 153.8 cm
K = 0.1073 per yr
t_0 = 0 yr

LENGTH-WEIGHT RELATIONSHIP -- W = a*L**b
(L in cm and W in kg)

a = 0.0000045
b = 3.1753

Table 2.3.2 Catch in numbers by length (rows) and age (columns) for the Icelandic cod in 1993. The centimeter group label 20 is fish ≥ 20cm and < 25cm.

	2	3	4	5	6	7	8	9	10	11	12	13	14	15
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	5	7	0	0	0	0	0	0	0	0	0	0	0	0
30	66	36	1	0	0	0	0	0	0	0	0	0	0	0
35	402	346	56	2	0	0	0	0	0	0	0	0	0	0
40	491	2048	1327	96	0	0	0	0	0	0	0	0	0	0
45	424	4548	4195	367	164	0	0	0	0	0	0	0	0	0
50	218	5001	6483	1696	748	24	73	8	0	0	0	0	0	0
55	60	3090	8767	2556	1709	86	125	33	50	8	0	0	0	0
60	17	1224	6965	3028	2135	202	239	117	65	0	0	0	0	0
65	0	504	2792	3673	2733	368	263	125	83	0	0	0	0	0
70	0	171	830	2713	3113	690	217	160	93	0	0	0	0	0
75	0	60	261	963	2519	906	403	182	98	18	0	0	0	0
80	0	43	152	383	1221	779	578	334	101	3	0	0	0	0
85	0	4	73	161	783	287	603	575	121	9	0	0	0	0
90	0	0	33	140	450	333	332	528	287	38	3	0	0	0
95	0	0	10	52	243	159	206	437	254	42	3	0	0	0
100	0	0	0	4	85	84	168	282	207	44	3	3	0	0
105	0	0	0	0	23	34	87	159	100	22	15	8	0	0
110	0	0	0	0	6	3	40	98	91	24	1	4	13	0
115	0	0	0	0	0	1	21	45	33	12	4	4	0	0
120	0	0	0	0	0	0	11	10	27	5	4	5	6	1
125	0	0	0	0	0	0	0	0	5	14	3	0	5	2
130	0	0	0	0	0	0	0	0	4	6	0	0	0	0
135	0	0	0	0	0	0	0	0	2	0	0	0	0	0
140	0	0	0	0	0	0	0	0	0	0	0	0	0	0
145	0	0	0	0	0	0	0	0	0	0	0	0	0	0
150	0	0	0	0	0	0	0	0	0	0	0	0	0	0
155	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 2.3.3 Icelandic ground fish survey indices by length (rows) and age (columns) for the Icelandic cod in 1993. The centimeter group label 20 is fish ≥ 20cm and < 25cm.

	1	2	3	4	5	6	7	8	9	10	11
5	2	0	0	0	0	0	0	0	0	0	0
10	31	0	0	0	0	0	0	0	0	0	0
15	3	2	0	0	0	0	0	0	0	0	0
20	0	24	0	0	0	0	0	0	0	0	0
25	0	25	29	2	0	0	0	0	0	0	0
30	0	8	102	8	0	0	0	0	0	0	0
35	0	1	147	25	1	0	0	0	0	0	0
40	0	0	99	82	4	0	0	0	0	0	0
45	0	0	29	149	14	2	0	0	0	0	0
50	0	0	8	143	30	6	0	0	0	0	0
55	0	0	2	69	42	14	1	0	0	0	0
60	0	0	0	16	30	21	2	1	0	0	0
65	0	0	0	3	21	25	4	2	1	0	0
70	0	0	0	1	9	17	5	2	1	0	0
75	0	0	0	0	3	11	5	3	2	0	0
80	0	0	0	0	1	5	3	3	2	0	0
85	0	0	0	0	0	2	2	3	2	0	0
90	0	0	0	0	0	1	1	2	1	0	0
95	0	0	0	0	0	0	0	1	1	1	0
100	0	0	0	0	0	0	0	1	1	1	0
105	0	0	0	0	0	0	0	1	1	2	1
110	0	0	0	0	0	0	0	0	0	1	1
115	0	0	0	0	0	0	0	0	0	1	0
120	0	0	0	0	0	0	0	0	0	0	0
125	0	0	0	0	0	0	0	0	0	0	0
135	0	0	0	0	0	0	0	0	0	0	0

Table 2.4.1 Vital rates for Icelandic haddock.

First year: 1974 Number of years: 20
First age in weighted mean F: 4 Last age in wt F: 7
Recruitment in last year: 50 Ages in oldest average: 3

Assumed recruitment values, brought forward in the VPA:
(Listed in reverse order, starting with the second last year)
40.000 167.000

Proportion of F and M before spawning:

Age	PropF	PropM
2	0.000	0.000
3	0.000	0.000
4	0.000	0.000
5	0.000	0.000
6	0.000	0.000
7	0.000	0.000
8	0.000	0.000
9	0.000	0.000

File input:

Stock weights: weights.ssbCatch weigths: weights
Stock mat: sex_mat Catch mat: sex_mat
Last year's F: F_last_year Multiplier: 1.00000

Von Bertalanffy Growth parameters

$L_\infty = 89.10$
$K = 0.183$
$t_0 = -0.681$

Length-Weight parameters W=a*L^b weight in grams, length in cm

a= 0.0111
b= 2.952

Table 2.4.2 Catch in numbers by length (rows) and age (columns) for the Icelandic haddock in 1993 (length groups are centimeters groups).

	1	2	3	4	5	6	7	8	9	10	11
19	0	0	0	0	0	0	0	0	0	0	0
20	10	0	0	0	0	0	0	0	0	0	0
21	26	0	0	0	0	0	0	0	0	0	0
22	51	0	0	0	0	0	0	0	0	0	0
23	65	0	0	0	0	0	0	0	0	0	0
24	53	0	0	0	0	0	0	0	0	0	0
25	23	0	0	0	0	0	0	0	0	0	0
26	13	0	6	0	0	0	0	0	0	0	0
27	17	0	0	0	0	0	0	0	0	0	0
28	0	18	0	0	0	0	0	0	0	0	0
29	0	0	24	0	0	0	0	0	0	0	0
30	9	23	14	0	0	0	0	0	0	0	0
31	0	16	49	0	0	0	0	0	0	0	0
32	7	13	92	0	0	0	0	0	0	0	0
33	0	6	167	0	0	0	0	0	0	0	0
34	0	24	183	8	0	0	0	0	0	0	0
35	0	10	309	9	0	0	0	0	0	0	0
36	0	39	383	8	0	0	0	0	0	0	0
37	0	24	528	29	0	0	0	0	0	0	0
38	0	19	679	62	0	0	0	0	0	0	0
39	0	7	800	108	0	0	0	0	0	0	0
40	0	3	1154	108	0	0	0	0	0	0	0
41	0	4	1132	148	22	0	0	0	0	0	0
42	0	4	1001	315	0	7	0	0	0	0	0
43	0	0	1043	329	12	0	0	0	0	0	0
44	0	4	895	484	33	4	0	0	0	0	0
45	0	0	779	544	49	0	0	18	0	0	0
46	0	0	614	636	28	17	0	15	0	0	0
47	0	0	561	690	38	21	0	7	0	0	0
48	0	0	374	853	63	30	0	21	0	0	0
49	0	0	322	777	74	22	6	26	0	0	0
50	0	0	228	845	123	19	15	11	0	0	0
51	0	0	151	751	102	37	22	29	5	0	0
52	0	0	100	782	197	37	10	20	5	0	0
53	0	0	31	759	202	48	13	33	5	0	0
54	0	0	34	672	218	63	33	54	0	0	0
55	0	0	15	635	232	63	71	15	5	0	0
56	0	0	14	621	212	75	29	57	5	0	0
57	0	0	29	518	235	56	54	48	0	0	0
58	0	0	14	422	150	112	46	97	5	0	0
59	0	0	5	371	171	65	25	66	39	0	0
60	0	0	7	282	218	131	78	125	13	0	0
61	0	0	0	241	107	96	67	73	0	0	0
62	0	0	0	190	109	132	81	88	11	0	0
63	0	0	0	156	106	73	56	76	8	2	0
64	0	0	0	69	105	73	65	96	19	0	0
65	0	0	0	71	84	99	64	94	3	0	0
66	0	0	0	21	73	73	72	96	17	4	0
67	0	0	0	20	62	87	71	75	17	0	0
68	0	0	0	25	59	67	74	86	15	4	0

Table 2.4.2 Continued.

	1	2	3	4	5	6	7	8	9	10	11
69	0	0	0	17	18	56	83	78	17	0	0
70	0	0	0	4	29	70	74	88	19	2	0
71	0	0	0	0	8	39	69	55	14	3	0
72	0	0	0	5	13	25	50	114	10	0	0
73	0	0	0	5	1	18	63	100	15	1	0
74	0	0	0	0	6	15	50	81	16	0	0
75	0	0	0	0	5	20	53	82	11	0	0
76	0	0	0	0	4	13	31	58	13	3	0
77	0	0	0	0	0	2	28	72	11	0	0
78	0	0	0	0	0	5	14	57	19	1	0
79	0	0	0	0	0	3	18	50	11	0	0
80	0	0	0	0	0	0	13	28	20	0	2
81	0	0	0	0	0	2	16	3	16	2	0
82	0	0	0	0	0	0	1	15	11	0	0
83	0	0	0	0	0	0	2	17	2	0	0
84	0	0	0	0	0	0	3	9	4	3	0
85	0	0	0	0	0	0	0	4	5	1	0
86	0	0	0	0	0	0	0	5	0	0	0
87	0	0	0	0	0	0	0	4	9	0	0
88	0	0	0	0	0	0	0	0	0	0	0
89	0	0	0	0	0	0	0	0	0	0	0
90	0	0	0	0	0	0	0	0	0	0	0

Table 2.4.3 Icelandic ground fish survey indices by length (rows) and age (columns) for the Icelandic haddock in 1993 (length groups are centimeter groups).

	1	2	3	4	5	6	7	8
10	0	0	0	0	0	0	0	0
11	1	0	0	0	0	0	0	0
12	2	0	0	0	0	0	0	0
13	4	0	0	0	0	0	0	0
14	4	0	0	0	0	0	0	0
15	7	0	0	0	0	0	0	0
16	14	0	0	0	0	0	0	0
17	17	0	0	0	0	0	0	0
18	16	0	0	0	0	0	0	0
19	8	0	0	0	0	0	0	0
20	2	1	0	0	0	0	0	0
21	0	2	0	0	0	0	0	0
22	0	4	0	0	0	0	0	0
23	0	8	0	0	0	0	0	0
24	0	12	0	0	0	0	0	0
25	0	15	0	0	0	0	0	0
26	0	19	1	0	0	0	0	0
27	0	14	3	0	0	0	0	0
28	0	13	11	0	0	0	0	0
29	0	9	26	0	0	0	0	0
30	0	6	41	0	0	0	0	0
31	0	5	63	0	0	0	0	0
32	0	2	87	0	0	0	0	0
33	0	0	108	0	0	0	0	0
34	0	0	104	1	0	0	0	0
35	0	0	105	1	0	0	0	0
36	0	0	85	3	0	0	0	0
37	0	0	72	4	0	0	0	0
38	0	0	54	7	0	0	0	0
39	0	0	39	10	0	0	0	0
40	0	0	28	13	0	0	0	0

	1	2	3	4	5	6	7	8
41	0	0	20	17	0	0	0	0
42	0	0	11	21	0	0	0	0
43	0	0	6	20	0	0	0	0
44	0	0	4	19	0	0	0	0
45	0	0	2	22	1	0	0	0
46	0	0	1	19	1	0	0	0
47	0	0	1	14	1	0	0	0
48	0	0	0	14	2	0	0	0
49	0	0	0	11	2	0	0	0
50	0	0	0	8	2	0	0	0
51	0	0	0	7	2	0	0	0
52	0	0	0	7	3	0	0	0
53	0	0	0	4	2	0	0	0
54	0	0	0	4	2	0	0	0
55	0	0	0	3	2	0	0	0
56	0	0	0	2	1	0	0	0
57	0	0	0	2	2	0	0	0
58	0	0	0	1	2	1	0	0
59	0	0	0	1	1	0	0	0
60	0	0	0	1	1	0	0	0
61	0	0	0	0	1	0	0	0
62	0	0	0	0	0	0	0	0
63	0	0	0	0	0	0	0	0
64	0	0	0	0	0	0	0	0
65	0	0	0	0	0	0	0	0
66	0	0	0	0	0	0	0	0
67	0	0	0	0	0	0	0	1
68	0	0	0	0	0	0	0	0
69	0	0	0	0	0	0	0	0
70	0	0	0	0	0	0	0	0

Table 2.5.1 True catch at age for the 'Clean' tuna stock.

1	1601	1938	11171	2957	2405	3429	2754	4708	12319	3620	4438	3871	4479	4397	5702
2	3770	4497	5253	29457	7621	6078	8521	6740	11362	29345	8519	10327	8910	10203	9914
3	5530	6269	7033	7931	43153	10868	8459	11592	8976	14826	37555	10700	12736	10796	12150
4	4406	4953	5442	5943	6471	34111	8343	6316	8432	6366	10262	25386	7067	8223	6817
5	3456	3880	4157	4386	4623	4874	24931	5928	4368	5683	4184	6583	15899	4324	4916
6	2678	3043	3256	3349	3410	3480	3560	17705	4098	2943	3733	2683	4120	9722	2583
7	1987	2358	2554	2624	2604	2567	2543	2528	12239	2760	1933	2393	1679	2519	5809
8	1469	1750	1979	2058	2040	1961	1875	1806	1748	8244	1813	1239	1498	1027	1505
9	1123	1293	1468	1595	1600	1536	1432	1332	1248	1177	5416	1162	776	916	613
10	778	989	1085	1183	1240	1205	1122	1017	921	841	773	3472	728	474	547

Table 2.5.2 True numbers at age for the 'Clean' tuna stock.

1	100000	101000	500000	116000	84000	108000	79000	124000	300000	82000	94000	77000	84000	78000	96000
2	81000	80427	80942	399278	92303	66602	85327	62193	97273	234500	63869	72955	59549	64731	59894
3	65000	62914	61790	61531	300331	68698	49049	62178	44844	69401	165551	44616	50429	40730	43811
4	51000	48230	45858	44250	43231	207021	46459	32544	40475	28640	43487	101779	26912	29845	23651
5	40000	37782	35022	32641	30875	29567	138783	30529	20962	25555	17725	26380	60519	15686	17051
6	31000	29633	27435	24928	22773	21114	19819	91187	19662	13233	15813	10751	15684	35268	8960
7	23000	22965	21518	19528	17392	15573	14153	13022	58728	12412	8188	9591	6391	9140	20145
8	17000	17039	16676	15316	13624	11893	10439	9299	8387	37074	7680	4966	5702	3725	5221
9	13000	12594	12373	11870	10685	9317	7972	6859	5989	5294	22941	4658	2953	3323	2128
10	9000	9631	9145	8807	8281	7307	6245	5238	4417	3781	3276	13914	2770	1721	1898

Table 2.5.3 Mean and standard deviation of length at age and mean weight at age.

Age	Mean Length	Standard Deviation	Mean Weight
1	135	5.9	24.8
2	190	8.3	68.1
3	226	10.0	115.2
4	250	11.3	156.5
5	266	12.3	189.2
6	277	13.1	213.7
7	285	13.1	231.3
8	290	14.0	243.3
9	293	14.3	252.1
10		14.5	257.8

Table 2.7.1 Age composition data for North Sea haddock in 1992.

Age	Number
0	262465
1	161360
2	180046
3	22646
4	4642
5	832
6	2415
7	316
8	217
9	206
10	121

Table 2.9.1 *Sebastes marinus.* Vital rates. Icelandic data.

Length/Weight relationship:

cond.	0.015
power	2.973

An idea about Von Bertalanffy parameters:
(Must be estimated)

L_∞:	55
K:	0.05
t_0:	-1.5

Natural mortality: 0.05

Table 2.10.1 Biological parameters for Canadian Redfish

Natural mortality: assumed about 0.1

Von Bertalanffys Parameter: $L_\infty = 38.9$
K = 0.13
t_0 = -0.35

These parameters were estimated in 1993 from commercial fleet.

Length weight relationship (males and females):

log W (g)= -1.9479 + 3.0604 log L (cm)

L50= 26 cm for females; unknown for males

Table 2.11.1 Landed catch (tonnes), commercial CPUE (tonnes/h), and relative biomass estimates (tonnes) from swept-volume trawl surveys for the Goose Island Gully stock of Pacific ocean perch from British Columbia, Canada.

Year	Catch	CPUE	Relative biomass
1959	1890		
1960	1679		
1961	1199	0.8430	
1962	1838	1.2070	
1963	3721	1.1247	
1964	3478	0.6974	
1965	7511	1.2178	63600
1966	20807`	1.0712	45500
1967	12120	0.7616	54200
1968	10258	0.6550	
1969	6914	0.6639	51800
1970	6481	0.6050	36800
1971	3461	0.4505	39100
1972	5660	0.7395	
1973	3756	0.5040	22300
1974	7291	0.6749	
1975	4329	0.6885	
1976	2442	0.7575	33100
1977	1694	0.5729	23000
1978	873	0.5850	
1979	959	0.6889	
1980	1367	0.9871	
1981	941	0.5972	
1982	628	0.4522	
1983	1454	2.0136	
1984	918	0.7453	24600
1985	743	1.0628	
1986	623	0.4977	
1987	1548	0.6290	
1988	990	0.5176	
1989	955	0.6053	
1990	1086	0.5887	
1991	725	0.4811	
1992	746	0.6036	
1993	744	0.6850	

Table 3.3.1 Parameter estimates from the Schaefer form of the Butterworth/Andrew observation error estimator for Gulf of Maine cod. Initial biomass was assumed to be 80% of carrying capacity and variances were estimated from 200 bootstraps.

Parameter	Estimate	S.E.	C.V.	Left	Right
R	0.217	0.386	1.779	0.000	1.223
K	166.883	221.490	1.327	39.661	725.788
-lnL	-19.070	4.449	-0.233	-28.101	-14.415
B_{t+1}	70.504	93.255	1.323	18.225	287.394
B_{t+1}/K	0.422	0.101	0.238	0.271	0.581
B_{t+1}/B_{msy}	0.845	0.201	0.238	0.543	1.163

Table 3.3.2 Parameter estimates from the Schaefer form of the Butterworth/Andrew observation error estimator for Pacific ocean perch. Initial biomass was assumed to be at carrying capacity and variances were estimated from 200 bootstraps.

Parameter	Estimate	S.E.	C.V.	Left	Right
R	0.019	0.055	2.841	0.000	0.091
K	346.967	1202111	3465	155.989	1365.800
-lnL	-24.211	4.352	-0.180	-33.987	-19.268
B_{t+1}	259.422	1202107	4634	122.903	1245.006
B_{t+1}/K	0.748	0.106	0.142	0.576	0.950
B_{t+1}/B_{msy}	1.495	0.213	0.142	1.152	1.900

Table 3.3.3 Parameter estimates from the Schaefer form of the Butterworth/Andrew observation error estimator for Icelandic redfish. Initial biomass was assumed to be at carrying capacity and variances were estimated from 50 bootstraps.

Parameter	Estimate	S.E.	C.V.	Left	Right
r	0.085	0.409	4.833	0.001	1.146
K	1157.662	515.945	0.446	246.194	1687.662
-lnL	-13.249	2.938	-0.222	-17.701	-8.123
B_{t+1}	163.769	85.864	0.524	23.278	294.320
B_{t+1}/K	0.141	0.028	0.200	0.088	0.184
B_{t+1}/B_{msy}	0.283	0.056	0.200	0.177	0.368

Table 3.6.1 Comparison of input data required for surplus production models, for the modified DeLury model, and for age-structured models. The data requirements are depicted along an assessment methods continuum from methods that required *LIMITED DATA* to those that require *EXTENSIVE DATA*. Items footnoted with[1] are always required. Other items may or may not be required depending on the specific variant of the model employed.

SURPLUS PRODUCTION MODELS	**MODIFIED DELURY MODEL**	**AGE-STRUCTURED MODELS**
←—— LIMITED DATA —————— EXTENSIVE DATA ——→		
Total catch (weight)[1]	Total catch (in number)[1,2]	Catch-at-age (in number)[1]
Index of abundance[1]	Indices of abundance[1,2]	Indices of abundance[1]
Natural mortality rate	Natural mortality rate[1,2]	Natural mortality rate[1]
	Partial recruitment[2]	Partial recruitment (some ages)
	Mean weight[2]	Mean weight-at-age
		Maturity ogive
		Objective function weights
	Objective function weights	

[1]Datum is required [2]Not age-specific

Table 3.6.2 Comparison of the management-related output from surplus production models, the modified DeLury model, and age-structured models.]The output state variables are depicted along an assessment methods continuum from methods that required *LIMITED DATA* to those that require *EXTENSIVE DATA*.

SURPLUS PRODUCTION MODELS	**MODIFIED DELURY MODEL**	**AGE-STRUCTURED MODELS**
←— LIMITED DATA ——	—— EXTENSIVE DATA —→	
Stock biomass	Population numbers[2]	Population numbers[1]
Catchability	Catchability[2]	Catchability[1]
Maximum sustainable yield (MSY)	Fishing mortality rates[2]	Fishing mortality rates[1]
Overfishing status	Population biomass[2]	Population biomass[1]
		Spawning stock biomass
	Stock projections[2]	Stock size projections

[1]Age-specific [2]Not age-specific

Table 3.6.3 Input data for the modified DeLury model - Gulf of Maine cod.

Using Spring Survey Indices
RECRUITS: 40-57 CM
FULLY-RECR: 58+

The survey provides indices of abundance for recruit and fully-recruited numbers at a point 0% into the calendar year.
The catch is taken a at point 50% into the calendar year.

Natural mortality is 0.2

CALENDAR YEAR	-- INDICES OF ABUNDANCE -- RECRUITS	FULLY-RECRUITED	TOTAL CATCH (millions)
1982	0.7860	1.9090	5.009000
1983	1.1680	1.3790	5.649000
1984	1.5820	1.0730	4.163000
1985	0.6180	1.6440	3.811000
1986	0.6570	0.5530	3.752000
1987	0.2920	0.4380	2.416000
1988	0.6770	0.6220	3.176000
1989	0.6300	0.5710	3.790000
1990	1.0060	0.5810	6.554000
1991	1.5170	0.6630	6.627000
1992	0.3100	1.8180	3.632000
1993	0.8680	0.8640	2.825000
1994	0.3170	0.5080	

MEAN WEIGHT (kg) AT THE TIME OF THE SURVEY

CALENDAR YEAR	RECRUITS	FULLY-RECRUITED
1982	1.059	4.401
1983	1.185	6.143
1984	1.137	3.479
1985	1.287	4.216
1986	1.324	4.288
1987	0.992	4.860
1988	1.050	4.209
1989	1.193	3.288
1990	1.210	3.637
1991	1.076	2.894
1992	0.986	4.400
1993	1.240	5.290
1994	1.135	4.607

Table 3.6.3 (continued). Input data for the modified DeLury model - Gulf of Maine cod.

Using Fall Survey Indices
RECRUITS: 37-54 CM
FULLY-RECR: 55+

The survey provides indices of abundance for recruit and fully-recruited numbers at a point 0% into the calendar year.
The catch is taken a at point 50% into the calendar year.

Natural mortality is 0.2

CALENDAR YEAR	-- INDICES OF ABUNDANCE -- RECRUITS	FULLY-RECRUITED	TOTAL CATCH (millions)
1982	0.3340	1.4340	5.168000
1983	4.1180	3.0200	5.649000
1984	1.1670	1.3100	4.168000
1985	0.5050	1.4570	3.811000
1986	0.9160	1.2230	3.759000
1987	0.5120	0.9870	2.416000
1988	1.3250	0.5710	3.176000
1989	1.9980	1.0950	3.790000
1990	2.2380	0.8500	6.580000
1991	1.5390	1.1680	6.661000
1992	0.3170	0.7640	3.632000
1993	0.5830	0.4330	2.825000
1994	0.4410	0.2650	

MEAN WEIGHT (kg) AT THE TIME OF THE SURVEY

CALENDAR YEAR	RECRUITS	FULLY-RECRUITED
1982	0.925	4.485
1983	1.129	2.776
1984	0.971	4.798
1985	0.961	5.100
1986	0.997	5.242
1987	0.982	3.859
1988	0.887	3.449
1989	0.884	3.207
1990	0.820	3.431
1991	0.923	3.837
1992	1.131	3.769
1993	0.971	3.864
1994	0.881	2.280

Table 3.6.4 Input data for the modified DeLury model - Icelandic cod.

RECRUITS: 35-49 CM
FULLY-RECR: 50+

The survey provides indices of abundance for recruit and fully-recruited numbers at a point 20% into the calendar year.
The catch is taken a at point 50% into the calendar year.

Natural mortality is 0.2

CALENDAR YEAR	-- INDICES OF ABUNDANCE -- RECRUITS	FULLY-RECRUITED	TOTAL CATCH (millions)
1985	67.0100	163.2400	100.726000
1986	62.0700	93.2100	121.920000
1987	87.5600	136.0200	138.349000
1988	156.2400	193.4400	133.377000
1989	62.8000	177.2500	117.080000
1990	23.8300	94.6000	110.193000
1991	31.8400	91.8000	101.148000
1992	46.6700	59.7500	93.126000
1993	55.5200	54.9200	94.724000
1994	17.1400	49.7900	

MEAN WEIGHT (kg) AT THE TIME OF THE SURVEY

CALENDAR YEAR	RECRUITS	FULLY-RECRUITED
1985	0.668	2.324
1986	0.552	2.775
1987	0.582	2.223
1988	0.626	2.014
1989	0.670	2.183
1990	0.578	2.631
1991	0.622	2.647
1992	0.552	2.597
1993	0.577	2.309
1994	0.639	2.405

Table 3.6.5 Input data for the modified DeLury model - Icelandic haddock.

RECRUITS: 36-45 CM
FULLY-RECR: 46+

The survey provides indices of abundance for recruit and fully-recruited numbers at a point 20% into the calendar year.
The catch is taken a at point 50% into the calendar year.

Natural mortality is 0.2

CALENDAR YEAR	-- INDICES OF ABUNDANCE -- RECRUITS	FULLY-RECRUITED	TOTAL CATCH (millions)
1985	517.0000	1561.0000	20.346000
1986	1248.0000	1084.0000	20.989000
1987	2758.0000	1498.0000	22.288000
1988	3510.0000	1723.0000	33.130000
1989	3160.0000	2356.0000	38.529000
1990	1989.0000	2731.0000	41.663000
1991	791.0000	1454.0000	29.064000
1992	2662.0000	1342.0000	26.026000
1993	3336.0000	1134.0000	31.686000
1994	4423.0000	1631.0000	

Indices of abundance are from the Icelandic survey. They are assumed to be proportional to stock numbers in mid-March.
The survey catches are classified into recruits and fully-recruited based on the definitons given at the beginning of this output.

MEAN WEIGHT (kg) AT THE TIME OF THE SURVEY

CALENDAR YEAR	RECRUITS	FULLY-RECRUITED
1985	0.765	2.054
1986	0.713	2.138
1987	0.673	1.781
1988	0.682	1.581
1989	0.748	1.495
1990	0.741	1.573
1991	0.712	1.795
1992	0.681	1.769
1993	0.668	1.527
1994	0.703	1.437

Table 3.6.6 Input data for the modified DeLury model - Sebastes marinus (Icelandic area).

RECRUITS: 34-36 CM
FULLY-RECR: 37+

The survey provides indices of abundance for recruit and fully-recruited numbers at a point 20% into the calendar year.
The catch is taken a at point 50% into the calendar year.

Natural mortality is 0.1

CALENDAR YEAR	-- INDICES OF ABUNDANCE -- RECRUITS	FULLY-RECRUITED	TOTAL CATCH (millions)
1985	35.9000	72.7000	68.300000
1986	43.5000	82.4000	67.300000
1987	42.3000	85.7000	65.100000
1988	32.8000	55.7000	81.300000
1989	29.7000	60.9000	50.800000
1990	20.5000	43.2000	60.100000
1991	21.3000	37.5000	52.900000
1992	17.5000	34.6000	59.700000
1993	16.6000	26.7000	49.800000
1994	18.1000	30.0000	

Indices of abundance are from the Icelandic survey. They are assumed to be proportional to stock numbers in mid-March.
The survey catches are classified into recruits and fully-recruited based on the definitons given at the beginning of this output.

MEAN WEIGHT (kg) AT THE TIME OF THE SURVEY

CALENDAR YEAR	RECRUITS	FULLY-RECRUITED
1985	0.587	0.905
1986	0.586	0.897
1987	0.586	0.914
1988	0.586	0.921
1989	0.586	0.922
1990	0.579	0.933
1991	0.585	0.907
1992	0.587	0.909
1993	0.584	0.895
1994	0.584	0.933

Table 3.6.7 Input data for the modified DeLury model - Canadian redfish.

RECRUITS: 23-25 CM
FULLY-RECR: 26+

The survey provides indices of abundance for recruit and fully-recruited numbers at a point 50% into the calendar year.
The catch is taken a at point 50% into the calendar year.

Natural mortality is 0.1

CALENDAR YEAR	-- INDICES OF ABUNDANCE -- RECRUITS	FULLY-RECRUITED	TOTAL CATCH (millions)
1990	41.9750	755.3980	151.168000
1991	17.8590	338.6190	139.284000
1992	35.9190	355.8090	170.260000
1993	47.7290	200.0090	111.855000
1994	5.0360	107.7440	

Indices of abundance are from the Canadian summer survey. They are swept area estimates assumed to be proportional to stock numbers at mid-yr. The survey catches are classified into recruits and fully-recruited based on the definitons given at the beginning of this output.

MEAN WEIGHT (kg) AT THE TIME OF THE SURVEY

CALENDAR YEAR	RECRUITS	FULLY-RECRUITED
1990	0.196	0.415
1991	0.191	0.428
1992	0.187	0.402
1993	0.188	0.387
1994	0.190	0.483

Table 3.7.1 Comparison of estimation performance by stock for methods tested in Section 3.

Stock / Method	Virgin biomass	Biomass 1994	Rel. depletion	"Fit"
SMAR				
DYNP	1,157,000	163,000	0.14	poor
APRO	920,000	147,000	0.16	good
AGEP	1,129,000	233,000	0.20	good
MDLU	na	75,000	na	good
GCOD				
DYNP	170,000	72,000	0.42	poor
AGEP	220,000	117,000	0.53	poor
MDLU	na	14,000	na	good
OFFI	na	6,000	na	
CRED				
REDF	900,000	100,000	0.11	poor ?
AGEP	1,000,000	196,000	0.20	moderate
MDLU	na	57,000	na	good
CPOP				
DYNP	347,000	259,000	0.75	poor
AGEP	320,000	256,000	0.80	poor
OFFI	na	30,000	na	

Table 4.2.1a ICELANDIC HADDOCK - Commercial catches

I. ALK age composition

Age / Year	1985	1986	1987	1988	1989	1990	1991	1992	1993
1	0	0	21	0	0	160	433	13	274
2	437	155	2277	136	65	401	2467	2723	214
3	1755	3736	7490	10309	2661	2756	1247	7367	11736
4	5005	3854	7538	15700	22997	8139	3938	4155	12590
5	6009	4925	2667	5539	9750	23904	6722	4278	3167
6	805	5710	2205	1245	3038	6590	13684	4005	1774
7	1545	515	1164	986	542	861	2971	5932	1520
8	2460	846	144	575	529	157	406	1319	2249
9	2198	883	189	57	157	73	44	142	392
10	159	371	218	82	59	38	12	14	26
11	68	34	89	88	37	19	4	12	3
Sum	20441	21029	24002	34717	39835	43098	31928	29960	33945

II. Kimura & Chikuni estimates

Age / Year	1985	1986	1987	1988	1989	1990	1991	1992	1993
1	0	0	233	9	0	296	1311	2429	380
2	390	110	3587	5439	5285	5109	3745	4218	8443
3	2518	3260	7092	12655	15521	15780	7954	9128	11426
4	4116	4471	6012	7844	9094	11047	7497	5299	6131
5	5159	5337	2550	4096	4605	5802	5032	3478	3634
6	2300	3523	1642	2028	2267	2482	3042	2244	1456
7	1753	1800	1165	979	1182	1123	1855	1355	1011
8	1885	1206	860	993	837	810	840	1070	729
9	138	23	35	12	3	15	207	101	85
10	2180	1299	825	661	1048	641	448	641	638
Sum	20438	21030	24001	34717	39840	43104	31931	29962	33933
SoPL	47975	46153	38838	51804	60150	64269	52136	45004	46740
SoPA	47975	46153	38838	51804	60150	64269	52136	45004	46739

III. Clark's estimates

Age / Year	1985	1986	1987	1988	1989	1990	1991	1992	1993
1	21	12	476	33	0	0	1203	2533	0
2	616	220	3162	5664	5968	6117	3481	4125	9435
3	2295	3175	7335	12447	14952	15015	8228	9168	10950
4	4325	4546	5993	7892	9220	11241	7440	5283	6143
5	5133	5337	2555	4104	4564	5751	5114	3503	3661
6	2258	3512	1642	1999	2245	2481	3028	2216	1380
7	1916	1892	1248	1052	1207	1158	1955	1444	1095
8	1537	1025	700	839	733	698	738	889	535
9	781	348	323	261	190	198	378	376	338
10	1557	964	568	426	761	445	367	426	408
Sum	20438	21030	24001	34717	39840	43104	31931	29962	33943
SoPL	47975	46153	38838	51804	60150	64269	52136	45004	46740
SoPA	47060	45615	38565	51330	9152	63750	52566	44717	46091

Table 4.2.1b ICELANDIC HADDOCK - Spring survey

I. ALK age composition

Age / Year	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
1	1732	3487	751	609	1314	2551	3692	844	764	1528
2	1039	5242	5668	1202	602	1054	5175	8053	1123	1543
3	603	1313	4481	4988	1240	1055	900	4768	8749	1635
4	490	242	1087	2251	3999	1216	438	1112	2370	5201
5	537	775	262	516	1061	2226	447	421	299	1102
6	54	701	211	42	250	863	717	315	81	176
7	227	20	126	59	17	85	178	331	35	73
8	148	223	13	48	15	27	6	43	92	34
9	143	62	23	4	8	4	0	6	22	90
Sum	4973	12065	12622	9719	8506	9081	11553	15893	13535	11382

II. Kimura & Chikuni estimates

Age / Year	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
1	1888	4998	5875	1391	1662	3418	8505	9659	2707	4078
2	1064	4794	4102	5063	2527	1695	1173	3705	8555	4640
3	617	1231	1538	2262	3070	2110	694	1569	1634	2020
4	514	282	540	567	763	1157	546	400	366	373
5	354	291	179	213	271	459	328	233	118	153
6	143	184	127	99	109	130	153	132	47	35
7	116	80	89	38	48	50	69	76	33	31
8	118	62	60	43	31	26	27	48	21	14
9	7	1	2	1	0	0	7	4	2	0
10	86	58	44	29	22	13	16	19	15	12
Sum 1-9	4822	11922	12510	9677	8480	9045	11501	15826	13482	11343
SoPL	4102	5002	6532	6588	6674	6575	4631	7003	7013	6865
SoPA	4097	4994	6527	6586	6674	6573	4628	7000	7010	6864

III. Clark's estimates

Age / Year	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
1	1359	6705	5716	2052	918	1483	4753	7296	4548	2361
2	658	1667	3744	4968	2824	2237	1655	4557	7221	5239
3	796	1046	1104	1360	3142	2124	1271	1170	297	2300
4	709	555	745	615	523	1497	1143	819	745	501
5	440	626	328	249	459	693	815	583	138	342
6	270	454	300	184	195	287	542	397	178	156
7	229	257	207	64	135	239	373	322	111	137
8	232	326	212	116	135	201	403	300	123	140
9	34	0	0	0	0	0	0	0	0	0
10	243	432	264	115	176	315	601	442	170	195
Sum 1-9	4727	11636	12355	9607	8329	8761	10954	15444	13361	11176
SoPL	4102	5002	6532	6588	6674	6575	4631	7003	7013	6865
SoPA	6973	10939	10003	7981	9120	11222	13540	13283	9236	9799

Table 4.2.2 TUNA : Clean simulated data - Catches at age

I. Reference age composition

Age / Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	1601	1938	11171	2957	2405	3429	2754	4708	12319	3620	4438	3871	4479	4397	5702
2	3770	4497	5253	29457	7621	6078	8521	6740	11362	29345	8519	10327	8910	10203	9914
3	5530	6269	7033	7931	43153	10868	8459	11592	8976	14826	37555	10700	12736	10796	12150
4	4406	4953	5442	5943	6471	34111	8343	6316	8432	6366	10262	25386	7067	8223	6817
5	3456	3880	4157	4386	4623	4874	24931	5928	4368	5683	4184	6583	15899	4324	4916
6	2678	3043	3256	3349	3410	3480	3560	17705	4098	2943	3733	2683	4120	9722	2583
7	1987	2358	2554	2624	2604	2567	2543	2528	12239	2760	1933	2393	1679	2519	5809
8	1469	1750	1979	2058	2040	1961	1875	1806	1748	8244	1813	1239	1498	1027	1505
9	1123	1293	1468	1595	1600	1536	1432	1332	1248	1177	5416	1162	776	916	613
10	778	989	1085	1183	1240	1205	1122	1017	921	841	773	3472	728	474	547
Sum	26798	30970	43398	61483	75167	70109	63540	59672	65711	75805	78626	67816	57892	52601	50556

II. Kimura & Chikuni estimates

Age / Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	1602	1937	11171	2958	2405	3429	2755	4708	12318	3620	4438	3870	4479	4397	5702
2	3757	4442	5344	29818	7722	6139	8657	6855	11539	29794	8669	10468	9077	10381	10101
3	5548	6266	6779	7637	43212	12038	8506	11732	9123	14598	38067	11686	12859	11031	12318
4	4122	5023	5805	6081	6742	32080	10368	6460	8346	6553	9386	23772	8183	8003	6812
5	2238	1578	1839	2517	3086	5844	20444	9129	5337	5841	5724	8094	13941	6322	5060
6	3965	6140	5344	4651	4315	3109	6333	11053	7123	5330	4043	3089	5035	6431	4327
7	4915	5268	6474	6103	4962	3938	3121	5981	5974	3261	1933	1454	1836	3562	2958
8	534	296	592	1251	1342	1406	697	1046	1470	868	536	421	366	677	739
9	32	9	26	145	262	466	274	273	442	371	303	311	166	198	256
10	44	6	21	324	1119	1658	2385	2436	4034	5567	5522	4641	1948	1596	2284
Sum	26756	30964	43395	61484	75166	70106	63537	59671	65705	75802	78622	67805	57889	52596	50556
SoPL	416959	482378	555399	738498	1010910	1062046	1019645	951823	903708	977709	1077838	995116	838677	748094	683308
SoPA	415783	482192	555400	738521	1010954	1062116	1019705	951843	903663	977610	1077644	994842	838658	748067	683276

III. Clark's estimates

Age / Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	1471	1916	11557	2811	2447	3499	2803	4856	12740	3542	4585	3960	4604	4501	5865
2	4076	4553	5411	31129	8038	6318	8999	7102	11921	31082	9042	10890	9422	10778	10472
3	5804	6270	6632	7378	43018	12333	8453	11619	8970	14300	37712	11788	12733	10905	12181
4	4006	4919	5534	5597	6711	31998	10427	6675	8378	6712	10084	24218	8378	8210	6903
5	1930	1970	2597	3442	3119	4386	19640	7994	4440	4487	3603	5672	12903	5138	4368
6	2987	3840	2684	1309	5702	7057	8423	13564	10247	8196	7637	6679	7028	9263	6186
7	6482	7496	8980	9820	0	0	761	3652	0	0	0	0	0	0	0
8	0	0	0	0	6132	0	0	0	4502	0	0	0	0	1917	1738
9	0	0	0	0	0	4431	4030	4208	4502	6231	0	0	2817	1882	2841
10	0	0	0	0	0	86	2	3	4	1253	5959	4598	3	3	3
Sum	26756	30964	43395	61484	75166	70106	63537	59672	65705	75802	78622	67805	57889	52596	50556
SoPL	416959	482378	555399	738498	1010910	1062046	1019645	951823	903708	977709	1077838	995116	838677	748094	683308
SoPA	412750	482880	549797	721805	1006779	1056557	1012303	944173	888239	956244	1068337	982168	829617	738786	673468

Table 4.2.3 CLEAN TUNA Kimura & Chikuni : VPA results.

Terminal Fs derived using XSA (Without F shrinkage)

Fishing mortalities (F) at age

YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
AGE															
1	0.026	0.021	0.042	0.029	0.035	0.045	0.041	0.046	0.060	0.049	0.062	0.066	0.071	0.075	0.079
2	0.079	0.093	0.076	0.150	0.097	0.117	0.152	0.136	0.152	0.200	0.159	0.203	0.217	0.232	0.246
3	0.150	0.183	0.201	0.147	0.338	0.217	0.236	0.316	0.270	0.293	0.423	0.332	0.411	0.447	0.476
4	0.142	0.197	0.257	0.280	0.188	0.455	0.294	0.284	0.390	0.318	0.311	0.514	0.411	0.488	0.554
5	0.102	0.074	0.103	0.169	0.224	0.247	0.594	0.458	0.402	0.524	0.509	0.486	0.656	0.654	0.665
6	0.399	0.443	0.382	0.407	0.486	0.369	0.462	0.767	0.805	0.927	0.873	0.575	0.644	0.738	1.478
7	2.410	1.593	1.264	1.045	1.060	1.196	0.791	1.133	1.432	1.175	1.128	0.947	0.830	1.520	0.951
8	2.652	1.367	0.773	0.915	0.683	1.057	0.691	0.680	0.999	0.833	0.597	0.811	0.663	0.872	2.350
9	0.267	0.321	0.375	0.429	0.483	0.537	0.591	0.645	0.699	0.754	0.808	0.863	0.918	0.973	1.028
+gp	0.267	0.321	0.375	0.429	0.483	0.537	0.591	0.645	0.699	0.754	0.808	0.863	0.918	0.973	1.028
FBAR 3- 7	0.641	0.498	0.441	0.410	0.459	0.497	0.475	0.591	0.660	0.647	0.649	0.571	0.590	0.769	0.825

Stock numbers at age (start of year) Numbers*10**-3

YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
AGE															
1	69067	101296	300731	115578	77604	86851	75845	115511	235765	83837	81968	66982	72587	67386	82943
2	54818	55098	81181	236110	91951	61361	68005	59603	90312	181882	65364	63094	51338	55376	51193
3	43986	41481	41091	61630	166330	68296	44683	47845	42596	63500	121954	45672	42186	33820	35945
4	34457	30993	28293	27509	43549	97079	45024	28887	28557	26620	38781	65403	26818	22904	17708
5	25635	24482	20830	17912	17020	29554	50454	27481	17806	15829	15865	23259	32037	14553	11511
6	13307	18964	18616	15390	12388	11142	18909	22810	14240	9749	7675	7810	11719	13615	6195
7	5969	7307	9971	10406	8392	6238	6309	9751	8674	5214	3159	2625	3599	5039	5329
8	634	439	1216	2305	2997	2381	1544	2342	2572	1697	1318	837	834	1285	903
9	150	37	92	460	756	1240	678	634	971	775	604	594	305	352	440
+gp	206	24	75	1019	3199	4367	5841	5593	8745	11458	10845	8732	3525	2787	3859
TOTAL N	248230	280121	502096	488319	424185	368509	317292	320458	450238	400561	347534	285008	244948	217117	216025
TOTALBIO	2554603	2678566	3331129	4128483	4446569	4145777	3637780	3200818	3359125	3663032	3590244	3128109	2535317	2125254	1887306
TOTSPBI	1835084	1897774	1943388	2461934	2945510	3039070	2806380	2340690	2089938	2300503	2413130	2271006	1852112	1489645	1236473

Table 4.4.1 Gulf of Maine cod. Summary Slice and SP-Key statistics. Iteration 6 was chosen as the SP-Key estimates. C-SSR is the sum square residual between the estimated catch at age at each iteration and the catch at age from age-length keys. RV-SSR is for numbers at age from the RV series. NLLS-MSR is the mean square residual from the NLLS used to tune the SPA.

Iteration	C-SSR	RV-SSR	NLLS-MSR
Slice	525476	18443511	67.42
2	538113	17711706	38.43
3	539951	17680611	38.03
4	539866	17684176	37.70
5	539500	17683127	37.59
6	539430	17683762	37.56

Table 4.4.2 Icelandic Haddock Summary Slice and SP-Key statistics. Iteration 10 was chosen as the SP-Key estimates. C-SSR is the sum square residual between the estimated catch at age at each iteration and the catch at age from age-length keys. RV-SSR is for numbers at age from the RV series. NLLS-MSR is the mean square residual from the NLLS used to tune the SPA.

Iteration	C-SSR	RV-SSR	NLLS-MSR
Slice	68066	22901671	9.77
2	41569	10566929	7.81
3	36298	9168084	7.15
4	34292	8770564	6.96
5	33942	8698756	6.93
6	34356	8766746	6.90
7	35015	8882342	6.88
8	35628	8991965	6.85
9	36130	9081212	6.85
10	36505	9147602	6.84

Table 4.5.1

Icelandic

Stock Numbers:

Length intervals	*1985*	*1986*	*1987*	*1988*	*1989*	*1990*	*1991*	*1992*
39-44	0.95	2.45	3.02	4.13	3.78	2.35	1.81	2.10
45-50	1.88	1.83	2.76	3.60	3.80	2.83	1.87	1.86
51-56	1.73	1.27	1.67	2.14	2.67	2.57	1.61	1.19
57-62	1.67	1.34	1.00	1.25	1.50	1.70	1.33	0.87
63-68	0.74	0.89	0.63	0.61	0.67	0.82	0.83	0.58
69-74	0.54	0.40	0.34	0.31	0.29	0.31	0.36	0.32
75-80	0.36	0.21	0.14	0.14	0.13	0.11	0.12	0.12
81-86	0.08	0.07	0.04	0.04	0.03	0.03	0.02	0.02

Fishing Mortality:

Length intervals	*1985*	*1986*	*1987*	*1988*	*1989*	*1990*	*1991*	*1992*
39-44	0.088	0.077	0.108	0.162	0.205	0.297	0.223	0.252
45-50	0.114	0.158	0.239	0.312	0.359	0.498	0.452	0.478
51-56	0.255	0.423	0.449	0.526	0.495	0.612	0.651	0.704
57-62	0.420	0.579	0.505	0.615	0.594	0.635	0.716	0.802
63-68	0.817	0.861	0.586	0.672	0.793	0.738	0.805	0.915
69-74	0.841	0.888	0.628	0.670	0.818	0.775	0.834	0.935
75-80	0.876	0.864	0.643	0.651	0.829	0.821	0.811	0.936
81-86	0.864	0.842	0.632	0.647	0.816	0.803	0.778	0.935
Ave(39-50)	0.101	0.118	0.174	0.237	0.282	0.398	0.338	0.365
Ave(50-62)	0.338	0.501	0.477	0.571	0.545	0.624	0.684	0.753
Ave(63-86)	0.850	0.864	0.622	0.660	0.814	0.784	0.807	0.930

Table 4.5.2

Gulf of Maine

Stock Numbers:

mean length	*1982*	*1983*	*1984*	*1985*	*1986*	*1987*	*1988*	*1989*
44	4.94	4.37	3.27	3.94	2.71	3.19	3.52	5.39
53	3.84	4.06	3.19	3.22	3	2.66	3.15	4.24
62	1.86	2.42	2.2	1.83	2.13	1.63	1.93	2.1
71	1.21	1.14	1.21	1.11	0.98	1.04	1.02	1.17
80	0.81	0.55	0.52	0.55	0.44	0.5	0.48	0.59
89	0.34	0.32	0.22	0.25	0.21	0.2	0.22	0.26
98	0.19	0.16	0.12	0.1	0.09	0.07	0.08	0.1
107	0.13	0.08	0.06	0.04	0.03	0.02	0.02	0.03
116	0.07	0.05	0.03	0.02	0.01	0.01	0	0.01

Fishing Mortality:

mean length	**1982**	**1983**	**1984**	**1985**	**1986**	**1987**	**1988**	**1989**
44	0.26	0.339	0.281	0.158	0.249	0.133	0.135	0.075
53	0.619	0.668	0.556	0.576	0.576	0.381	0.494	0.43
62	0.709	0.798	0.786	0.846	0.766	0.658	0.619	0.684
71	0.808	1.031	0.825	0.92	0.817	0.75	0.521	0.74
80	0.794	0.921	0.733	0.928	0.762	0.781	0.687	0.72
89	0.74	0.859	0.808	0.941	0.923	0.812	0.737	0.61
98	0.75	0.877	0.831	0.952	0.995	0.854	0.607	0.655
107	0.763	0.867	0.831	0.882	0.918	0.895	0.683	0.652
116	0.768	0.877	0.837	0.924	0.946	0.892	0.523	0.704
Ave(53-62)	0.664	0.733	0.671	0.711	0.671	0.520	0.557	0.557
Ave(71-116)	0.771	0.905	0.811	0.925	0.894	0.831	0.626	0.680

Table 4.6.1 Canadian Unit 1 Redfish commercial catch (C) and surveyed (S) catch-at-length standardised to (approximately) 1000 individuals per year.

Length	C1981	C1982	C1983	C1984	C1985	C1986	C1987	C1988	C1989	C1990	C1991	C1992	C1993	S1990	S1991	S1992	S1993	S1994
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	4	1	2	1	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	137	2	2	1	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	349	19	5	4	1
10	0	0	0	0	0	0	0	0	0	0	0	0	0	78	95	5	3	4
11	0	0	0	0	0	0	0	0	0	0	0	0	0	2	238	21	2	7
12	0	0	0	0	0	0	0	0	0	0	0	0	0	2	262	76	4	19
13	0	0	0	1	0	0	0	0	0	0	0	0	0	3	94	145	9	27
14	0	0	0	0	0	0	0	0	0	0	0	0	0	5	11	149	15	29
15	0	0	0	0	0	0	0	0	0	0	0	0	1	10	12	64	32	39
16	0	0	0	0	1	0	0	0	0	0	0	1	13	14	11	5	60	50
17	0	0	0	1	1	1	2	0	0	0	1	1	5	20	13	5	49	51
18	0	0	0	1	1	2	4	1	0	0	0	1	4	15	11	7	18	38
19	0	0	0	1	1	2	8	1	0	0	0	2	3	5	7	5	9	20
20	1	0	0	4	2	5	14	2	0	0	0	2	2	2	4	4	6	10
21	3	1	1	6	6	10	23	4	1	0	1	2	4	2	3	5	9	4
22	3	1	2	5	6	10	40	14	4	1	1	2	2	2	2	7	16	6
23	4	4	5	5	13	15	52	37	13	3	2	3	4	3	2	13	35	7
24	17	7	10	6	23	28	60	83	45	10	7	5	4	5	3	16	58	10
25	51	19	14	11	27	41	43	124	99	36	16	11	8	11	5	16	54	13
26	107	35	24	19	27	57	36	117	141	103	48	36	23	24	8	23	57	26
27	180	92	44	32	30	66	35	69	147	163	109	85	59	42	17	42	72	39
28	186	162	93	53	45	66	38	37	98	167	158	133	130	59	27	66	72	33
29	132	188	153	82	62	63	41	31	58	121	150	151	166	53	34	70	71	60
30	80	155	167	131	99	84	49	37	49	73	116	125	149	34	29	63	87	83
31	43	100	150	135	114	97	63	51	48	55	79	87	103	20	21	44	85	70
32	37	60	107	121	125	100	81	59	53	52	62	63	65	13	13	39	53	71
33	34	42	64	96	111	93	83	71	56	45	53	55	46	10	10	22	35	54
34	26	31	41	72	87	74	85	69	52	47	52	52	43	11	7	19	25	47
35	16	25	32	53	59	53	68	57	40	37	43	44	38	12	7	16	17	38
36	20	21	25	44	43	38	50	40	30	28	29	38	30	14	7	10	13	36
37	15	20	23	35	34	27	37	30	22	20	23	30	29	10	5	12	9	31
38	13	10	16	30	30	23	30	22	15	14	17	23	22	9	5	6	8	27
39	11	7	10	24	18	18	21	16	11	11	12	18	18	8	3	6	5	20
40	11	5	7	16	14	10	15	11	7	7	8	11	12	4	3	4	3	12
41	9	4	4	7	8	7	9	7	6	3	5	8	7	5	2	2	1	6
42	2	2	2	5	6	4	7	4	3	2	3	6	5	2	1	1	1	4
43	0	1	1	2	4	2	3	3	2	1	2	3	3	1	1	1	1	5
44	0	1	1	1	3	2	2	2	1	1	1	2	1	1	0	0	1	2
45	0	1	0	1	1	1	1	1	0	0	1	1	1	0	0	0	0	0
46	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
47	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
48	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
49	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
50	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sum	1001	999	1000	1000	1001	1000	1000	1000	1001	1000	999	1001	1000	1001	995	998	1001	1000

Table 4.6.4.1. Symbols and their corresponding definitions

Symbol	Definition
L_∞	von Bertalanffy's L_∞ (cm)
σ_L	SD in L_∞ (cm)
K	von Bertalanffy's K (y^{-1})
σ_L	SD in K (y^{-1})
a	intercept of natural mortality function (y^{-1})
b	instantaneous coefficient of natural mortality function (l^{-1})
μ_C	mean of commercial Gaussian selectivity (cm)
σ_C	SD of commercial Gaussian selectivity (cm)
F	instantaneous fishing mortality (y^{-1})
μ_S	mean of survey Gaussian selectivity (cm)
σ_S	SD of survey Gaussian selectivity (cm)
r	coefficient of recruitment variance over length (l^{-1})
V(l)	recruitment variance-at-length
M(l)	natural mortality-at-length (y^{-1})
ω	ratio scaling parameter for commercial to survey selectivity

Table 5.4.1 Time series estimates of hidden mortality.

North Sea Haddock:

Age	*1982*	*1983*	*1984*	*1985*	*1986*	*1987*	*1988*	*1989*	*1990*	*1991*	*1992*	*1993*
1	0.000	0.095	0.190	0.285	0.380	0.475	0.501	0.527	0.552	0.578	0.603	0.629
2	0.000	0.095	0.190	0.285	0.380	0.475	0.475	0.474	0.474	0.473	0.472	0.472
3	0.000	0.095	0.190	0.285	0.380	0.475	0.449	0.422	0.395	0.368	0.341	0.315
4	0.000	0.095	0.190	0.285	0.380	0.475	0.422	0.369	0.316	0.263	0.210	0.157
5	0.000	0.095	0.190	0.285	0.380	0.475	0.396	0.317	0.238	0.158	0.079	0.000
6	0.000	0.095	0.190	0.285	0.380	0.475	0.370	0.264	0.159	0.054	0.052	0.157
7	0.000	0.095	0.190	0.285	0.380	0.475	0.370	0.264	0.159	0.054	0.052	0.157
8	0.000	0.095	0.190	0.285	0.380	0.475	0.370	0.264	0.159	0.054	0.052	0.157

4T Southern Gulf Cod:

Age	*1982*	*1983*	*1984*	*1985*	*1986*	*1987*	*1988*	*1989*	*1990*	*1991*	*1992*
4	0.000	0.000	0.000	0.000	0.000	0.126	0.251	0.377	0.503	0.629	0.754
5	0.000	0.000	0.000	0.000	0.000	0.115	0.229	0.344	0.458	0.573	0.688
6	0.000	0.000	0.000	0.000	0.000	0.103	0.207	0.310	0.414	0.517	0.621
7	0.000	0.000	0.000	0.000	0.000	0.092	0.185	0.277	0.369	0.462	0.554
8	0.000	0.000	0.000	0.000	0.000	0.081	0.163	0.244	0.325	0.406	0.488
9	0.000	0.000	0.000	0.000	0.000	0.070	0.140	0.210	0.281	0.351	0.421
10	0.000	0.000	0.000	0.000	0.000	0.070	0.140	0.210	0.281	0.351	0.421
11	0.000	0.000	0.000	0.000	0.000	0.070	0.140	0.210	0.281	0.351	0.421

Table 6.8.1 Summary of regressions between assessment-based biomass estimates and survey indices.

A. Georges Bank Yellowtail Flounder, excluding 1993 data

DEP VAR: Y_BIO N: 20 MULTIPLE R: 0.888 SQUARED MULTIPLE R: 0.789
ADJUSTED SQUARED MULTIPLE R: .778 STANDARD ERROR OF ESTIMATE: 0.344

VARIABLE	COEFFICIENT	STD ERROR	STD COEF	TOLERANCE	T	P(2 TAIL)
CONSTANT	1.769	0.082	0.000	.	21.647	0.000
X_SURVEY	0.703	0.086	0.888	1.000	8.211	0.000

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
REGRESSION	7.998	1	7.998	67.416	0.000
RESIDUAL	2.135	18	0.119		

B. Georges Bank Cod

DEP VAR: Y_BIO N: 15 MULTIPLE R: 0.687 SQUARED MULTIPLE R: 0.472
ADJUSTED SQUARED MULTIPLE R: .431 STANDARD ERROR OF ESTIMATE: 0.154

VARIABLE	COEFFICIENT	STD ERROR	STD COEF	TOLERANCE	T	P(2 TAIL)
CONSTANT	3.911	0.110	0.000	.	35.407	0.000
X_SURVEY	0.188	0.055	0.687	1.000	3.409	0.005

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
REGRESSION	0.275	1	0.275	11.623	0.005
RESIDUAL	0.308	13	0.024		

C. 4T-Vn Southern Gulf Cod, excluding 1993 data

DEP VAR: Y_BIO N: 22 MULTIPLE R: 0.874 SQUARED MULTIPLE R: 0.764
ADJUSTED SQUARED MULTIPLE R: .752 STANDARD ERROR OF ESTIMATE: 0.230

VARIABLE	COEFFICIENT	STD ERROR	STD COEF	TOLERANCE	T	P(2 TAIL)
CONSTANT	3.468	0.194	0.000	.	17.895	0.000
X_SURVEY	0.407	0.051	0.874	1.000	8.049	0.000

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
REGRESSION	3.427	1	3.427	64.791	0.000
RESIDUAL	1.058	20	0.053		

D. Gulf of Maine Cod, Delury Biomass estimates vs Spring Survey wt/tow

DEP VAR: Y_BIO N: 11 MULTIPLE R: 0.884 SQUARED MULTIPLE R: 0.782
ADJUSTED SQUARED MULTIPLE R: .758 STANDARD ERROR OF ESTIMATE: 0.210

VARIABLE	COEFFICIENT	STD ERROR	STD COEF	TOLERANCE	T	P(2 TAIL)
CONSTANT	9.079	0.203	0.000	.	44.663	0.000
X_SURVEY	0.704	0.124	0.884	1.000	5.685	0.000

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
REGRESSION	1.428	1	1.428	32.325	0.000
RESIDUAL	0.398	9	0.044		

Table 7.1.1

	MDLU	DYNP	AGEP	TSCA	TSCL	RELF	APRO	OFFI	RCCP	SLIC	SPKE	LACO
GCOD												
Recruitment												
1980												
1981												
1982	3.500			10739	4.940			4328	1.008	94403	113271	
1983	8.775			5673	4.370			6208	0.7058	84371	113998	
1984	6.991			4219	3.270			3325	0.7302	72446	69848	
1985	2.867			6107	3.940			3306	0.4818	77823	97975	
1986	4.046			3959	2.710			4821	0.4421	102715	141304	
1987	2.204			5958	3.190			3216	0.6369	138710	151790	
1988	5.221			7882	3.520			4766	0.9734	154297	192764	
1989	5.504			15073	5.390			8516	1.5257	89195	108945	
1990	8.749			2820	5.380			14075	0.2335	53931	49956	
1991	10.411			2479	3.890			2101	0.1327	50821	48458	
1992	1.773			4488	3.090			1674	0.2943	41666	65298	
1993	3.692			3426	3.300			2725	0.4034	45912	30854	
1994	2.014							3169	0.2694			
Fishing mortality												
1980												
1981												
1982	0.51			0.57	0.77	39.87		0.60	0.51	0.55	0.42	
1983	0.75			0.82	0.91	25.10		0.89	0.84	0.62	0.49	
1984	0.55			0.72	0.81	15.01		0.93	0.83	0.49	0.39	
1985	0.63			0.79	0.92	23.37		1.13	1.31	0.55	0.38	
1986	0.79			0.81	0.89	26.67		1.07	1.22	0.45	0.32	
1987	0.64			0.76	0.83	78.11		1.13	0.82	0.41	0.27	
1988	0.79			0.73	0.63	58.61		0.93	0.66	0.38	0.29	
1989	0.87			0.73	0.68	36.90		0.93	0.88	0.51	0.36	
1990	1.25			0.71	0.67	57.33		0.89	0.88	0.43	0.40	
1991	0.98			0.79	1.01	38.57		0.96	0.66	0.65	0.50	
1992	0.84			0.83	0.79	70.08		1.13	0.87	0.50	0.35	
1993	1.07			0.86	0.63	21.91		1.15	0.76	0.48	0.37	
1994									0.76			
Expl. biomass												
1980		109.00	191199									
1981		103.68	182627									
1982	52.36	99.67	171512	15110	19737			17442		227929	301423	
1983	42.95	94.80	159447	21845	21495			13060		229513	298117	
1984	35.89	89.70	147574	13752	16263			10601		211901	285276	
1985	38.19	87.90	137829	12795	16525			8524		214574	304089	
1986	26.33	86.23	129538	12053	14313			7637		203728	296716	
1987	19.16	85.61	125545	10578	11283			7727		197475	284606	
1988	14.46	87.13	126544	11368	10927			8573		220328	302881	
1989	15.65	88.21	128061	14354	13840			11785		254606	351545	
1990	19.38	86.84	127979	18042	16526			17322		310257	393748	
1991	21.24	80.72	124783	21262	26144			18022		318832	429465	
1992	28.82	71.98	122789	15095	16264			9094		245804	361875	
1993	19.70	69.97	125654	12089	12110			6026		204691	289384	
1994	14.29	70.50										
Spawning stock biomass												
1980												
1981												
1982								26508	4.2115	269324	380939	
1983								21497	4.6009	268929	375824	
1984								16577	4.122	246891	359880	
1985								14848	3.6199	245750	373488	
1986								14131	2.7797	233195	356022	
1987								14057	2.2845	231719	362561	
1988								17509	2.7657	263754	396220	
1989								24793	3.9299	308180	449394	
1990								30139	4.5282	359554	496637	
1991								23819	4.1105	350944	504750	
1992								14565	2.9061	268994	413607	
1993								10722	1.8943	227173	350624	
1994									1.4134			

Table 7.1.2

ICOD												
Recruitment												
	MDLU	DYNP	AGEP	TSCA	TSCL	RELF	APRO	OFFI	RCCP	SLIC	SPKE	LACO
1980								144.03				
1981								143.26				
1982								133.58				
1983								226.27				
1984								138.87				
1985	148.93							144.07	7091			
1986	162.20							336.79	5257			
1987	230.79							281.95	16019			
1988	319.86							168.81	18401			
1989	133.93							80.86	7385			
1990	56.22							131.18	2607			
1991	74.31							109.80	4660			
1992	109.38							150.00	3085			
1993	125.55							155.00	5049			
1994	39.97							60.00	2930			
Fishing mortality												
1980								0.45				
1981								0.68				
1982								0.78				
1983								0.78				
1984								0.62				
1985	0.33					8.92		0.66	1.14			
1986	0.32					12.13		0.78	0.69			
1987	0.36					14.39		0.83	0.72			
1988	0.40					10.61		0.97	0.94			
1989	0.39					9.36		0.68	0.73			
1990	0.41					12.59		0.72	0.30			
1991	0.56					11.50		0.78	0.93			
1992	0.64					17.66		0.78	0.75			
1993	0.70					21.24		0.82	0.77			
1994								0.77	0.86			
Expl. biomass												
1980								1548				
1981								1263				
1982								979				
1983								795				
1984								900				
1985	842							920	38780			
1986	889							853	22283			
1987	718							1035	20109			
1988	753							1063	19881			
1989	898							1032	21076			
1990	823							841	23870			
1991	563							706	28964			
1992	394							565	14422			
1993	321							570	10079			
1994	302							593	8812			
Spawning stock biomass												
1980								602				
1981								389				
1982								266				
1983								214				
1984								219				
1985								269				
1986								268				
1987								253				
1988								193				
1989								270				
1990								349				
1991								238				
1992								252				
1993								228				
1994												

Table 7.1.3

IHAD												
Recruitment												
	MDLU	DYNP	AGEP	TSCA	TSCL	RELF	APRO	OFFI	RCCP	SLIC	SPKE	LACO
1980								36.302				
1981								9.651				
1982								41.689				
1983								29.827				
1984								19.722				
1985	10.363				0.950			41.287	1475	108365	150061	
1986	28.174				2.450			88.008	3887	100723	219935	
1987	45.622				3.020			164.040	5141	80132	94500	
1988	60.116				4.130			46.399	1320	54308	70768	
1989	57.671				3.780			25.653	918	67071	94336	
1990	36.883				2.350			25.879	1004	161315	237700	
1991	16.896				1.810			113.092	3799	300829	471623	
1992	39.537				2.100			167.000	7285	97636	94181	
1993	53.986				2.610			40.000	1493	66123	16094	
1994	84.028							50.000	1543			
Fishing mortality												
1980								0.38				
1981								0.52				
1982								0.46				
1983								0.47				
1984								0.50				
1985	0.68				0.85	19.37		0.52	0.40	0.15	0.11	
1986	0.80				0.86	22.37		0.79	0.61	0.20	0.14	
1987	0.69				0.62	18.00		0.64	0.76	0.21	0.18	
1988	0.71				0.66	24.05		0.66	0.62	0.28	0.24	
1989	0.69				0.81	18.90		0.66	0.49	0.33	0.22	
1990	0.87				0.78	12.33		0.59	0.74	0.49	0.27	
1991	0.97				0.81	15.43		0.62	0.49	0.49	0.22	
1992	1.03				0.93	17.18		0.72	0.87	0.49	0.20	
1993	0.91				1.15	32.77		0.67	0.43	0.65	0.17	
1994									0.64			
Expl. biomass												
1980								293.147				
1981								260.351				
1982								230.005				
1983								194.578				
1984								155.470				
1985	77.127				11637			150.298		268260	453075	
1986	54.088				11399			137.648		197545	343752	
1987	55.579				8307			157.227		171142	245693	
1988	76.258				11227			239.356		175561	248000	
1989	93.358				13334			251.500		173316	290704	
1990	96.145				14694			209.603		152724	293270	
1991	71.786				12489			172.528		119012	268598	
1992	47.640				10951			184.021		98952	244770	
1993	55.190				11876			230.950		114709	306856	
1994	80.411							240.548				
Spawning stock biomass												
1980								114.721				
1981								122.146				
1982								132.039				
1983								119.435				
1984								91.632				
1985								106.363	5474			
1986								79.367	5628			
1987								59.432	7220			
1988								98.674	10014			
1989								144.799	10945			
1990								155.848	10046			
1991								126.050	7027			
1992								92.858	8502			
1993								115.787	11492			
1994								179.185	14456			

