Advisory Committee on Fishery Management

REPORT OF THE
WORKING GROUP ON METHODS OF FISH STOCK ASSESSMENT

ICES Headquarters, Copenhagen, Denmark

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1 INTRODUCTION

1.1 Participants

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1.2 Terms of Reference

It was decided at the 82nd Annual Science Conference in 1994 (C. Res. 1994/2:6:17) that the Working Group on Methods of Fish Stock Assessment (Chairman: Dr. G. Stefánsson) will meet at ICES Headquarters from 6-14 February 1995 to:

a) develop alternative assessment methods based on limited data for those stocks where there is a high degree of uncertainty in age determination or which have a long life span;

b) consider the utility of methods designed to estimate catch-at-age data directly from catch-at-length data;

c) in view of the growing problem of misreported and non-reported catches, describe assessment methods which are tolerant of missing or biased landings data and consider the usefulness of methods which use only fishery-independent data.

1.3 Working Papers

Working papers were available on some of the topics. These are listed in Section 10.

1.4 Notation

The Working Group updated the standard notation used previously and has attempted to adhere to the new standard in this report. Appendix A lists the revised standard.

1.5 Structure of the Report

The three items in the Terms of Reference, *alternative assessment methods, length based techniques* and *unreliable catches* have been consolidated as far as possible in order to maximize the output from the meeting. This has been done by applying several methods to several data sets, as indicated in Tables 1.5.1-1.5.3.

Section 2 describes some of the data sets made available to the meeting. These have been chosen to illustrate certain aspects of fish stock assessment such as missing catch data, missing age data etc.

Several biomass-production methods are considered in Section 3 and examples are given of when and how such models can be used for different data sets, including some possible future directions.

The issues related to length-to-age conversions have been extended to include assessment methods based on length distributions (Section 4), attempts have been made to compare outputs from as many models as possible for each stock, in particular comparing length-based methods to biomass-production models and "official" assessments, whenever such assessments are available.

Unreported catches and related issues are considered in Sections 5 and 6. Several methods can potentially discover (using some diagnostics) or correct for (using survey data) bias in catch data. The output from these methods is compared both between methods and with what is known to have happened in the various fisheries.

Finally, Section 7 compares all the various approaches to diagnostics and assessments and Section 8 contains a short summary of the report.

1.6 Estimating Quantities from Uninformative, Missing or Misleading Data

If information about ages is 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.

1.6.1 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?

1.6.2 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?

1.6.3 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 Table 1.5.1. 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 (Fig 2.2.1a) and survey indices of abundance at length (e.g. Fig 2.2.1b) were 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 1994), which in addition to using the spring and fall surveys also 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 on the basis of all available samples of length and age or weight.

Catch at length and abundance at length are 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 have 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

$$N.,a+1,y+1 = (Nl,a,y * Beta(p,q)) exp(- F.,a,y + M)$$
$$(2.5.1)$$

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 was 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 both for 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 (Nov. 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 (NWWG., 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 (NAFODivisions 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, even though 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 on the basis of 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

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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:

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

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:

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

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 maximizing 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 parametrized 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 to be 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 (Fig 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 (Fig 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 (Fig 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

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

(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:

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

$$r_y = q_r R_{0y} \quad (3.6.0)$$

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

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

(3.6.4)

where

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

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_e^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,

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

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

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

(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:

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

where:

μ_{r0y}	mean length of the recruiting year class at the beginning of the year

Ψ a function relating μ_{oy} 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:

$$N_{Oy} = \frac{\hat{n}_y}{\hat{q}_n} \quad for \; y = 1, \ldots, Y \tag{3.6.10}$$

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

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

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

$$F_{R+N,y} = Z_{R+N,y} - M \tag{3.6.12}$$

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)

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

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

$$F_{Ry} = \overline{P}_{Ry} F_{Ny} \tag{3 (3.6.14)}$$

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

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

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 Fig 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 (Fig 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 Völstad (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 estimator of the difference between two cumulative distribution functions. This estimator is given by

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

H and G would be 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 results 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, eg. 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:

$$P = X . Q$$

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 are 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 fairly 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 (Fig. 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.*, (1995) 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 analyzing 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 analyzed 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

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

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

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 minimizing 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 analyzing 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 analyzing 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 (Anon, 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 Anon. (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, ie: 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:

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

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

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:

$$u_{a,a-1+y} = q'_{a'} u^r_y e^{-\sum_{i=1}^{a-1} Z_{i,i-1+y}} \qquad (5.2.4)$$

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

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

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;

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

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:

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

$$(5.2.7)$$

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.;

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

$$(5.2.8)$$

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;

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

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;

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

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

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

$$(5.2.11)$$

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

Assuming

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

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

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

$$(5.2.13)$$

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

$$q_{s,1} \leq q_{s,2} \leq q_{s,3} = q_{s,4} = \ldots = q_{s,A} \qquad (5.2.14)$$

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

$$s_1 \leq \min(s_a, \; a = 2 \ldots A) \qquad (5.2.15)$$

Finally, for identifiability and sensibility, it was assumed that

$$s_a \geq 0, \qquad f_y \geq 0, \qquad \frac{1}{Y} \sum_{y=1}^{Y} f_y = 1, \qquad q_{1,1} = 0 \qquad (5.2.16)$$

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:

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

$$(5.2.17)$$

5.2.3 Analysis of test data sets

The models described above were used to analyze those test data sets for which survey abundance indices were available. For the single survey model all the data were analyzed with the model incorporating the penalty function except the North Sea haddock data, where euqation (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 Anon (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 analyzed 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

Fig. 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

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

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

where $\tilde{E}$ (y,f) denotes the expected annual effort and $\bar{P}$ (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

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

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:

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

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. $\beta(1,y)$, $\chi(1,f)$, $\chi(aa,1)$) are automatically aliased and set to 0. In the case of $\beta(1,y)$ and $\chi(1,f)$ this is exactly what is required to satisfy the conditions given in equation 5.3.4. The only

inconvenience of this is that $\chi(aa,1)$ is set to 0 and the other $\chi(aa,f)$ are scaled to this level. In general this will mean that $\chi(aa,f)$ 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 $\alpha(y,f)$ would be based upon current effort, the mean population equivalent term $\beta(aa,y)$ would be based on the relative population given by reliable fleets and surveys, and the catchability equivalent term $\chi(aa,f)$ 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 :

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

and

$$\ln\{Y(1,y,f)\} = \alpha(y,f) + \varepsilon$$ (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 was 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 $a \leq a_m$

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

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 exist even though the bias correction factor is consistently different from 1 (e.g. Fig. 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 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 (Fig. 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.

Year class(k)$_{EGFS}$ - Year class(k)$_{SGFS}$ = constant + k(δ_{EGFS}-δ_{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

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

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 stylized 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:

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

where β_y is not necessarily related to fishing mortality. Constraints need to be placed on the β_y for identifiability: eg $\Sigma\beta_y = 0$, $\Sigma\beta_y^2 = 1$ 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

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

Models (6.5.1) and (6.5.2) can be fitted by generalized nonlinear 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 $(1-\alpha)\%$ 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 B_{vpa} is an assessment based estimate of biomass in year y, 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

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

$$(6.8.3)$$

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

Suppose it is hypothesized that catches in the terminal year are fully reported and the fishery- independent abundance index is available. If H_o 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 B_y, times an arbitrary multiplier δ, lies below the $(1-\alpha)\%$ 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 α can 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<0.0xx). 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 recognized 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 N_a,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 normalization. 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 summarizing 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 modeling. 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.

9   RECOMMENDATIONS

Several of the methods discussed in this report could provide useful assessments when reliable data are not available for VPA analyses.

In order for the methods to be used by Working Groups, ICES should implement these methods on the ICES computer system, thoroughly test them, and ensure that Working Group members receive proper guidance in their use. Also, ACFM could identify specific methods to be applied to specific stocks.

The Working Group recommends that length data be sampled, reported and analyzed on the finest scale possible (e.g. 1 cm for cod).

The Working Group recommends that age-based production models be further developed to incorporate stock-specific data. For example, if survey length distributions are available, such data may potentially provide information on recent and future recruitment levels.

The Working Group further recommends that these age-based production models and length-based models be applied as a general tool for estimating overall biomass trends and for examining the impacts of various harvesting strategies.

The Working Group recommends that methods alternative to VPA be considered by ACFM for stocks, whether or not classical VPA-type data are available.

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10.1   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

L4   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

L7   Mohn, R. Simultaneous estimation of age abundance using an iterated sequential population and age length key analyses.

L8   Pope

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.

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Supporting documents

S1   Evans, G.T. 1994. Disentangling the inferences of sequential population analysis can reveal underlying problems .ICES Doc. C.M.1994/D:7.

S2   Gavaris, S. 1994. ADAPT. User's guide. Version 1.1

S3   Anon.1993. Report of the North-Western Working Group. ICES Doc. C.M. 1993/Assess:18.

S4   Skagen, D. 1994. Revision and extension of the Seasonal Extended Survivor Analysis (SXSA). W. Doc. to the Norway Pout and Sandeel Assessment Working Group 1994.

S5   Pope, J.G. Some hasty thoughts on estimating TACs from length data using GLM's.

S6   Sinclair, A., Zwanenburg, K. and Hurley, P. 1993. Estimating trends in F from length frequency data DFD Atlantic Fisheries Res. Doc. 93/66..

Anderson-Darling estimator

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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, Ca	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		

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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)
$L = L \infty (1-\exp(-K(t-t_0)))$

$L \infty$ = 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)
$L = L \infty (1-\exp(-K(t-t_0)))$

$L \infty$ = 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

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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 $\geq$ 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.ssb   Catch 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

	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	Stand. Dev.	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: $L\infty = 38.9$
$\quad\quad\quad K \quad = 0.13$
$\quad\quad\quad t_0 \quad = -0.35$

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 ——→

SURPLUS PRODUCTION MODELS	MODIFIED DELURY MODEL	AGE-STRUCTURED MODELS
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·

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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 ——→

SURPLUS PRODUCTION MODELS	MODIFIED DELURY MODEL	AGE-STRUCTURED MODELS
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

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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 | -- INDICES OF ABUNDANCE -- | | TOTAL CATCH |
YEAR	RECRUITS	FULLY-RECRUITED	(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	-- INDICES	OF ABUNDANCE --	TOTAL CATCH
YEAR	RECRUITS	FULLY-RECRUITED	(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	RECRUITS	FULLY-
YEAR		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	-- INDICES OF ABUNDANCE --		TOTAL CATCH
YEAR	RECRUITS	FULLY-RECRUITED	(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	-- INDICES OF ABUNDANCE -- 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 --		TOTAL CATCH (millions)
	RECRUITS	FULLY-RECRUITED	
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 --		TOTAL CATCH (millions)
	RECRUITS	FULLY-RECRUITED	
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

SURRF4

Table 4.6.1 Canadian Unit 1 Redfish commercial catch (C) and surveyed (S) catch-at-length standardized to (approximately) 1000 individuals per year.																		
Length (cm)	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	0	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	1	0	1	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	1000	1001	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

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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

GCOD

	MDLU	DYNP	AGEP	TSCA	TSCL	RELF	APRO	OFFI	RCCP	SLIC	SPKE	LACO
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			6516	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								26506	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												

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 7.1.3

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

	MDLU	DYNP	AGEP	TSCA	TSCL	RELF	APRO	OFFI	RCCP	SLIC	SPKE	LACO
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

	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												

Spawning stock biomass

	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												

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

	MDLU	DYNP	AGEP	TSCA	TSCL	RELF	APRO	OFFI	RCCP	SLIC	SPKE	LACO
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

	MDLU	DYNP	AGEP	TSCA	TSCL	RELF	APRO	OFFI	RCCP	SLIC	SPKE	LACO
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

	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												

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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

	MDLU	DYNP	AGEP	TSCLBAC	TSCLFOR	RELF	APRO	OFFI	RCCP	SLIC	SPKE	LACO
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

	MDLU	DYNP	AGEP	TSCLBAC	TSCLFOR	RELF	APRO	OFFI	RCCP	SLIC	SPKE	LACO
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

	MDLU	DYNP	AGEP	TSCLBAC	TSCLFOR	RELF	APRO	OFFI	RCCP	SLIC	SPKE	LACO
1980												
1981												
1982												
1983												
1984												
1985												
1986												
1987												
1988												
1989												
1990												
1991												
1992												
1993												
1994												

Table 7.1.9

CPOP	MDLU	DYNP	AGEP	TSCA	TSCL	RELF	APRO	OFFI	RCCP	SLIC	SPKE	LACO
Recruitment												
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
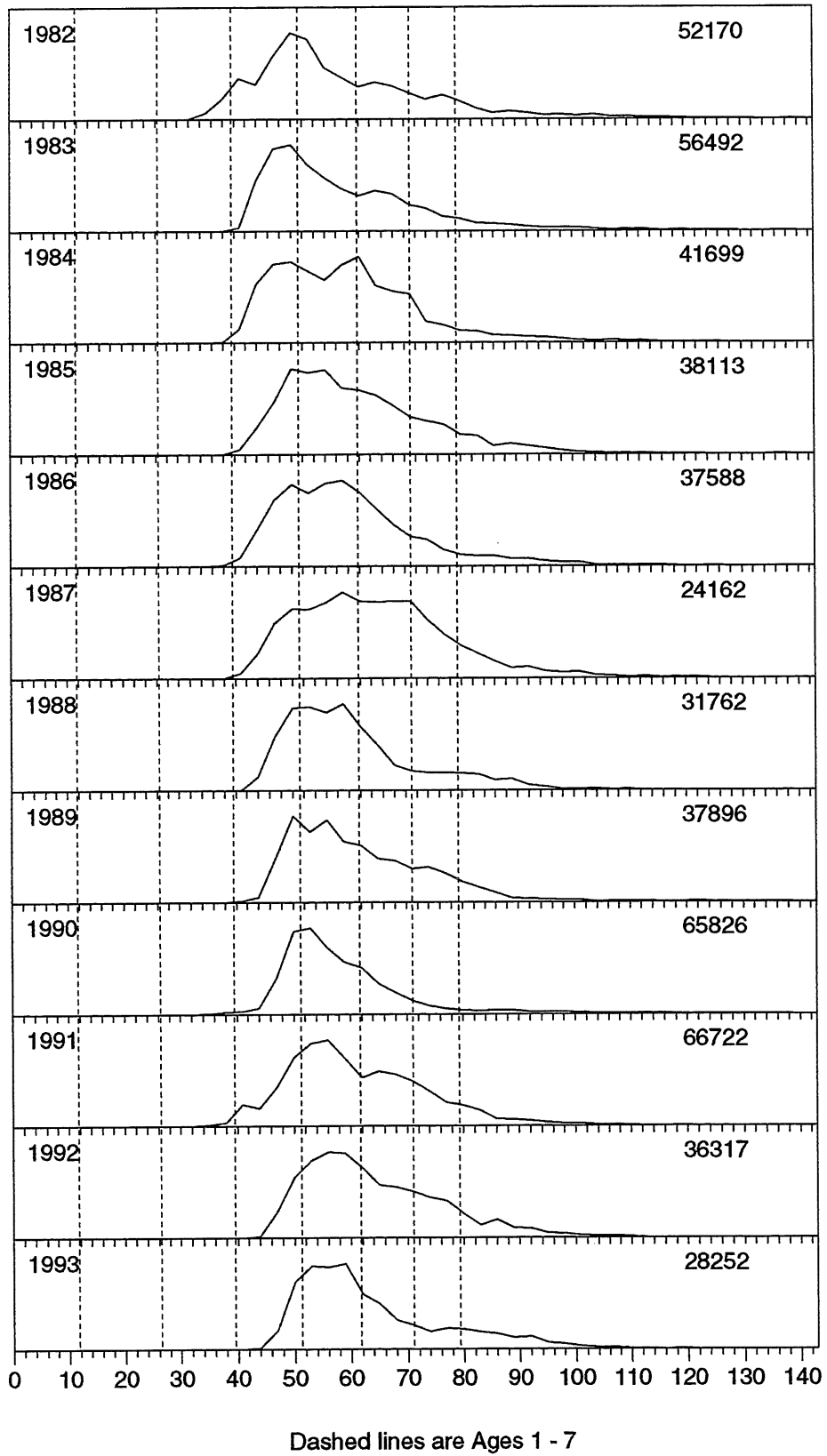
Figure 2.2.1.b GOM Cod Survey1 at Length
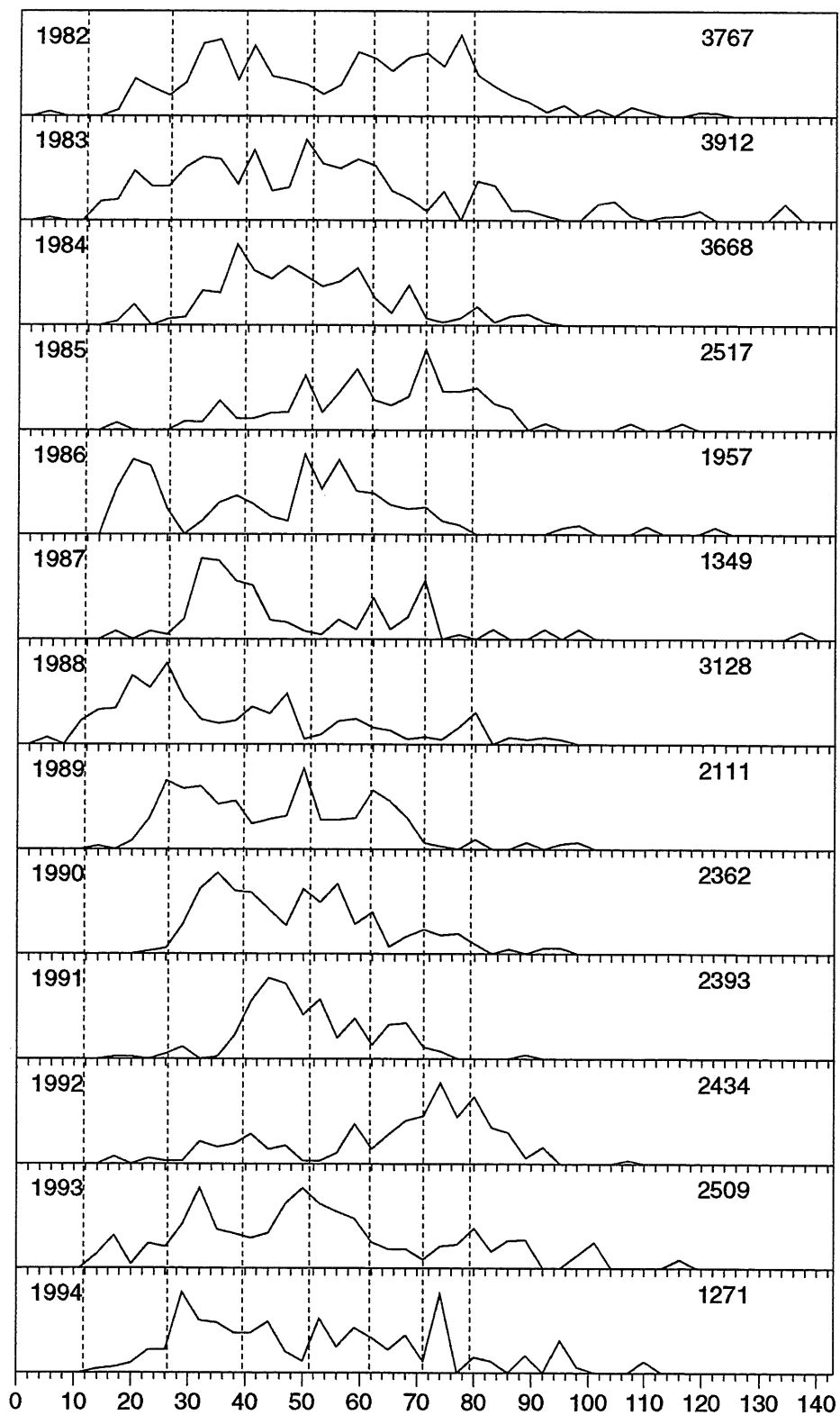
Dashed lines are Ages 1 - 7

Figure 2.4.1.a Iceland haddock catch at length.

1985	20438
1986	21030
1987	24001
1988	34717
1989	39840
1990	43104
1991	31931
1992	29962
1993	33943

10   20   30   40   50   60   70   80   90   100
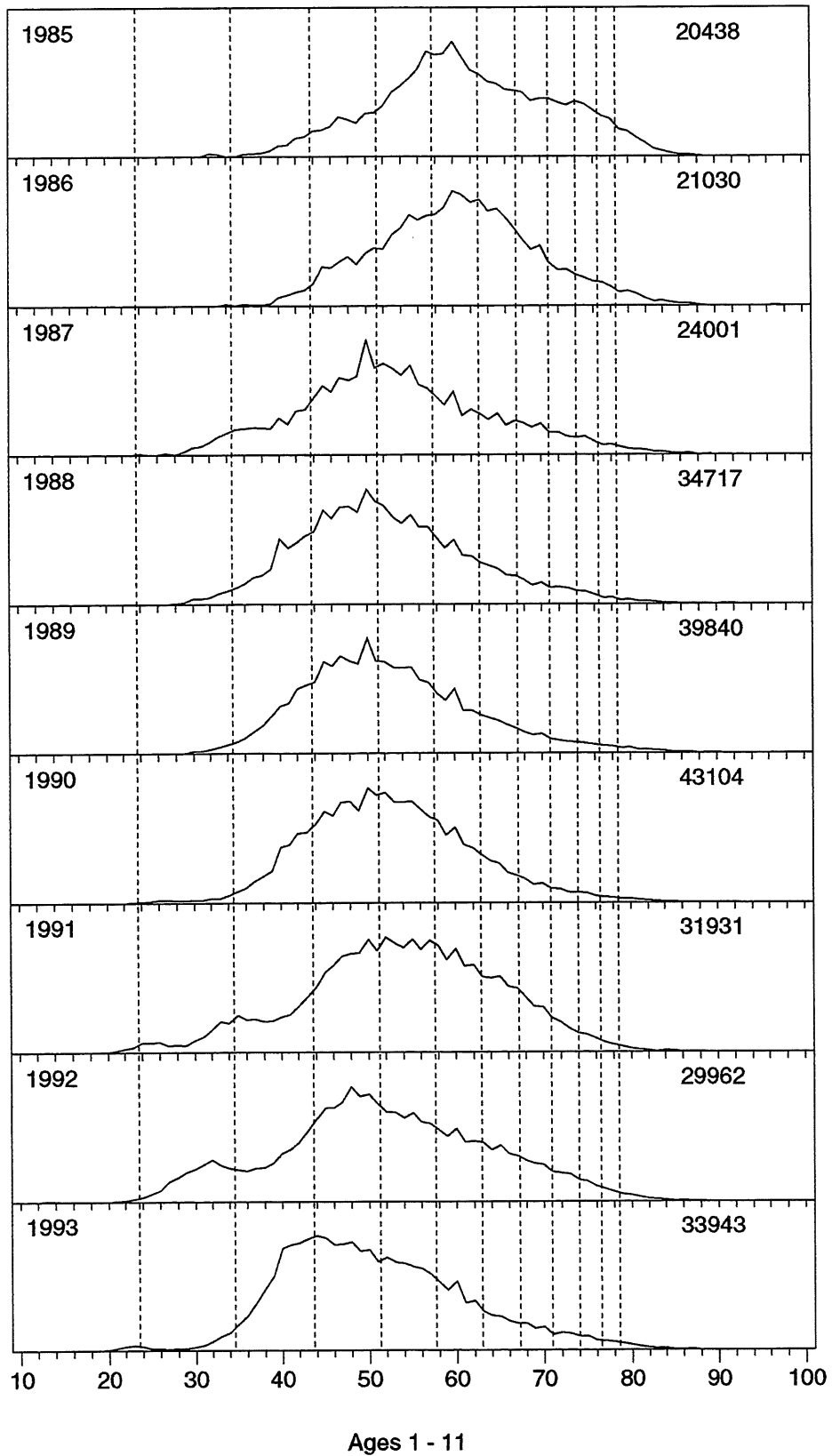
Ages 1 - 11

Figure 2.4.1.b Iceland haddock abundance at length.
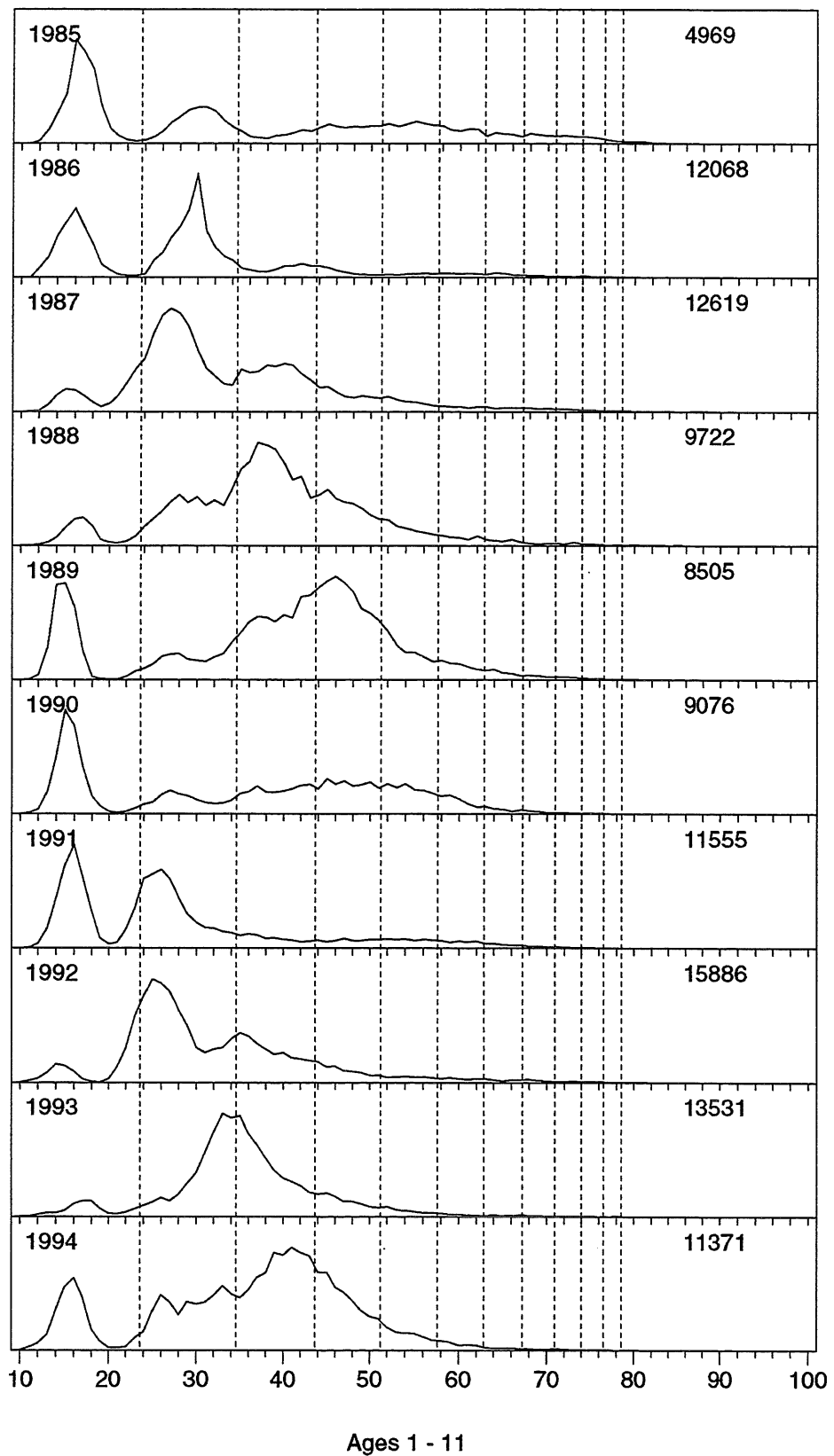
Ages 1 - 11

Figure 2.5.1. Simulated Tuna Catch at lenghth

1980	26797
1981	30969
1982	43398
1983	61483
1984	75168
1985	70109
1986	63540
1987	59672
1988	65710
1989	75805
1990	78628
1991	67816
1992	57893
1993	52600
1994	50557

100   150   200   250   300   350

Dashed lines are ages1-10

89

Figure 2.6.1. Noisy Tuna Catch at lenghth

1980	25654
1981	47513
1982	68657
1983	72179
1984	75884
1985	71330
1986	90756
1987	63082
1988	58752
1989	80355
1990	88907
1991	81231
1992	71444
1993	60552
1994	59280

100   150   200   250   300   350
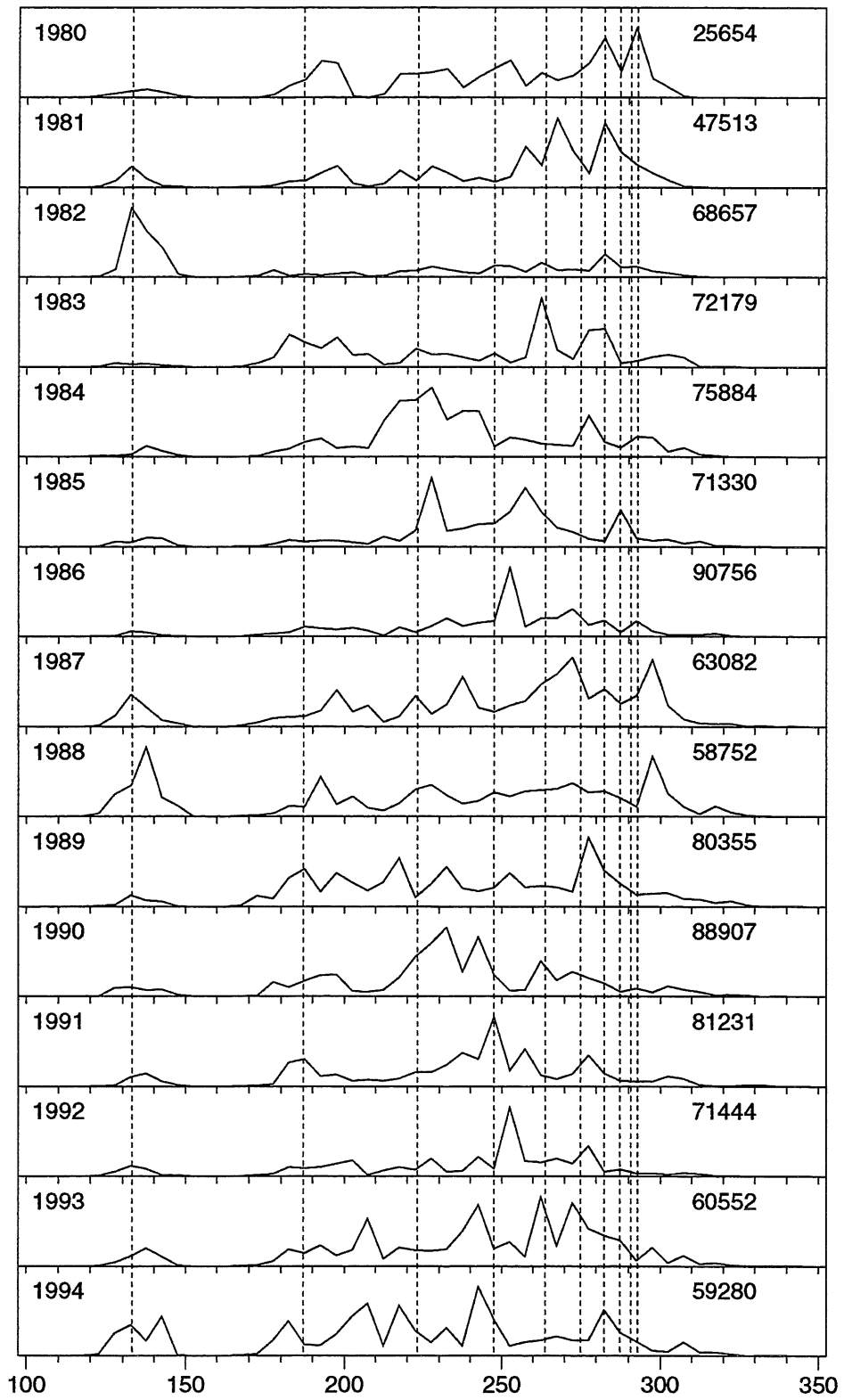
Dashed lines are ages 1-10

Figure 2.9.1.a Iceland Redfish catch at length
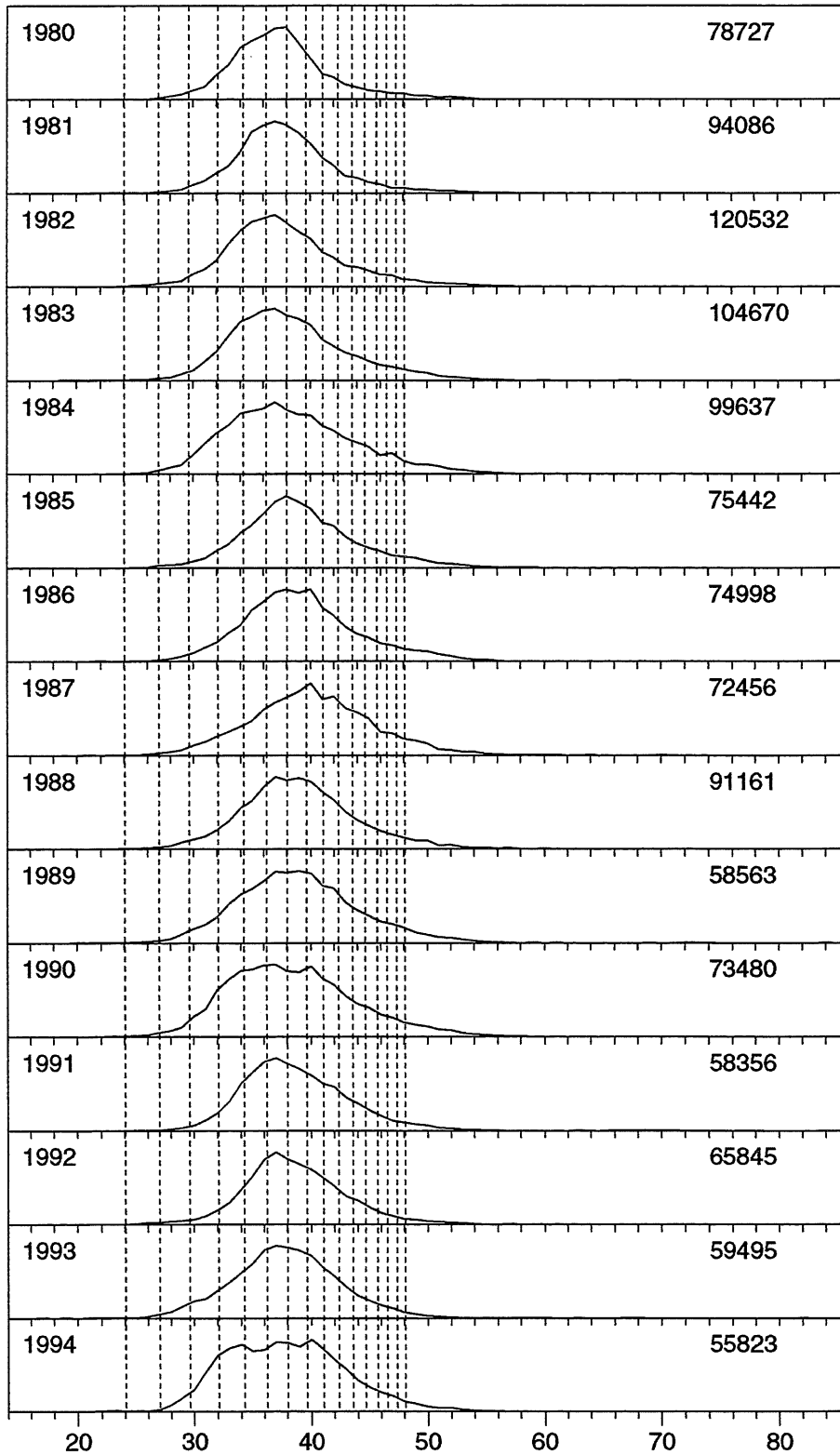
Dashed lines are even ages 10 - 40

Figure 2.9.1.b Iceland Redfish survey at length
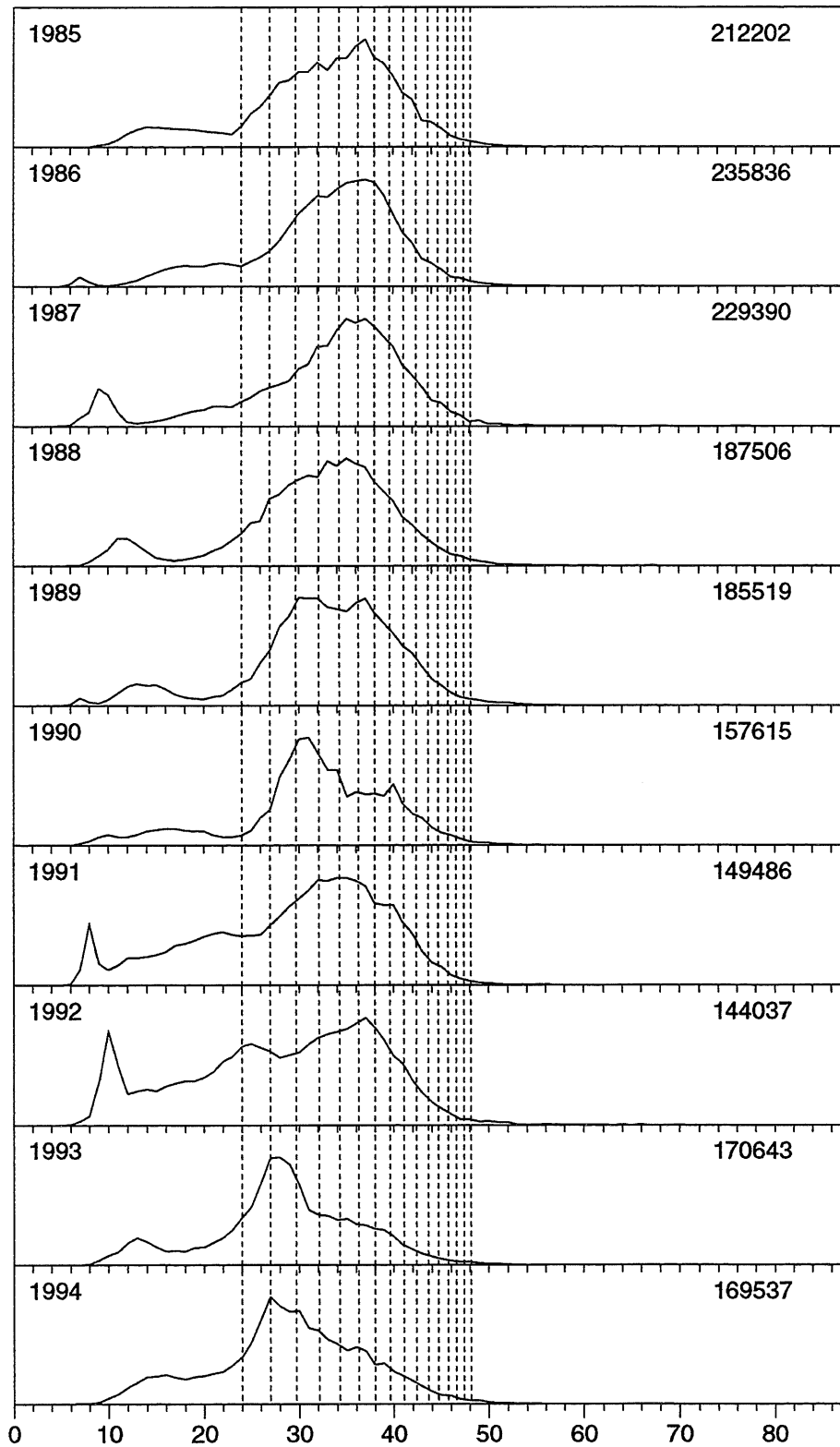
Dashed lines are even ages 10 - 40

Fig 3.3.1: Dynamic production results for Gulf of Maine cod
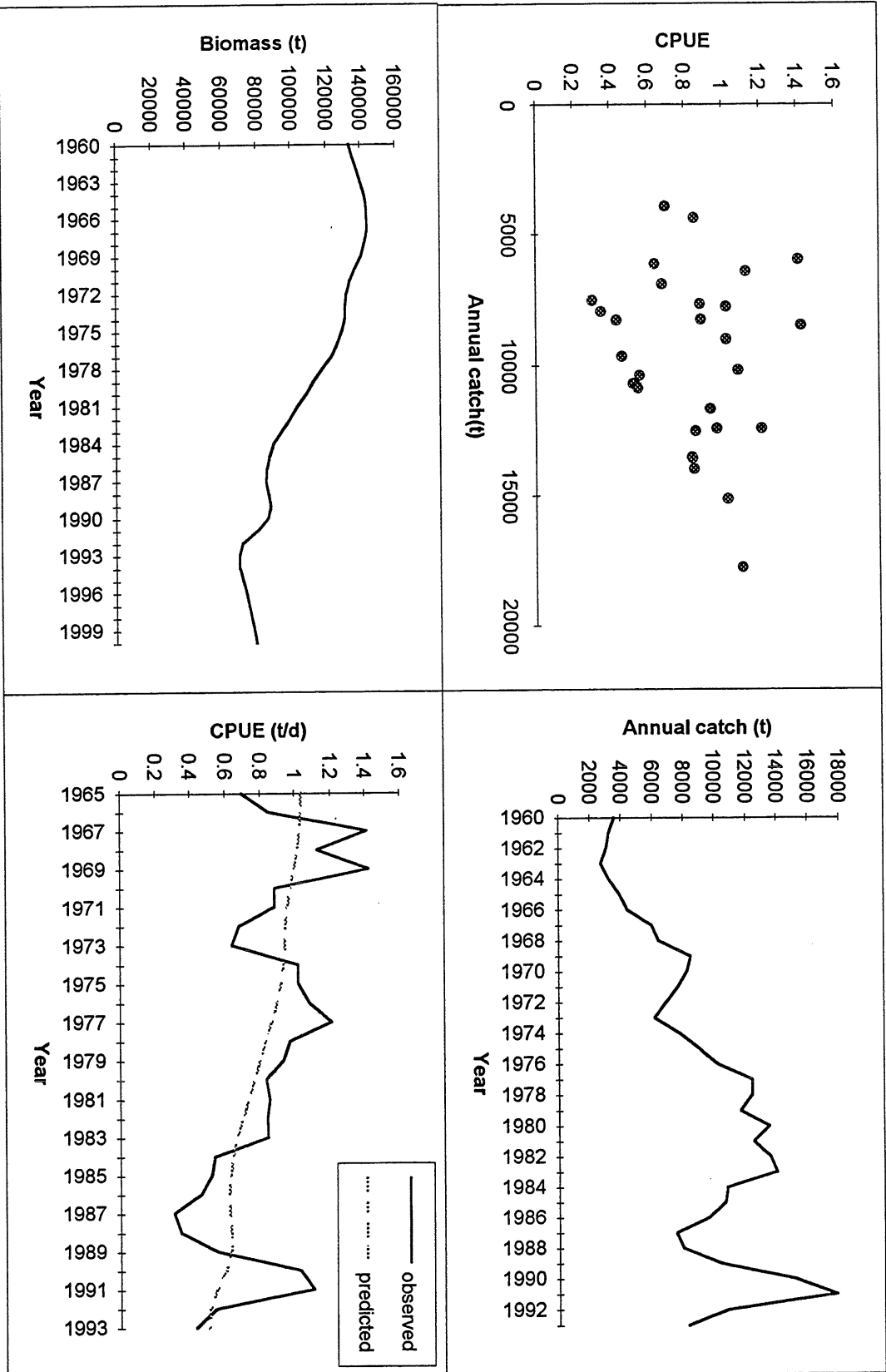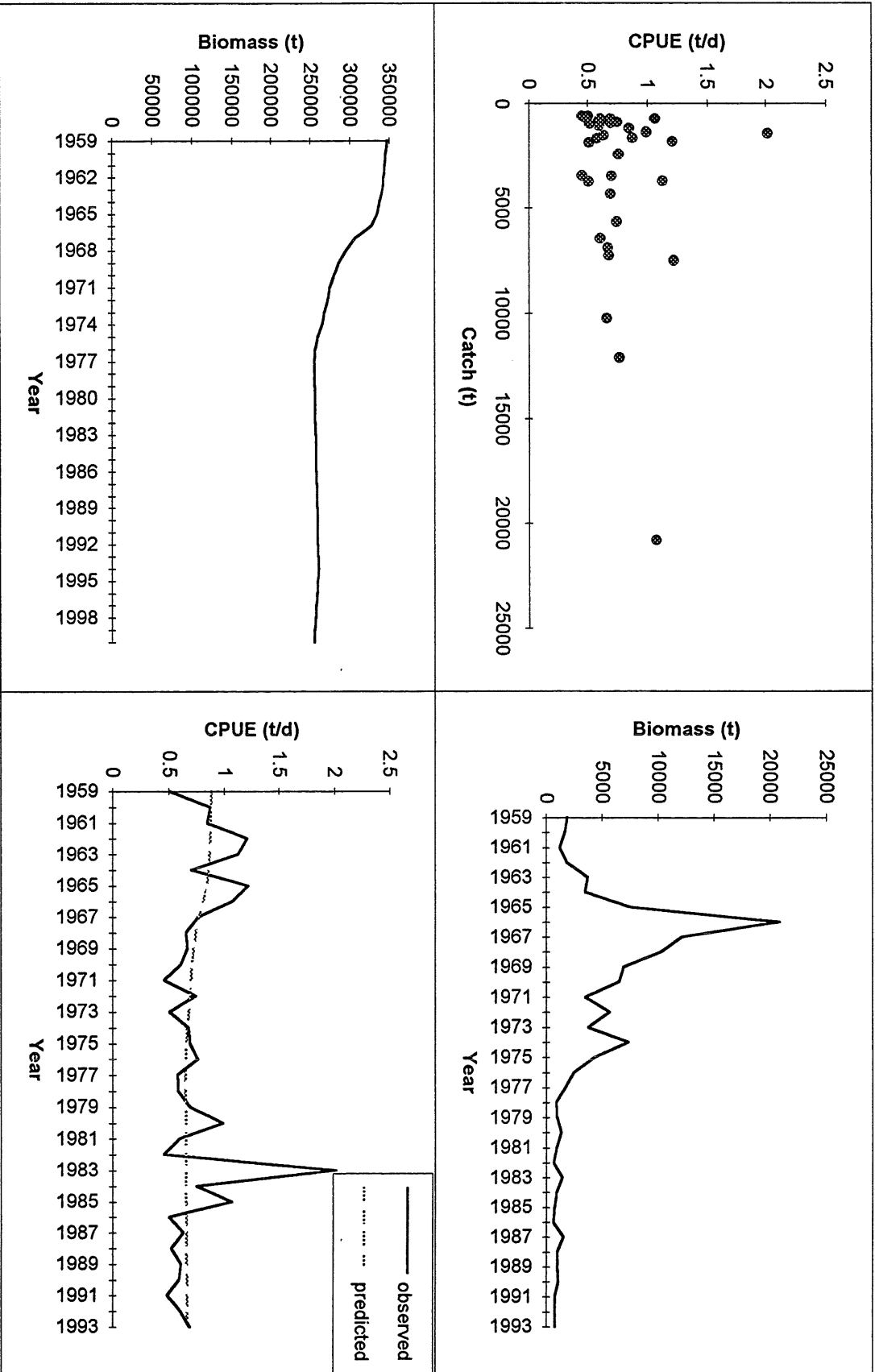
Fig 3.3.2 Dynamic production model results for Canadian Pacific ocean perch