Table 7.1.4

CTUN												
Recruitment												
	MDLU	DYNP	AGEP	TSCA	TSCL	RELF	APRO	OFFI	RCCP	SLIC	SPKE	LACO
1980								0.714				0.614
1981								0.721				0.900
1982								3.568				2.671
1983								0.828				1.027
1984								0.599				0.689
1985								0.771				0.771
1986								0.564				0.673
1987								0.885				1.026
1988								2.141				2.095
1989								0.585				0.744
1990								0.671				0.728
1991								0.549				0.595
1992								0.599				0.645
1993								0.557				0.599
1994								0.685				0.736
Fishing mortality												
1980								0.40				1.13
1981								0.48				0.89
1982								0.56				0.78
1983								0.64				0.73
1984								0.72				0.82
1985								0.80				0.89
1986								0.88				0.83
1987								0.96				1.06
1988								1.04				1.17
1989								1.12				1.15
1990								1.20				1.15
1991								1.28				1.01
1992								1.36				1.05
1993								1.44				1.36
1994								1.52				1.45
Expl. biomass												
1980												
1981												
1982												
1983												
1984												
1985												
1986												
1987												
1988												
1989												
1990												
1991												
1992												
1993												
1994												
Spawning stock biomass												
1980												
1981												
1982												
1983												
1984												
1985												
1986												
1987												
1988												
1989												
1990												
1991												
1992												
1993												
1994												

Table 7.1.5

4HAD												
Recruitment												
	MDLU	DYNP	AGEP	TSCA	TSCL	RELF	APRO	OFFI	RCCP	SLIC	SPKE	LACO
1980												
1981												
1982									1.540			
1983									0.770			
1984									2.517			
1985									0.640			
1986									0.713			
1987									1.686			
1988									0.185			
1989									0.303			
1990									0.264			
1991									1.010			
1992									1.203			
1993									1.750			
1994									0.419			
Fishing mortality												
1980												
1981												
1982				0.76					1.34			
1983				0.93					0.91			
1984				0.73					0.85			
1985				0.65					0.83			
1986				0.69					0.99			
1987				0.71					0.95			
1988				0.79					0.89			
1989				0.73					0.76			
1990				0.87					1.03			
1991				0.81					1.18			
1992				0.71					0.77			
1993				0.85					0.98			
1994									0.97			
Expl. biomass												
1980												
1981												
1982												
1983												
1984												
1985												
1986												
1987												
1988												
1989												
1990												
1991												
1992												
1993												
1994												
Spawning stock biomass												
1980												
1981												
1982									4.494			
1983									1.035			
1984									0.847			
1985									1.169			
1986									1.003			
1987									0.537			
1988									0.788			
1989									0.546			
1990									0.273			
1991									0.229			
1992									0.431			
1993									0.753			
1994									0.896			

Table 7.1.6

4COD												
Recruitment												
	MDLU	DYNP	AGEP	TSCA	TSCL	RELF	APRO	OFFI	RCCP	SLIC	SPKE	LACO
1980												
1981												
1982				73944					118978			
1983				160444					140803			
1984				191426					83380			
1985				97785					74493			
1986				83352					61834			
1987				135500					48434			
1988				131461					33257			
1989				139760					30931			
1990				179293					30087			
1991				211269					20993			
1992				191627					13229			
1993												
1994												
Fishing mortality												
1980												
1981												
1982				0.38					0.72			
1983				0.40					0.67			
1984				0.48					0.10			
1985				0.46					0.47			
1986				0.42					0.74			
1987				0.32					0.35			
1988				0.34					0.62			
1989				0.43					0.96			
1990				0.53					1.07			
1991				0.62					1.28			
1992				0.79					0.85			
1993												
1994												
Expl. biomass												
1980												
1981												
1982									167649			
1983									136439			
1984									161884			
1985									241978			
1986									234778			
1987									189062			
1988									185417			
1989									148333			
1990									95570			
1991									63864			
1992									47149			
1993												
1994												
Spawning stock biomass												
1980												
1981												
1982												
1983												
1984												
1985												
1986												
1987												
1988												
1989												
1990												
1991												
1992												
1993												
1994												

Table 7.1.7

CRED												
Recruitment												
	MDLU	DYNP	AGEP	TSCA	TSCL	RELF	APRO	OFFI	RCCP	SLIC	SPKE	LACO
1980												
1981												
1982												
1983												
1984												
1985												
1986												
1987												
1988												
1989												
1990	43.604											
1991	18.869											
1992	37.876											
1993	49.437											
1994	5.287											
Fishing mortality												
1980												
1981												
1982												
1983												
1984												
1985												
1986												
1987												
1988												
1989												
1990	0.31					0.15						
1991	0.27					0.37						
1992	0.61					0.46						
1993	0.70					0.83						
1994												
Expl. biomass												
1980			304707				161.996					
1981			325739				186.982					
1982			339456				205.889					
1983			350099				220.068					
1984			359586				236.413					
1985			362327				252.401					
1986			358846				257.761					
1987			350539				261.244					
1988			334526				256.532					
1989			314967				241.821					
1990	284.055		290947				225.962					
1991	206.744		265361				198.912					
1992	142.038		231968				173.338					
1993	79.855		207679				126.615					
1994	57.130		196436				106.019					
Spawning stock biomass												
1980												
1981												
1982												
1983												
1984												
1985												
1986												
1987												
1988												
1989												
1990												
1991												
1992												
1993												
1994												

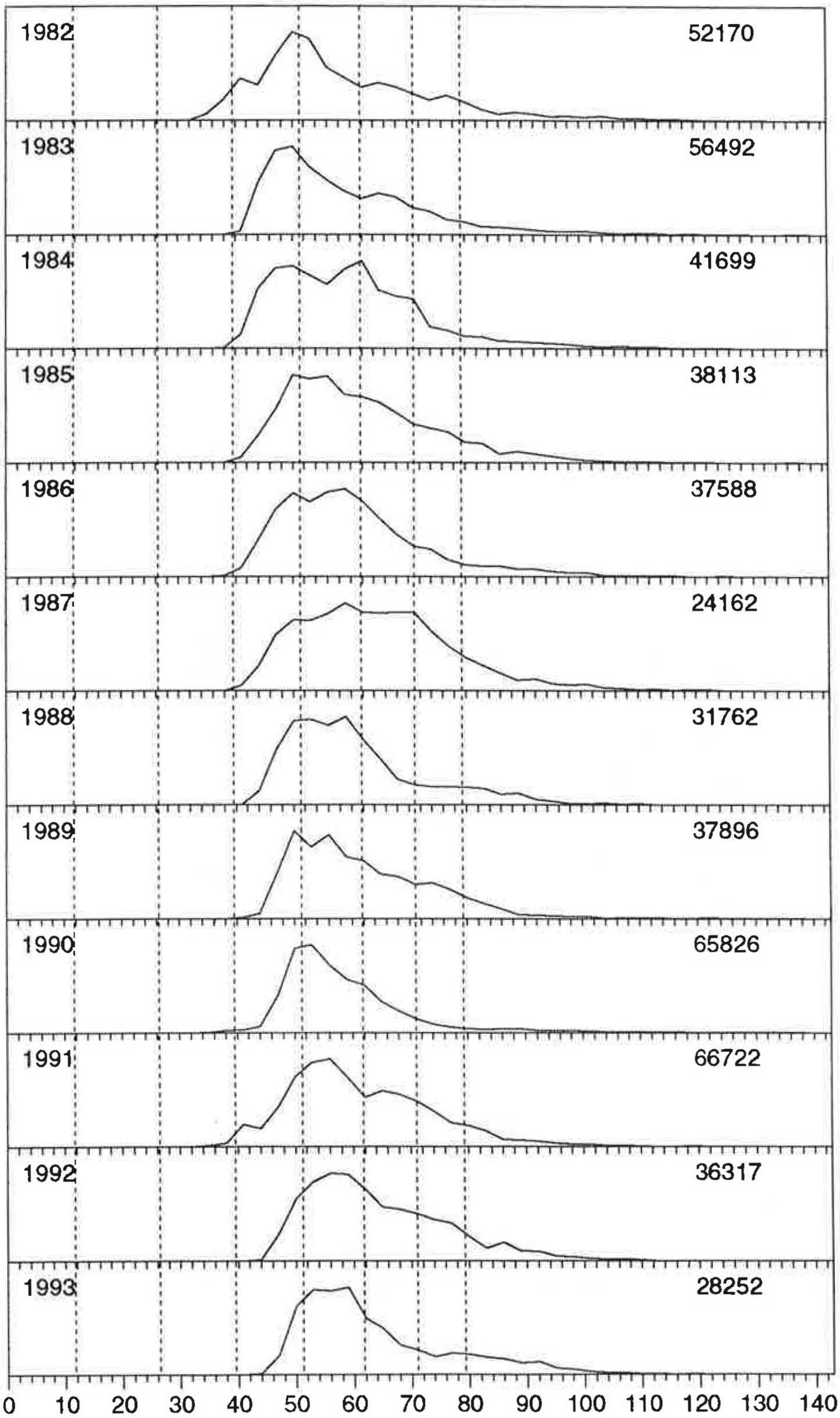
Table 7.1.8

IMAR												
Recruitment												
	MDLU	DYNP	AGEP	TSCLBAC	TSCLFOR	RELF	APRO	OFFI	RCCP	SLIC	SPKE	LACO
1980				23.42	38.96							
1981				21.19	35.88							
1982				23.15	36.4							
1983				21	31.17							
1984				20.93	27.17							
1985	85.509			15.85	22.95							
1986	96.468			14.74	23.06							
1987	86.64			15.11	18.79							
1988	73.45			18.55	30.43							
1989	63.908			17.03	28.04							
1990	48.044			22.29	31.25							
1991	52.668			17.25	23.46							
1992	45.052			12.75	18.29							
1993	45.162			16.93	16.93							
1994	42.897											
Fishing mortality												
1980				0.19	0.14		0.06					
1981				0.22	0.15		0.08					
1982				0.28	0.18		0.12					
1983				0.27	0.17		0.12					
1984				0.26	0.16		0.13					
1985	0.38			0.24	0.13	1.00	0.11					
1986	0.41			0.23	0.13	0.82	0.12					
1987	0.45			0.23	0.12	0.80	0.14					
1988	0.56			0.27	0.13	1.31	0.19					
1989	0.43			0.19	0.11	0.68	0.14					
1990	0.53			0.21	0.13	0.97	0.19					
1991	0.52			0.20	0.16	1.19	0.17					
1992	0.70			0.25	0.21	1.43	0.22					
1993	0.69			0.24	0.24	1.72	0.22					
1994						1.30	0.13					
Expl. biomass												
1980		857.784	783014				1125304					
1981		814.539	730746				1063851					
1982		759.144	664450				989176					
1983		683.362	598602				892989					
1984		619.646	543049				808576					
1985	182.618	559.253	499523				727885					
1986	182.239	516.408	463567				665987					
1987	184.260	472.846	427287				604510					
1988	170.108	427.308	383502				542403					
1989	141.095	369.652	348628				469510					
1990	129.272	339.123	319306				426678					
1991	104.914	296.261	292148				372792					
1992	94.440	265.240	267893				333239					
1993	74.213	227.142	246990				288120					
1994	67.429	195.043	232785				251274					
Spawning stock biomass												
1980												
1981												
1982												
1983												
1984												
1985												
1986												
1987												
1988												
1989												
1990												
1991												
1992												
1993												
1994												

Table 7.1.9

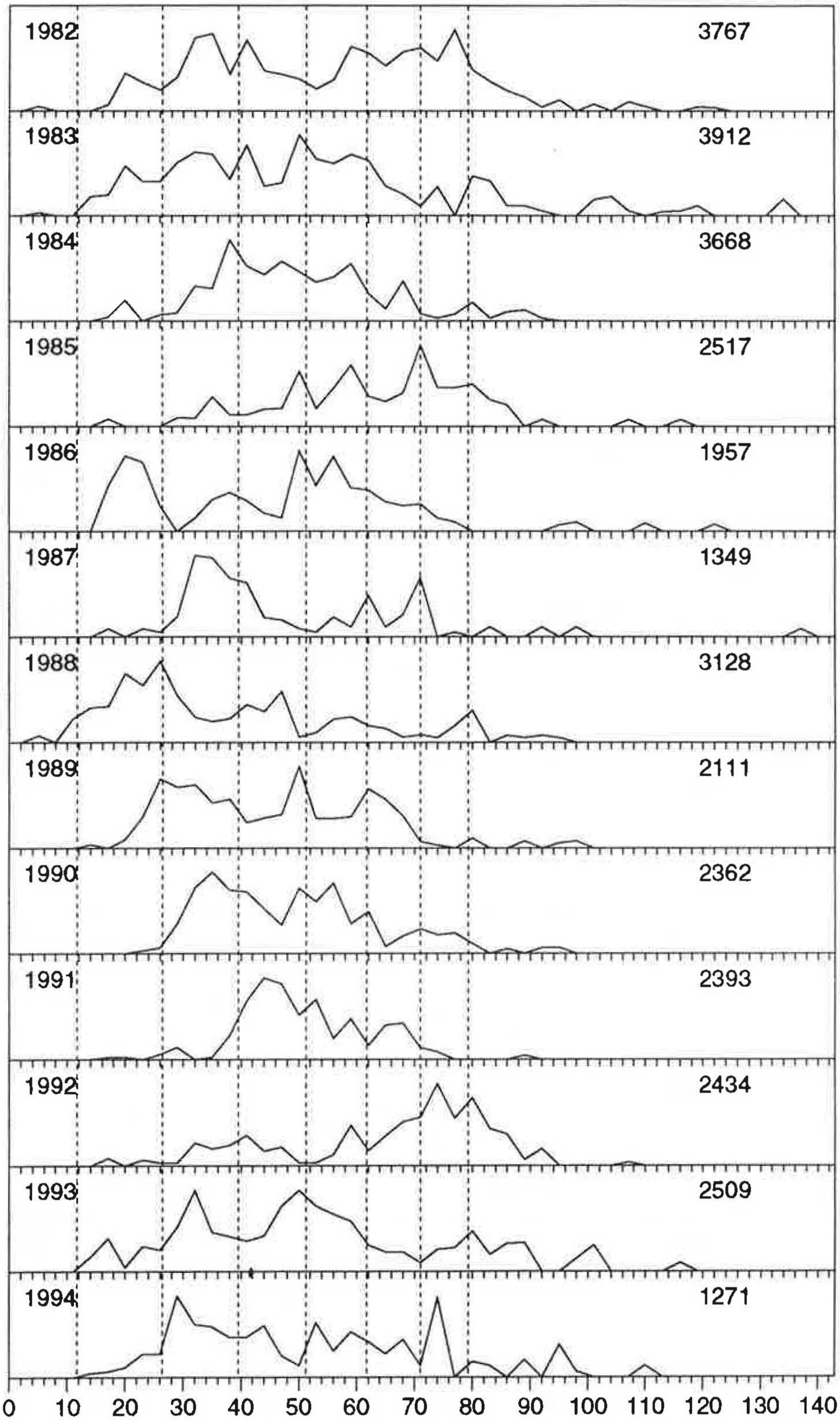
CPOP												
Recruitment												
	MDLU	DYNP	AGEP	TSCA	TSCL	RELF	APRO	OFFI	RCCP	SLIC	SPKE	LACO
1980												
1981												
1982												
1983												
1984												
1985												
1986												
1987												
1988												
1989												
1990												
1991												
1992												
1993												
1994												
Fishing mortality												
1980												
1981												
1982												
1983												
1984												
1985												
1986												
1987												
1988												
1989												
1990												
1991												
1992												
1993												
1994												
Expl. biomass												
1980		255.932	235730					19500				
1981		255.911	237007					19000				
1982		256.317	238676					18800				
1983		257.032	240098					18700				
1984		256.914	241382					18000				
1985		257.333	243017					18900				
1986		257.923	244788					20000				
1987		258.628	246139					22000				
1988		258.400	247292					23000				
1989		258.733	248719					25000				
1990		259.098	250075					27000				
1991		259.328	251520					29000				
1992		259.917	253105					30500				
1993		260.479	254649					32000				
1994		261.038	256481					34500				
Spawning stock biomass												
1980												
1981												
1982												
1983												
1984												
1985												
1986												
1987												
1988												
1989												
1990												
1991												
1992												
1993												
1994												

Figure 2.2.1.a GOM Cod Catch at Length



Dashed lines are Ages 1 - 7

Figure 2.2.1.b GOM Cod Survey1 at Length



Dashed lines are Ages 1 - 7

Figure 2.4.1.a Iceland haddock catch at length.

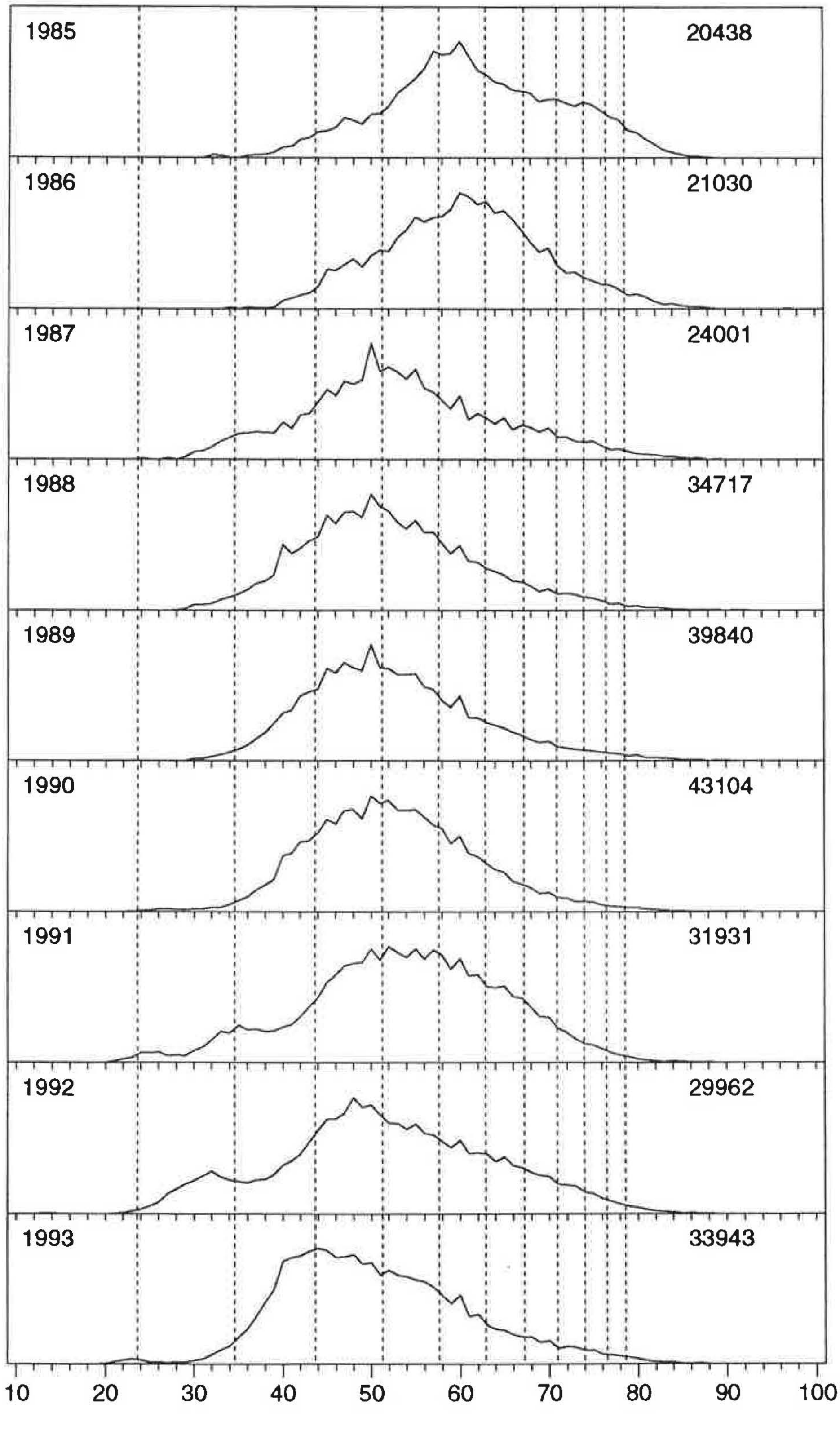


Figure 2.4.1.b Iceland haddock abundance at length.

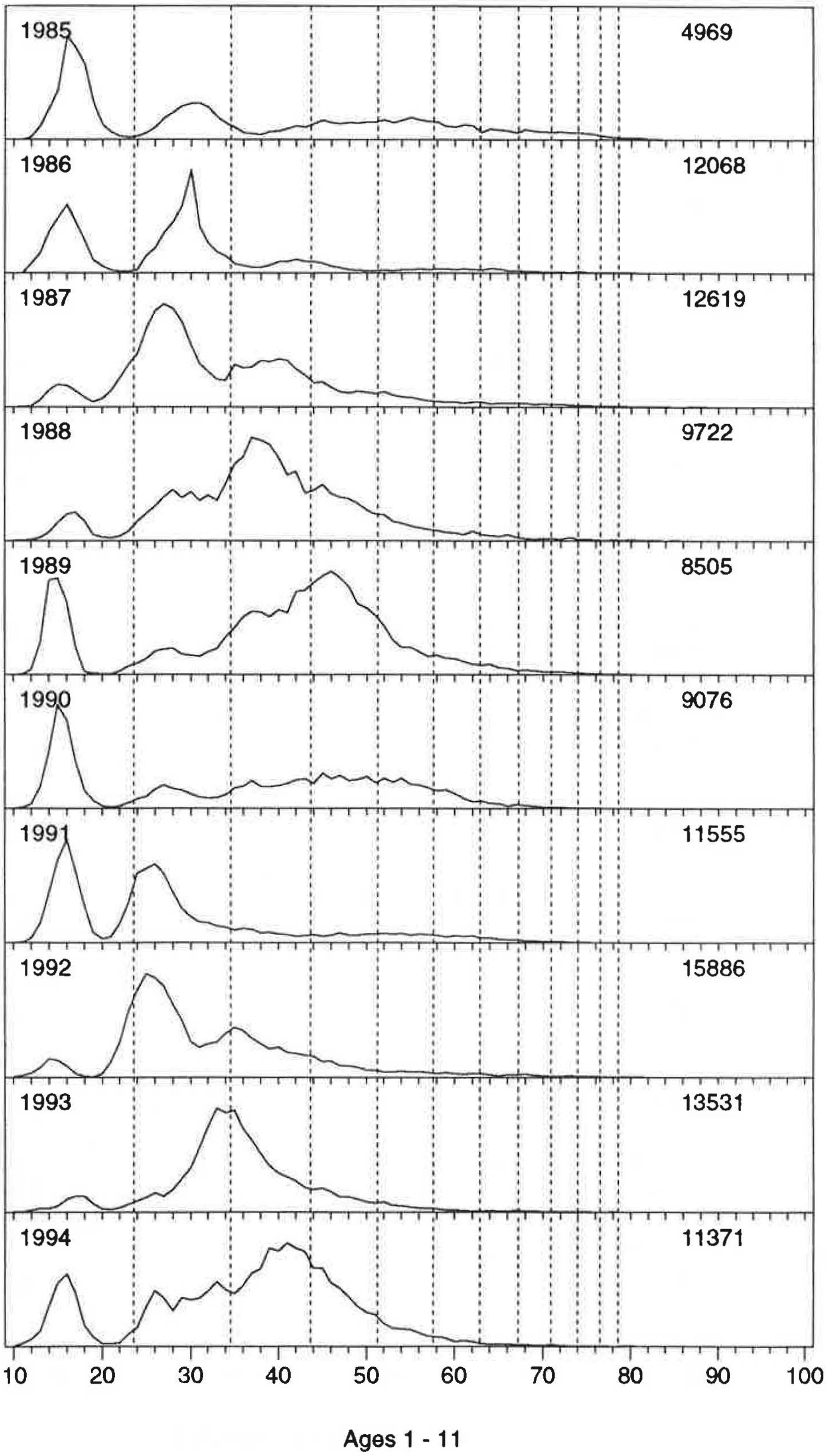
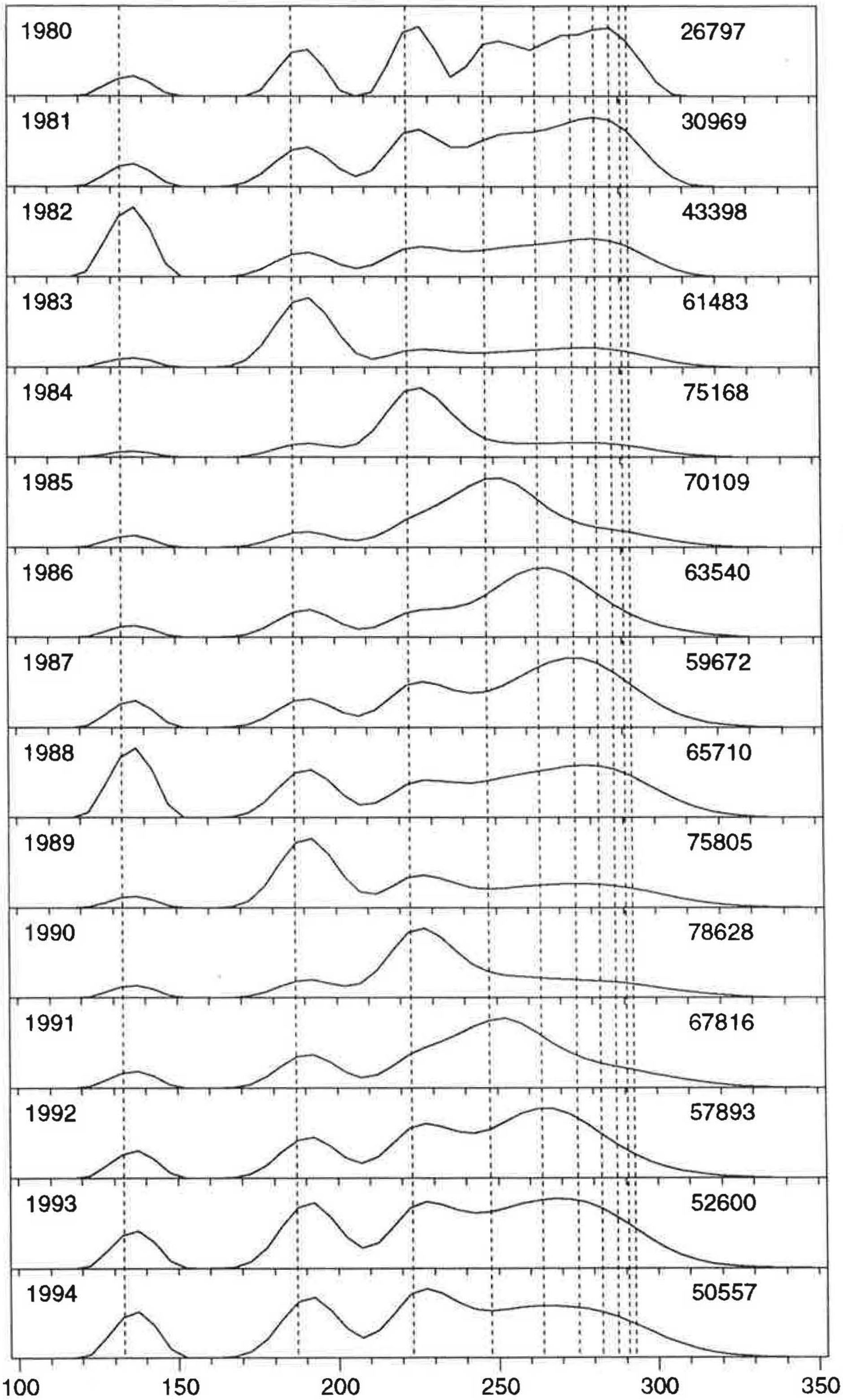
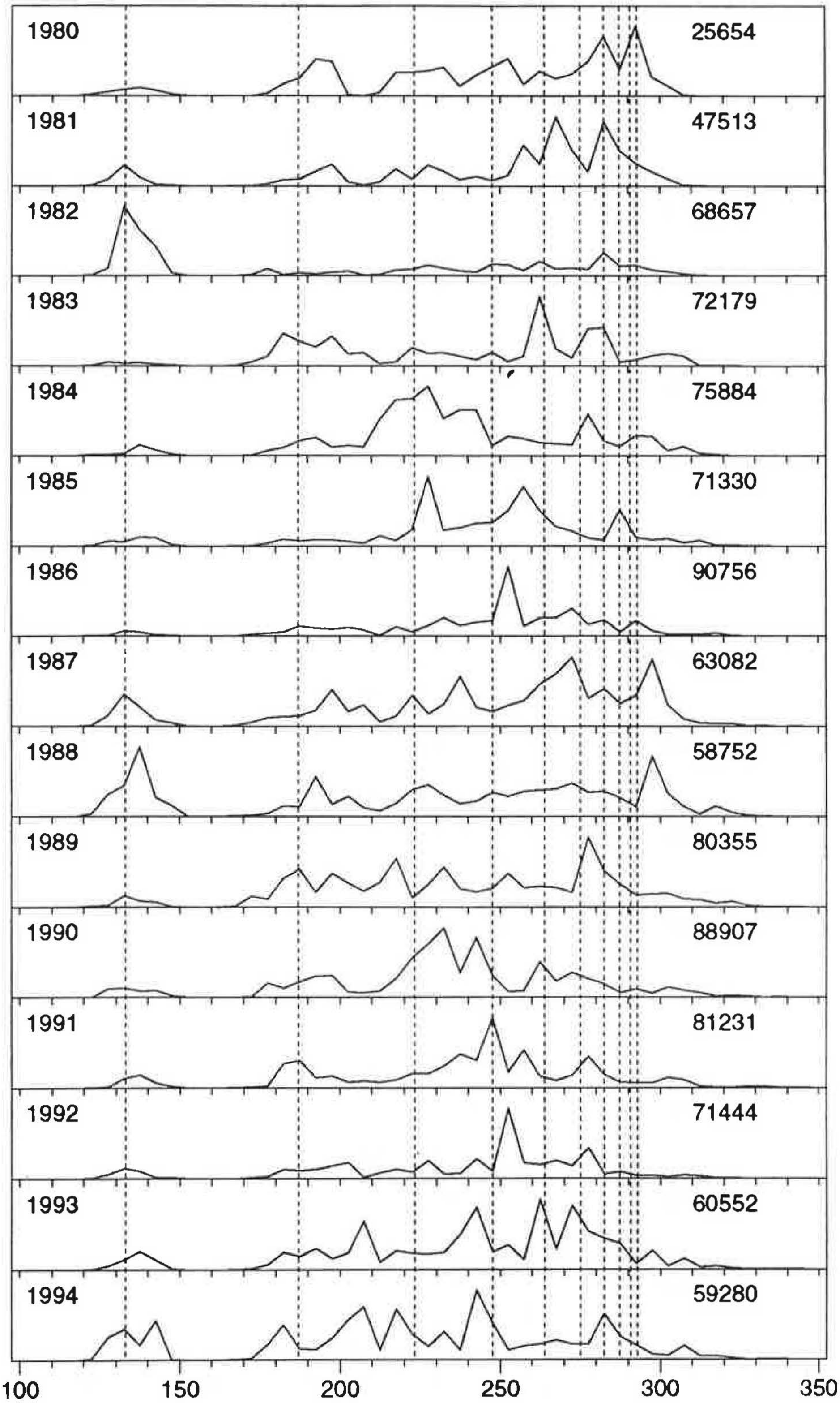


Figure 2.5.1. Simulated Tuna Catch at lenghth



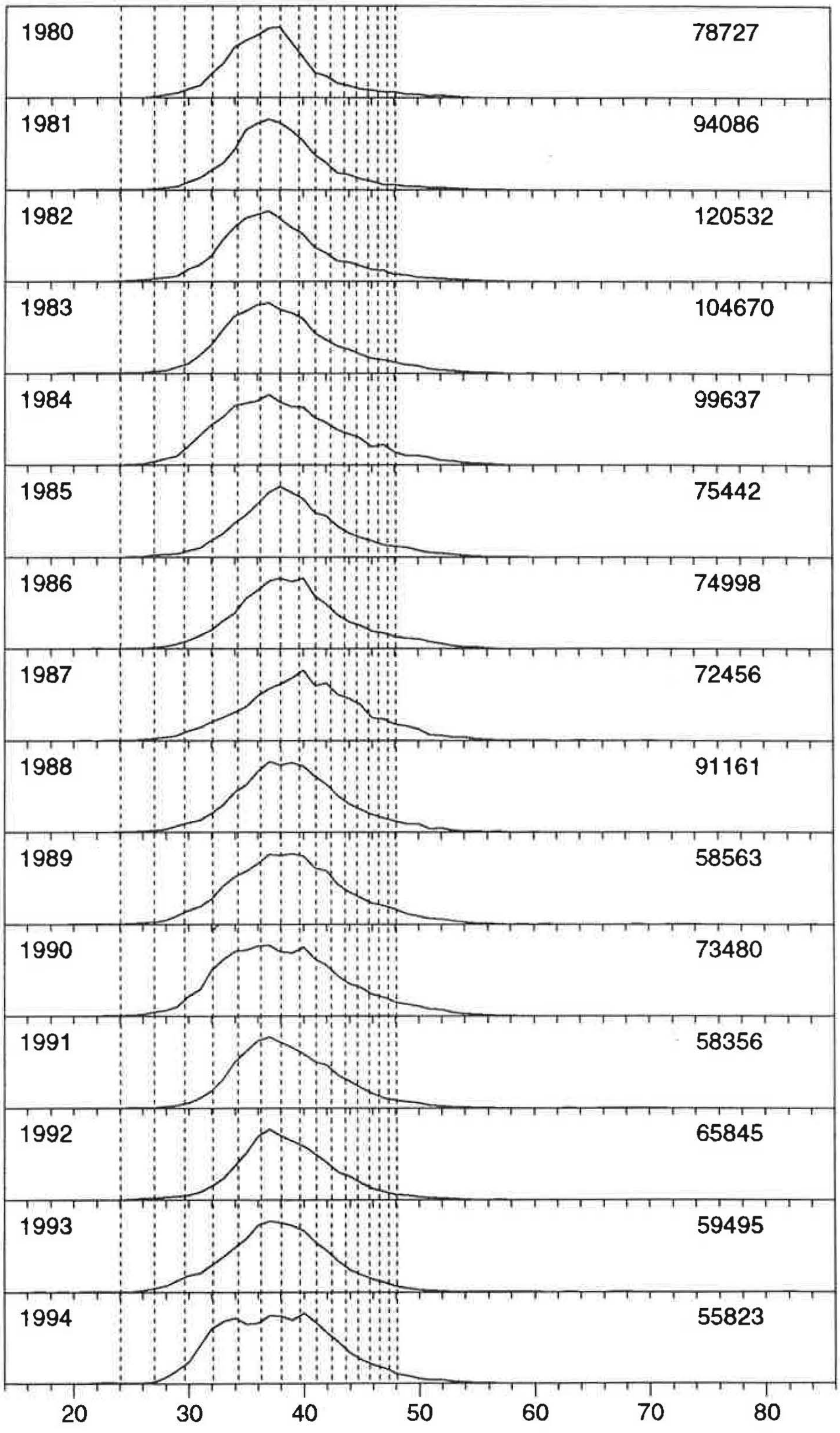
Dashed lines are ages1-10

Figure 2.6.1. Noisy Tuna Catch at lenghth



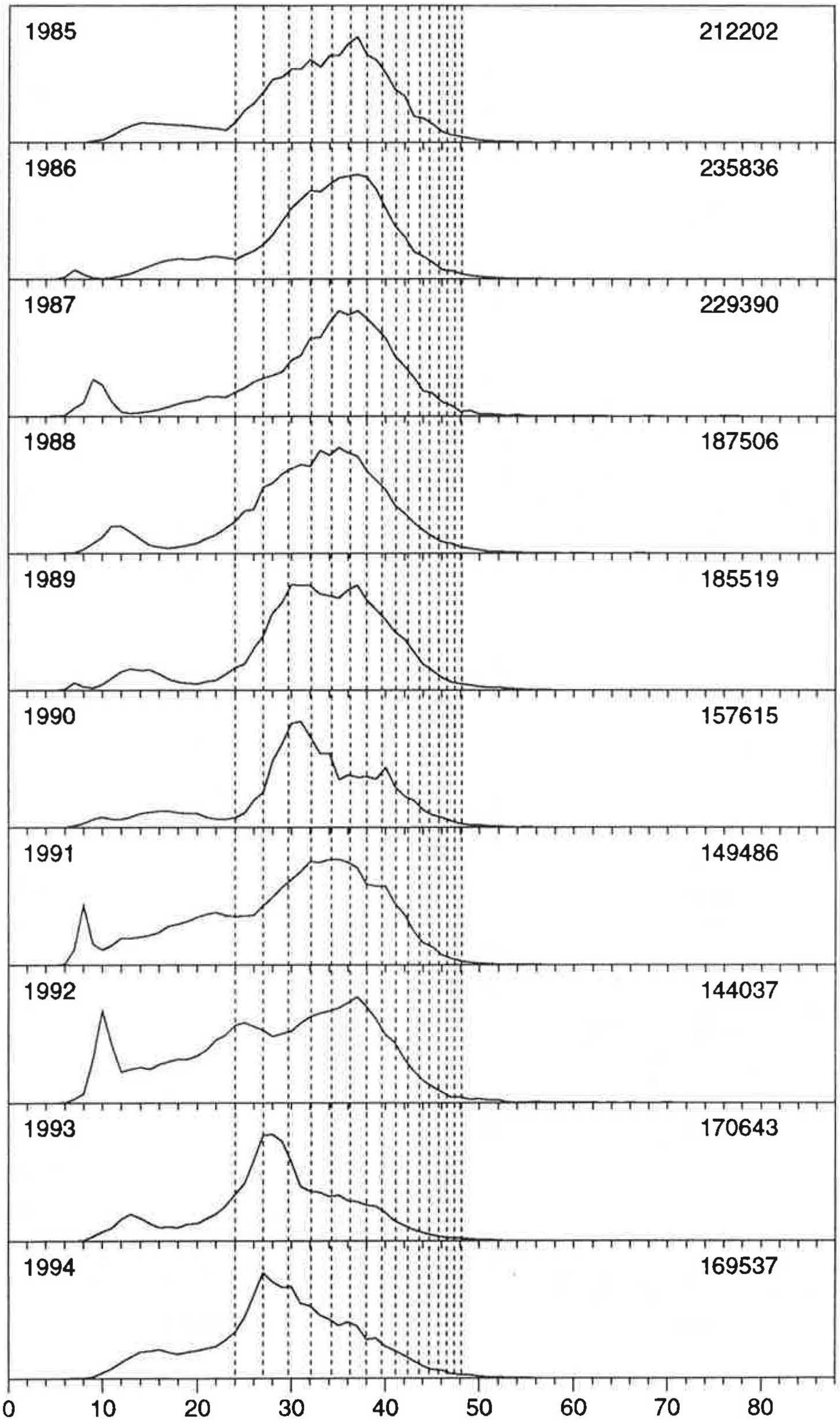
Dashed lines are ages1-10

Figure 2.9.1.a Iceland Redfish catch at length



Dashed lines are even ages 10 - 40

Figure 2.9.1.b Iceland Redfish survey at length



Dashed lines are even ages 10 - 40

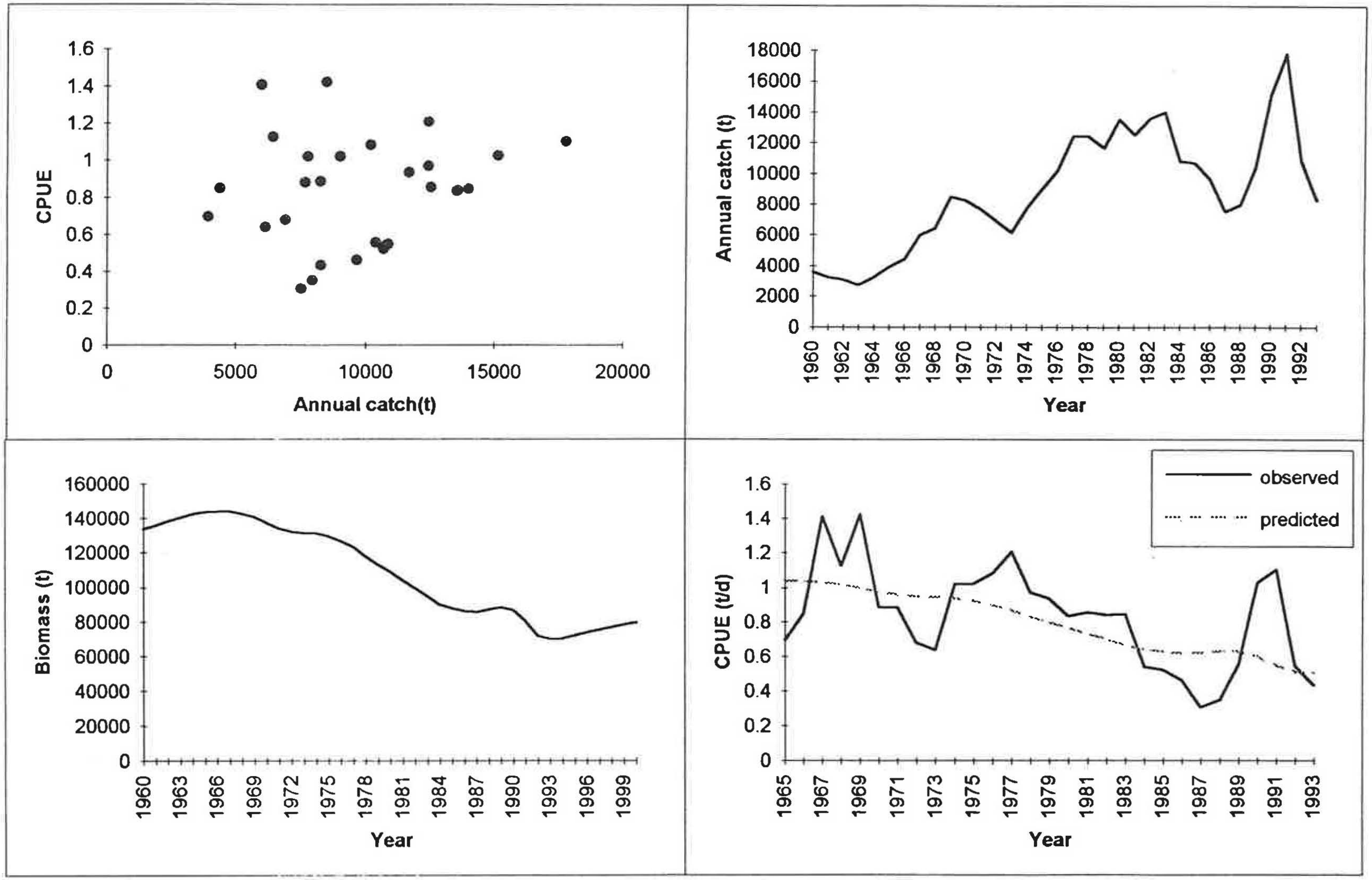


Fig 3.3.1: Dynamic production results for Gulf of Maine cod

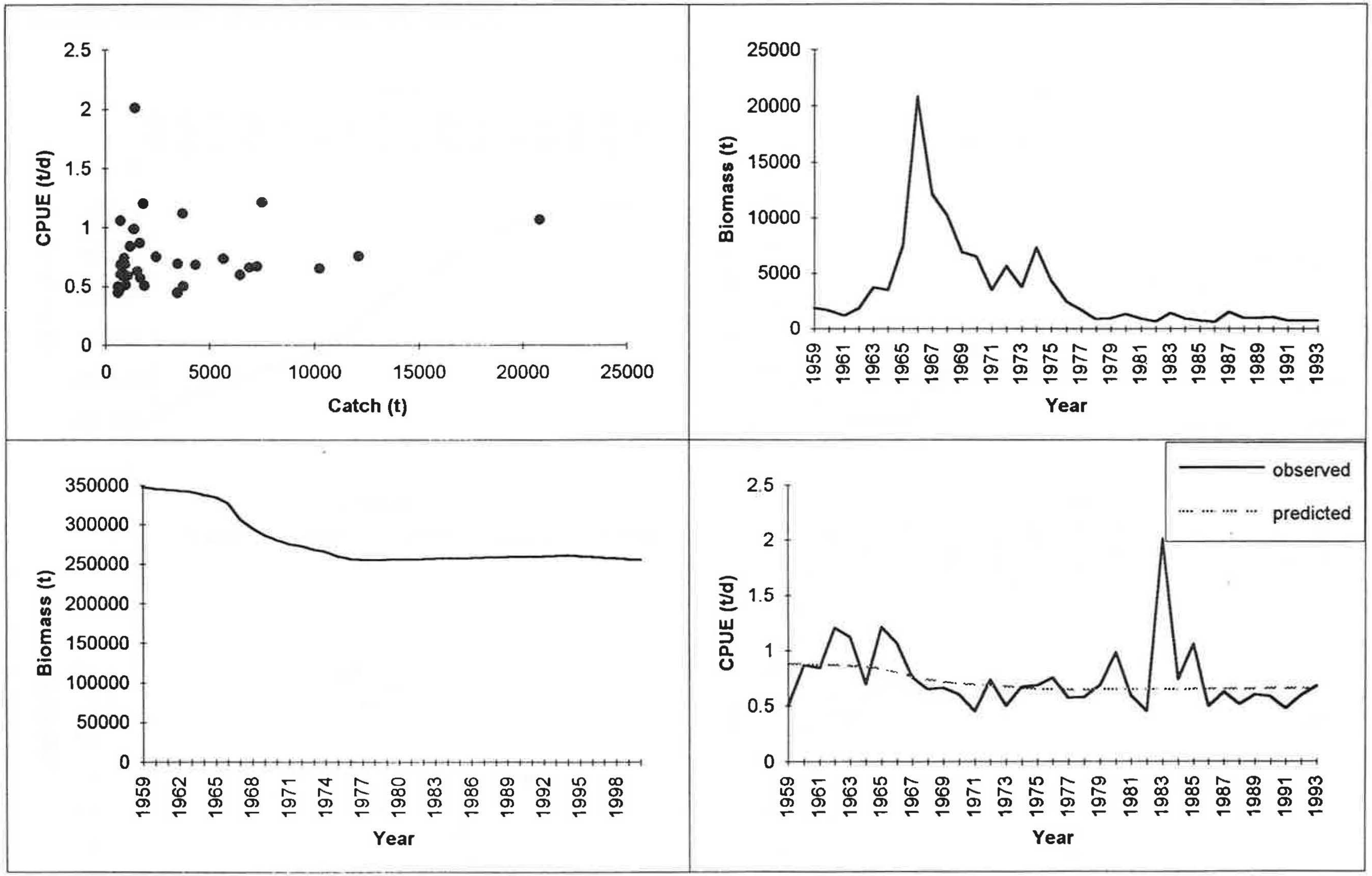


Fig 3.3.2 Dynamic production model results for Canadian Pacific ocean perch

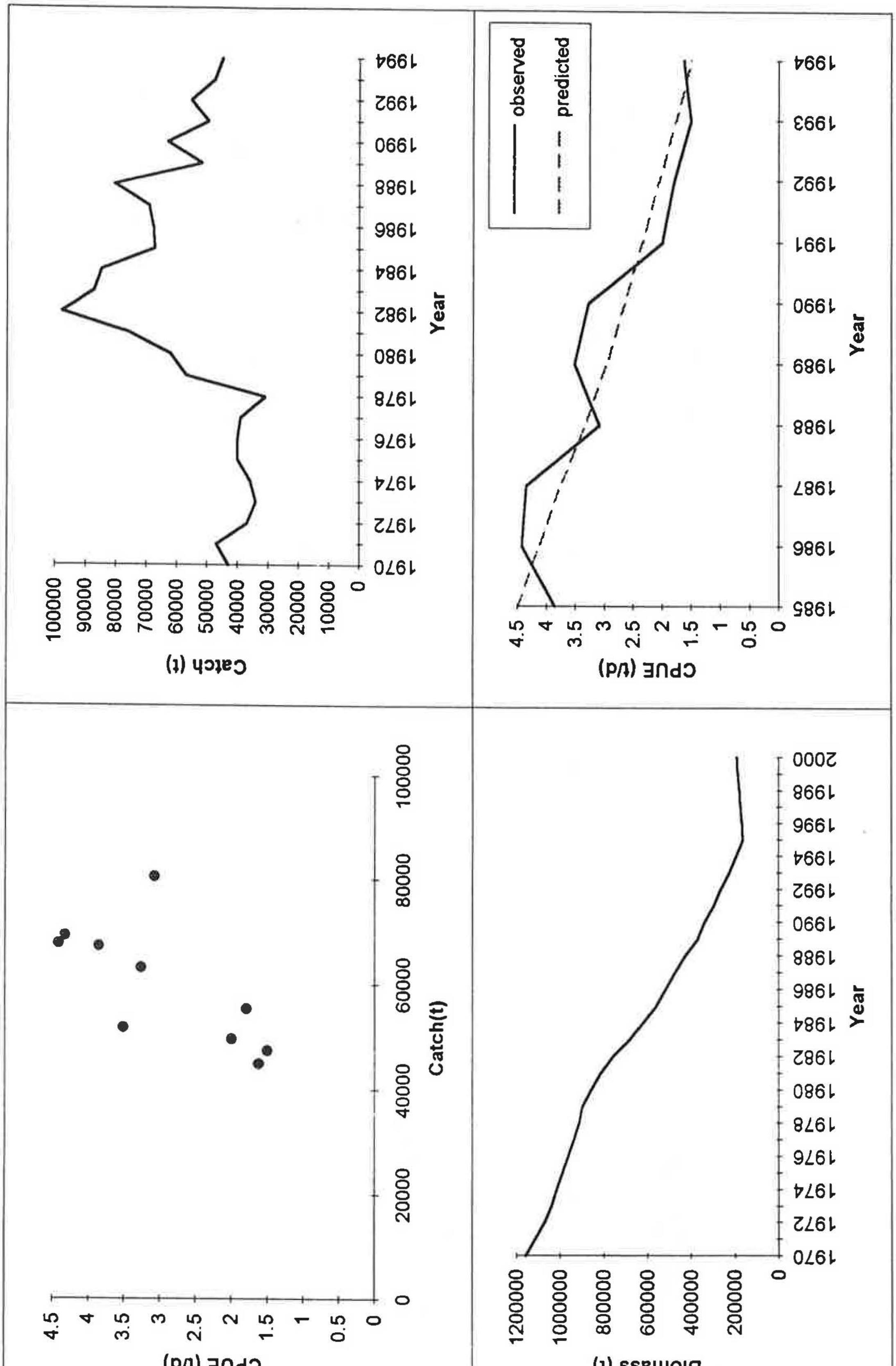


Fig 3.3.3 Dynamic production results for Icelandic redfish

Figure 3.4.1 Input parameters for the spreadsheet-implemented age-based stock-production model analysis of Icelandic *S. marinus* data: Commercial selection pattern (S), weights at age (W), natural mortality (M) and survey selection pattern.

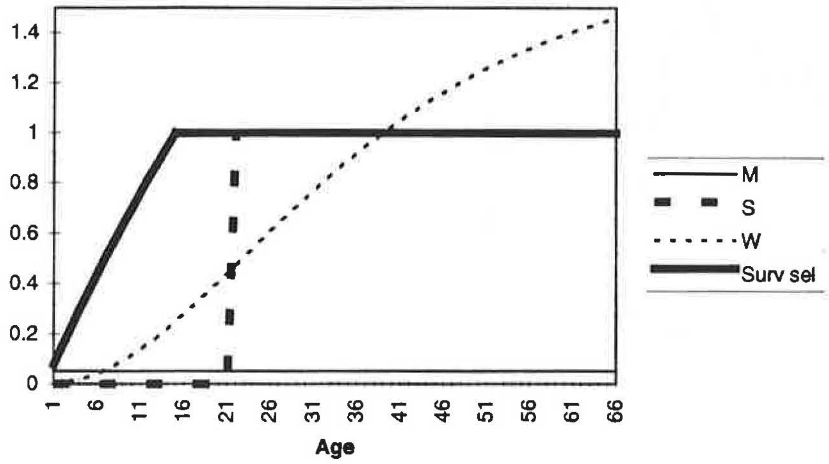


Figure 3.4.2 Output from the spreadsheet-implemented age-based stock-production model analysis of Icelandic *S. marinus* data: Observed (U) and fitted (Uhat) biomass trends. Forward projection is based on assuming an annual catch of 25000 t.

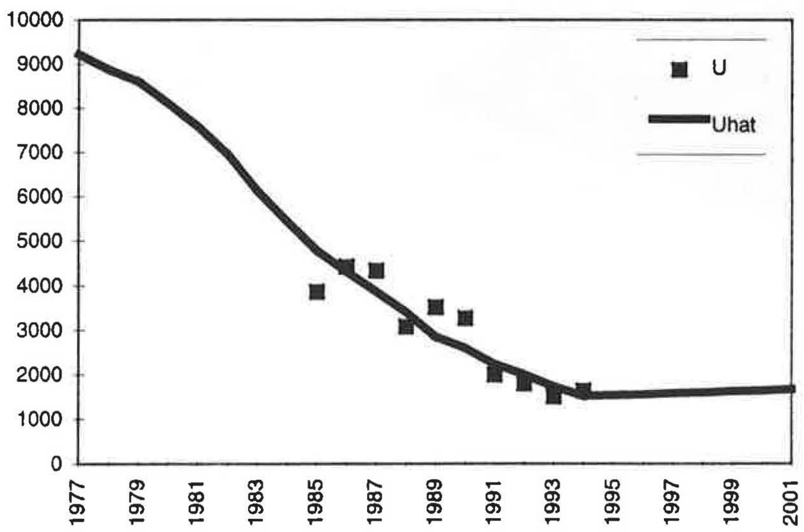


Figure 3.4.3 Fishing mortality by year, as estimated from the spreadsheet-implemented age-based stock-production model analysis of Icelandic *S. marinus* data. Forward projection is based on assuming an annual catch of 25000 t.

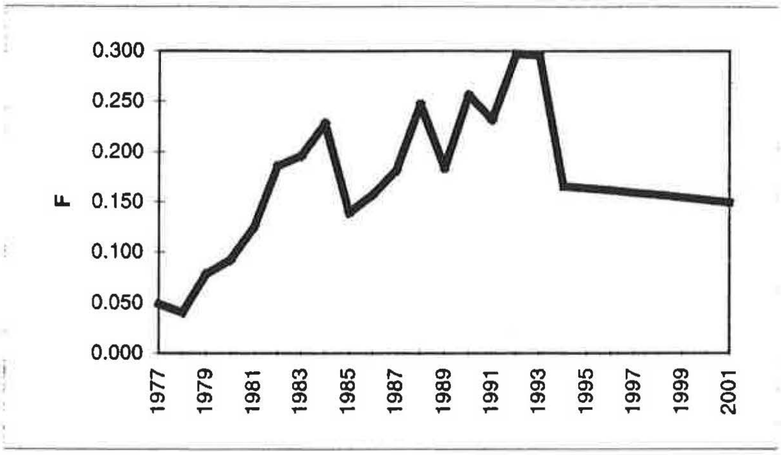


Figure 3.4.4 Plot of SSE-surface for values of KS in the (log-scale) range 0.009-29.9and K in the range 0.045-0.065.

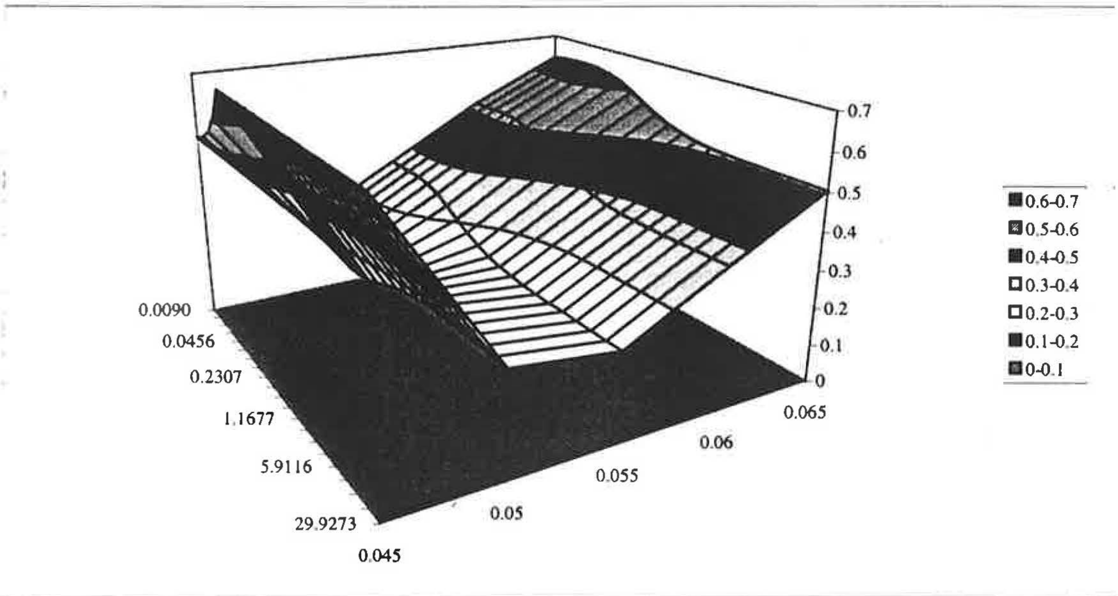


Figure 3.4.5 Fishable biomass and fishing mortality of Oceanic *S. mentella*

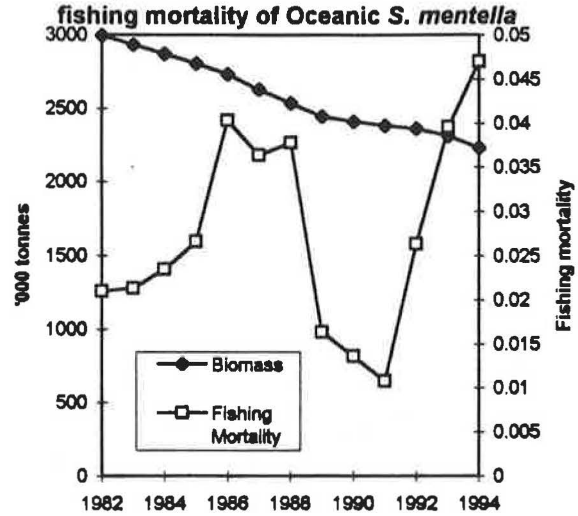


Figure 3.4.6 Oceanic *S. Mentella* - Length distribution in the stock 1994

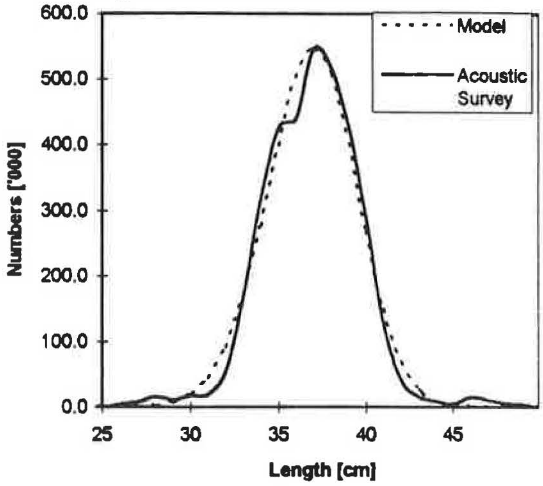


Figure 3.4.7 Fishable biomass and catch of Canadian (Unit 1) redfish.

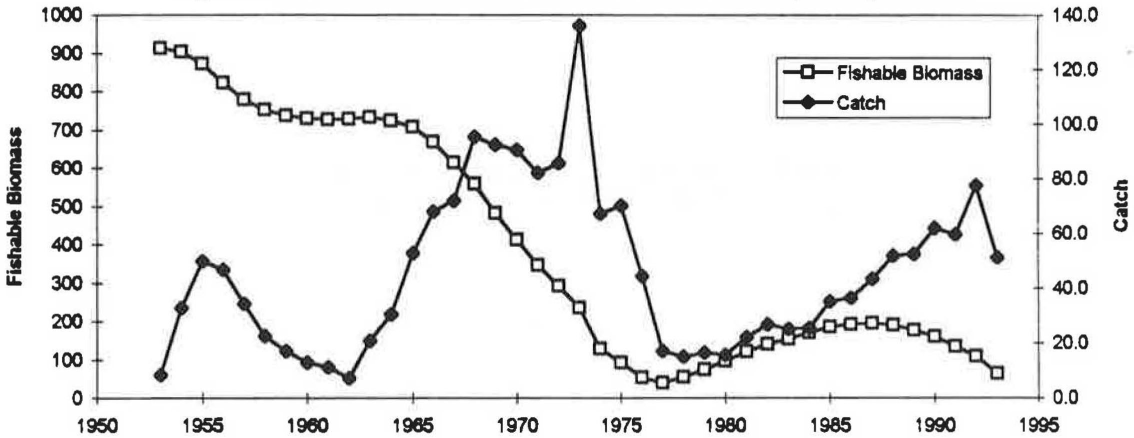


Figure 3.4.8 Unit 1 redfish; length distribution of 1981 catches

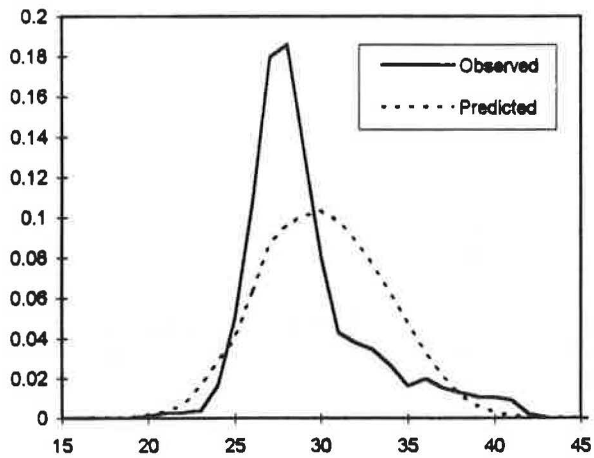


Figure 3.4.9 Unit 1 redfish; length distribution of 1992 catches.

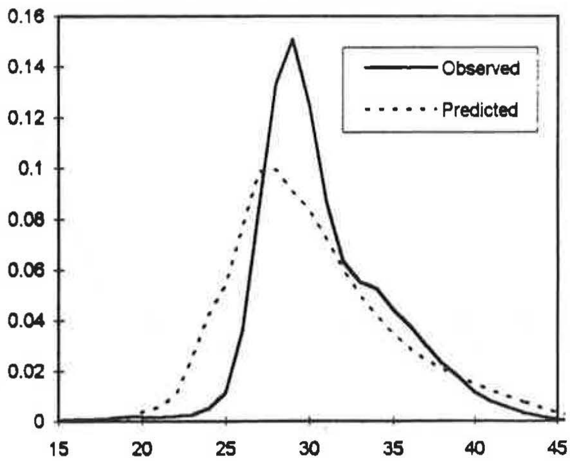


Fig 3.5.1 Iceland S. marinus : Bayesian stock production model
Mean stock trajectory with relative abundance data

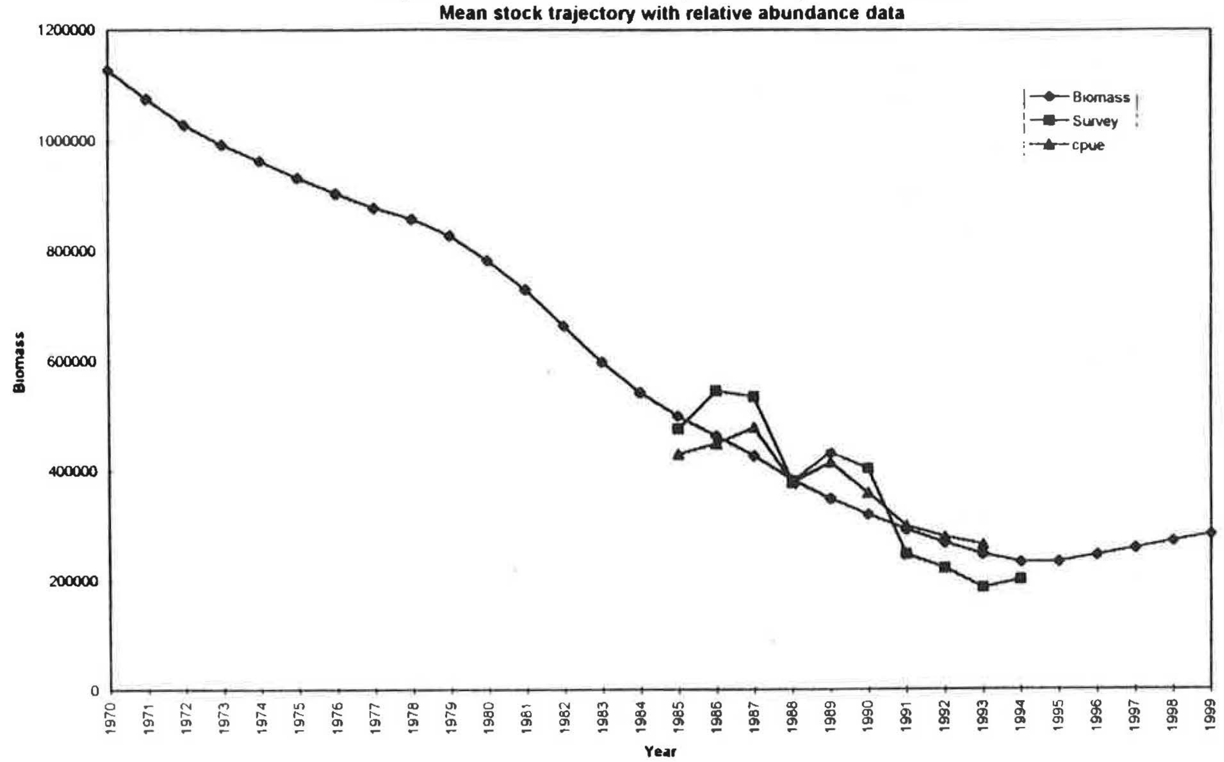


Fig 3.5.2 Iceland S. marinus : Bayesian stock production model
Posterior distribution for virgin biomass

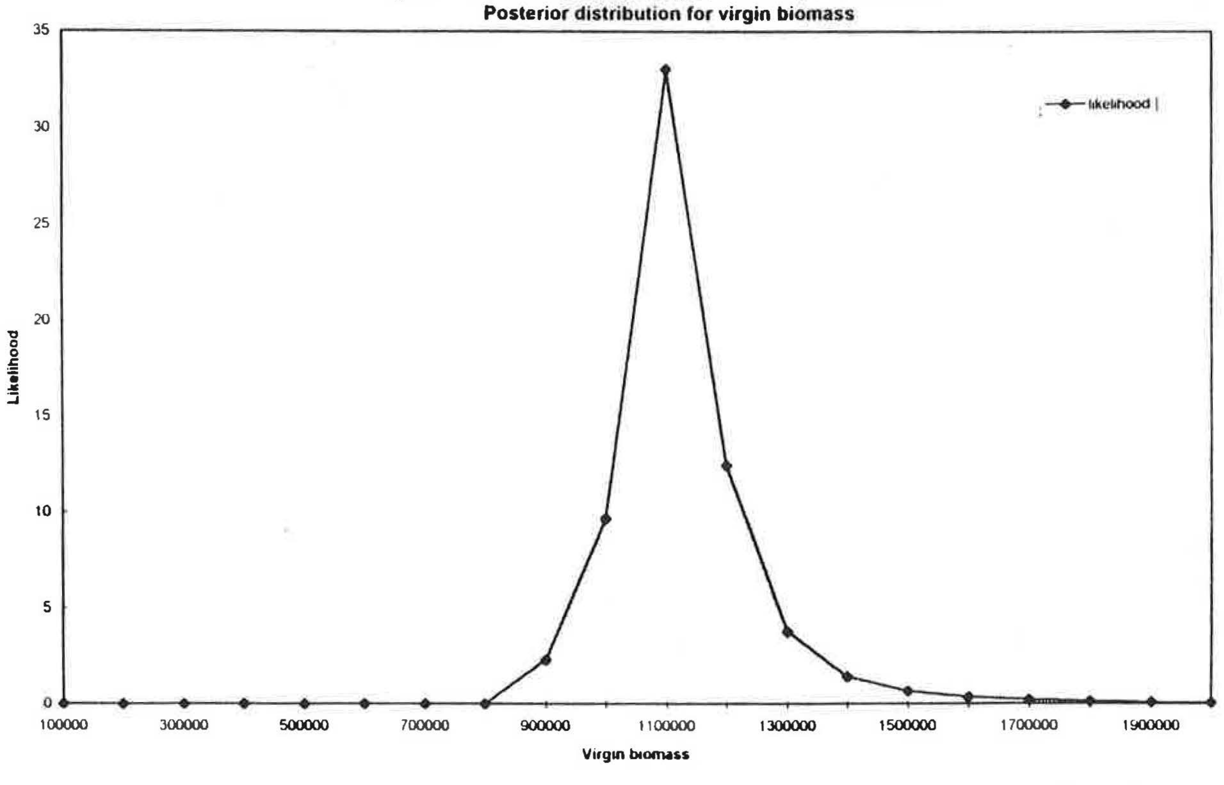


Fig 3.5.3 Gulf of Maine Cod : Bayesian stock production model
Mean stock trajectory with relative abundance data

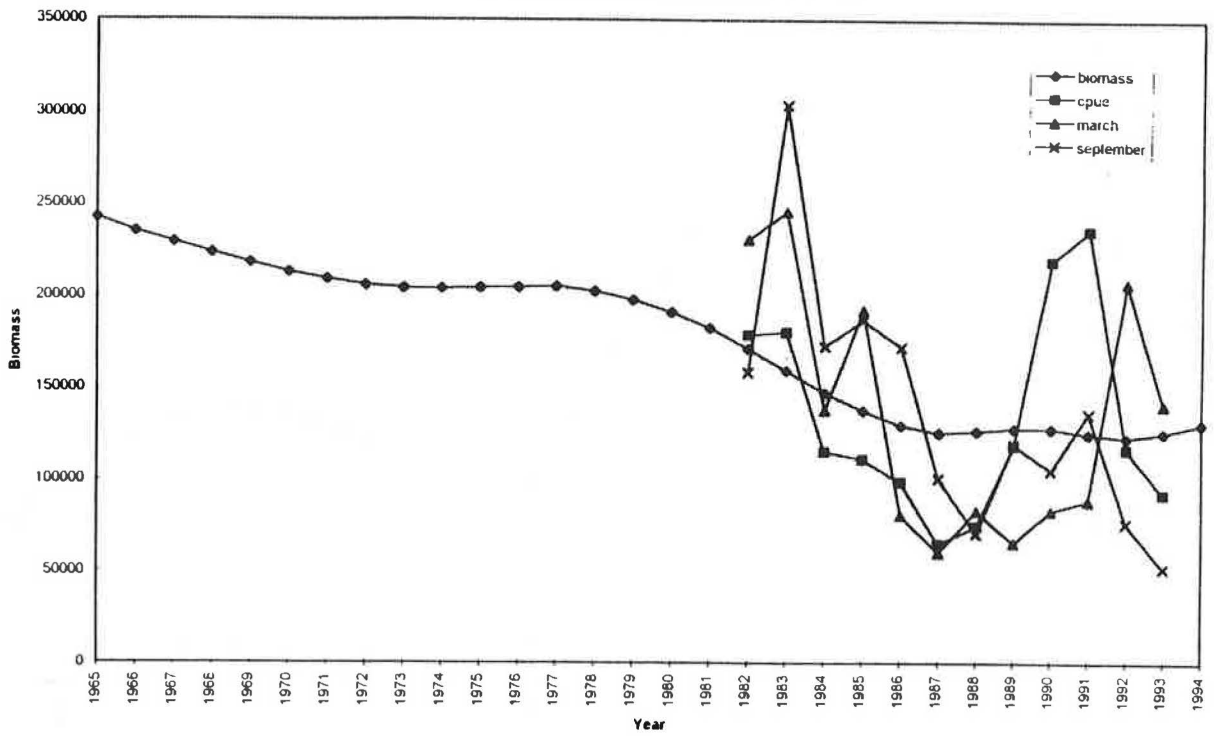


Fig 3.5.4 Gulf of Maine Cod : Bayesian stock production model
Posterior distribution for virgin biomass

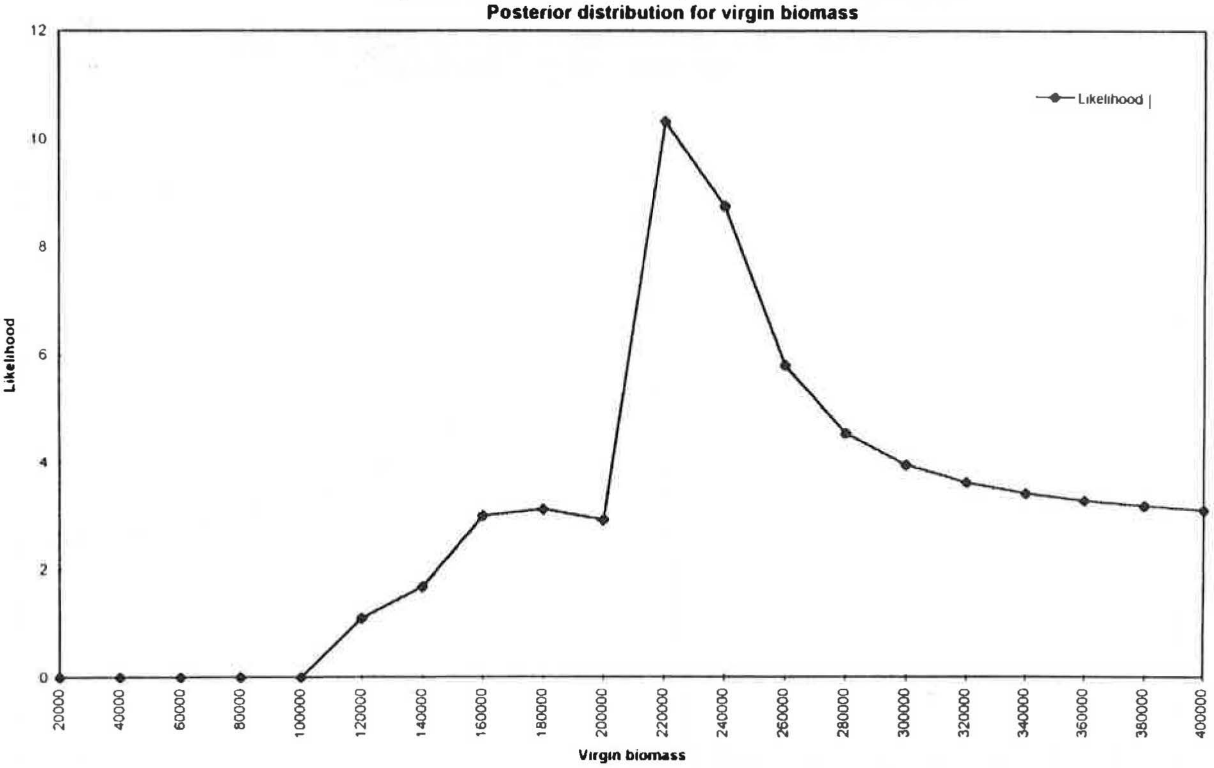


Fig 3.5.5 Gulf St Lawrence redfish : Bayesian stock production model
Mean stock trajectory with relative abundance data

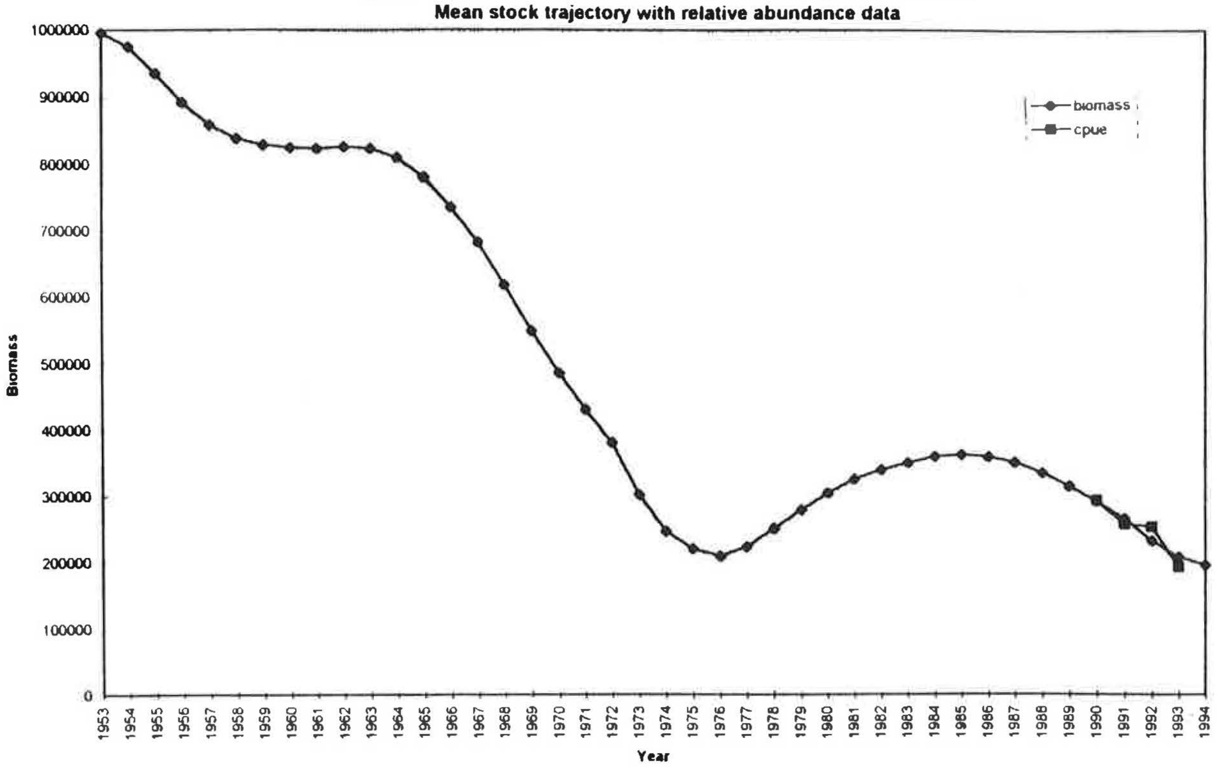
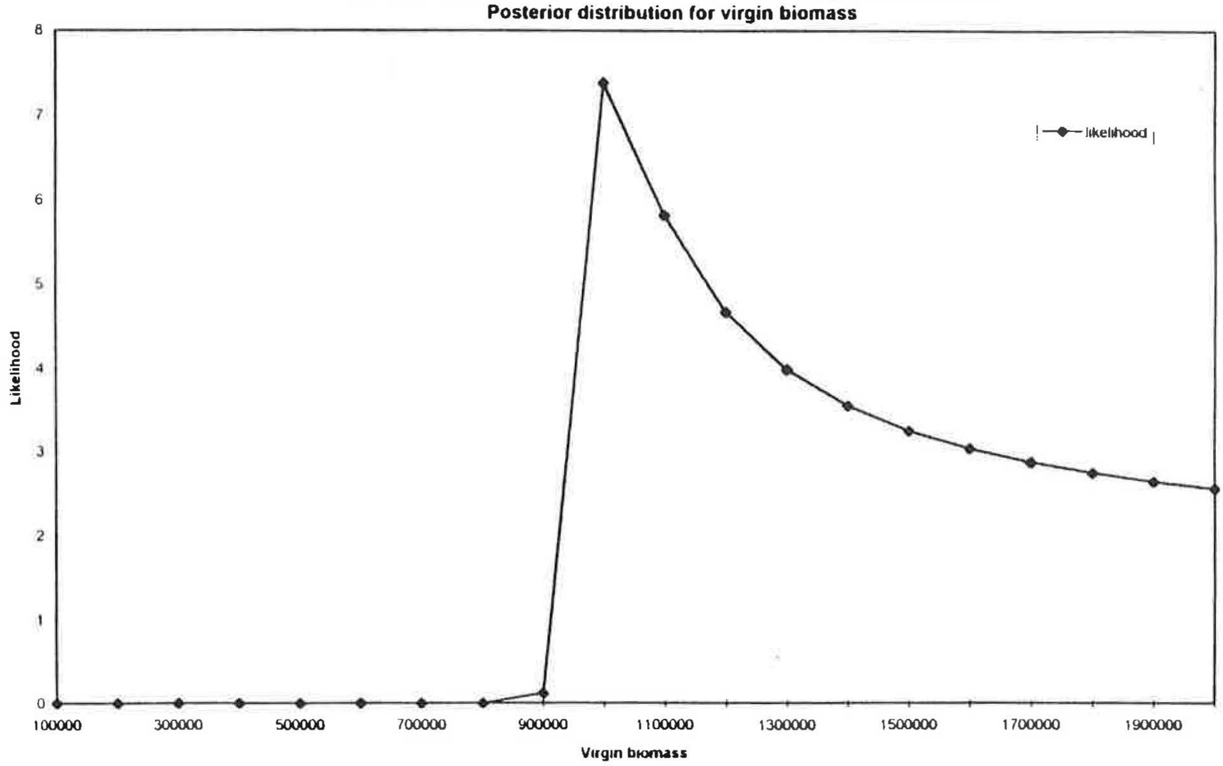


Fig 3.5.6 Gulf St Lawrence redfish : Bayesian stock production model
Posterior distribution for virgin biomass



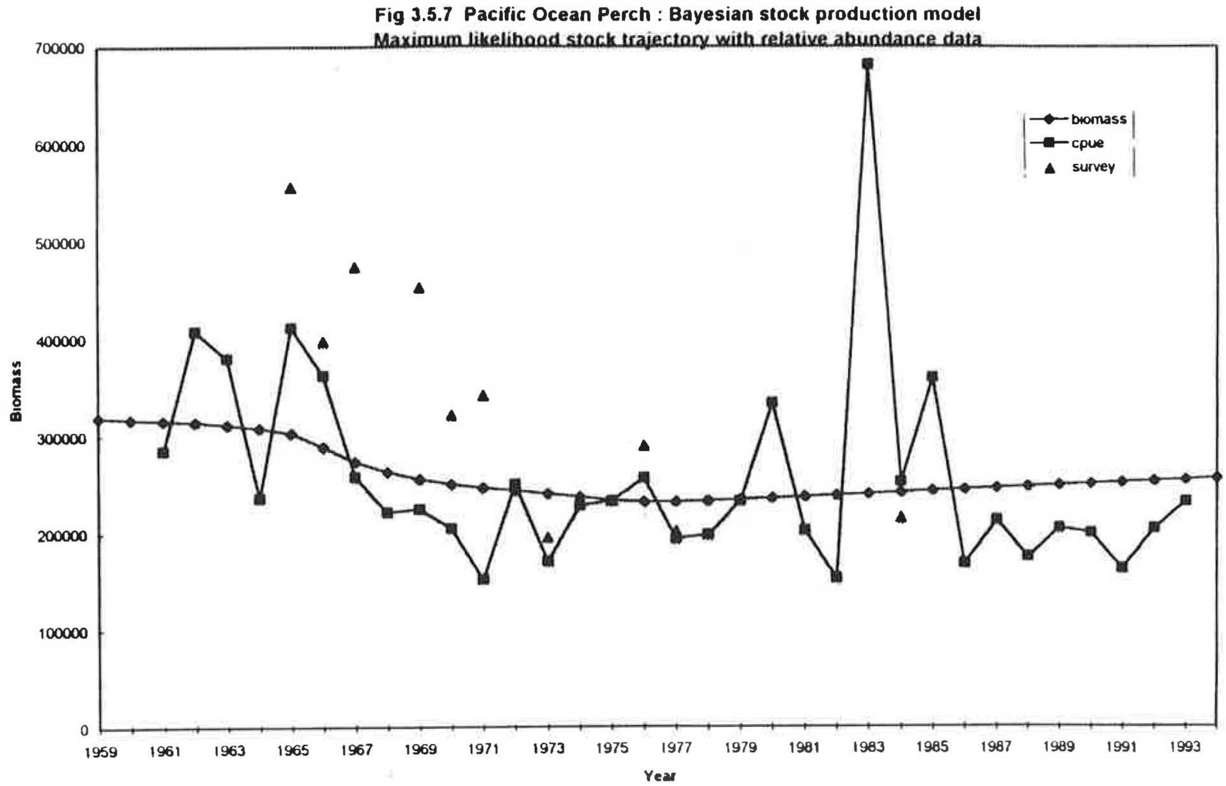


Fig 3.5.7 Pacific Ocean Perch : Bayesian stock production model
Maximum likelihood stock trajectory with relative abundance data
biomass
cpue
survey
Biomass
Year
0
100000
200000
300000
400000
500000
600000
700000
1959
1961
1963
1965
1967
1969
1971
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993

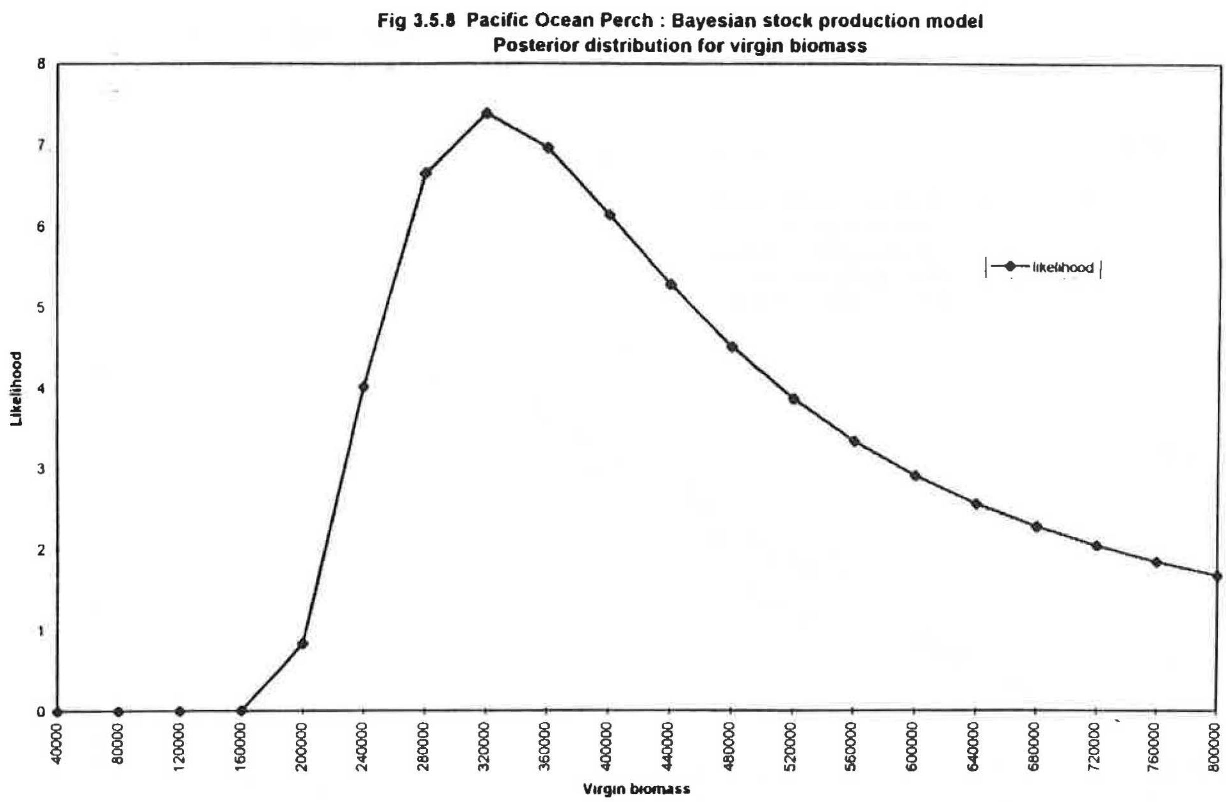


Fig 3.5.8 Pacific Ocean Perch : Bayesian stock production model
Posterior distribution for virgin biomass
likelihood
Likelihood
Virgin biomass
0
1
2
3
4
5
6
7
8
40000
80000
120000
160000
200000
240000
280000
320000
360000
400000
440000
480000
520000
560000
600000
640000
680000
720000
760000
800000

Figure 3.6.1a **Diagnostics for the modified DeLury model - Gulf of Maine cod using spring survey indices.**

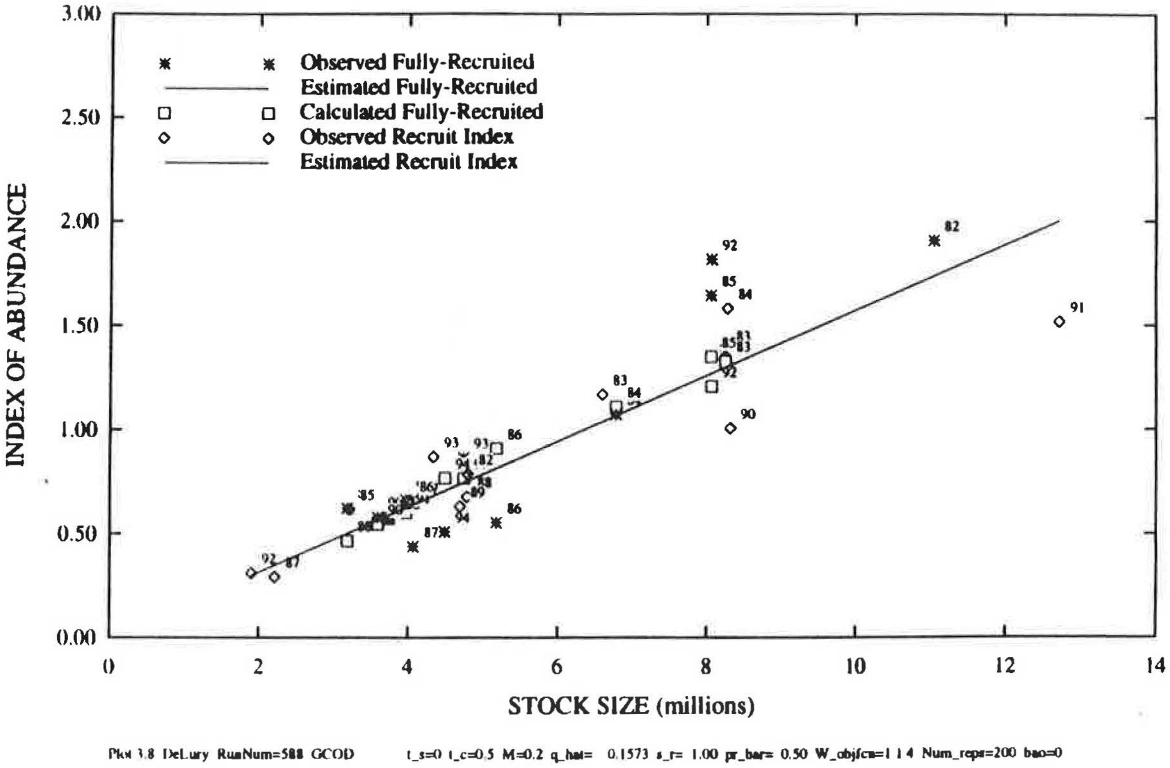


Figure 3.6.1b **Diagnostics for the modified DeLury model - Gulf of Maine cod using fall survey indices.**

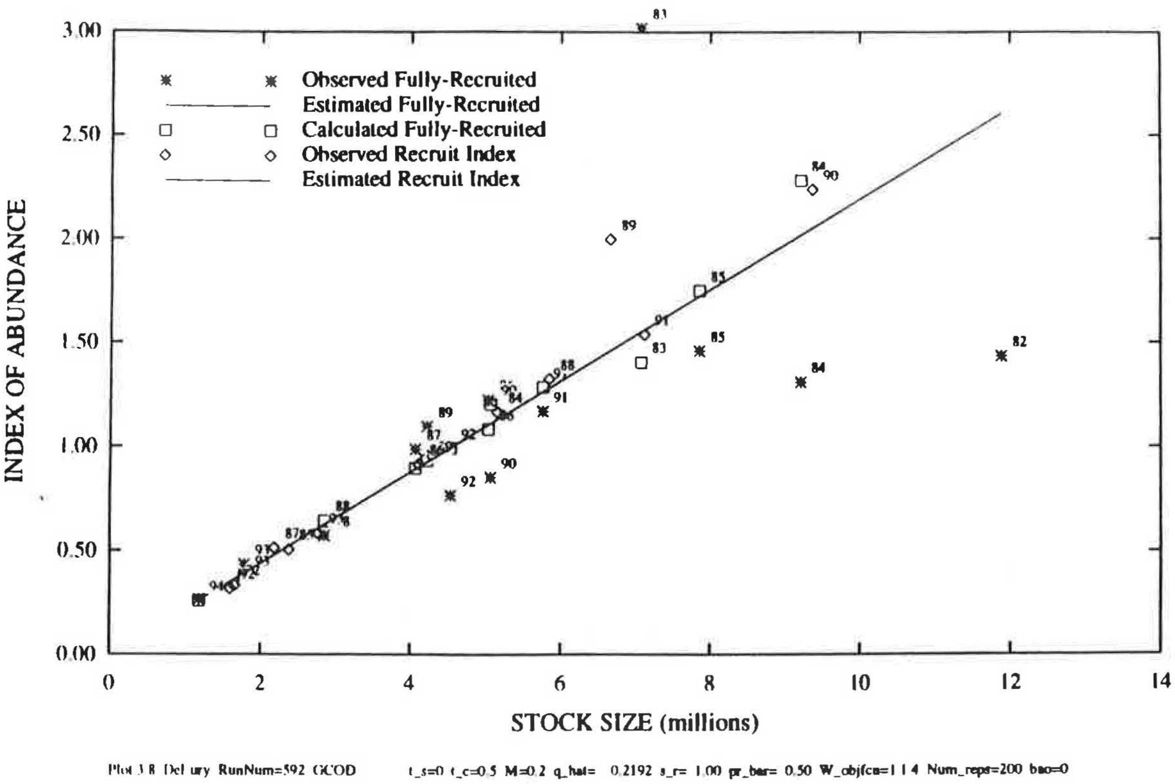


Figure 3.6.2a Modified DeLury model results - Gulf of Maine cod using spring and fall survey indices.

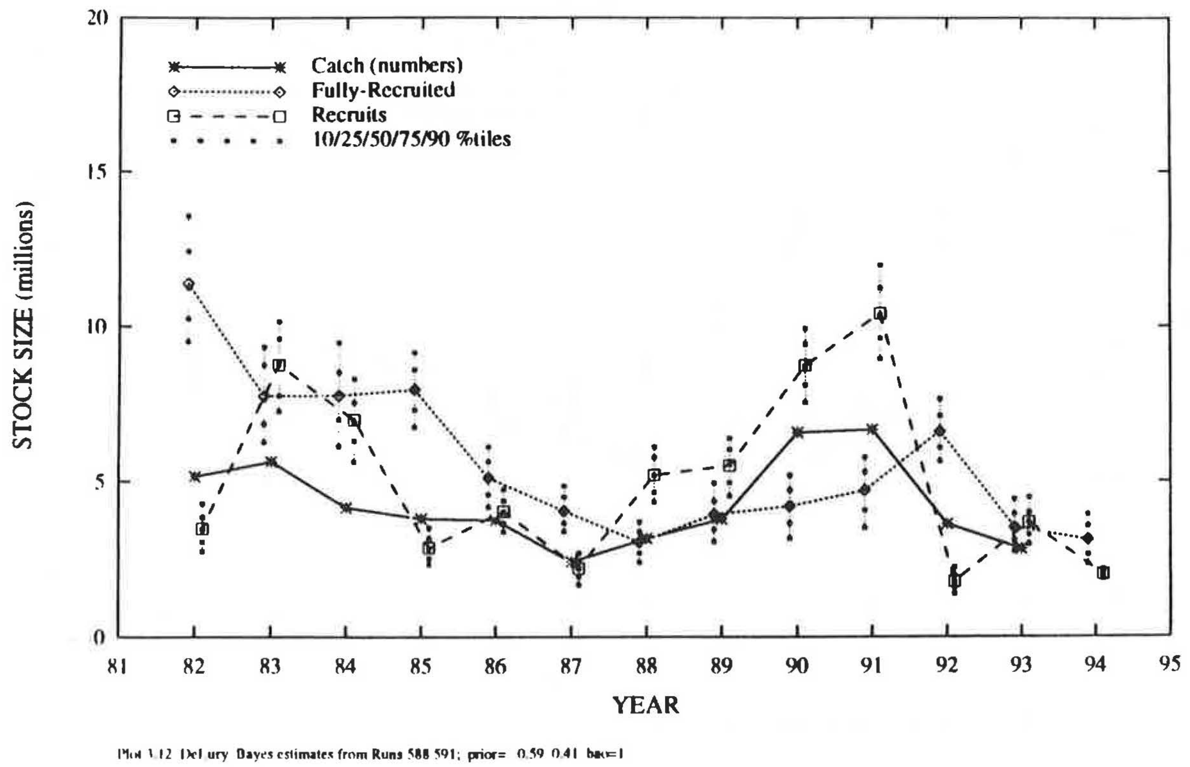


Figure 3.6.2b Modified DeLury model results - Gulf of Maine cod using spring and fall survey indices.

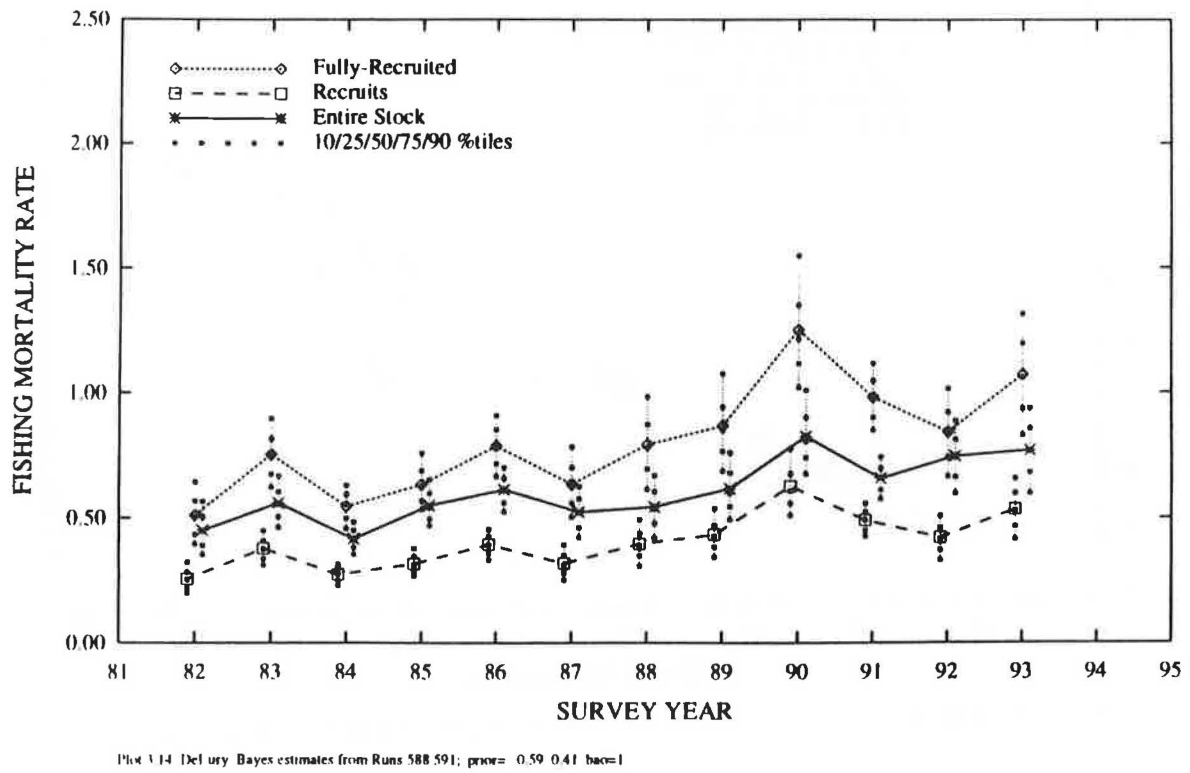


Figure 3.6.2c **Modified DeLury model results - Gulf of Maine cod using spring and fall survey indices.**

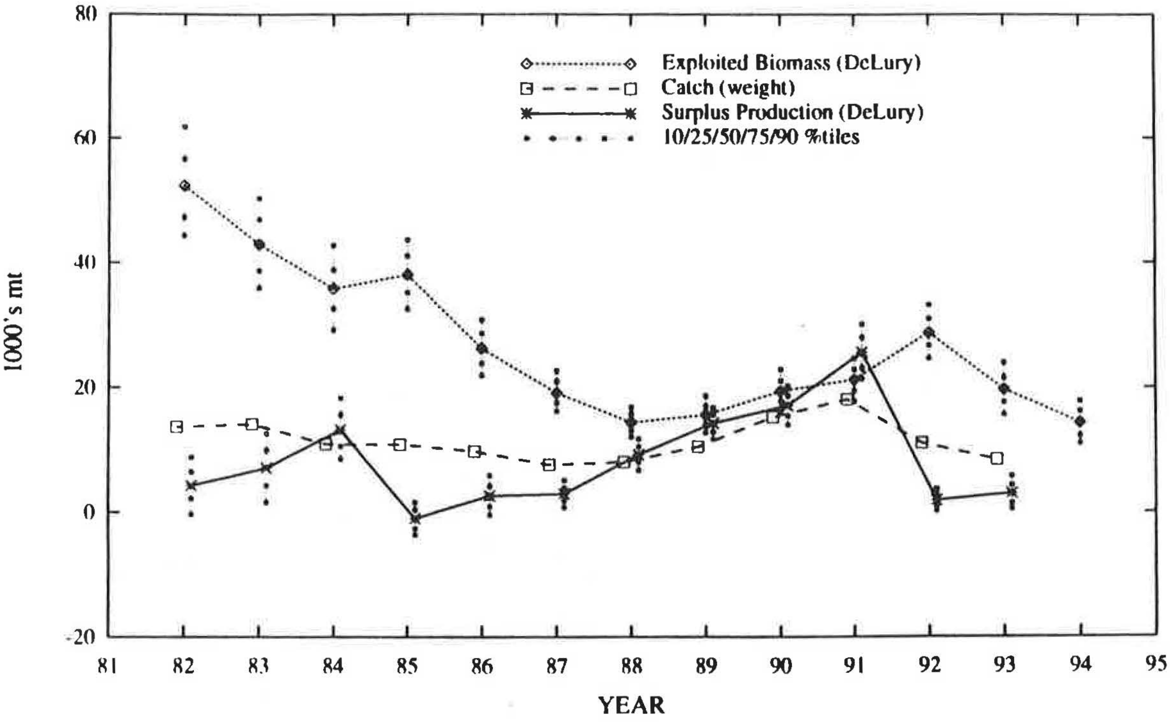


Figure 3.6.3a **Modified DeLury model results - Icelandic cod.**

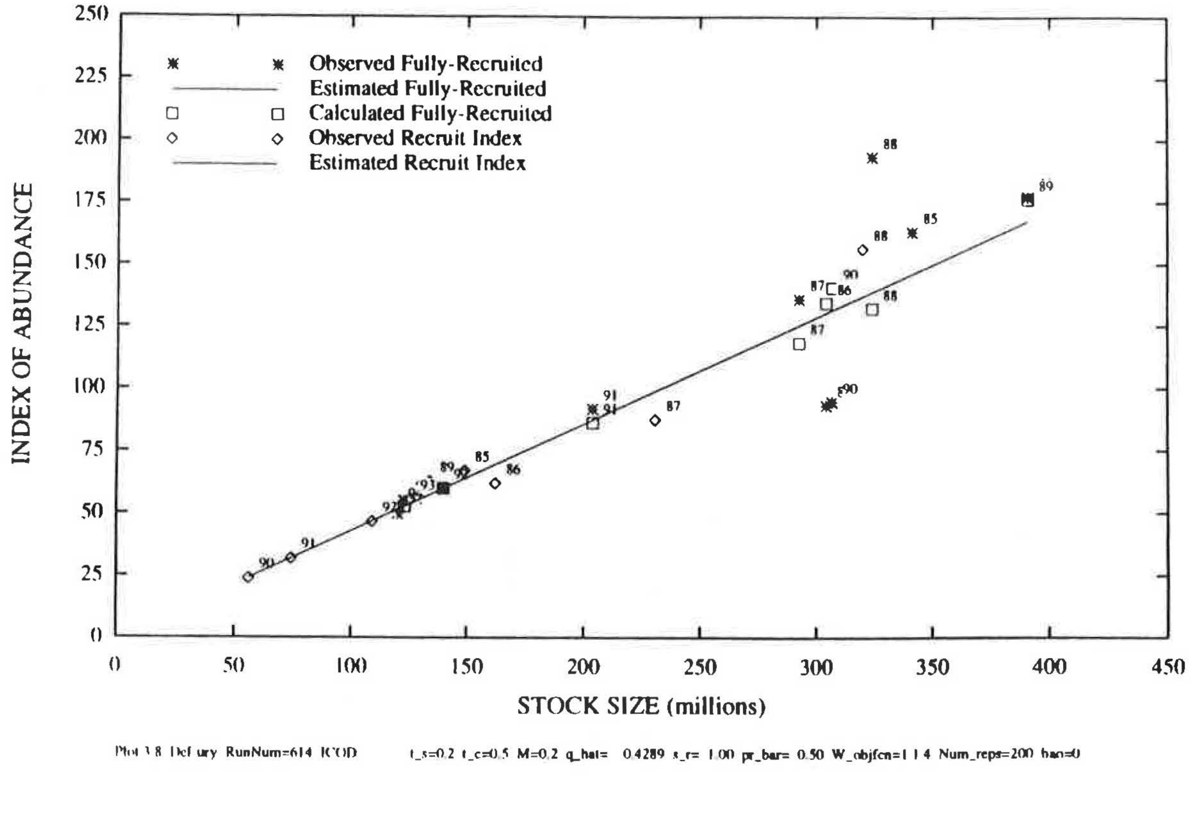


Figure 3.6.3b **Modified DeLury model results - Icelandic cod.**

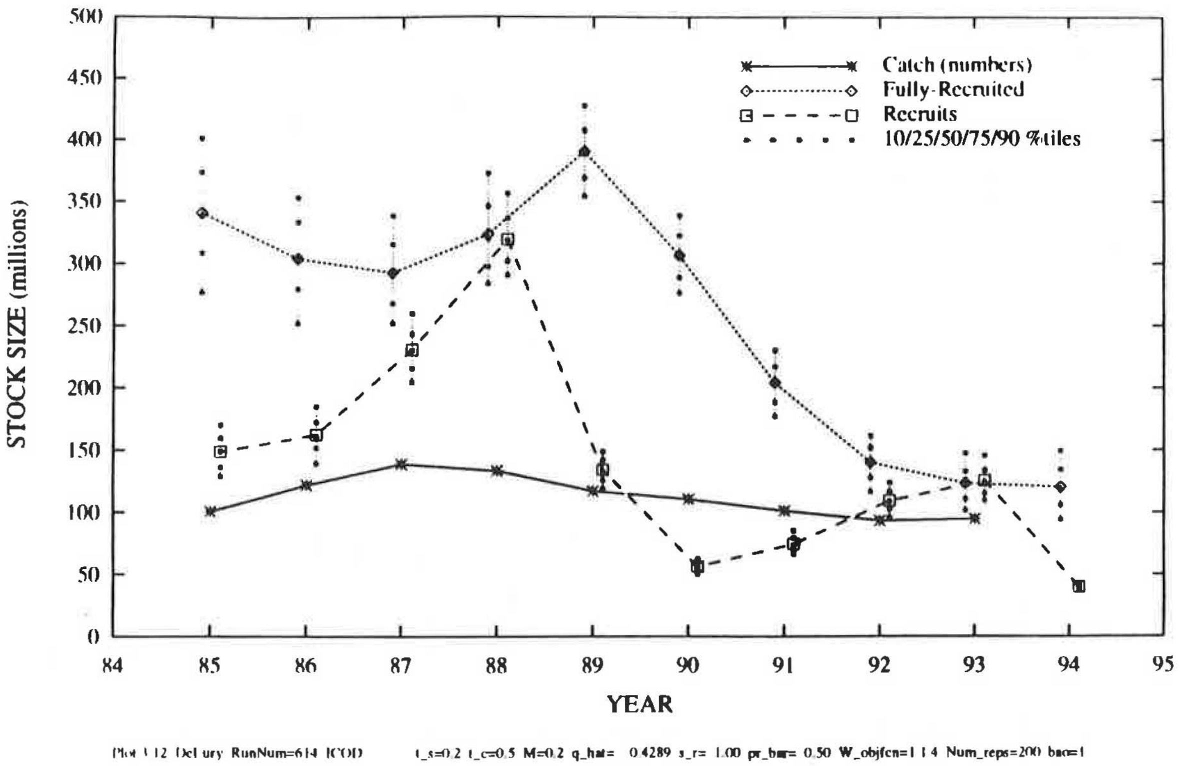


Figure 3.6.3c **Modified DeLury model results - Icelandic cod.**

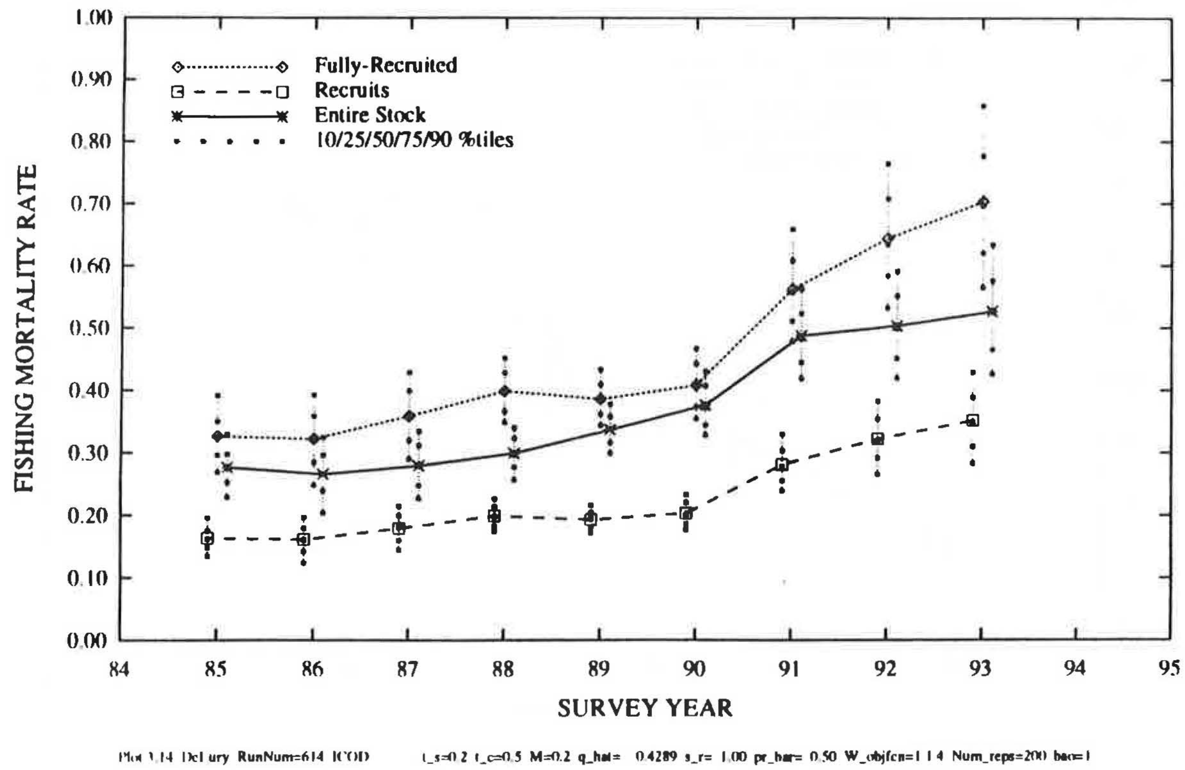


Figure 3.6.3d Modified DeLury model results - Icelandic cod.

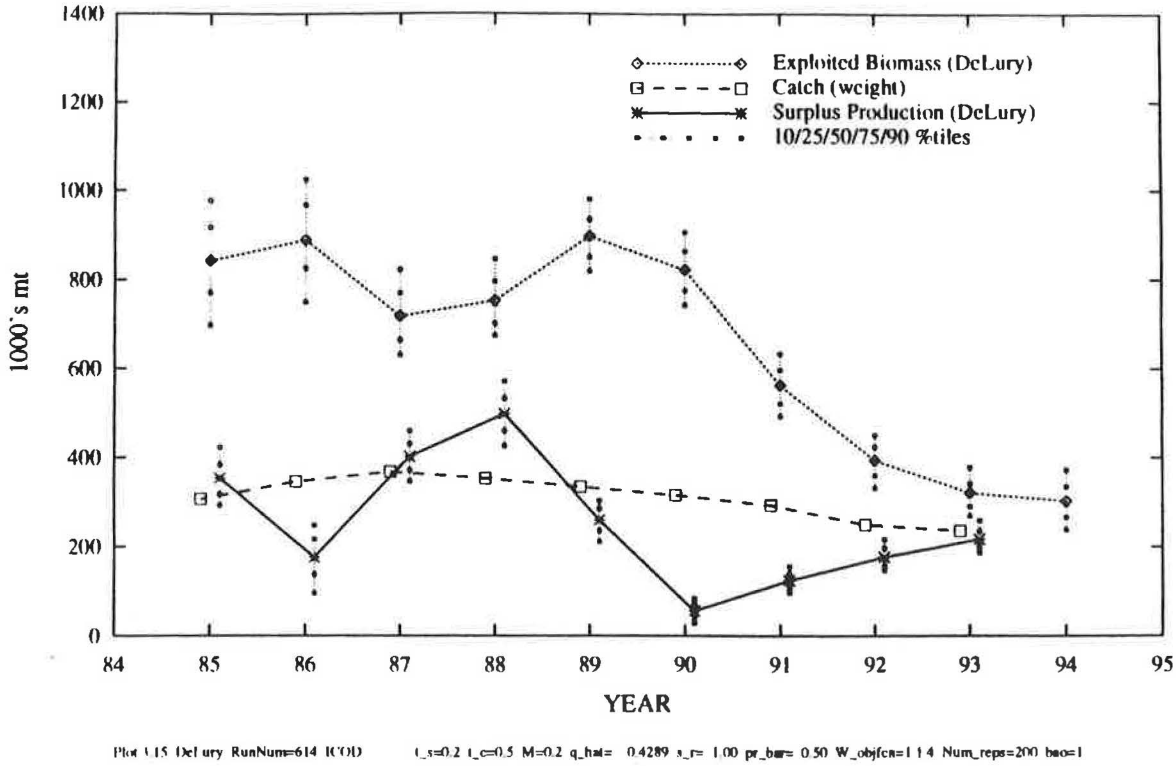


Figure 3.6.4a Modified DeLury model results - Icelandic haddock.

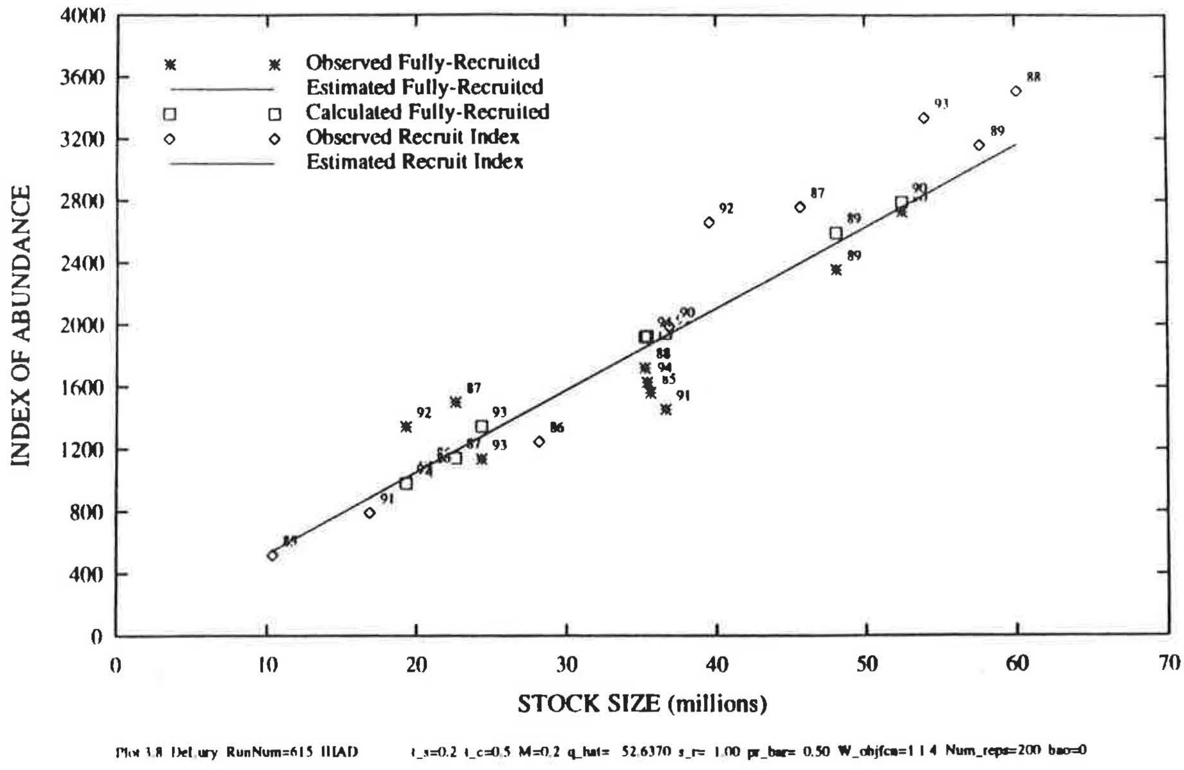


Figure 3.6.4b Modified DeLury model results - Icelandic haddock.

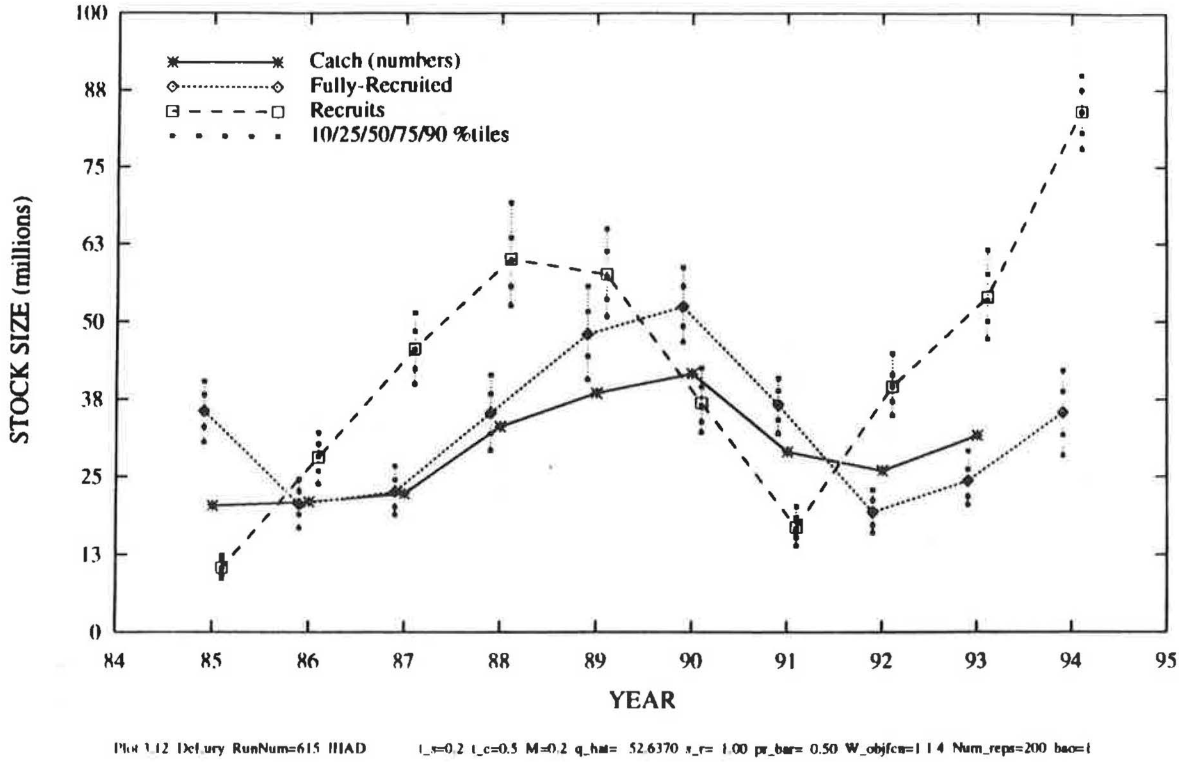


Figure 3.6.4c Modified DeLury model results - Icelandic haddock.

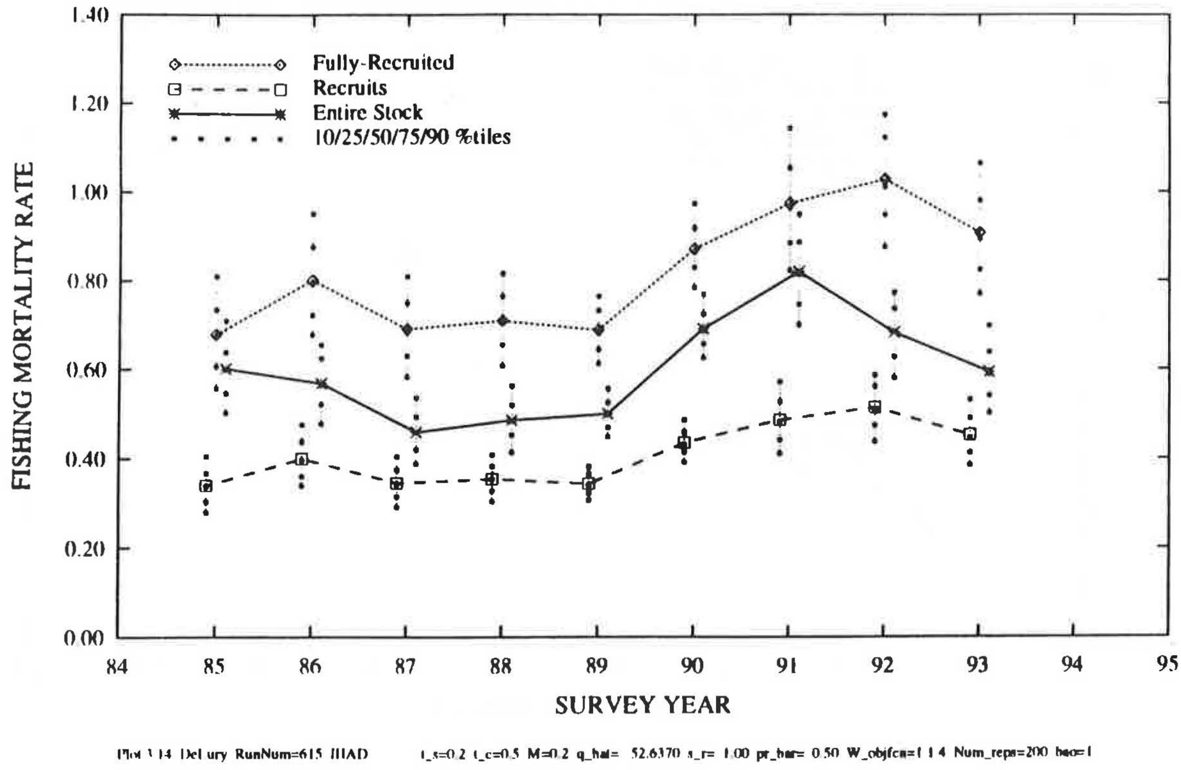


Figure 3.6.4d Modified DeLury model results - Icelandic haddock.

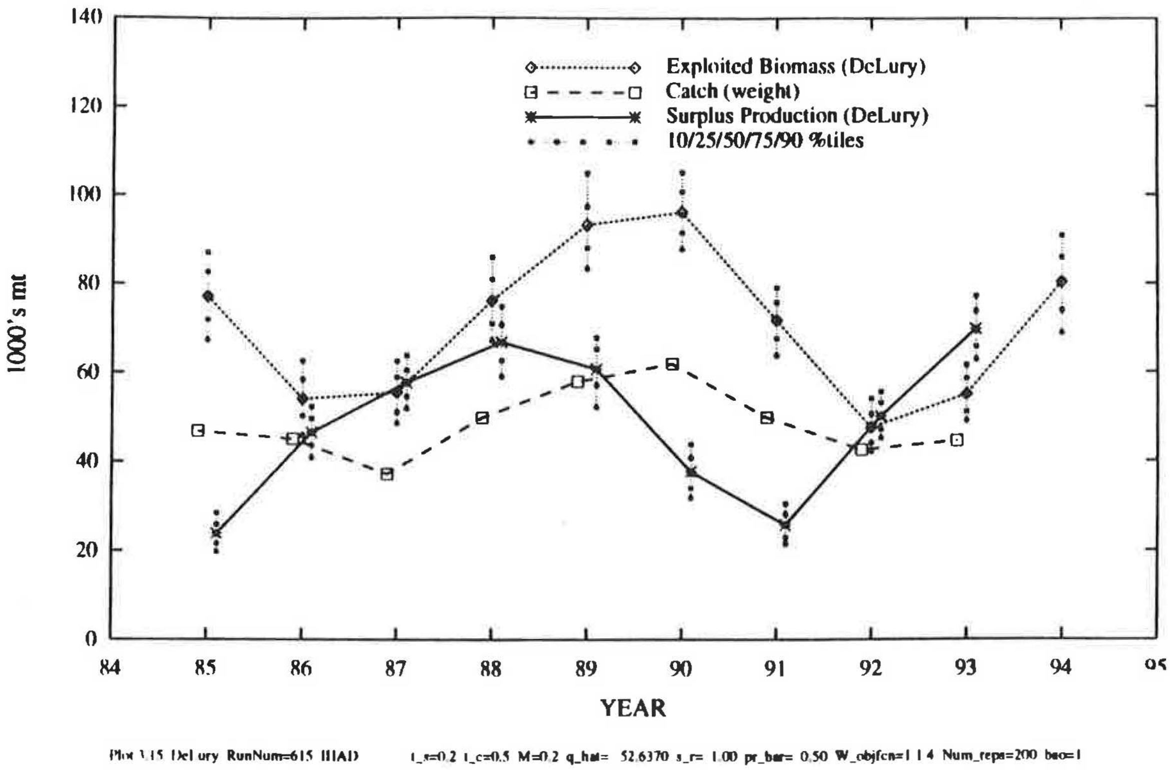


Figure 3.6.5a Modified DeLury model results - Icelandic redfish (S. marinus).

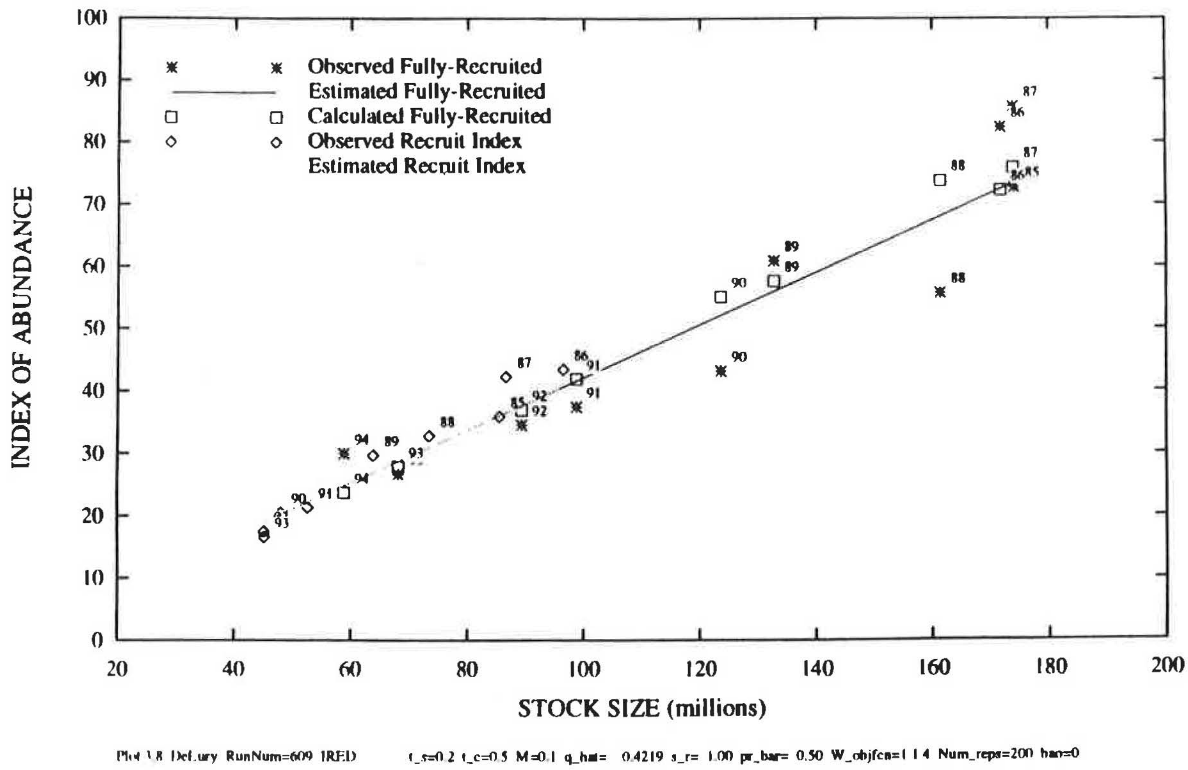


Figure 3.6.5b Modified DeLury model results - Icelandic redfish (S. marinus).

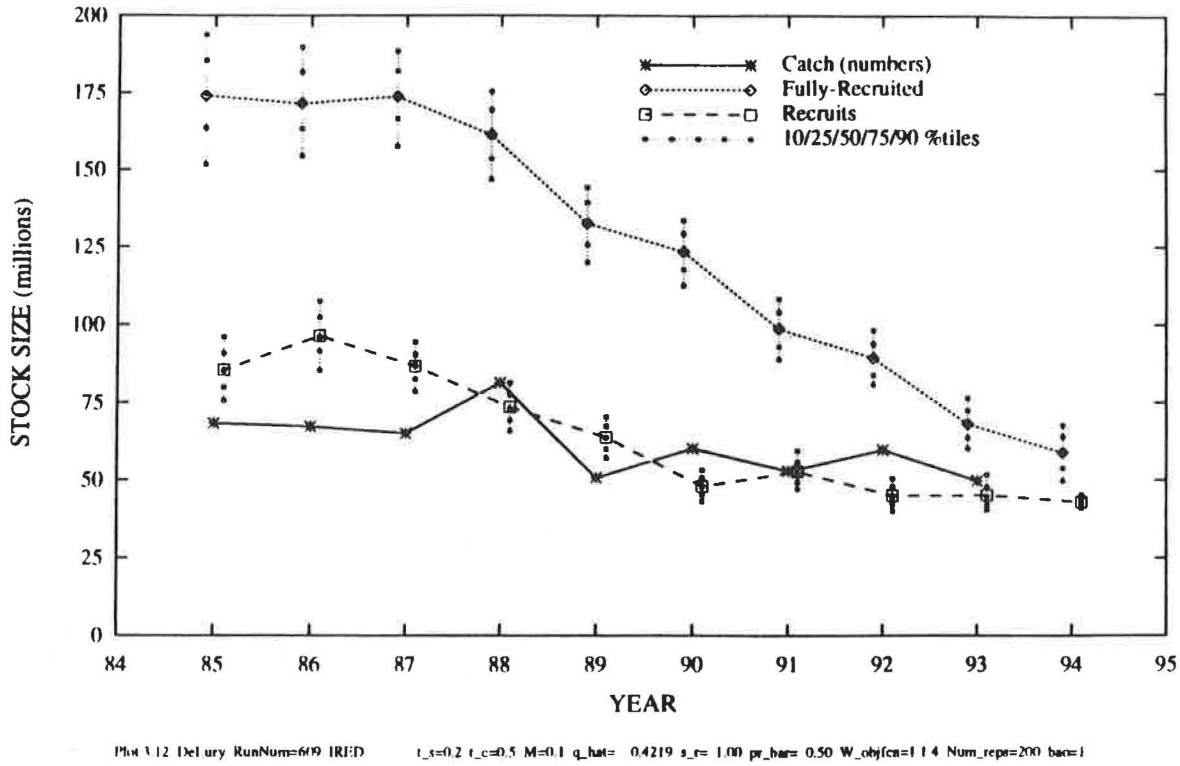


Figure 3.6.5c Modified DeLury model results - Icelandic redfish (S. marinus).