Fig 3.3.3 Dynamic production results for Icelandic redfish
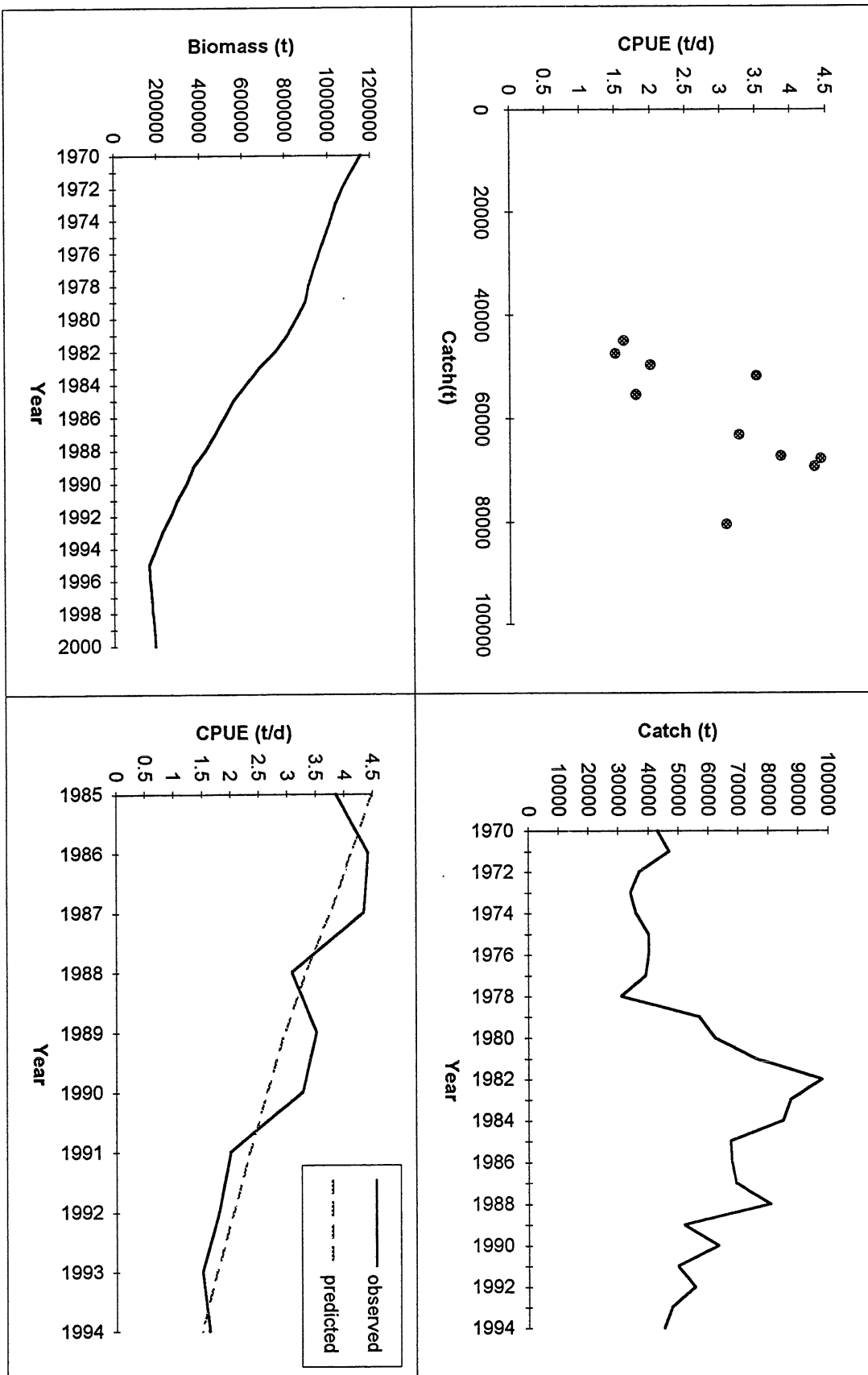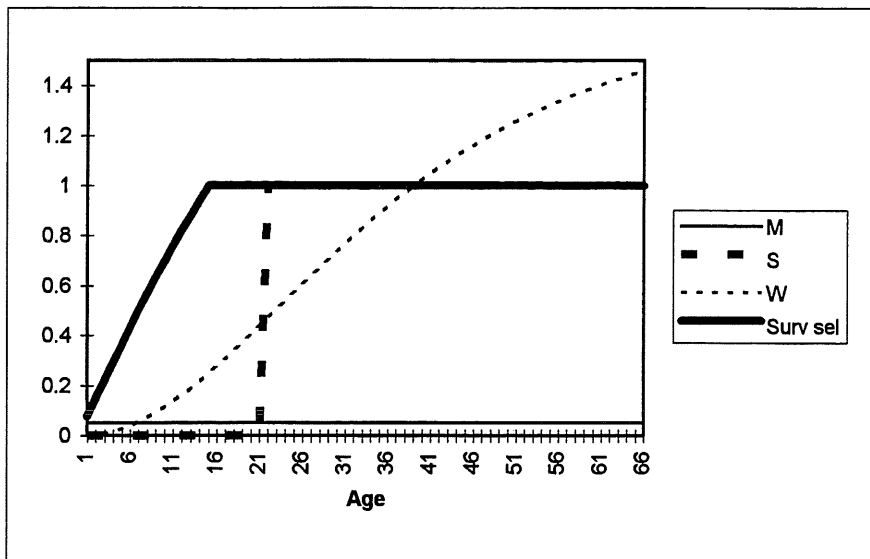
Figure 3.4.1. Input parameters for the spreadsheet-implemented age-based stock production model analysis of Icelandic *S. marinus* data: commercial selection pattern (S), weights at age (W), natural mortality (M) and survey selection pattern.
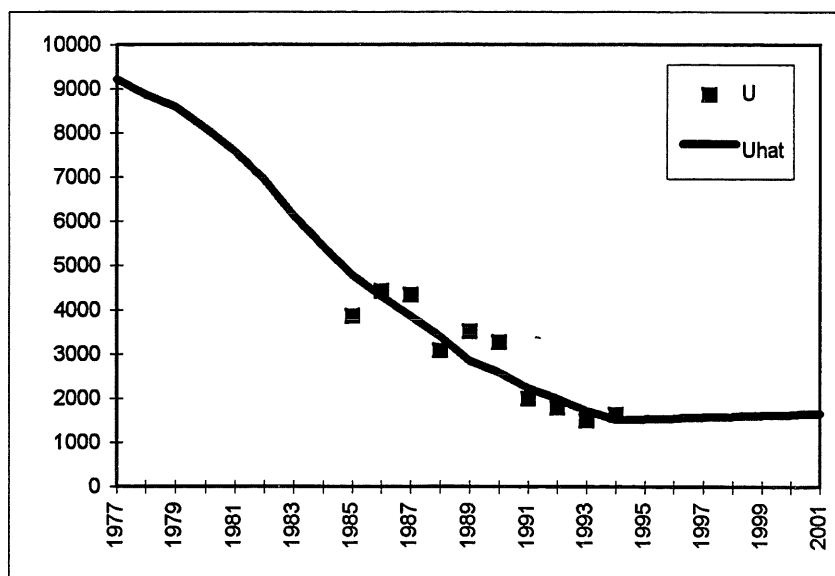
Figure 3.4.2. Output from the spreadsheet-implemented age-based stock production model analysis of Icelandic *S. marinus* data: observed (U) and fitted (Uhat) biomass trends. Forward projection is based on assuming an annual catch of 25,000 t.
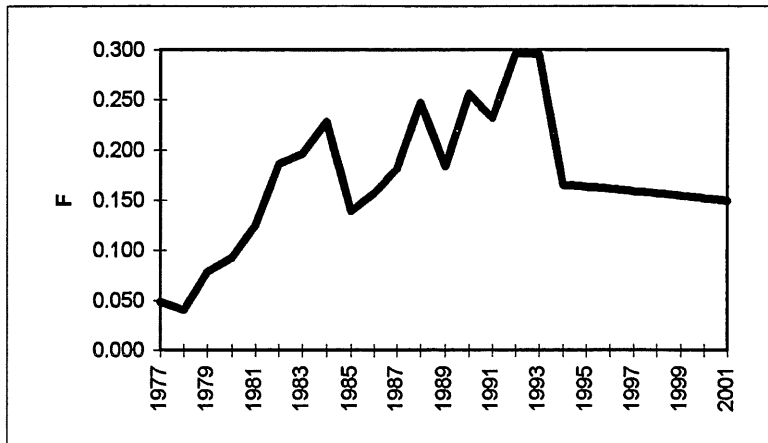
Figure 3.4.3. Fishing mortality by year, as estimated from the spreadsheet-implemented age-based stock-production model analysis of Icelandic *S. marinus* data. Forward projection is based on assuming an annual catch of 25000 t.
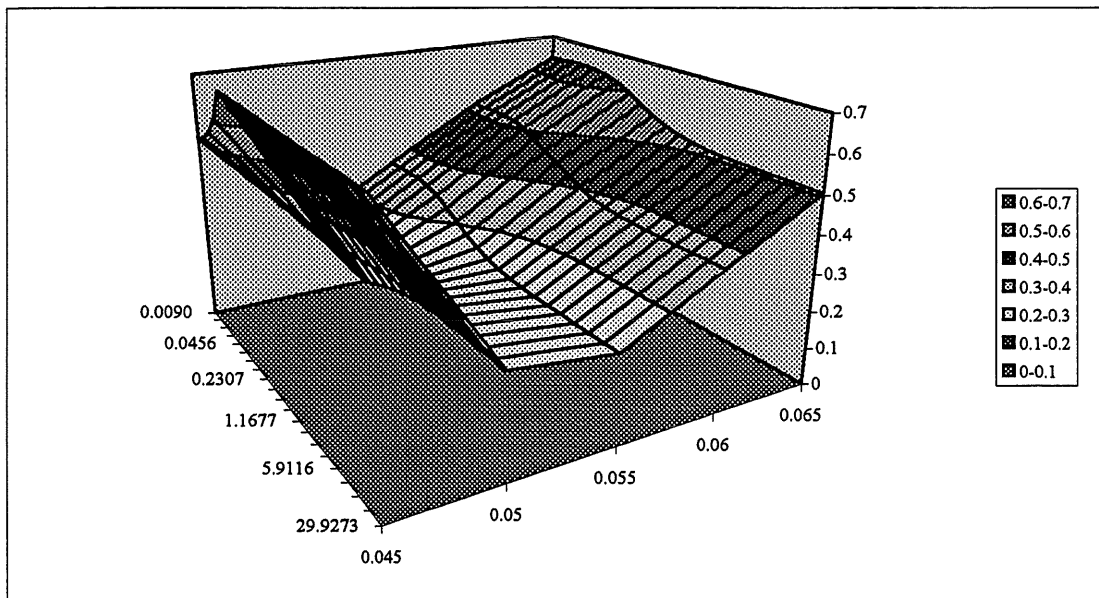
Figure 3.4.4. Plot of SSE-surface for values of KS in the (log-scale) range 0.009-29.9 and K in the range 0.045-0.065.

Figure 3.4.5 Fishable biomass and fishing mortality of Oceanic *S. mentella*
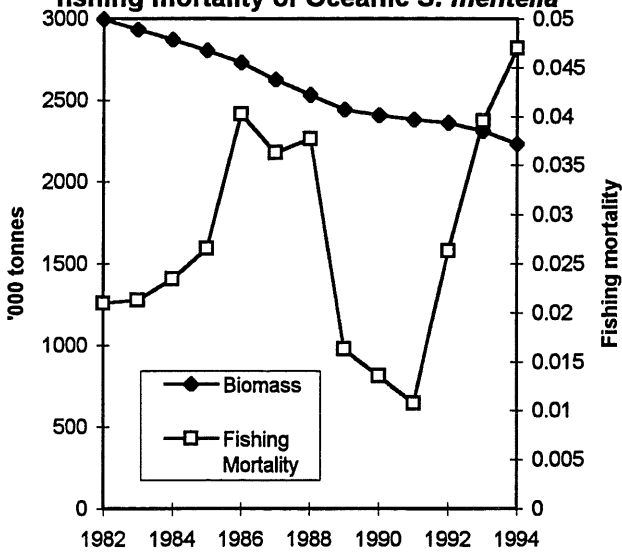
Figure 3.4.6 Oceanic *S. Mentella* - Length distribution in the stock 1994
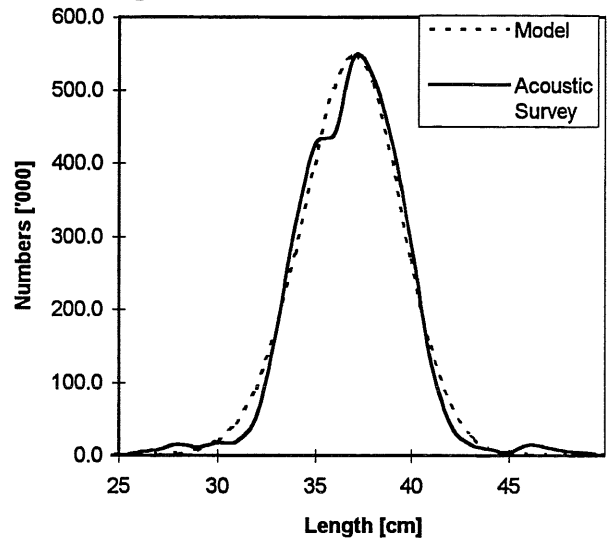
Figure 3.4.7 Fishable biomass and catch of Canadian (Unit 1) redfish.
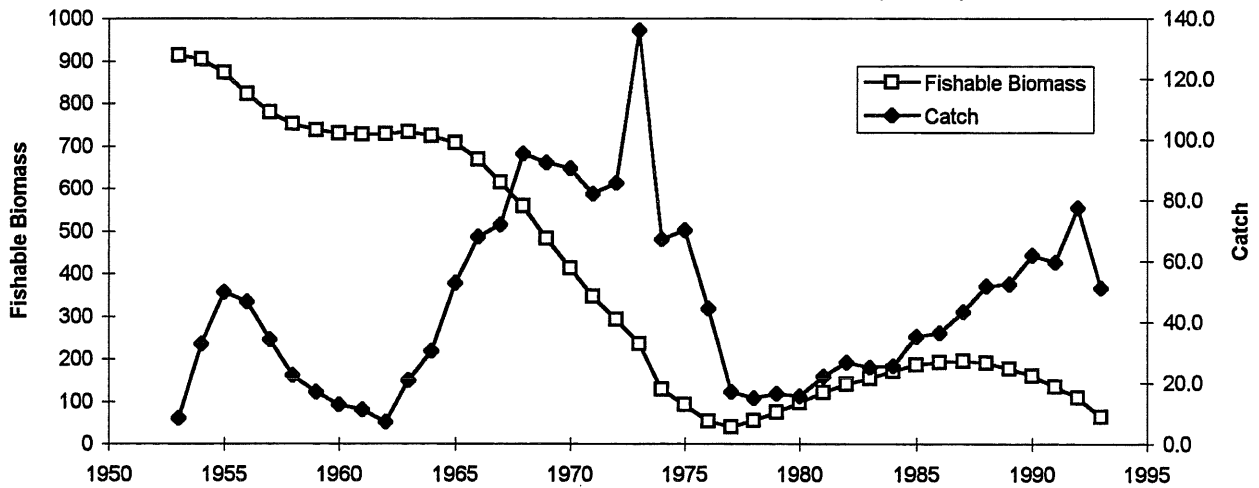
Figure 3.4.8 Unit 1 redfish; length distribution of 1981 catches
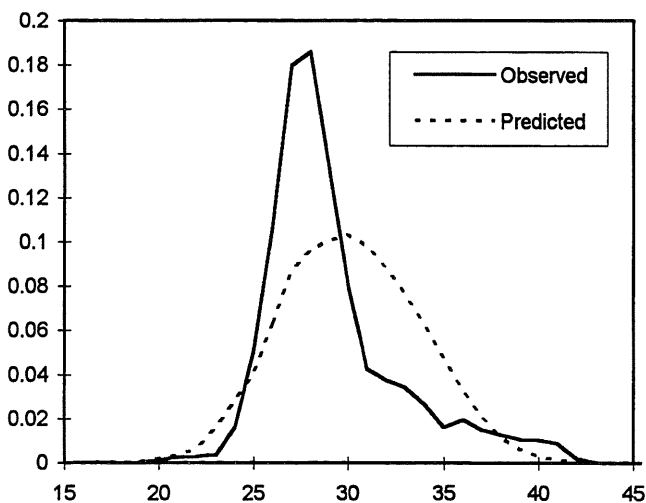
Figure 3.4.9 Unit 1 redfish; length distribution of 1992 catches.

98
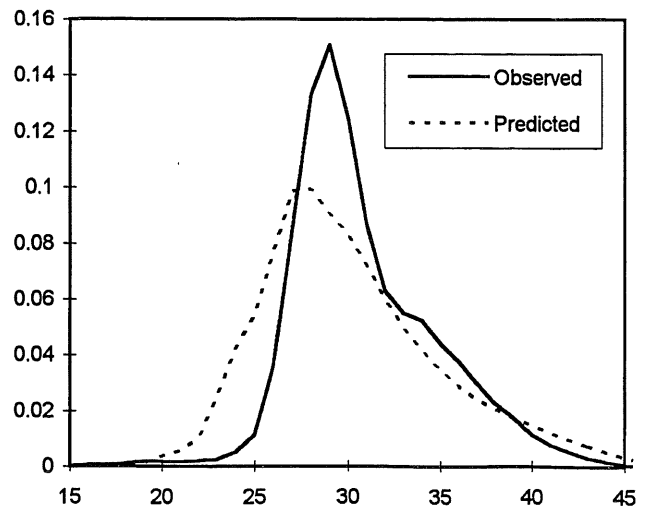
Figure 3.4.10 Contour plot of the multi-nominal log-likelihood function as a function of recruitment and a selection parameter in Unit 1 redfish.

100
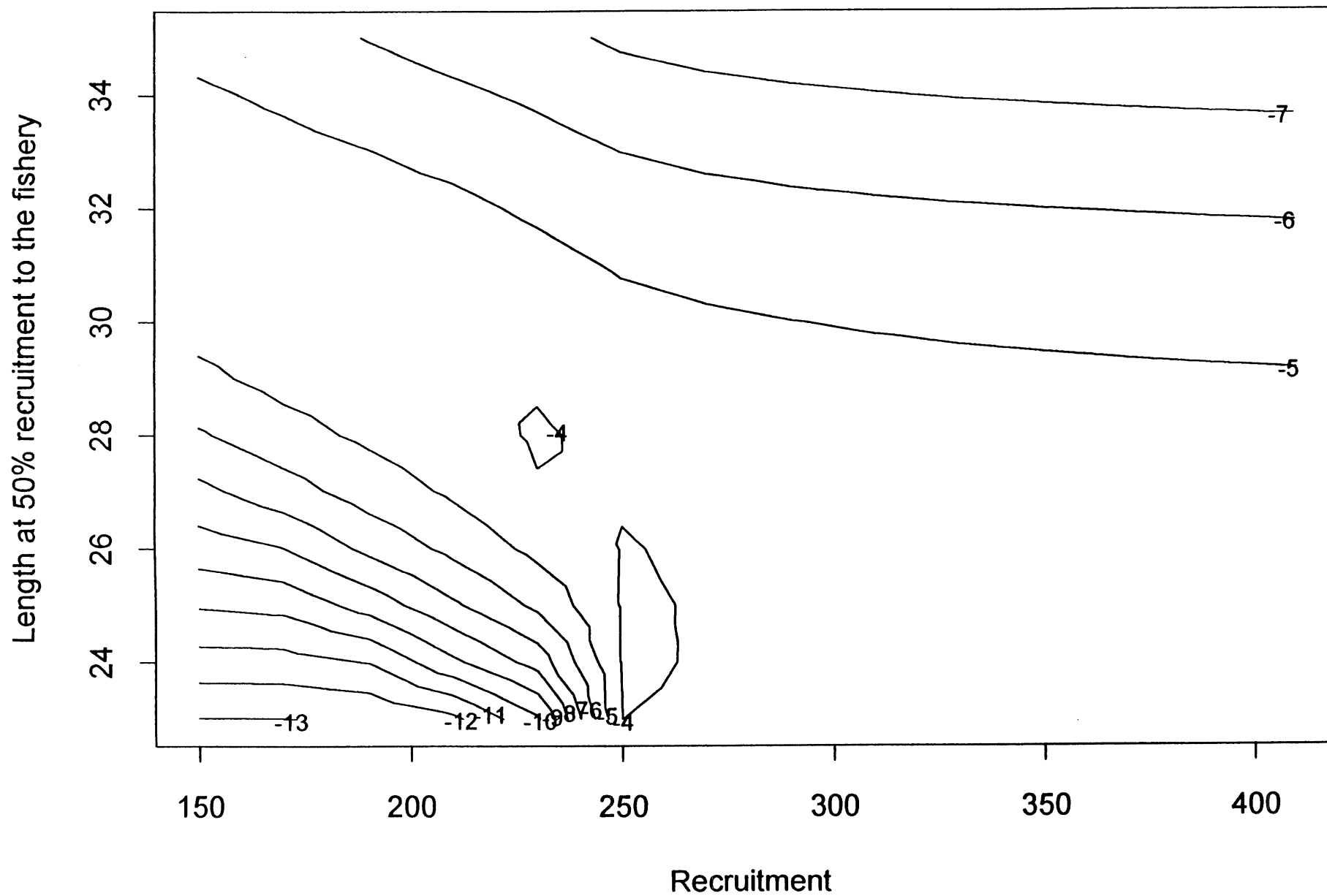
Fig 3.5.1 Iceland S. marinus : Bayesian stock production model
Mean stock trajectory with relative abundance data
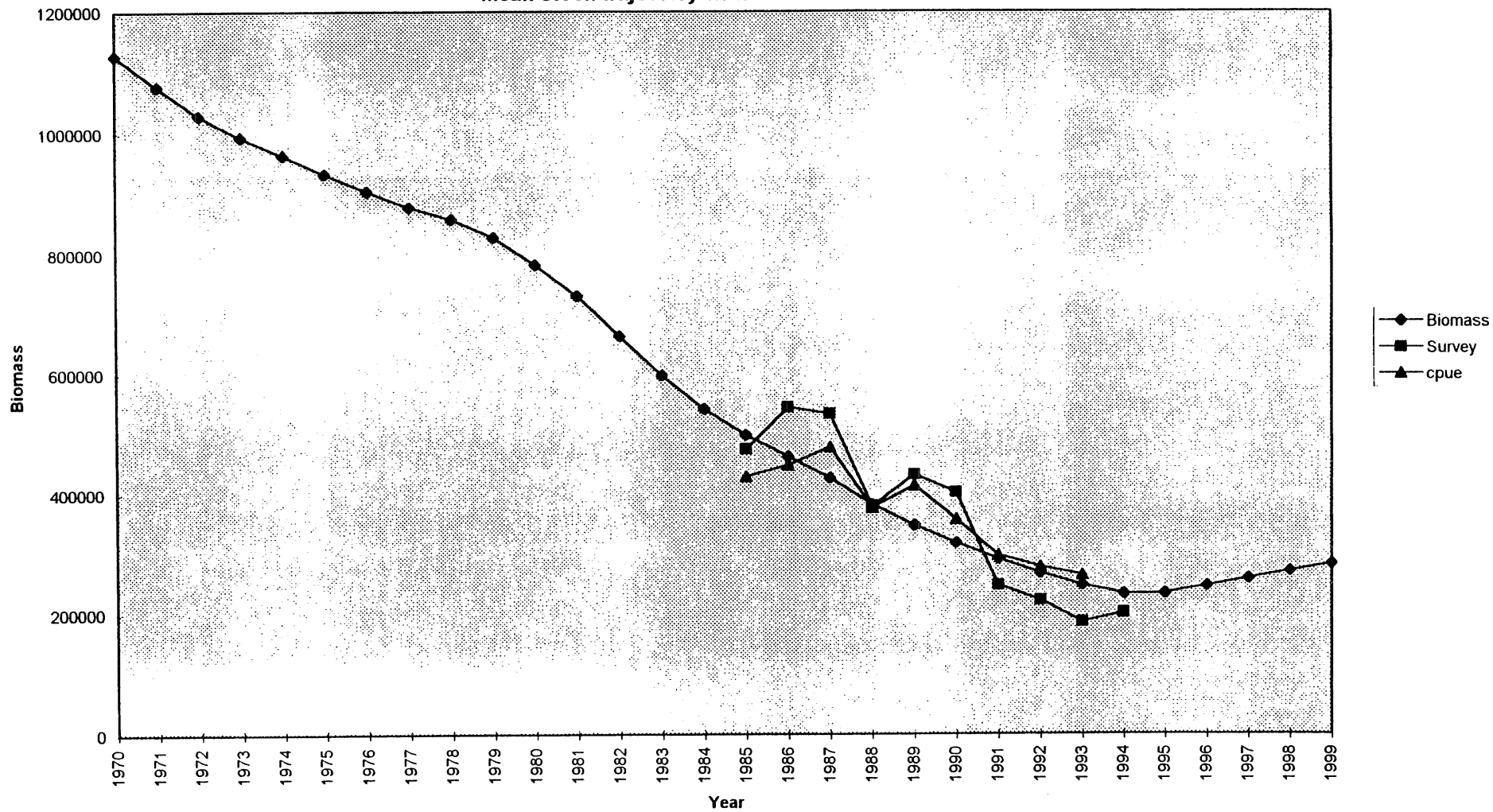
**Fig 3.5.2 Iceland S. marinus : Bayesian stock production model
Posterior distribution for virgin biomass**

102
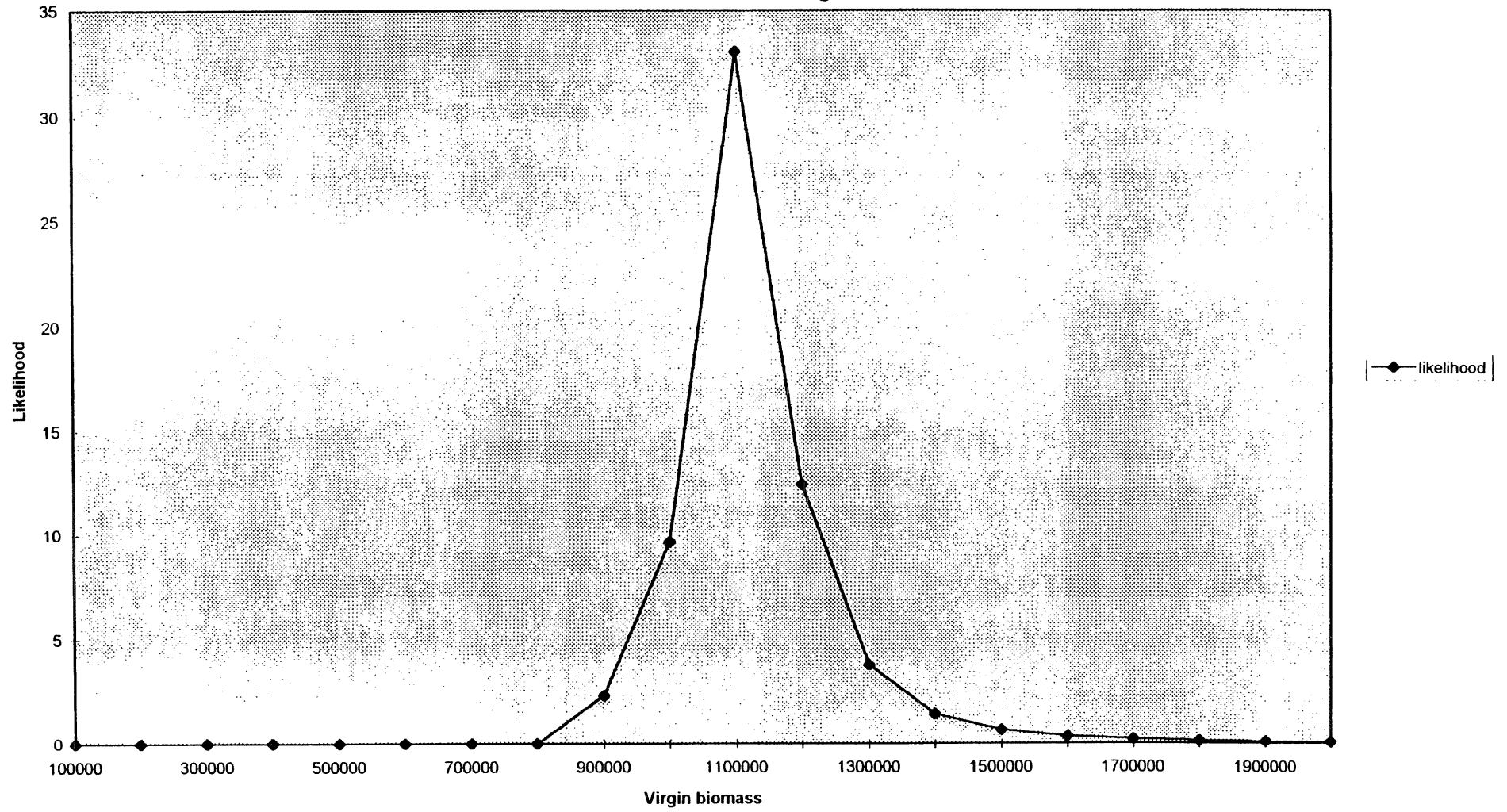
Fig 3.5.3 Gulf of Maine Cod : Bayesian stock production model
Mean stock trajectory with relative abundance data
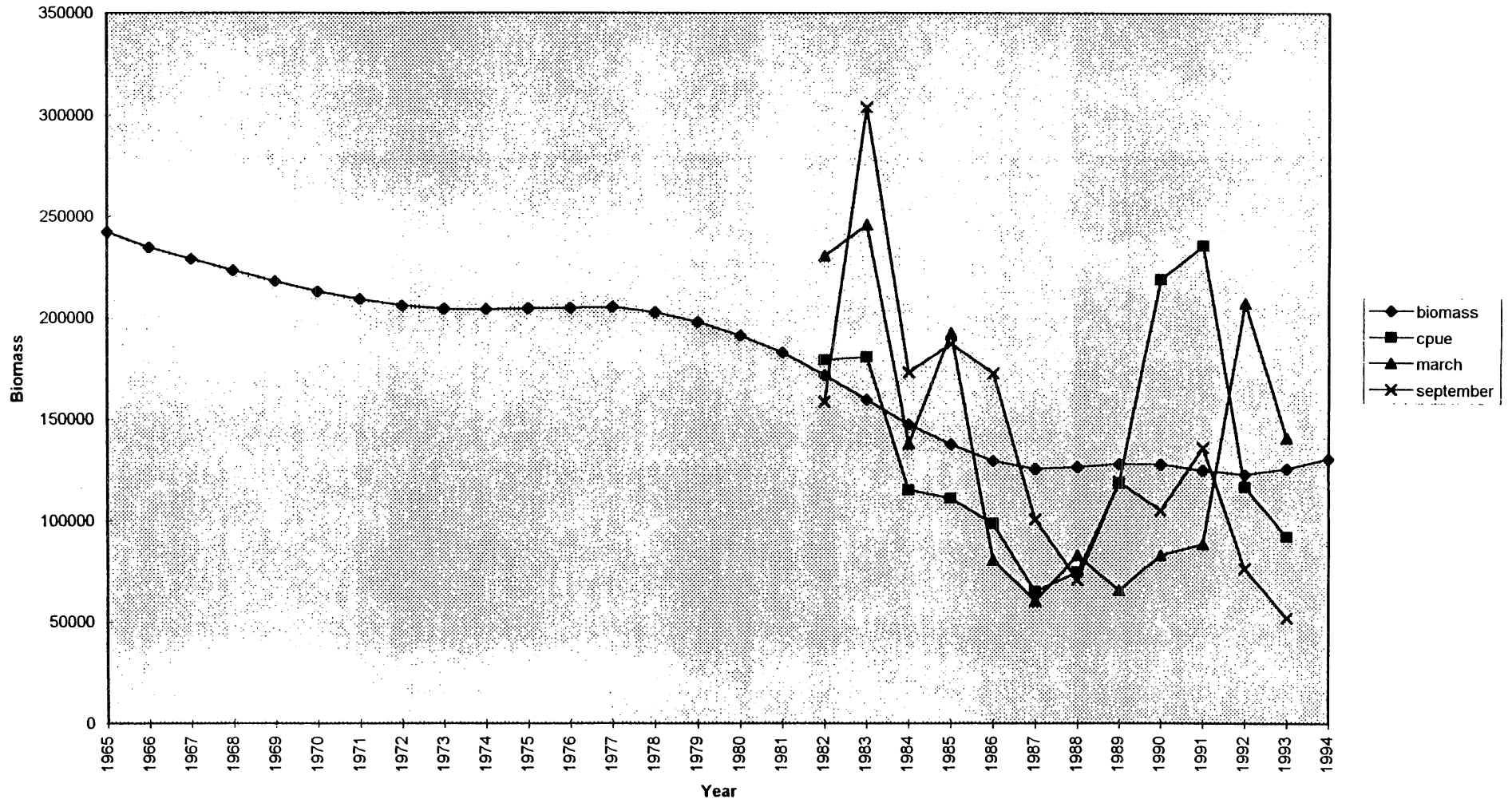
Fig 3.5.4 Gulf of Maine Cod : Bayesian stock production model
Posterior distribution for virgin biomass

104
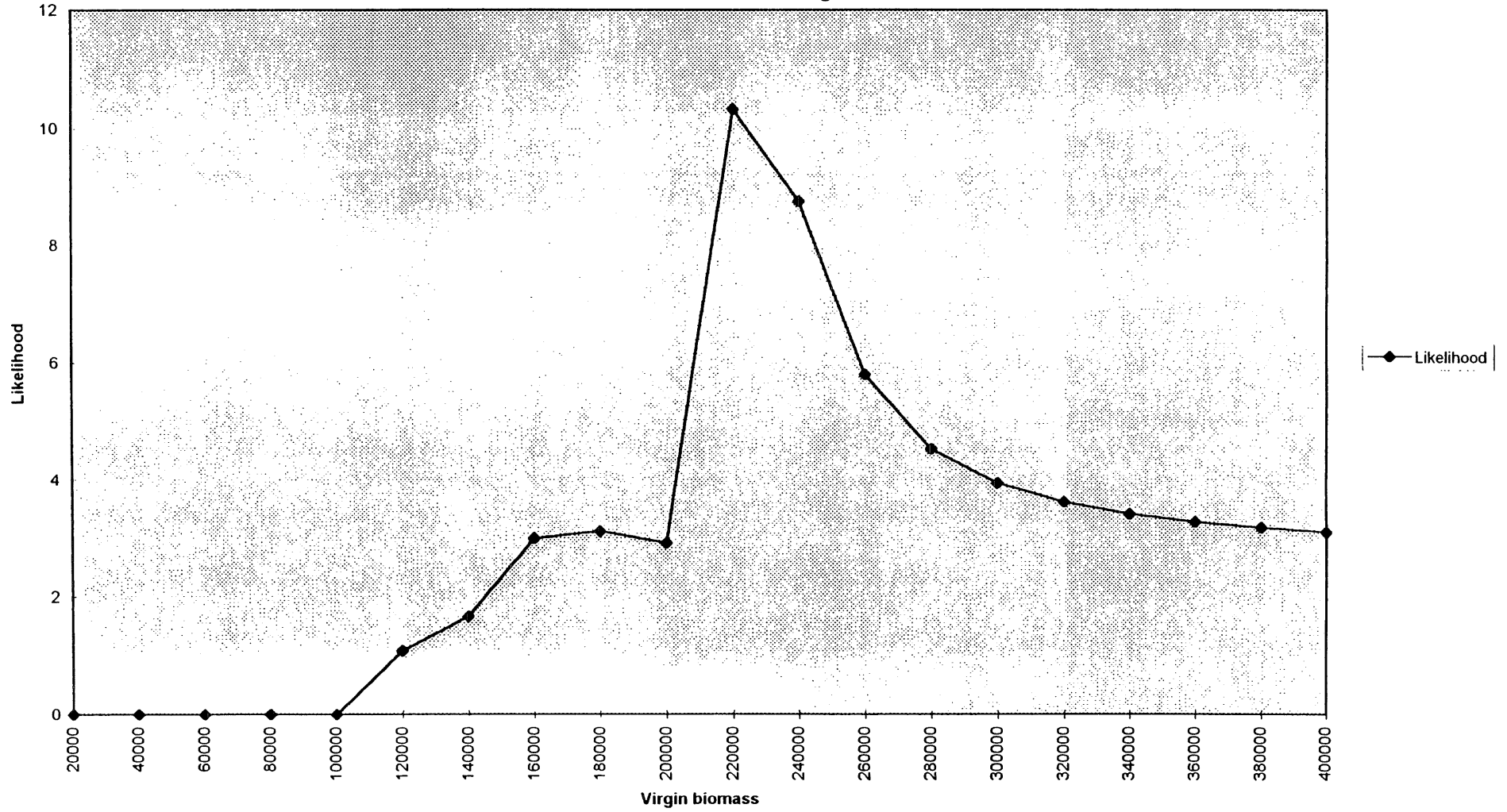
Fig 3.5.5 Gulf St Lawrence redfish : Bayesian stock production model
Mean stock trajectory with relative abundance data
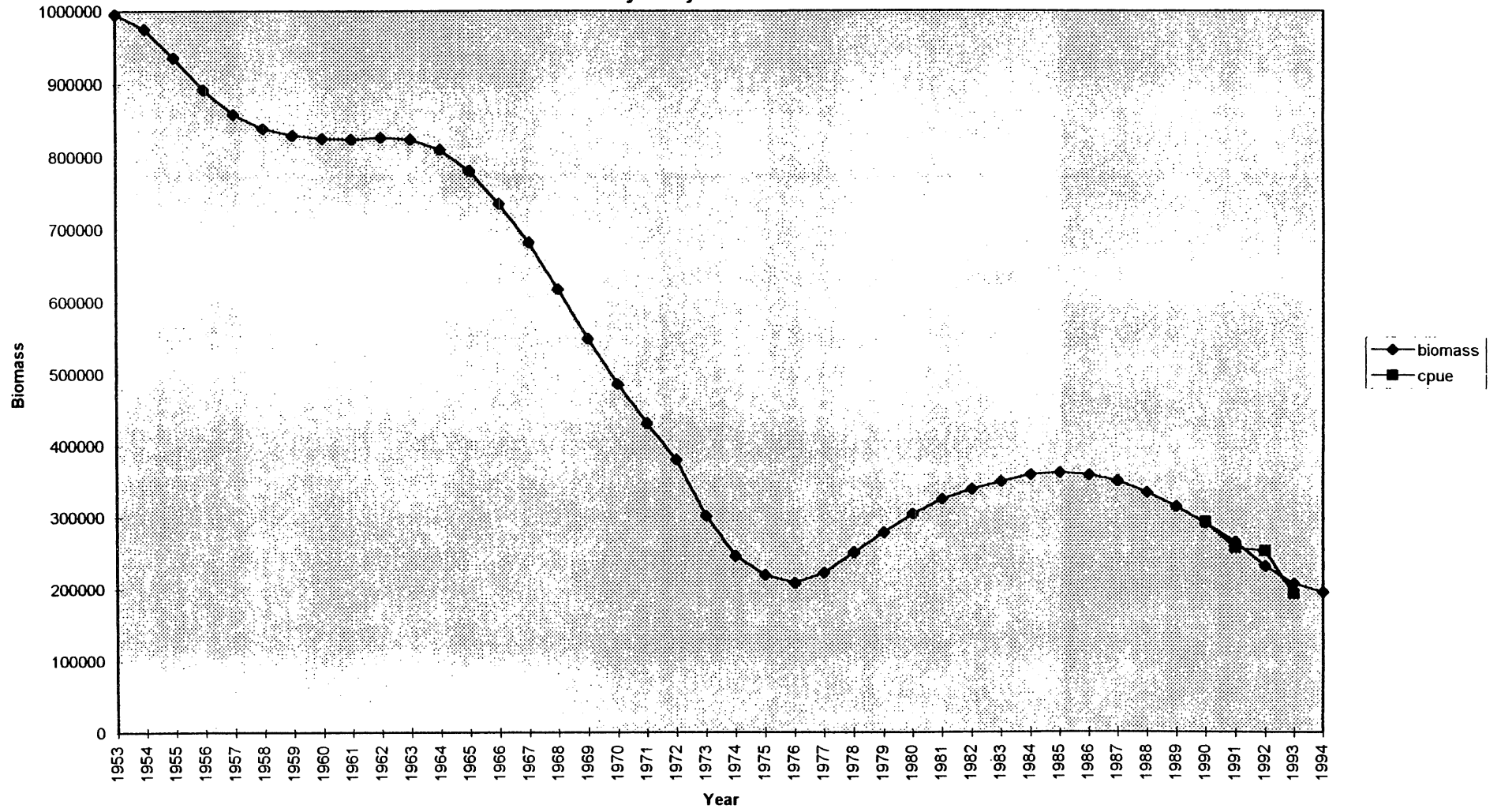
Fig 3.5.6 Gulf St Lawrence redfish : Bayesian stock production model
Posterior distribution for virgin biomass