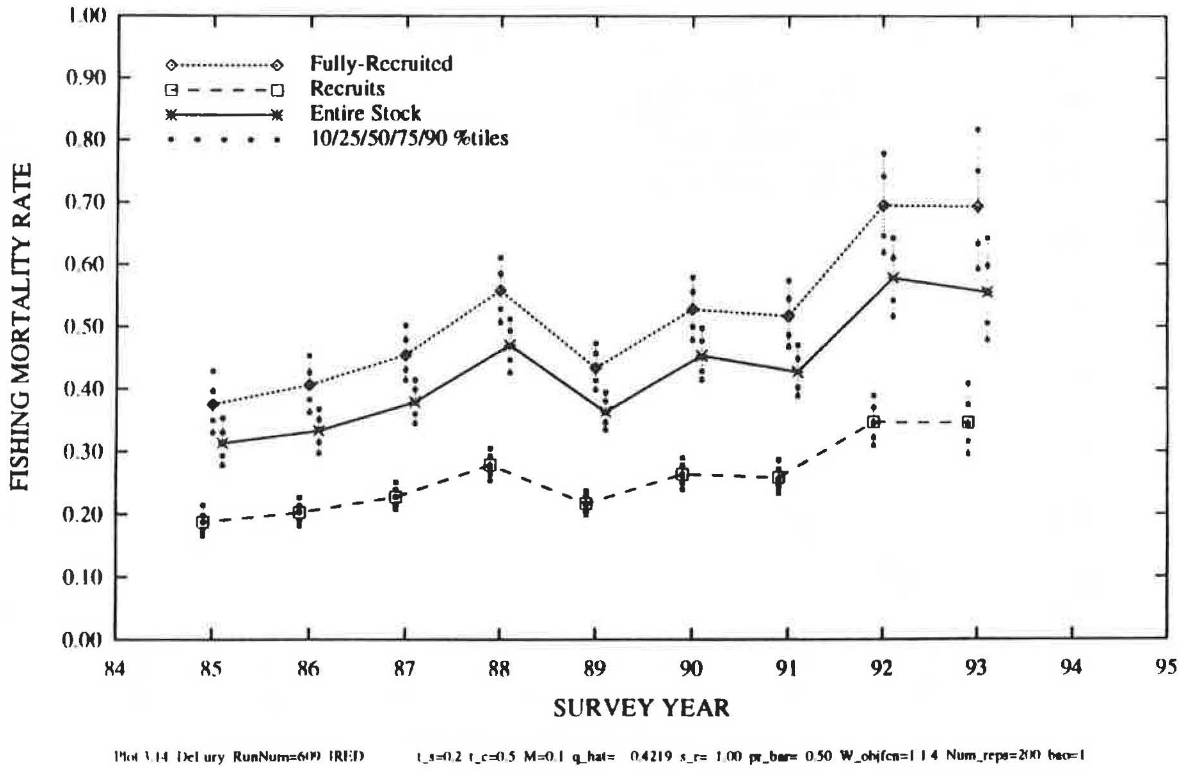


Figure 3.6.5d Modified DeLury model results - Icelandic redfish (S. marinus).

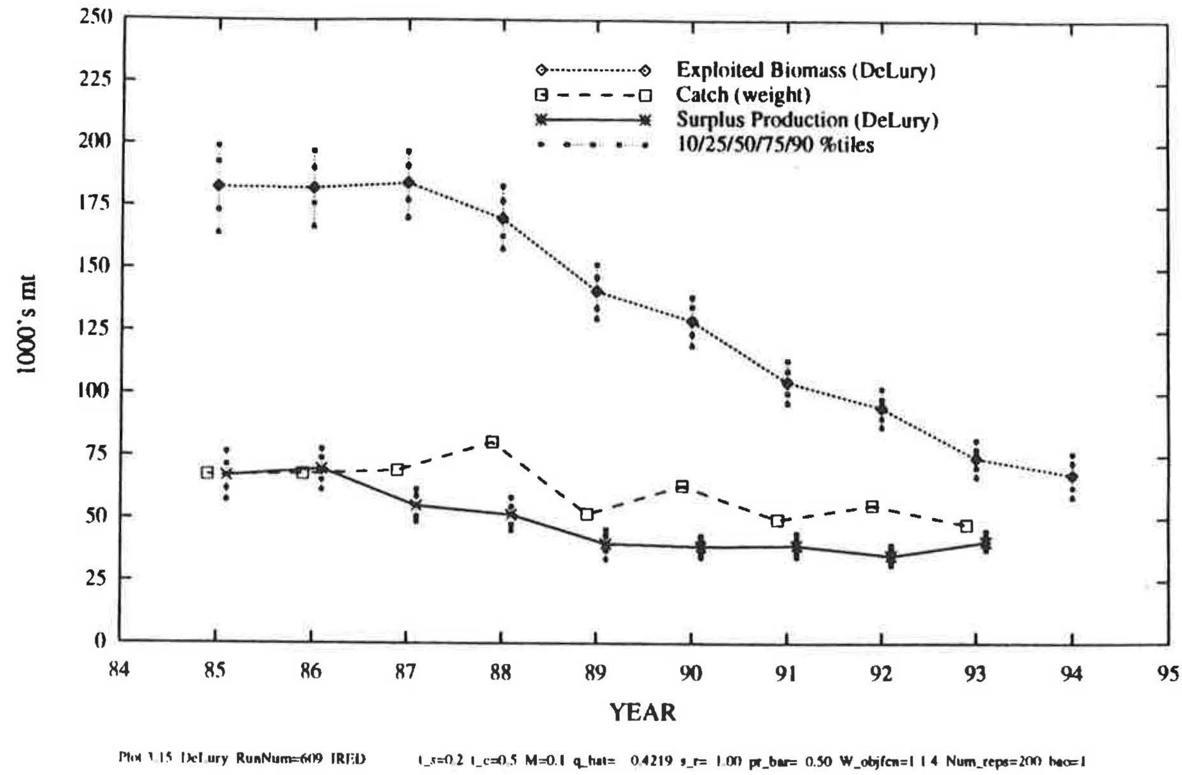


Figure 3.6.6a Modified DeLury model results - Canadian redfish.

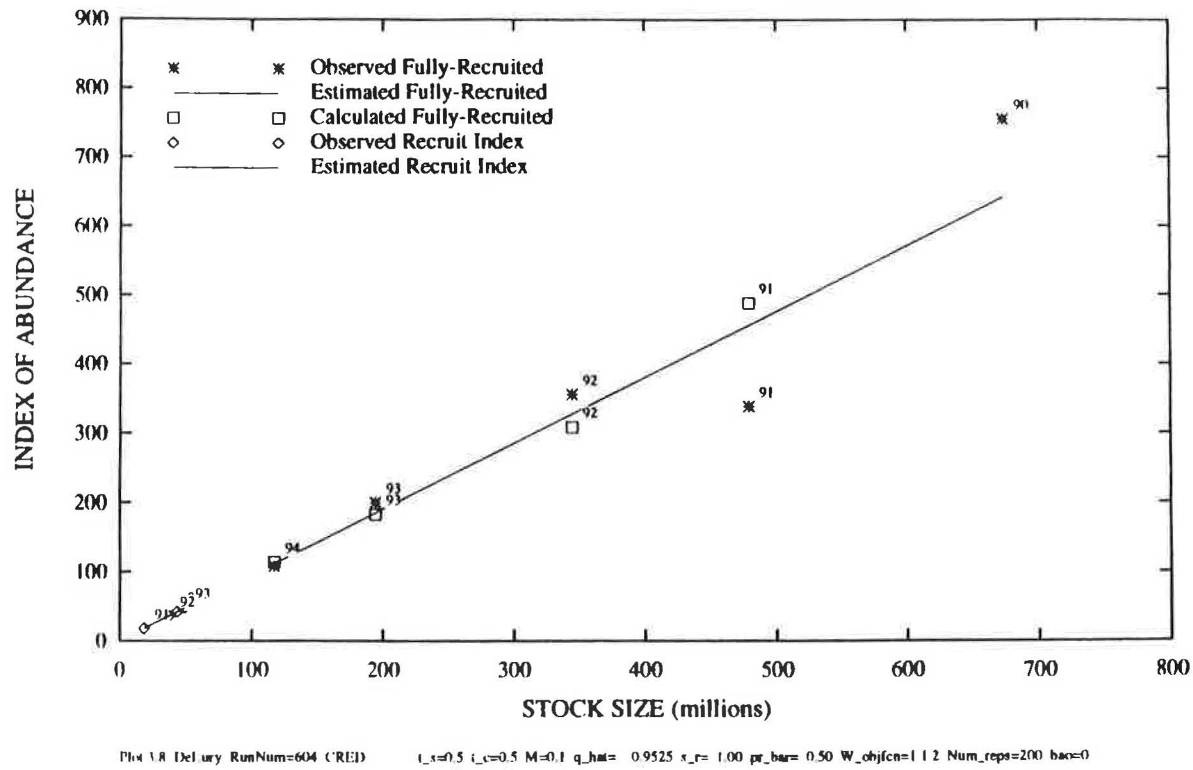


Figure 3.6.6b Modified DeLury model results - Canadian redfish.

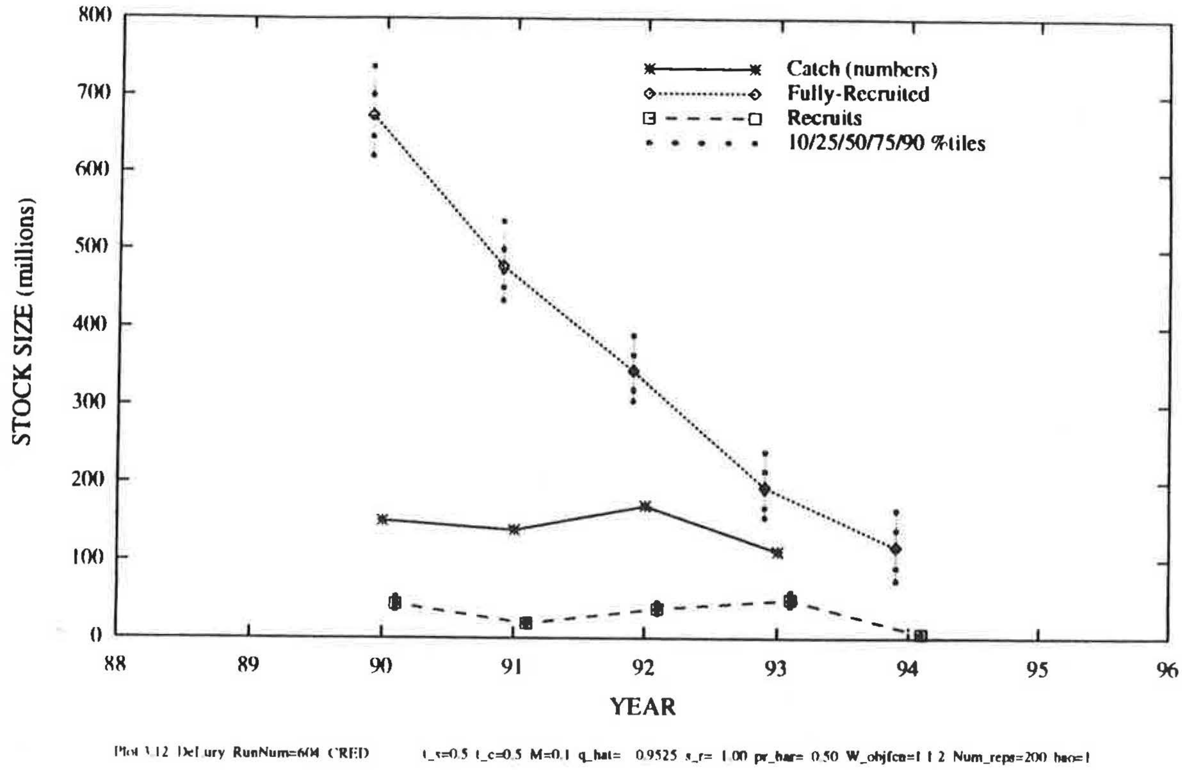


Figure 3.6.6c Modified DeLury model results - Canadian redfish.

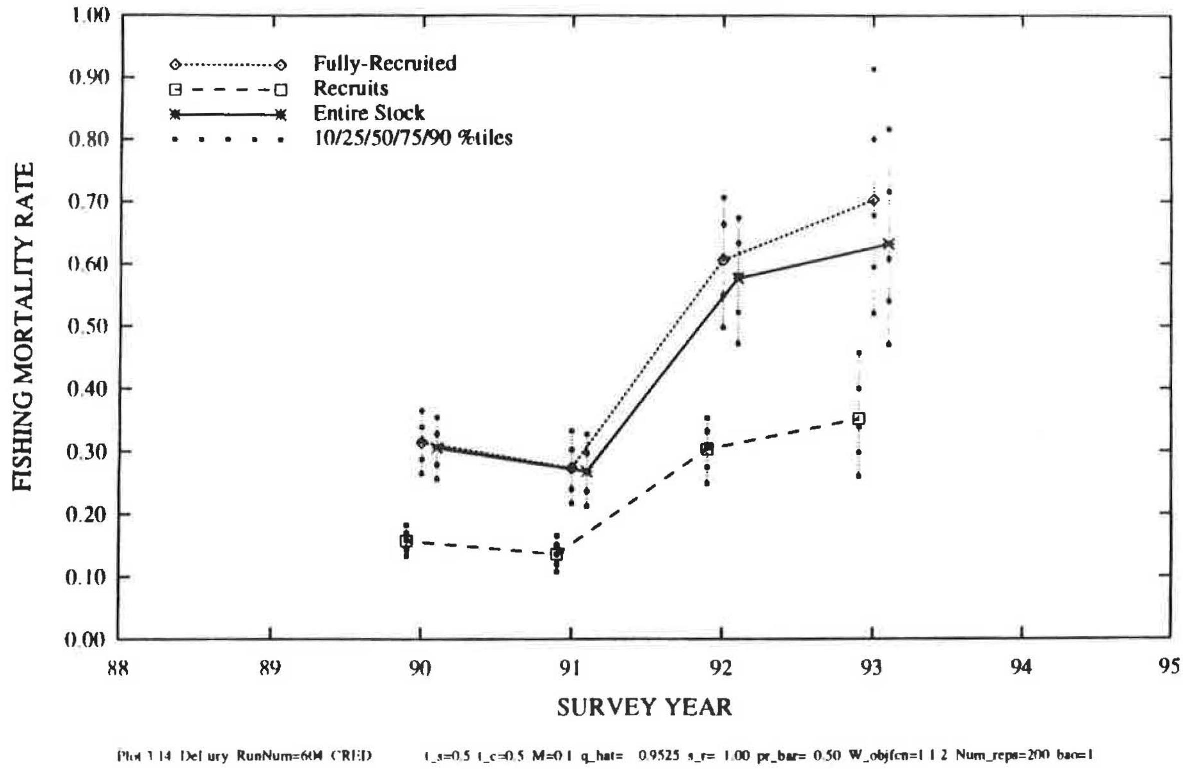


Figure 3.6.6d Modified DeLury model results - Canadian redfish.

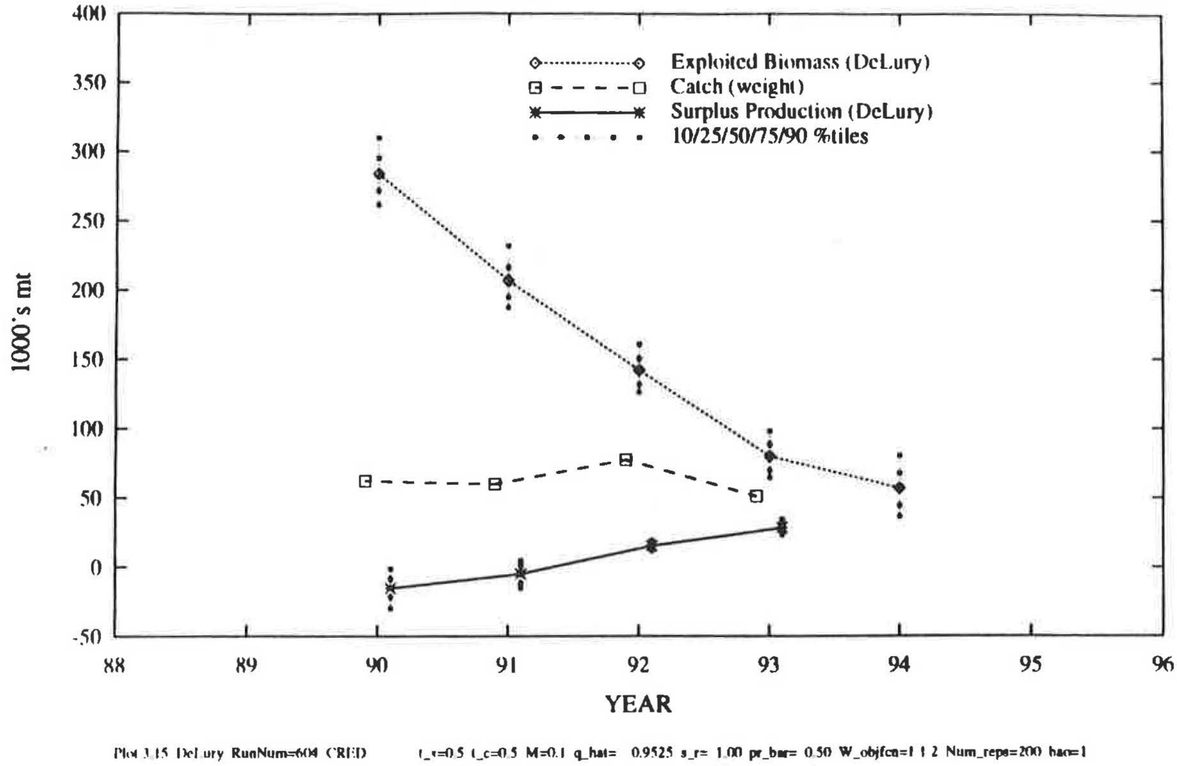


Figure 4.3.1 GOM Cod Slicing and SP-Key residual pattern.

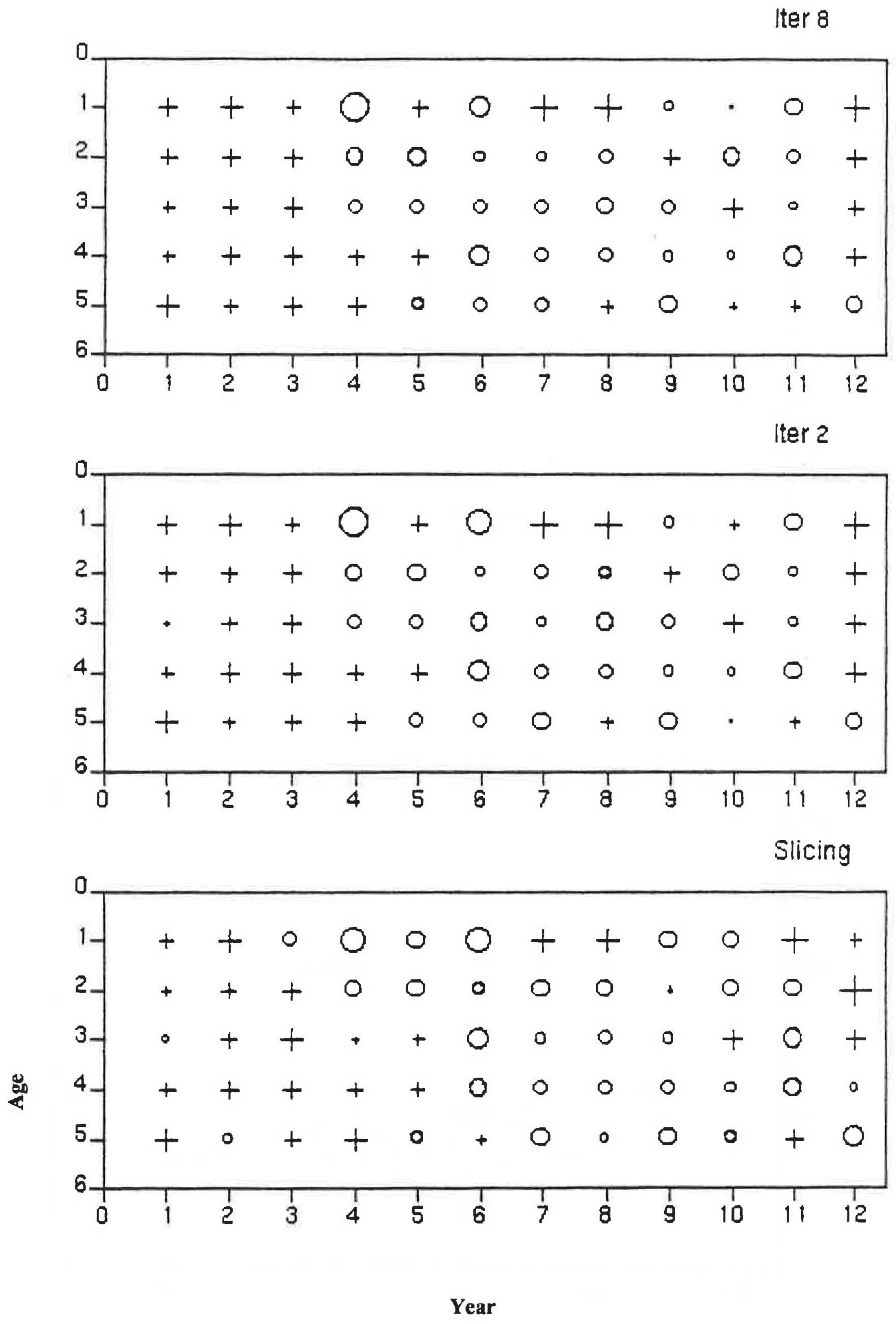
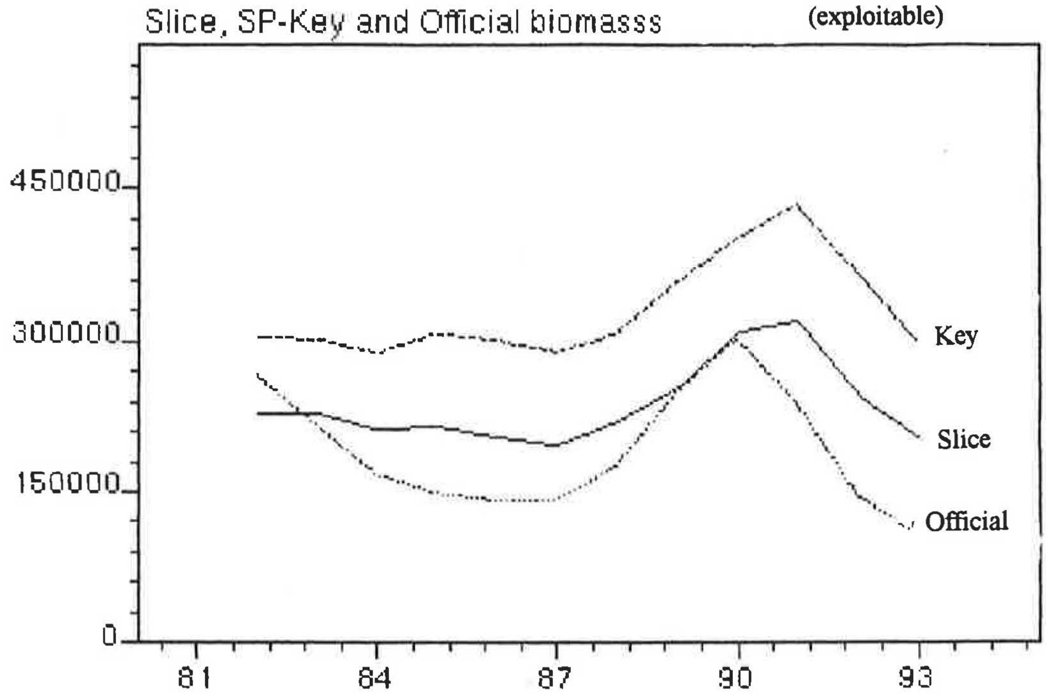


Figure 4.3.2 GOM cod slicing and SP-key estimates of B and F.



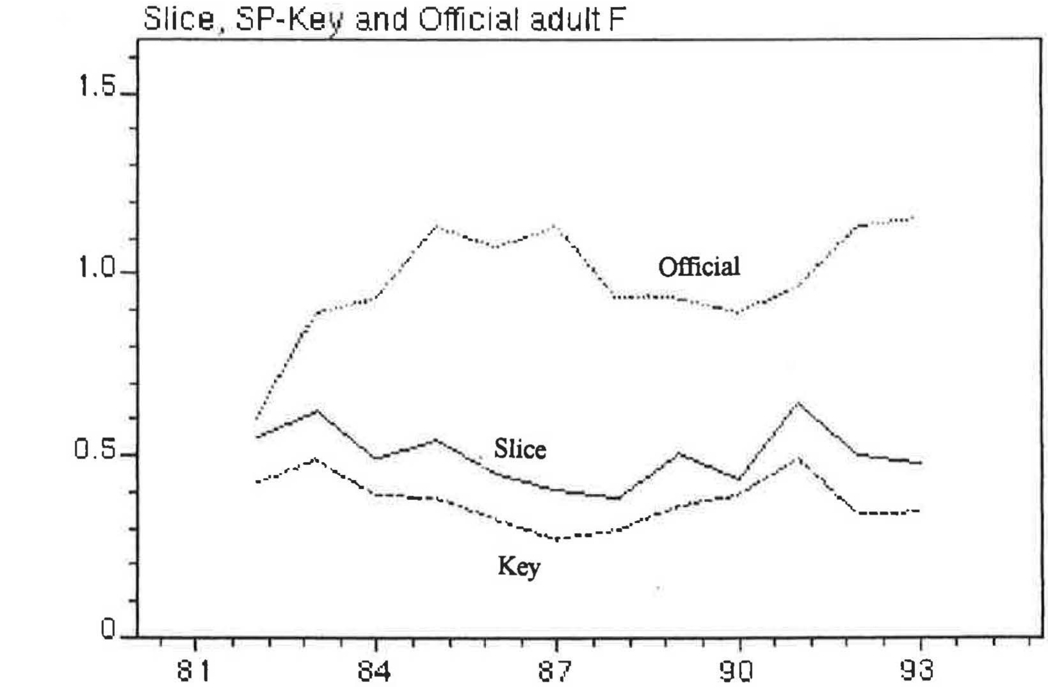
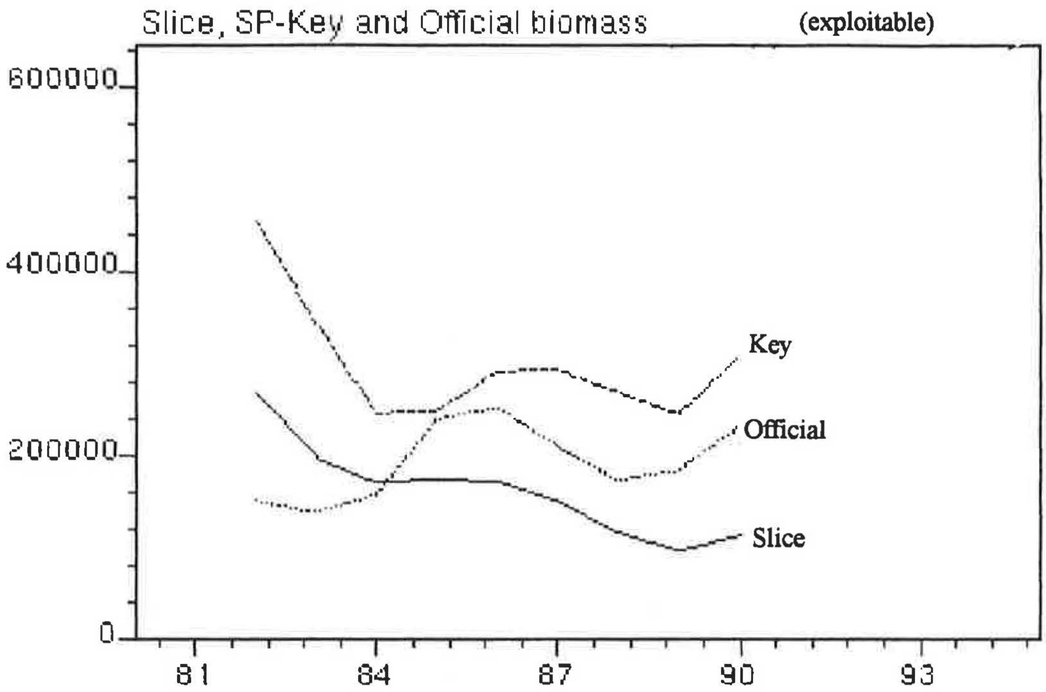


Figure 4.3.3 Iceland haddock Slicing and SP-Key estiamtes



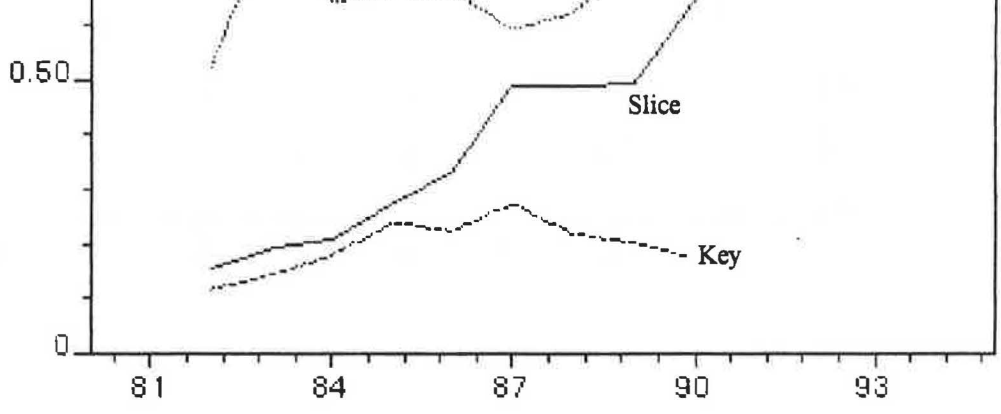


Figure 4.3.4 IHAD slicing and SP-key residuals.

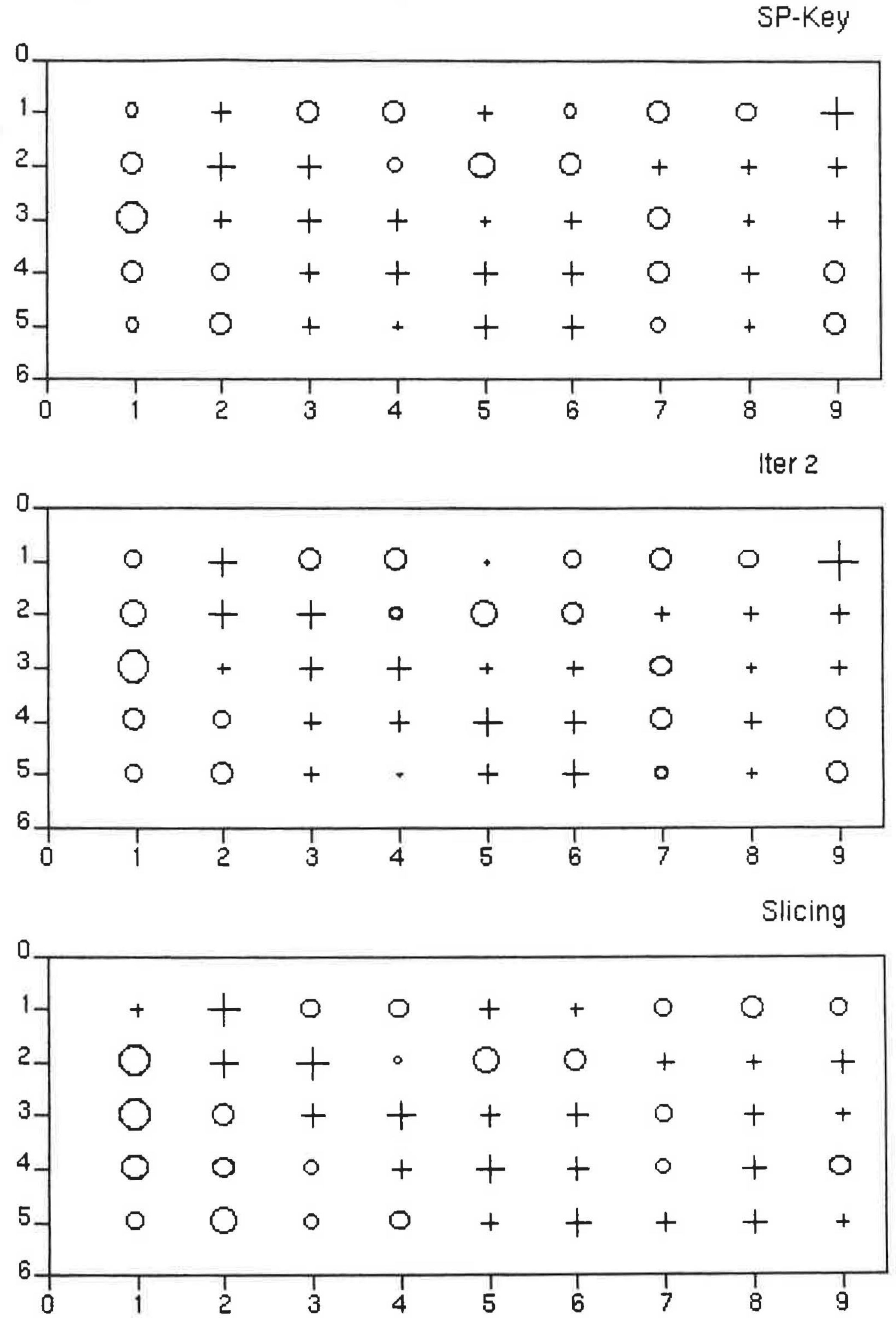
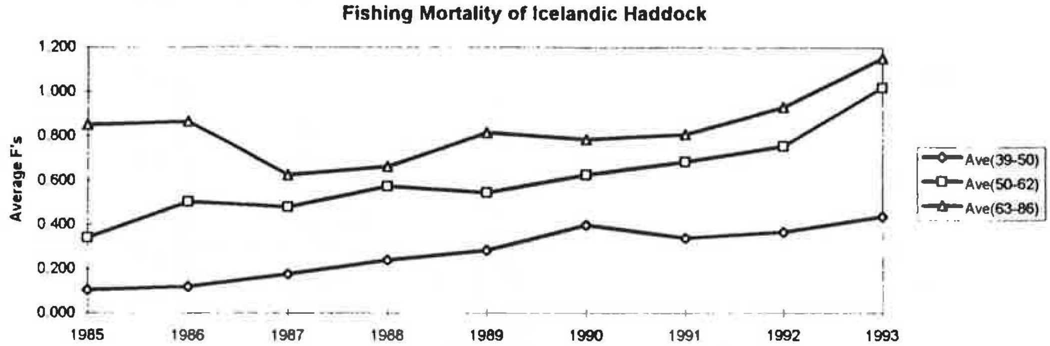


Figure 4.5.1 Time Series Estimates of Catch-at-Length.



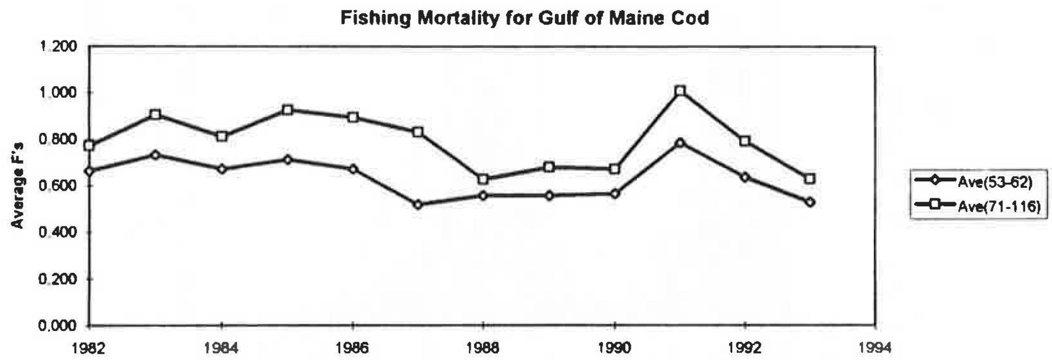


Figure 4.6.1 **Unit 1 Redfish: trends over time**

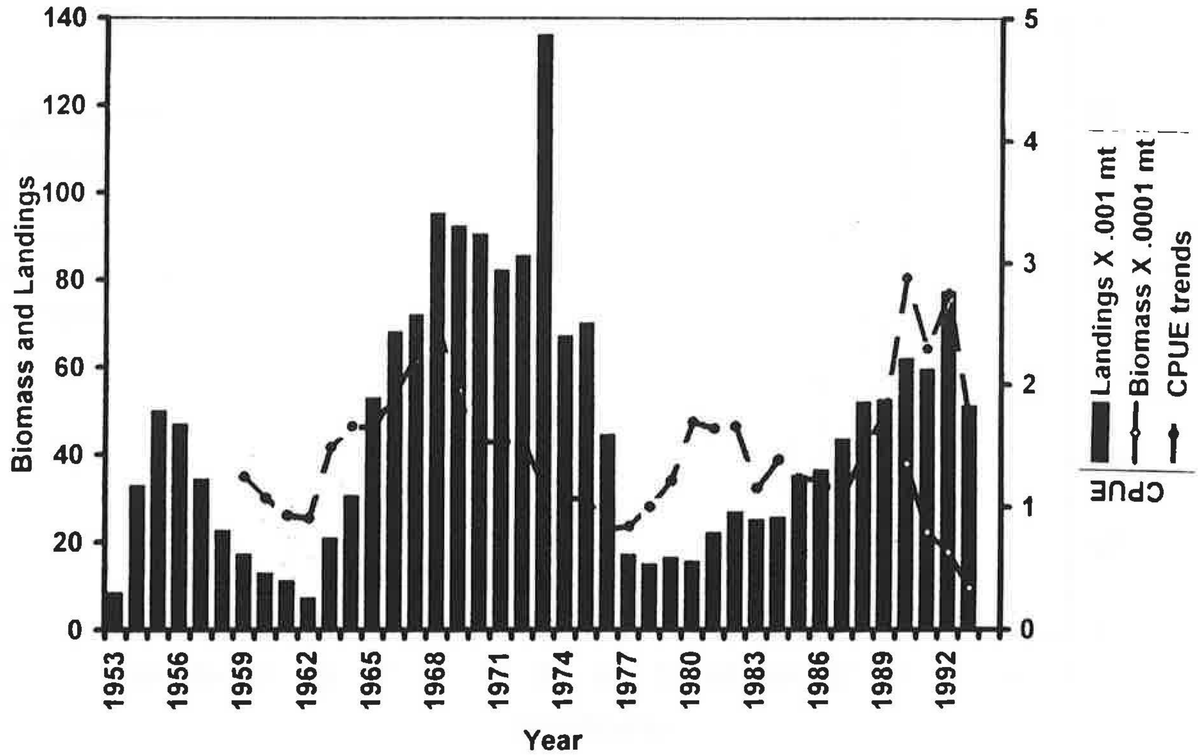


Figure 4.6.2

Defining selectivity curve

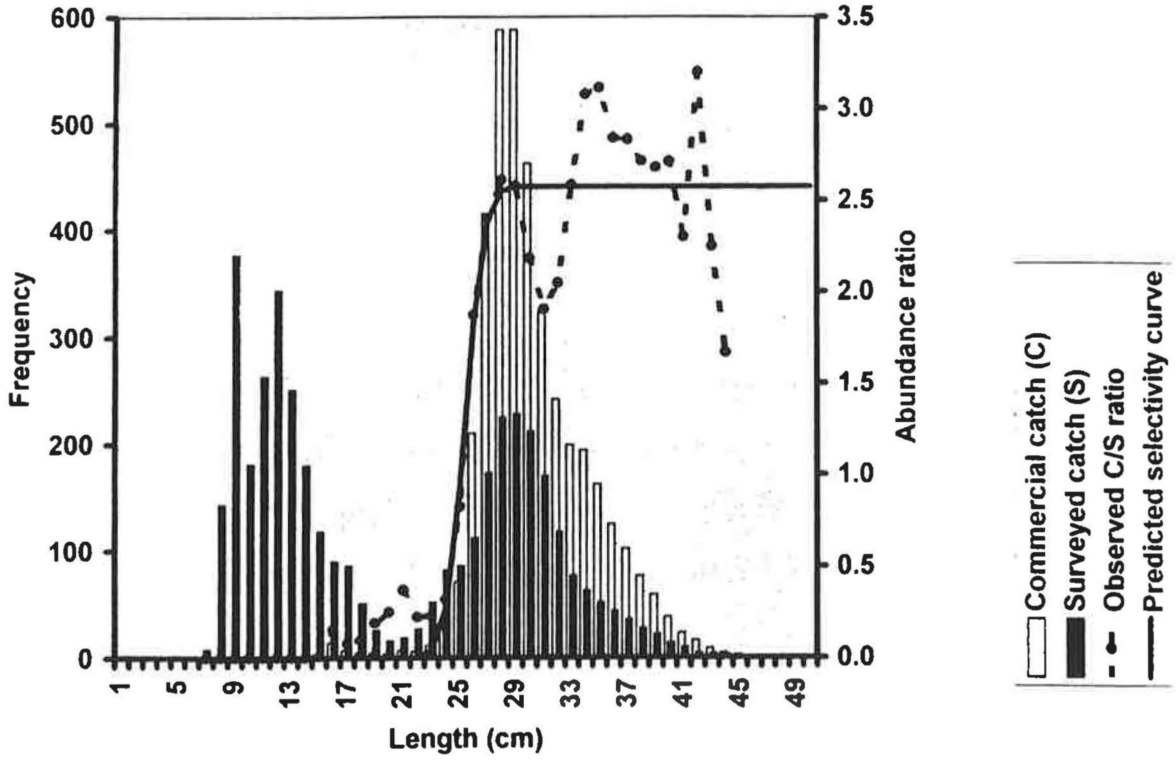


Figure 4.6.3 Unit 1 Redfish: surveyed frequencies by year and averaged over years 1990-94

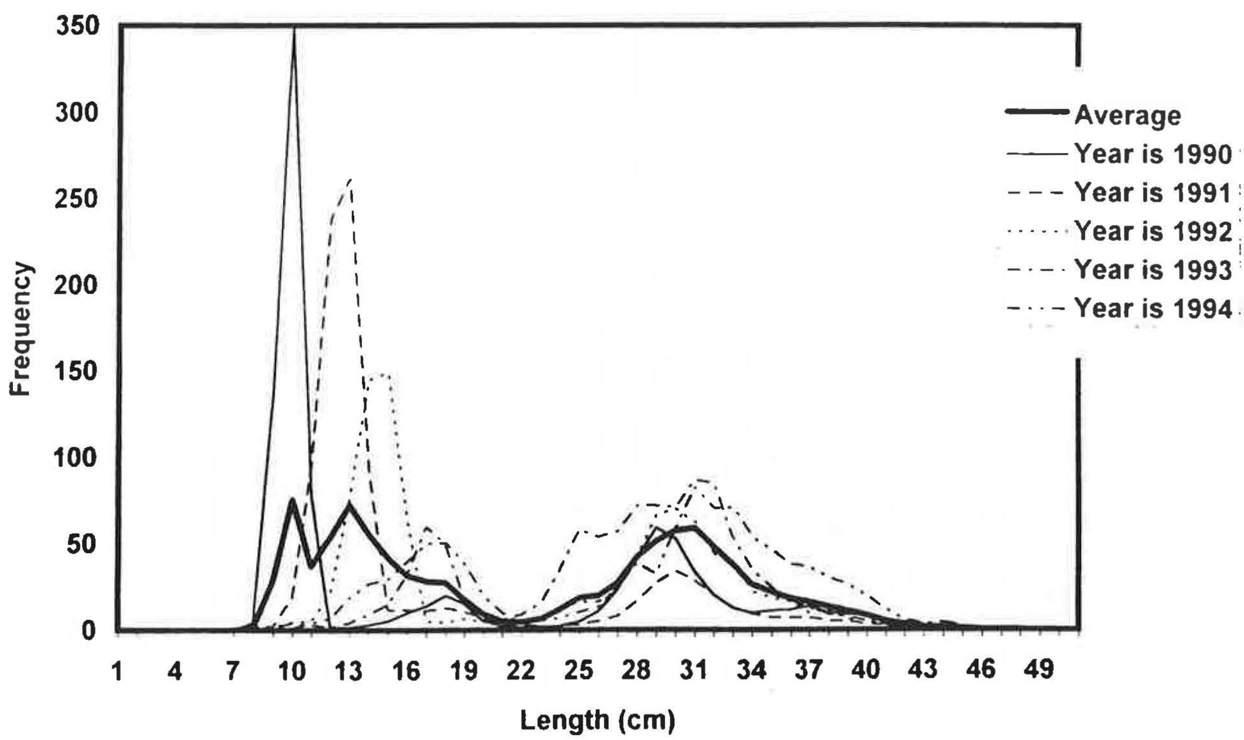


Figure 4.6.4 **Unit 1 Redfish: surveyed observed and predicted length frequencies**

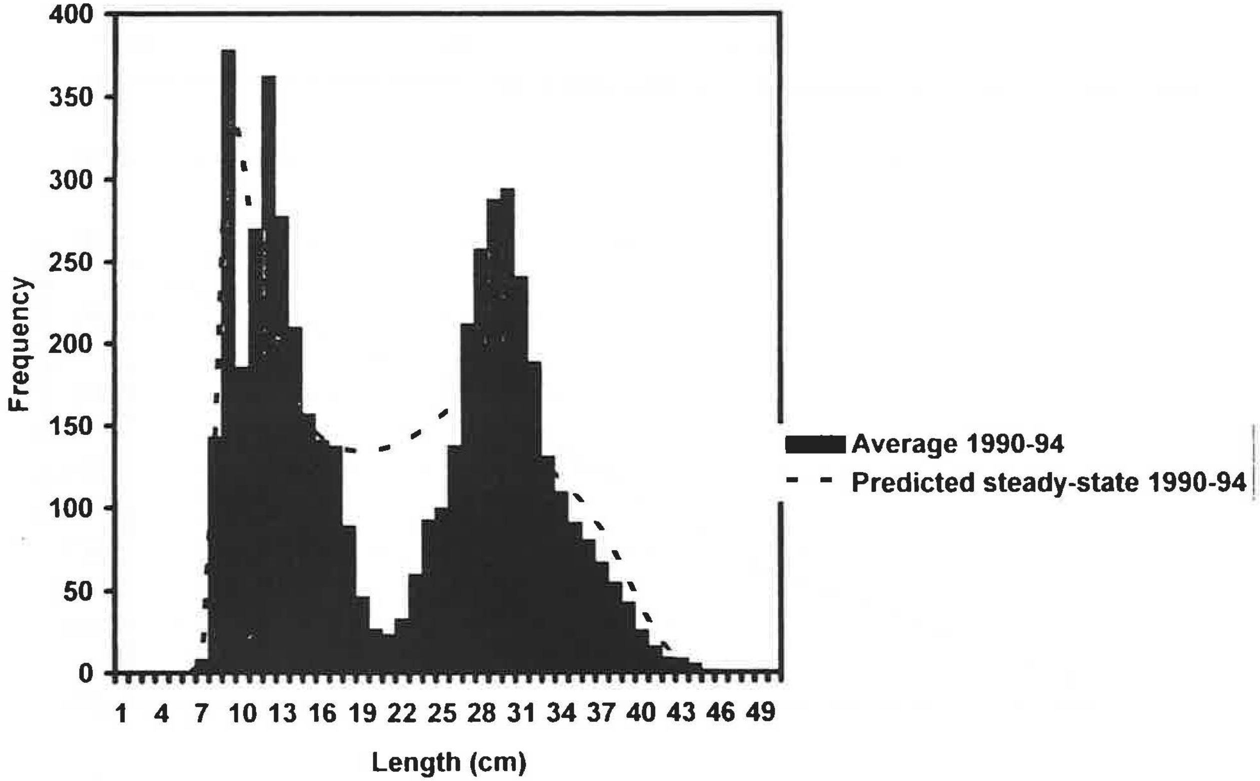


Figure 4.6.5 Unit 1 Redfish: harvest rate relative to 100% for the 1990-93 average

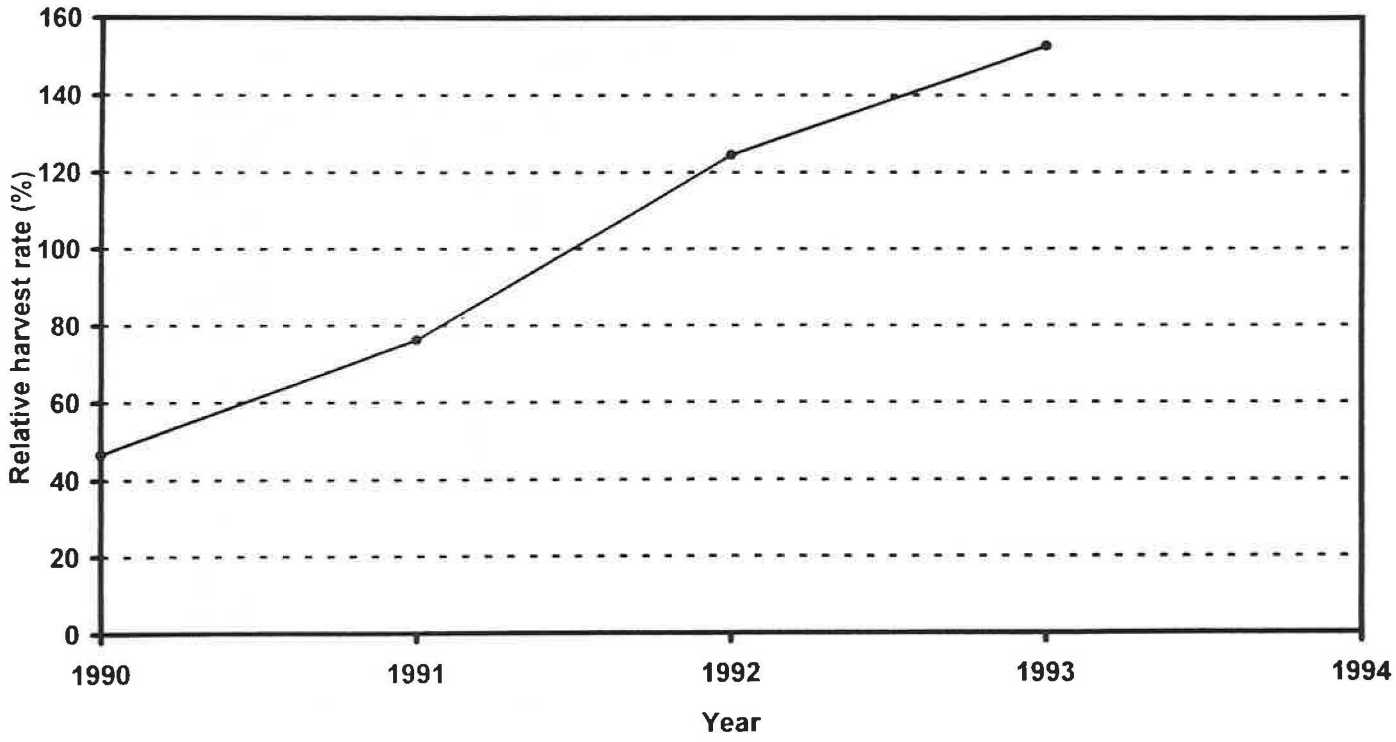


Figure 4.6.6a Unit 1 Redfish: observed and predicted length frequencies for 1990

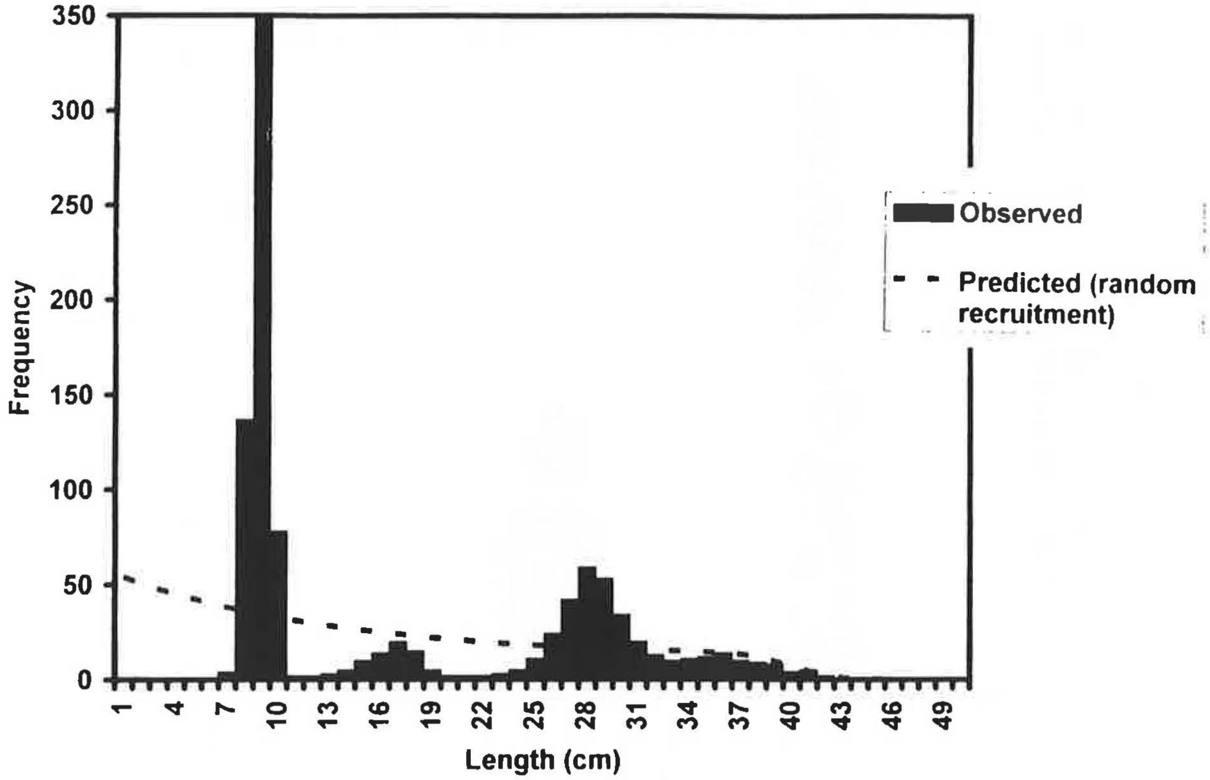


Figure 4.6.6b Unit 1 Redfish: observed and predicted length frequencies for 1991

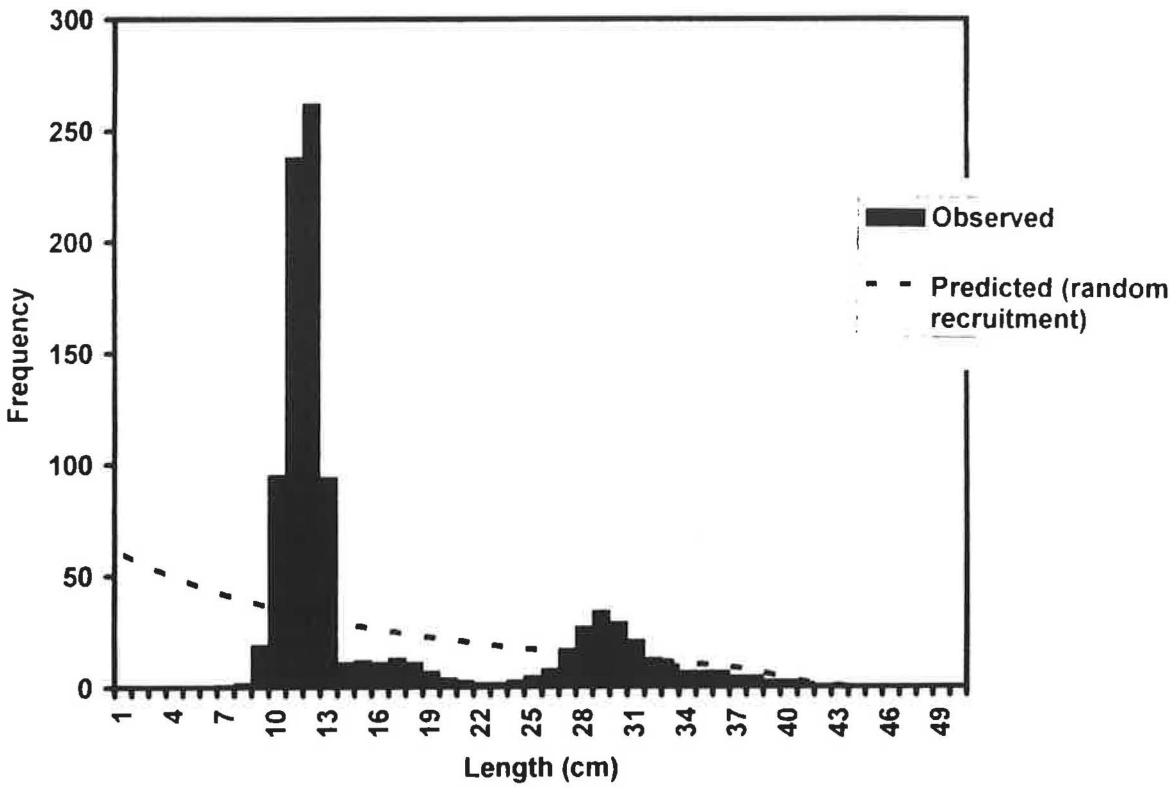


Figure 4.6.6c Unit 1 Redfish: observed and predicted length frequencies for 1992

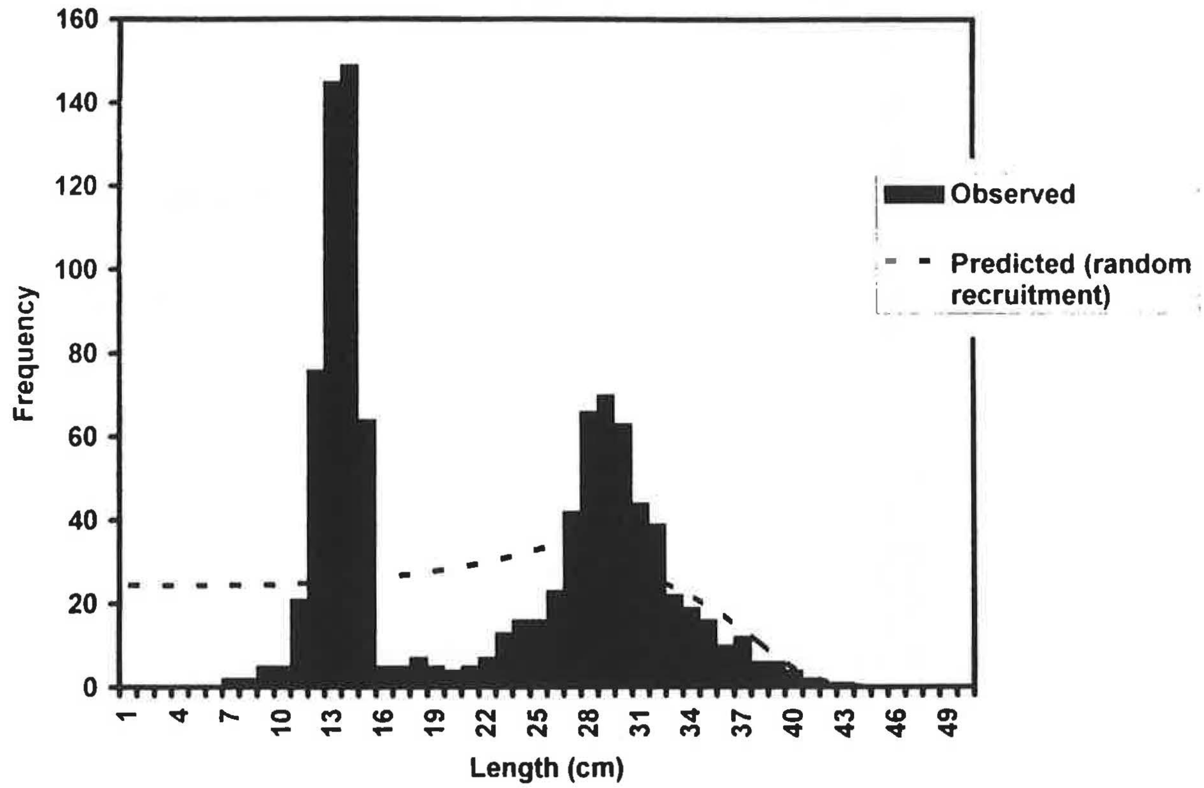


Figure 4.6.6d Unit 1 Redfish: observed and predicted length frequencies for 1993

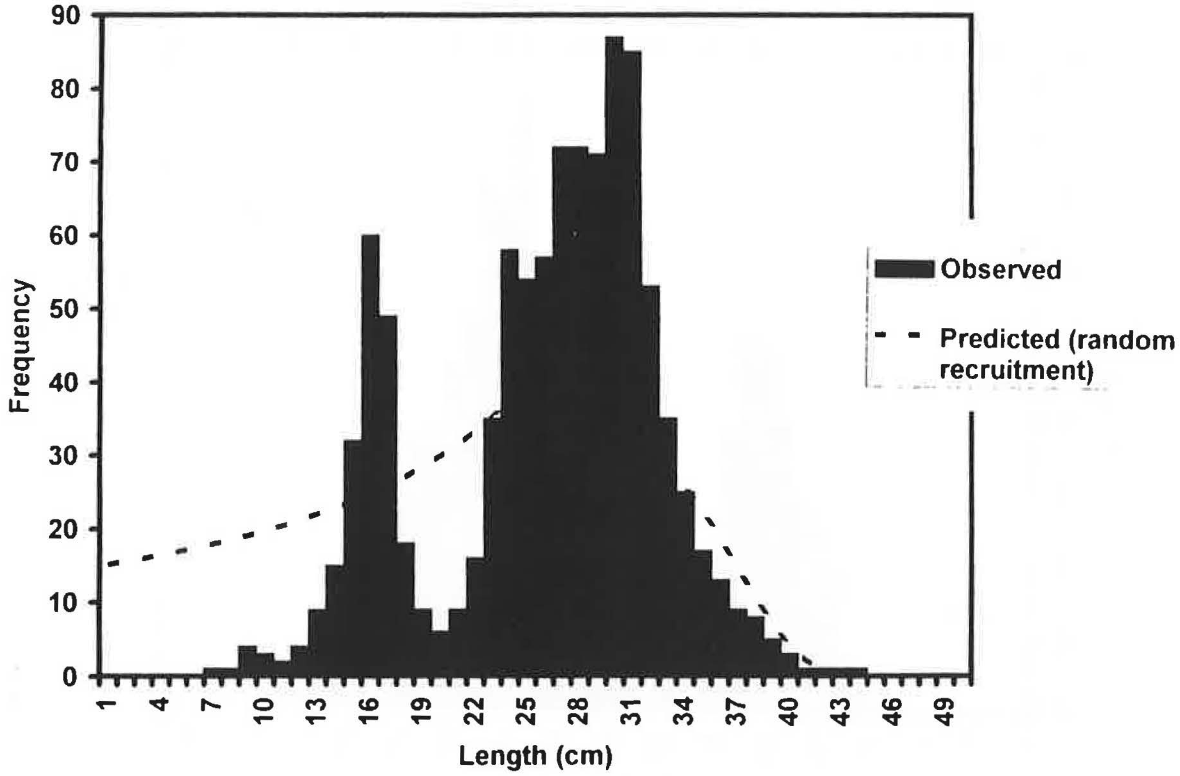


Figure 4.6.6e Unit 1 Redfish: observed and predicted length frequencies for 1994

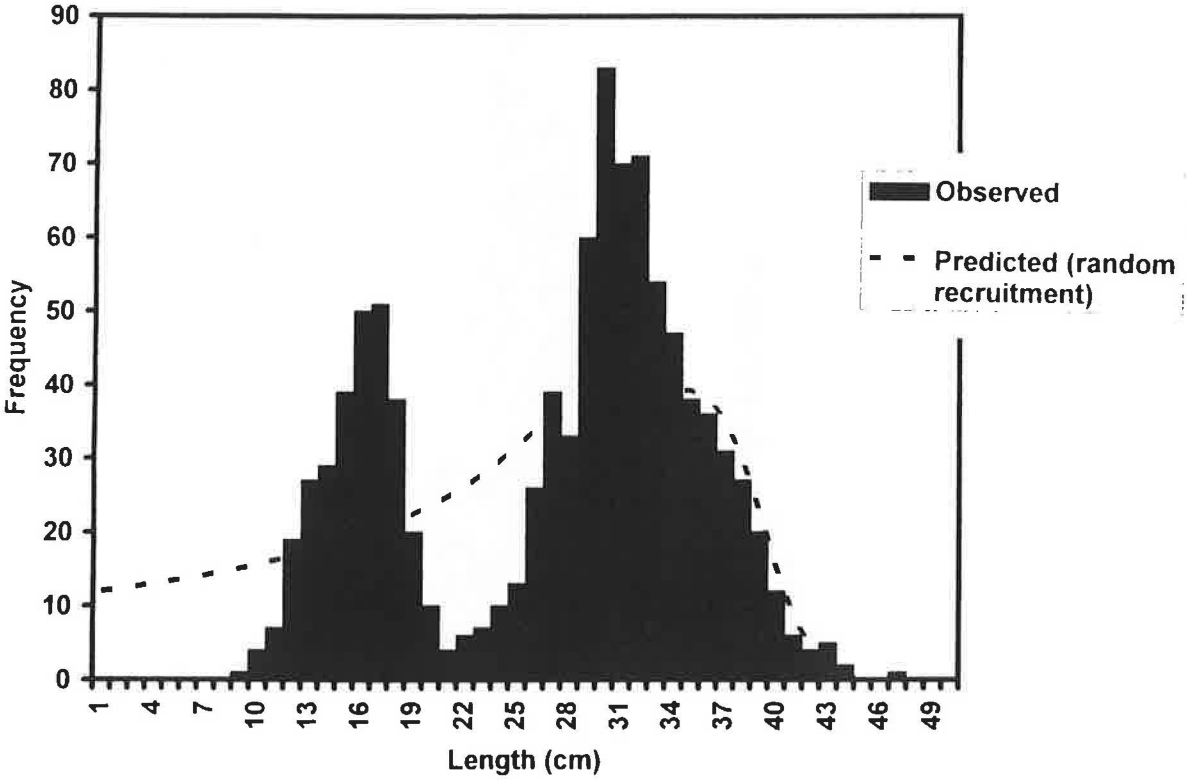


Fig. 5.2.1.North Sea Haddock. Stock trends estimated from surveys and VPA

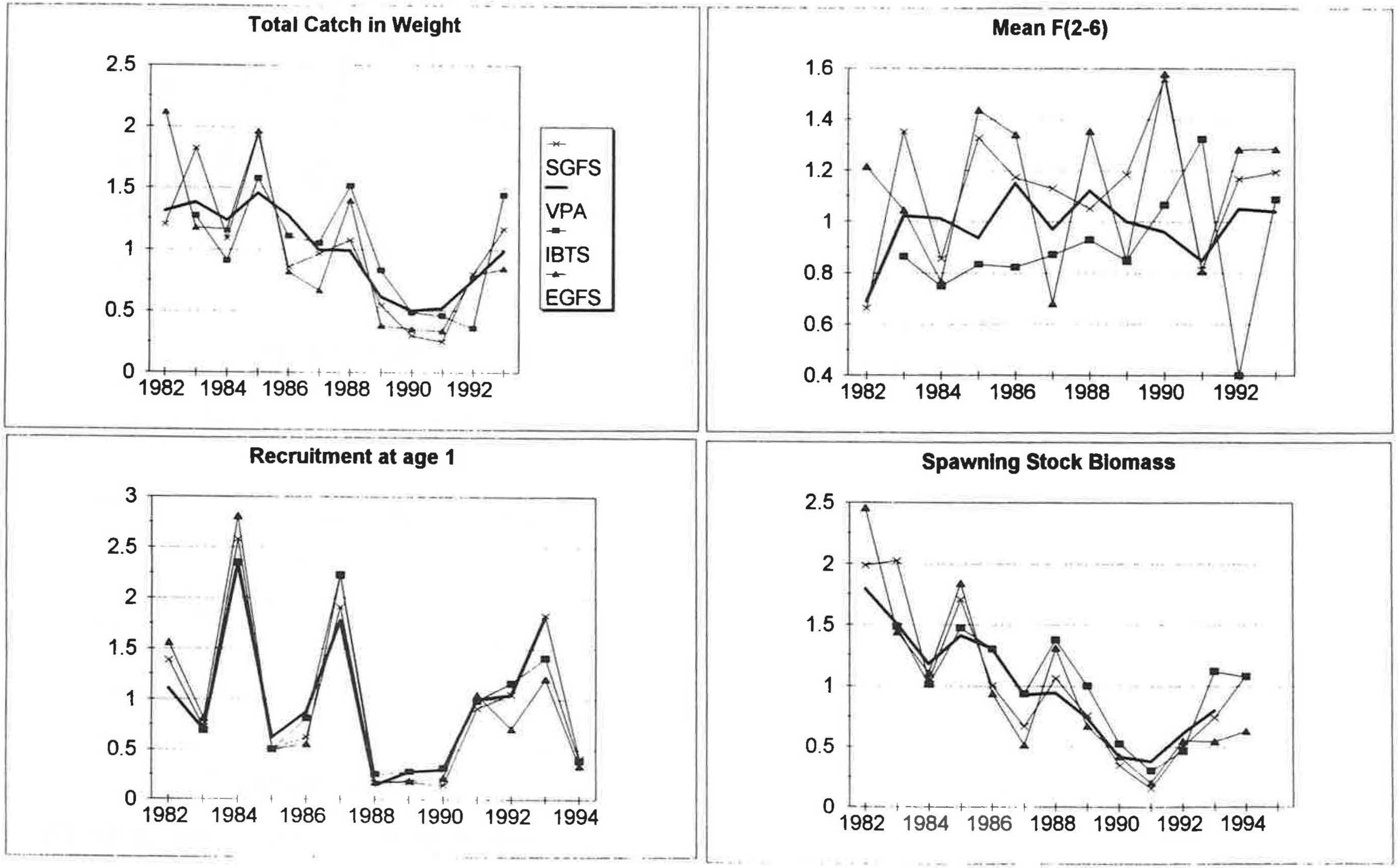
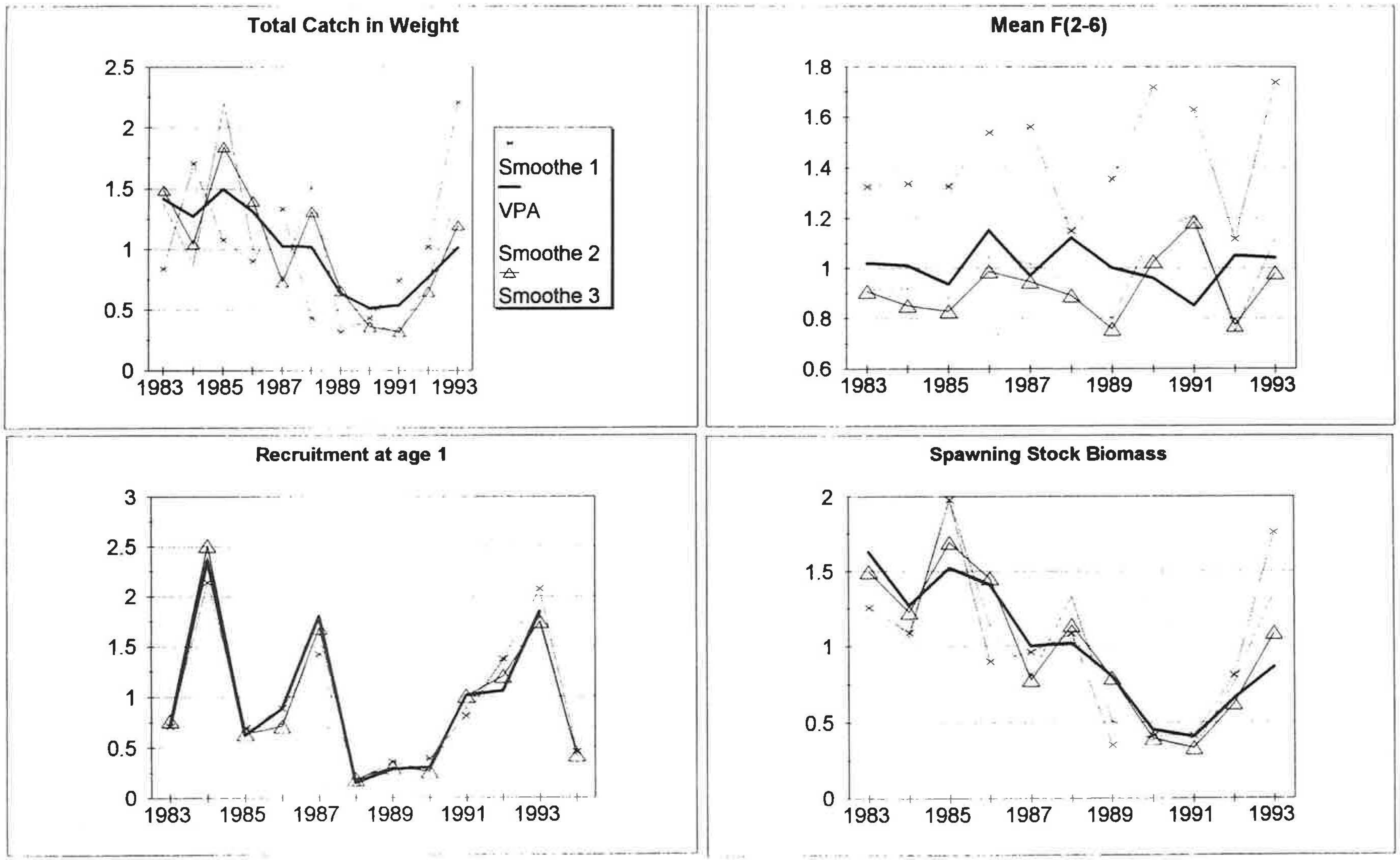


Fig. 5.2.2.North Sea Haddock. Stock trends estimated from surveys and VPA. Multiple survey model.



5.2.3. Gulf of Maine cod. Stock trends estimated from surveys and VPA

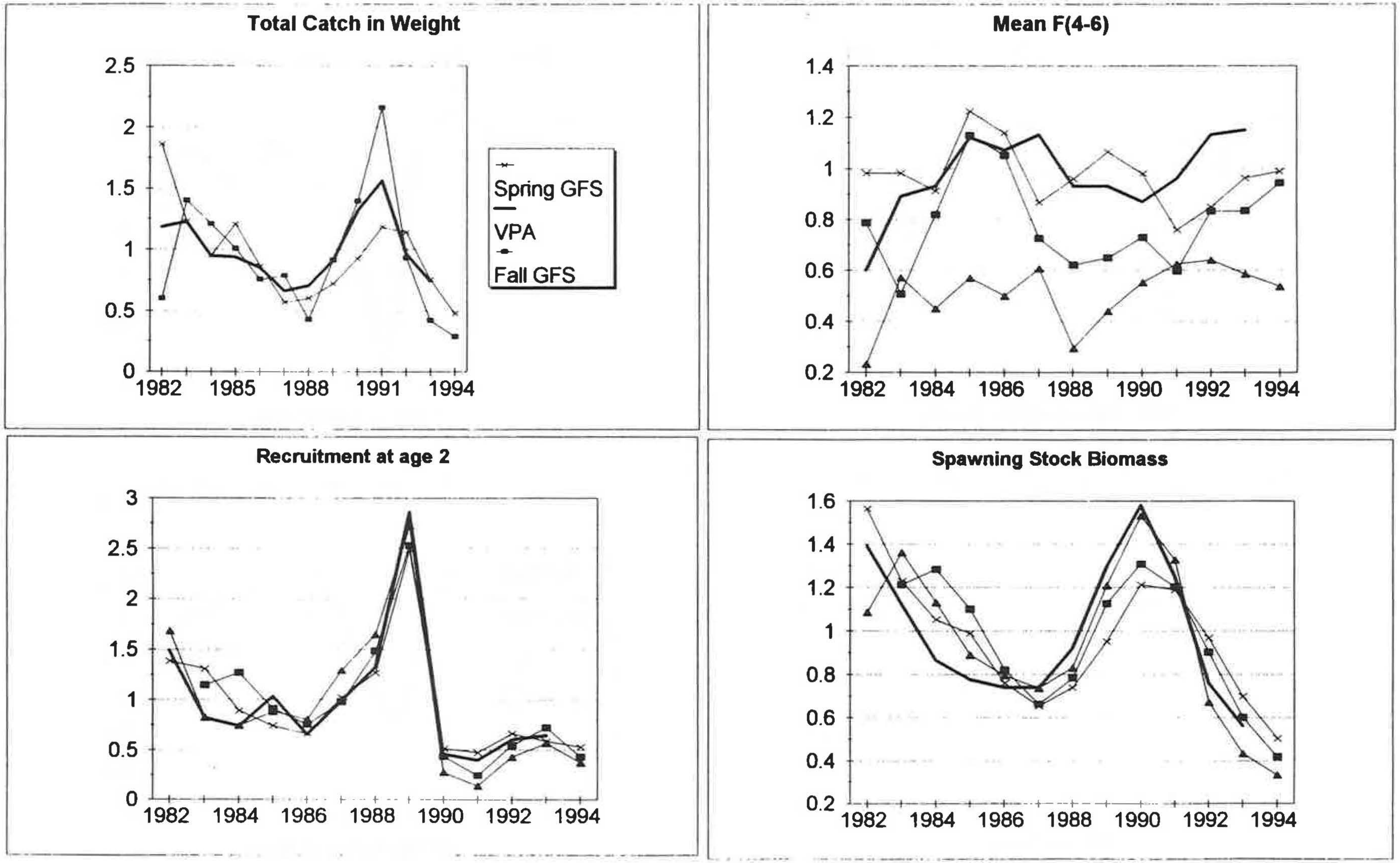


Fig. 5.2.4. Gulf of Maine Cod. Stock trends estimated from surveys and VPA. Multiple survey model.

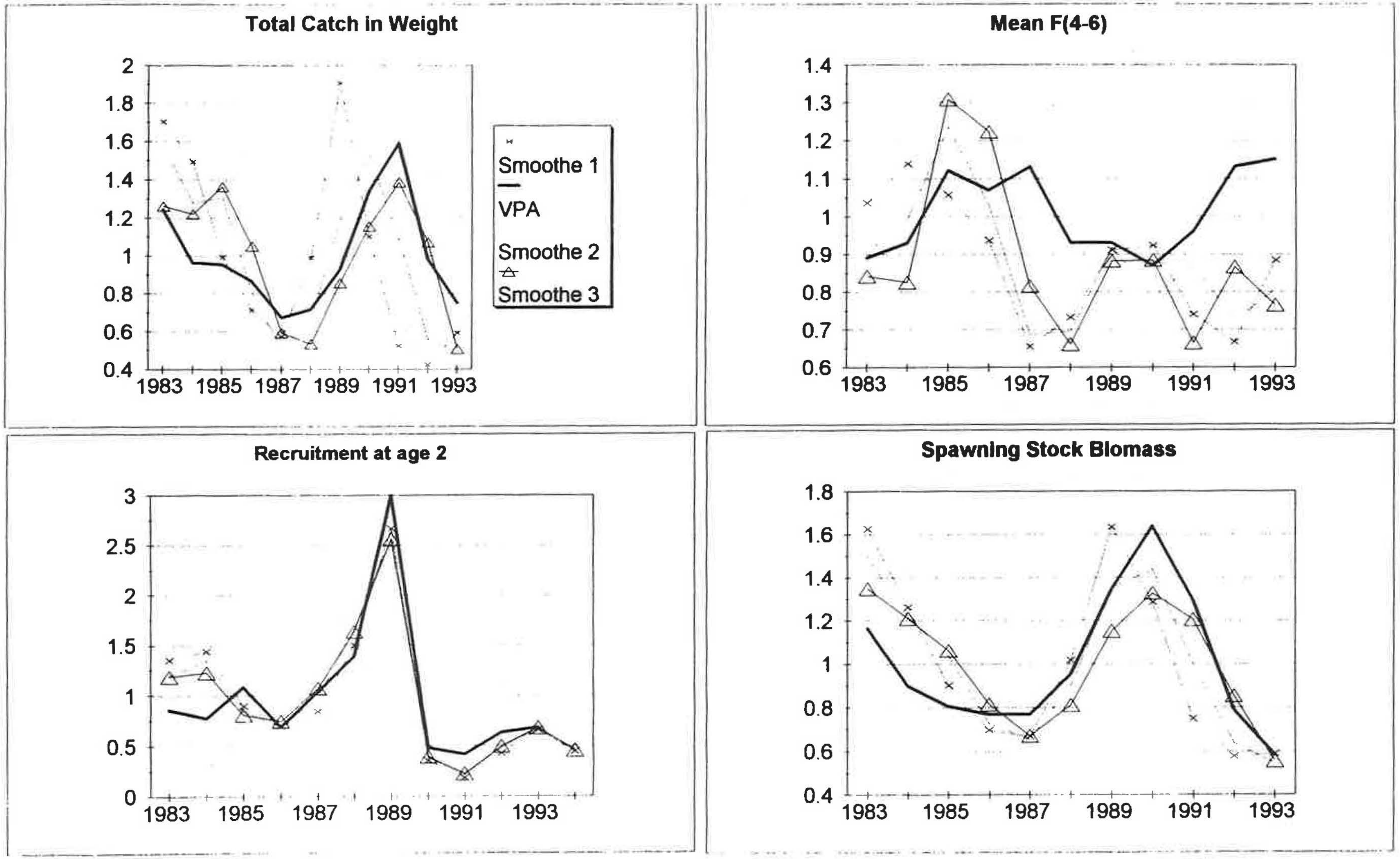


Fig. 5.2.5. Southern Gulf of St Lawrence cod. Stock trends estimated from survey and VPA.

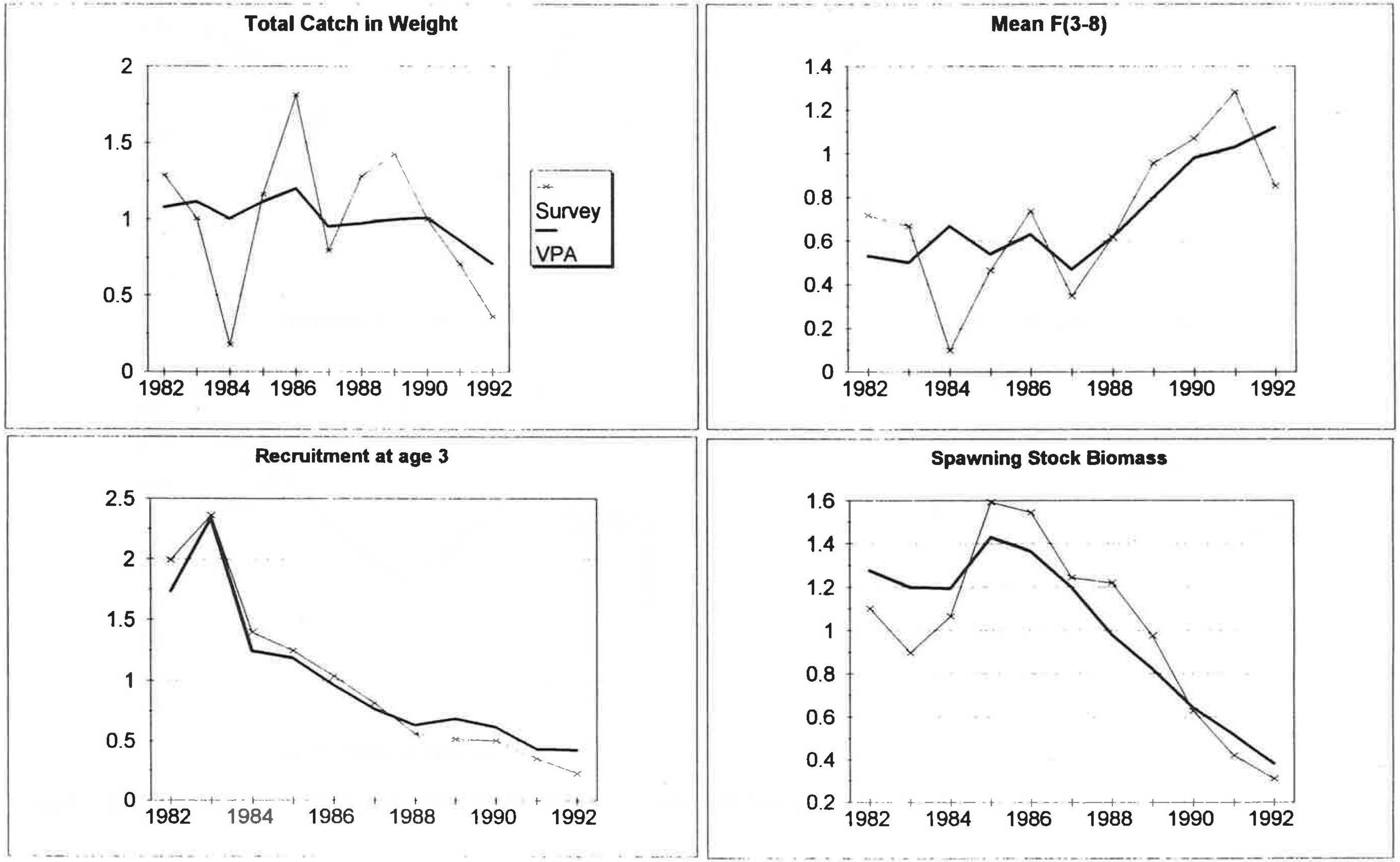


Fig. 5.2.6. Icelandic haddock. Stock trends estimated from surveys and VPA.

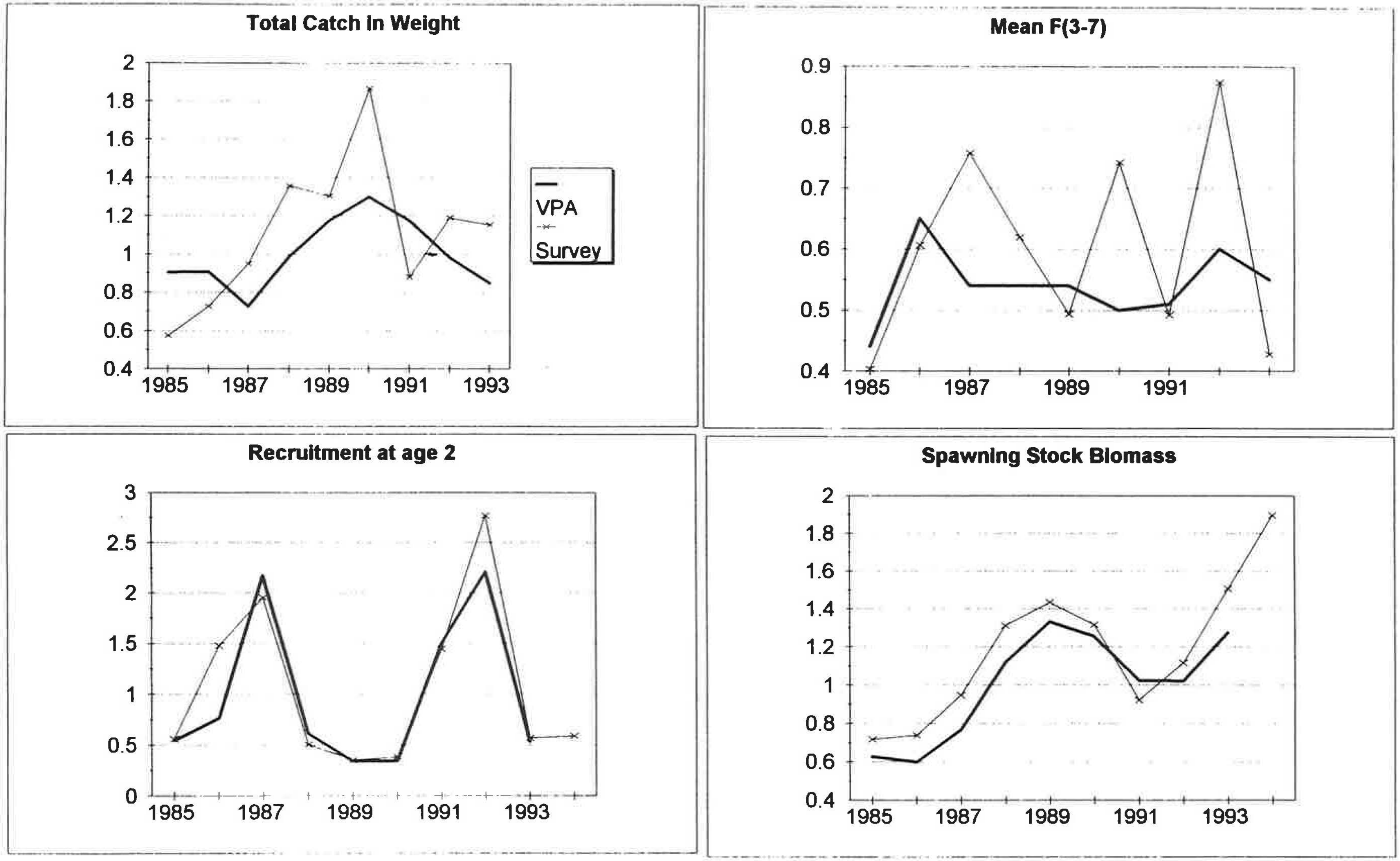
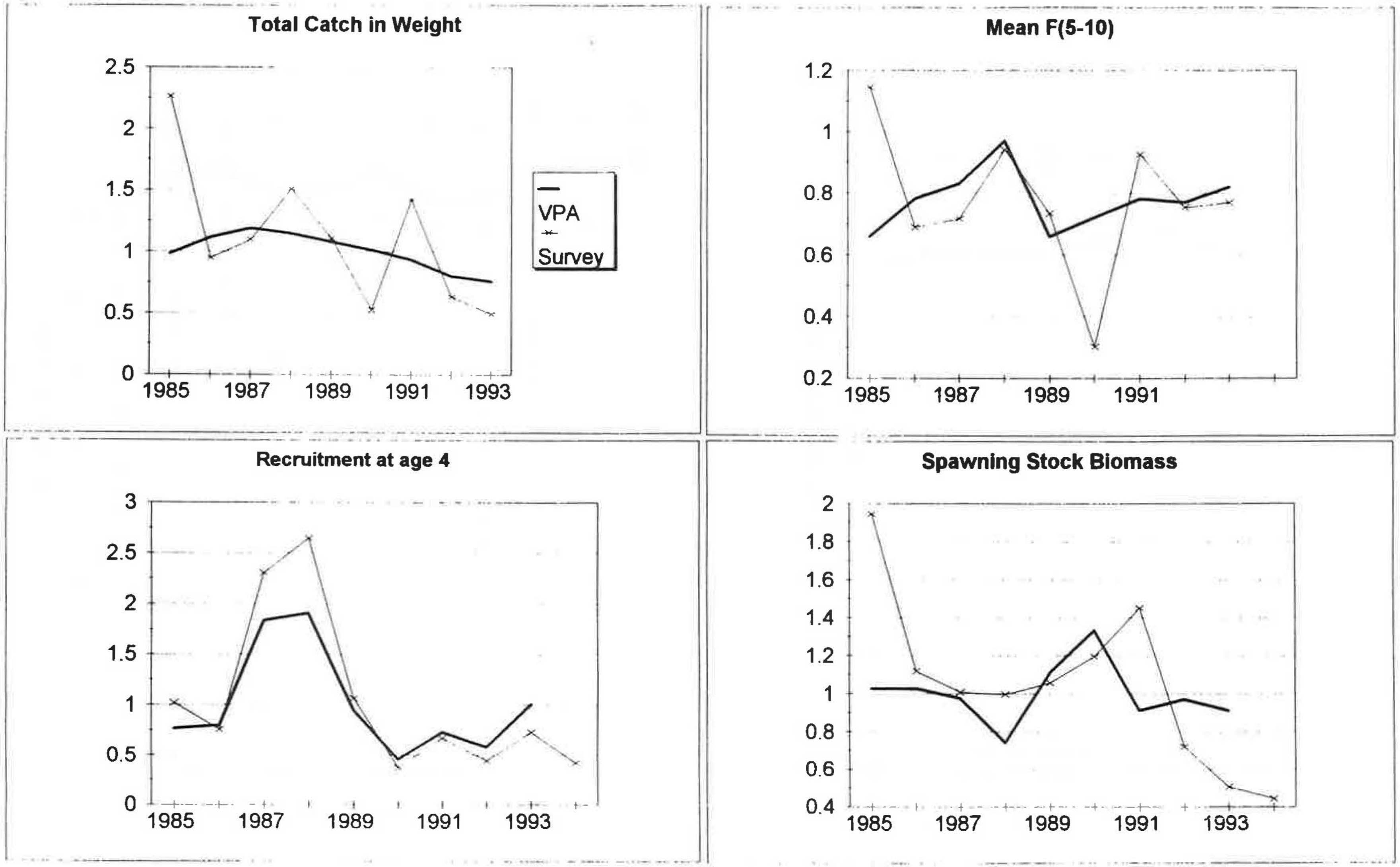
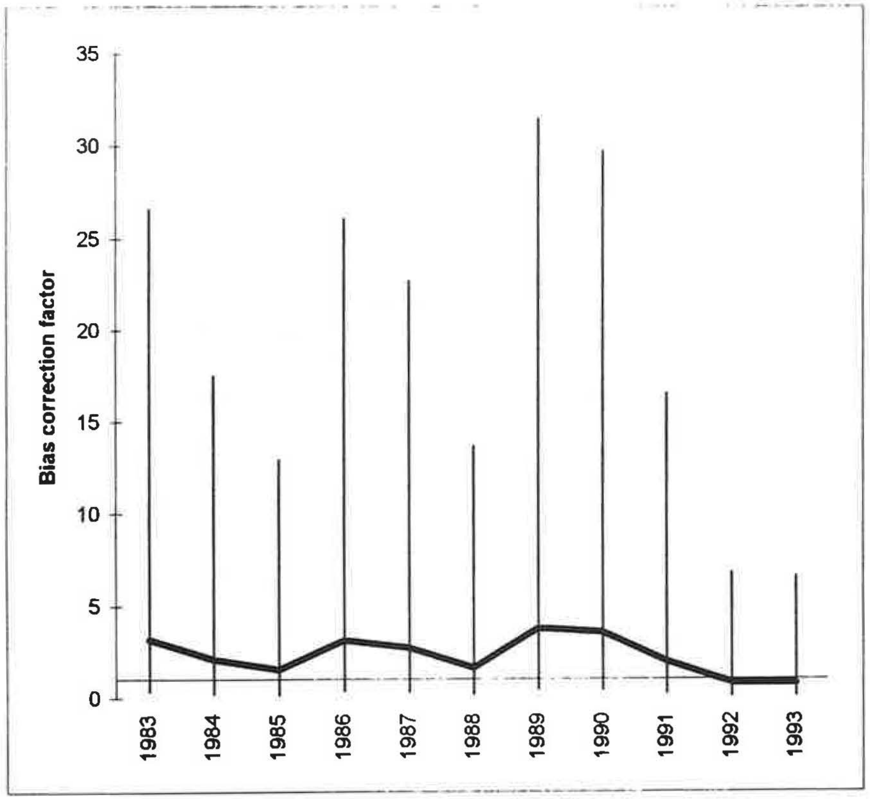


Fig. 5.2.7. Icelandic cod. Stock trends estimated from surveys and VPA.



(a) Model fitted to survey only



(b) Model fitted to surveys and fleet catch-at-age data
Note : change in bias scale

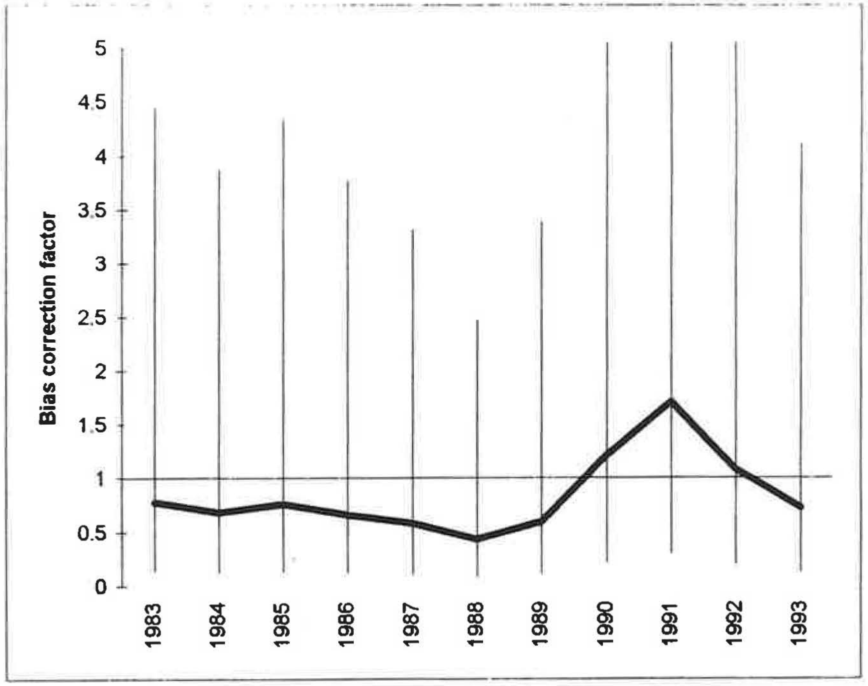


Figure 5.3.1 Mis-reporting bias estimated by the fit of a modified stage 1 ITCOTCIO model to data for Gulf of Maine cod. Ages 2 - 6.

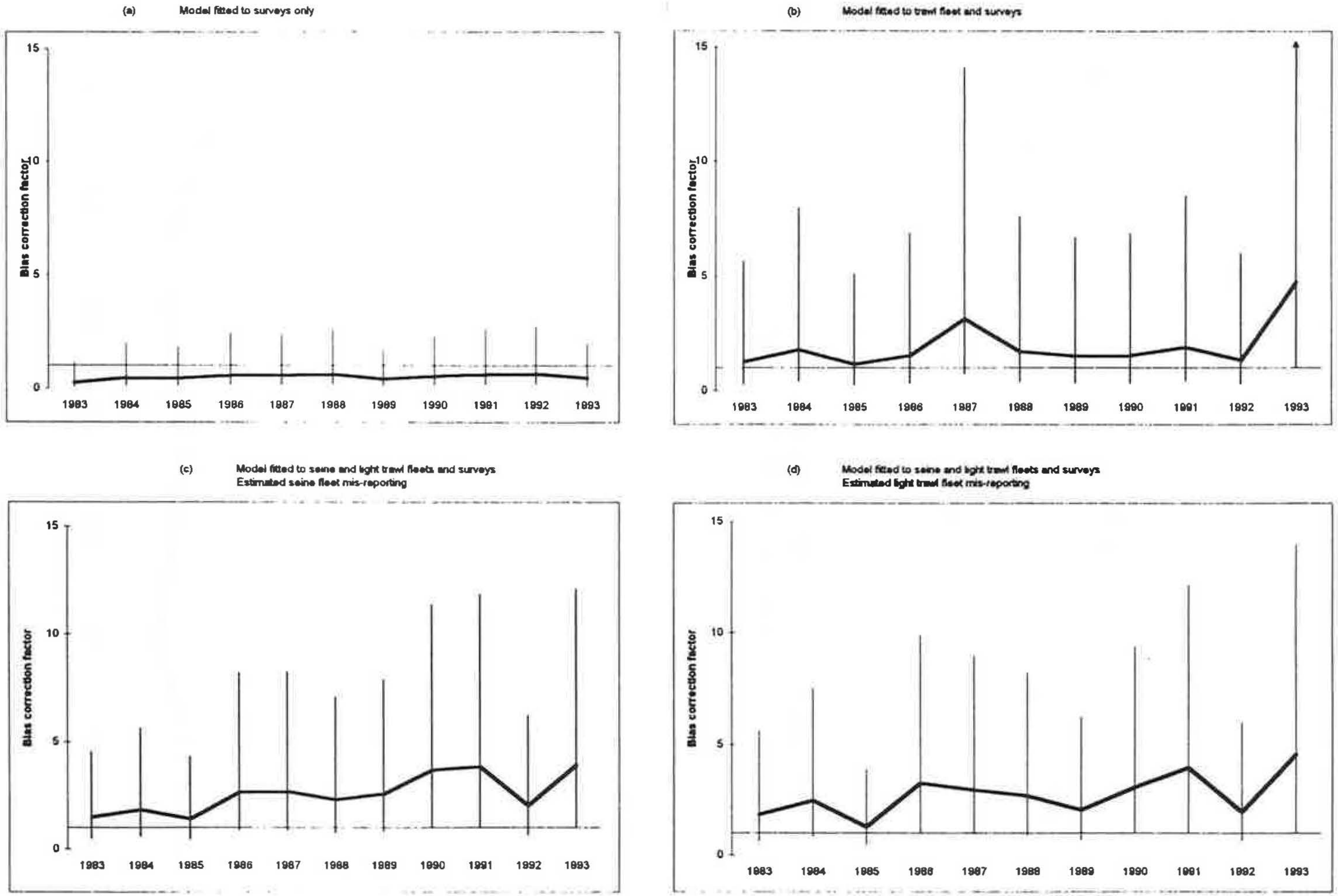


Figure 5.3.2 Mis-reporting bias estimated by the fit of a modified stage 1 ITCOTCIO model to data for North Sea haddock. Ages 2 - 5.

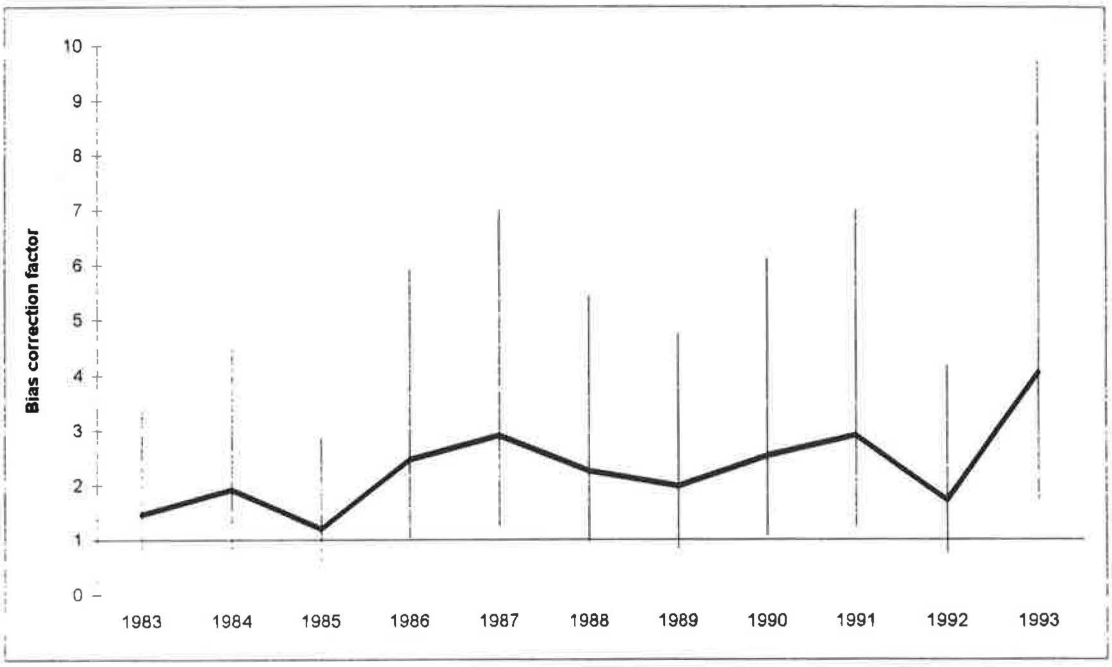


Figure 5.3.3 Mis-reporting bias estimated by the fit of a modified stage 1 ITCOTCIO model to data for North Sea haddock. All fleets. Ages 2 - 5.

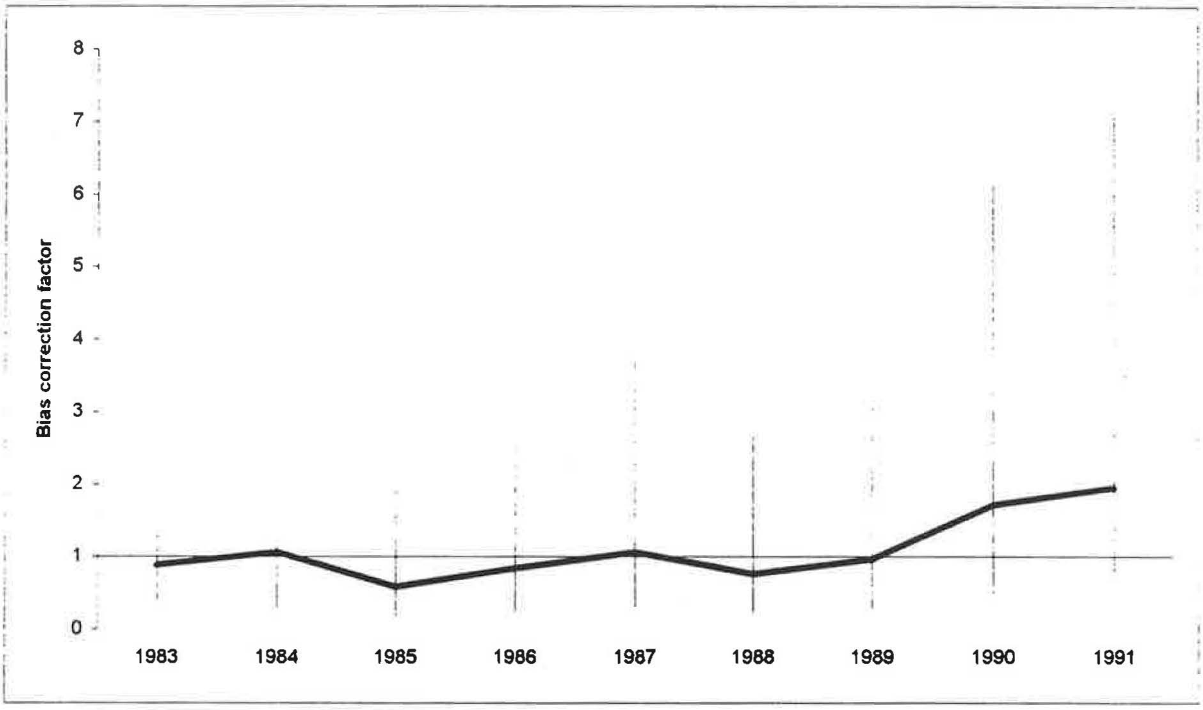


Figure 5.3.4 Mis-reporting bias estimated by the fit of a modified stage 1 ITCOTCIO model to data for Southern Gulf cod. Ages 4 - 11.

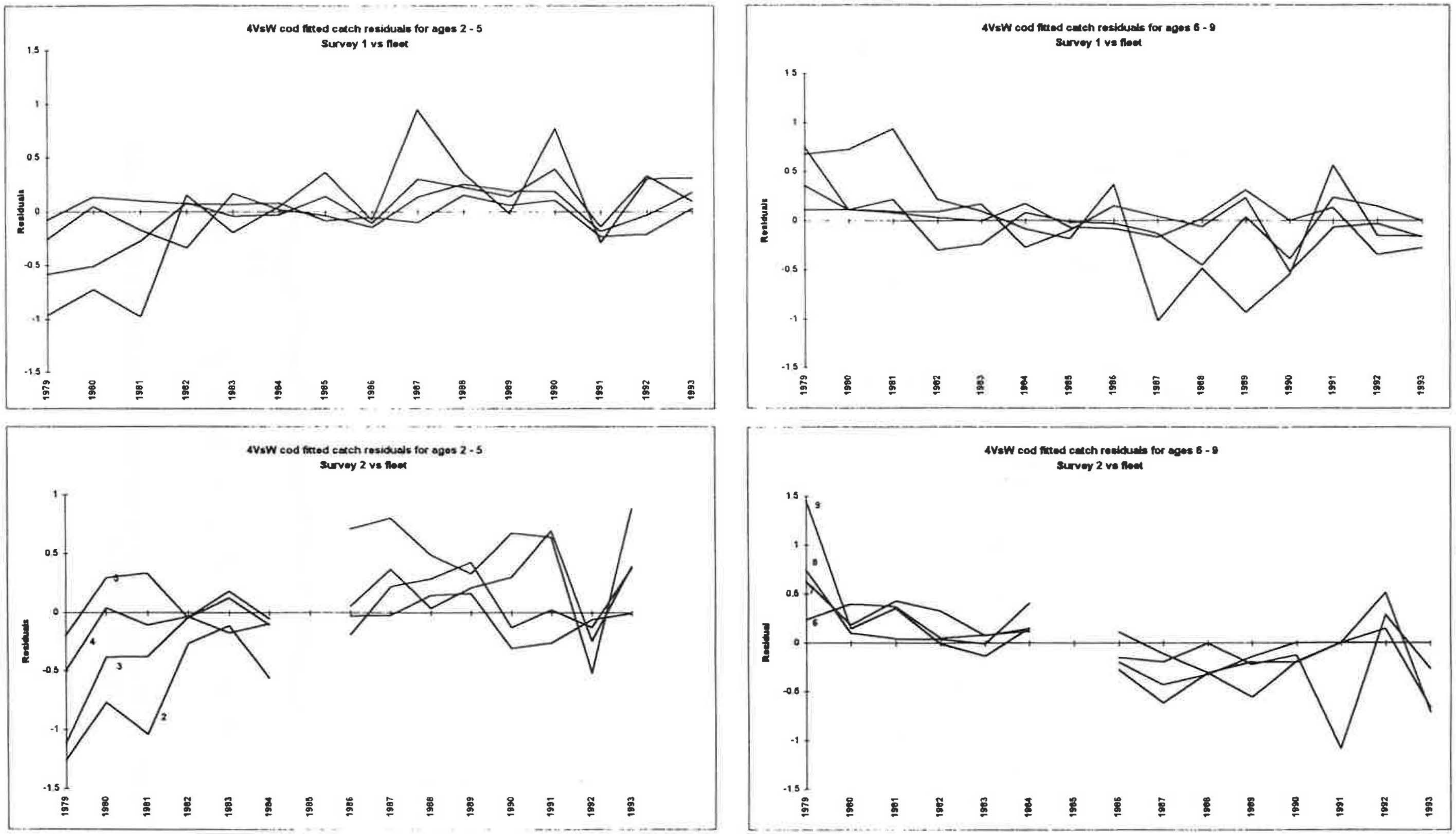
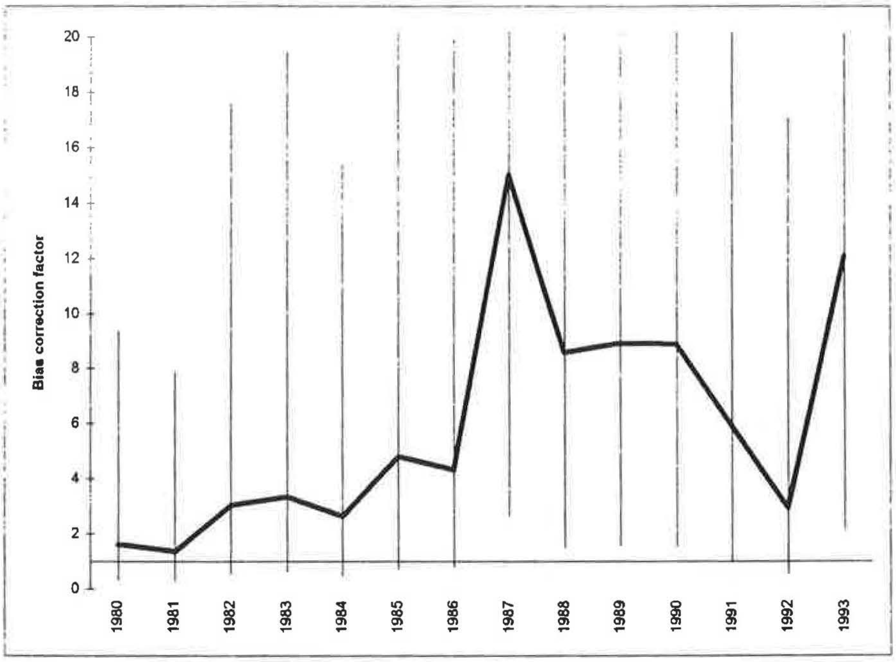


Figure 5 3 5 The residuals from the fit of the modified stage 1 ITCOTCIO model to the catch-at-age data for the 4VsW cod

(a) Model fitted to ages 2 - 5
Upper confidence limits truncated at 20



(b) Model fitted to ages 6 - 9

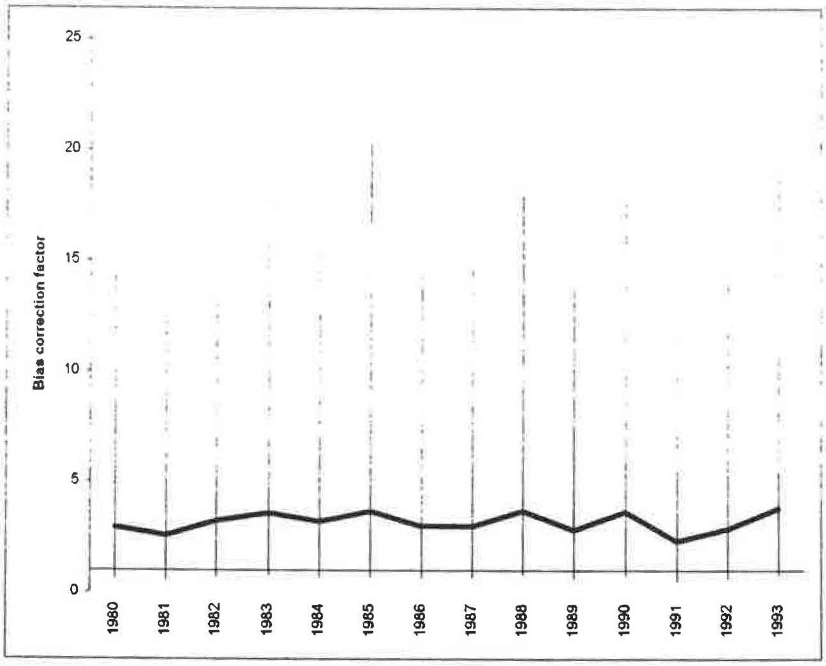


Figure 5.3.6 Mis-reporting bias estimated by the fit of a modified stage 1 ITCOTCIO model to data for 4VsW Cod.

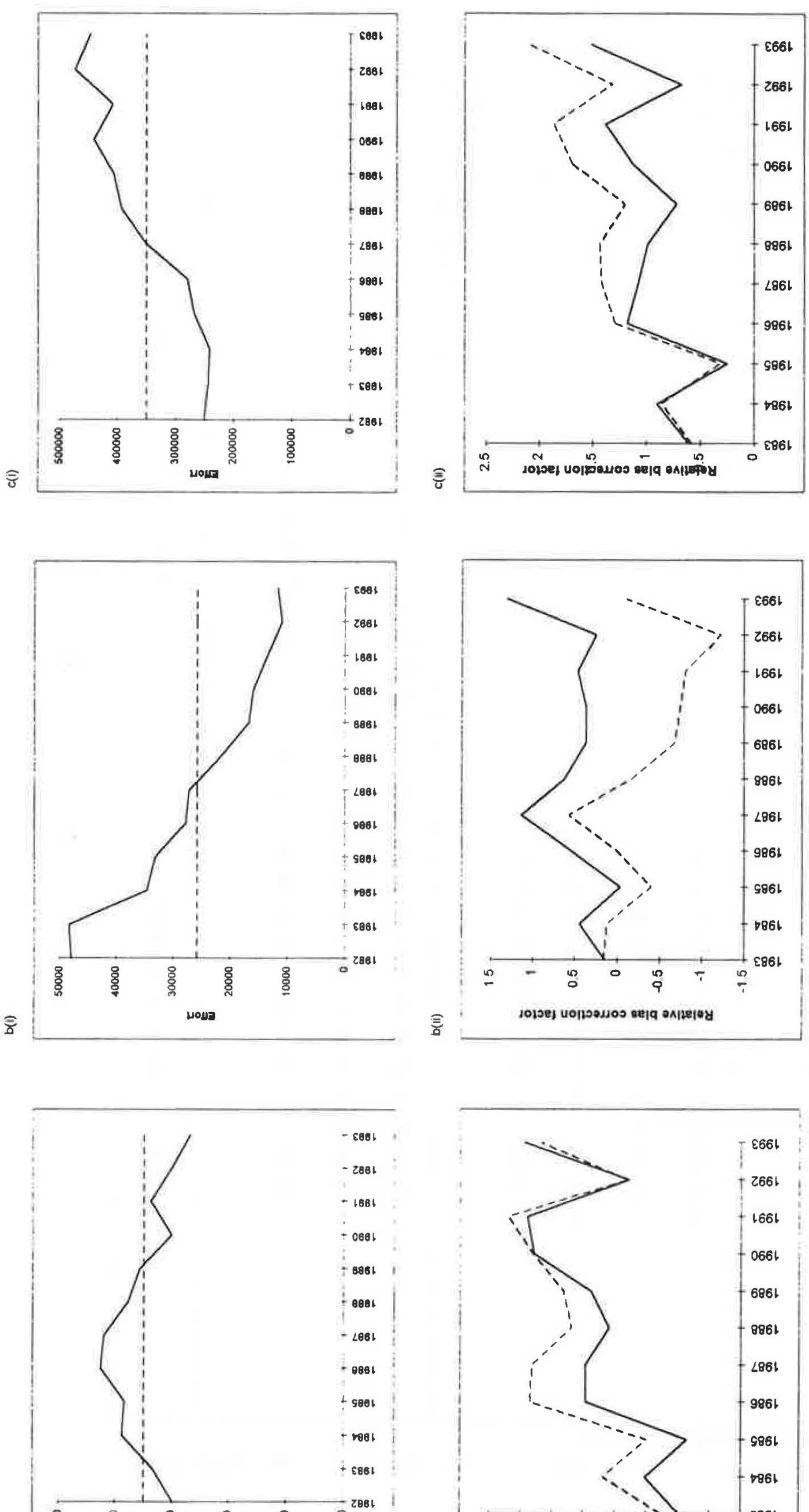


Figure 5.3.7 The effect of patterns in the level of effort on trends in the estimated relative bias correction factor

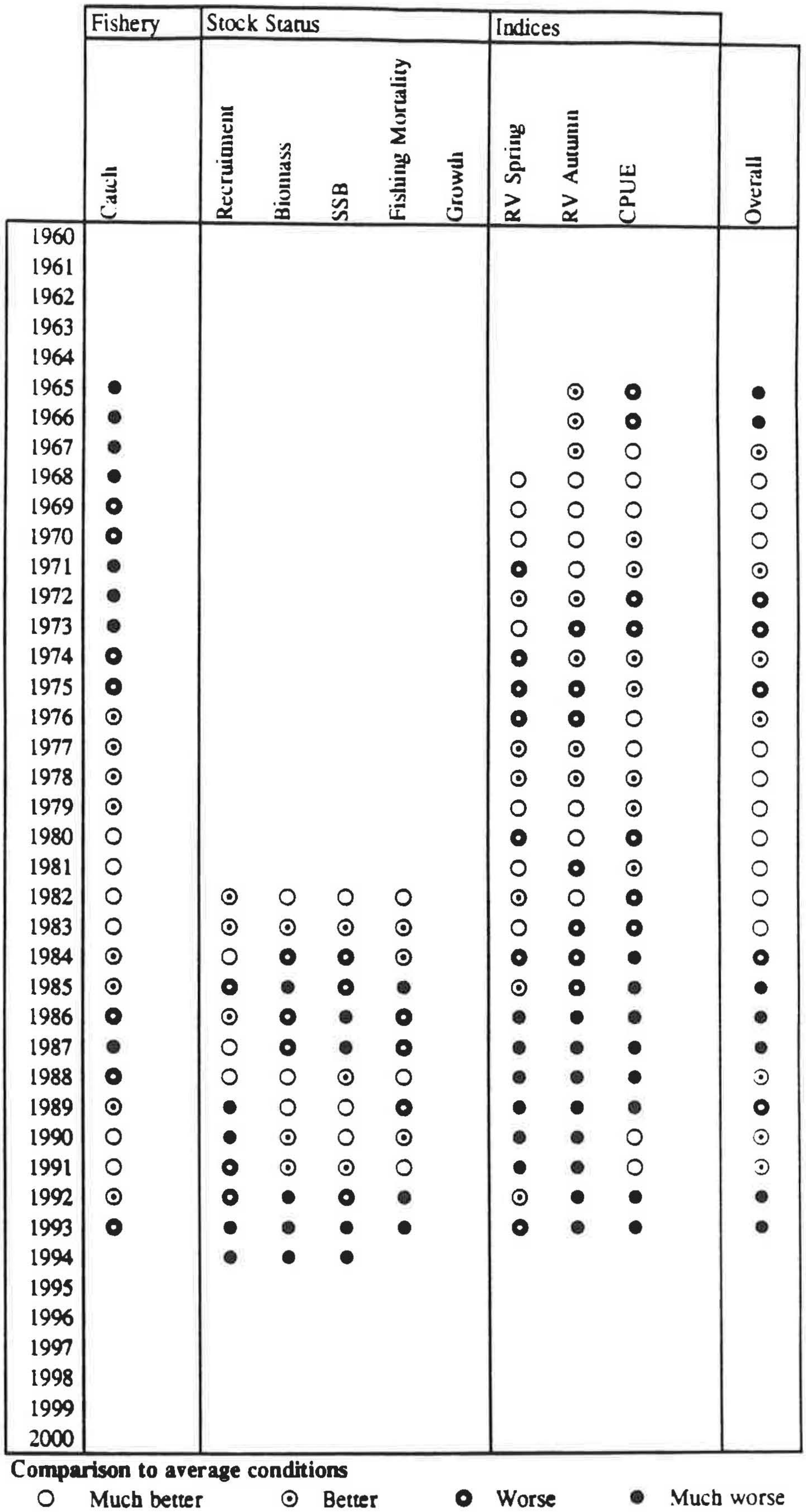


Figure 6.2.1 Time series of stock condition of Gulf of Maine cod expressed in four categories for each diagnostic.

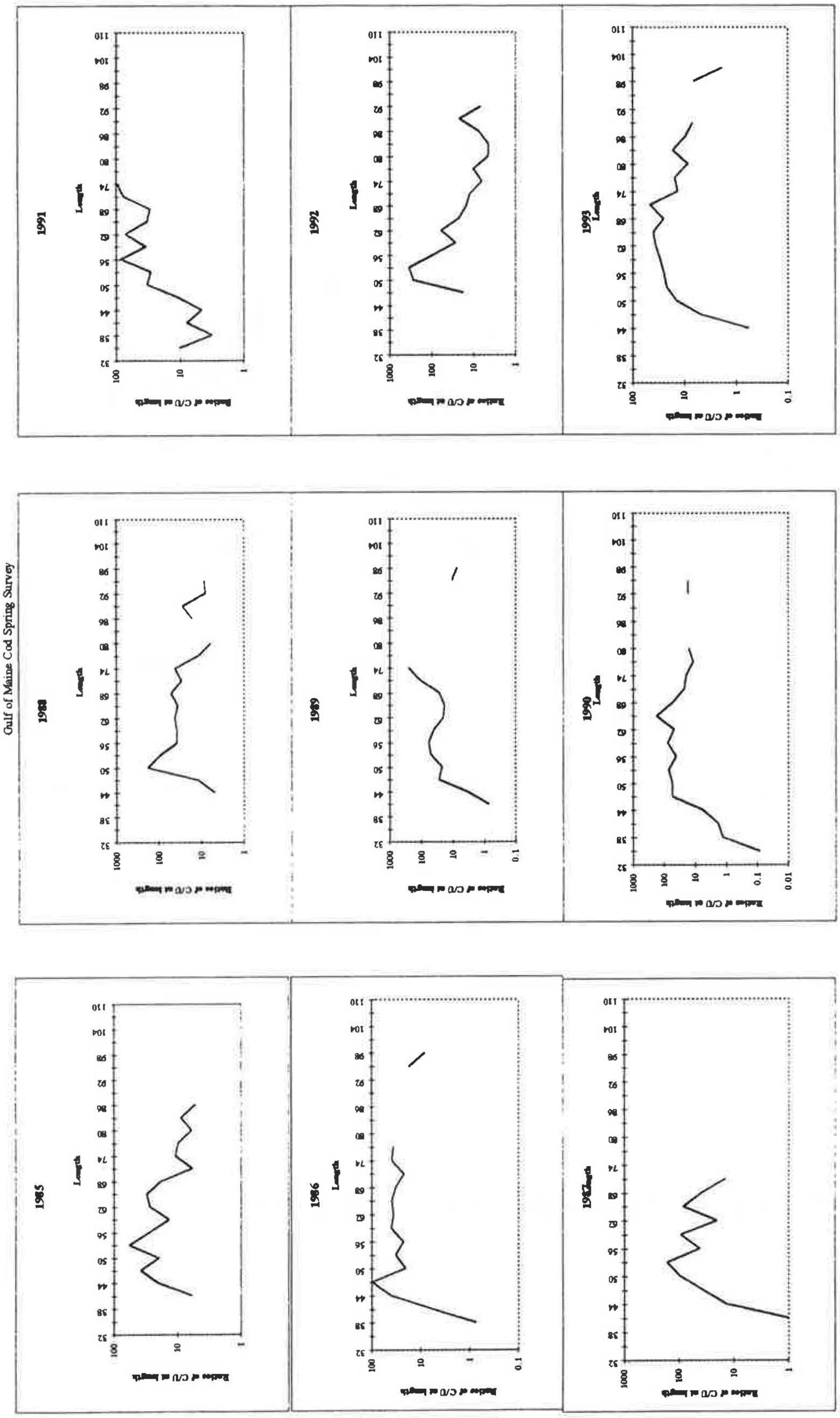


Figure 6.3.1 Size selectivity ogive for Gulf of Maine cod.

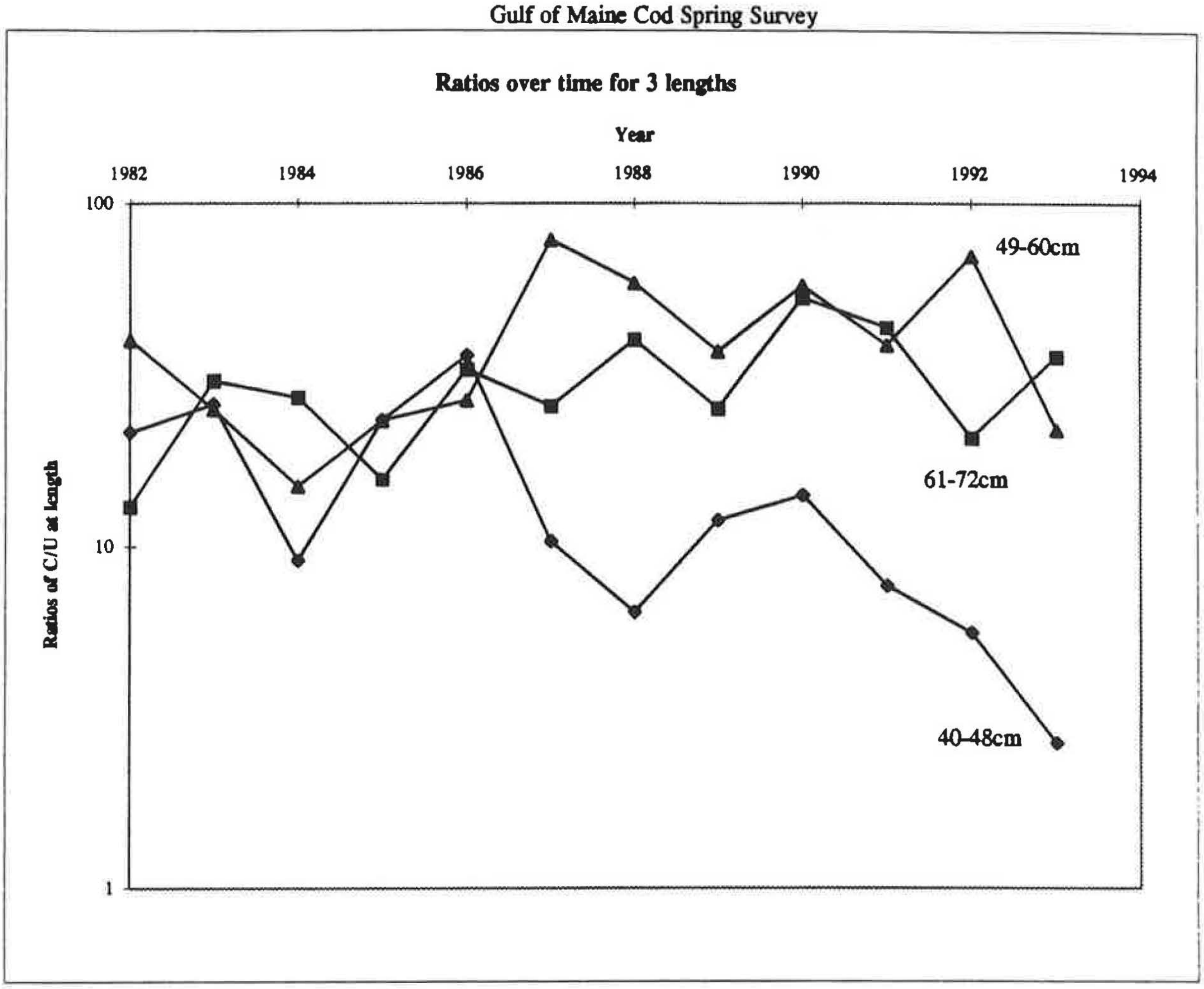


Figure 6.3.2 Time trends in Cyl/Uyl for selected lengths in Gulf of Maine cod.