106
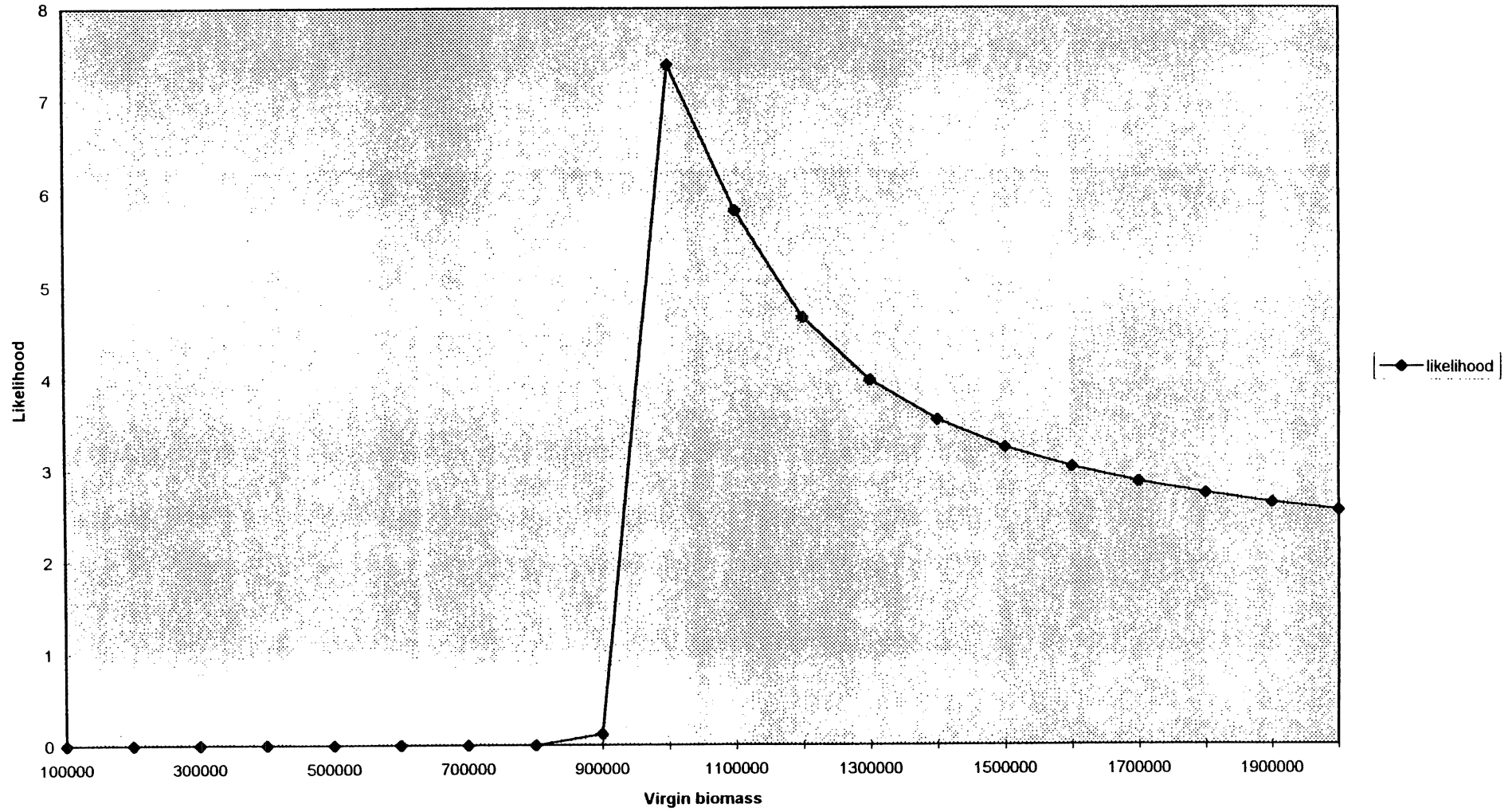
Fig 3.5.7 Pacific Ocean Perch : Bayesian stock production model
Maximum likelihood stock trajectory with relative abundance data
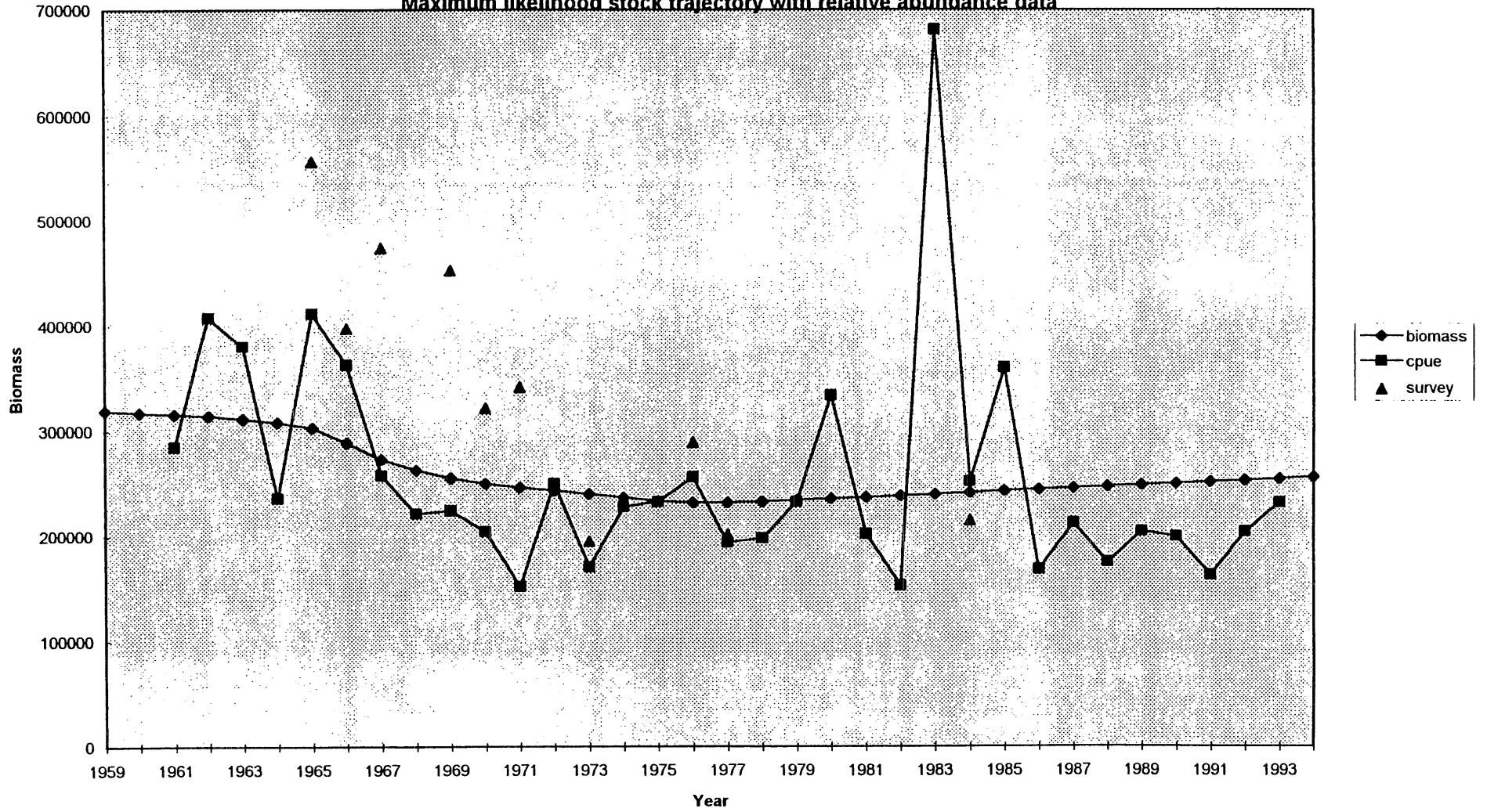
Fig 3.5.8 Pacific Ocean Perch : Bayesian stock production model
Posterior distribution for virgin biomass

107
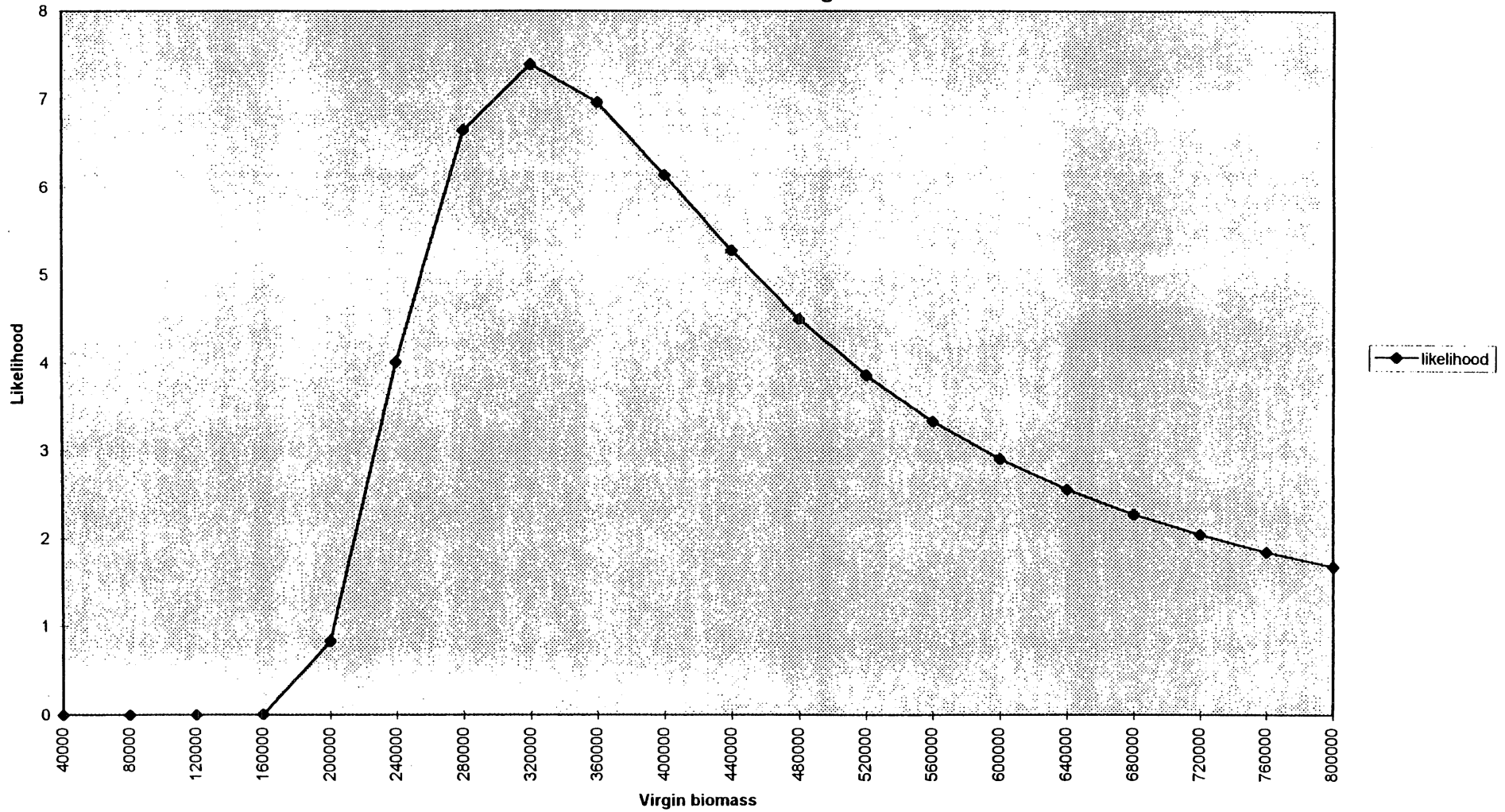
Figure 3.6.1a   **Diagnostics for the modified DeLury model - Gulf of Maine cod using spring survey indices.**
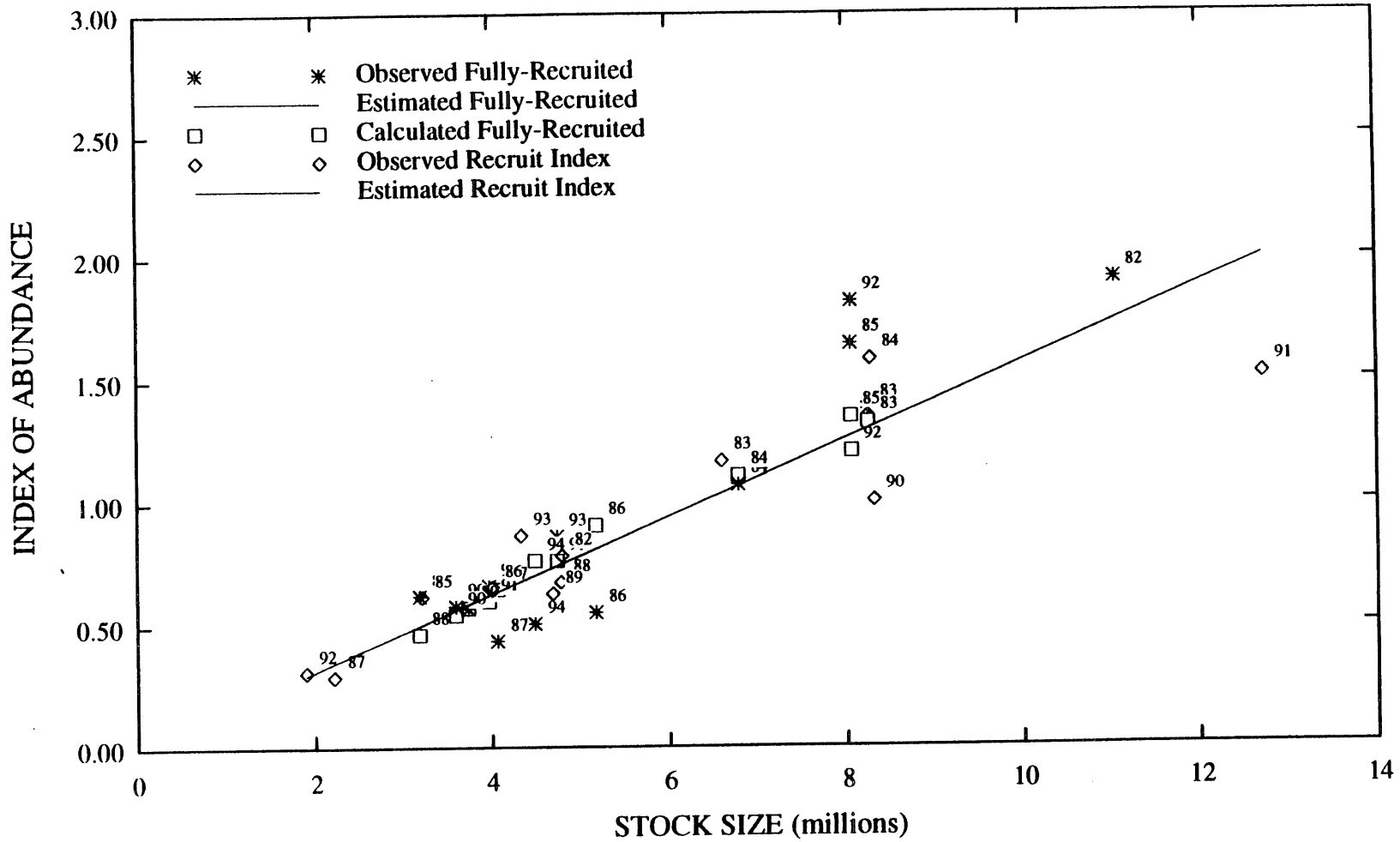
Plot 3.8 DeLury RunNum=588 GCOD   t_s=0 t_c=0.5 M=0.2 q_hat= 0.1573 s_r= 1.00 pr_bar= 0.50 W_objfcn=1 1 4 Num_reps=200 bao=0

Figure 3.6.1b   Diagnostics for the modified DeLury model - Gulf of Maine cod using fall survey indices.
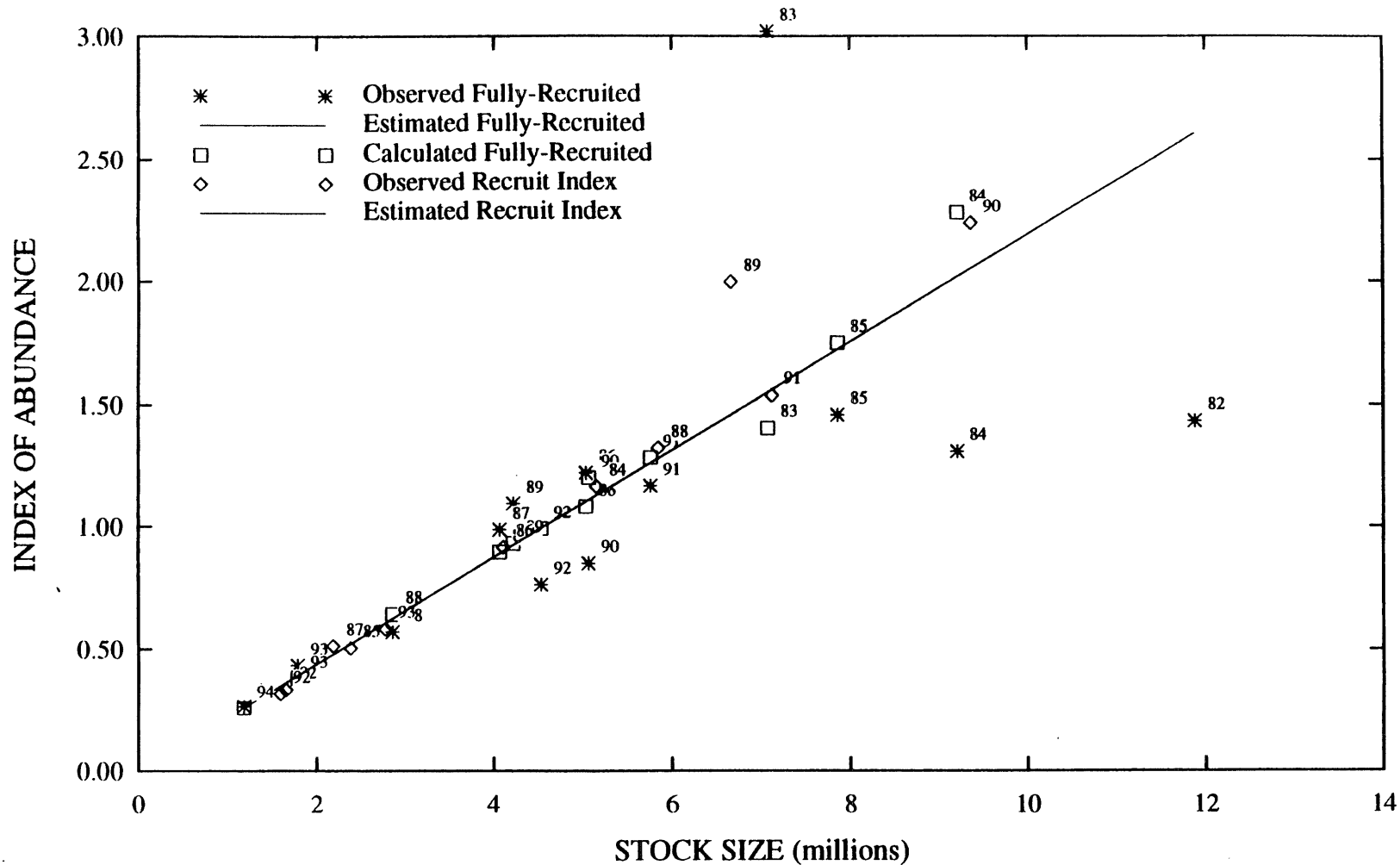
Plot 3.8 DeLury RunNum=592 GCOD   t_s=0 t_c=0.5 M=0.2 q_hat= 0.2192 s_r= 1.00 pr_bar= 0.50 W_objfcn=1 1 4 Num_reps=200 bao=0

Figure 3.6.2a   **Modified DeLury model results - Gulf of Maine cod using spring and fall survey indices.**
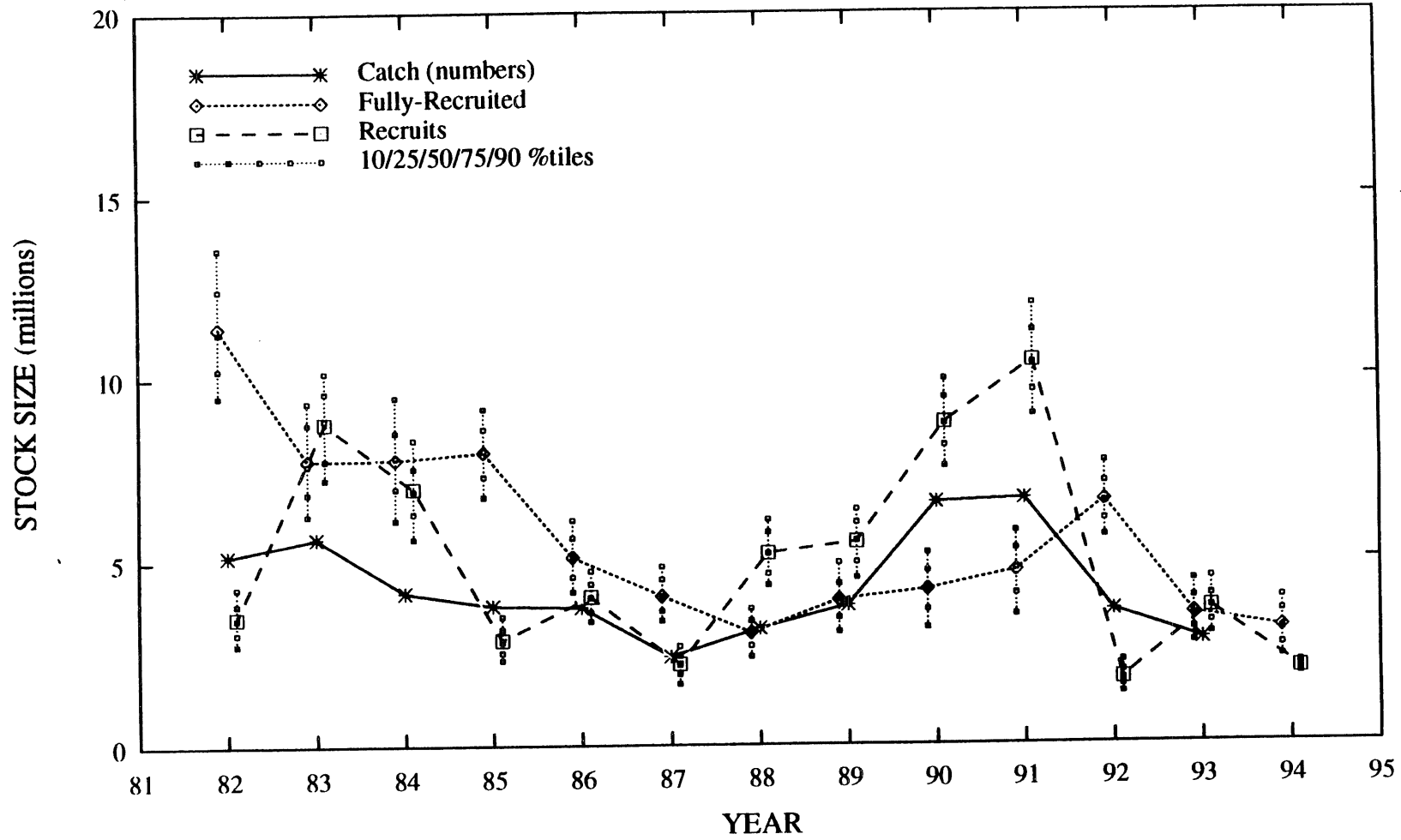
Plot 3.12 DeLury Bayes estimates from Runs 588 591; prior= 0.59 0.41 bao=1

Figure 3.6.2b   Modified DeLury model results - Gulf of Maine cod using spring and fall survey indices.
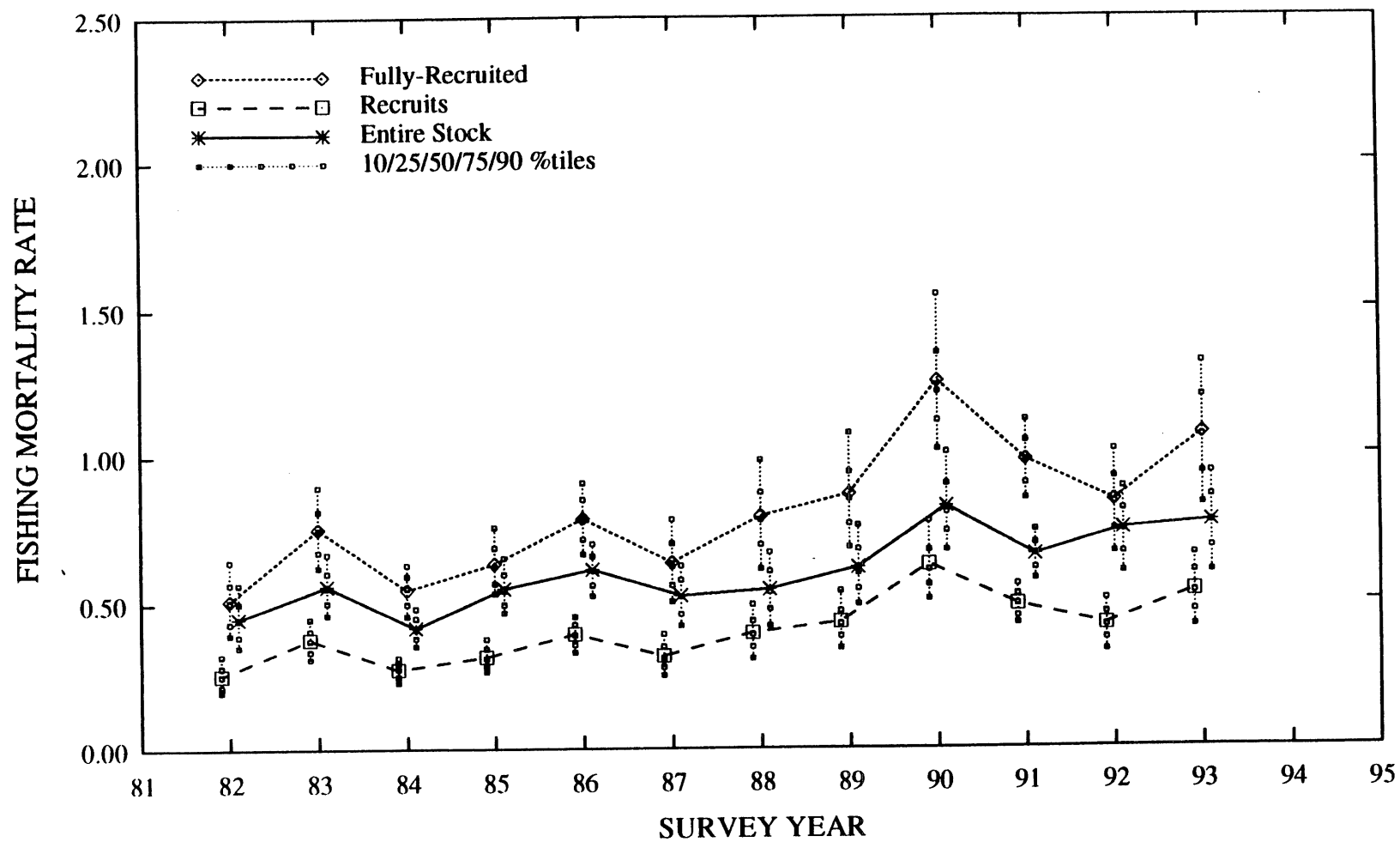
Plot 3.14 DeLury Bayes estimates from Runs 588 591; prior= 0.59 0.41 bao=1

Figure 3.6.2c **Modified DeLury model results - Gulf of Maine cod using spring and fall survey indices.**
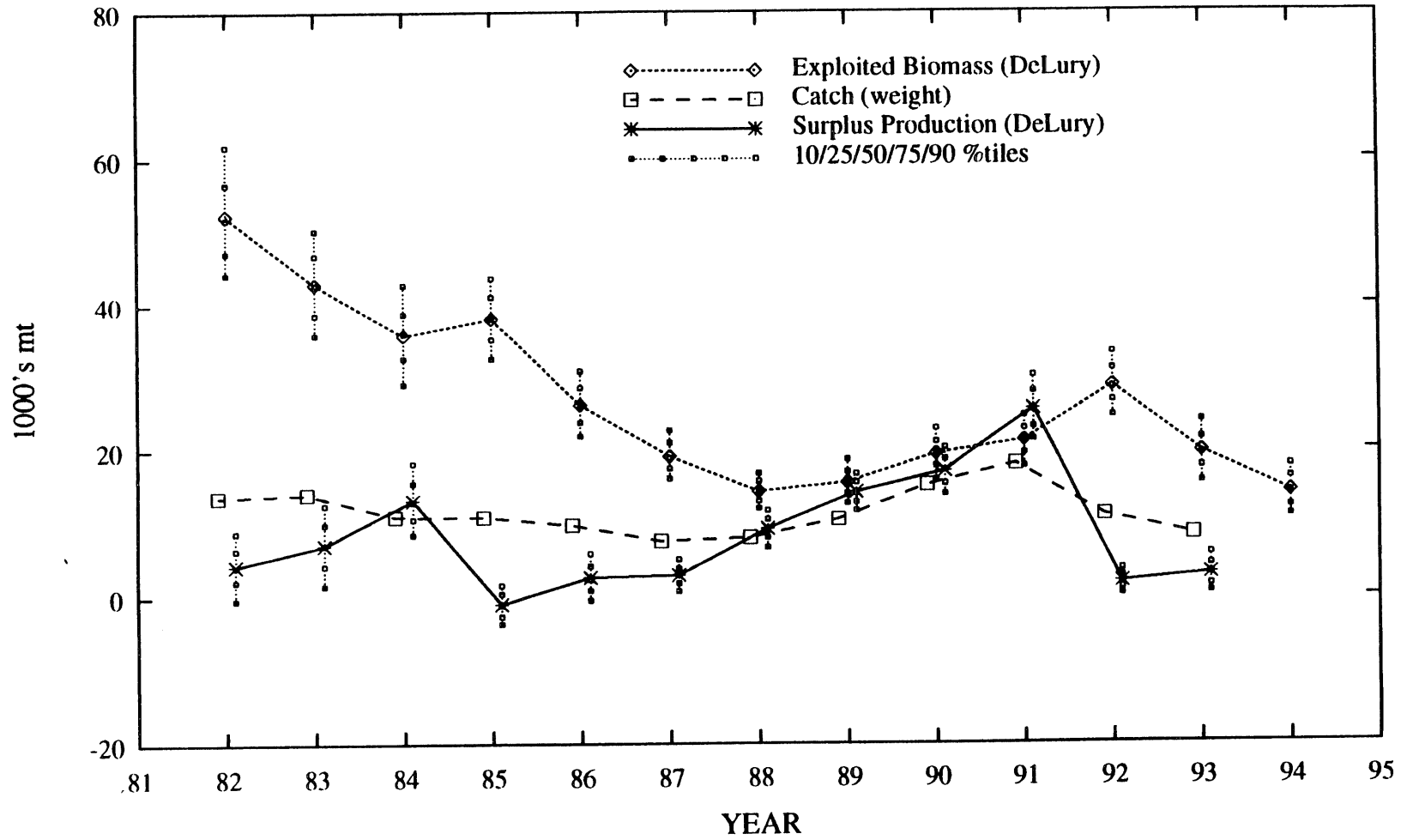
Plot 3.15 DeLury Bayes estimates from Runs 588 591; prior= 0.59 0.41 bao=1

Figure 3.6.3a   Modified DeLury model results - Icelandic cod.
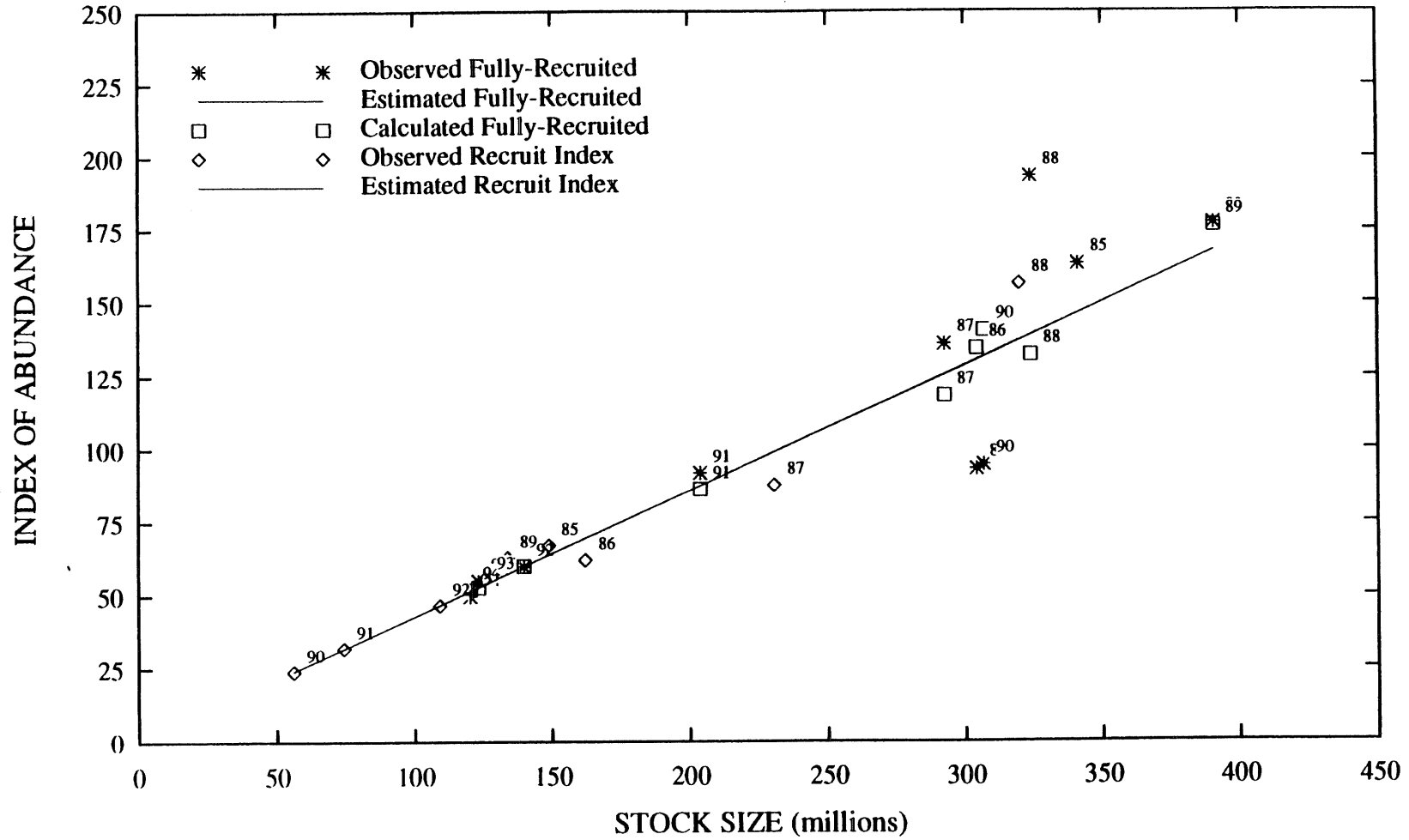
Plot 3.8 DeLury RunNum=614 ICOD   t_s=0.2 t_c=0.5 M=0.2 q_hat= 0.4289 s_r= 1.00 pr_bar= 0.50 W_objfcn=1 1 4 Num_reps=200 bao=0

Figure 3.6.3b   Modified DeLury model results - Icelandic cod.
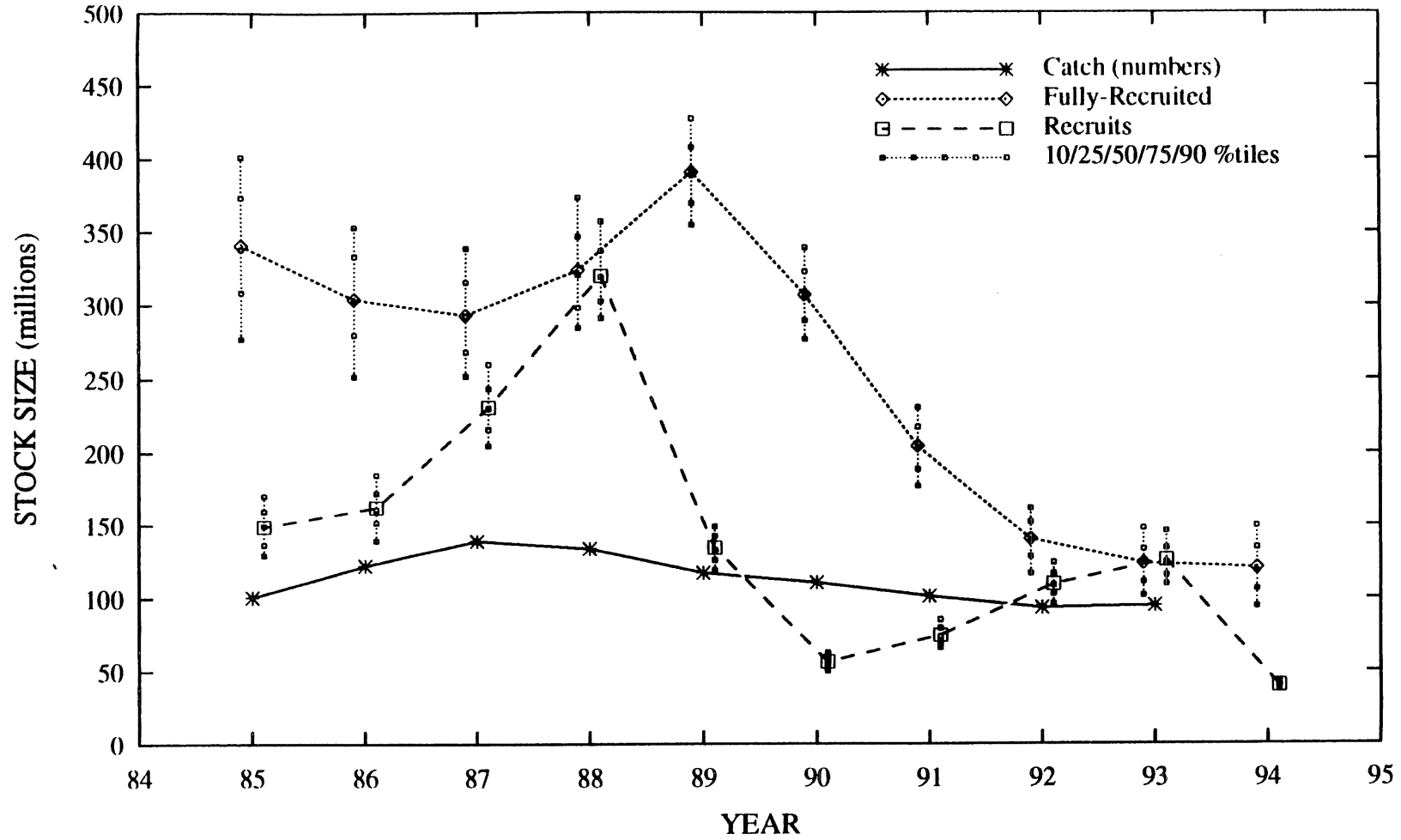
Plot 3.12 DeLury RunNum=614 ICOD   t_s=0.2 t_c=0.5 M=0.2 q_hat= 0.4289 s_r= 1.00 pr_bar= 0.50 W_objfcn=1 1 4 Num_reps=200 bao=1

Figure 3.6.3c   Modified DeLury model results - Icelandic cod.
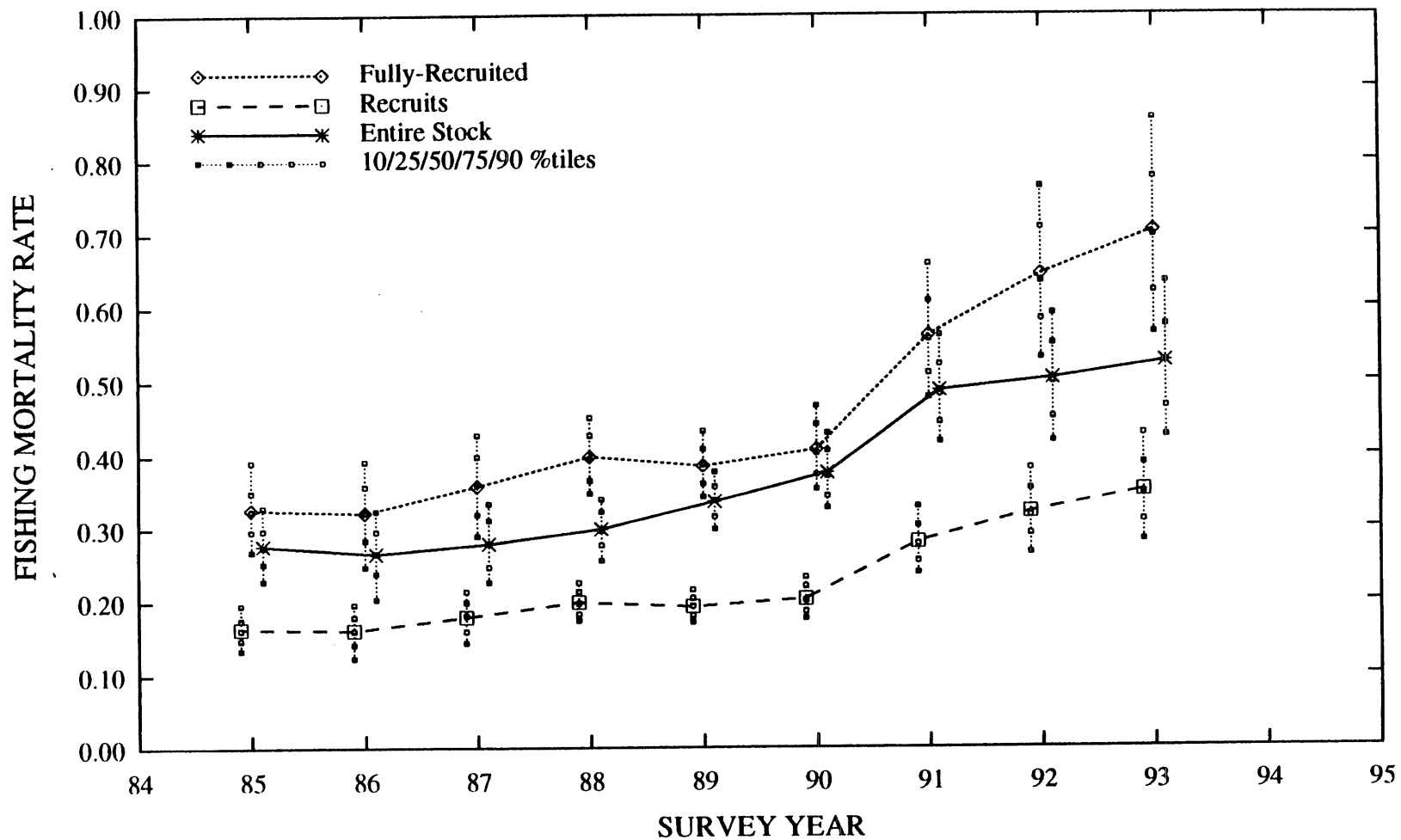
Plot 3.14 DeLury RunNum=614 ICOD   t_s=0.2 t_c=0.5 M=0.2 q_hat= 0.4289 s_r= 1.00 pr_bar= 0.50 W_objfcn=1 1 4 Num_reps=200 bao=1

Figure 3.6.3d   Modified DeLury model results - Icelandic cod.
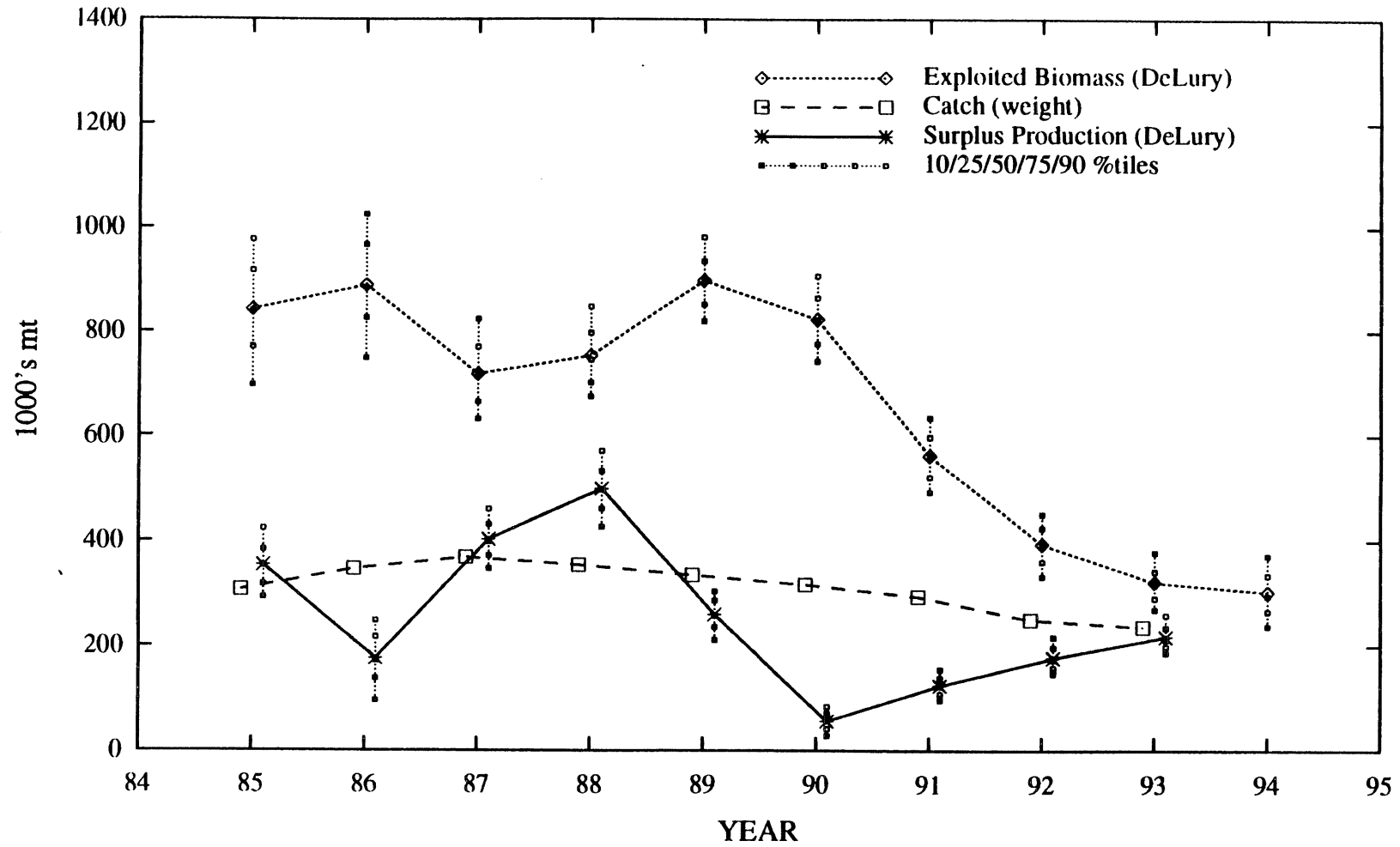
Plot 3.15 DeLury RunNum=614 ICOD   t_s=0.2 t_c=0.5 M=0.2 q_hat= 0.4289 s_r= 1.00 pr_bar= 0.50 W_objfcn=1 1 4 Num_reps=200 bao=1

Figure 3.6.4a   Modified DeLury model results - Icelandic haddock.
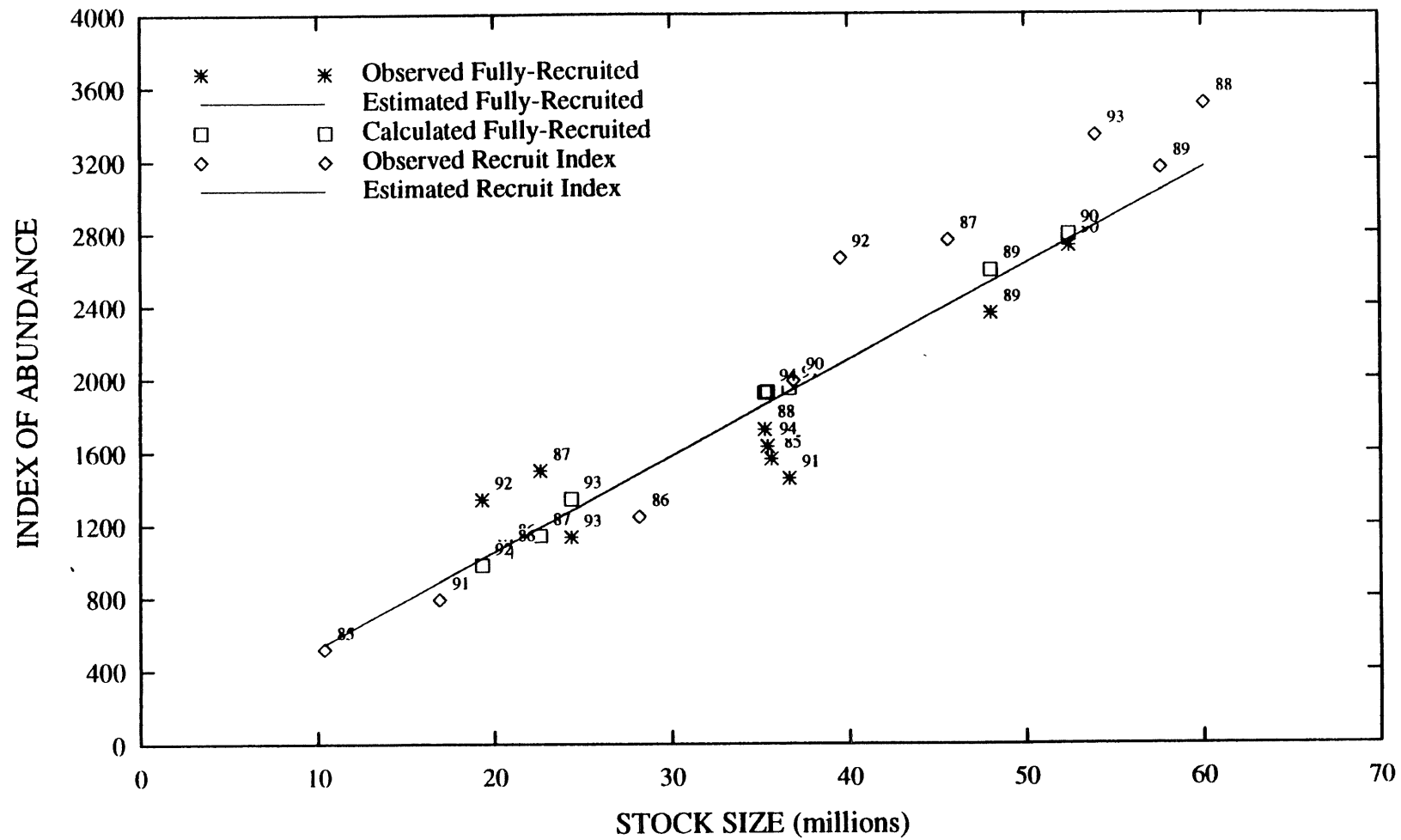
Plot 3.8 DeLury RunNum=615 IHAD   t_s=0.2 t_c=0.5 M=0.2 q_hat= 52.6370 s_r= 1.00 pr_bar= 0.50 W_objfcn=1 1 4 Num_reps=200 bao=0

Figure 3.6.4b   Modified DeLury model results - Icelandic haddock.
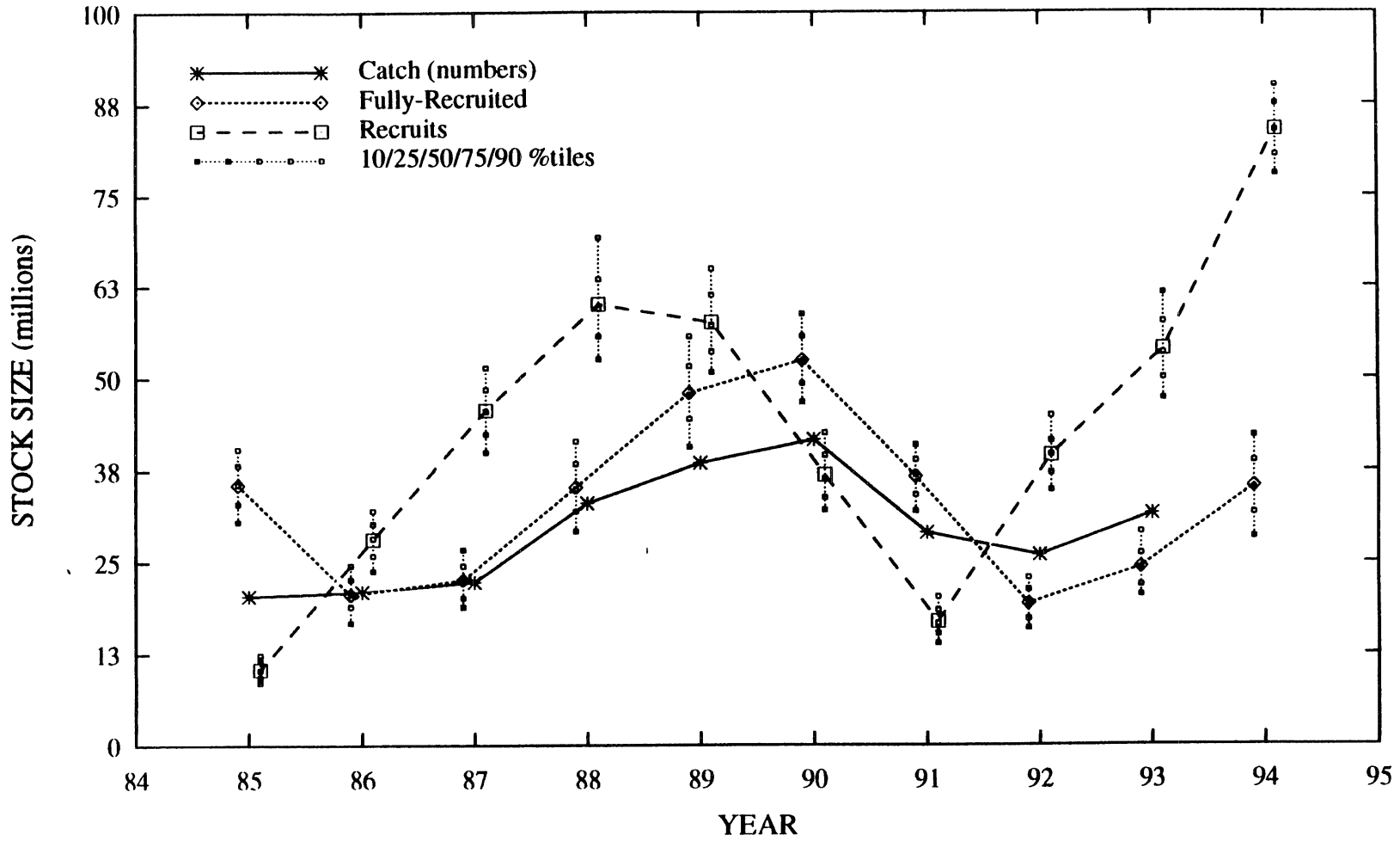
Figure 3.6.4c   Modified DeLury model results - Icelandic haddock.
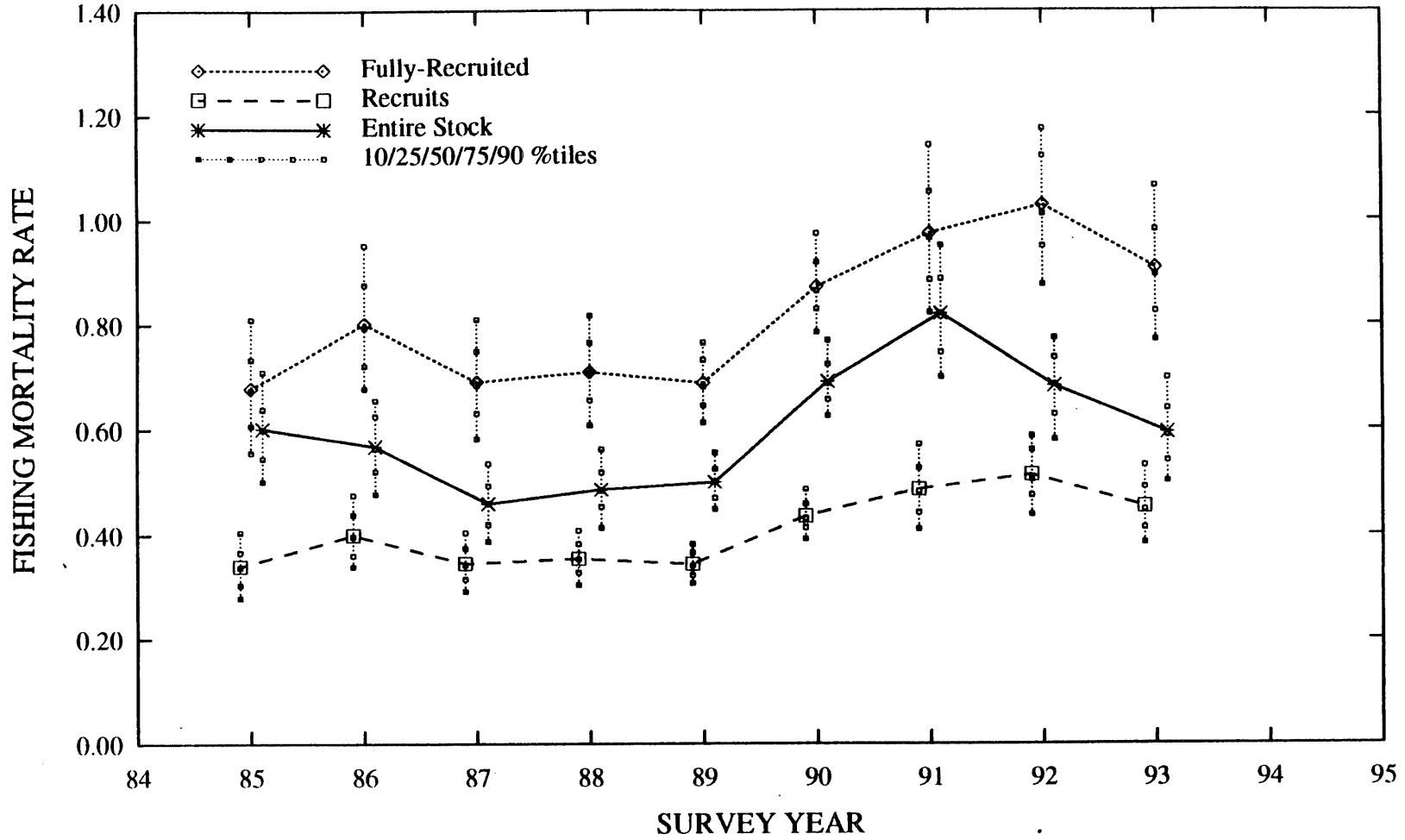
Plot 3.14 DelLury RunNum=615 IHAD   l_s=0.2 l_c=0.5 M=0.2 q_hat= 52.6370 s_r= 1.00 pr_bar= 0.50 W_objfcn=1 1 4 Num_reps=200 bao=1

Figure 3.6.4d   **Modified DeLury model results - Icelandic haddock.**
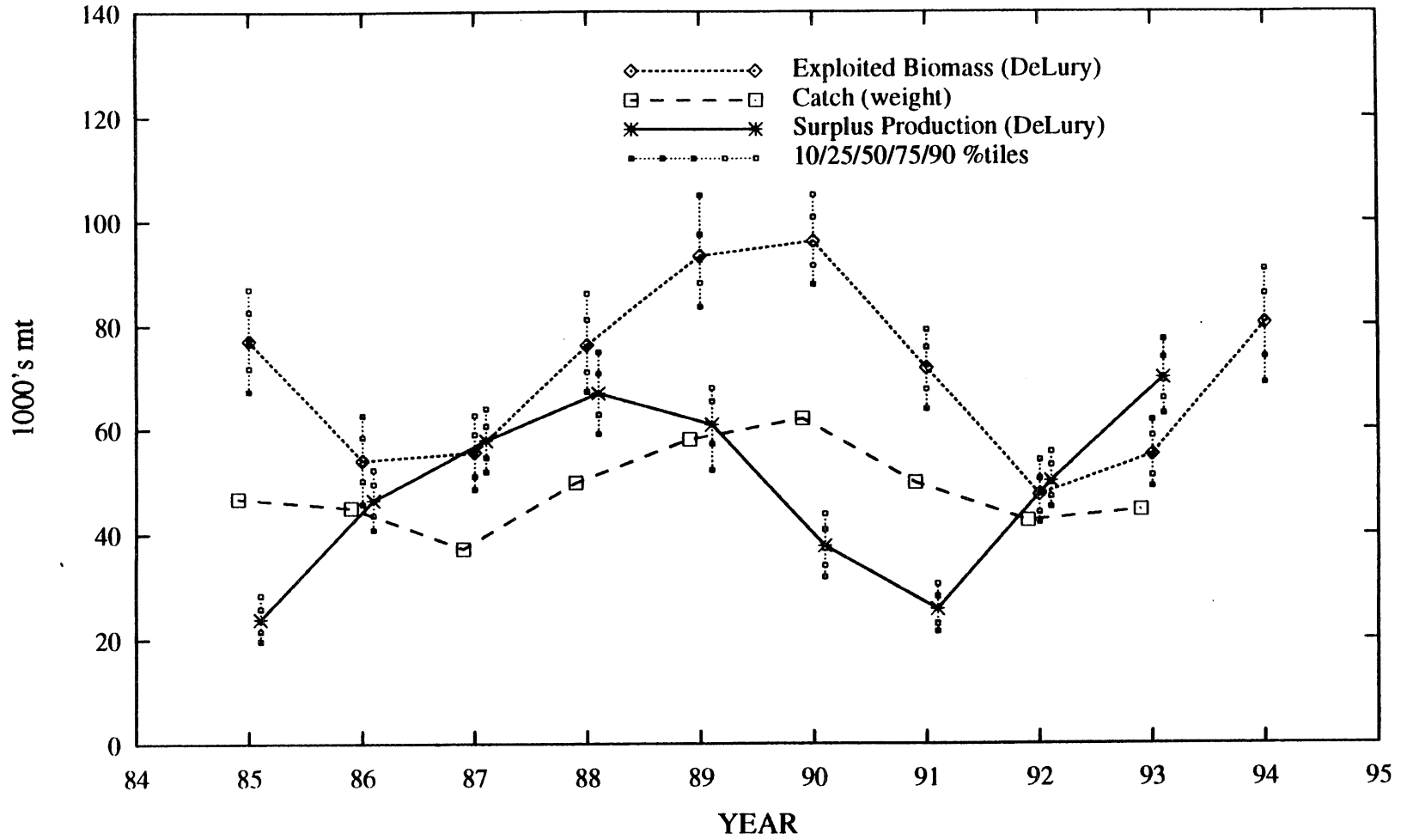
Plot 3.15 DeLury RunNum=615 IHAD   t_s=0.2 t_c=0.5 M=0.2 q_hat= 52.6370 s_r= 1.00 pr_bar= 0.50 W_objfcn=1 1 4 Num_reps=200 bao=1

Figure 3.6.5a   Modified DeLury model results - Icelandic redfish (S. marinus).
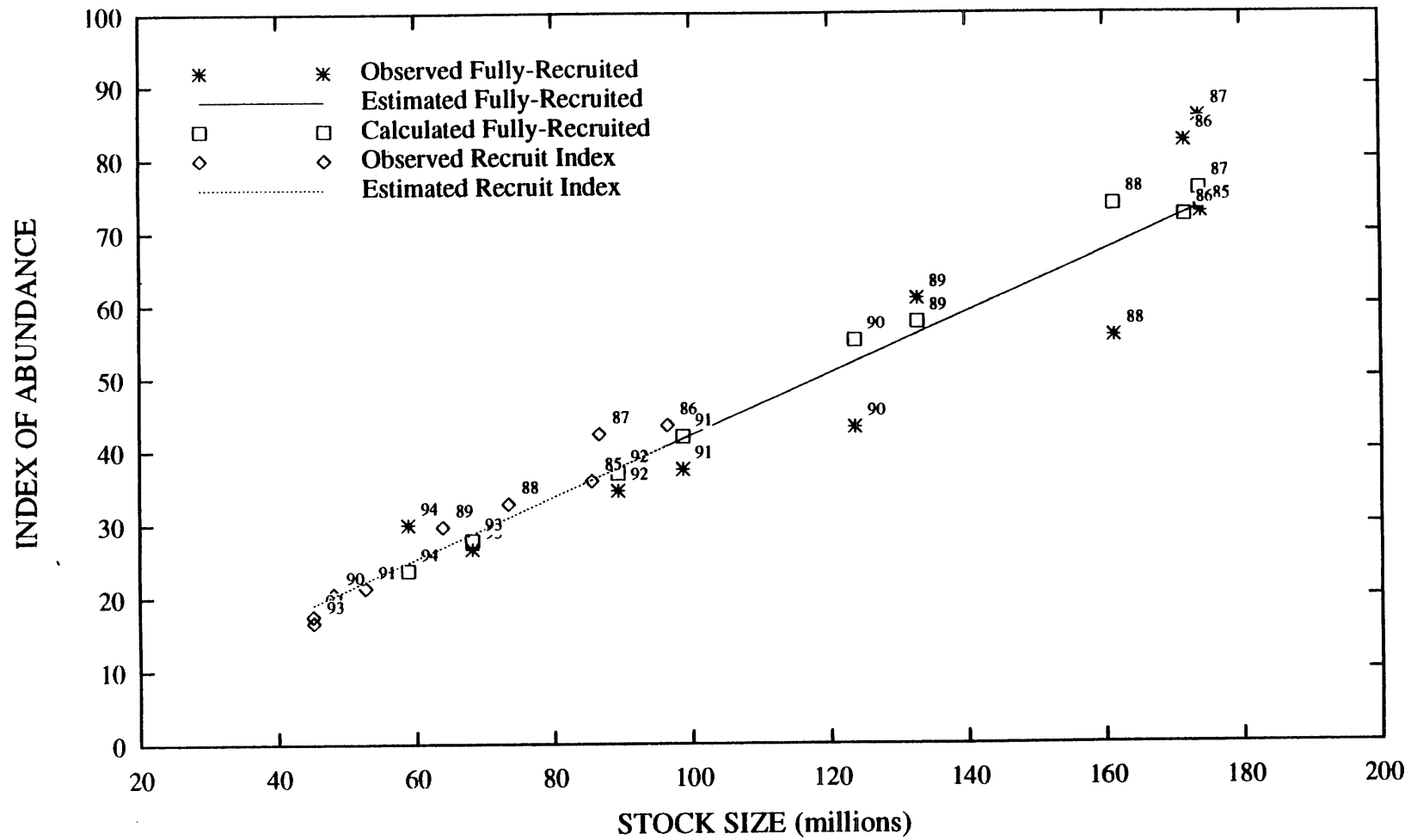
Plot 3.8 DeLury RunNum=609 IRED   t_s=0.2 t_c=0.5 M=0.1 q_hat= 0.4219 s_r= 1.00 pr_bar= 0.50 W_objfcn=1 1 4 Num_reps=200 bao=0

Figure 3.6.5b   Modified DeLury model results - Icelandic redfish (S. marinus).
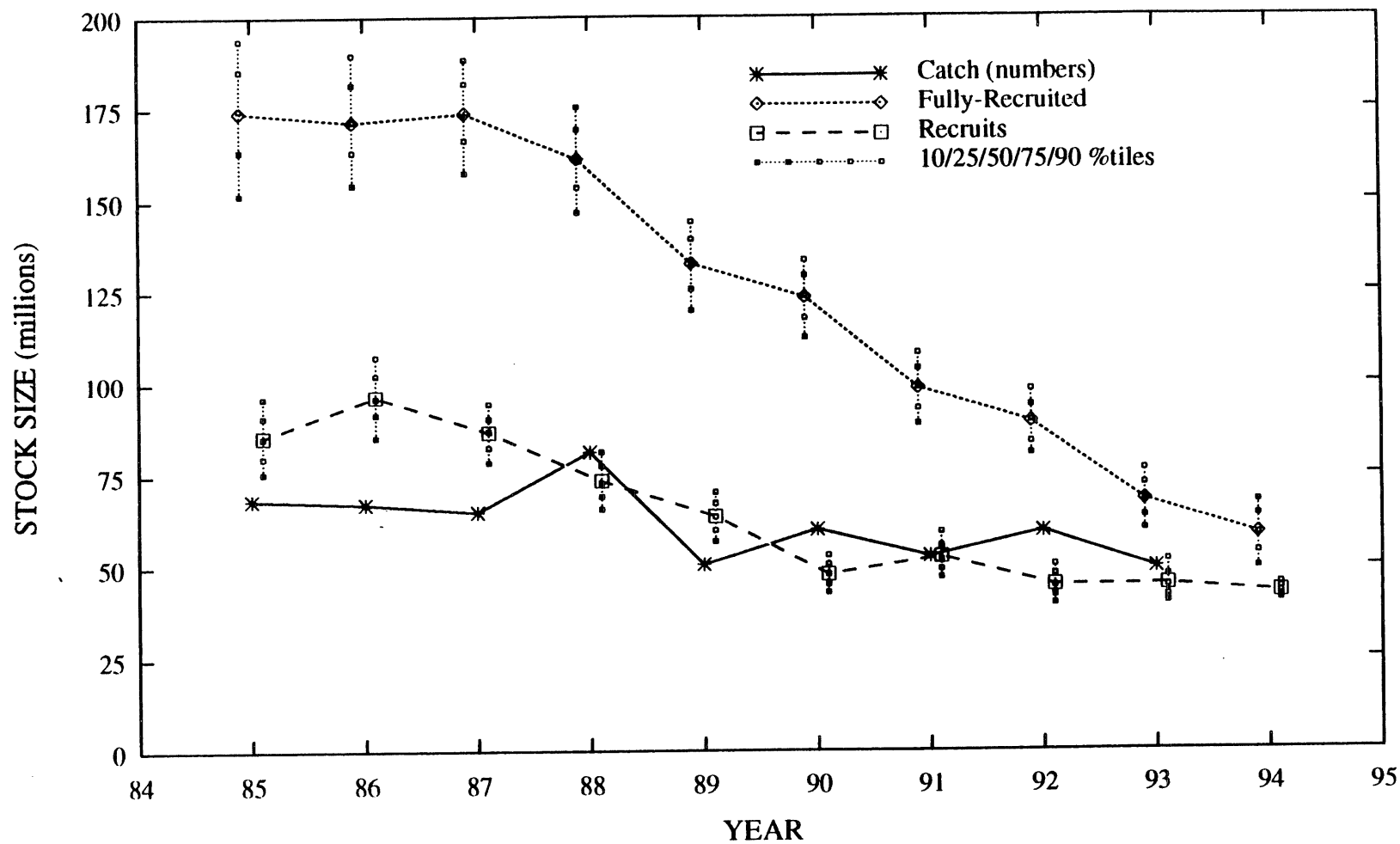
Plot 3.12 DeLury RunNum=609 IRED   t_s=0.2 t_c=0.5 M=0.1 q_hat= 0.4219 s_r= 1.00 pr_bar= 0.50 W_objfcn=1 1 4 Num_reps=200 bao=1

Figure 3.6.5c   Modified DeLury model results - Icelandic redfish (S. marinus).
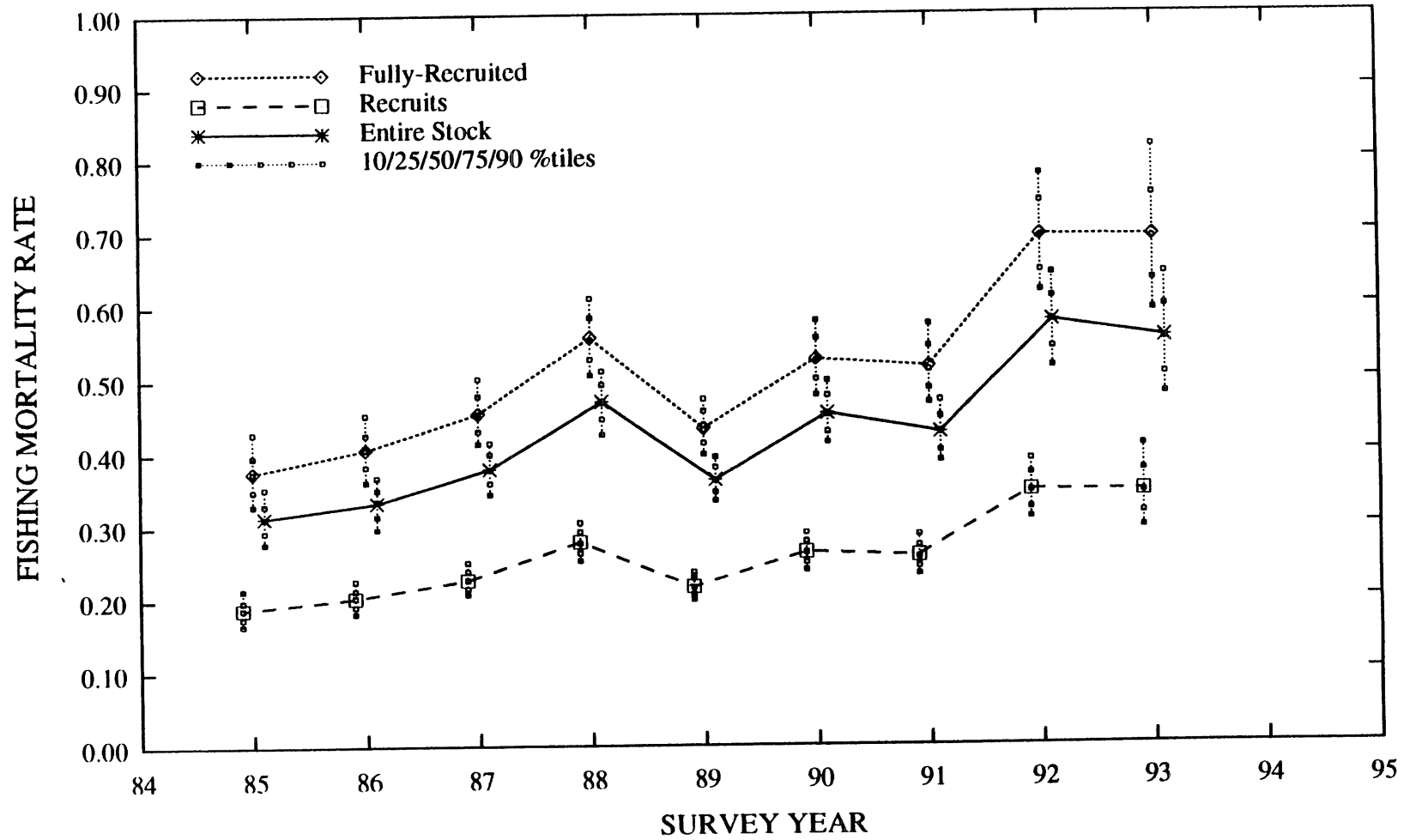
Plot 3.14 DeLury RunNum=609 IRED   t_s=0.2 t_c=0.5 M=0.1 q_hat= 0.4219 s_r= 1.00 pr_bar= 0.50 W_objfcn=1 1 4 Num_reps=200 bao=1

Figure 3.6.5d   Modified DeLury model results - Icelandic redfish (S. marinus).
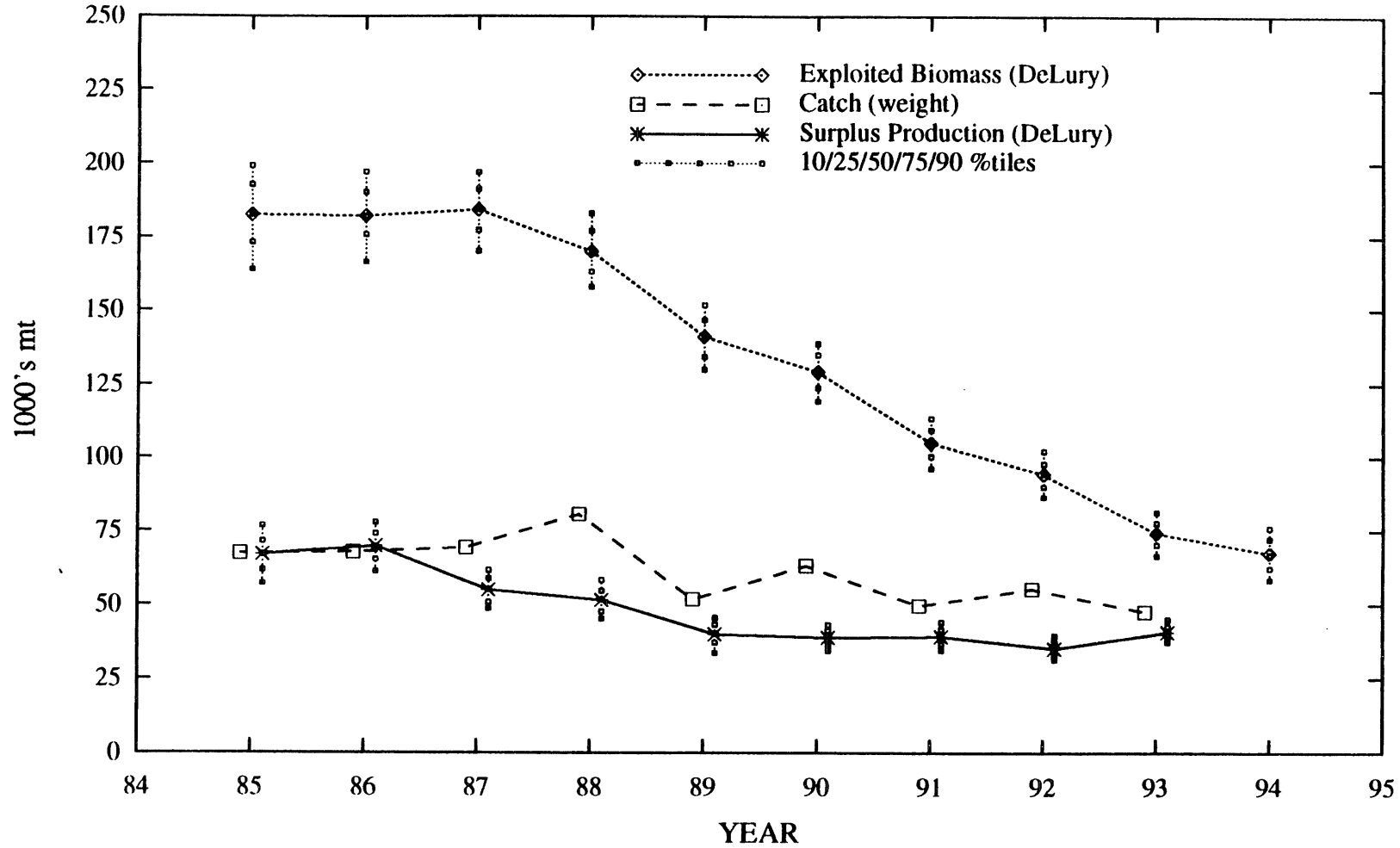
Plot 3.15 DeLury RunNum=609 IRED   t_s=0.2 t_c=0.5 M=0.1 q_hat= 0.4219 s_r= 1.00 pr_bar= 0.50 W_objfcn=1 1 4 Num_reps=200 bao=1

Figure 3.6.6a   Modified DeLury model results - Canadian redfish.
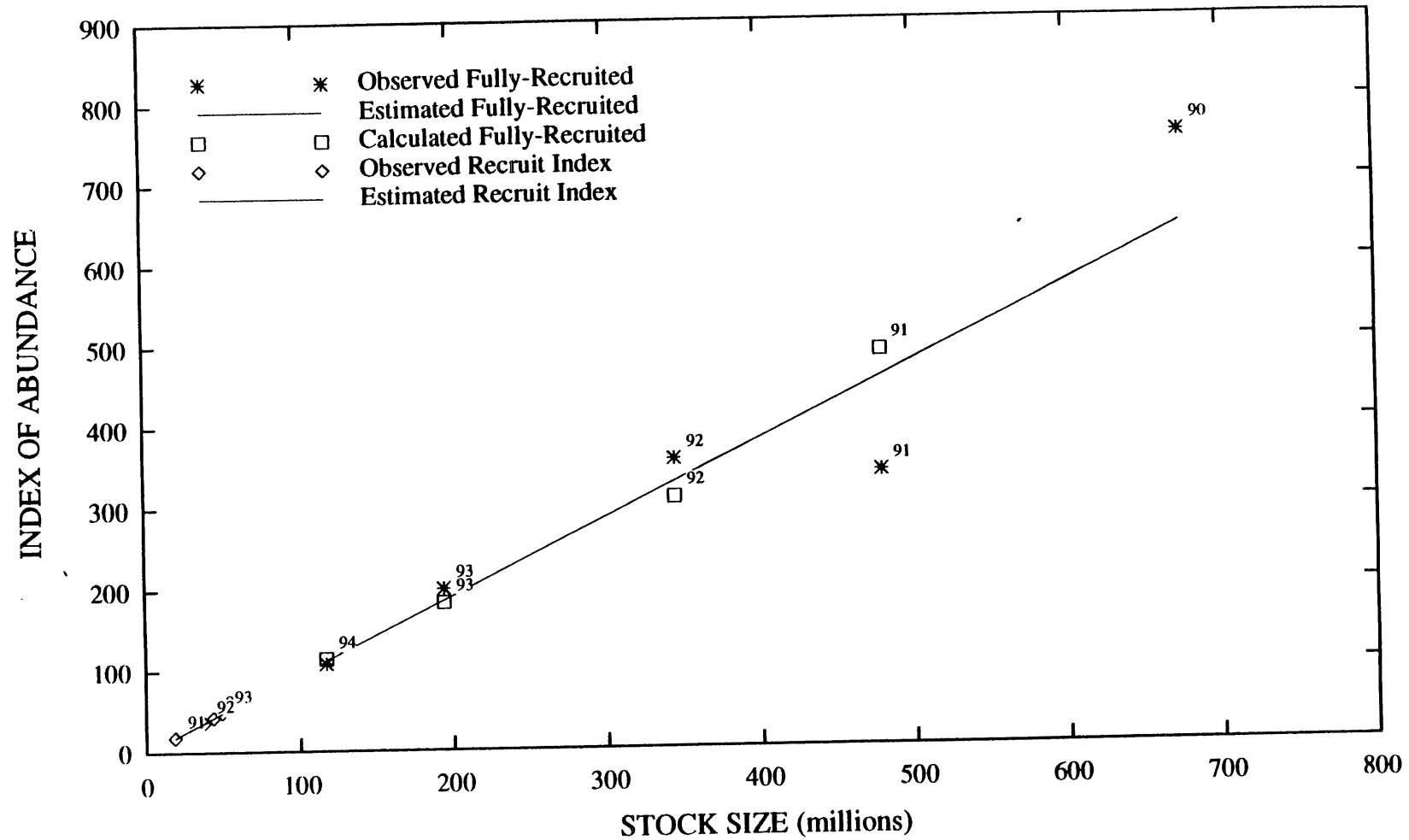
Plot 3.8 DeLury RunNum=604 CRED   t_s=0.5 t_c=0.5 M=0.1 q_hat= 0.9525 s_r= 1.00 pr_bar= 0.50 W_objfcn=1 1 2 Num_reps=200 bao=0

Figure 3.6.6b   Modified DeLury model results - Canadian redfish.
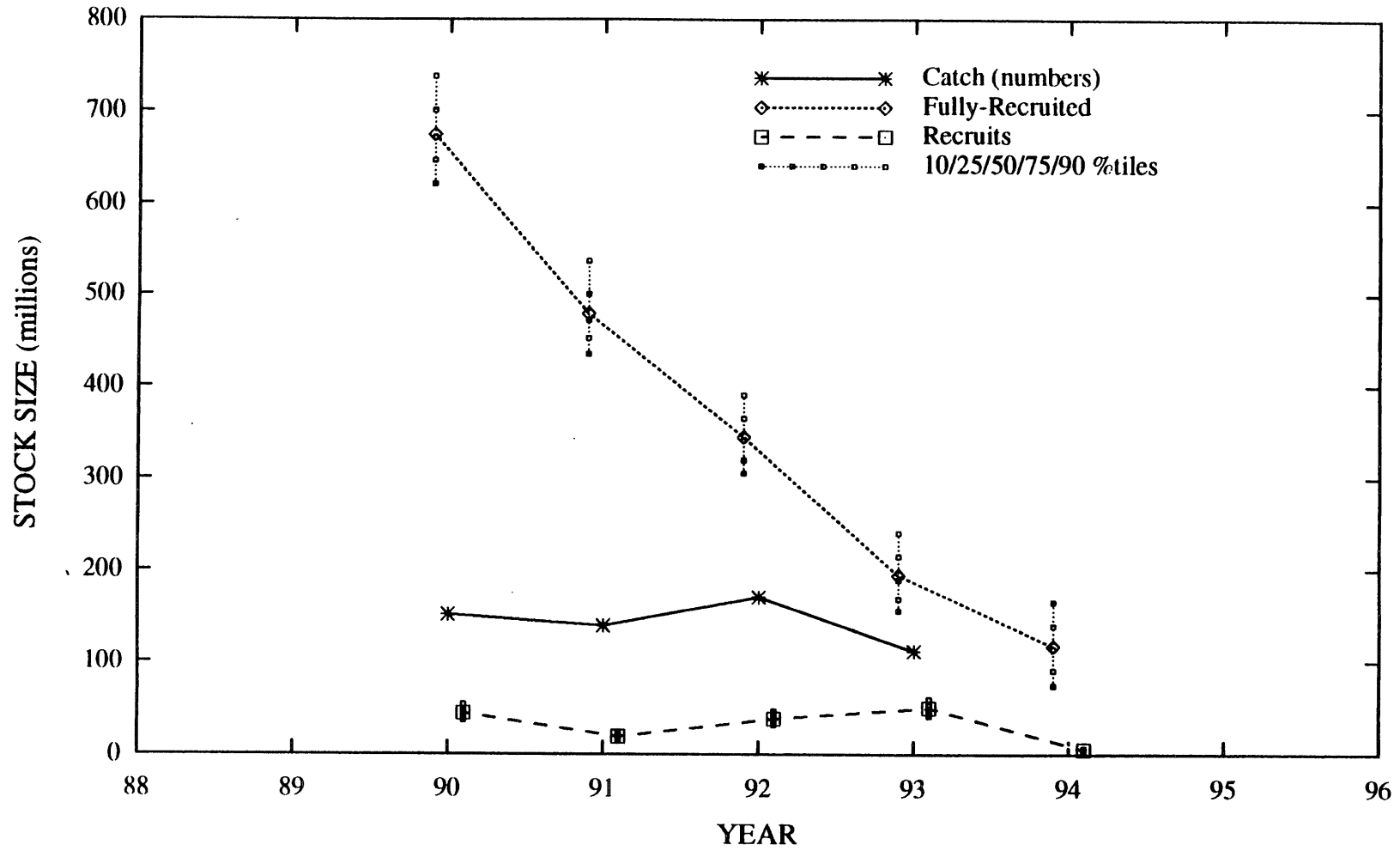
Figure 3.6.6c   Modified DeLury model results - Canadian redfish.
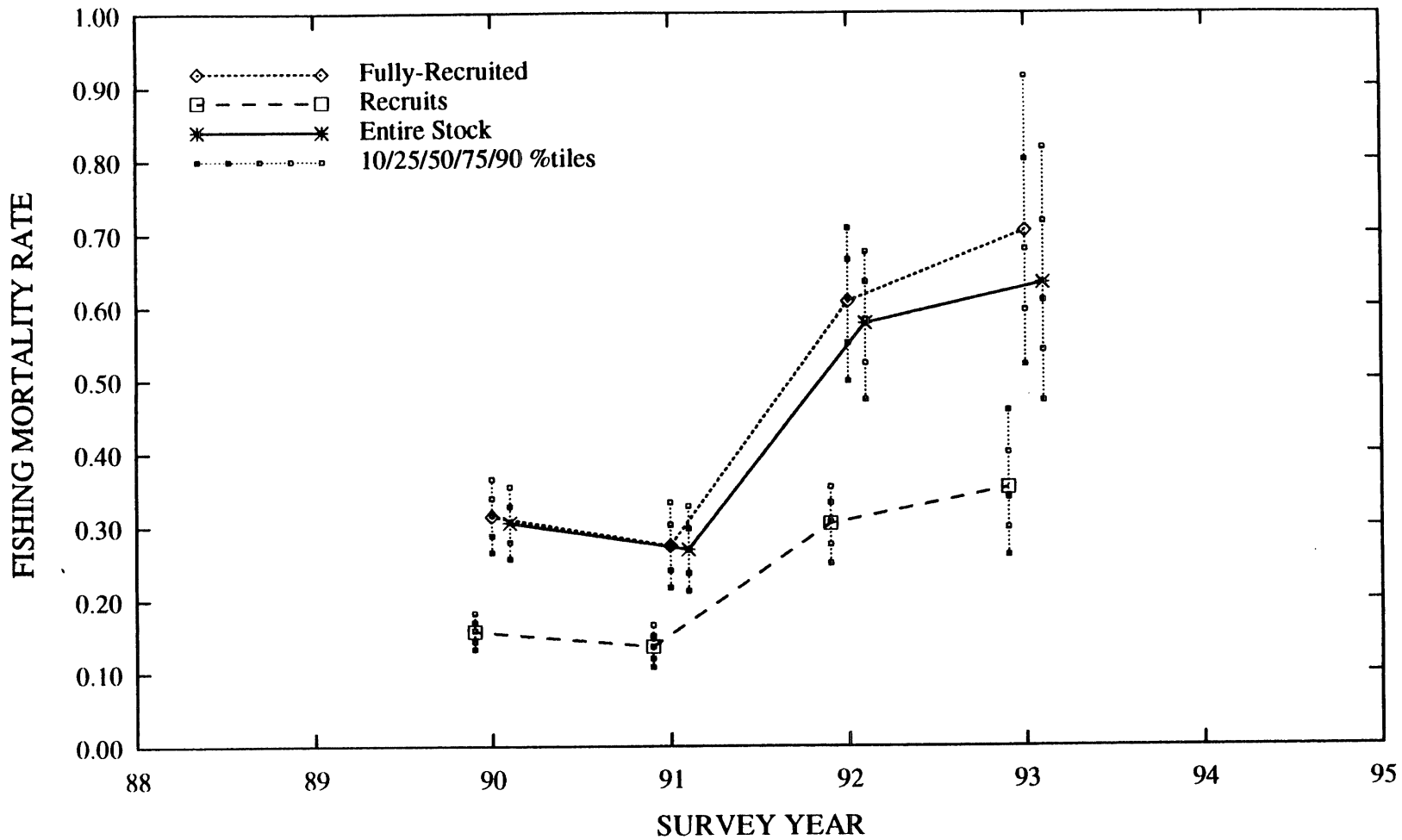
Figure 3.6.6d   Modified DeLury model results - Canadian redfish.
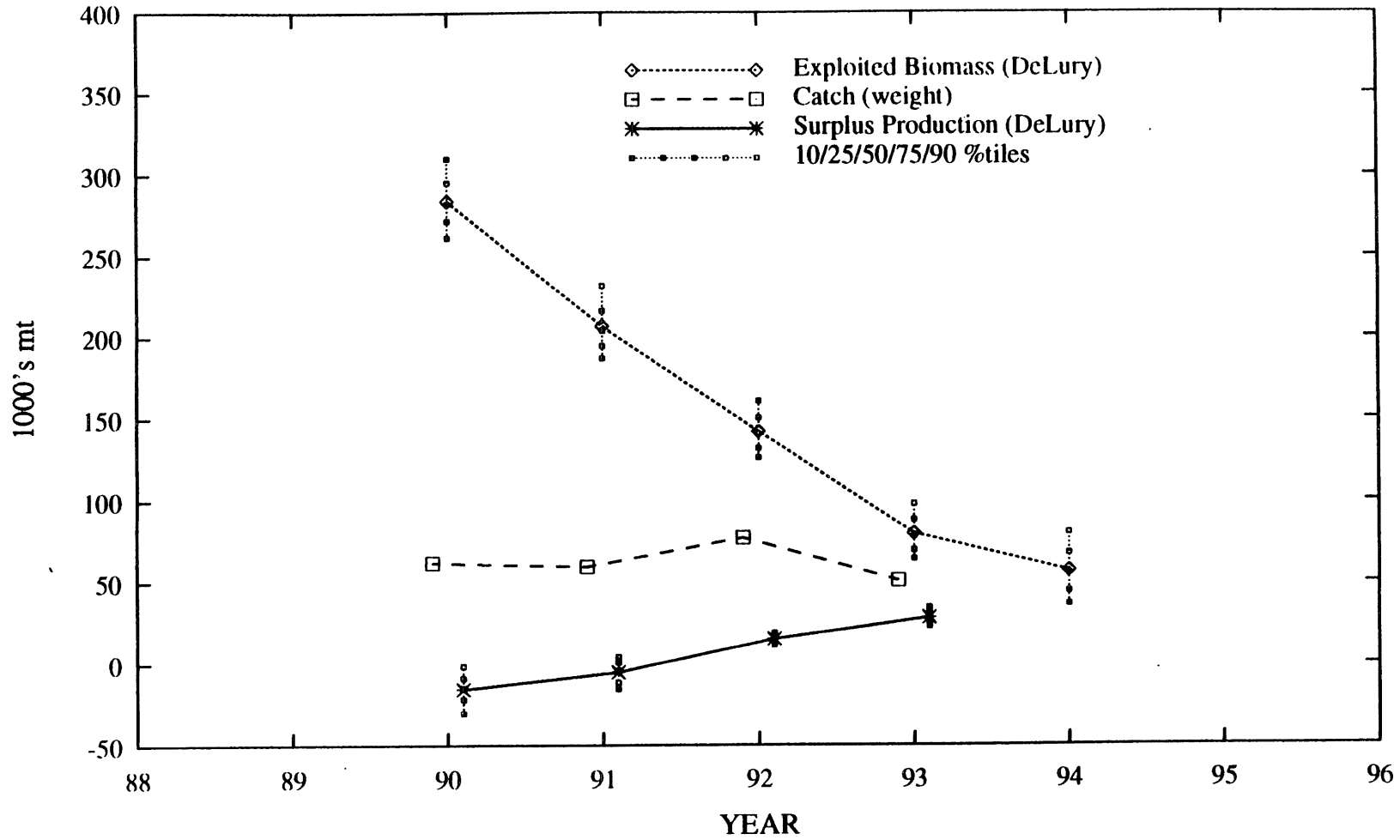
Plot 3.15 DeLury RunNum=604 CRED   t_s=0.5 t_c=0.5 M=0.1 q_hat= 0.9525 s_r= 1.00 pr_bar= 0.50 W_objfcn=1 1 2 Num_reps=200 bao=1