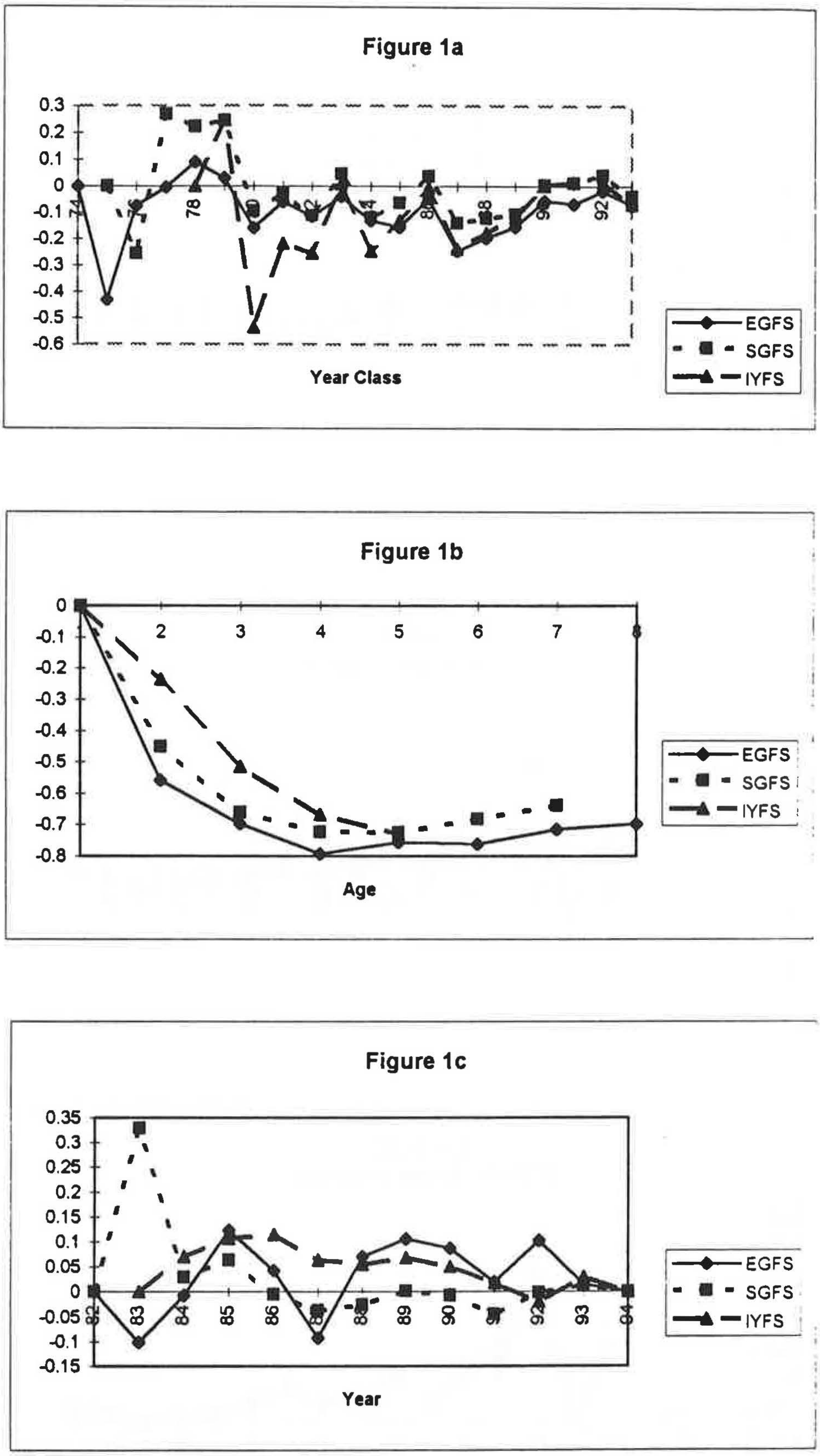
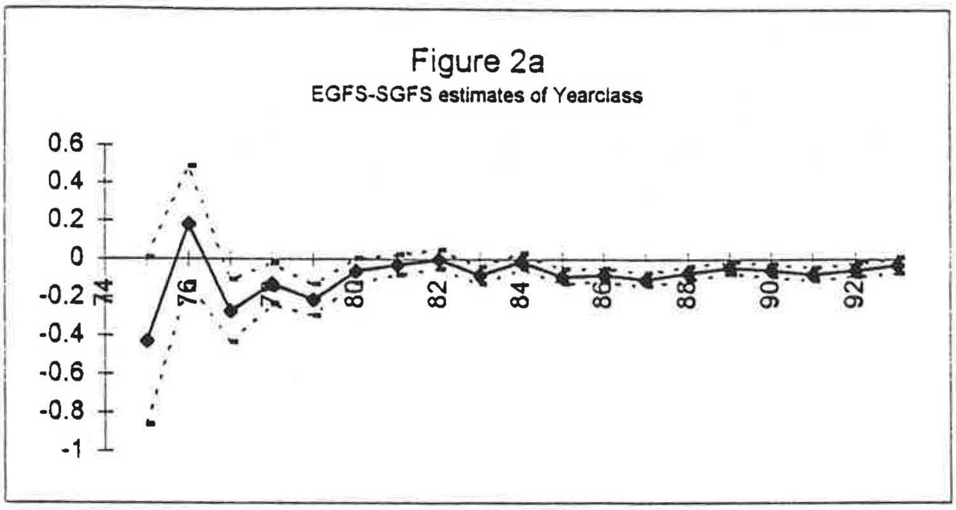
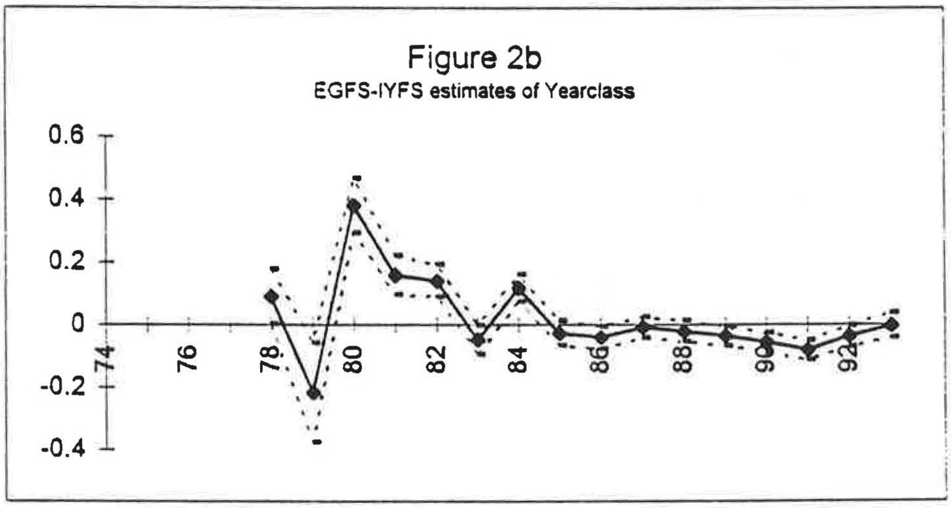


Figure 6.4.1 Year class, age and year efforts in survey indices for North Sea haddock.





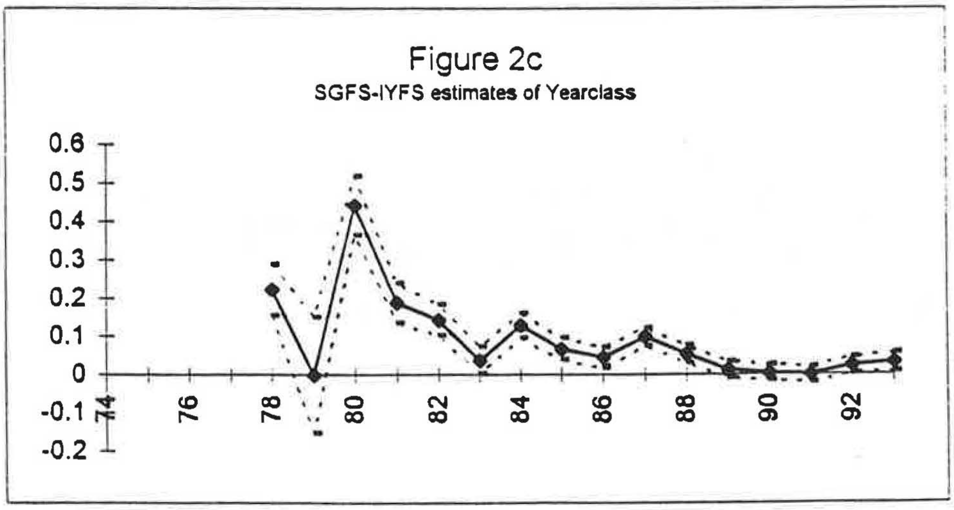


Figure 6.4.2 Trends in year class efforts in combined survey indices for North Sea haddock.

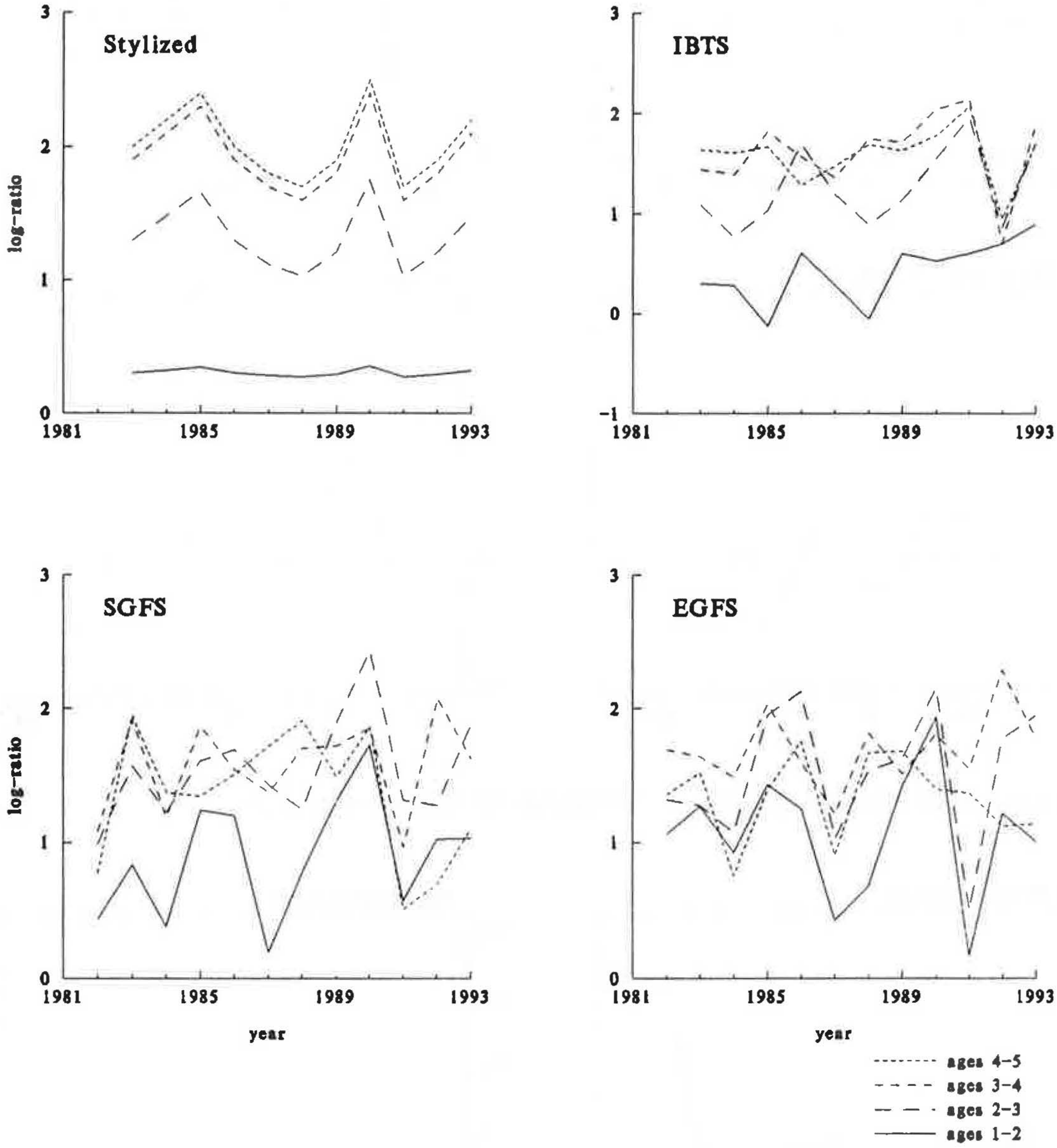


Figure 6.5.1 Observed log ratios of indices of abundance plotted against year by each age for North Sea haddock.

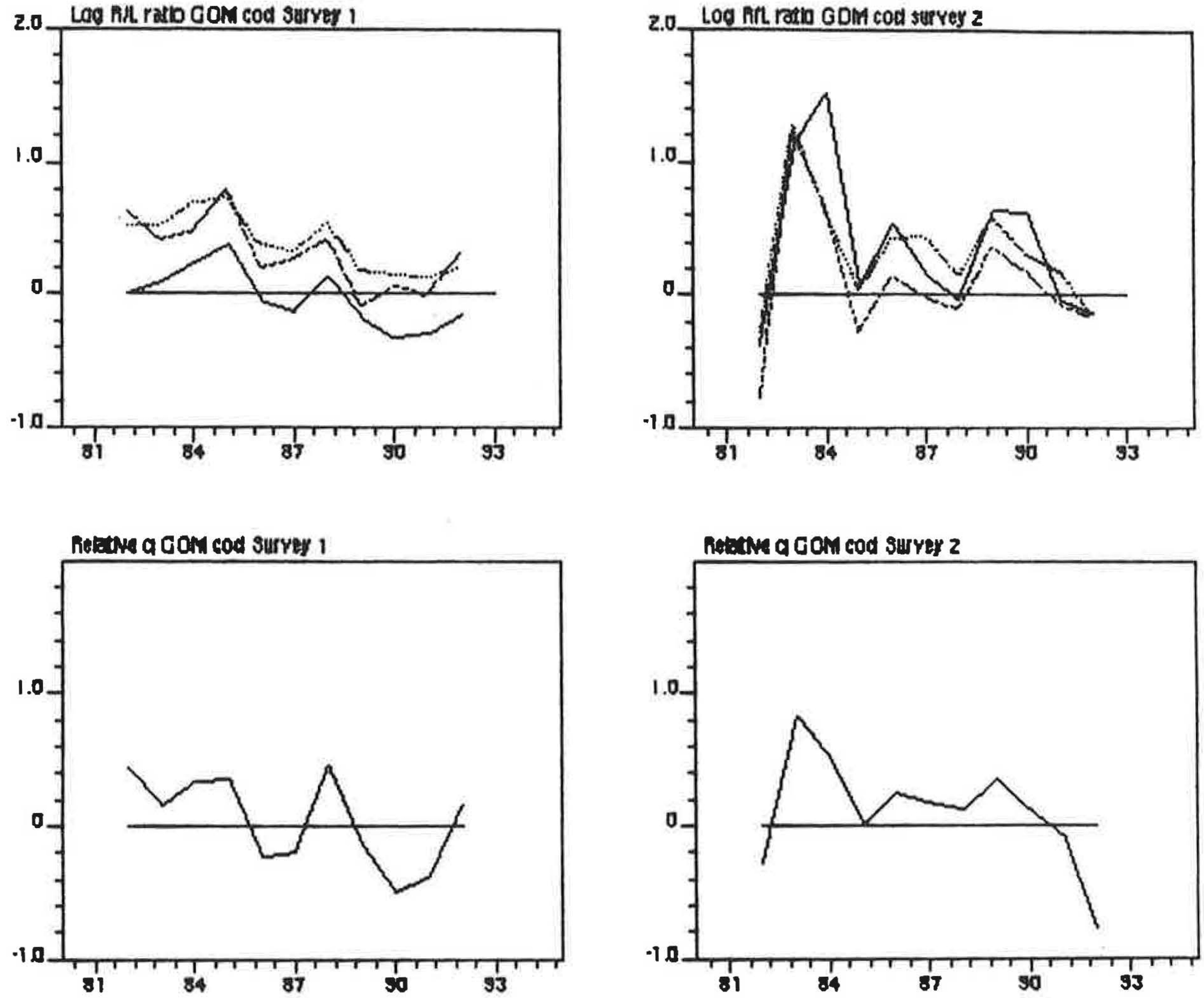


Figure 6.6.1 Right left ratio and relative q estimates for Gulf of Maine cod.

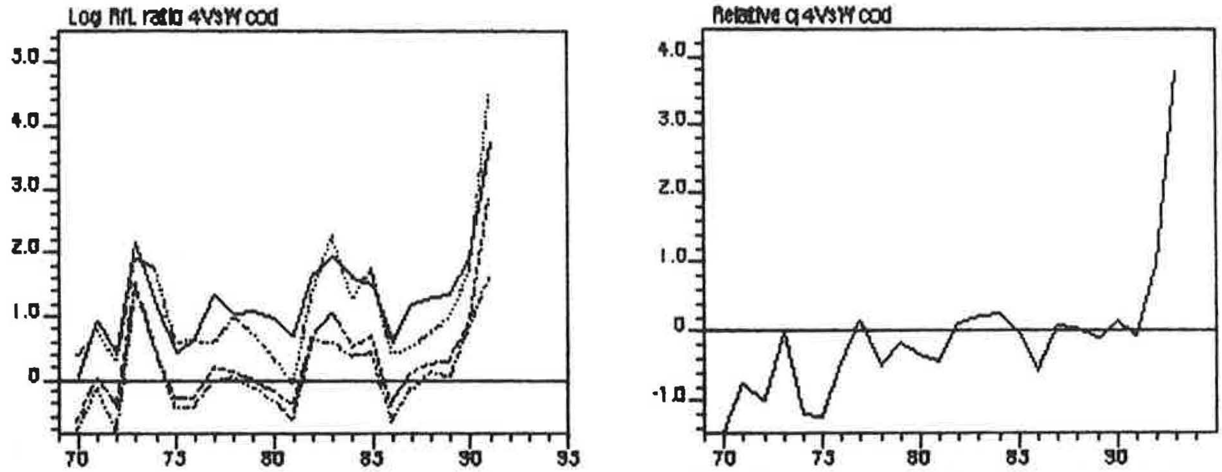


Figure 6.6.2 Right left ratio and relative q estimates for 4VsW cod

Figure 6.7.1 GOM cod.

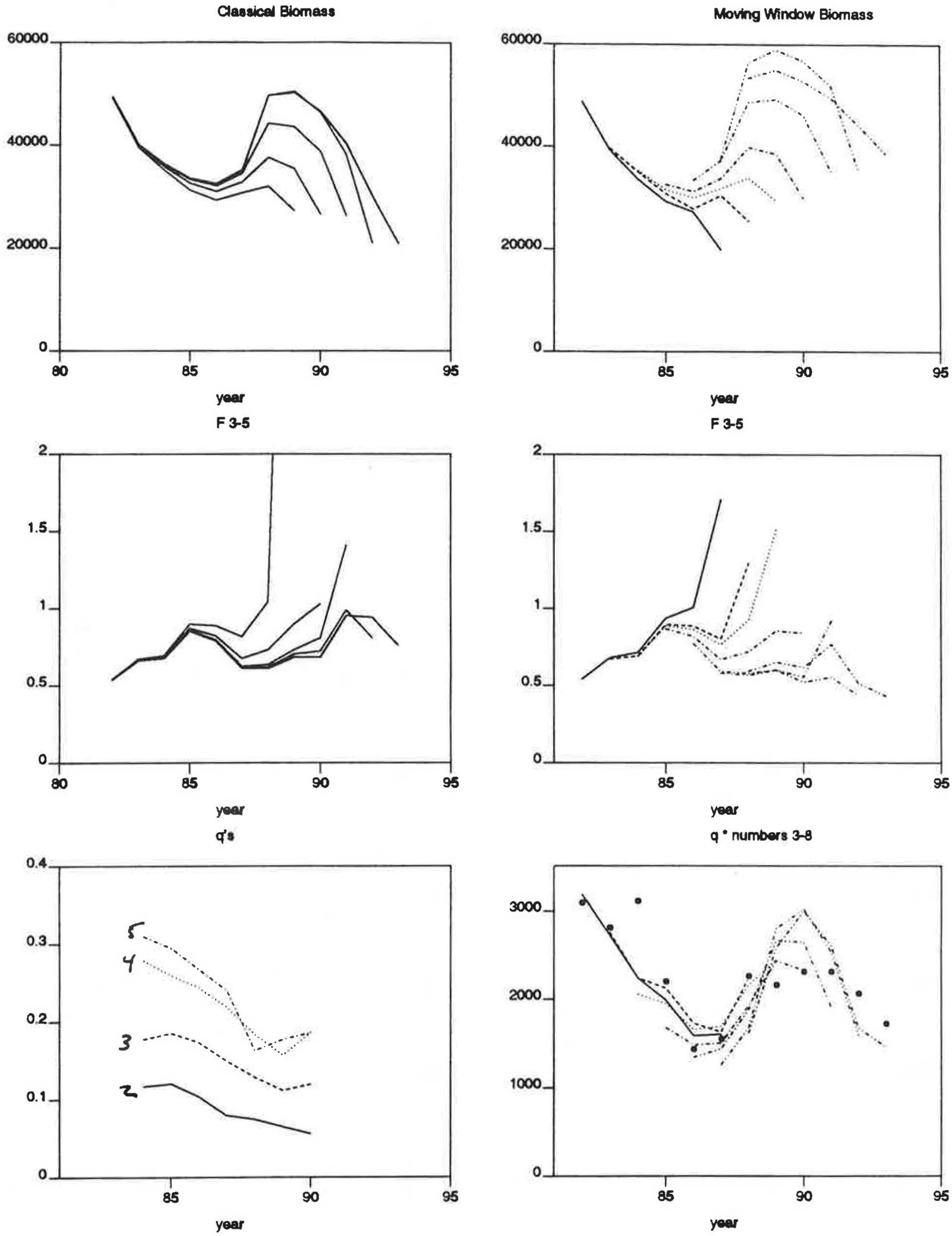
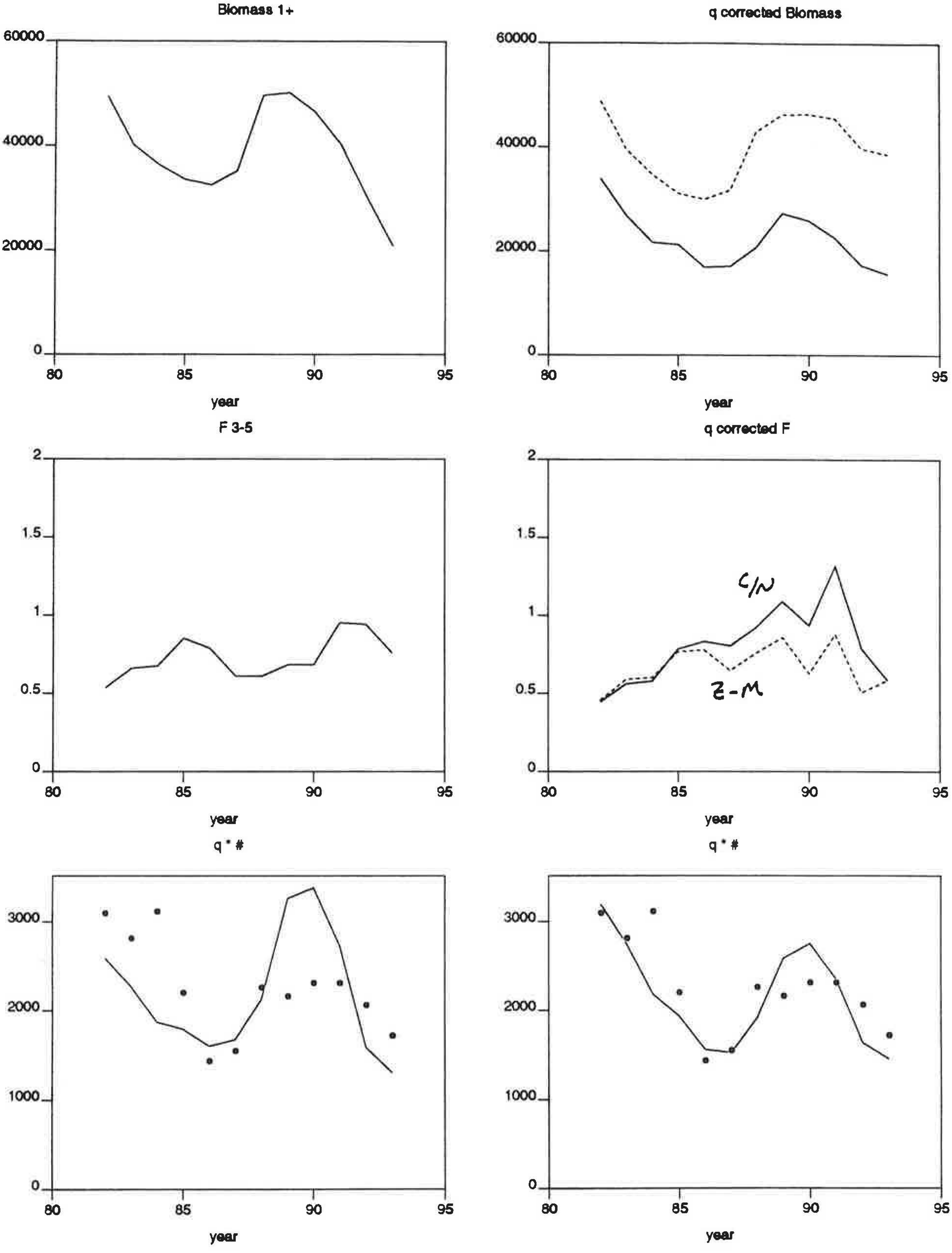


Figure 6.7.2 GOM cod.



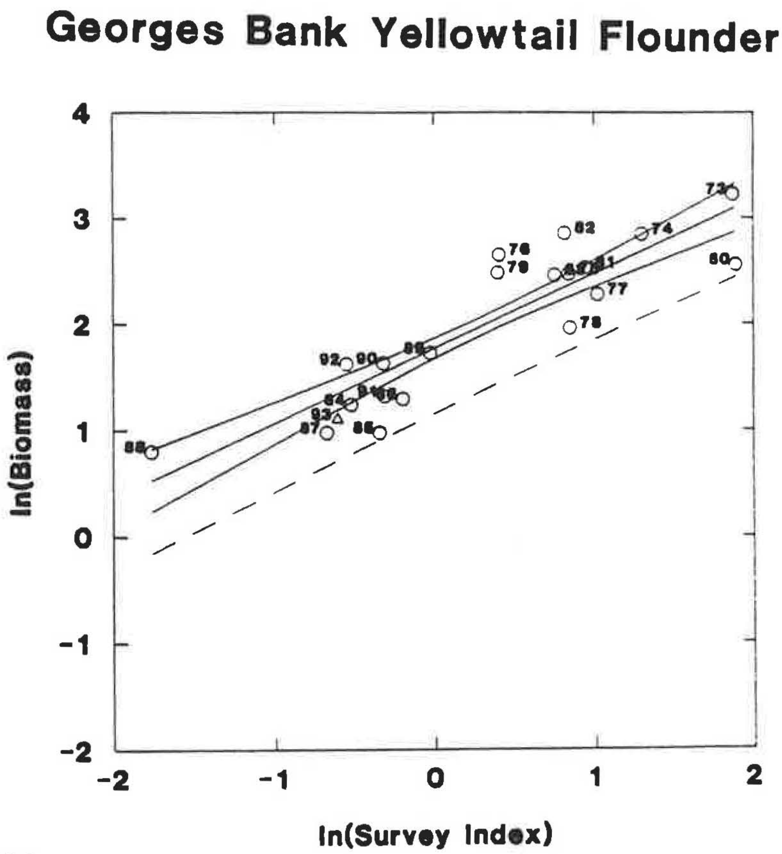


Figure 6.8.1a

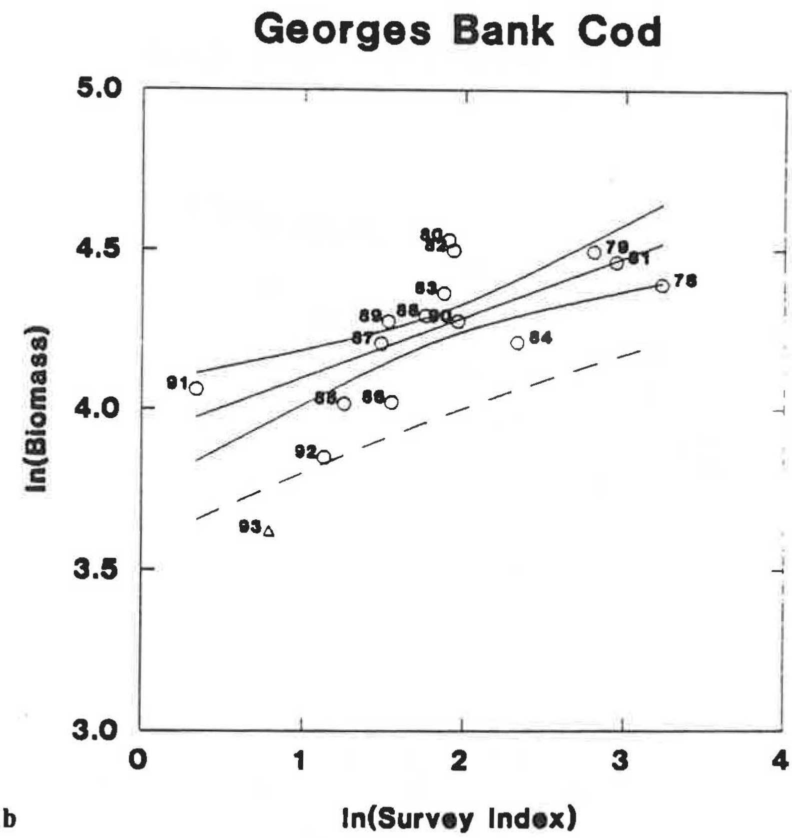


Figure 6.8.1b

Gulf of Maine Cod

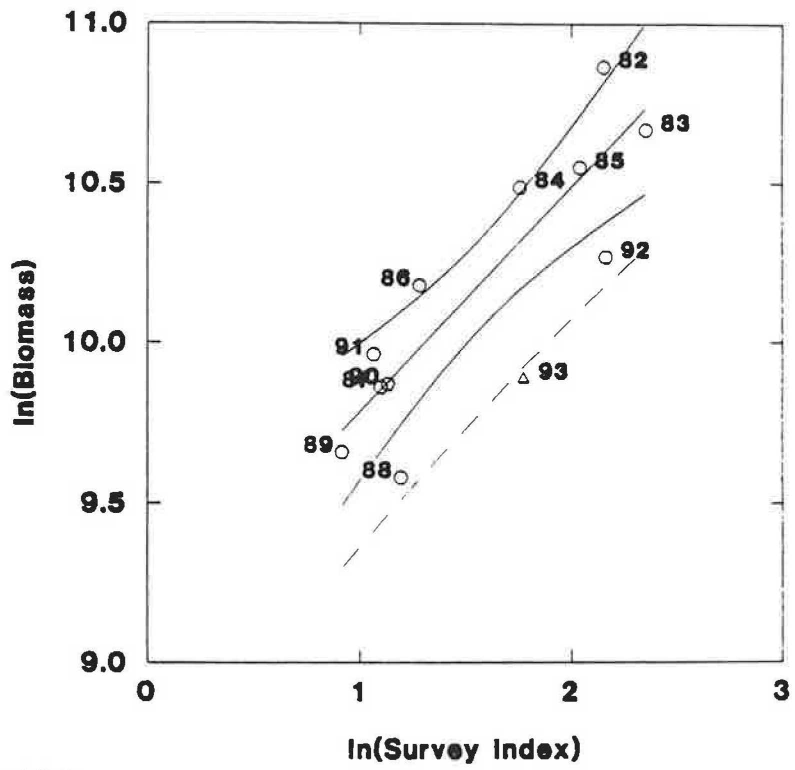


Figure 6.8.1c

4T-Vn Southern Gulf Cod

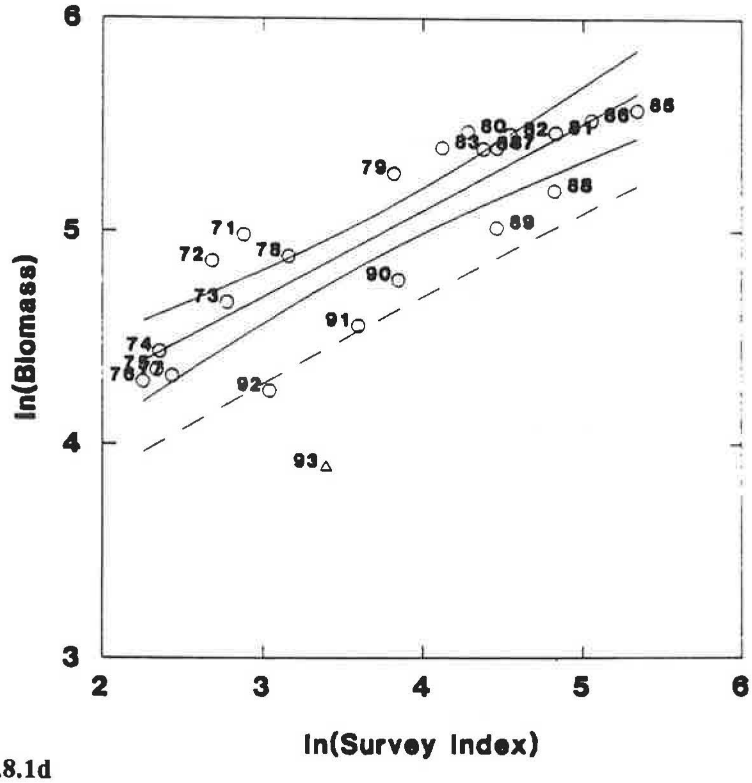


Figure 6.8.1d

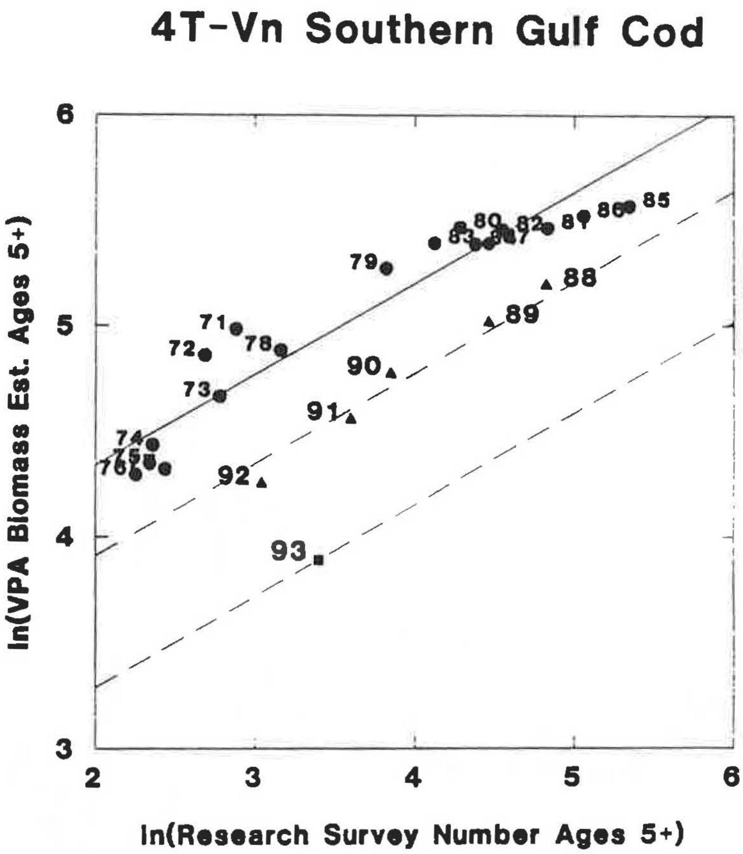


Figure 6.8.2

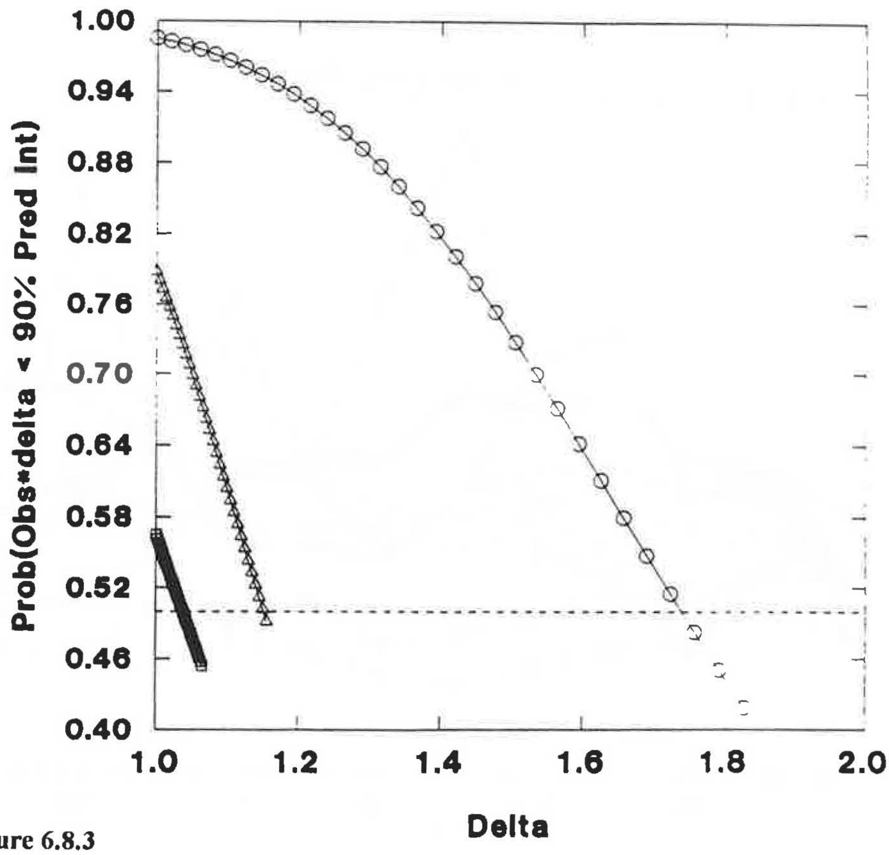


Figure 6.8.3

Figure 7.1.1 Comparison of methods.
Gulf of Maine Cod.

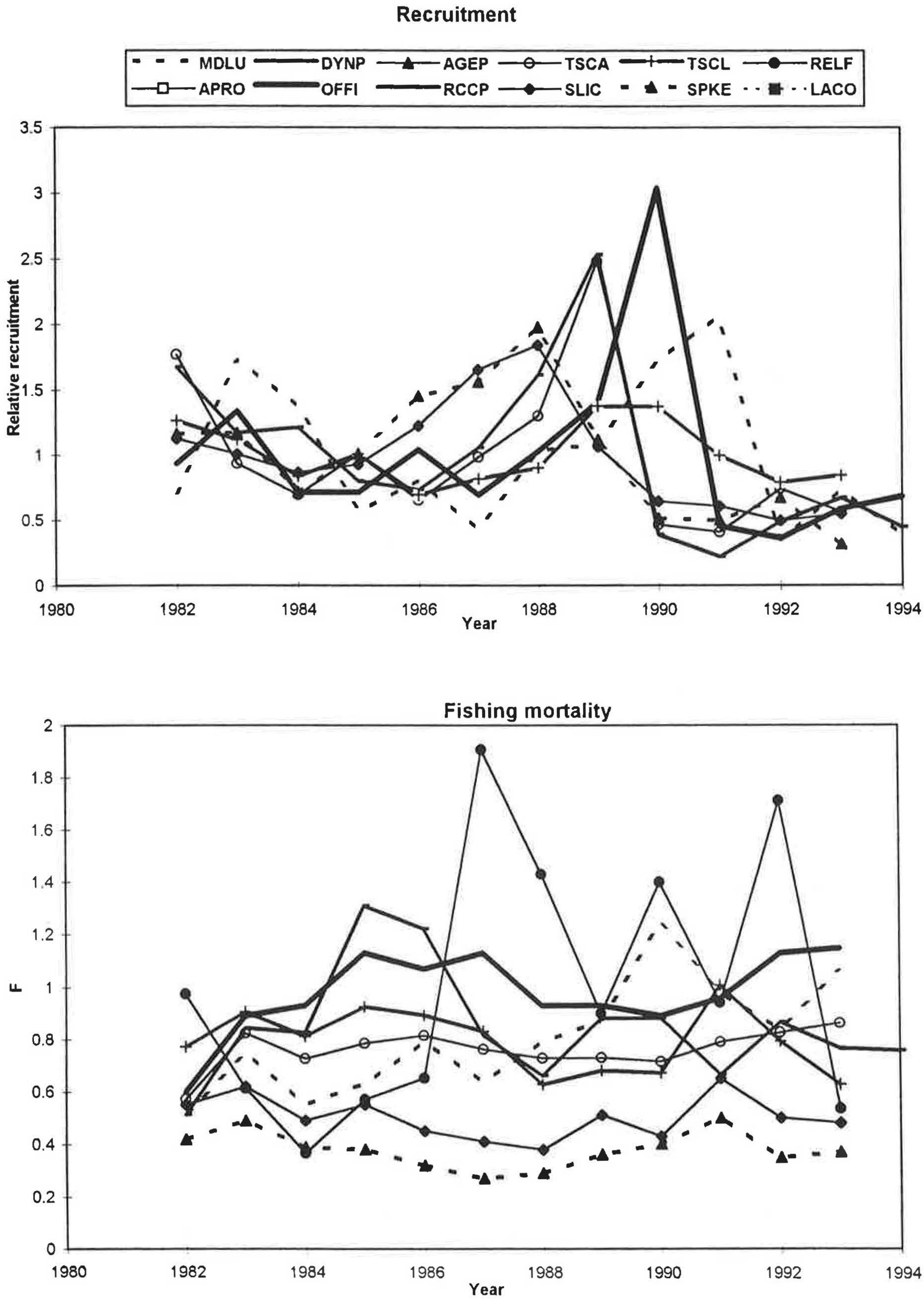
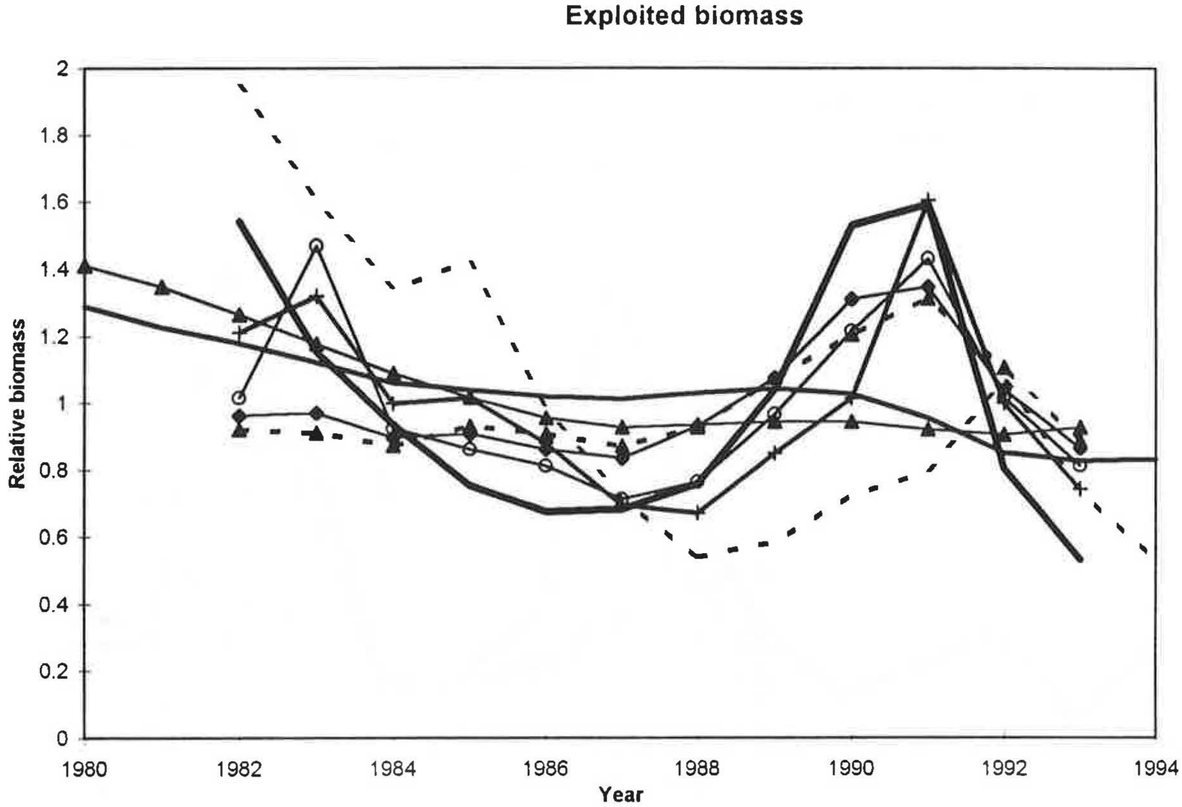


Figure 7.1.1 Cont.



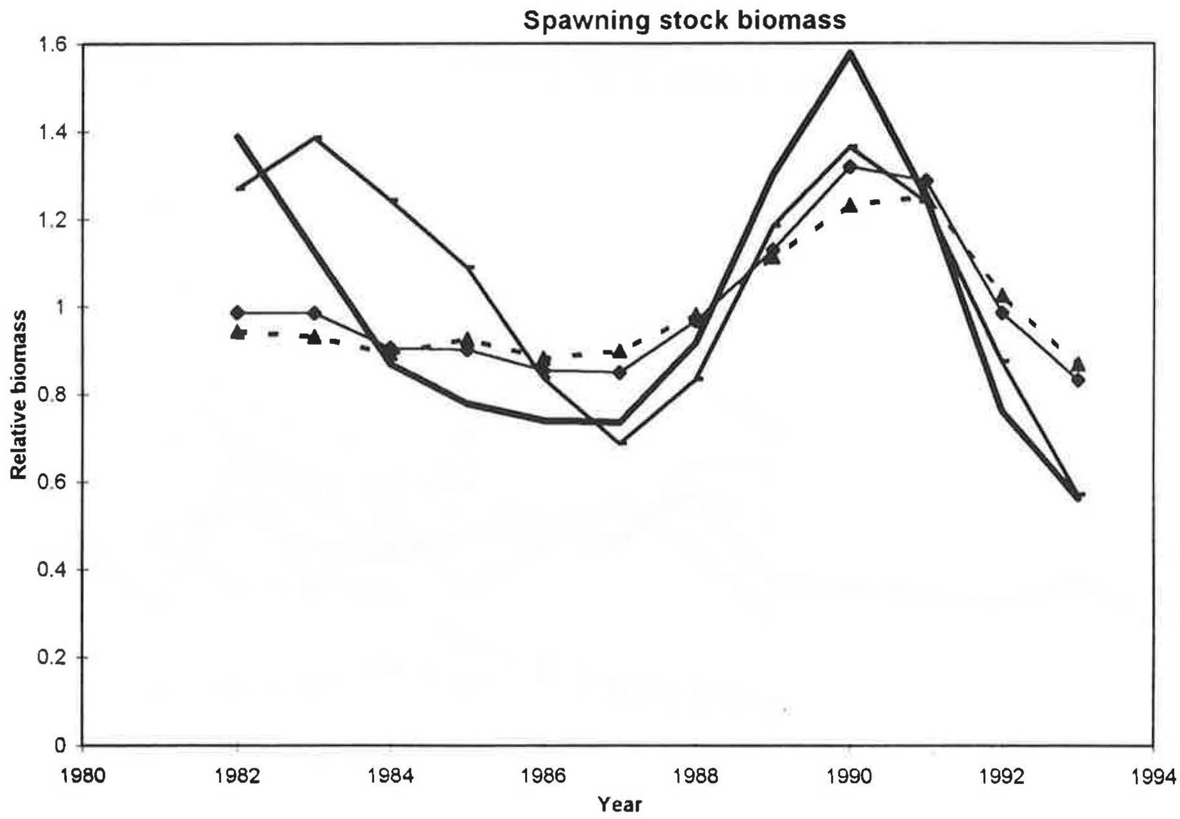
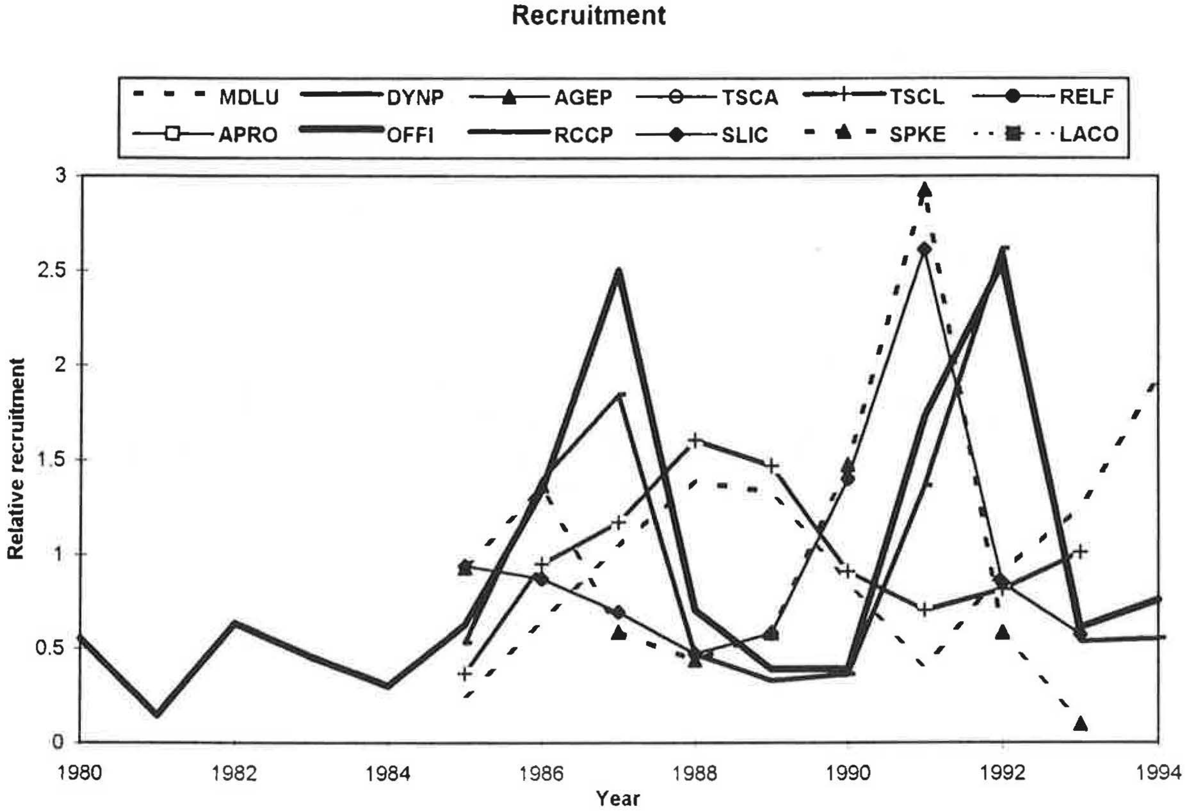


Figure 7.1.2 Comparison of methods.
Icelandic Haddock.



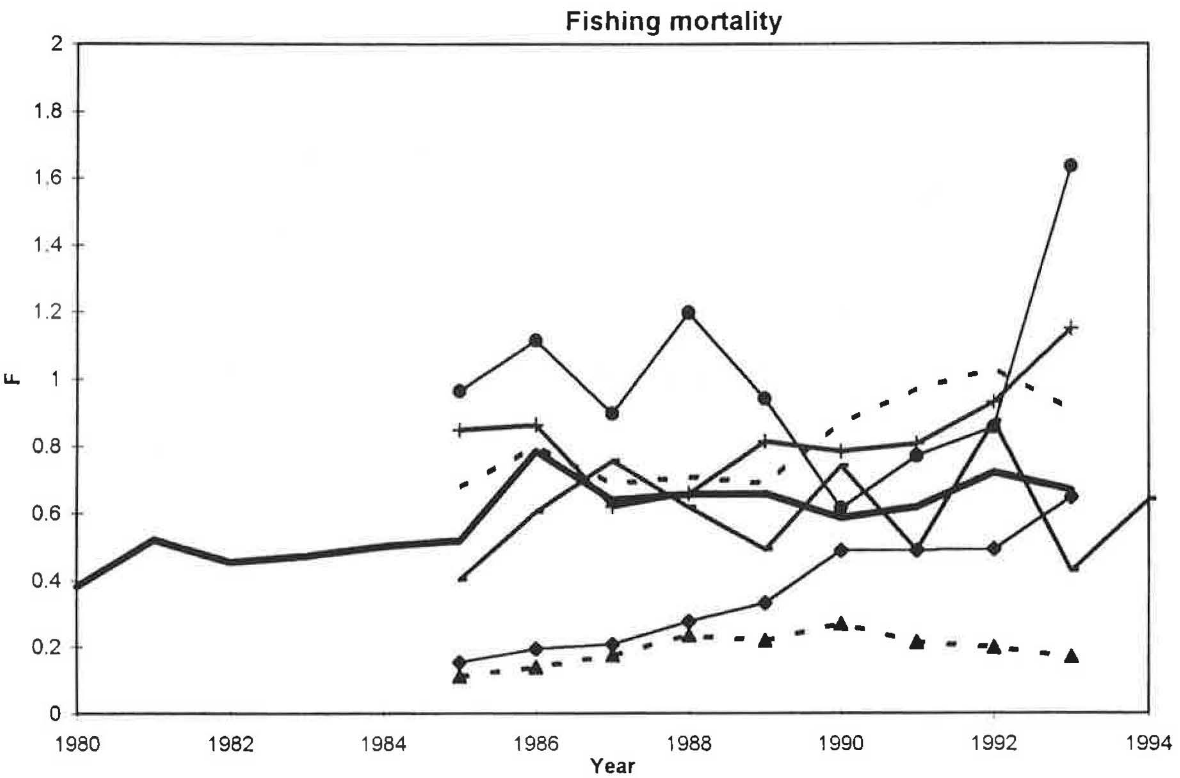
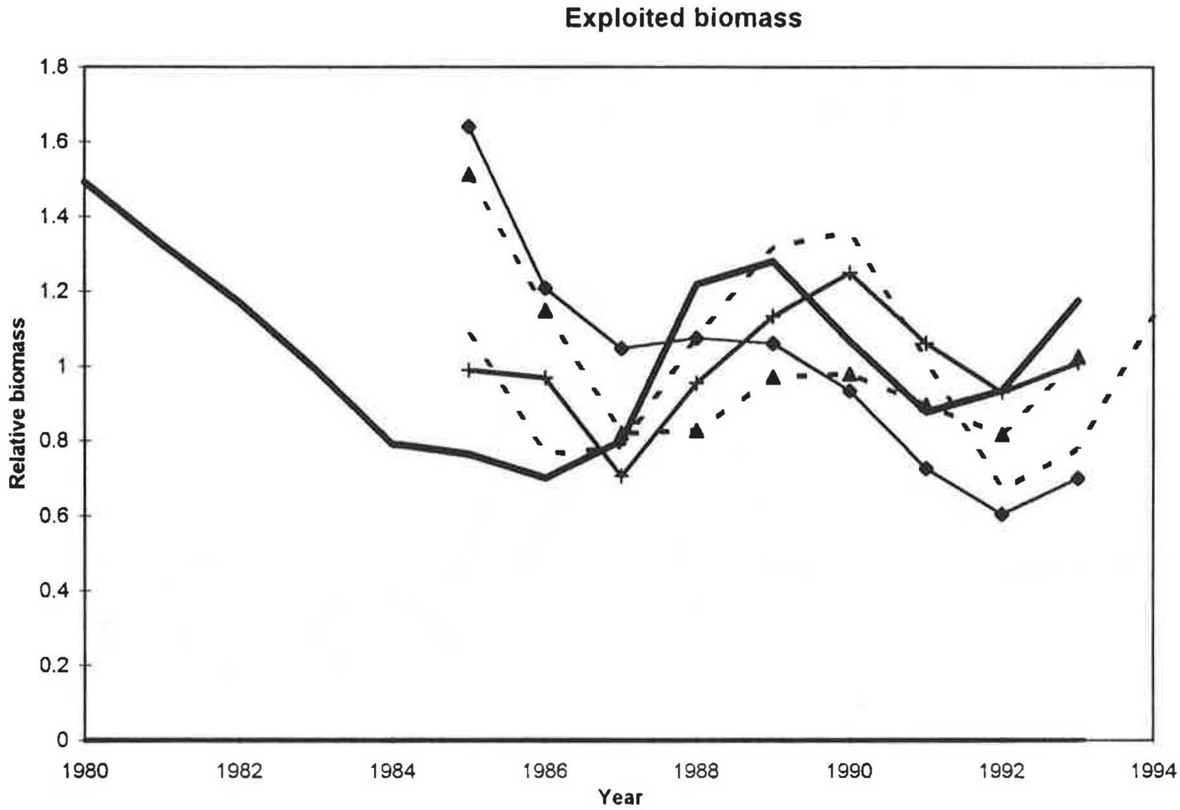


Figure 7.1.2 Cont.



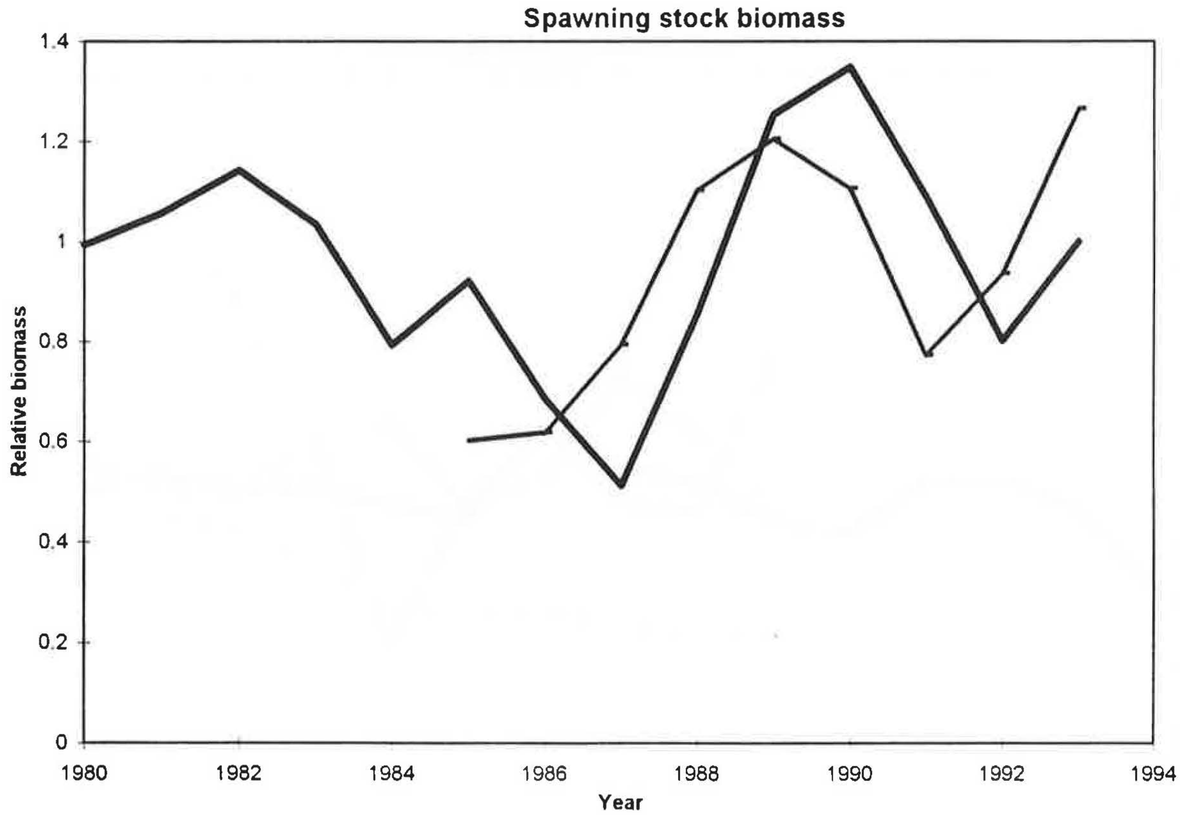


Figure 7.1.3 Comparison of methods.
Icelandic Cod.

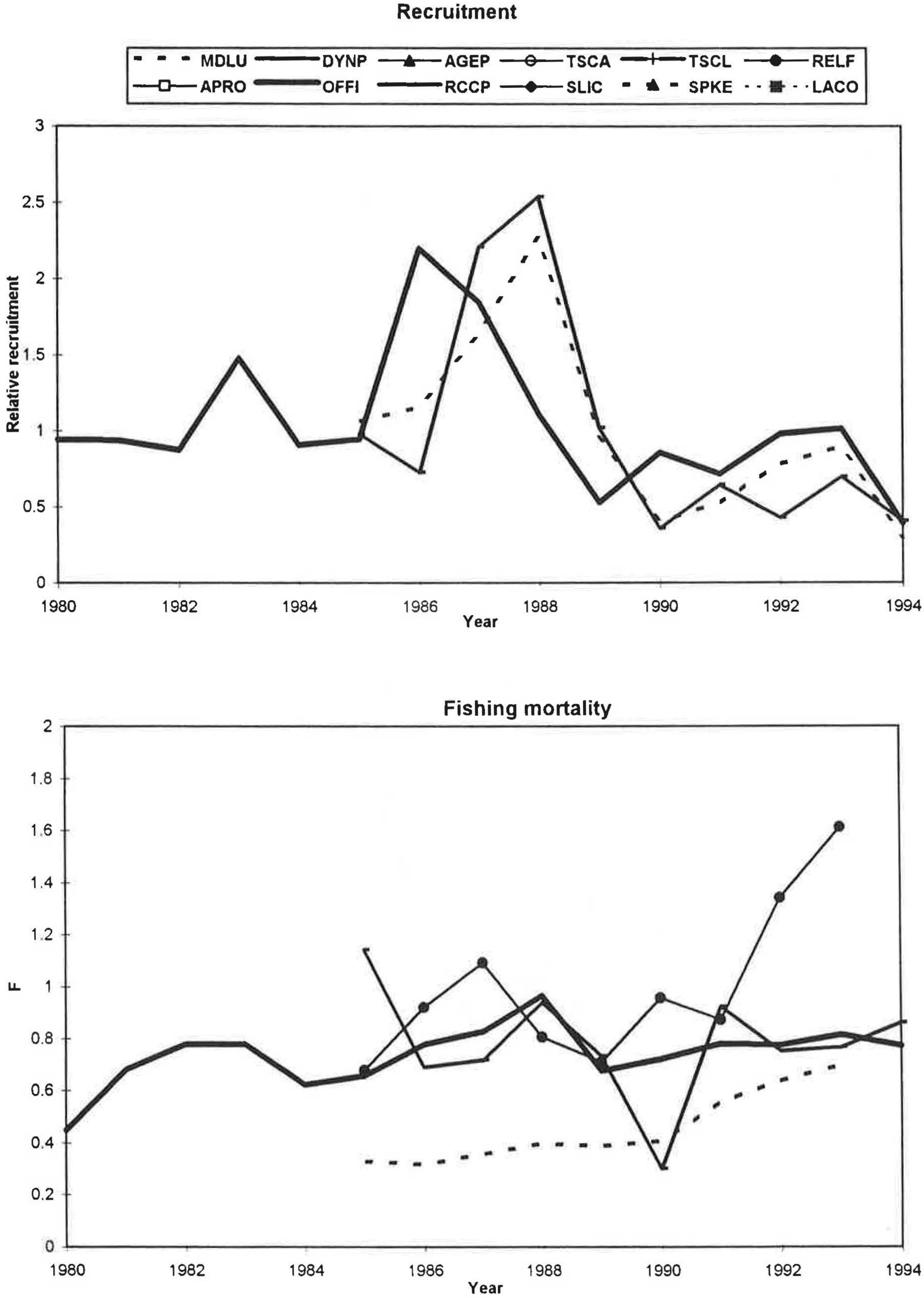
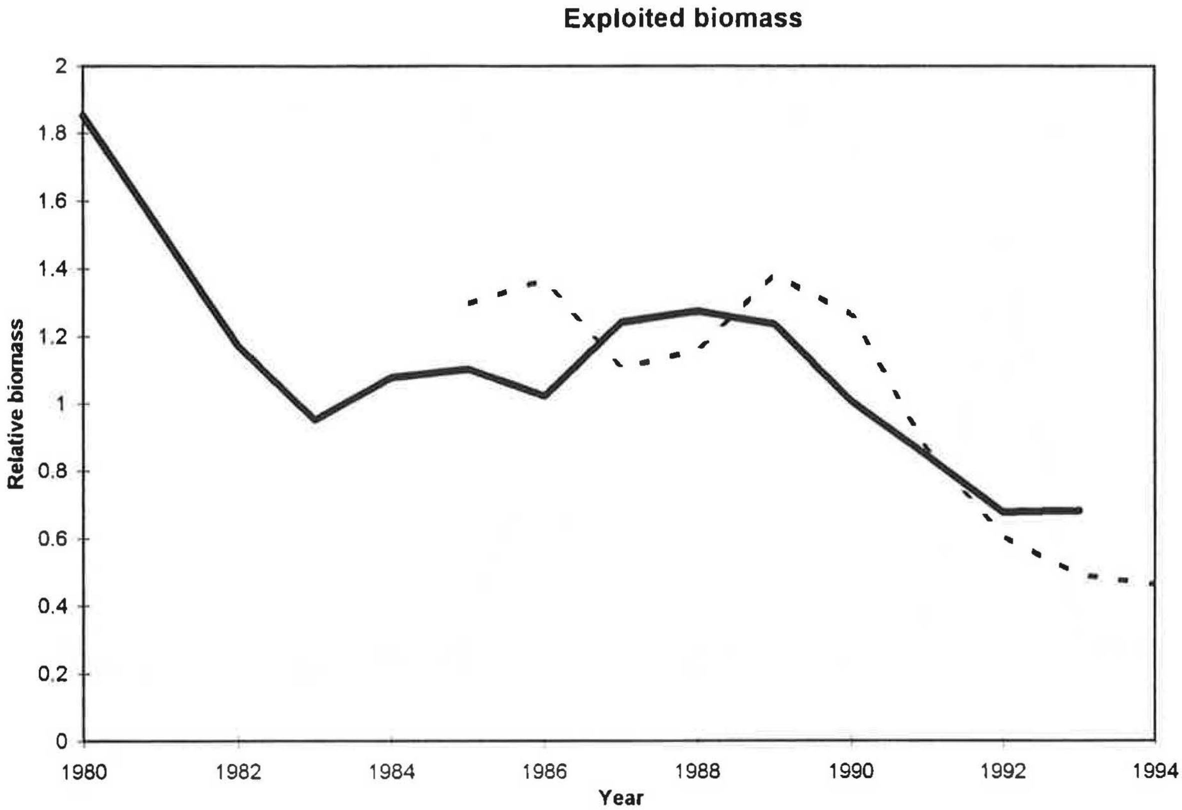


Figure 7.1.3 Cont.



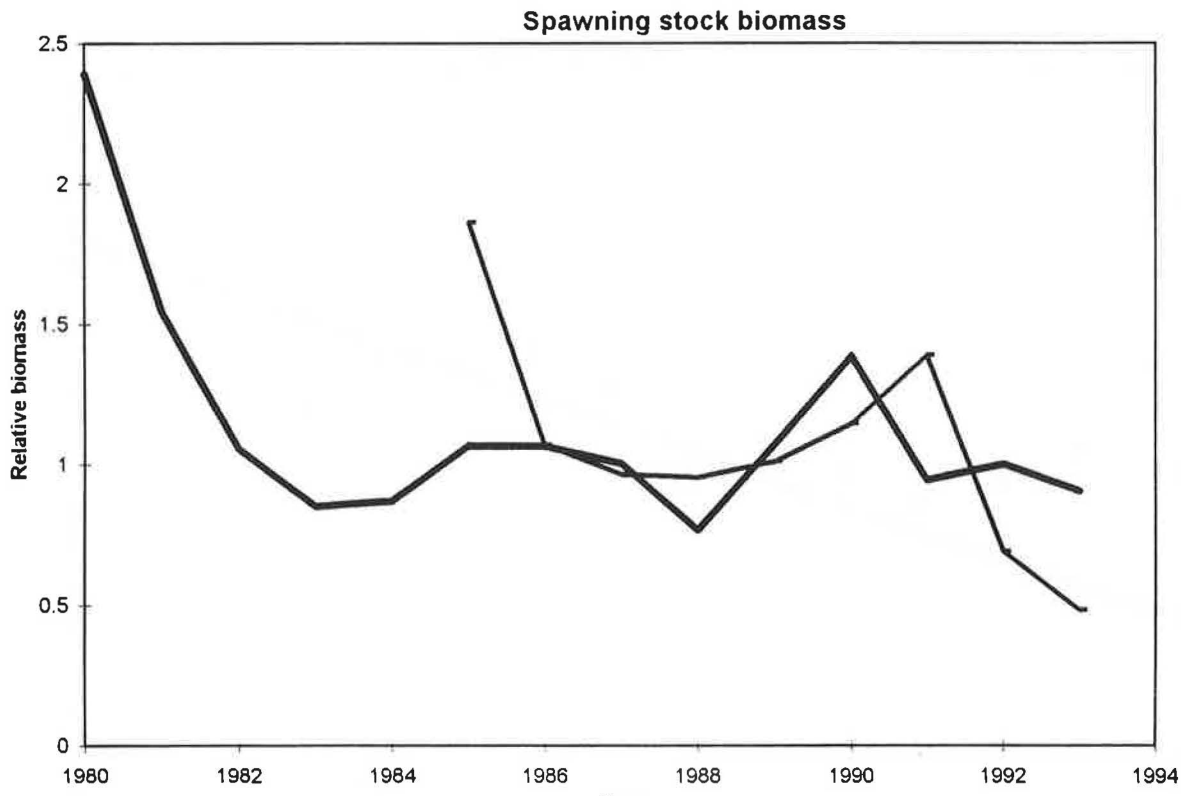
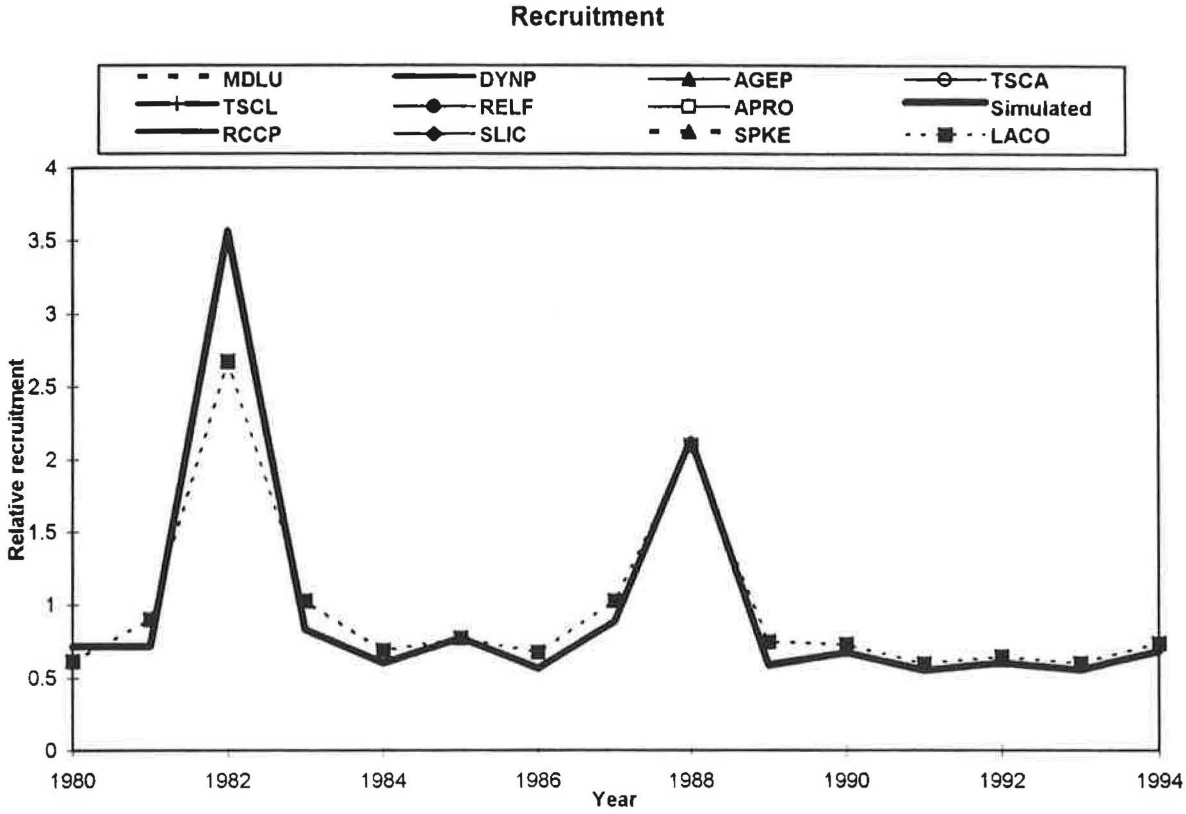


Figure 7.1.4 Comparison of methods.
"Clean" simulated tuna.



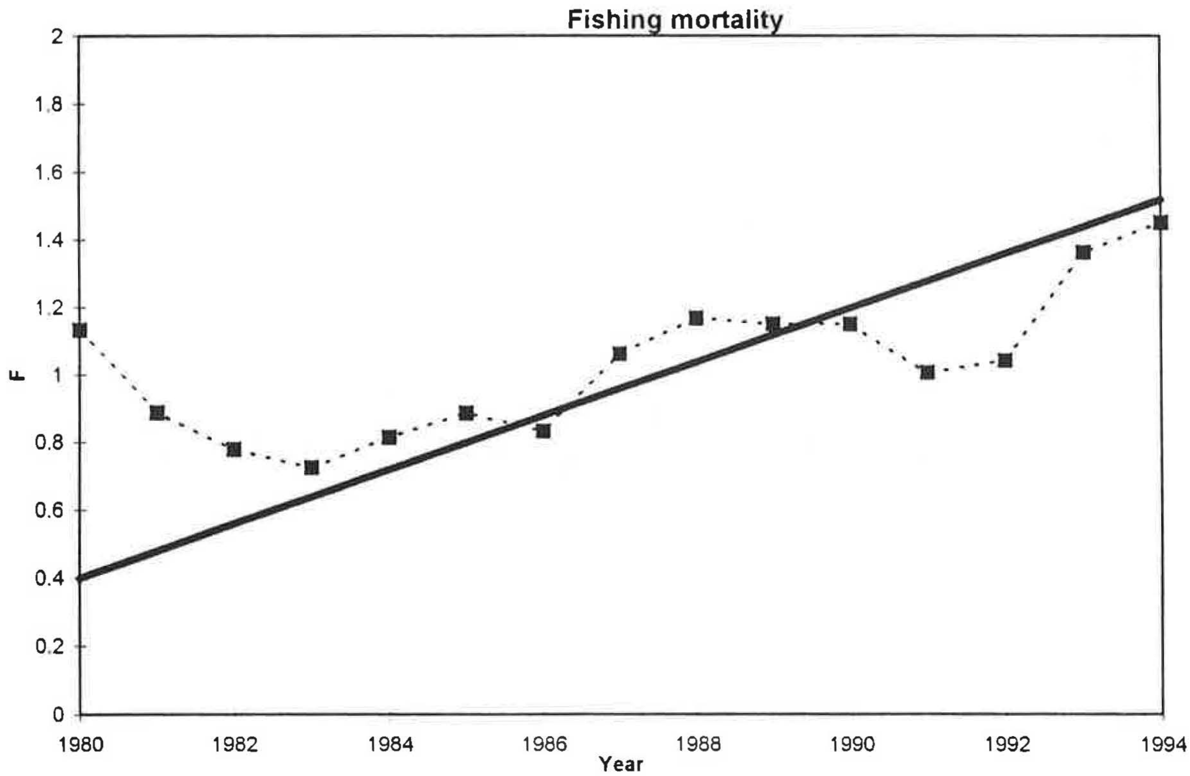


Figure 7.1.5 Comparison of methods.
North Sea Haddock.

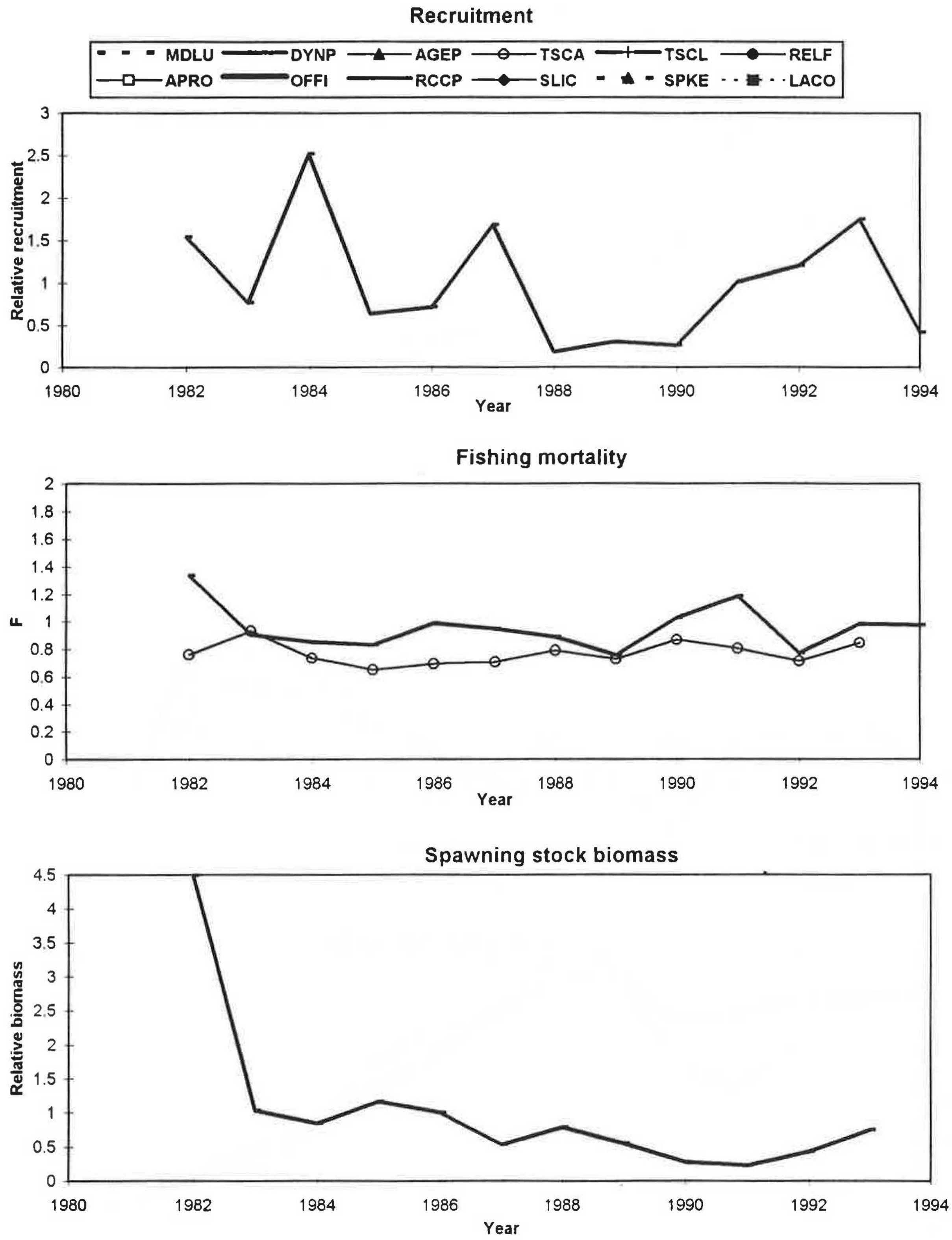


Figure 7.1.6 Comparison of methods.
Southern Gulf cod
4T 4Vn (Nov-May).

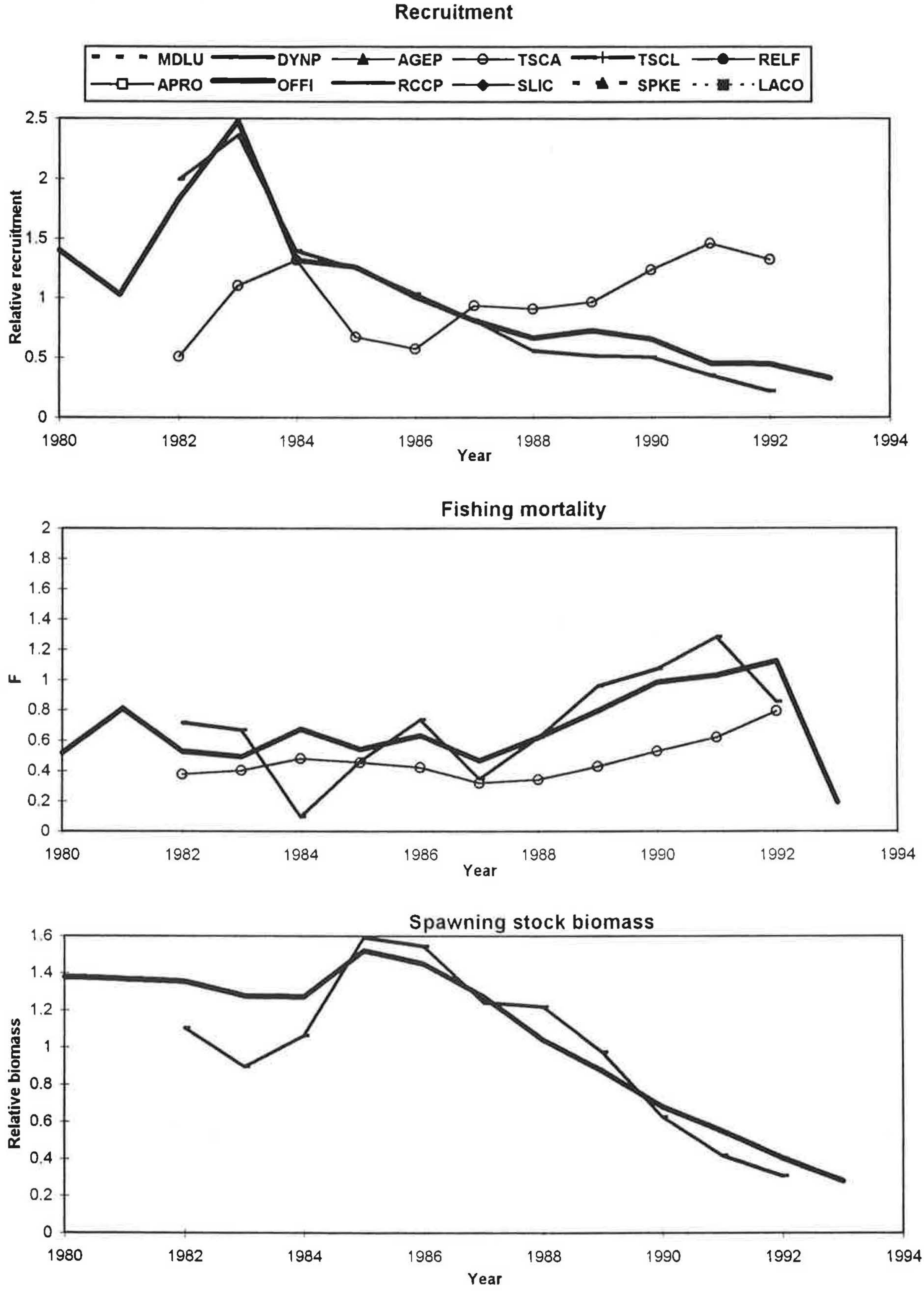


Figure 7.1.7 Comparison of methods.
Canadian Redfish.

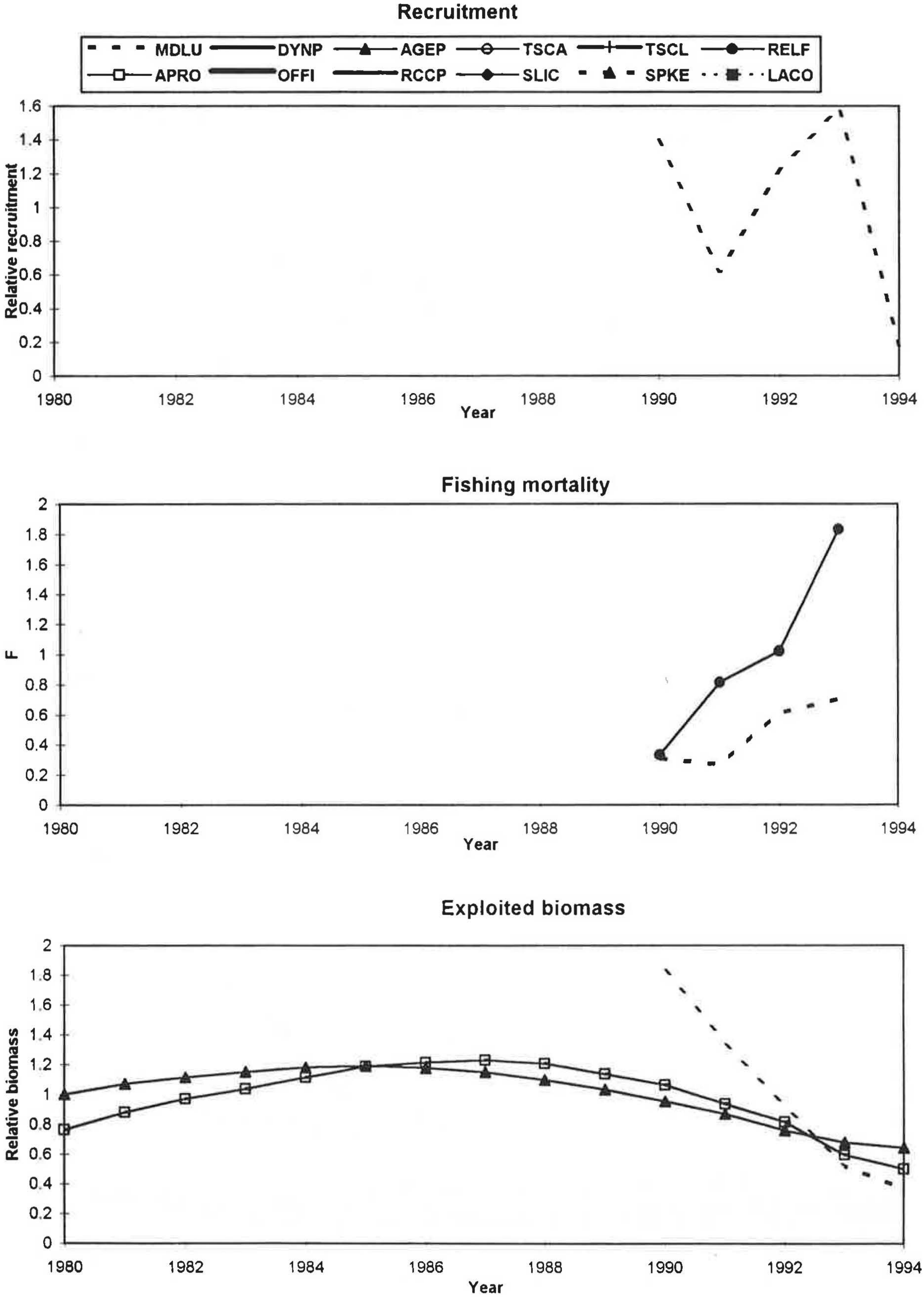
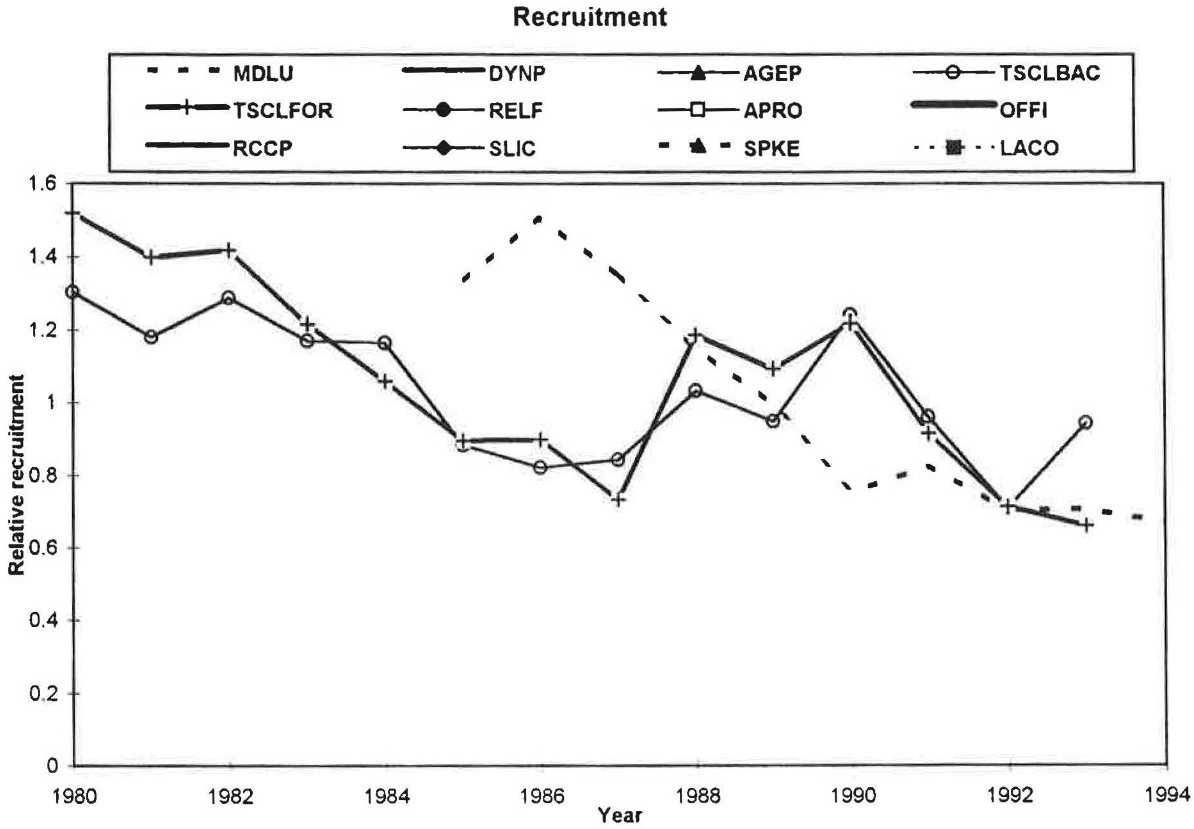


Figure 7.1.8 Comparison of methods.
Icelandic data on *S. marinus.*



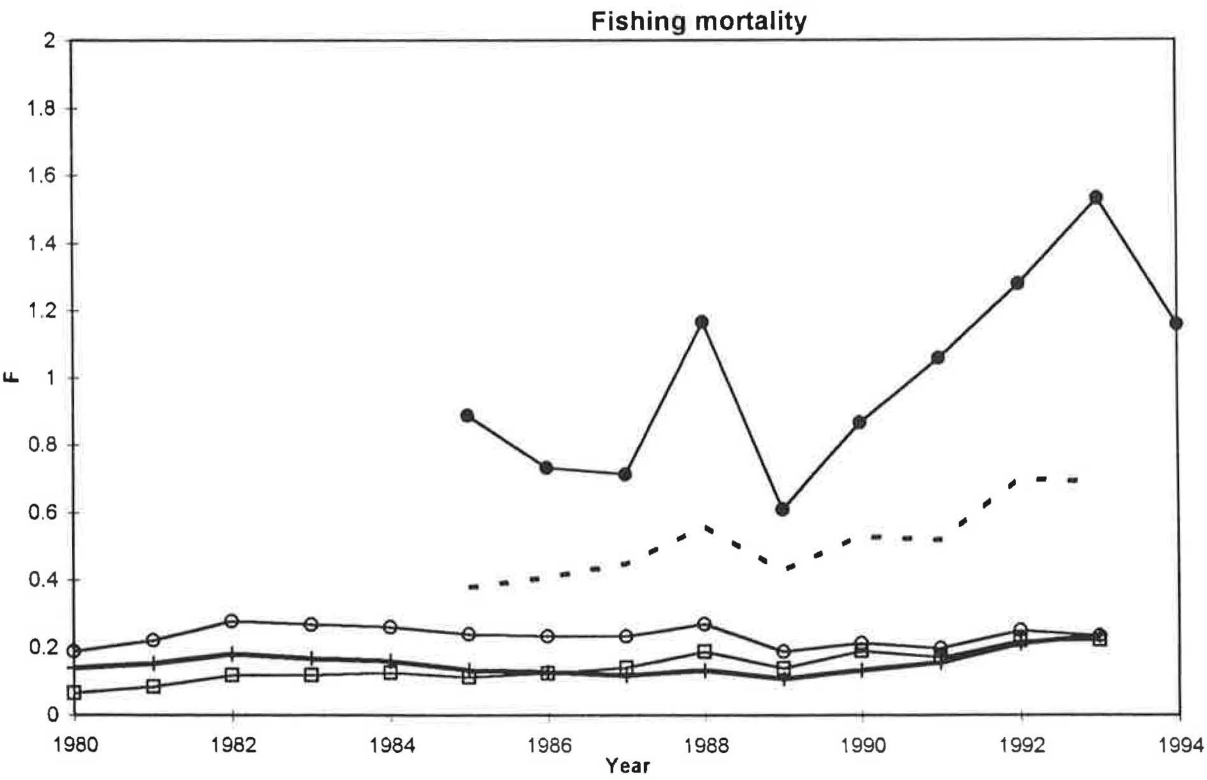


Figure 7.1.8 Cont.

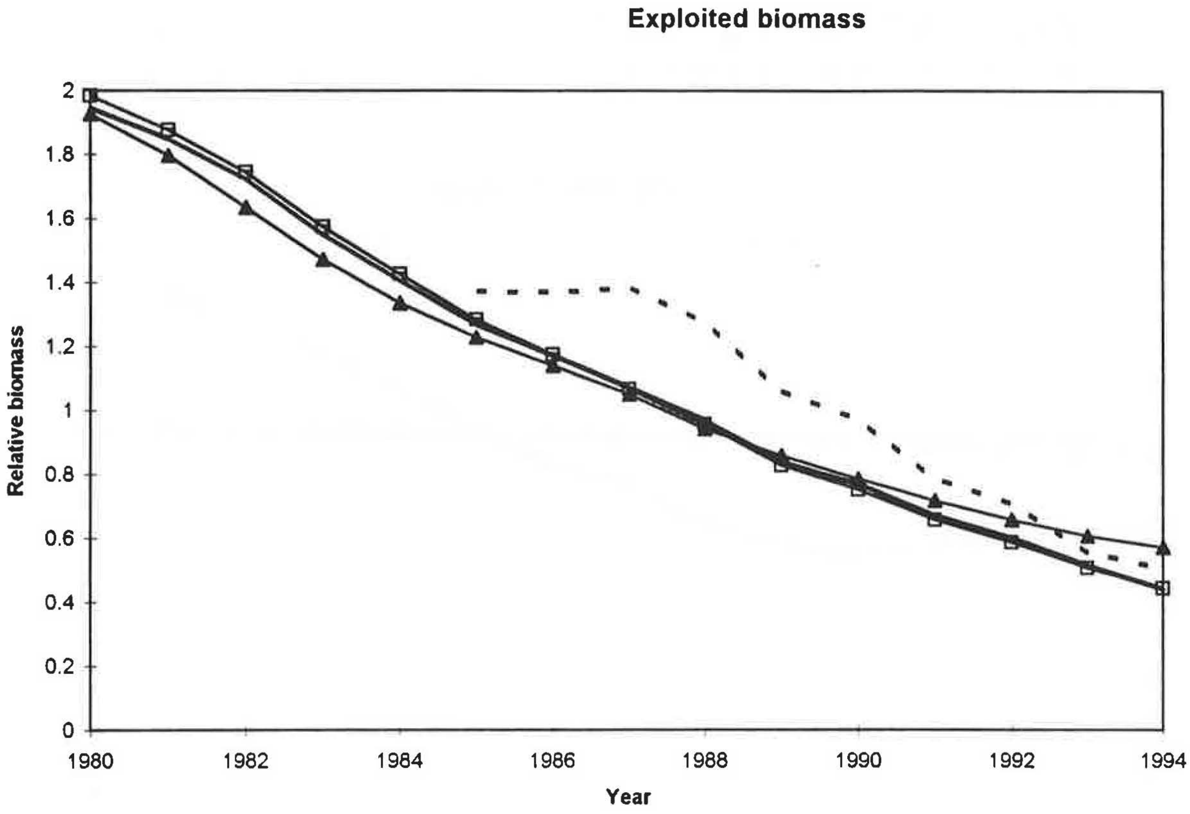


Figure 7.1.9 Comparison of methods.
Pacific Ocean Pearch.

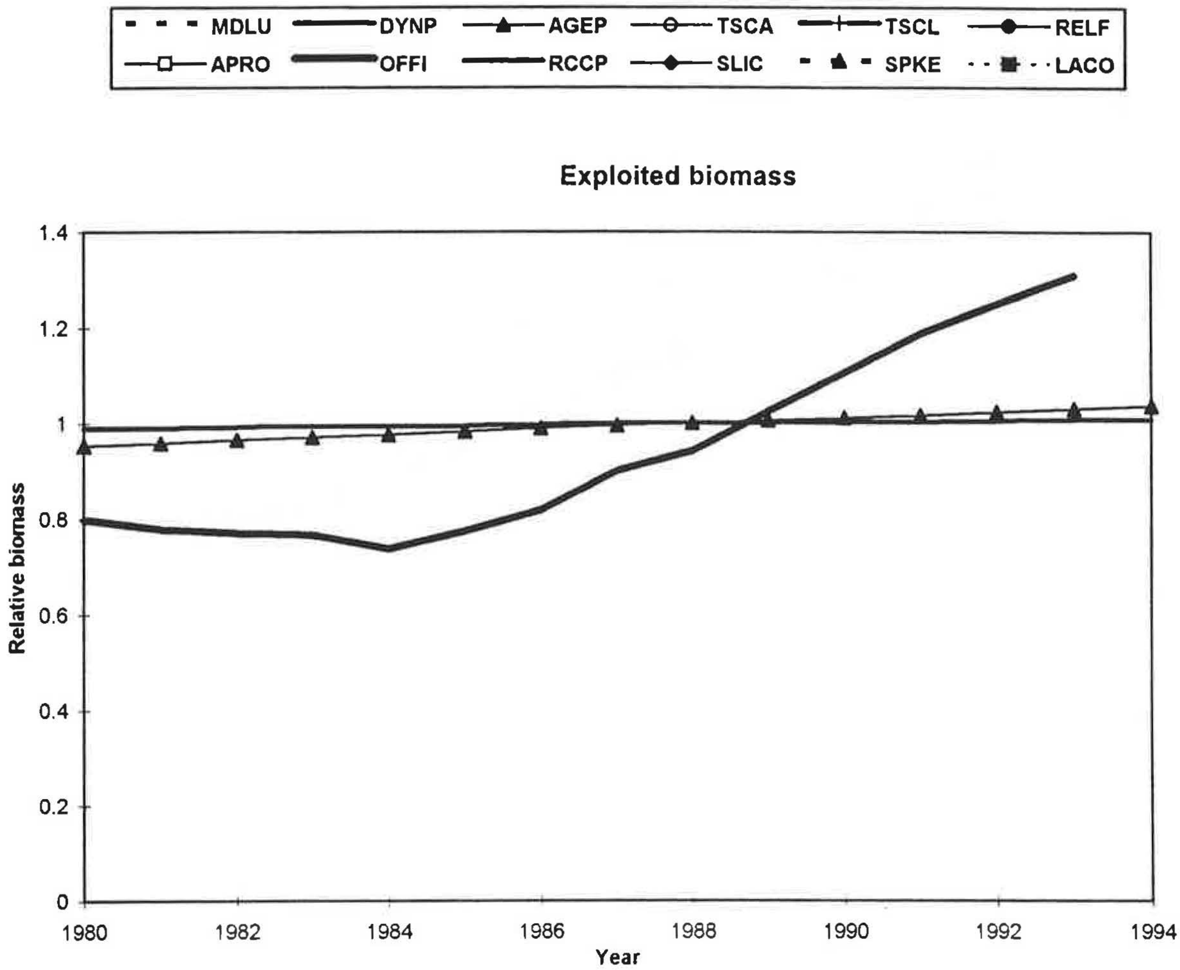


Figure 7.2.1a

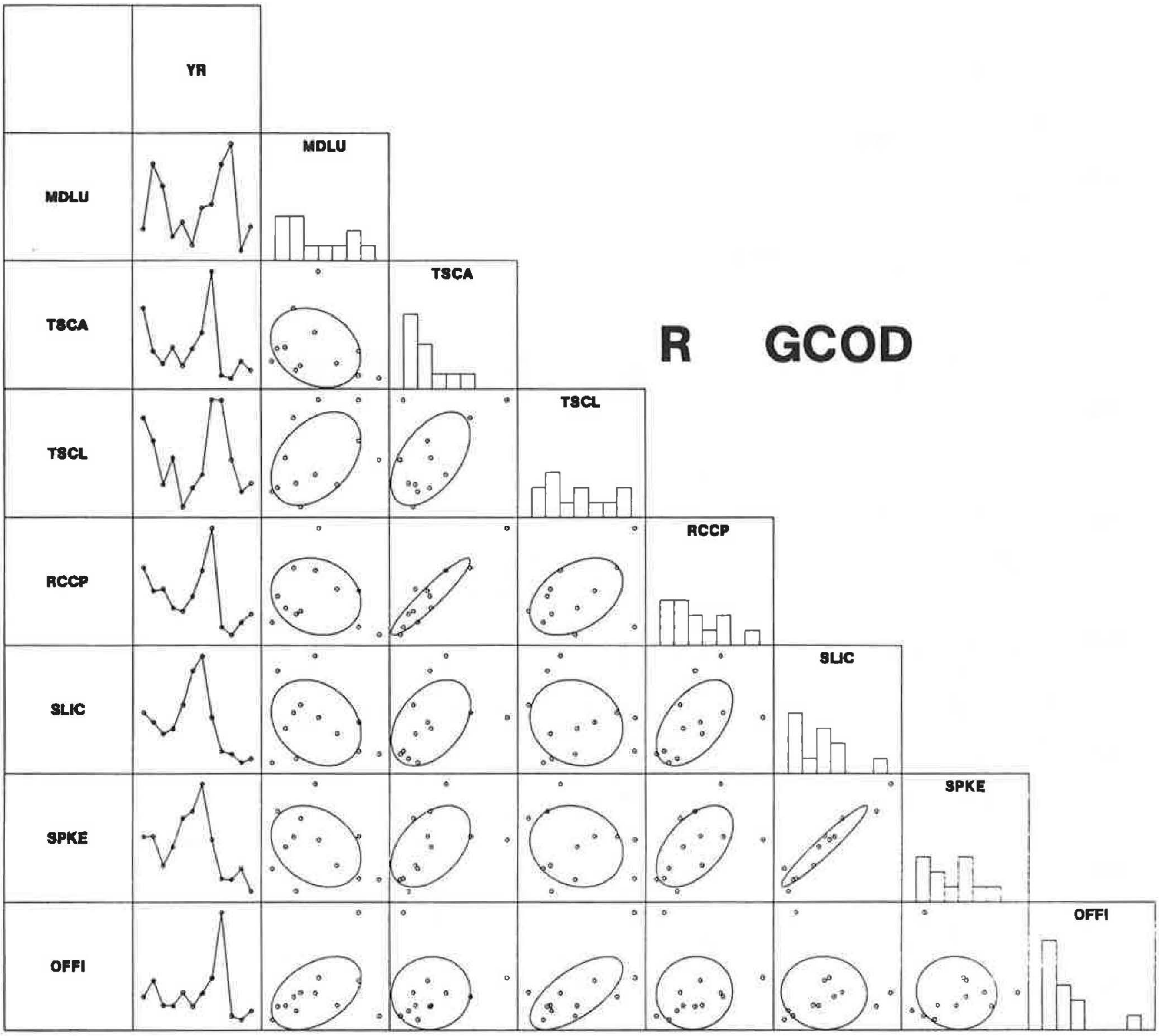


Figure 7.2.1b

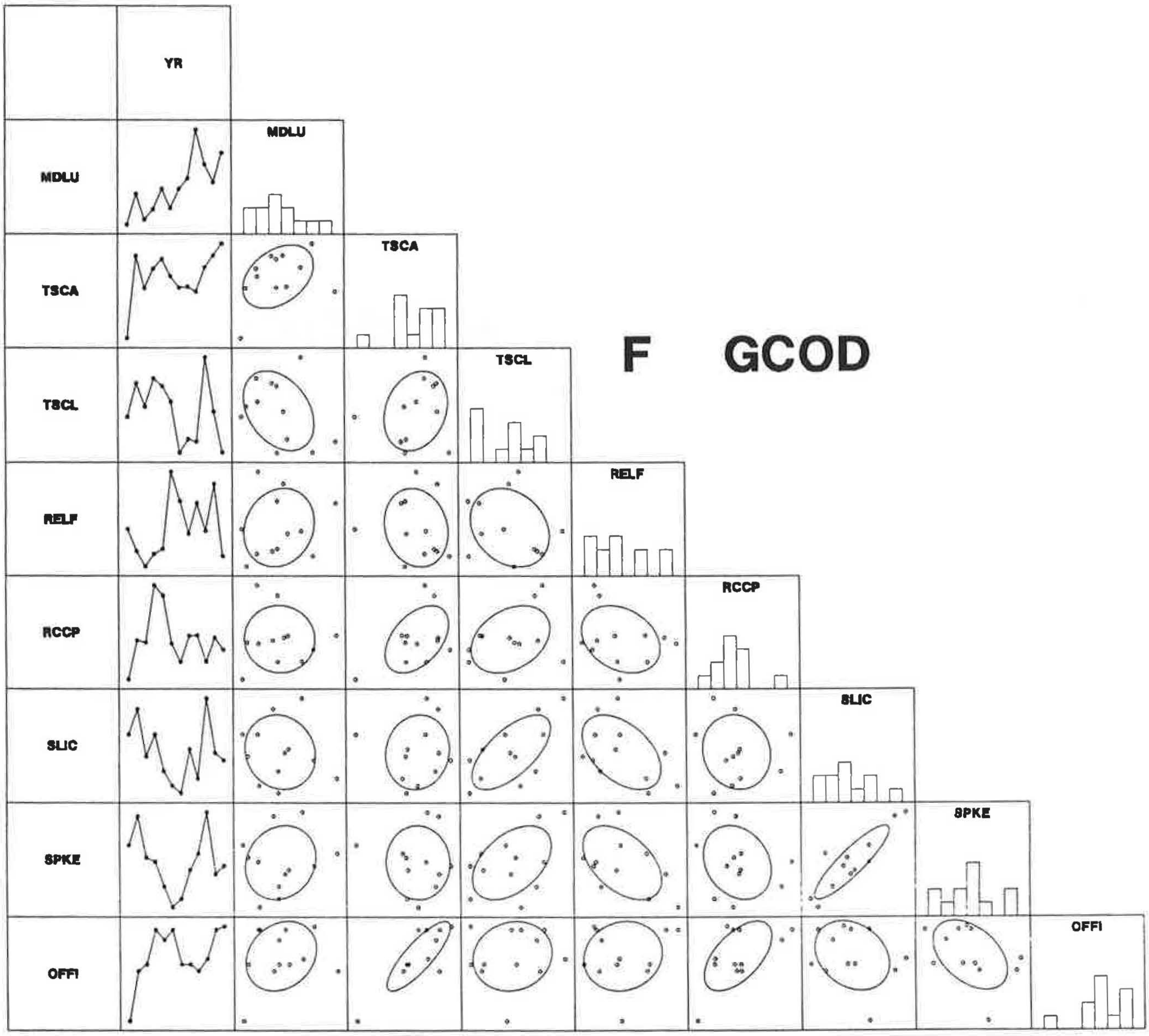


Figure 7.2.1c

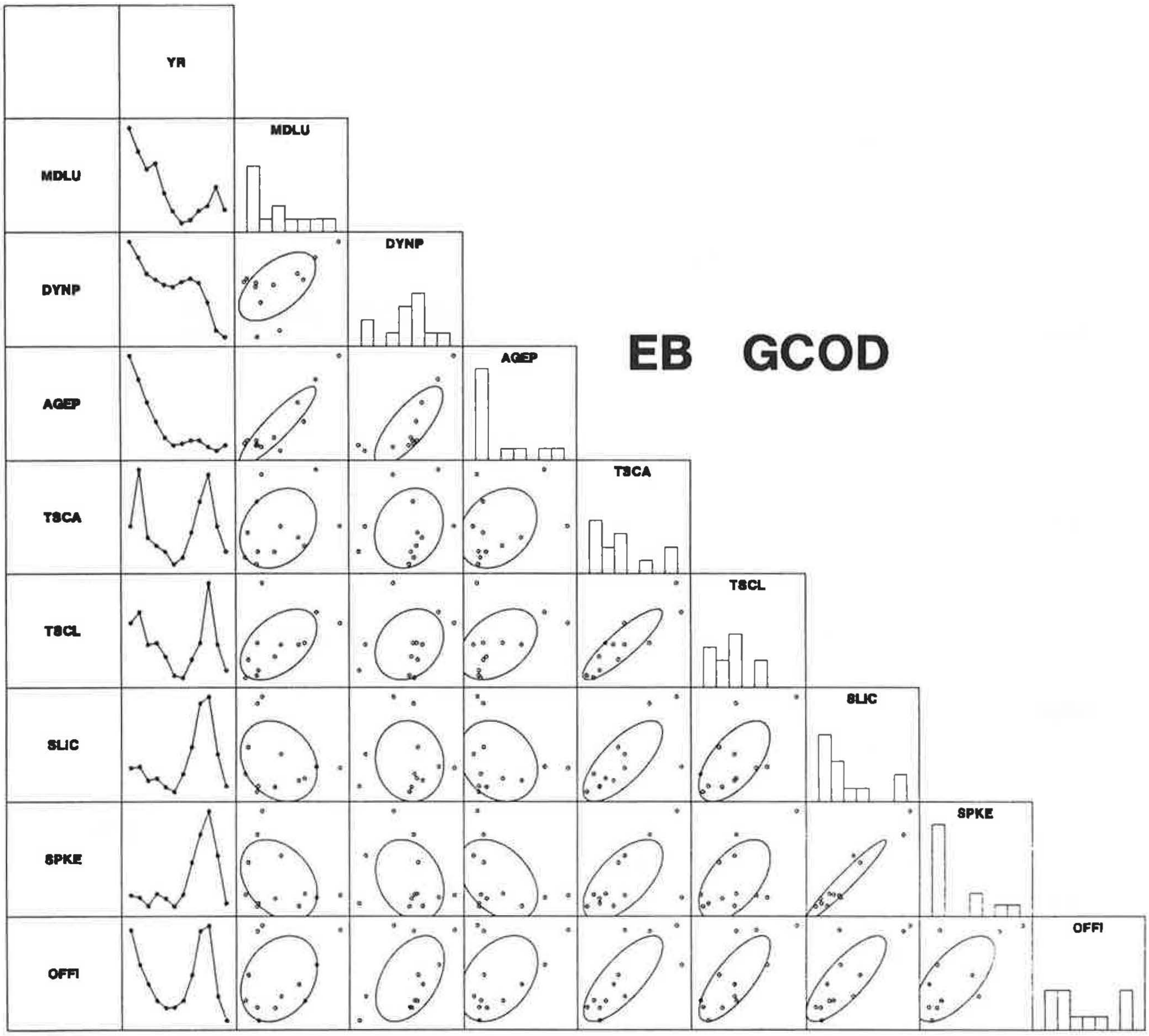


Figure 7.2.1d

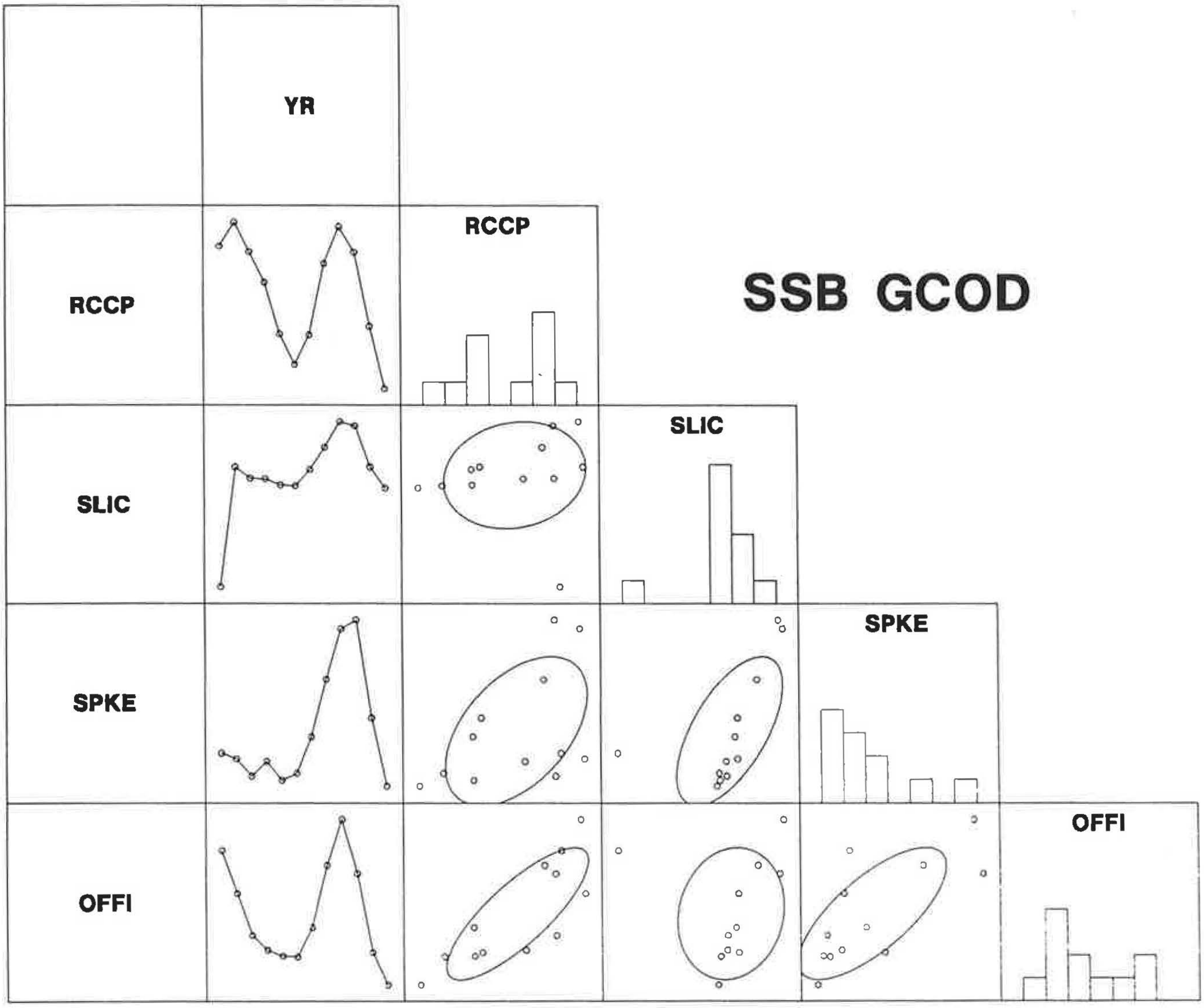
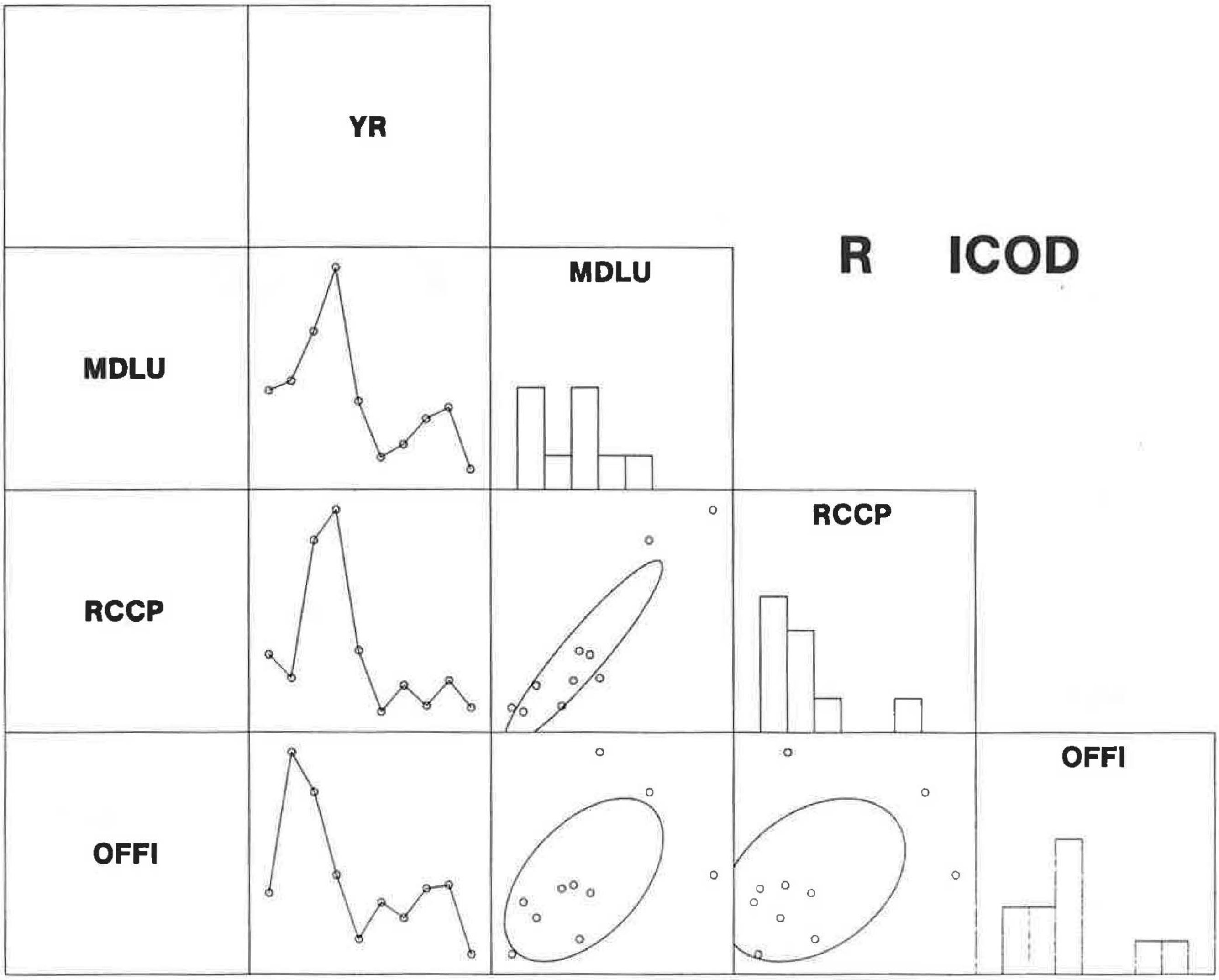


Figure 7.2.2a



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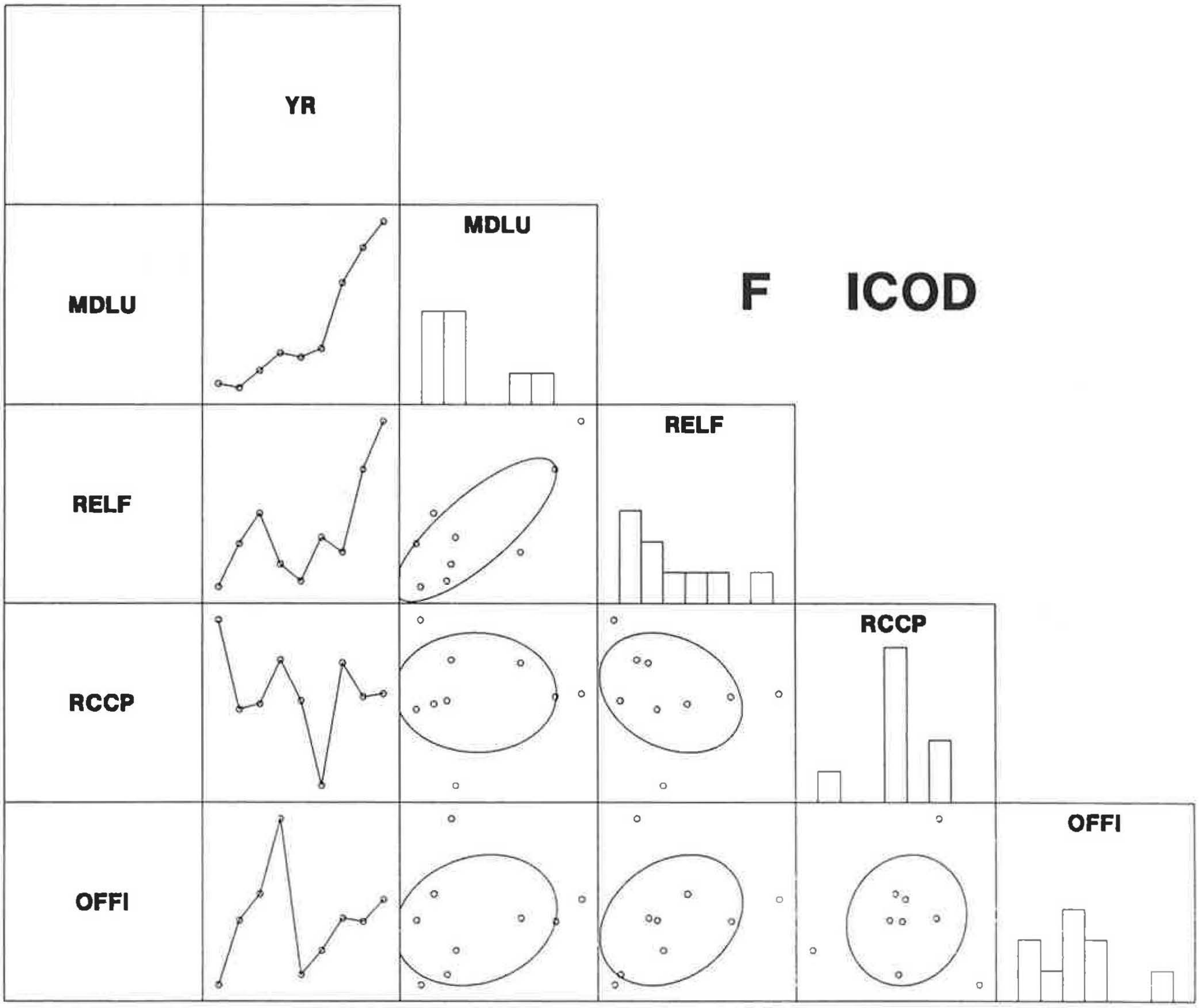

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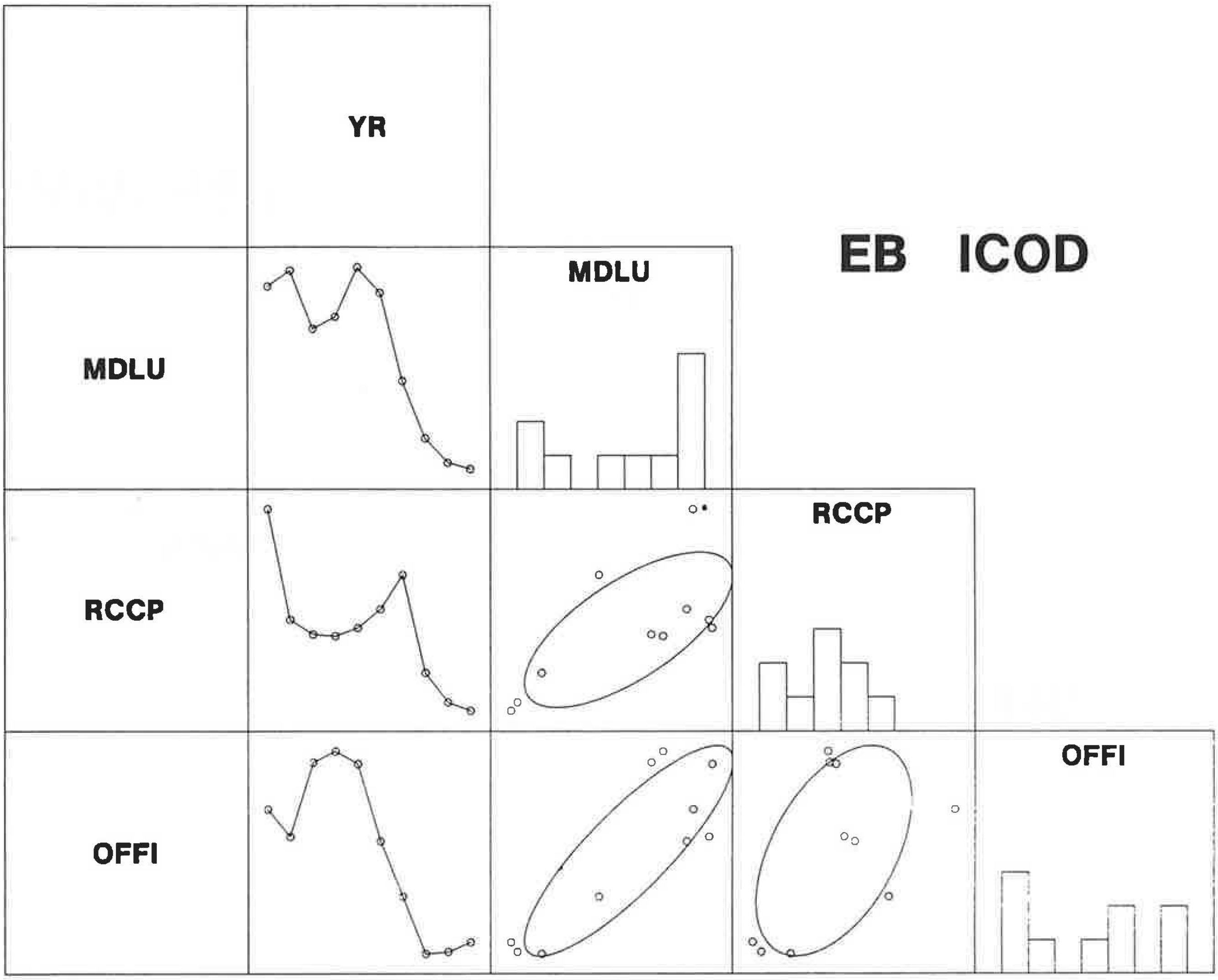

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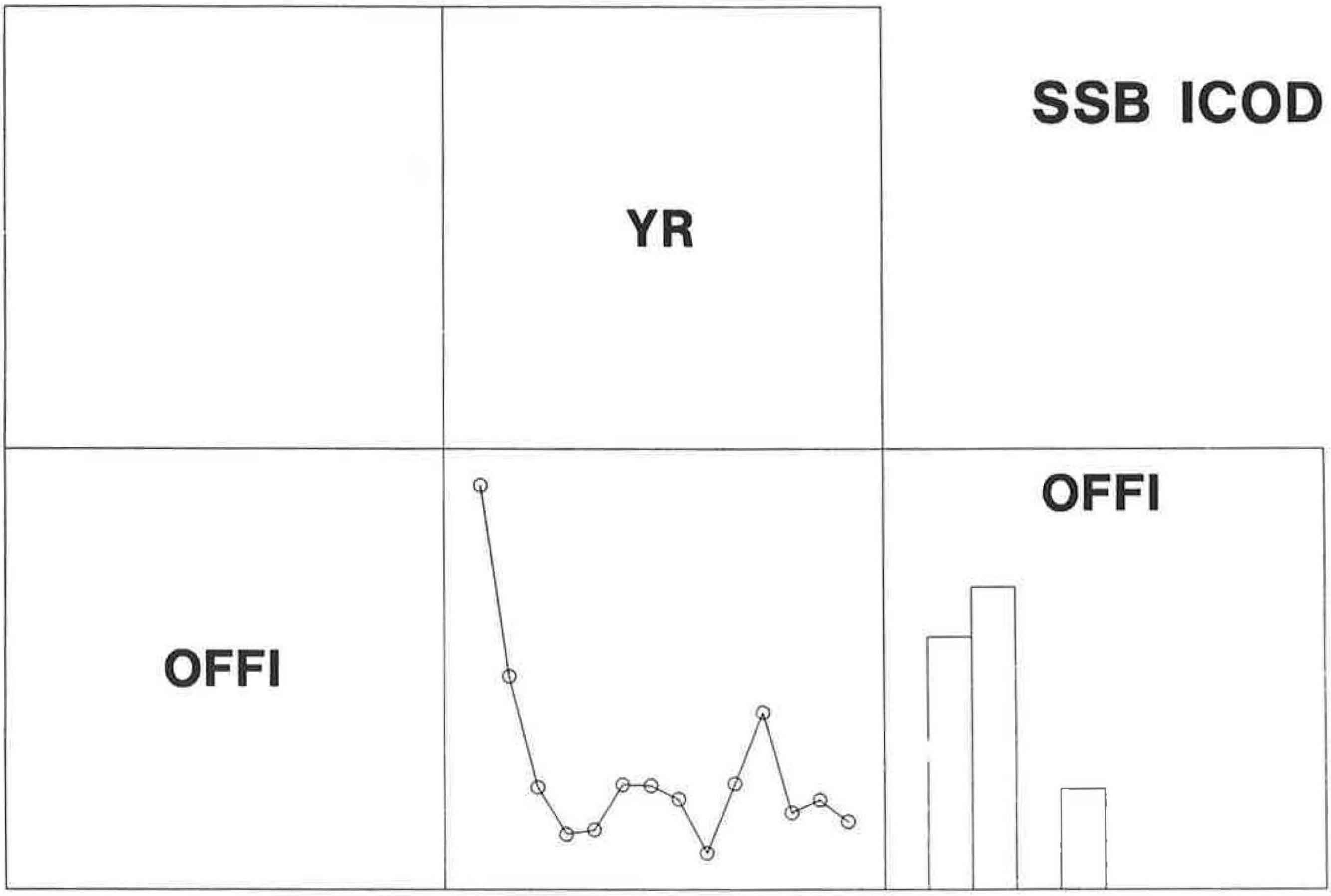