Figure 4.3.1   GOM Cod Slicing and SP-Key residual pattern.
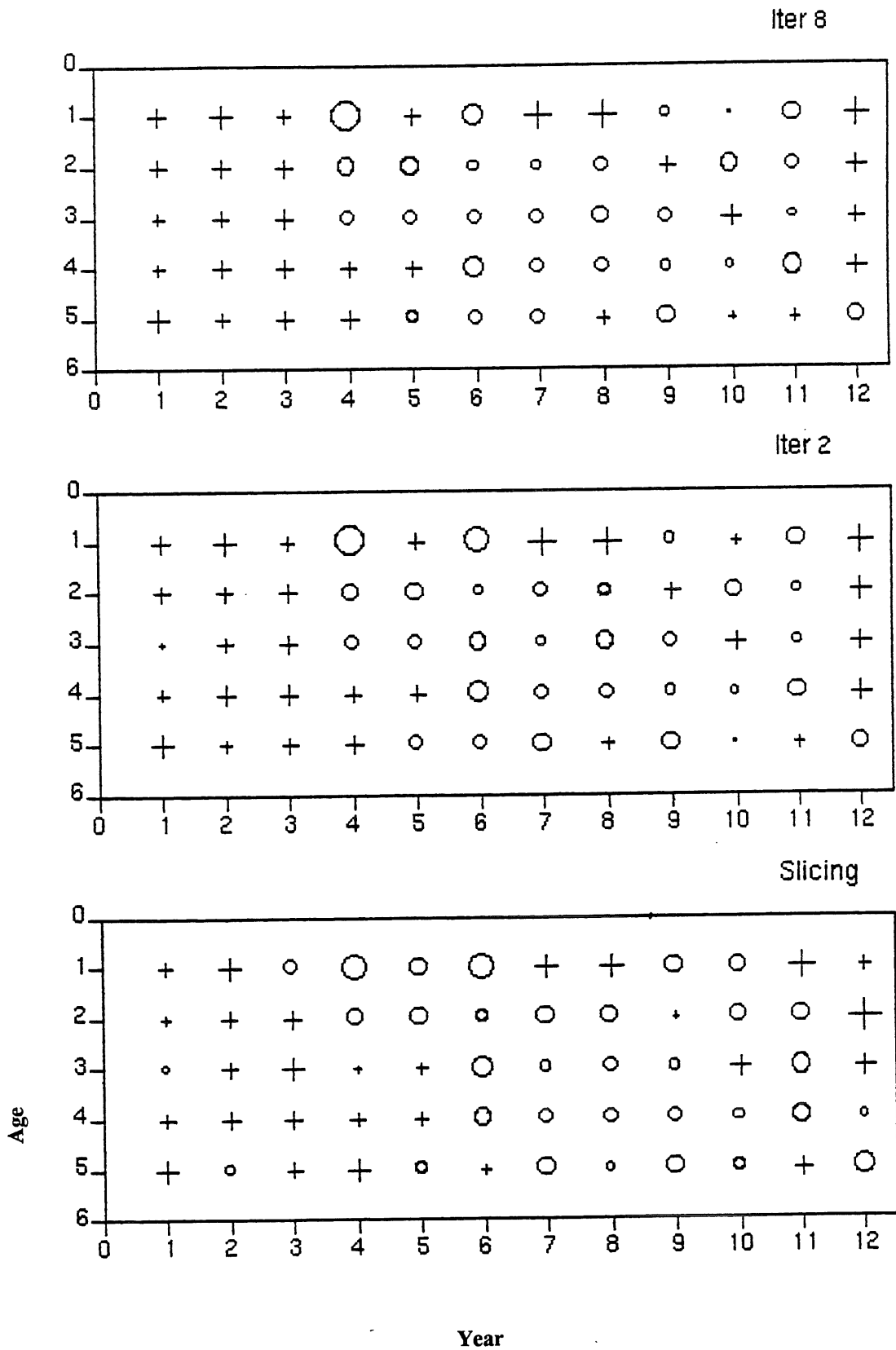
Figure 4.3.2 GOM cod slicing and SP-key estimates of B and F.

Slice, SP-Key and Official biomasss   (exploitable)

Key

Slice

Official

450000

300000

150000

0

81   84   87   90   93

Slice, SP-Key and Official adult F

1.5

Official

1.0

Slice

0.5

Key

0

81   84   87   90   93
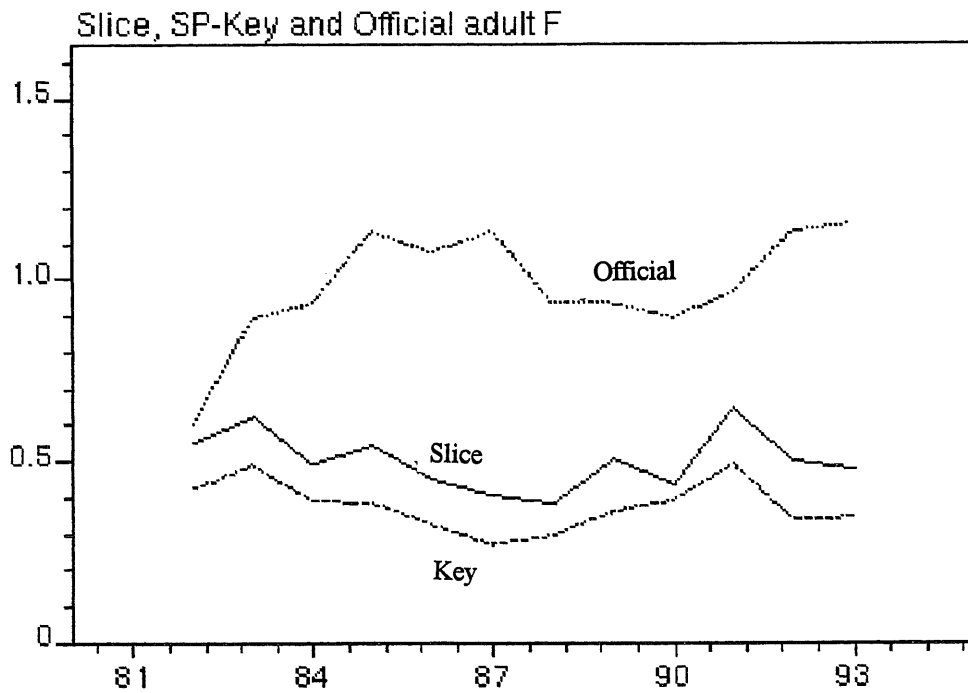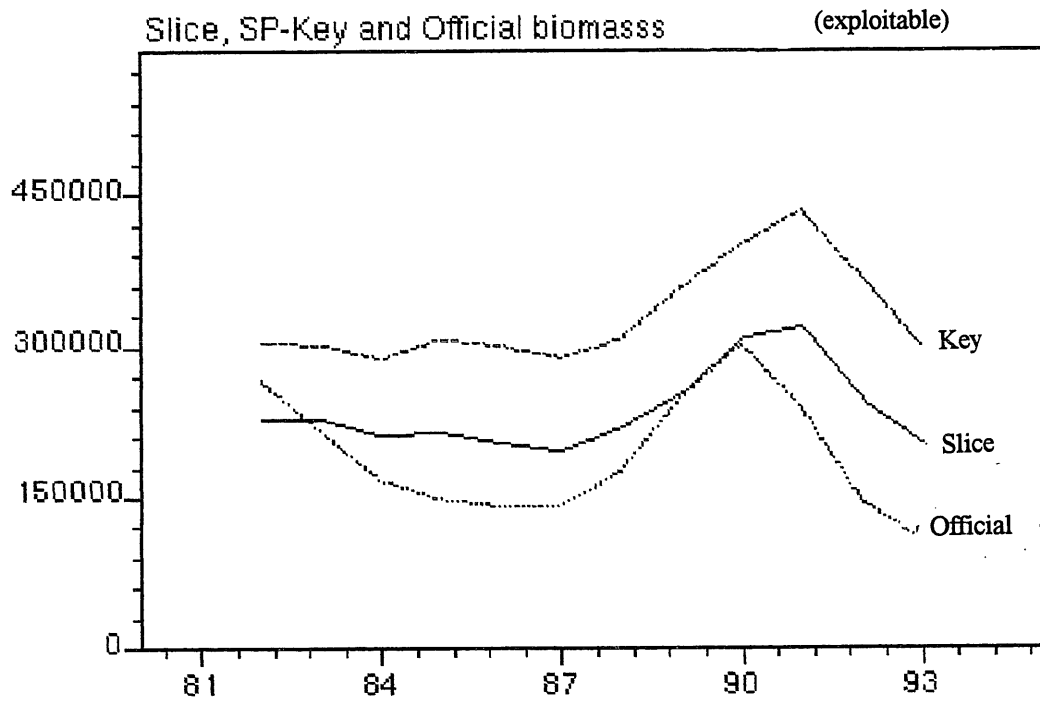
Figure 4.3.3 Iceland haddock Slicing and SP-Key estiamtes

Slice, SP-Key and Official biomass   (exploitable)

Slice, SP-Key and Official adult F
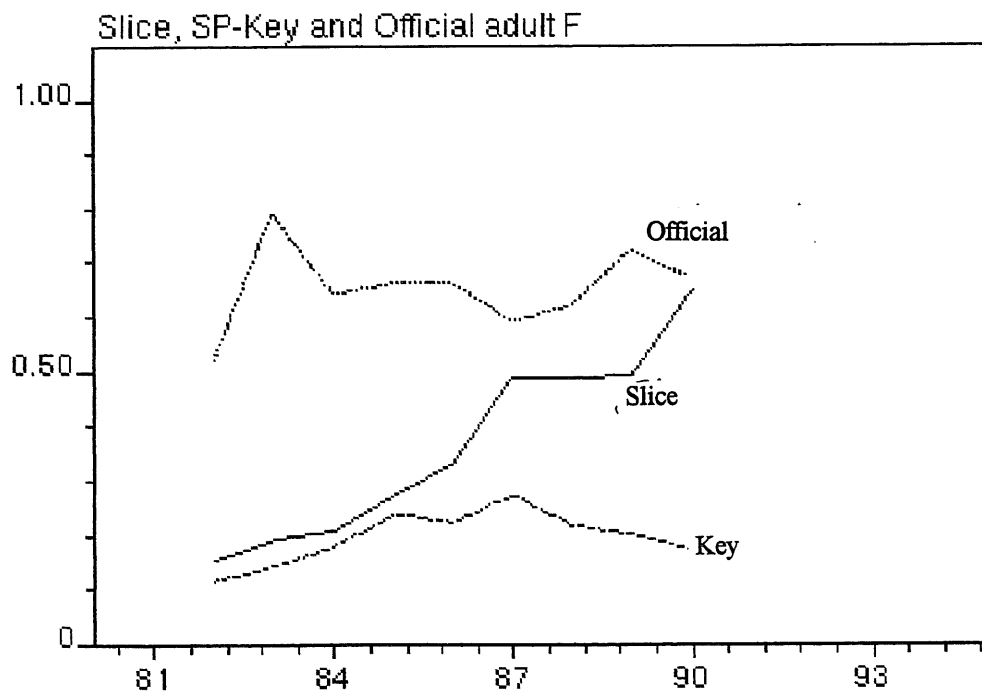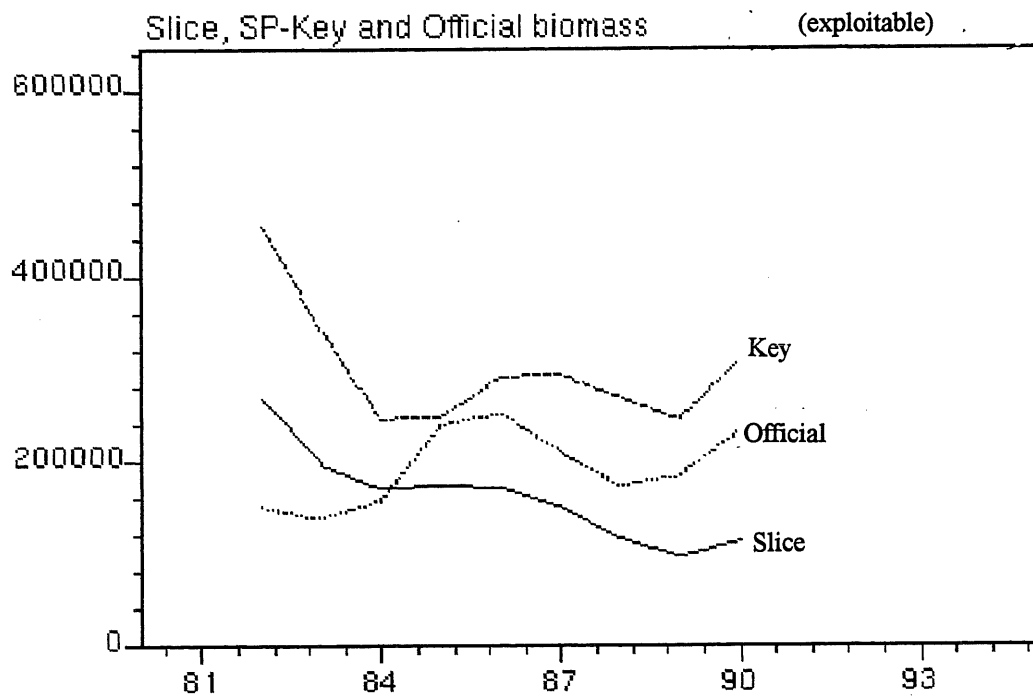
Figure 4.3.4 IHAD slicing and SP-key residuals.

SP-Key

Iter 2

Slicing
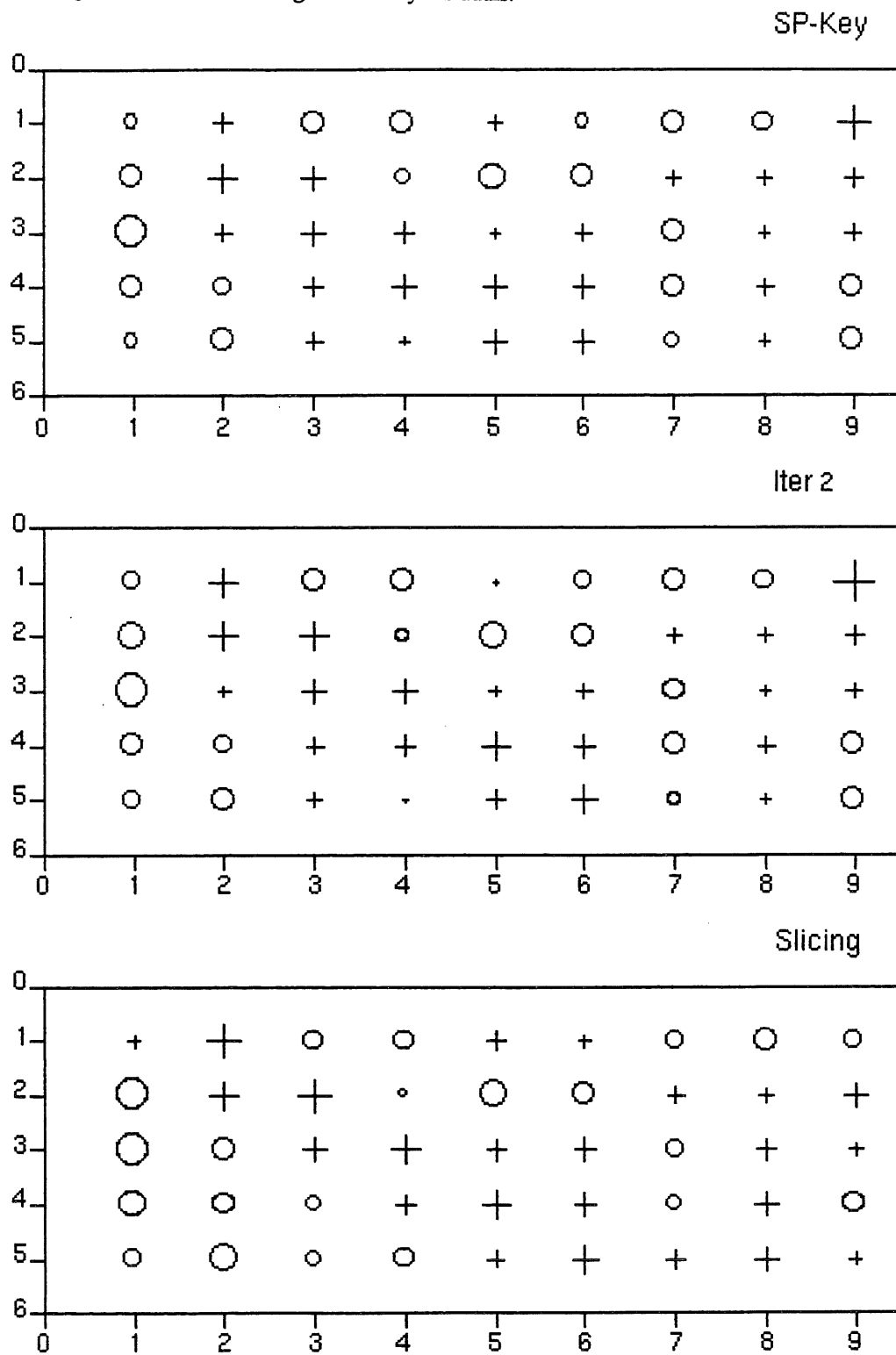
Figure 4.5.1 Time Series Estimates of Catch-at-Length.

Fishing Mortality of Icelandic Haddock

Fishing Mortality for Gulf of Maine Cod

/gg/cl-rep.xls
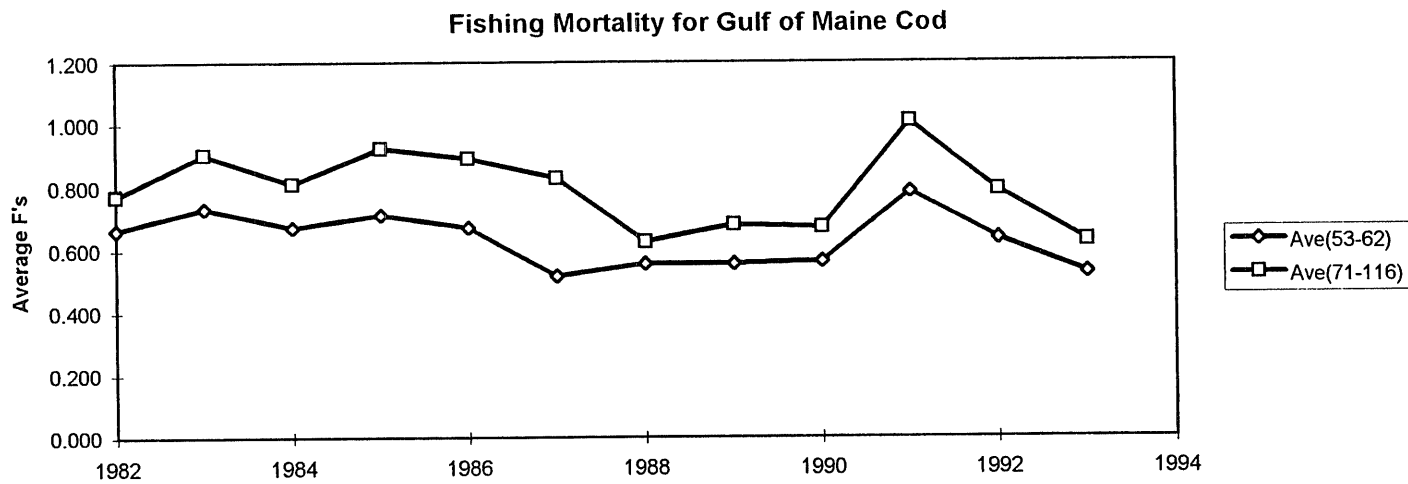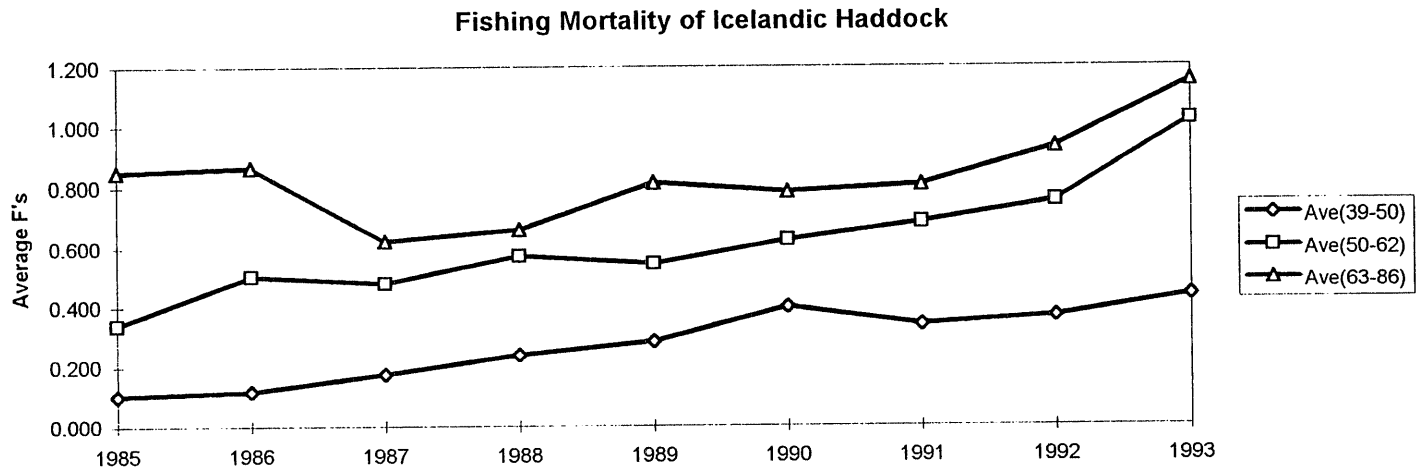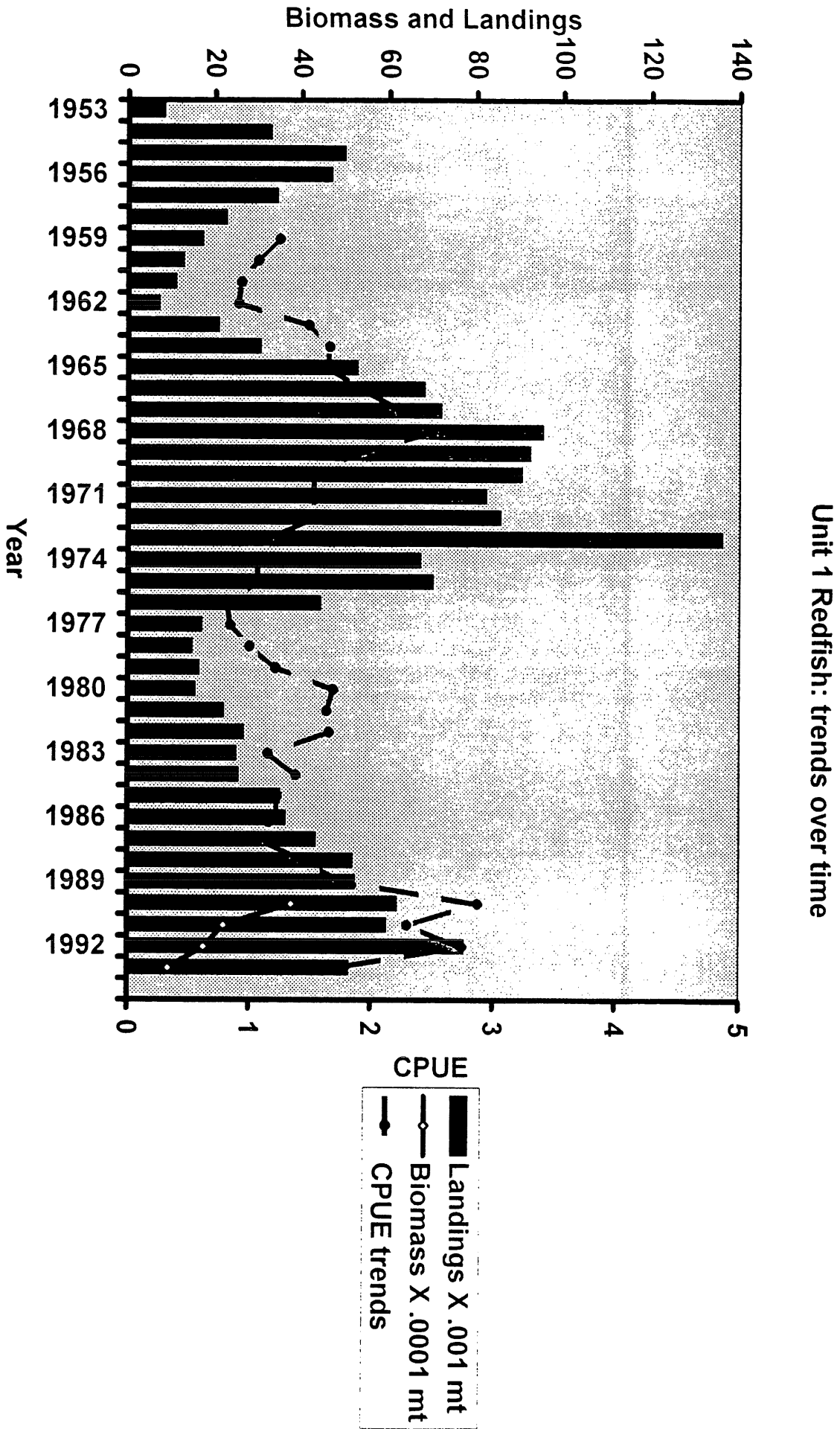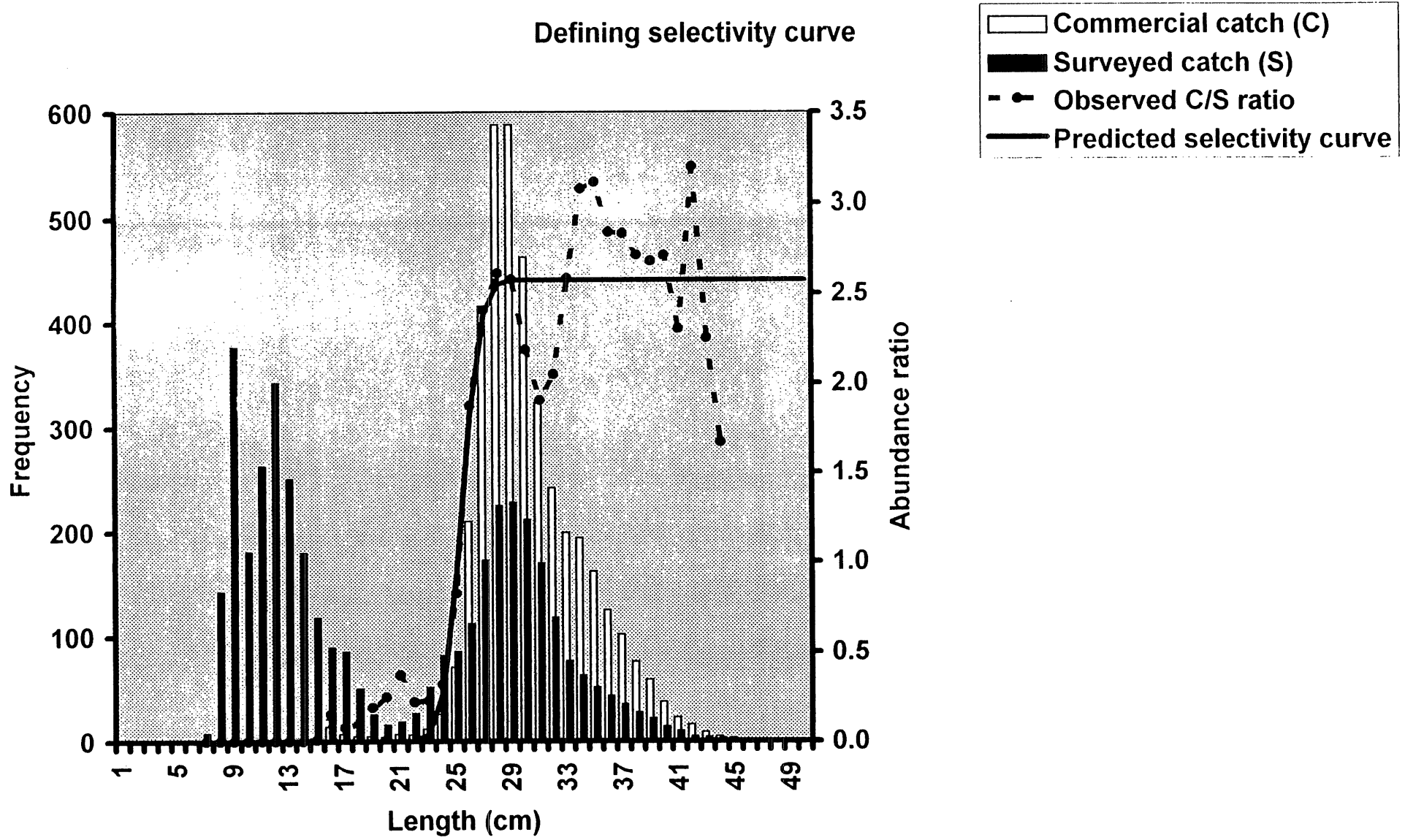
Figure 4.6.1

Figure 4.6.2

Unit 1 Redfish: surveyed frequencies by year and averaged over years 1990-94
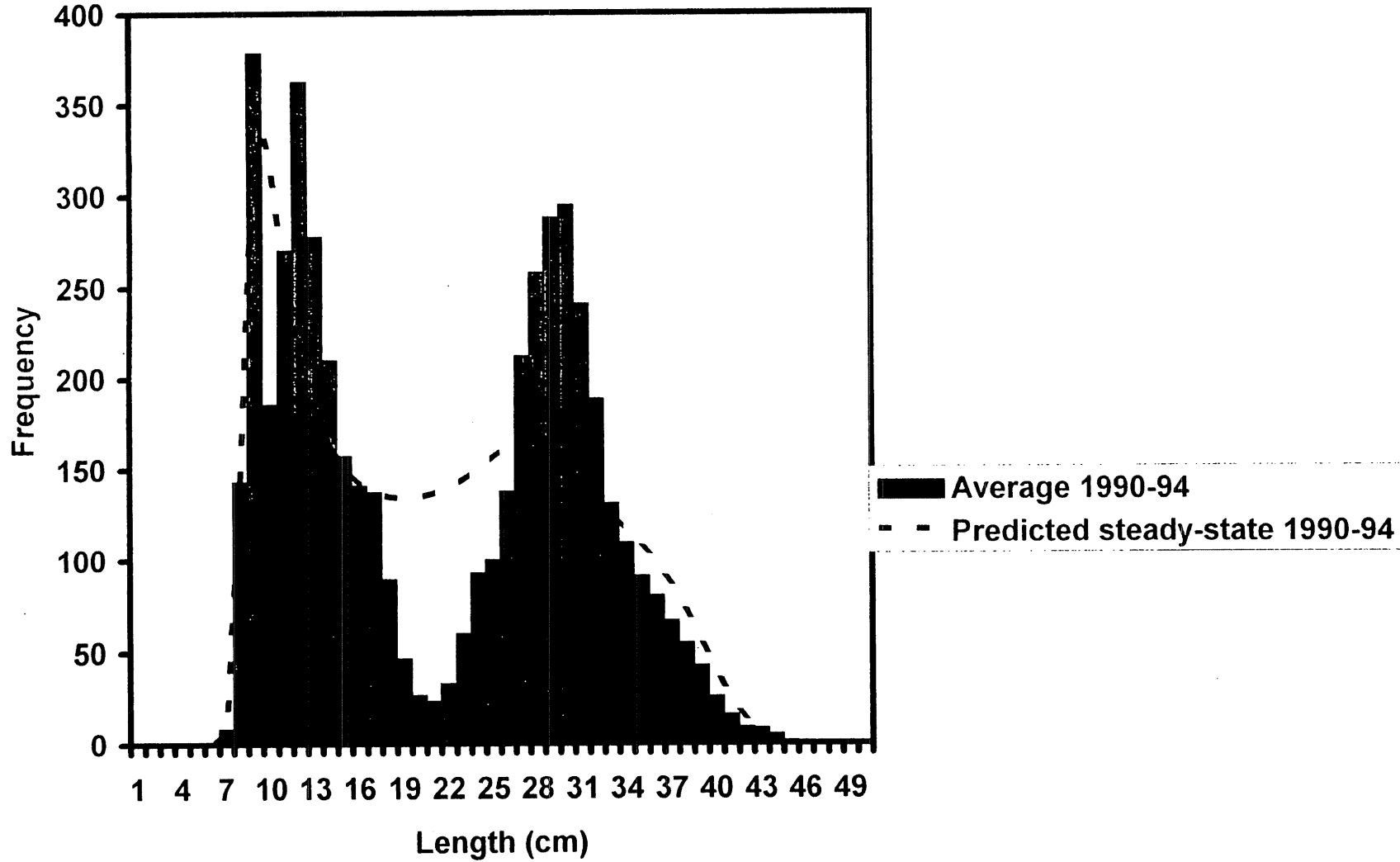
Figure 4.6.3

Figure 4.6.4

Unit 1 Redfish: harvest rate relative to 100% for the 1990-93 average
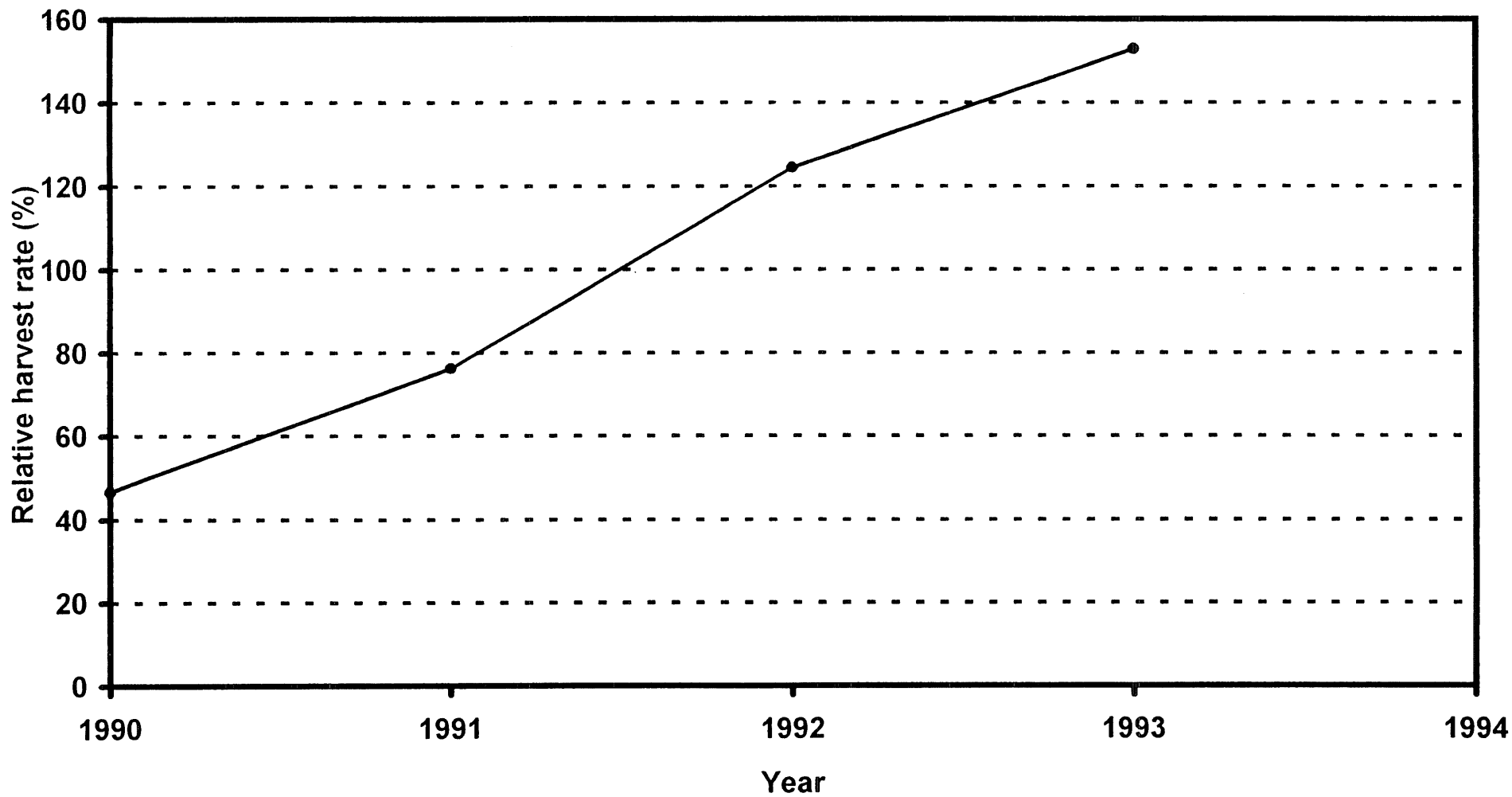
Figure 4.6.5

Unit 1 Redfish: observed and predicted length frequencies for 1990
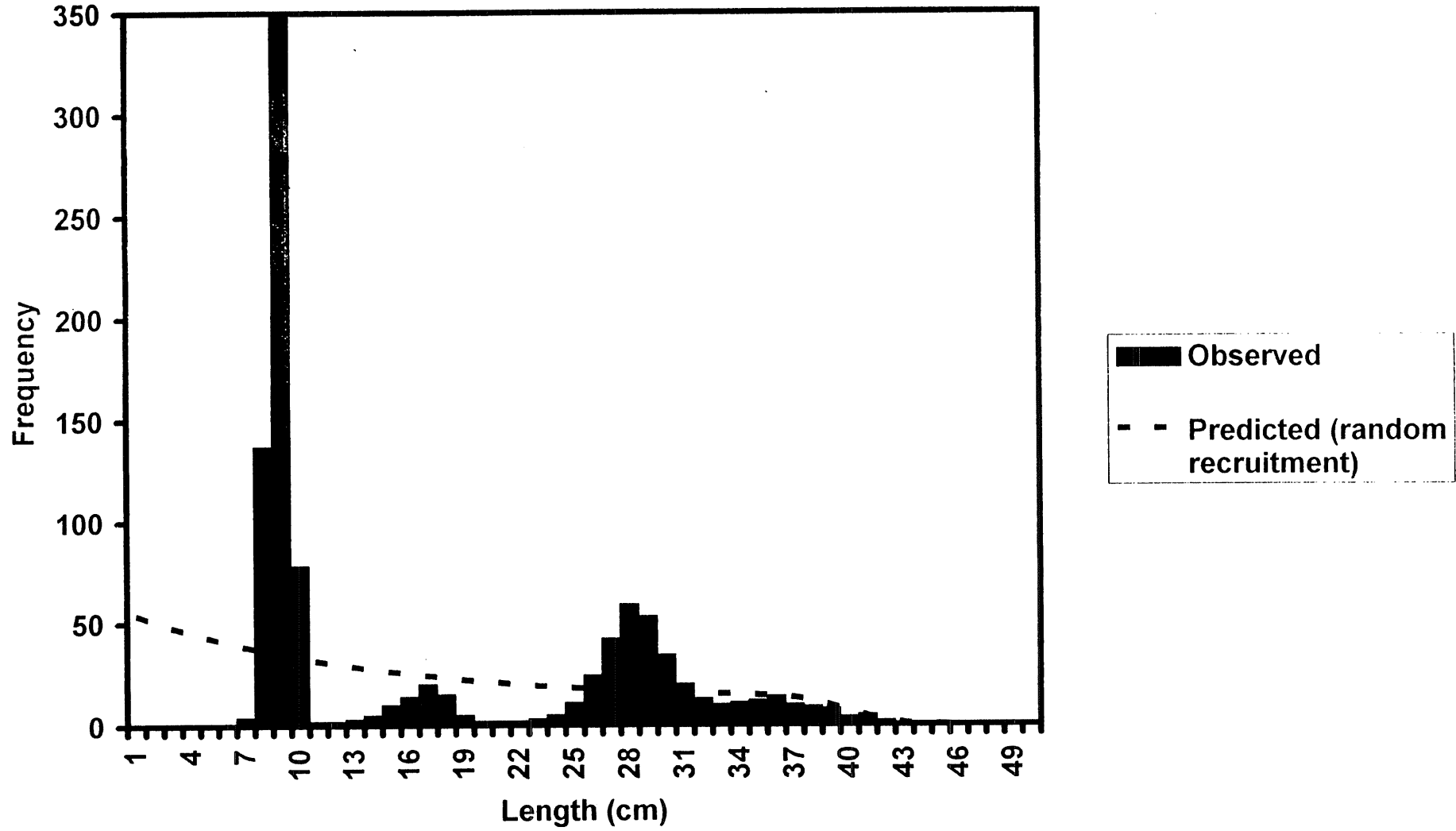
Figure 4.6.6a

Unit 1 Redfish: observed and predicted length frequencies for 1991
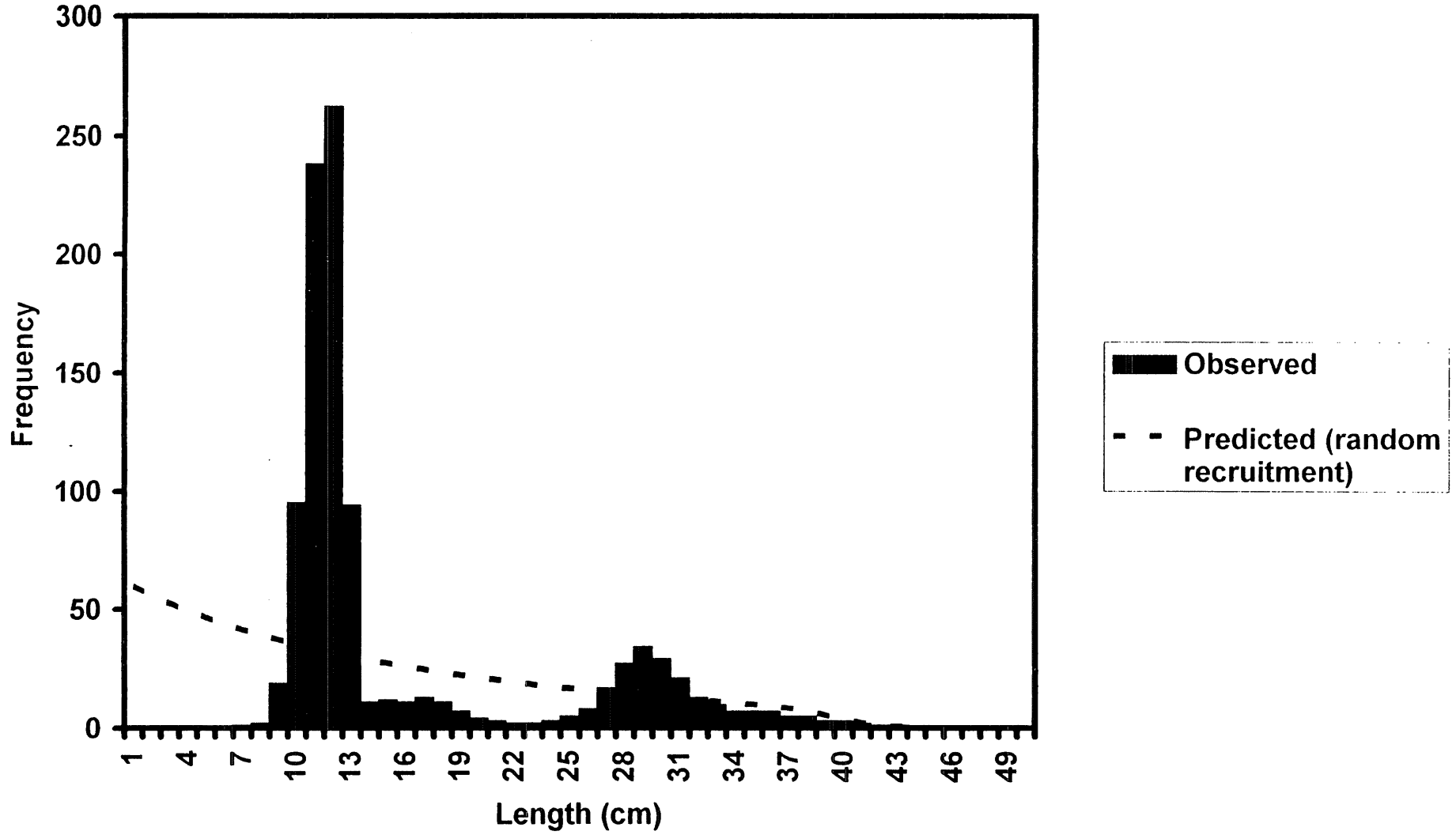
Figure 4.6.6b

Unit 1 Redfish: observed and predicted length frequencies for 1992
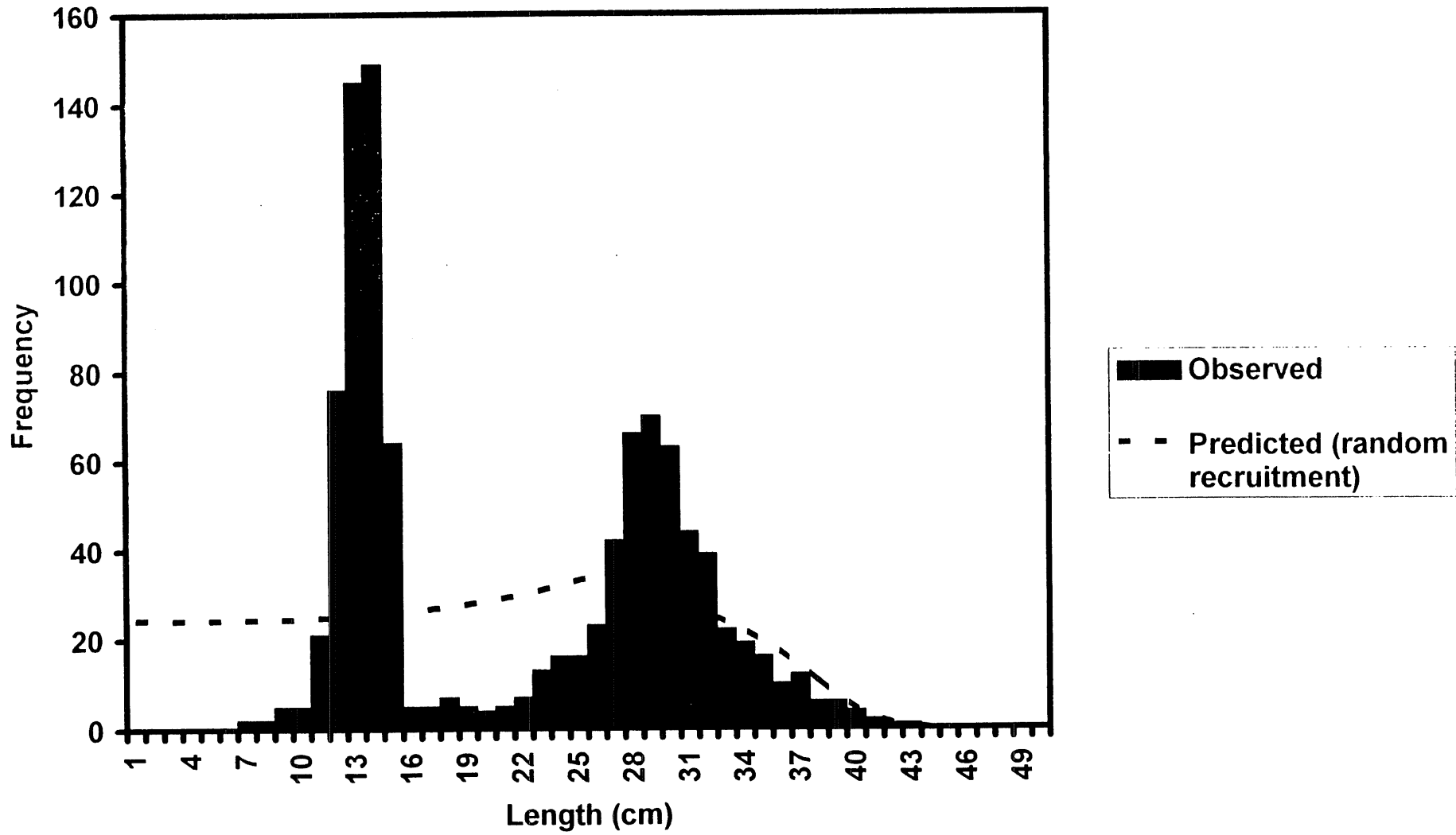
Figure 4.6.6c

Unit 1 Redfish: observed and predicted length frequencies for 1993
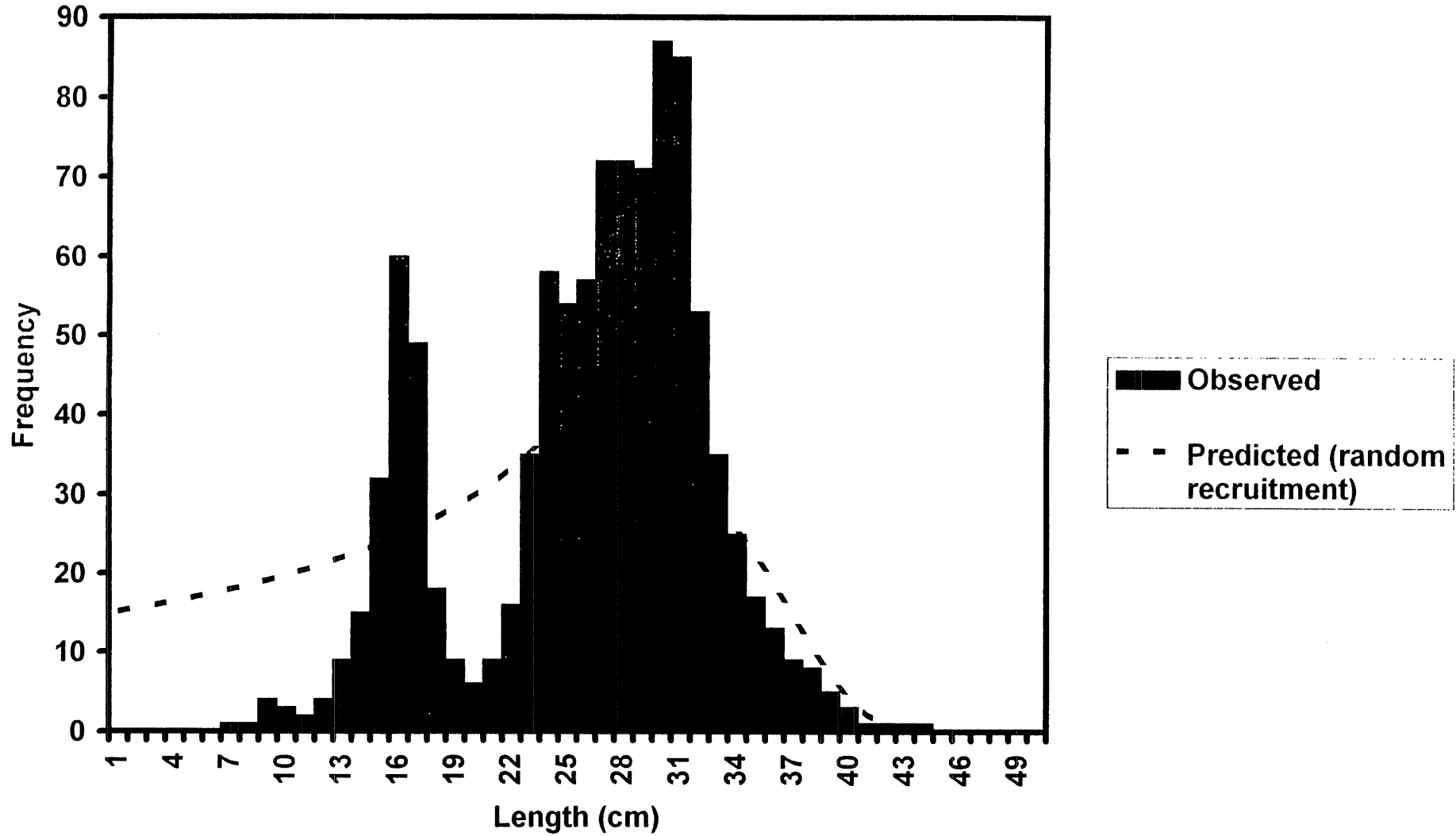
Figure 4.6.6d

Unit 1 Redfish: observed and predicted length frequencies for 1994
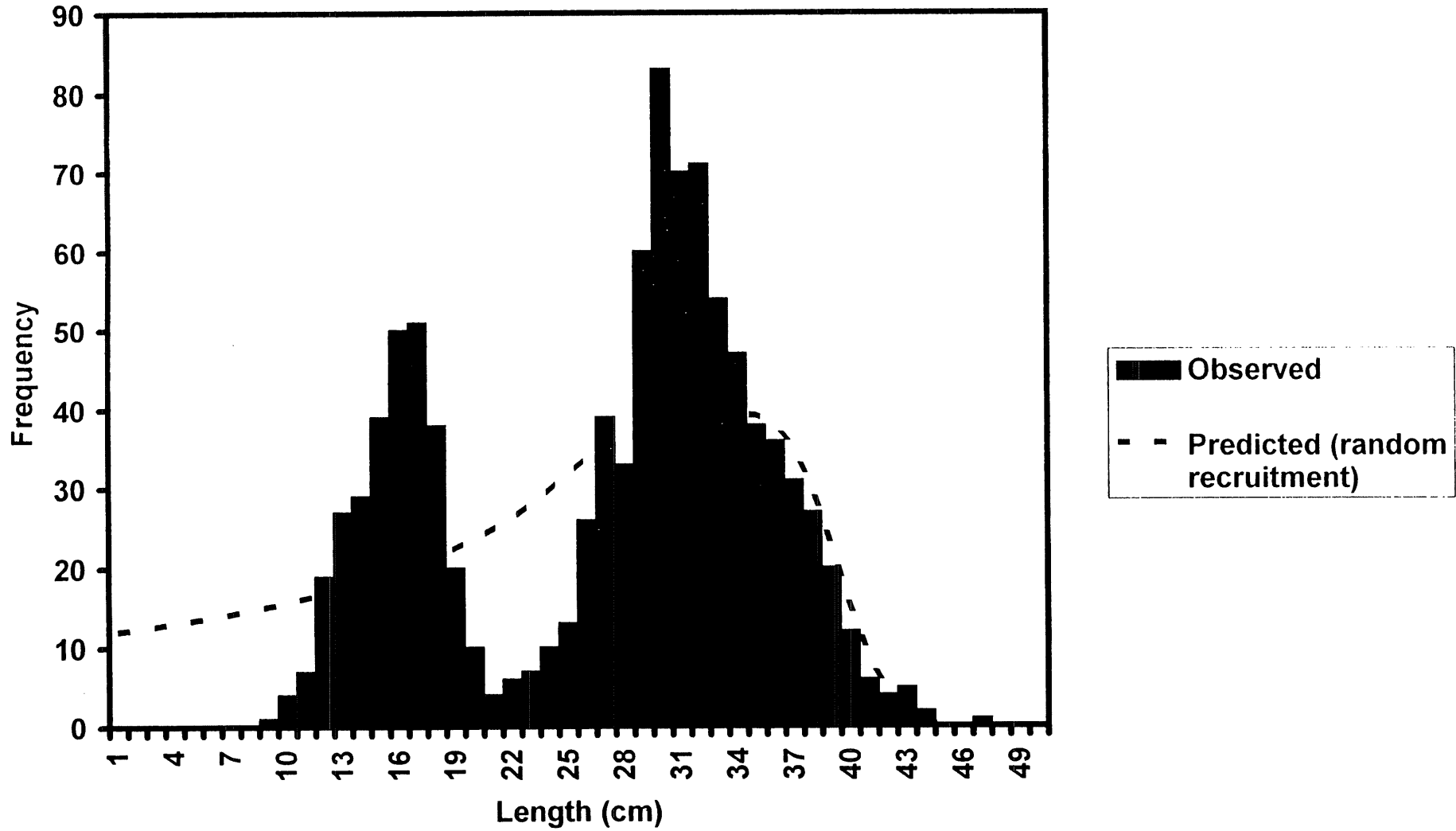
Figure 4.6.6e

Fig. 5.2.1.North Sea Haddock. Stock trends estimated from surveys and VPA
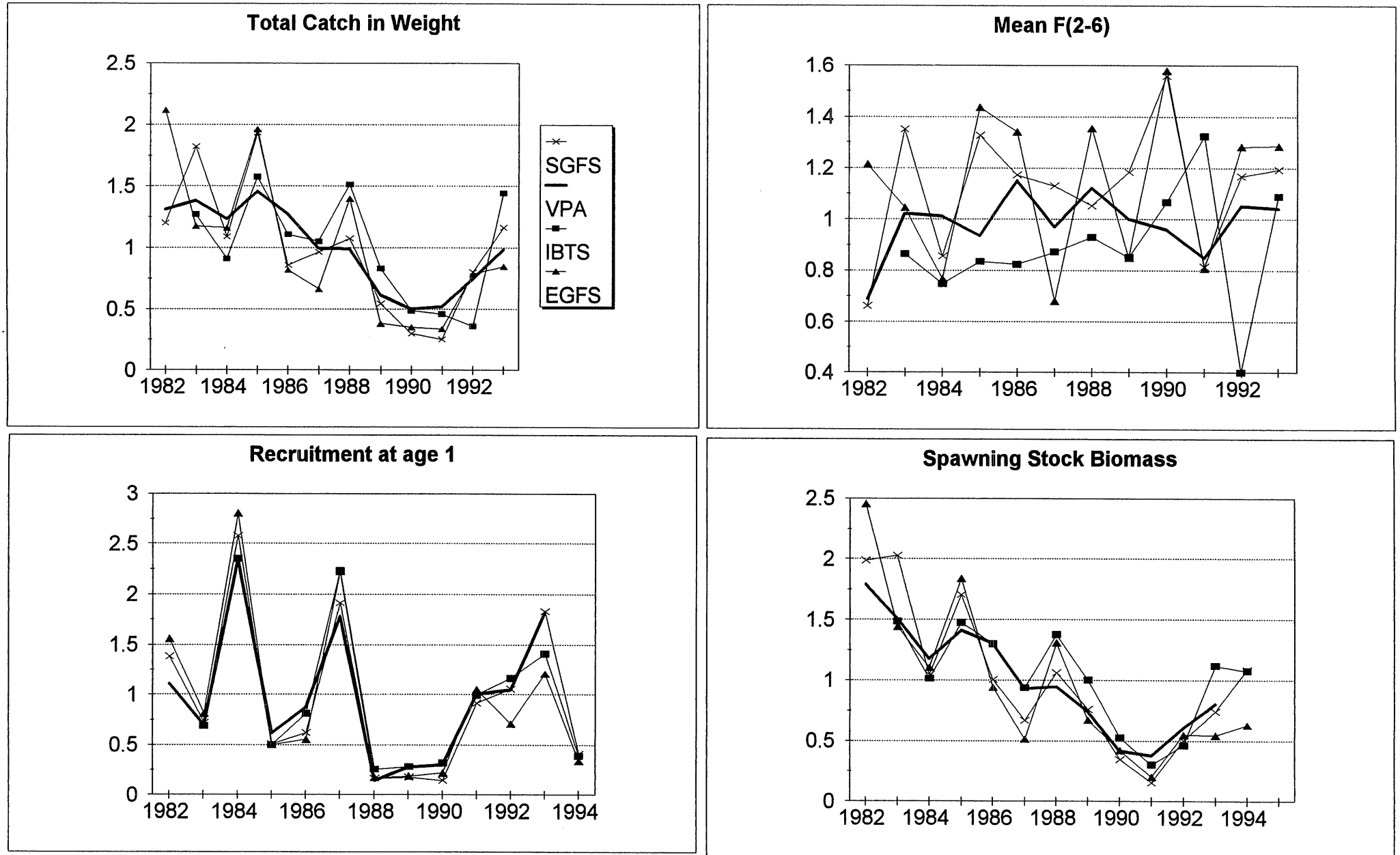
Fig. 5.2.2.North Sea Haddock. Stock trends estimated from surveys and VPA. Multiple survey model.

Total Catch in Weight

Legend:
- --×-- Smoothe 1
- ▬ VPA
- ·········· Smoothe 2
- △ Smoothe 3

Mean F(2-6)