Figure 7.2.3a

Figure 7.2.3b

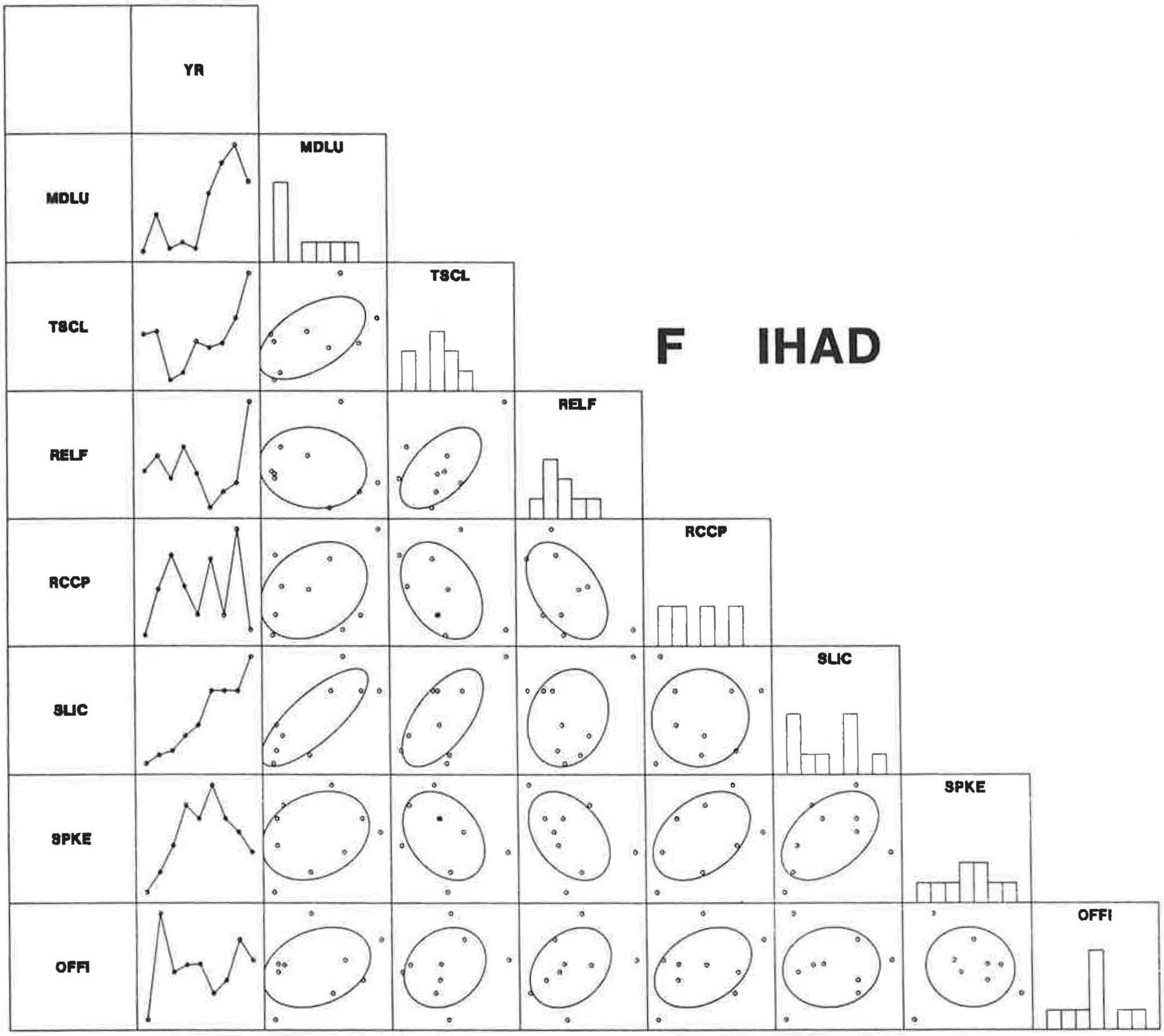


Figure 7.2.3c

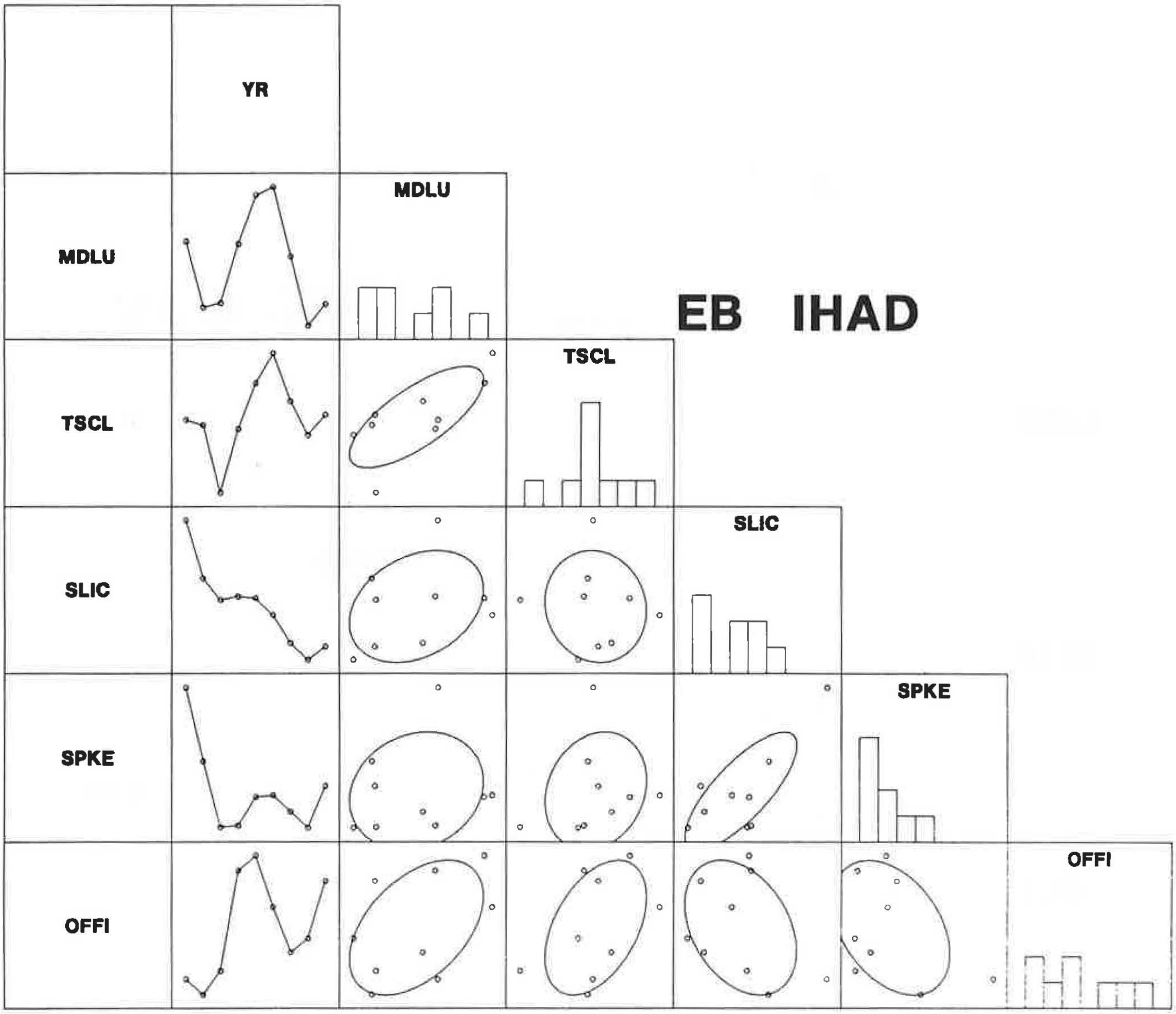


Figure 7.2.3d

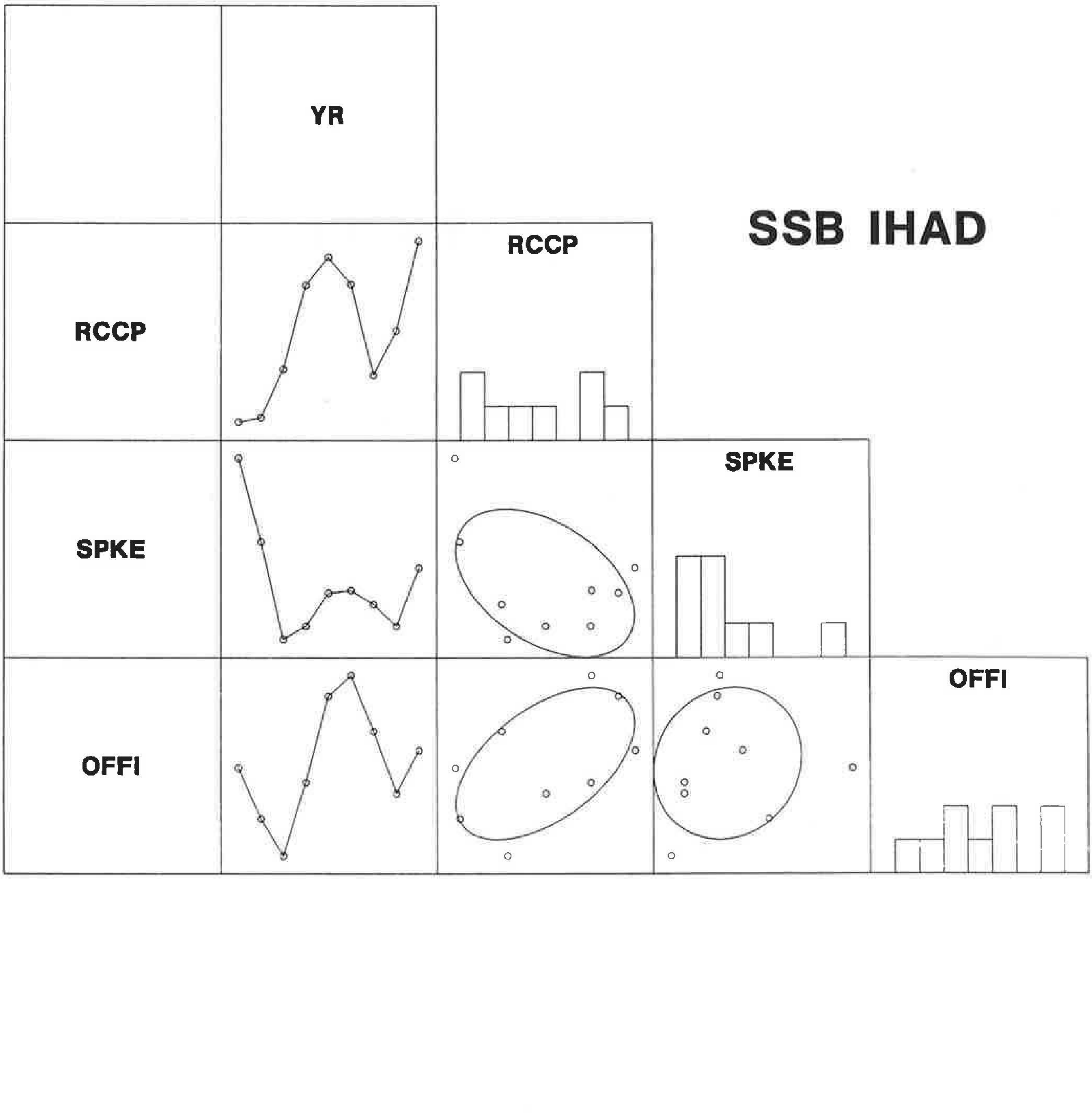


Figure 7.2.4a

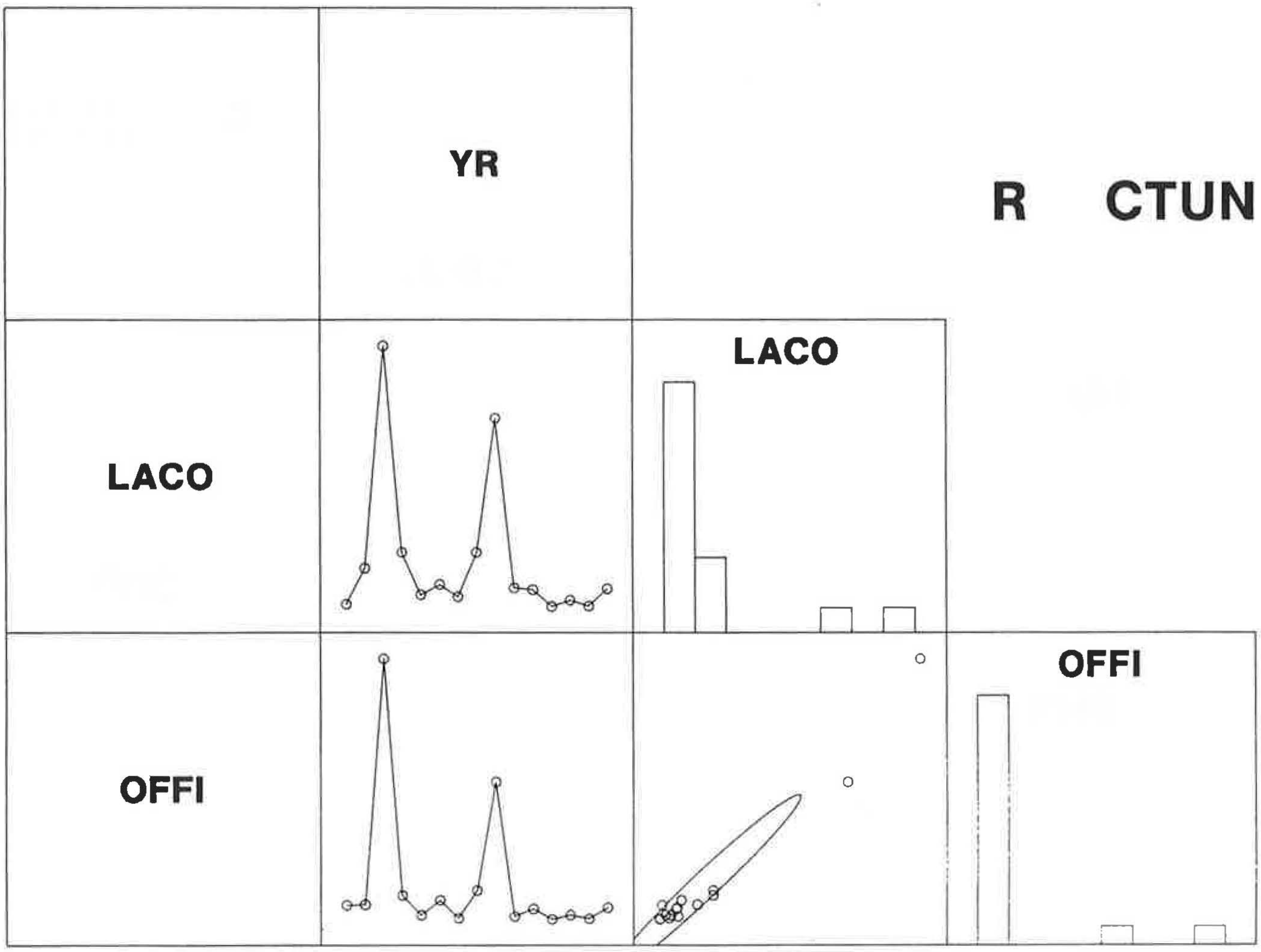


Figure 7.2.4b

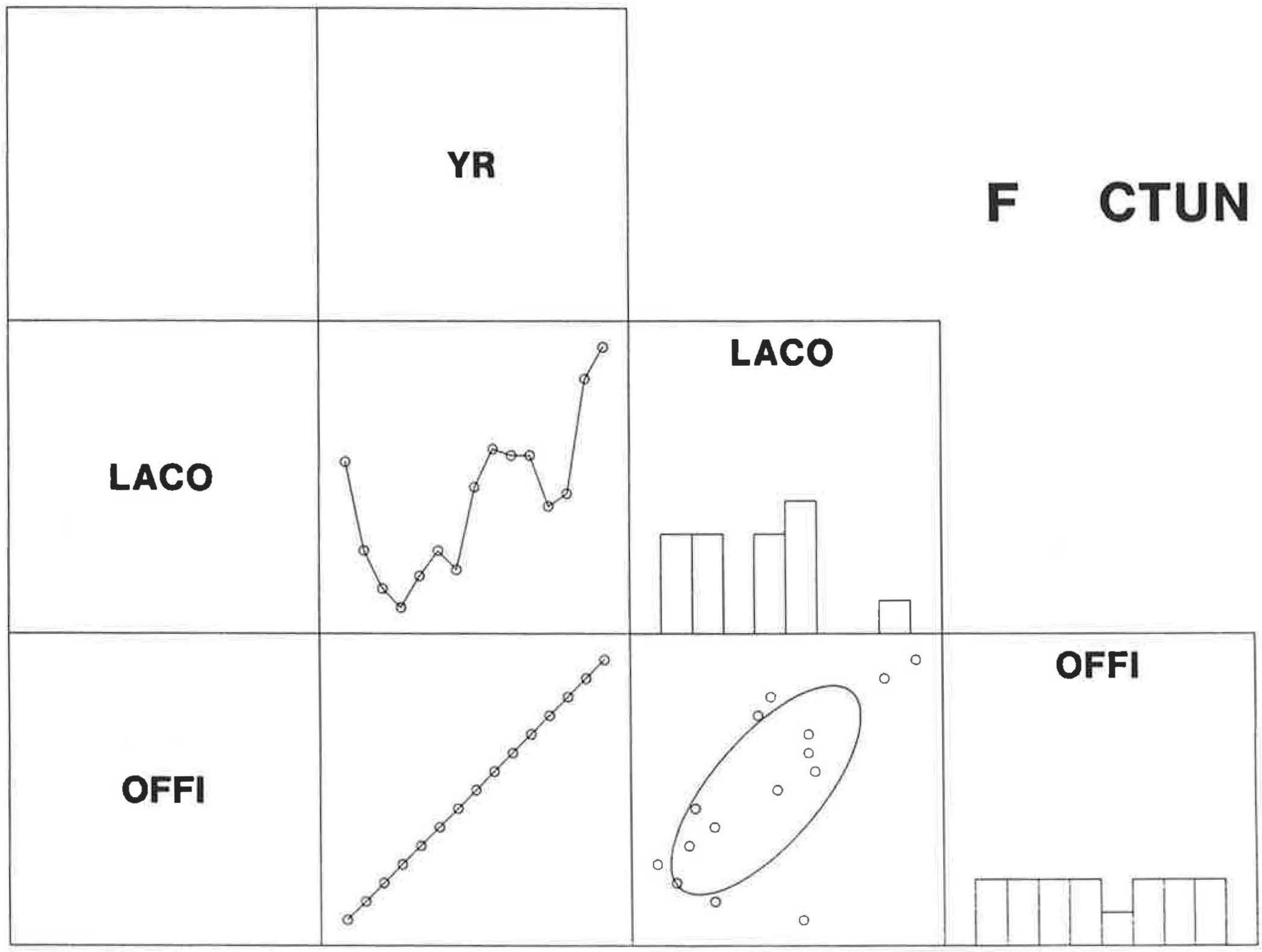
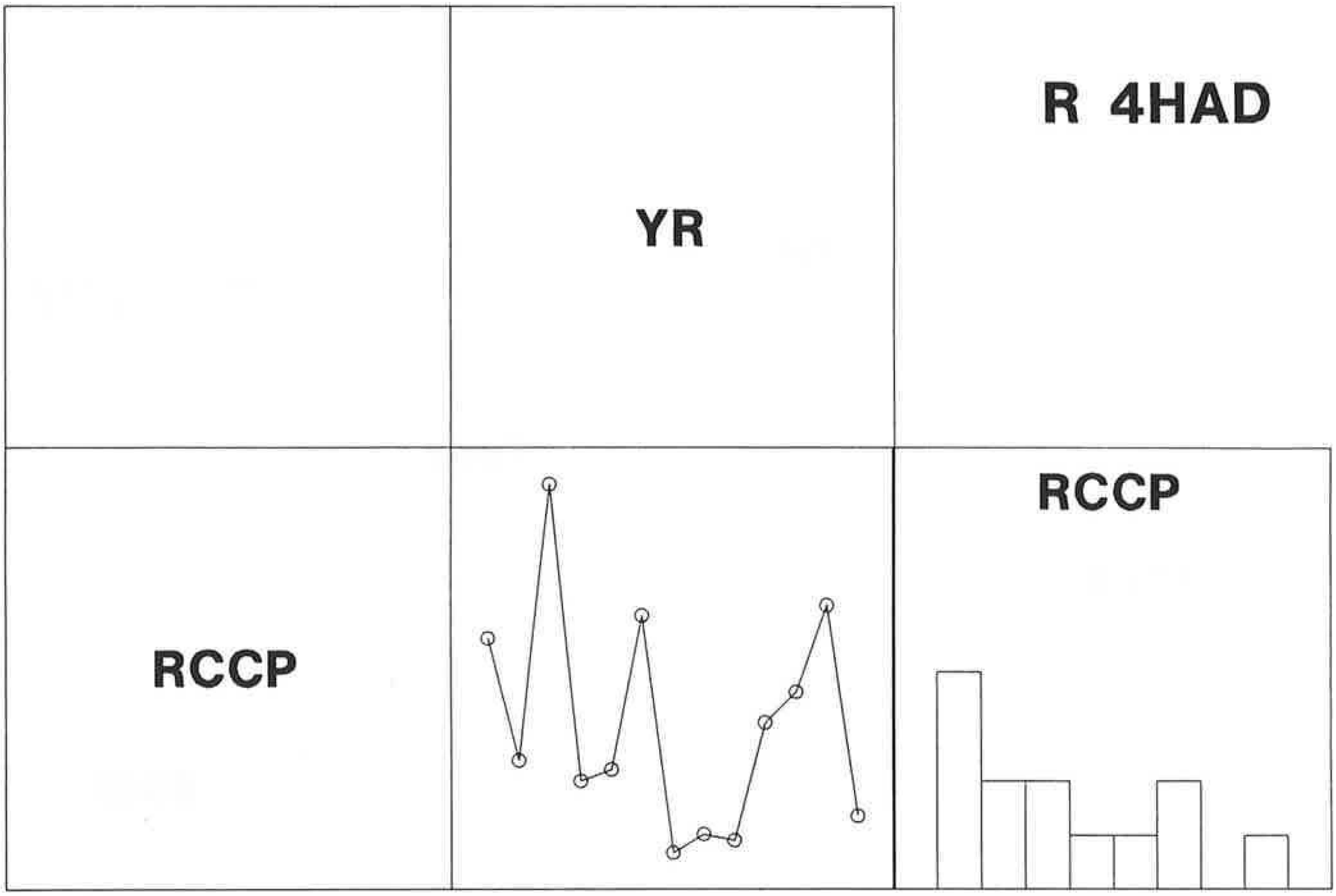


Figure 7.2.5a



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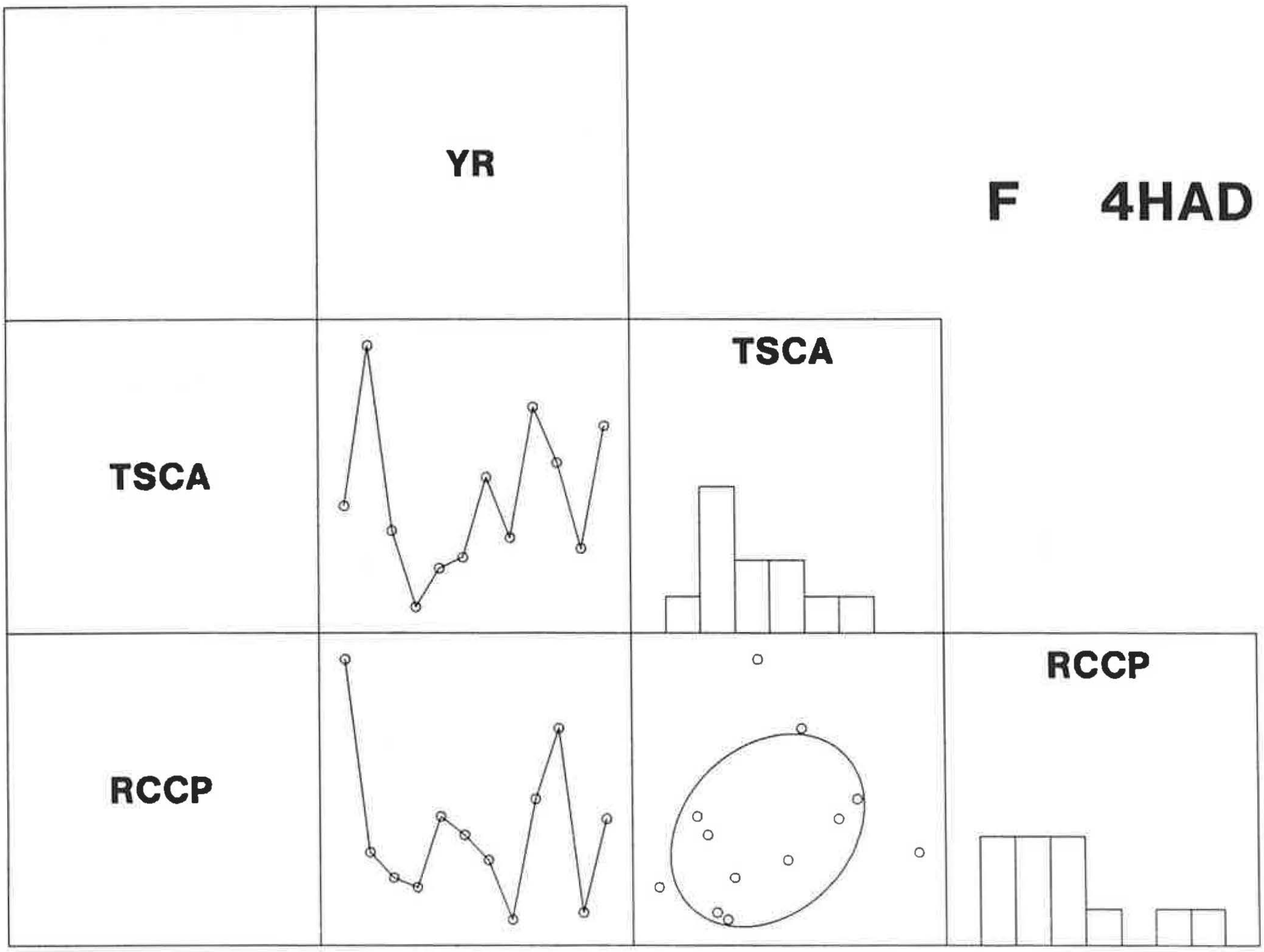
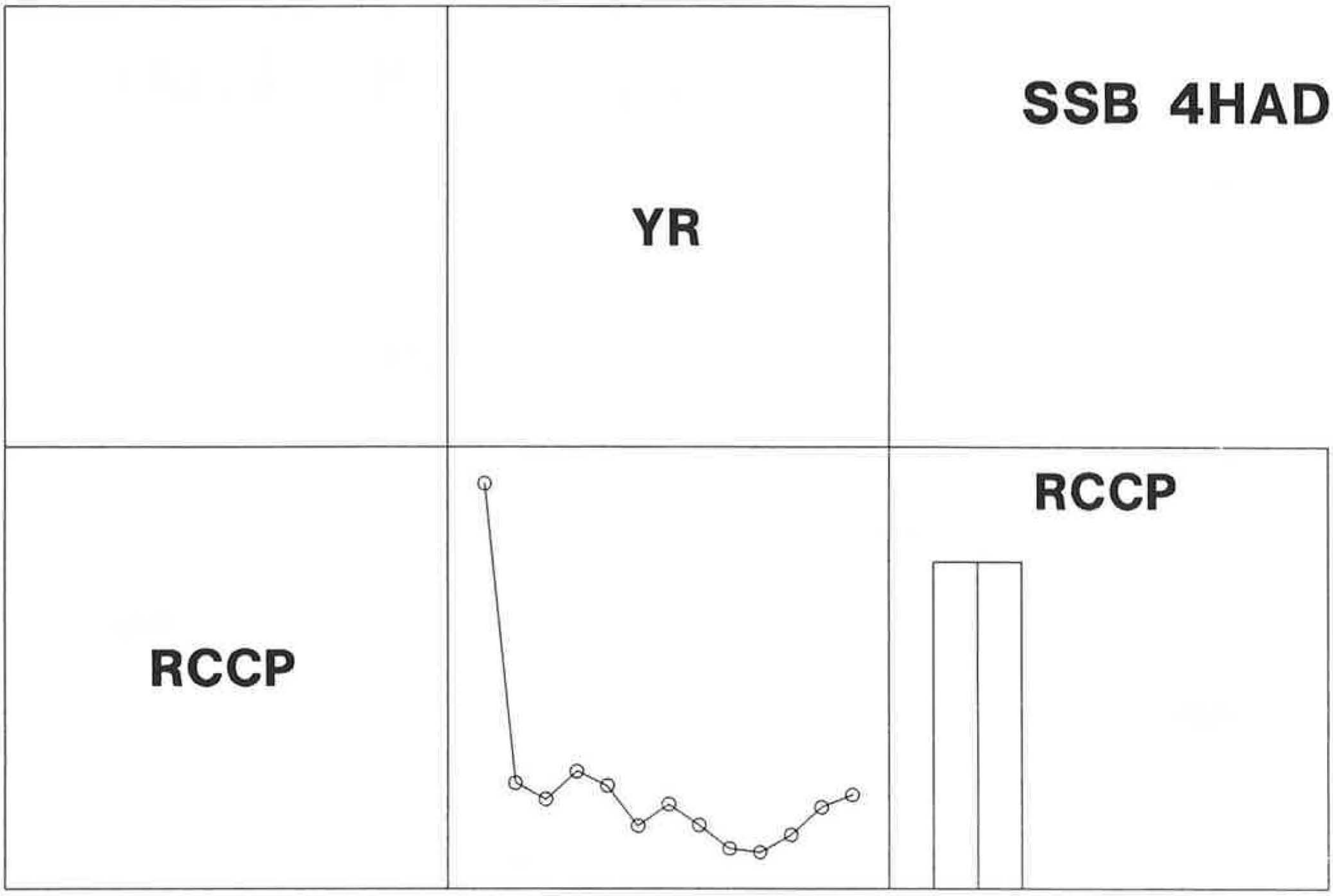


Figure 7.2.5c



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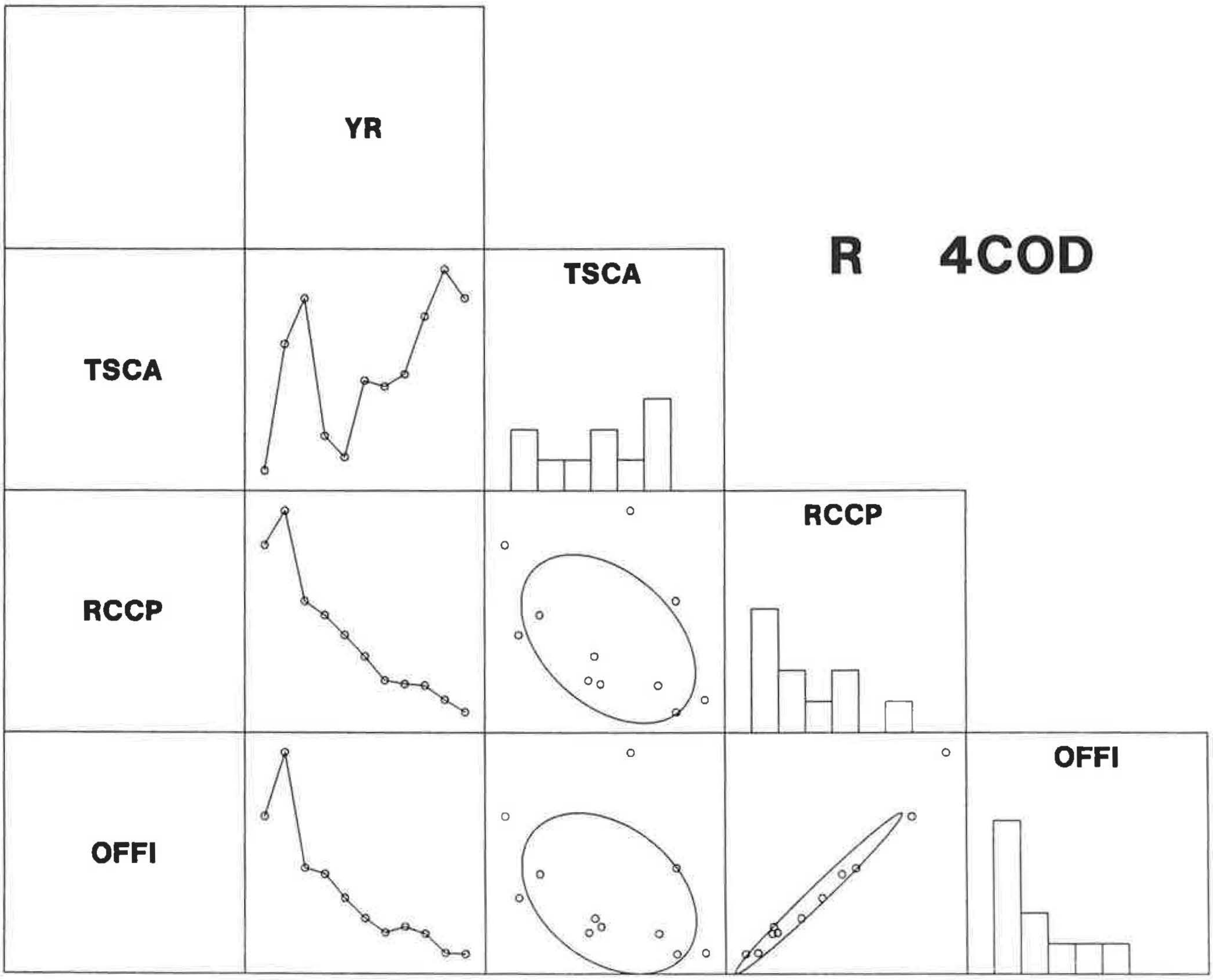

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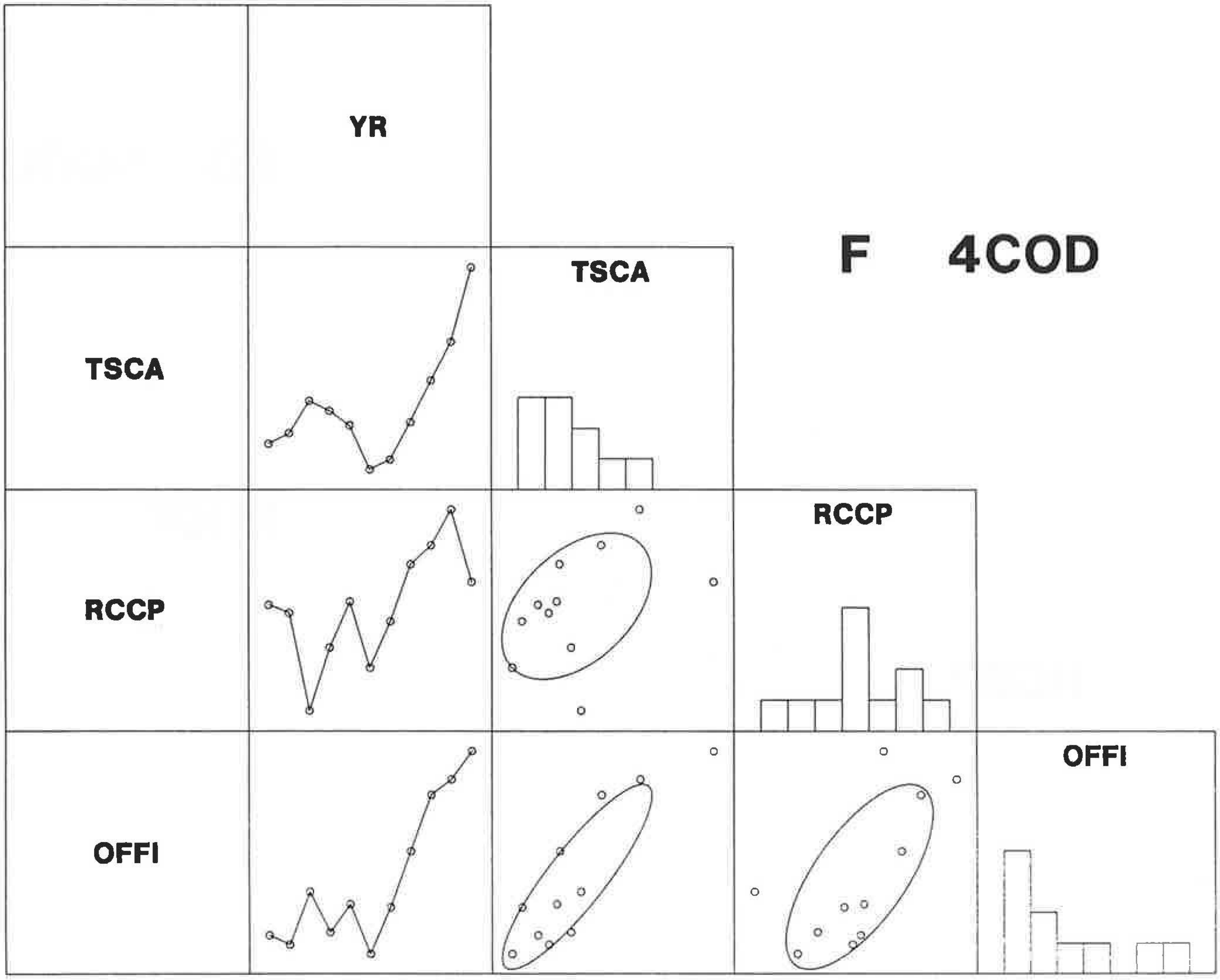
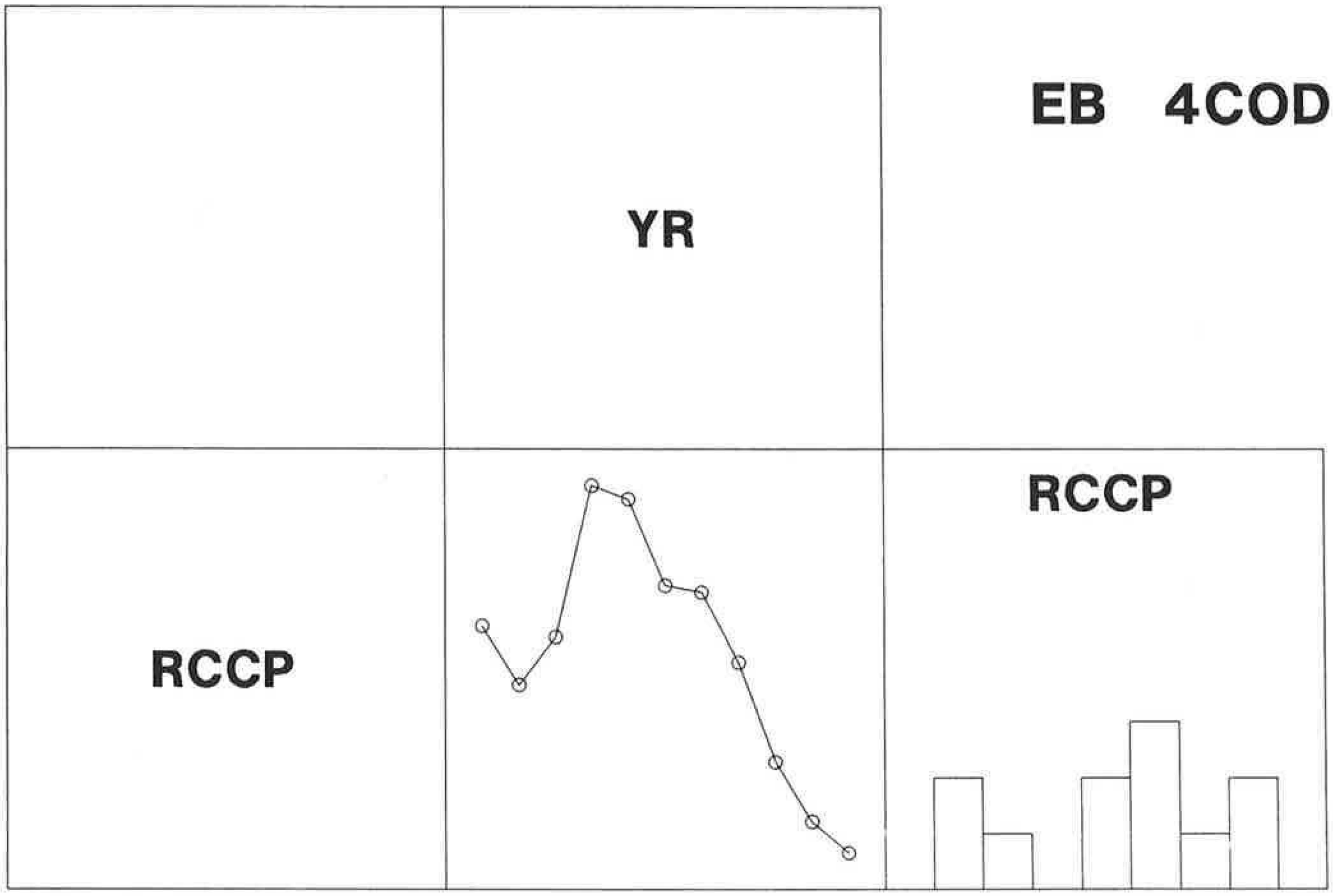


Figure 7.2.6c



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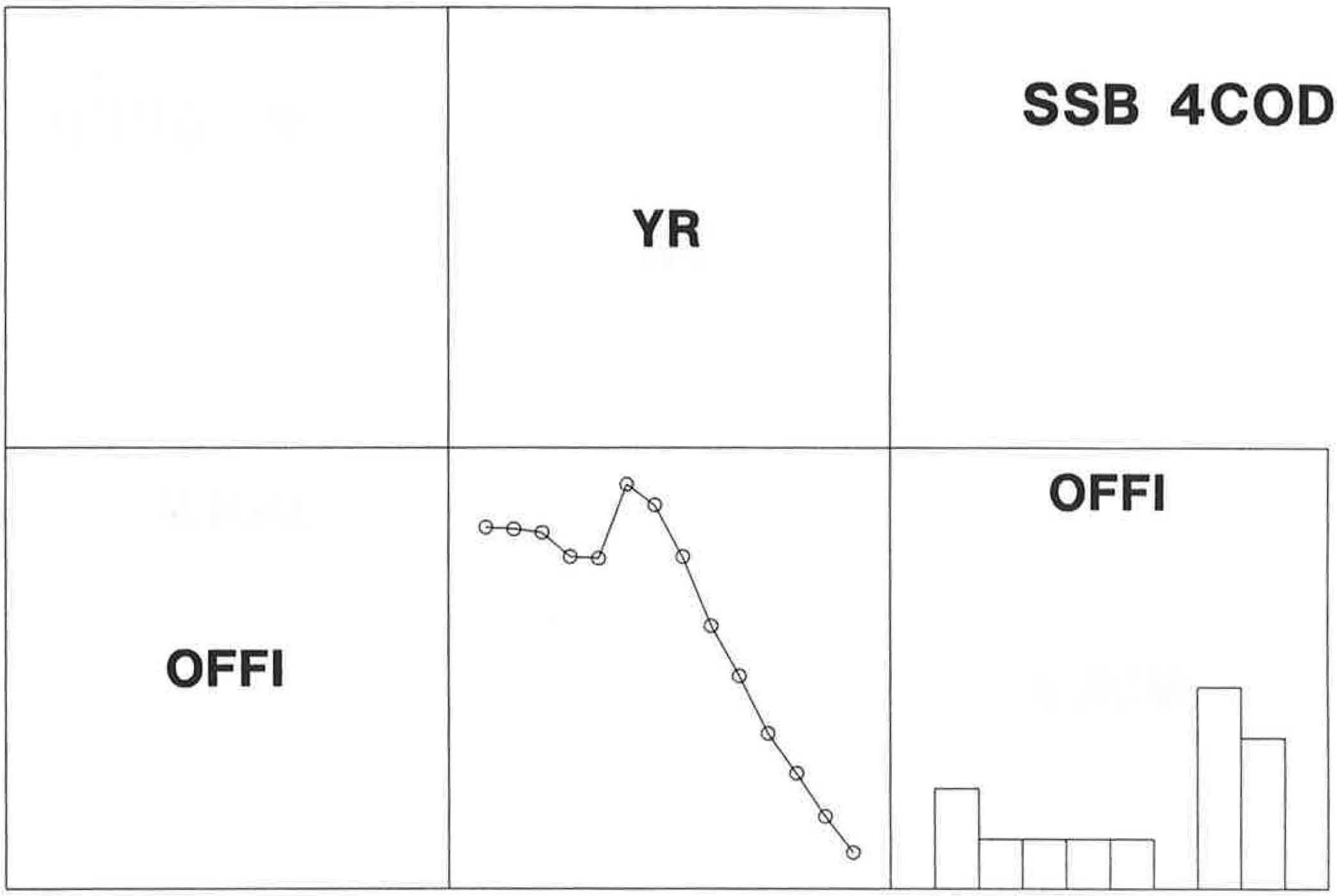

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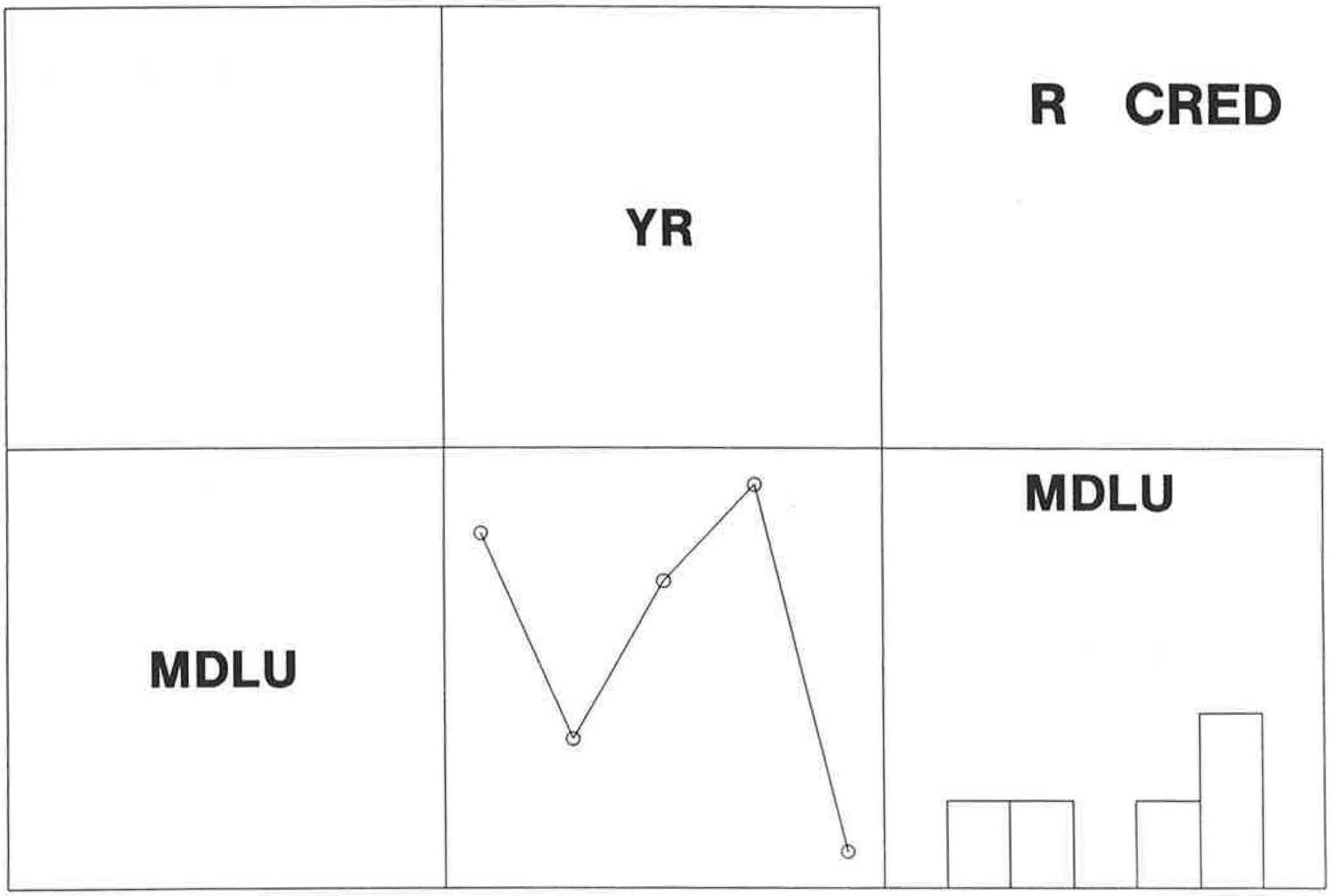

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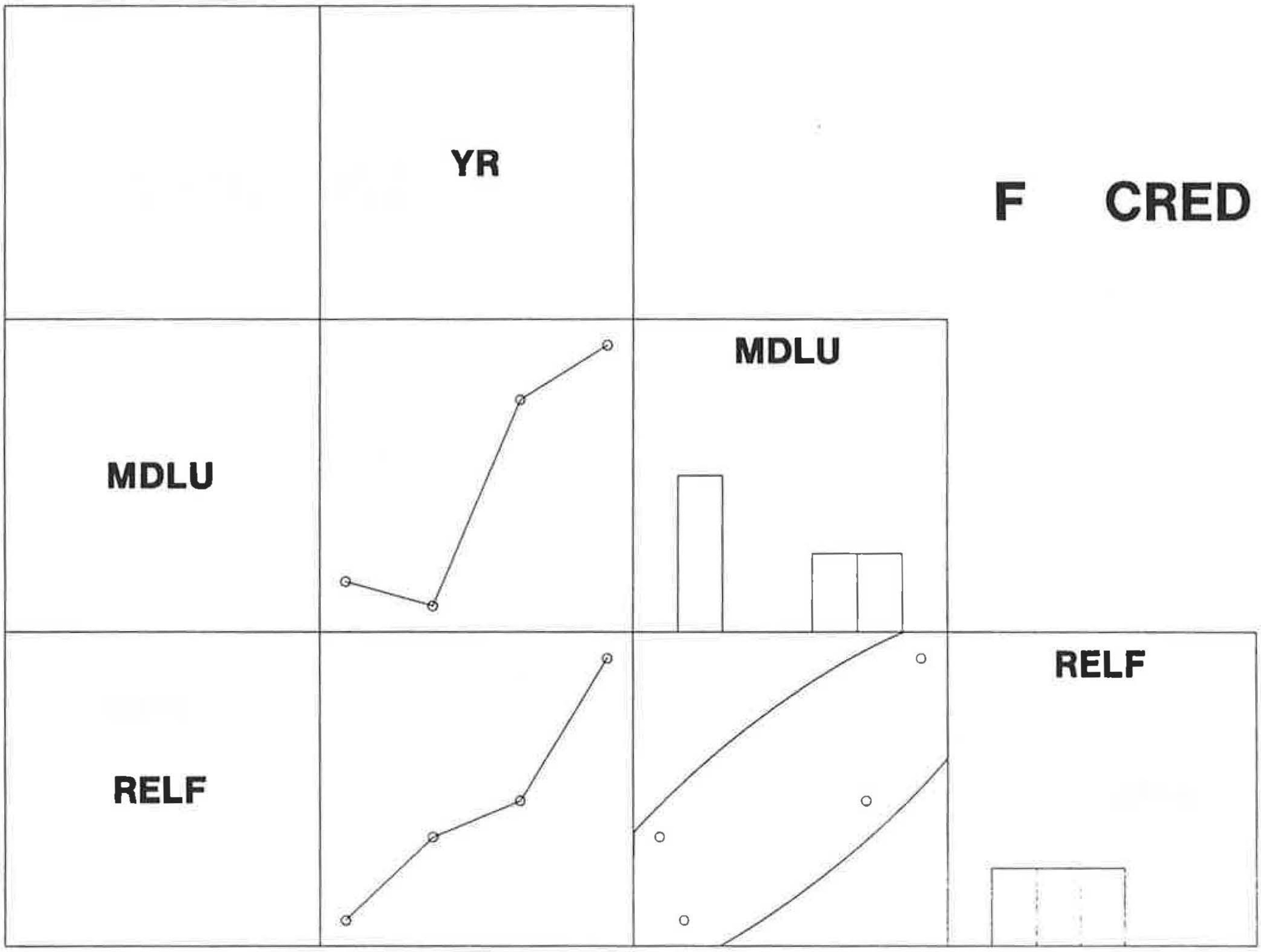

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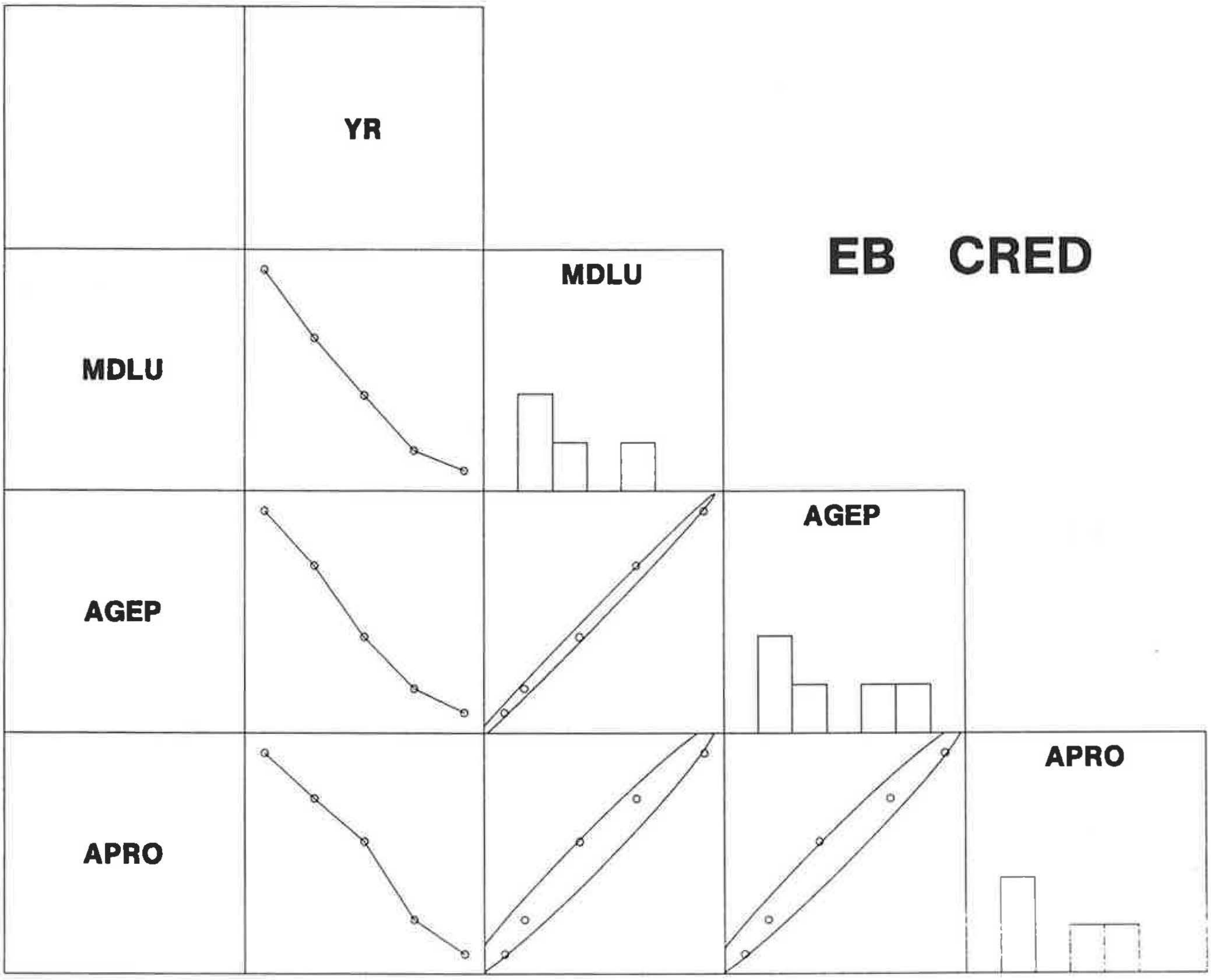

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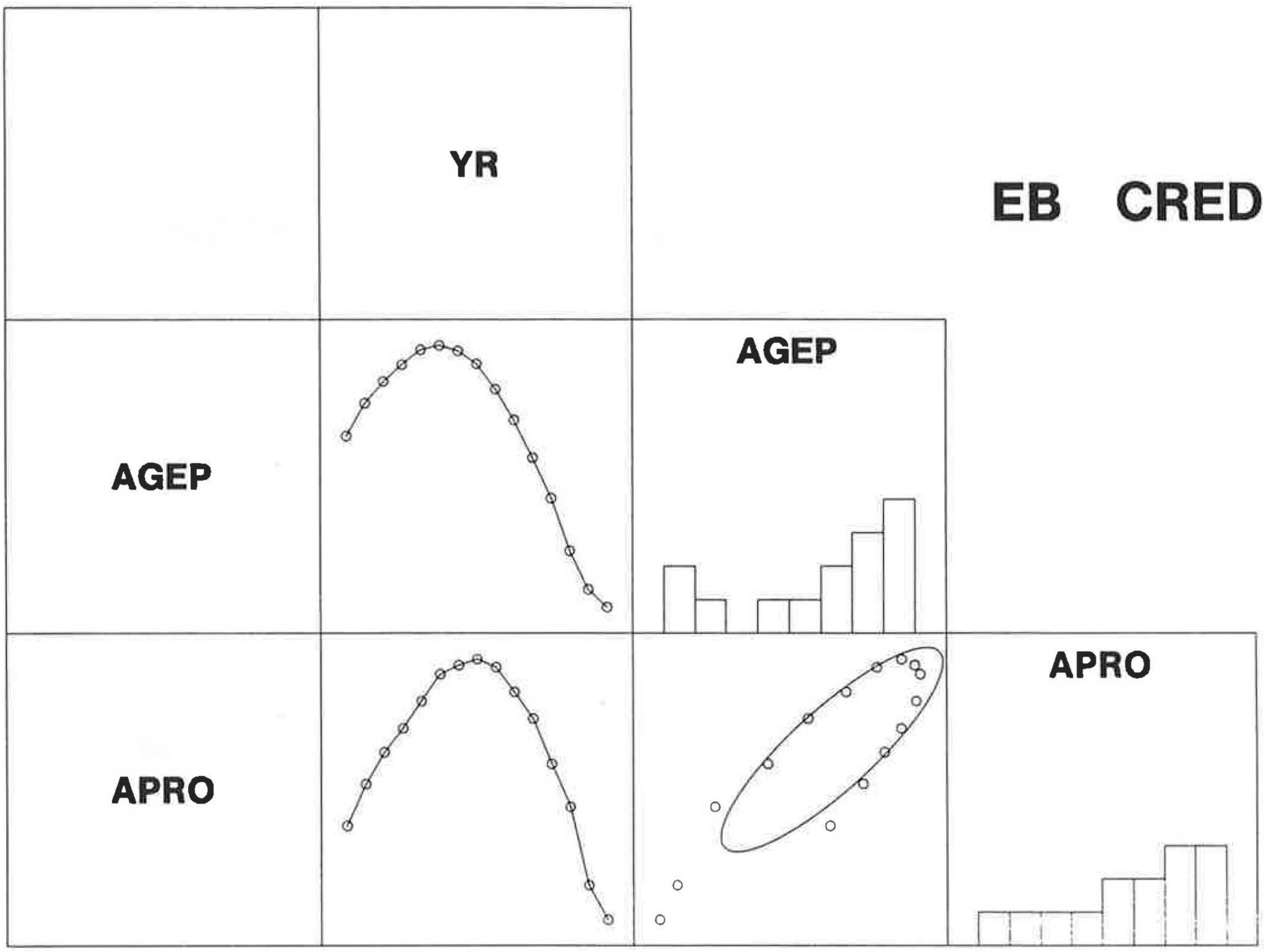

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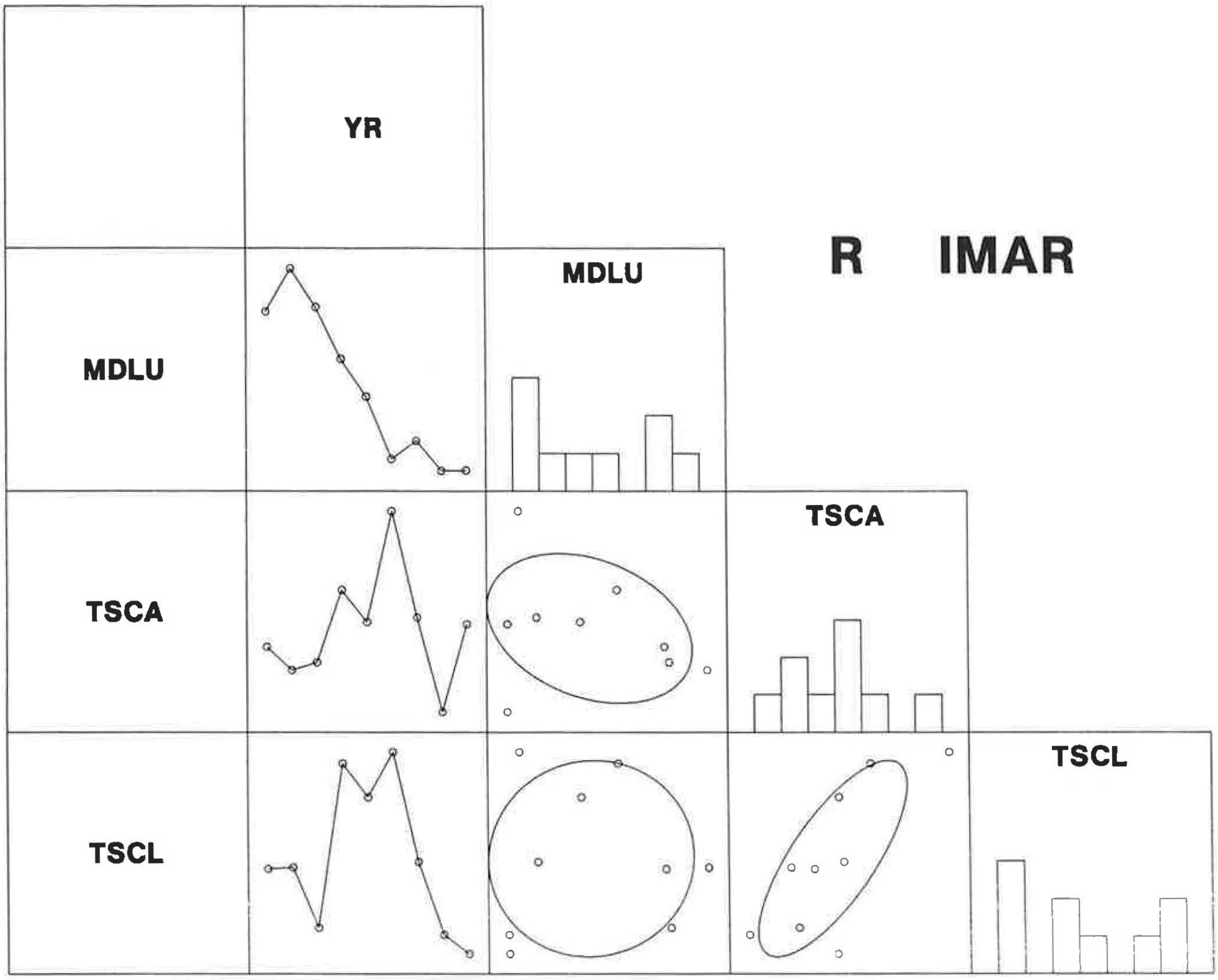

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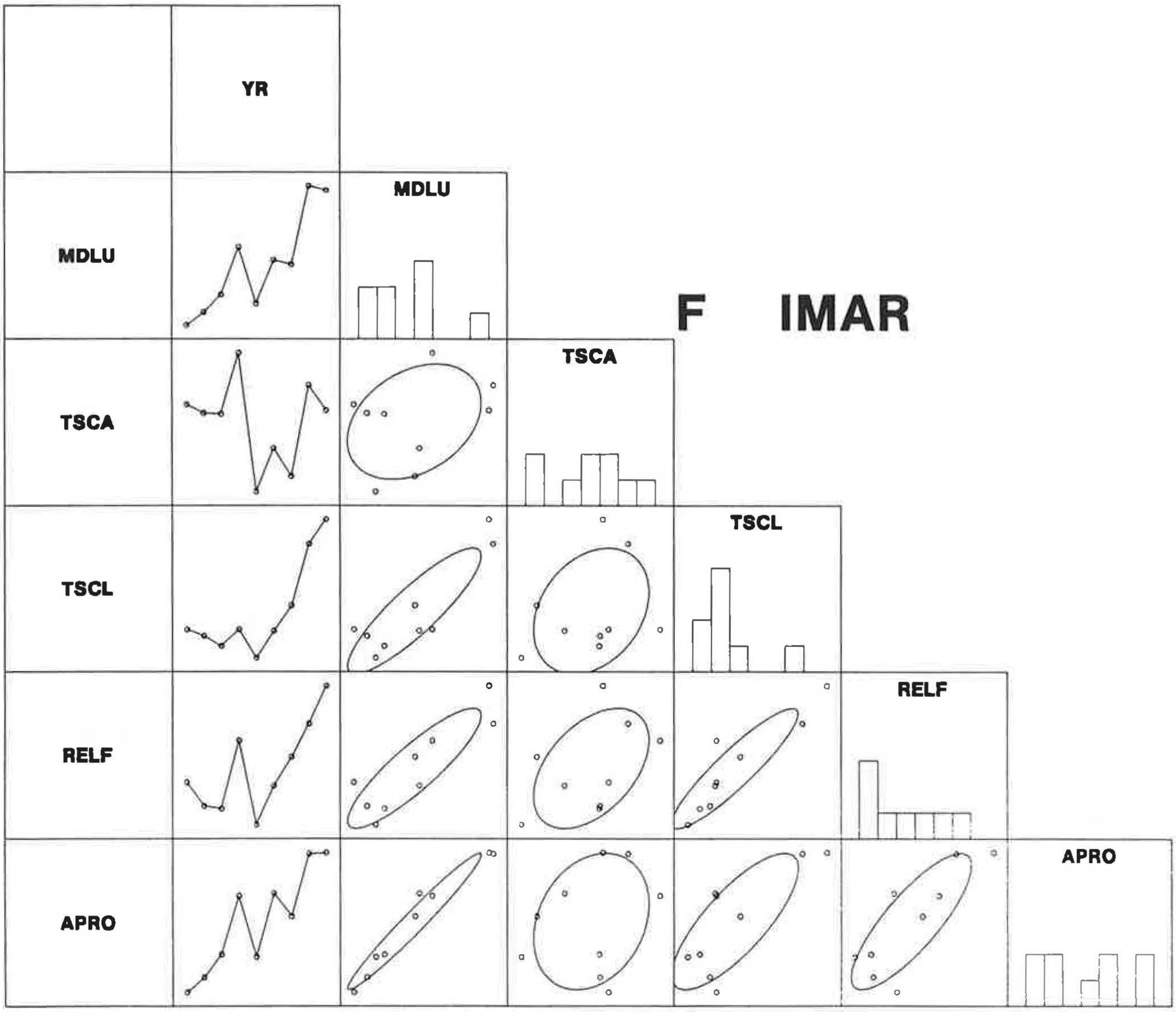

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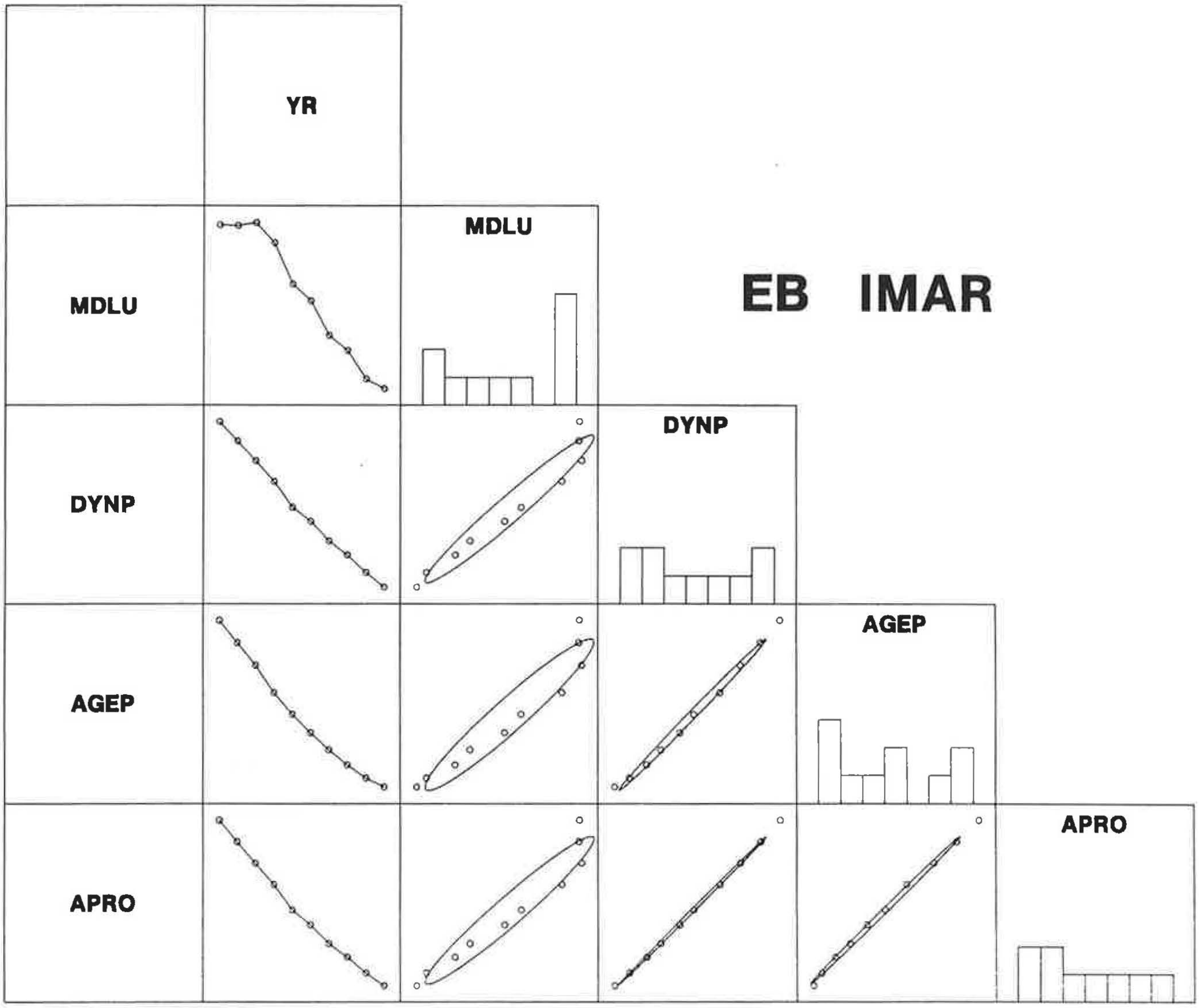

Figure 7.2.9