Recruitment at age 1

Spawning Stock Biomass
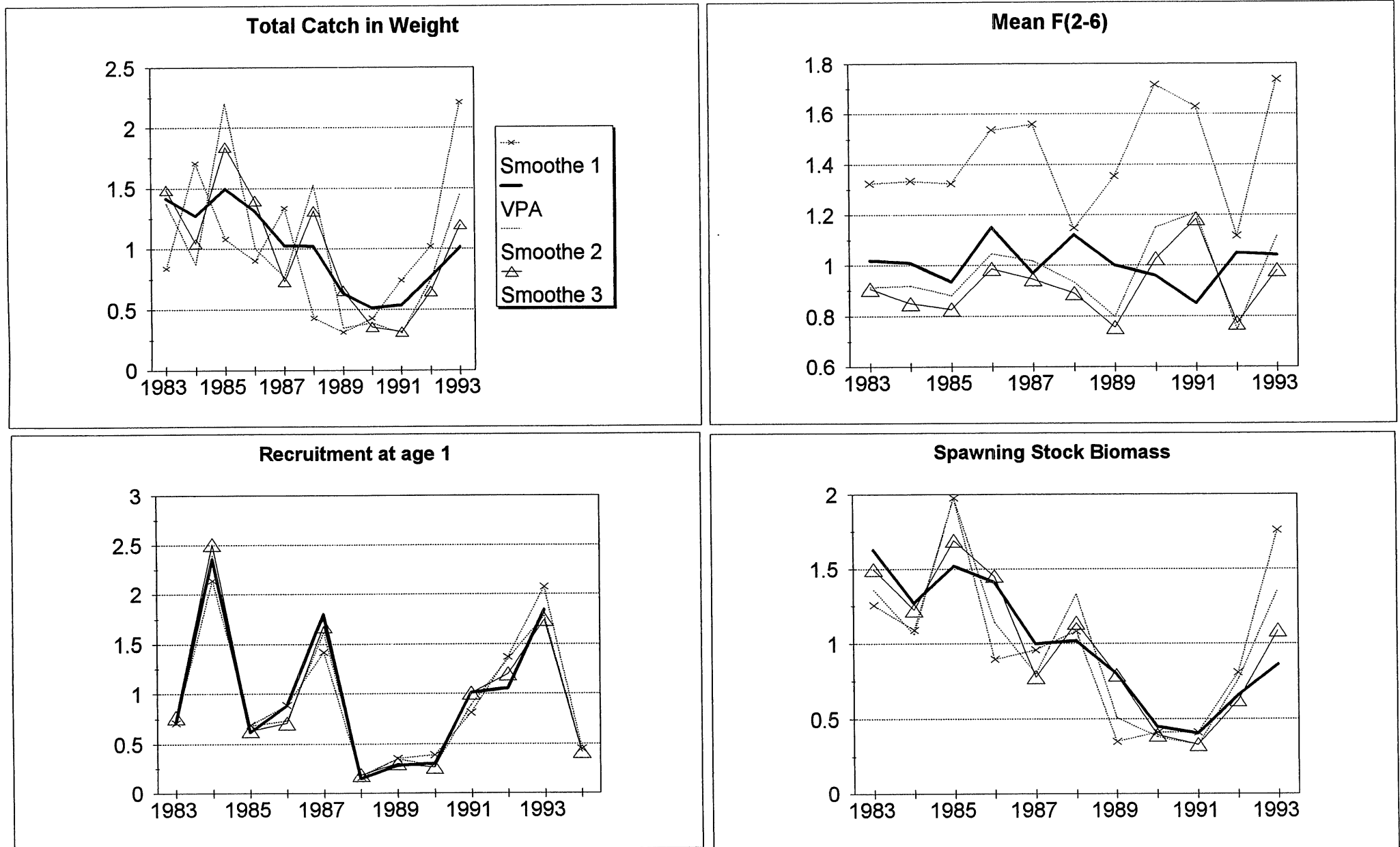
5.2.3. Gulf of Maine cod. Stock trends estimated from surveys and VPA
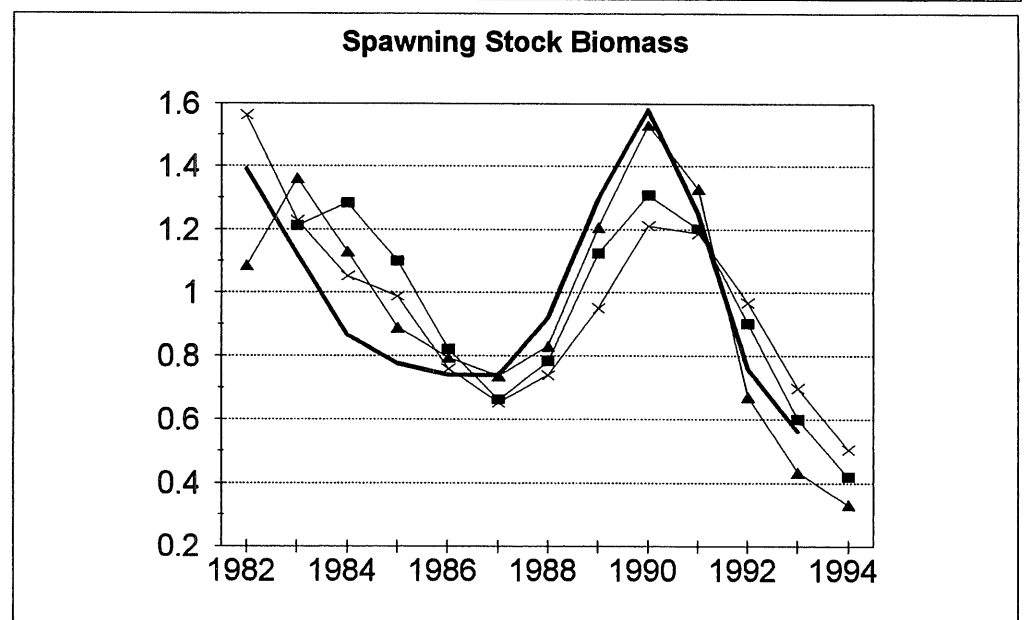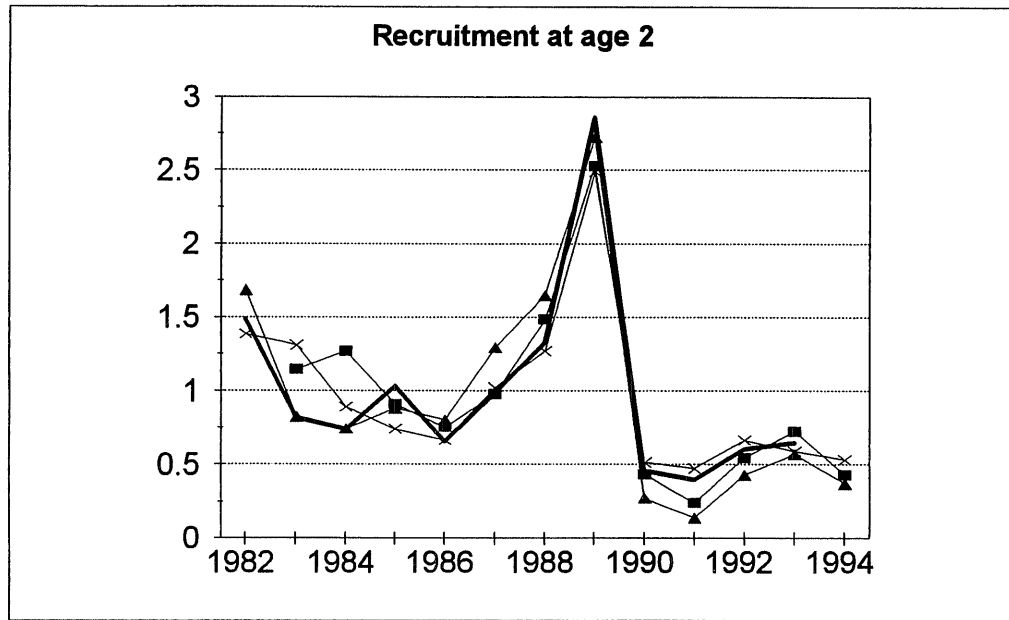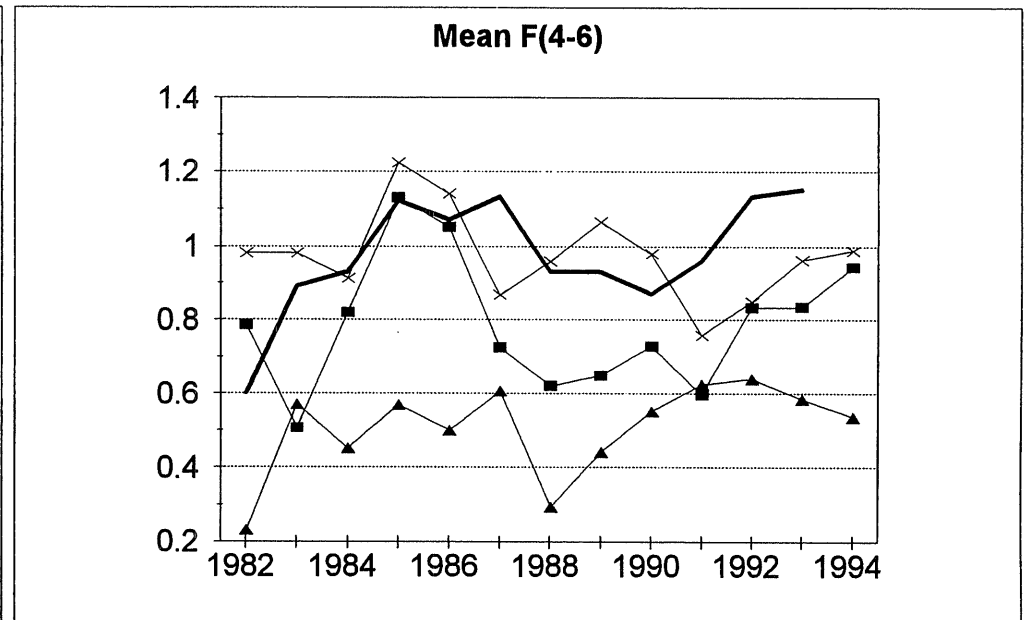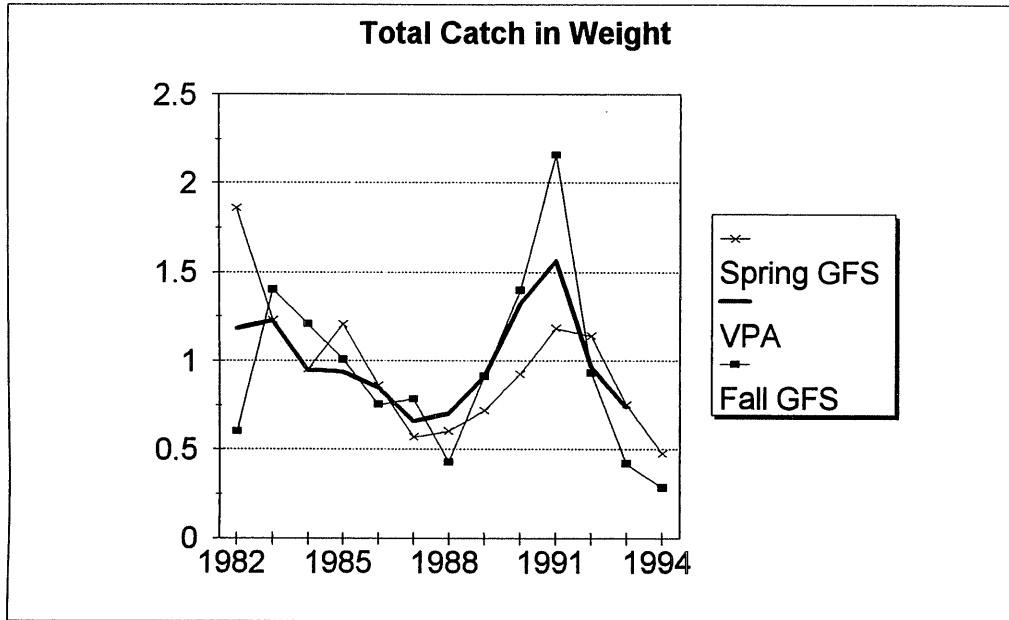
Fig. 5.2.4. Gulf of Maine Cod. Stock trends estimated from surveys and VPA. Multiple survey model.
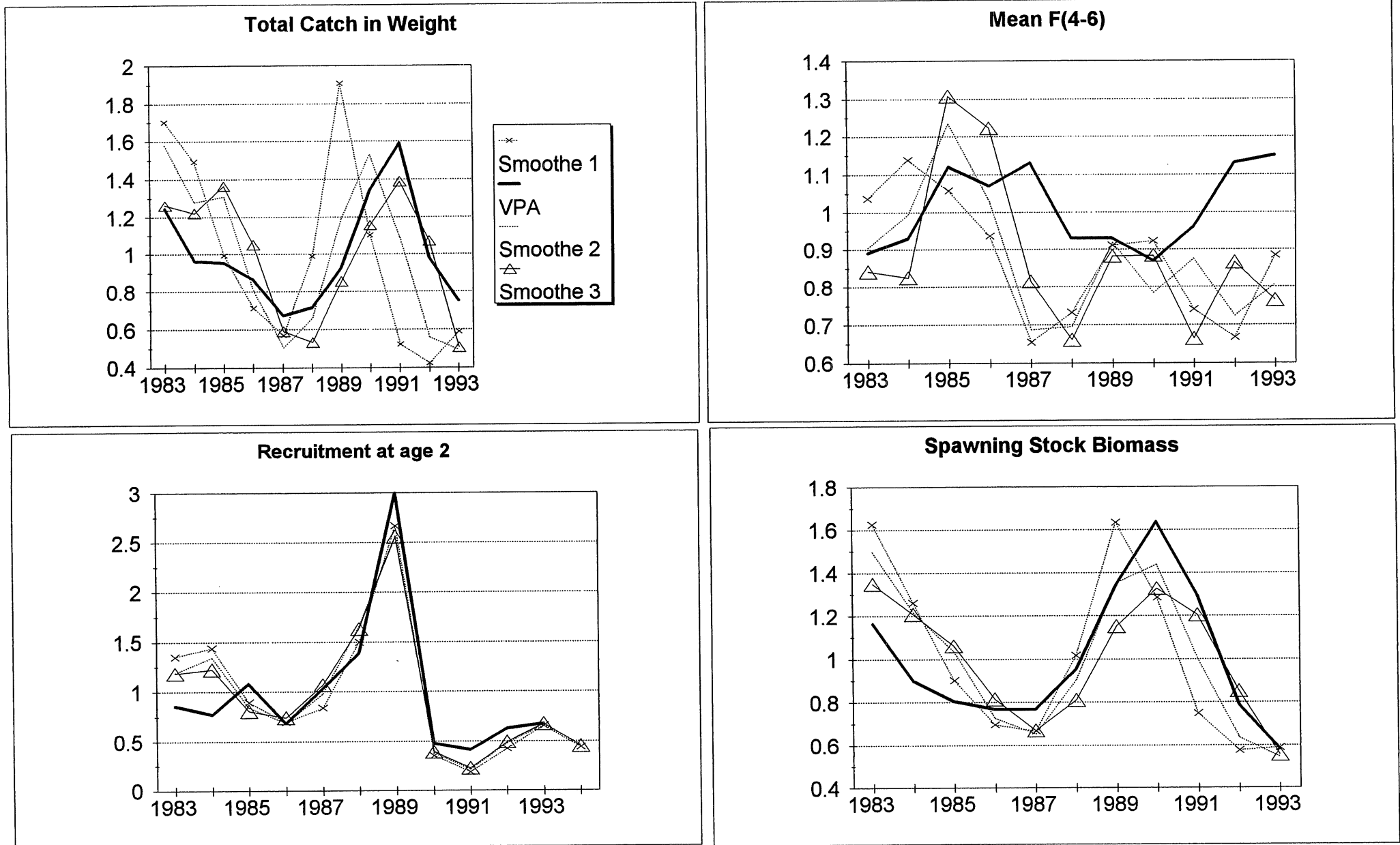
Fig. 5.2.5. Southern Gulf of St Lawrence cod. Stock trends estimated from survey and VPA.
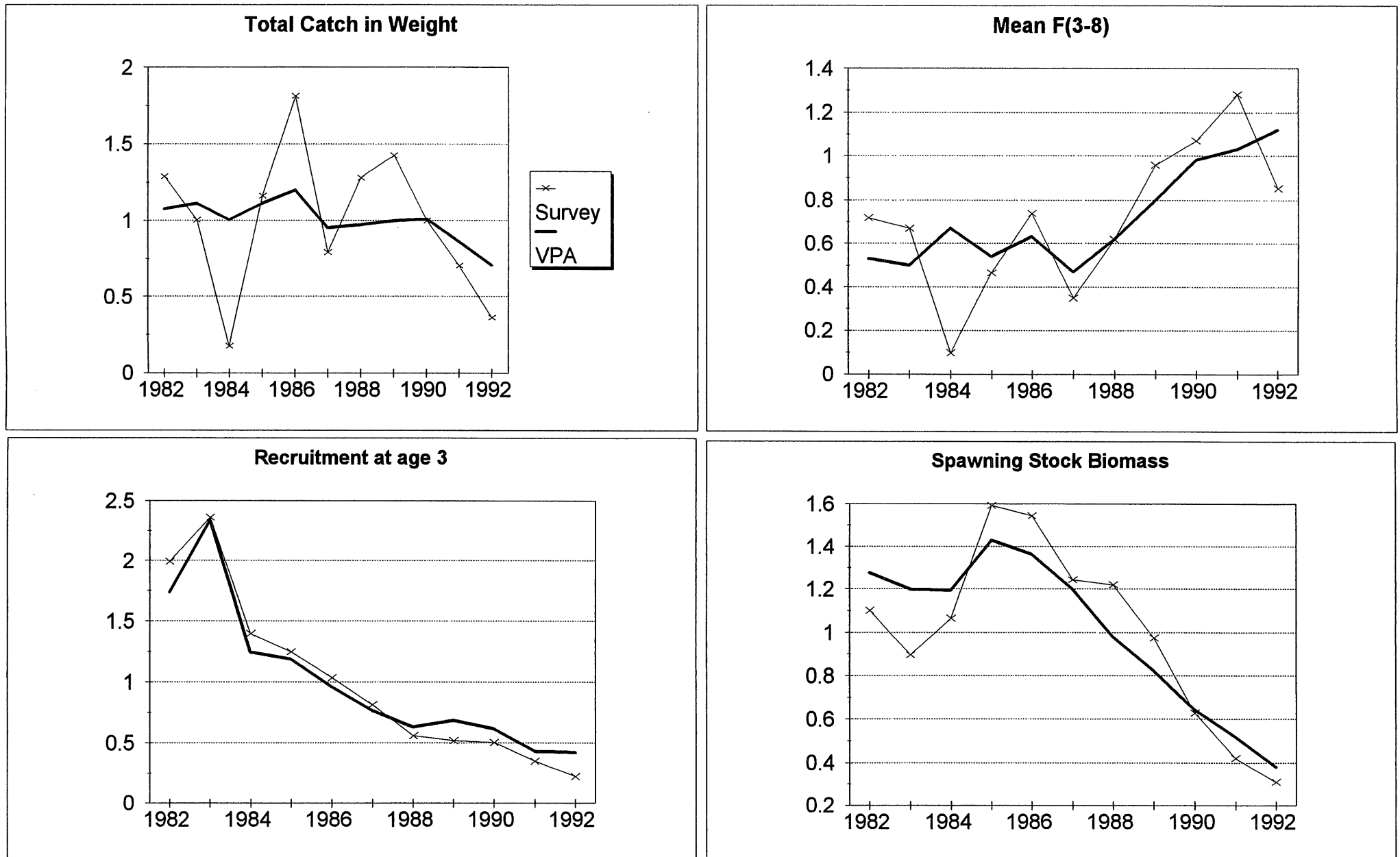
Fig. 5.2.6. Icelandic haddock. Stock trends estimated from surveys and VPA.
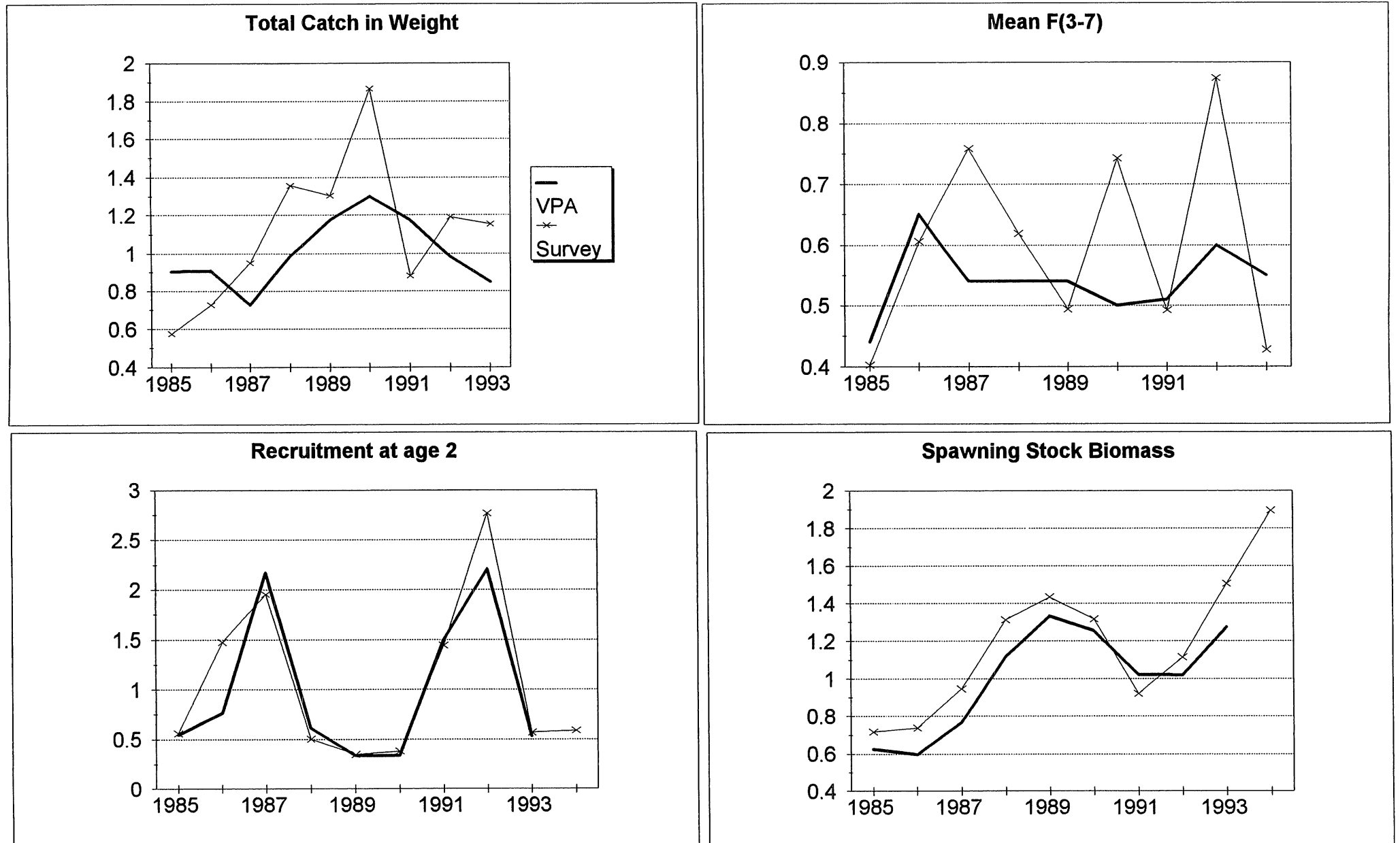
Fig. 5.2.7. Icelandic cod. Stock trends estimated from surveys and VPA.
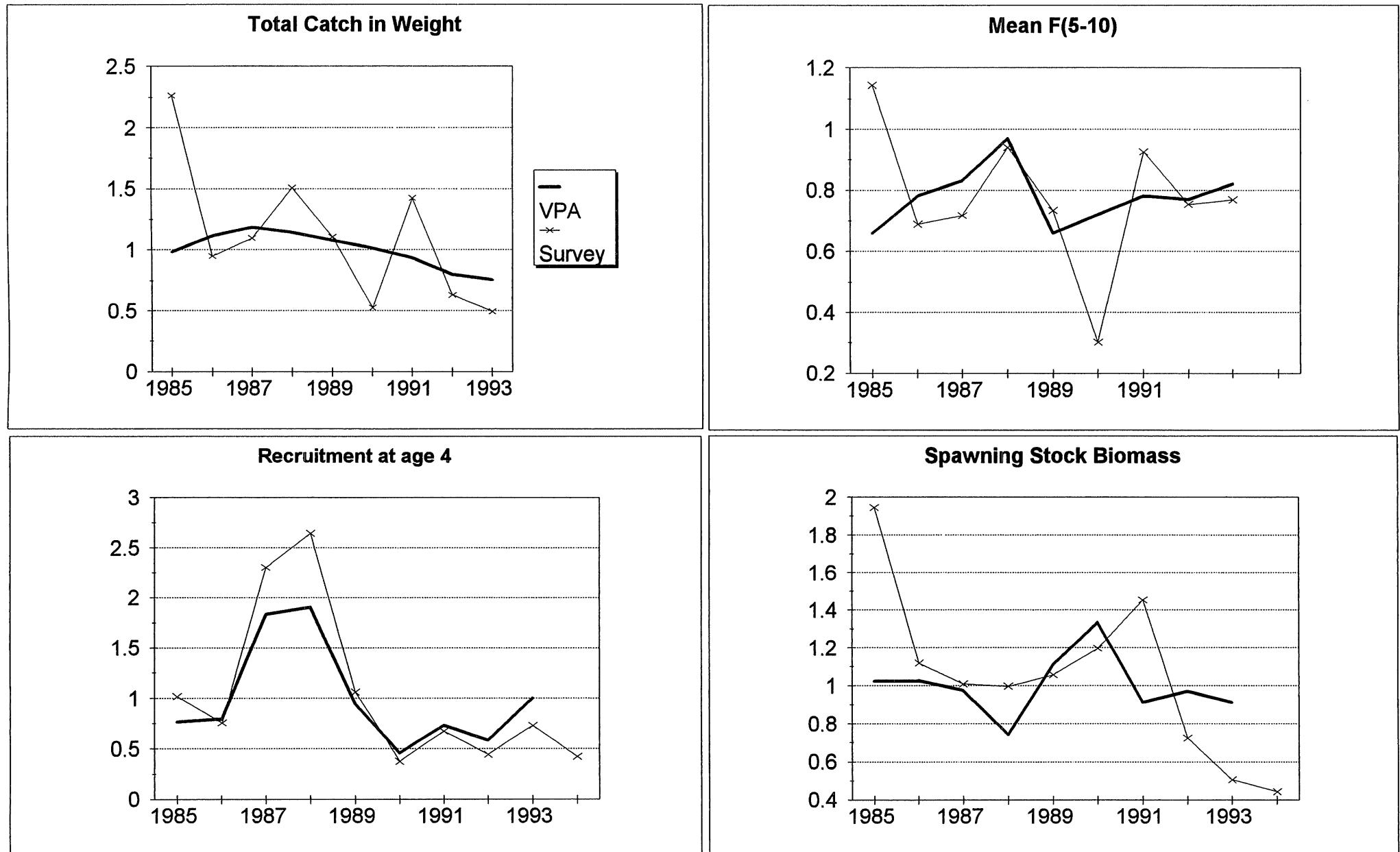
(a)   Model fitted to survey only
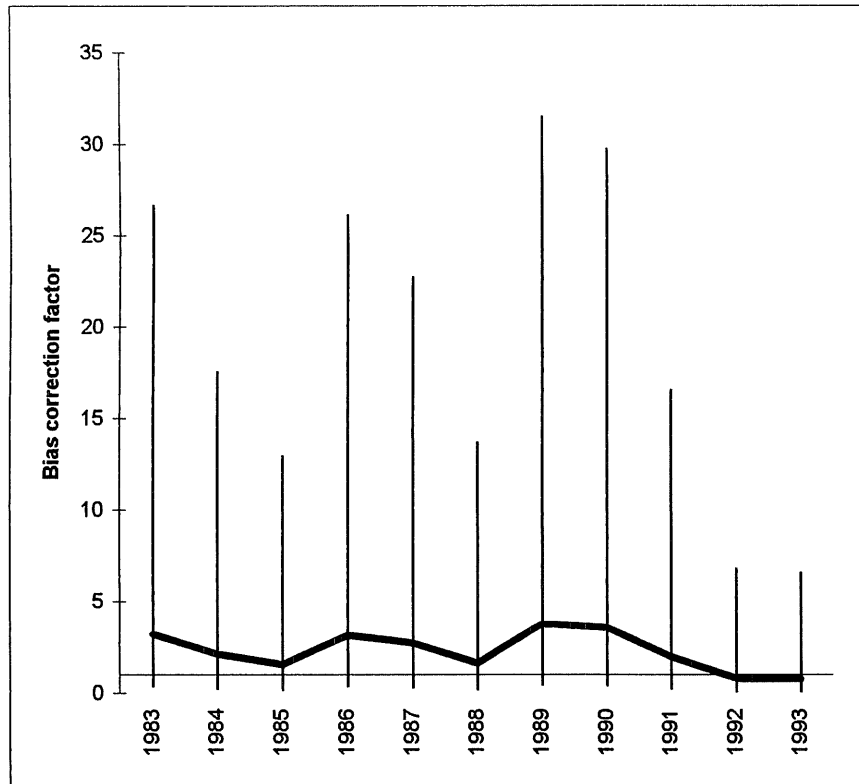
(b)   Model fitted to surveys and fleet catch-at-age data
        Note : change in bias scale
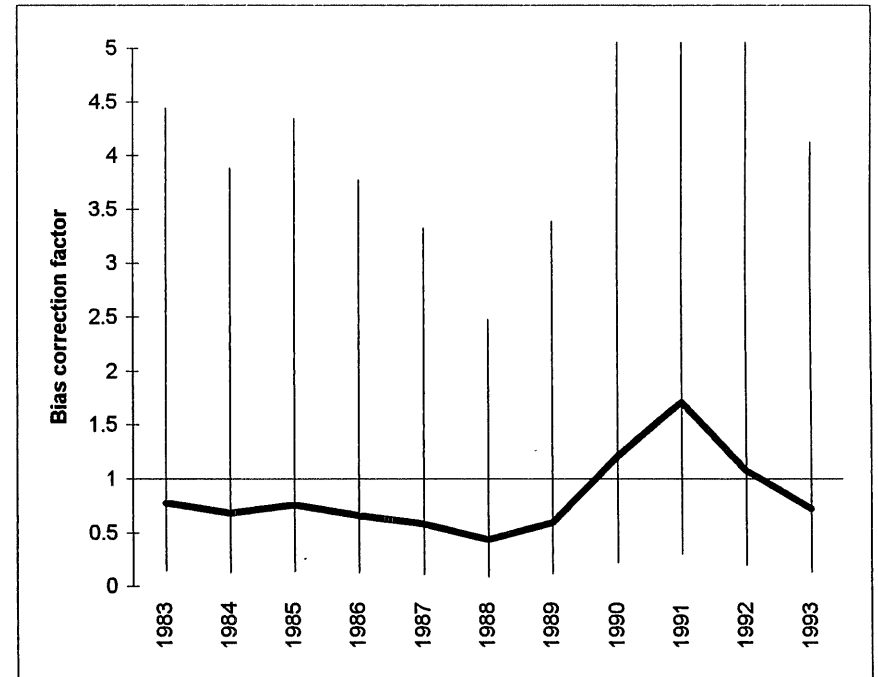
Figure 5.3.1   Mis-reporting bias estimated by the fit of a modified stage 1 ITCOTCIO model
                 to data for Gulf of Maine cod. Ages 2 - 6.
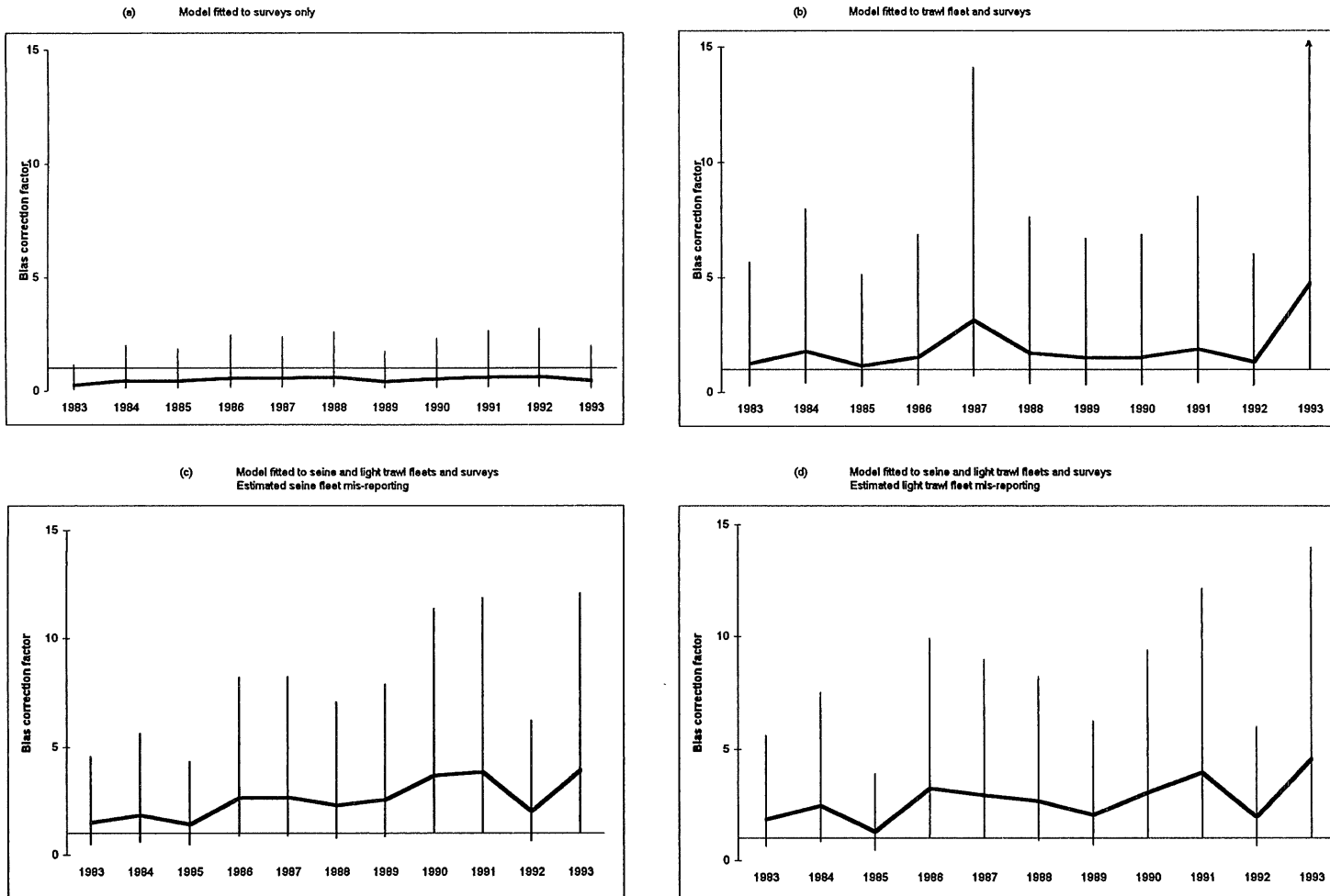
Figure 5.3.2   Mis-reporting bias estimated by the fit of a modified stage 1 ITCOTCIO model
to data for North Sea haddock. Ages 2 - 5.
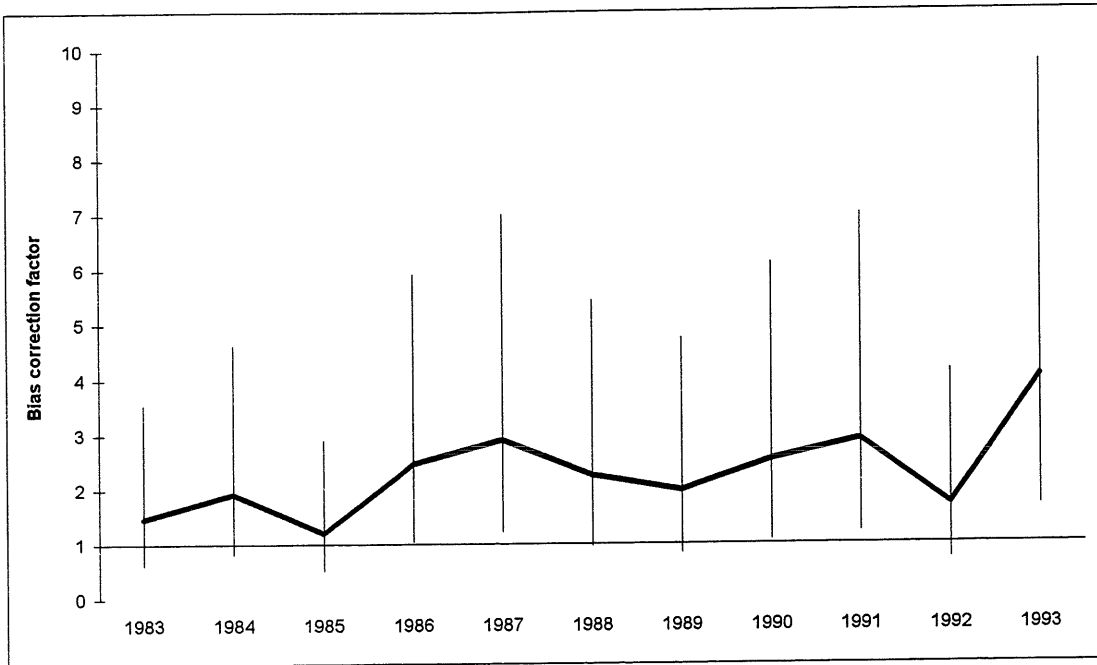
Figure 5.3.3   Mis-reporting bias estimated by the fit of a modified stage 1 ITCOTCIO model
to data for North Sea haddock. All fleets. Ages 2 - 5.
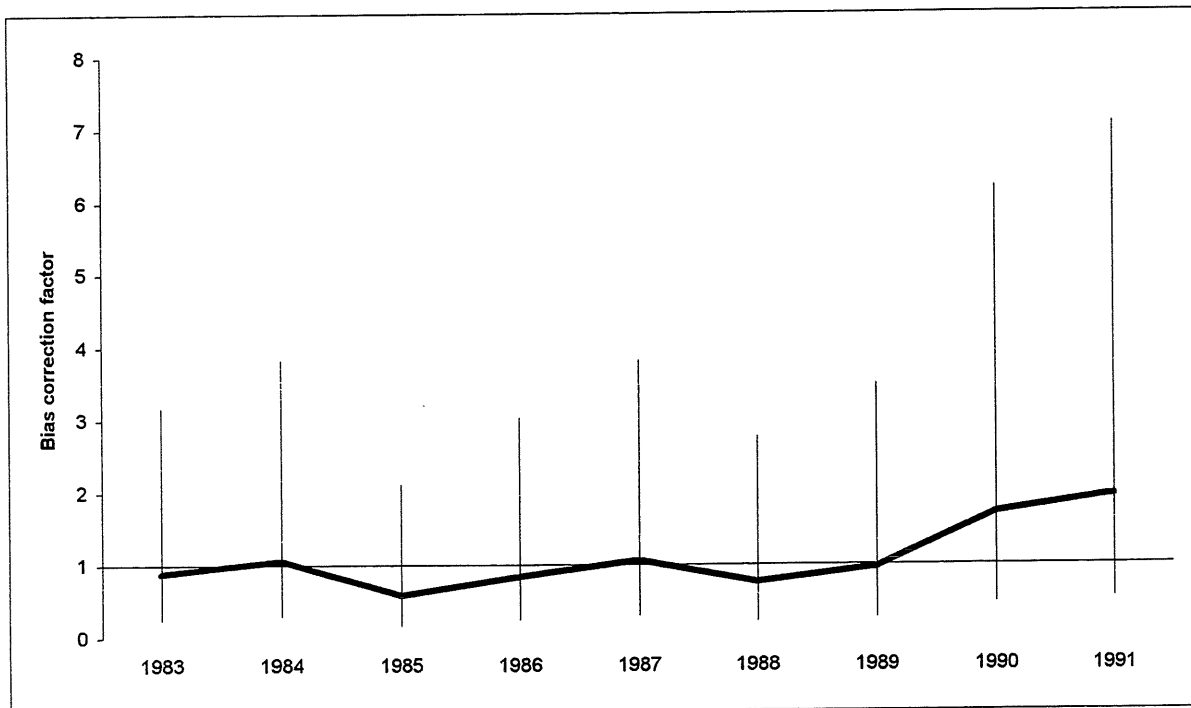
Figure 5.3.4   Mis-reporting bias estimated by the fit of a modified stage 1
ITCOTCIO model to data for Southern Gulf cod. Ages 4 - 11.
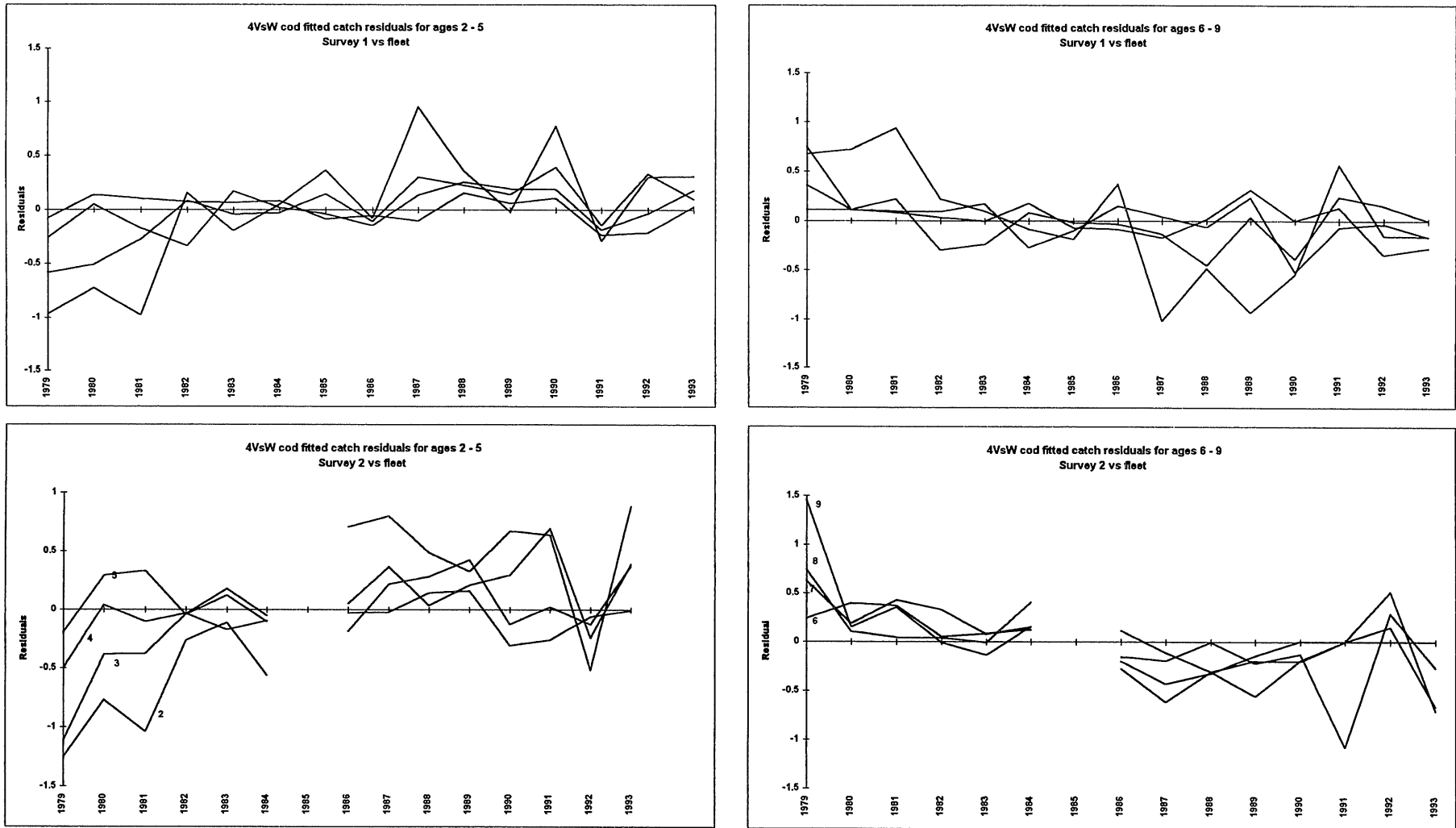
Figure 5.3.5 The residuals from the fit of the modified stage 1 ITCOTCIO model to the catch-at-age data for the 4VsW cod
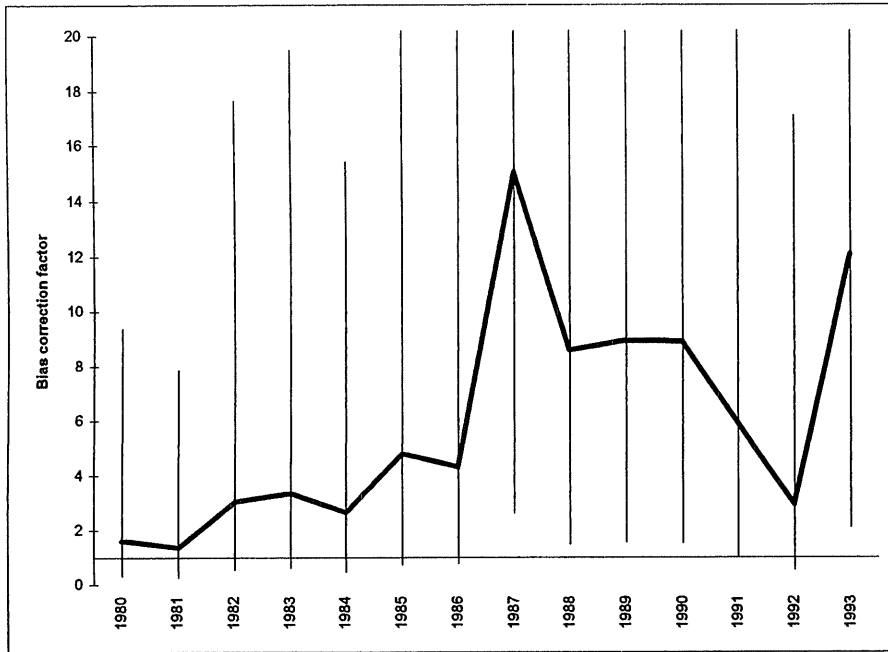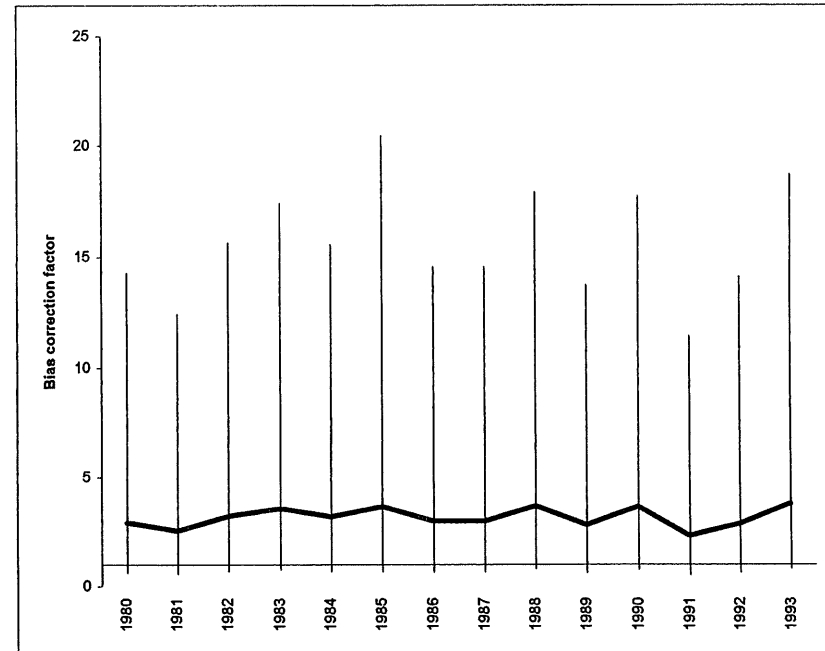
Figure 5.3.6   Mis-reporting bias estimated by the fit of a modified stage 1 ITCOTCIO model
                to data for 4VsW Cod.

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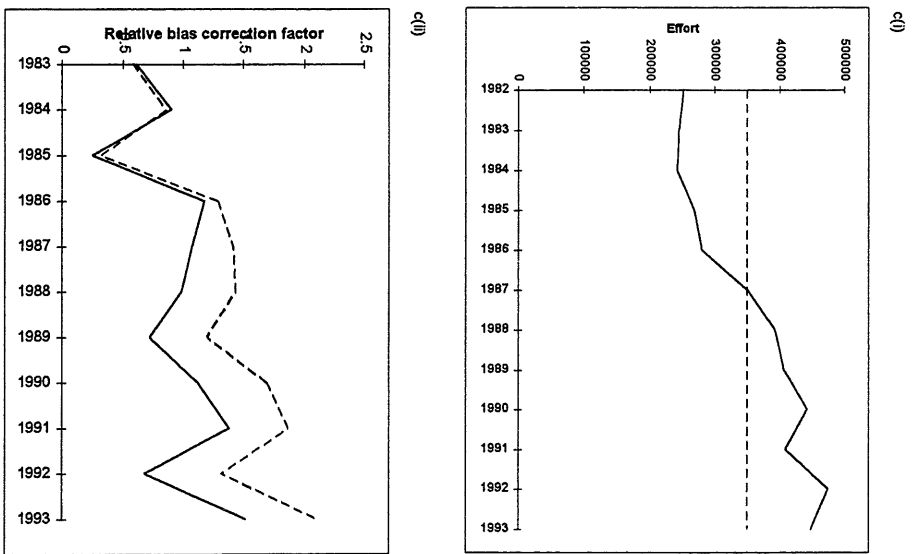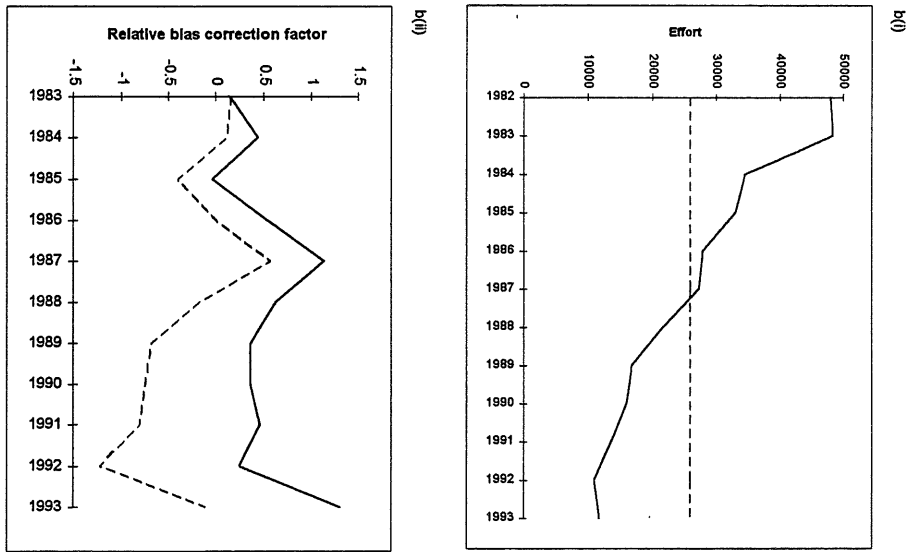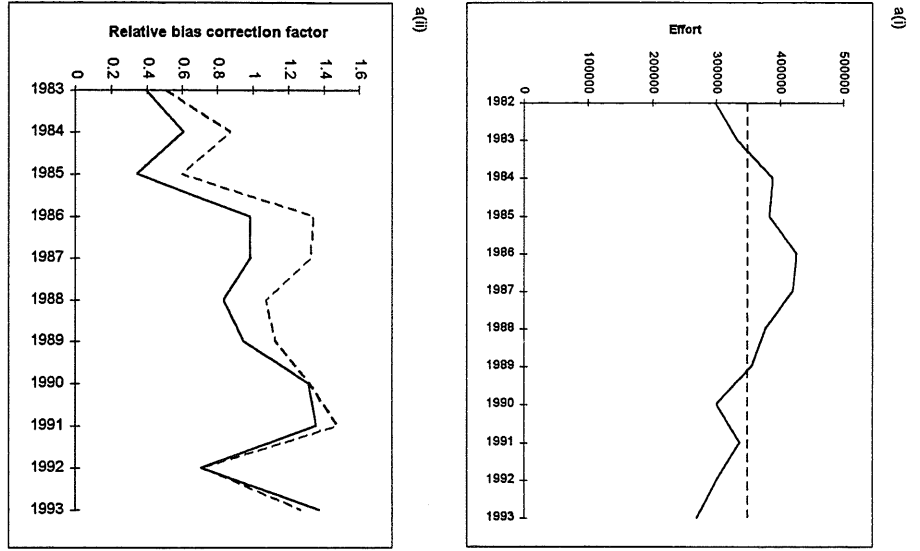
Figure 5.3.7 The effect of patterns in the level of effort on trends in the estimated relative bias correction factor

Year	Fishery — Catch	Stock Status — Recruitment	Biomass	SSB	Fishing Mortality	Growth	Indices — RV Spring	RV Autumn	CPUE	Overall
1960										
1961										
1962										
1963										
1964										
1965	●							⊙	◉	●
1966	●							⊙	◉	●
1967	●							⊙	○	⊙
1968	●						○	○	○	○
1969	◉						○	○	○	○
1970	◉						○	○	⊙	○
1971	●						◉	○	⊙	⊙
1972	●						⊙	⊙	◉	◉
1973	●						○	◉	◉	◉
1974	◉						◉	⊙	◉	⊙
1975	◉						◉	◉	◉	◉
1976	⊙						◉	◉	○	⊙
1977	⊙						⊙	⊙	○	○
1978	⊙						⊙	⊙	⊙	○
1979	⊙						○	○	⊙	○
1980	○						◉	○	◉	○
1981	○						○	◉	⊙	○
1982	○	⊙	○	○	○		⊙	○	◉	○
1983	○	⊙	⊙	⊙	⊙		○	◉	◉	○
1984	⊙	○	◉	◉	⊙		◉	◉	●	◉
1985	⊙	◉	●	◉	●		⊙	◉	●	●
1986	◉	⊙	◉	●	◉		●	●	●	●
1987	●	○	◉	●	◉		●	●	●	●
1988	◉	○	○	⊙	○		●	●	●	⊙
1989	⊙	●	○	○	◉		●	●	●	◉
1990	○	●	⊙	○	⊙		●	●	○	⊙
1991	○	◉	⊙	⊙	○		●	●	○	⊙
1992	⊙	◉	●	◉	●		⊙	●	●	●
1993	◉	●	●	●	●		◉	●	●	●
1994		●	●	●						
1995										
1996										
1997										
1998										
1999										
2000										

Comparison to average conditions

○ Much better   ⊙ Better   ◉ Worse   ● Much worse

Figure 6.2.1 Time series of stock condition of Gulf of Maine cod expressed in four categories for each diagnostic.
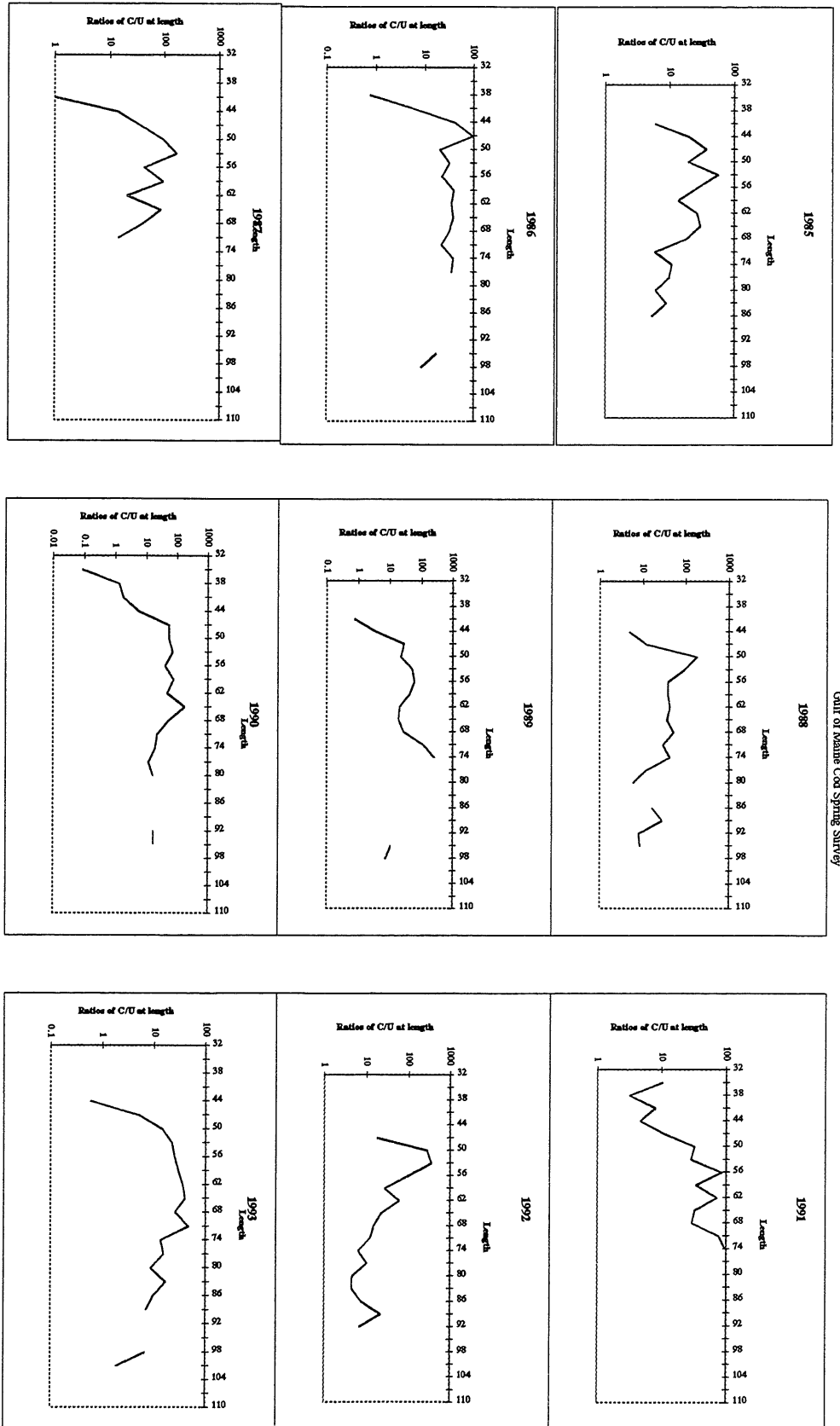
Figure 6.3.1 Size selectivity ogive for Gulf of Maine cod.
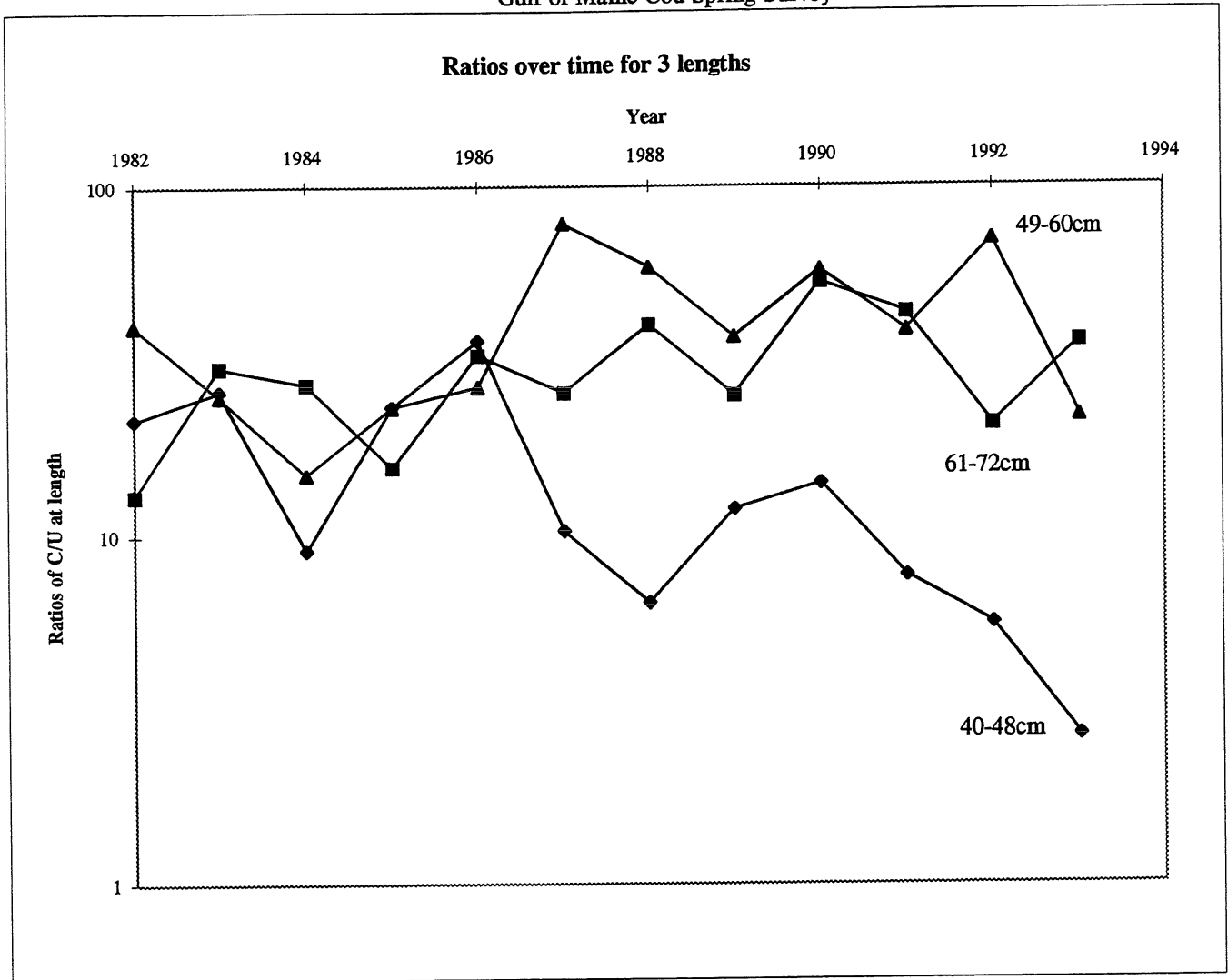
Figure 6.3.2 Time trends in Cyl/Uyl for selected lengths in Gulf of Maine cod.
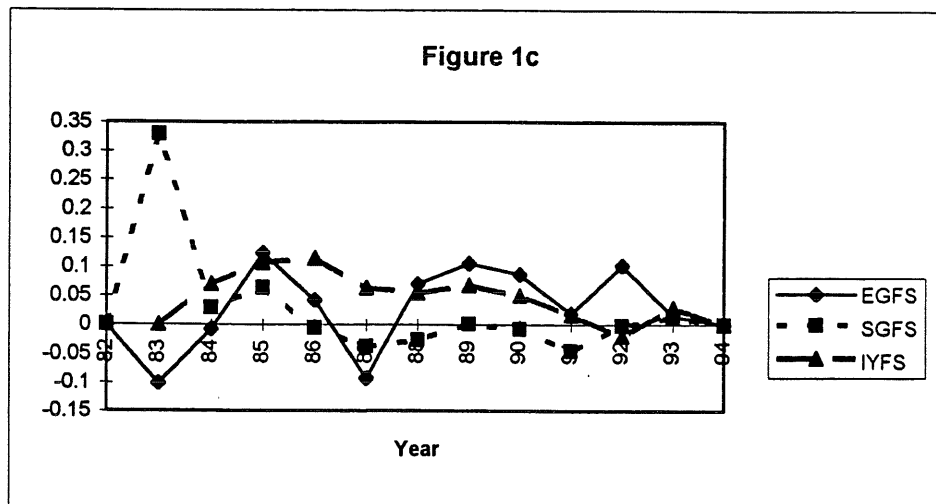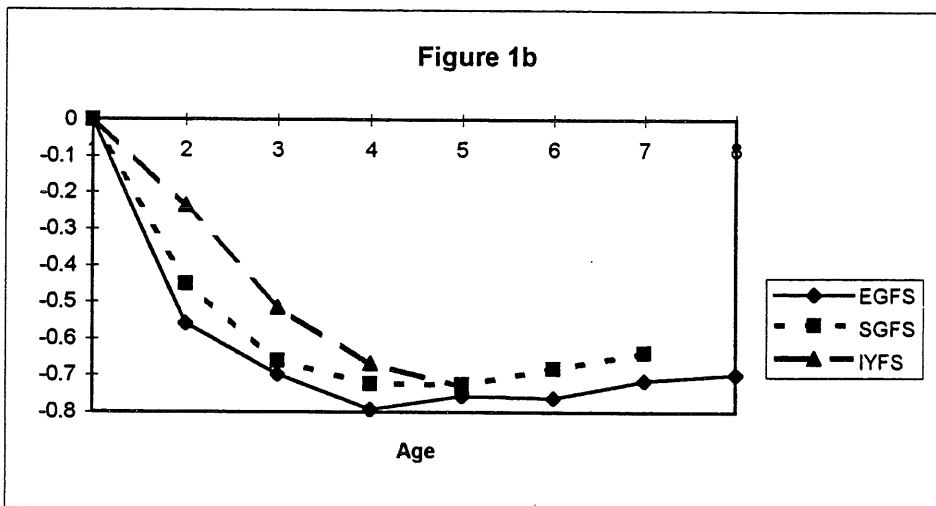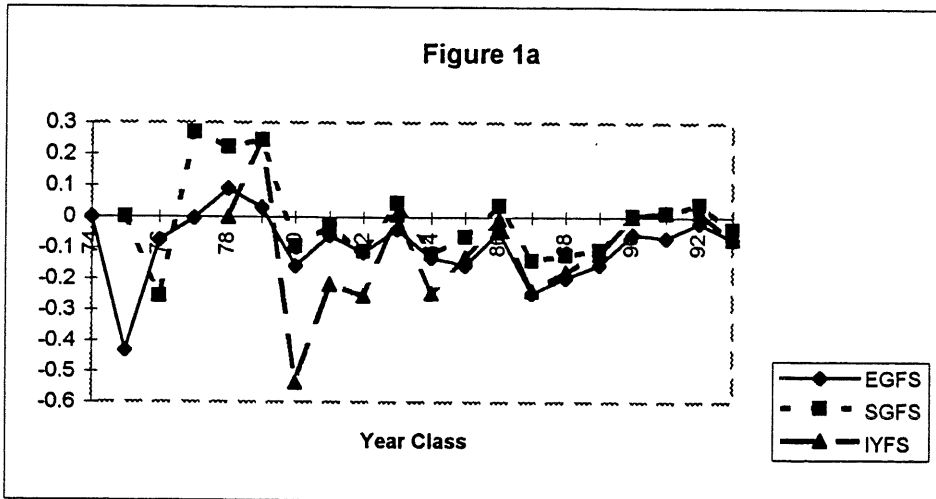
Figure 6.4.1 Year class, age and year efforts in survey indices for North Sea haddock.

Figure 2a
EGFS-SGFS estimates of Yearclass

Figure 2b
EGFS-IYFS estimates of Yearclass

Figure 2c
SGFS-IYFS estimates of Yearclass
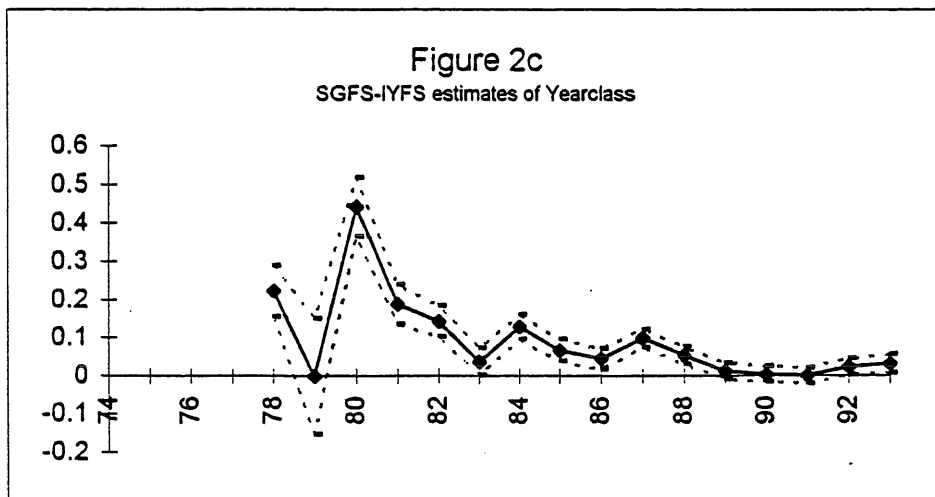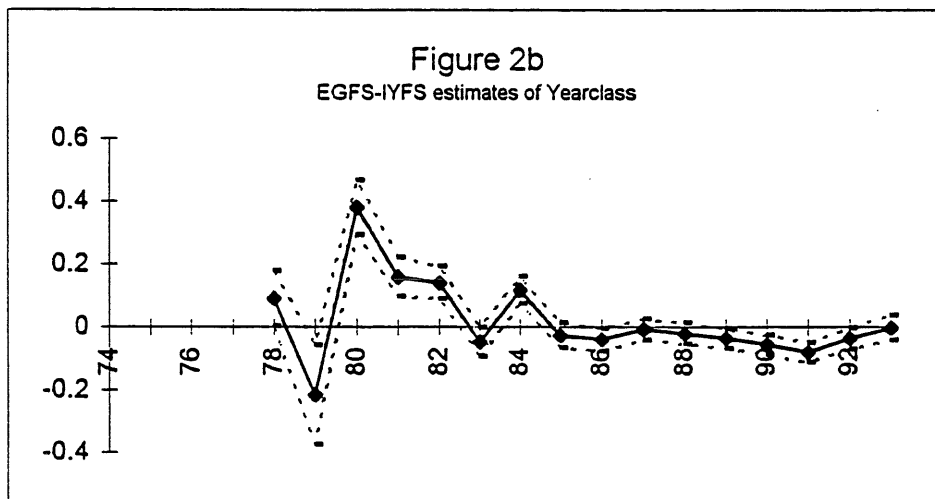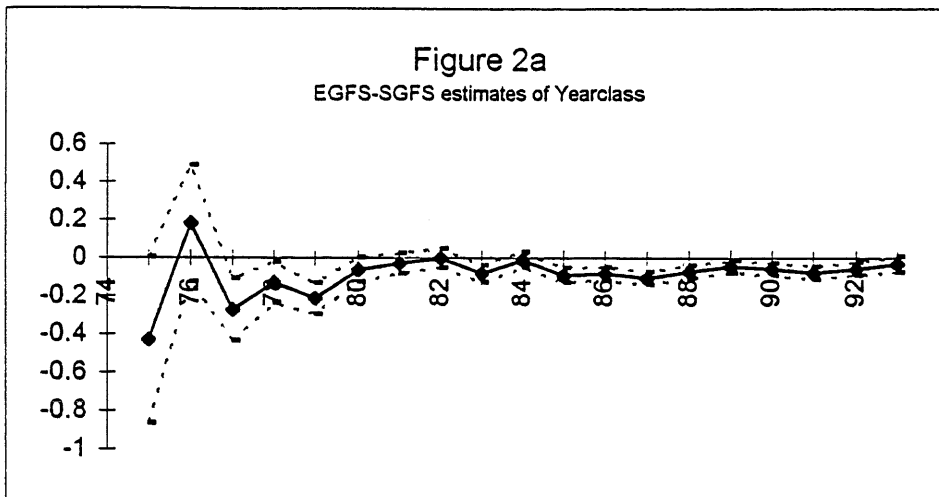
Figure 6.4.2 Trends in year class efforts in combined survey indices for North Sea haddock.

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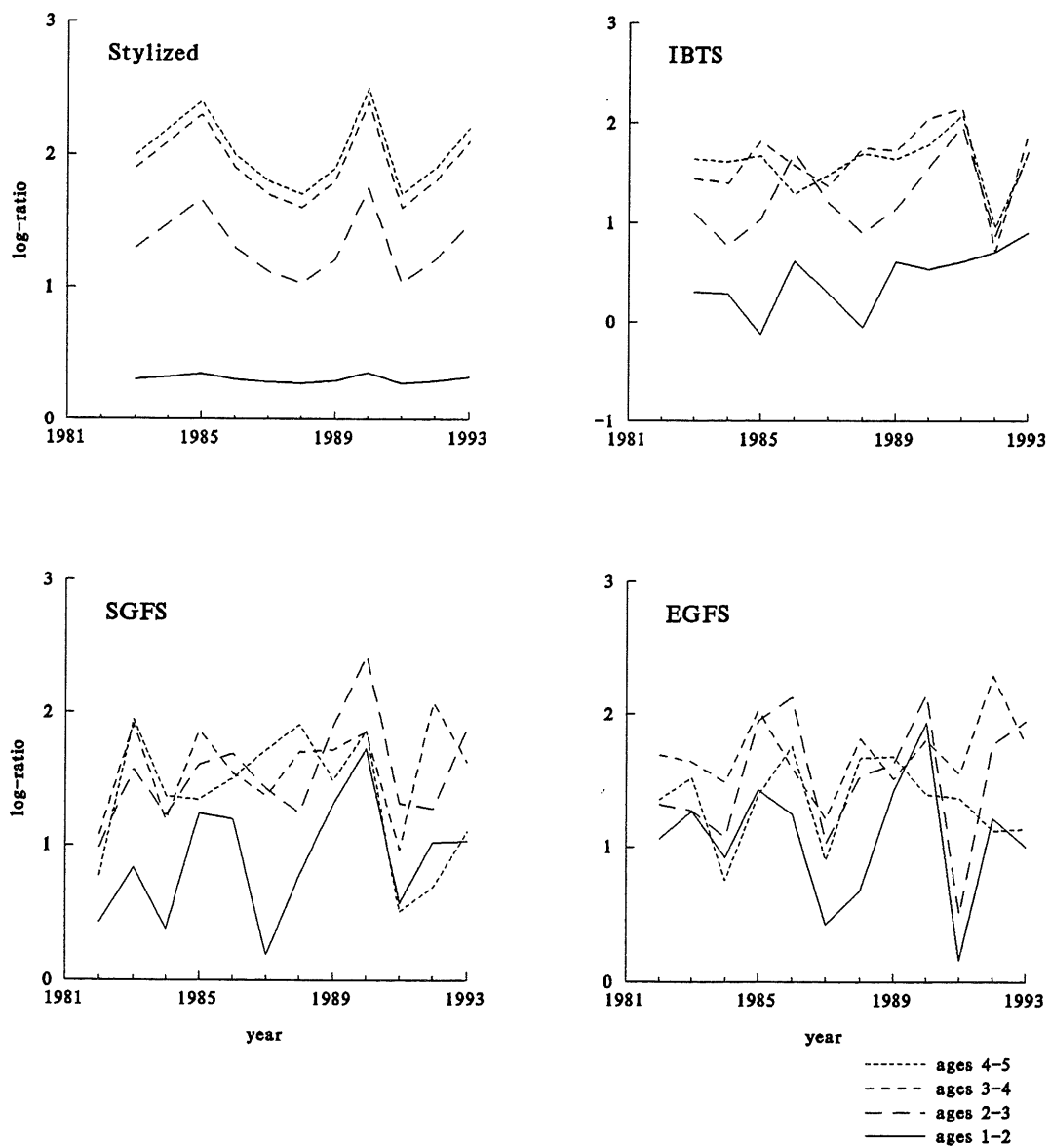
Figure 6.5.1 Observed log ratios of indices of abundance plotted against year by each age for North Sea haddock.

Figure 6.6.1 Right left ratio and relative q estimates for Gulf of Maine cod.

Log R/L ratio GOM cod Survey 1

Log R/L ratio GOM cod survey 2

Relative q GOM cod Survey 1

Relative q GOM cod Survey 2
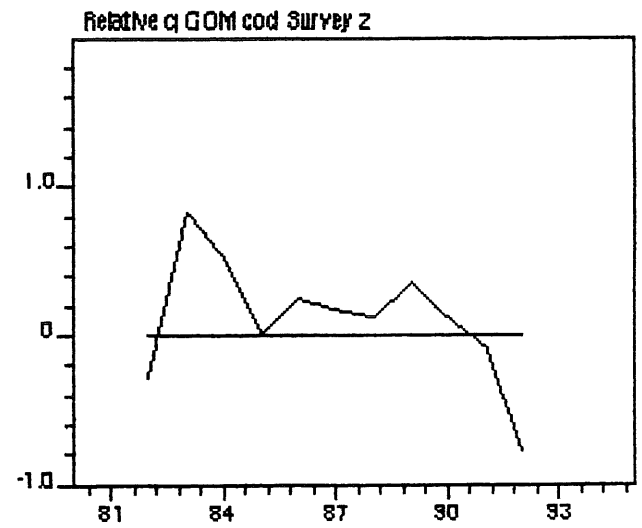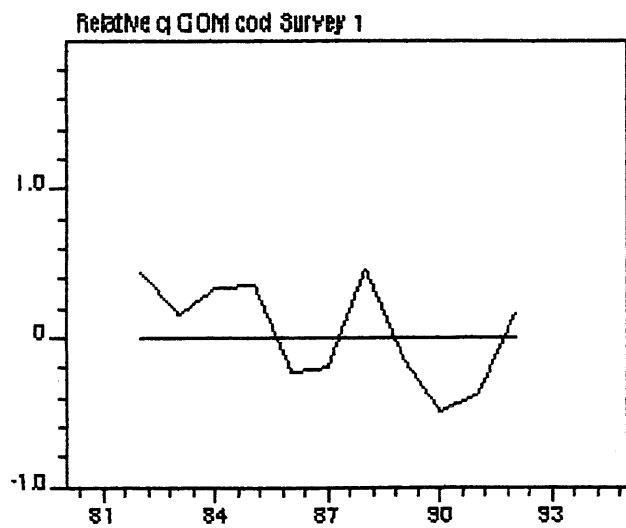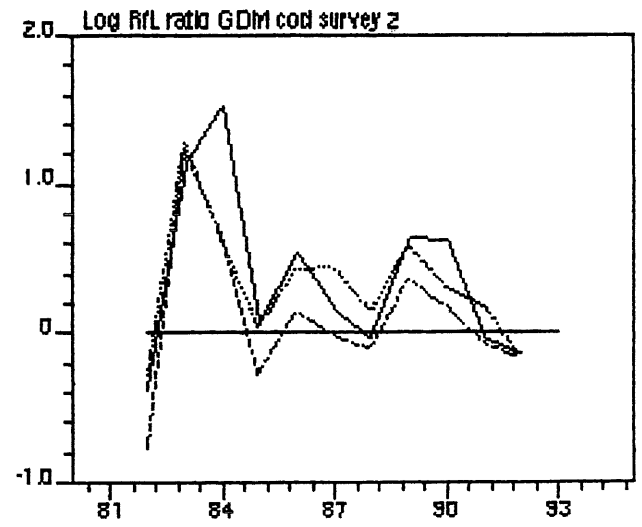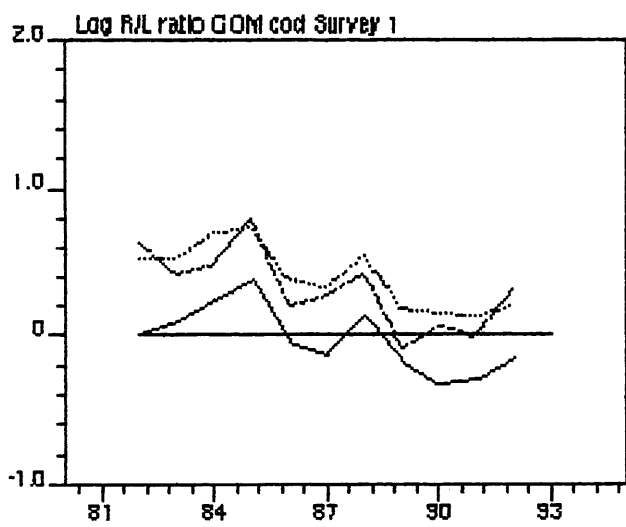
Figure 6.6.2 Right left ratio and relative q estimates for 4VsW cod

Figure 6.7.1 RV1 GOM cod.

Classical Biomass

Moving Window Biomass

year

year

F 3-5

F 3-5

year

year

q's

q * numbers 3-8

year

year

Figure 6.7.2 GOM cod.

Biomass 1+

q corrected Biomass

F 3-5

q corrected F

q * #

q * #

retroDisc Thu Feb 9 12:41:03 1995
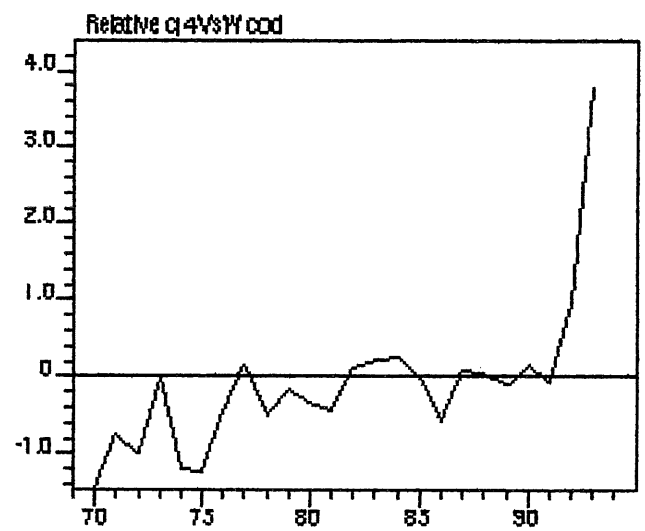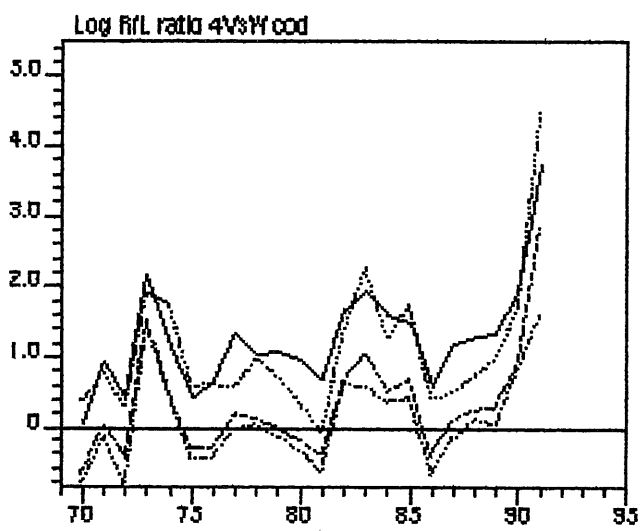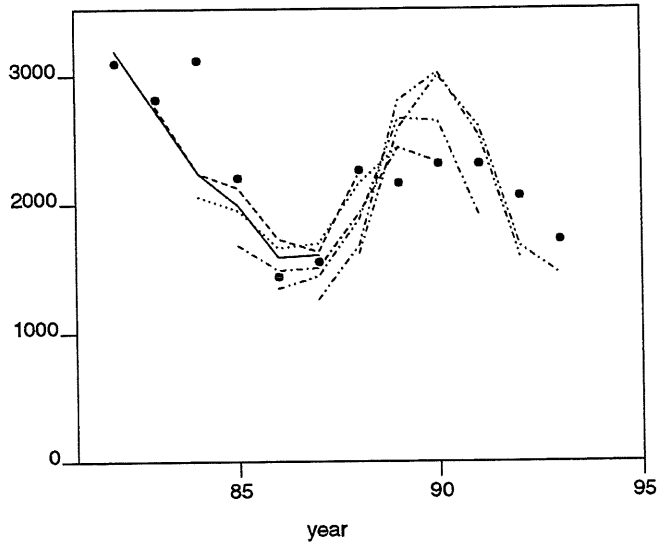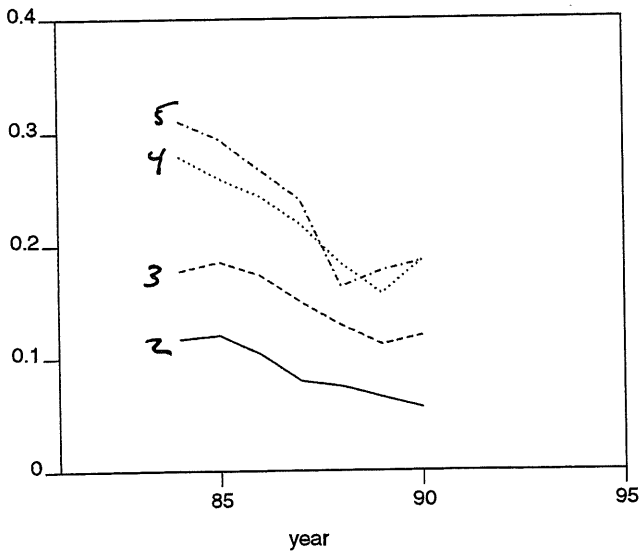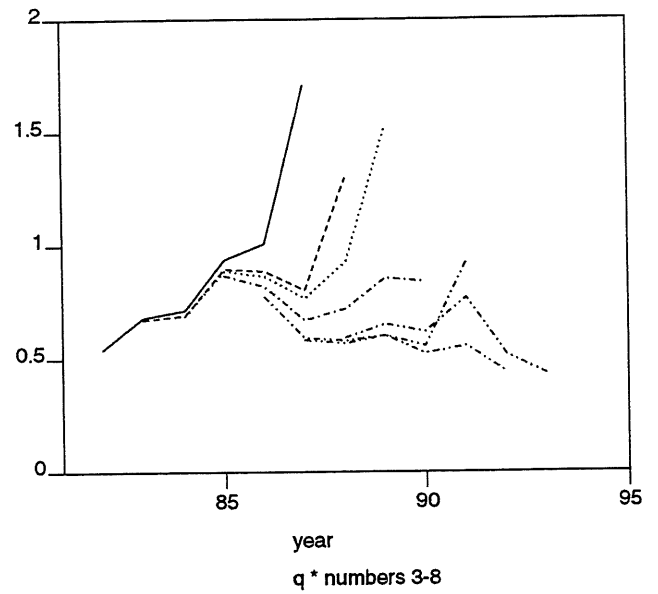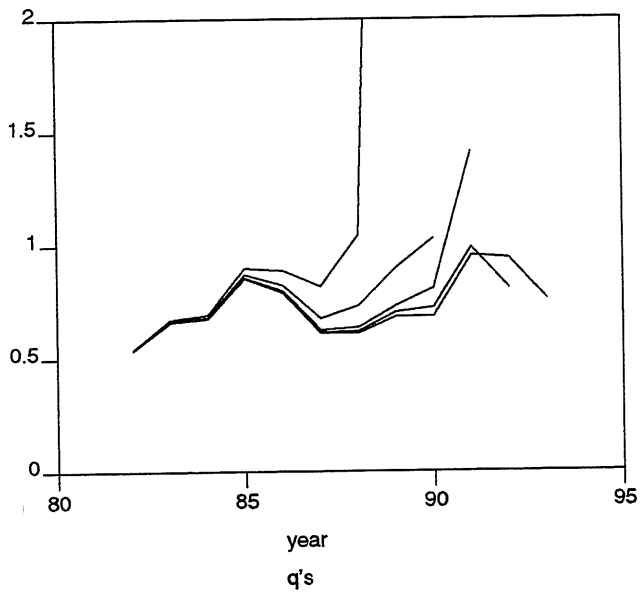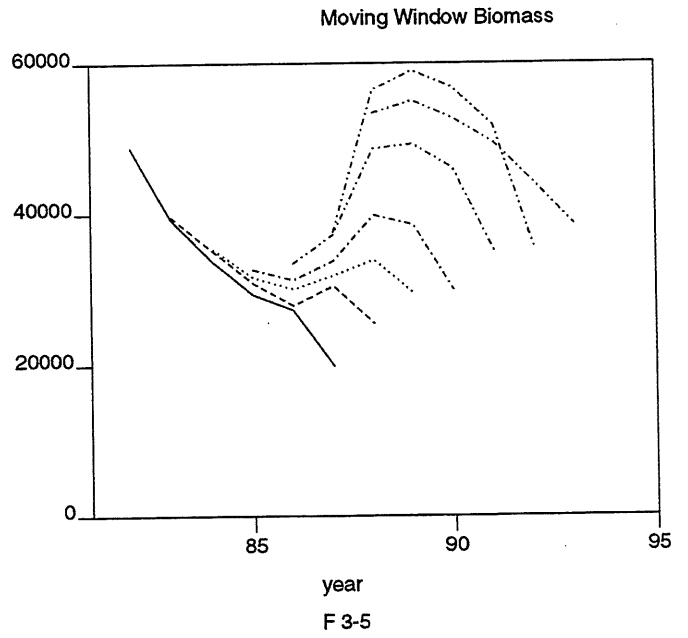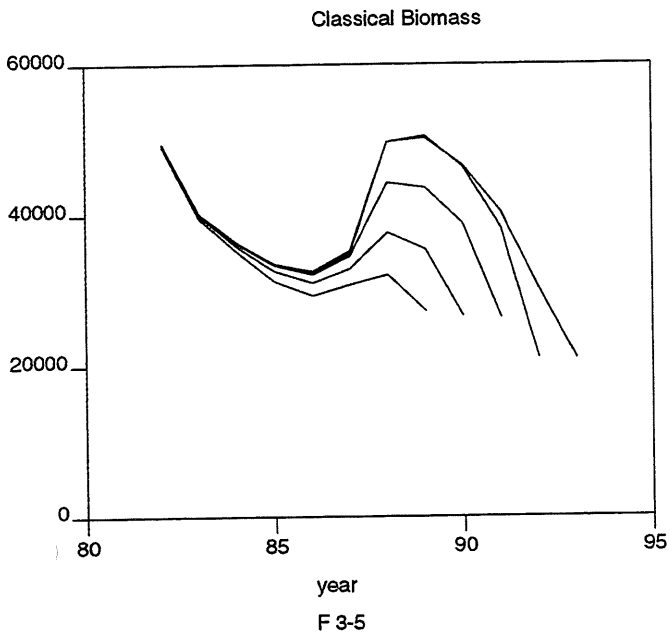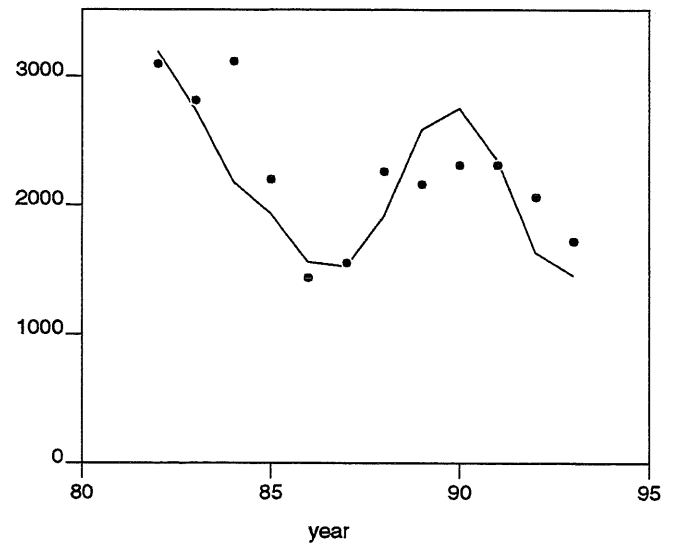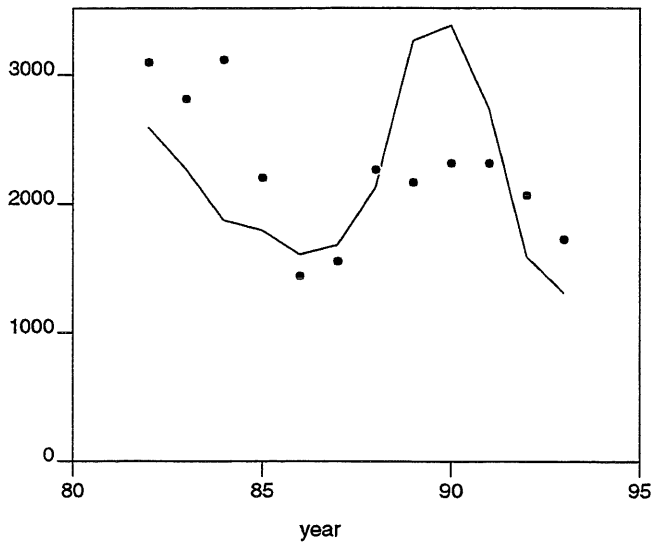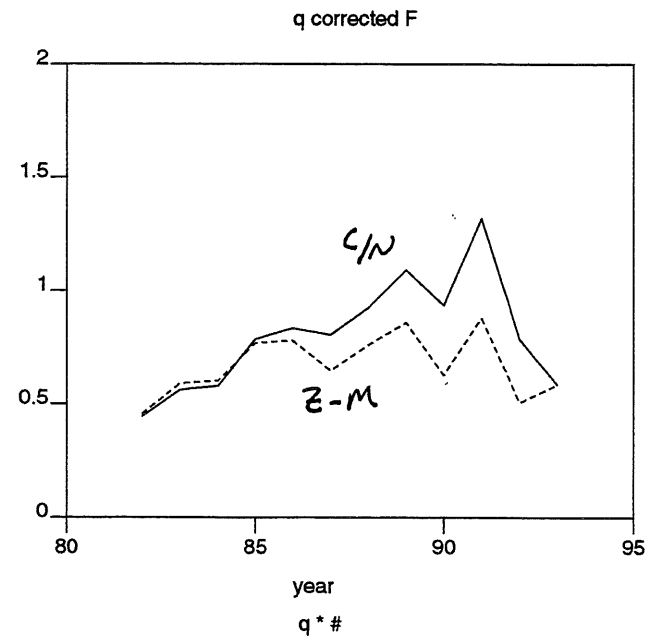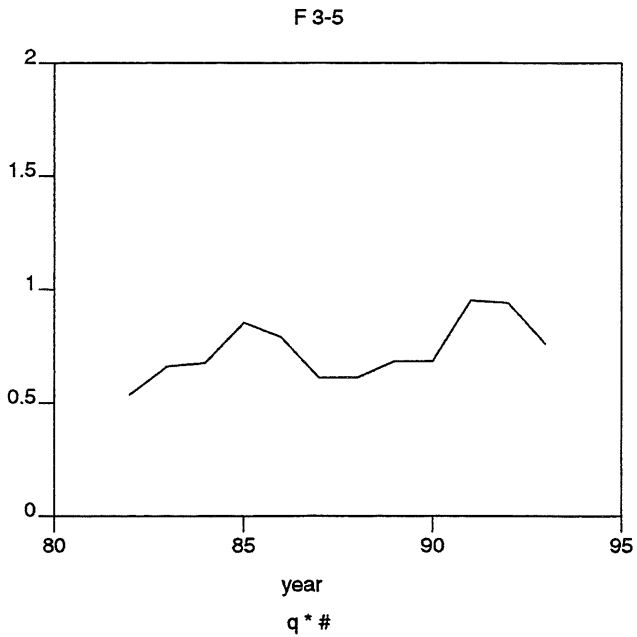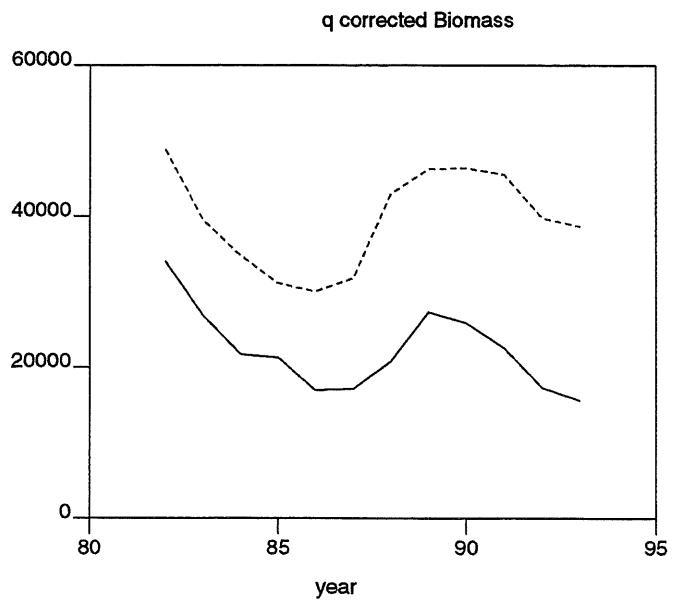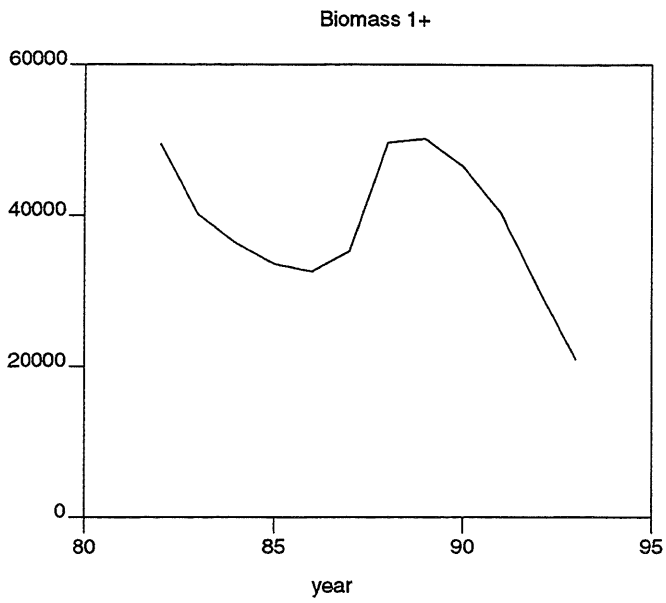
Georges Bank Yellowtail Flounder
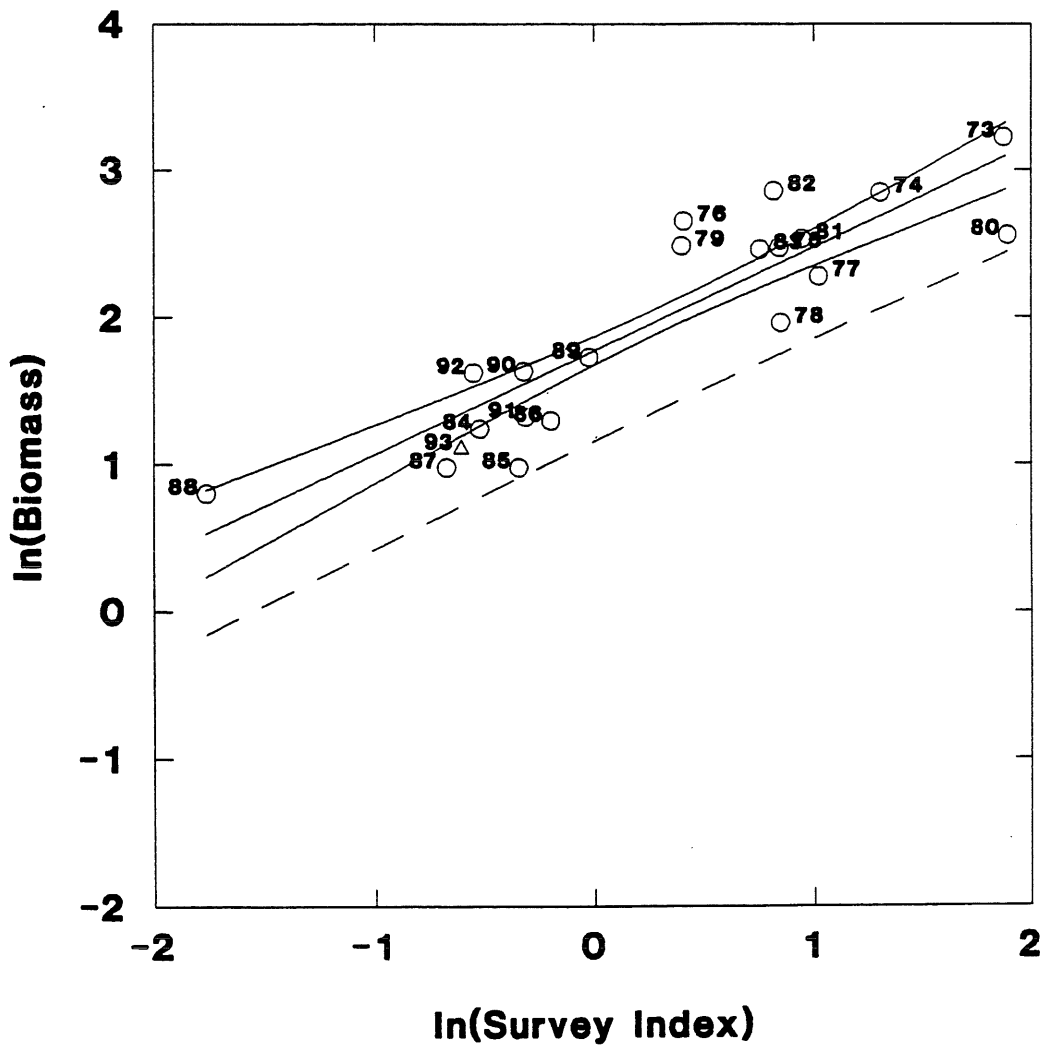
Figure 6.8.1a

Georges Bank Cod
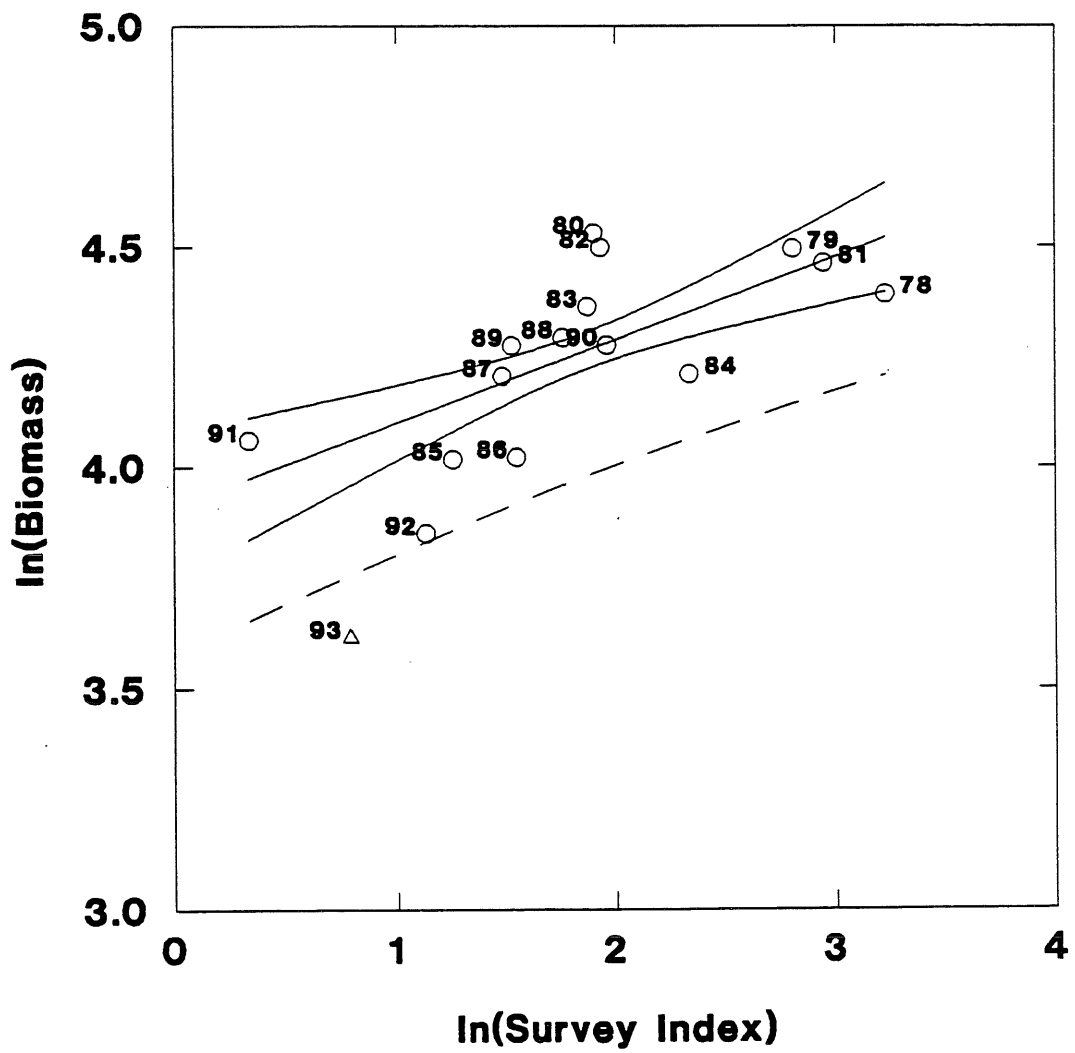
Figure 6.8.1b
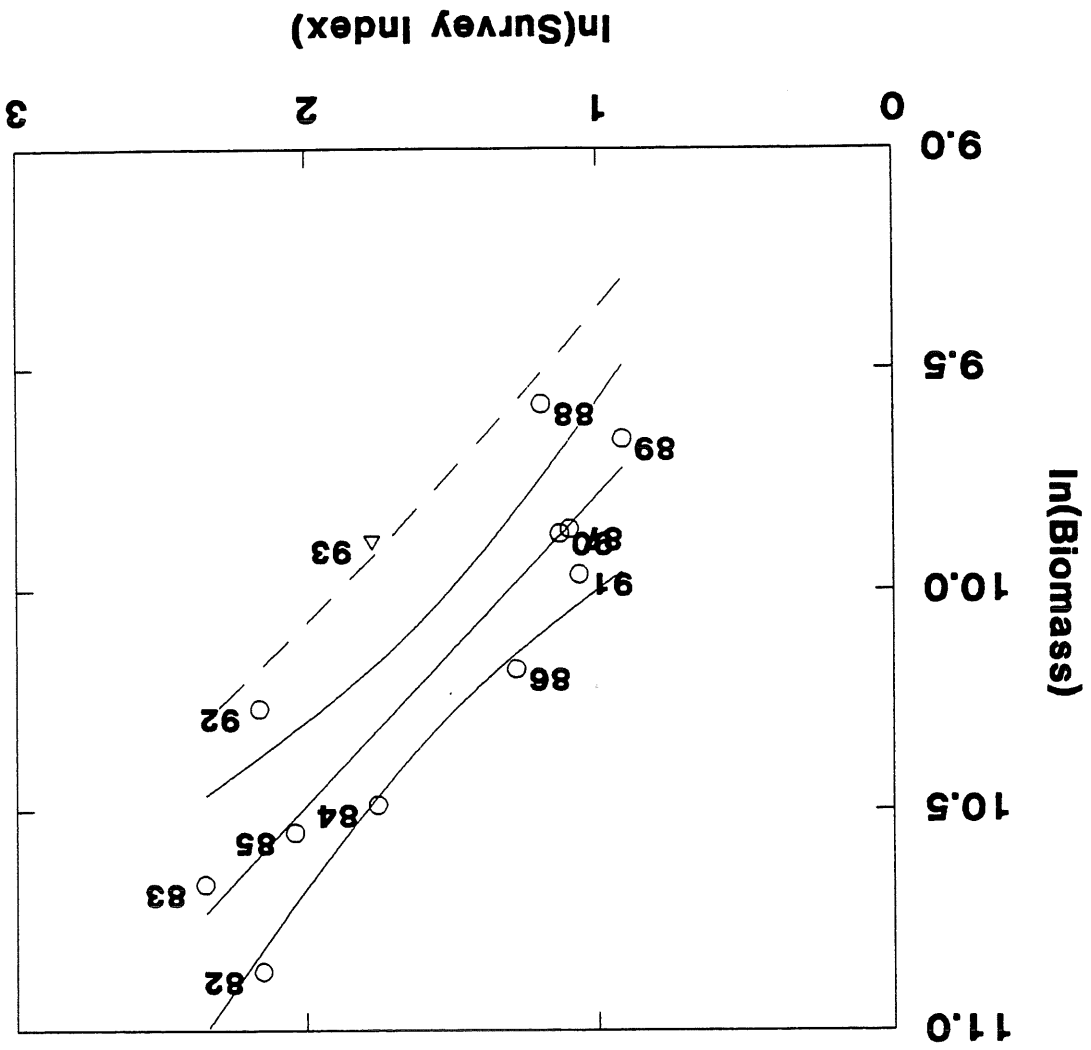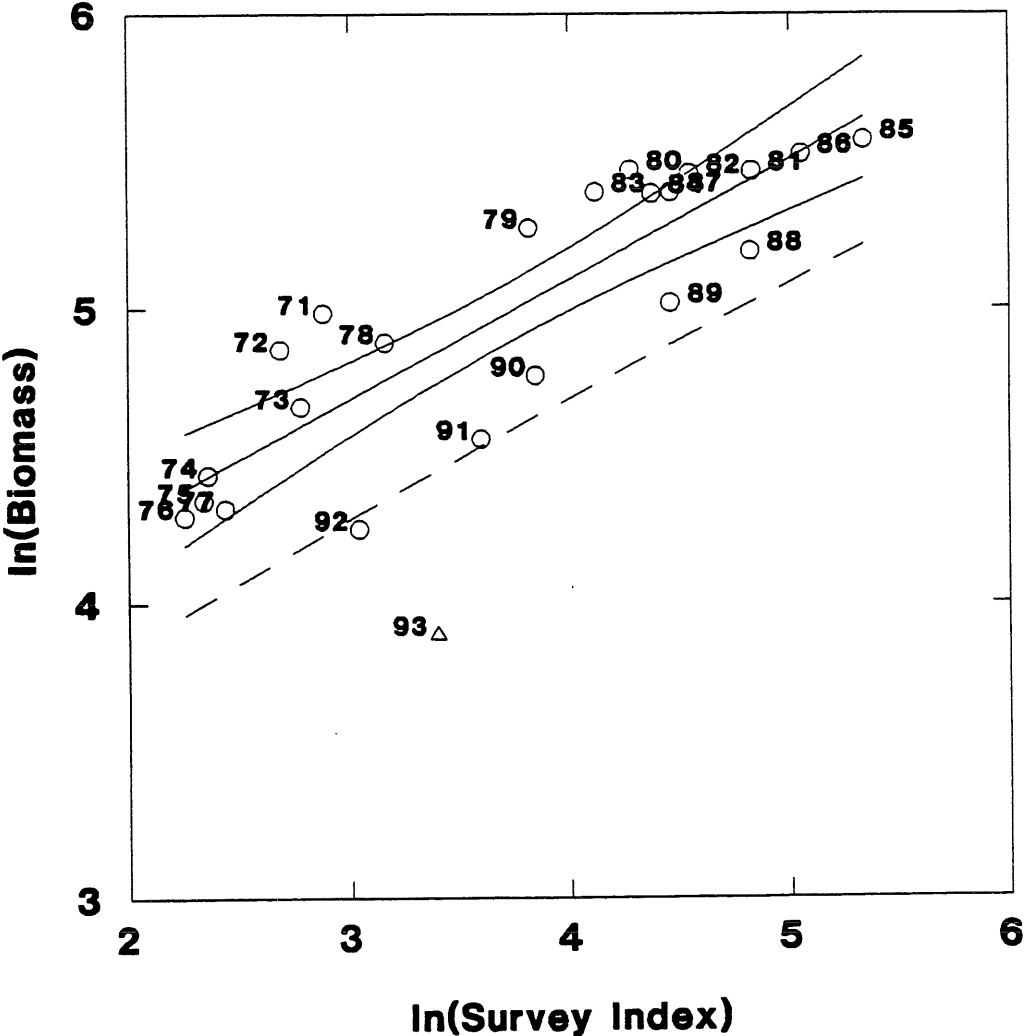
Figure 6.8.1c

Gulf of Maine Cod

4T-Vn Southern Gulf Cod
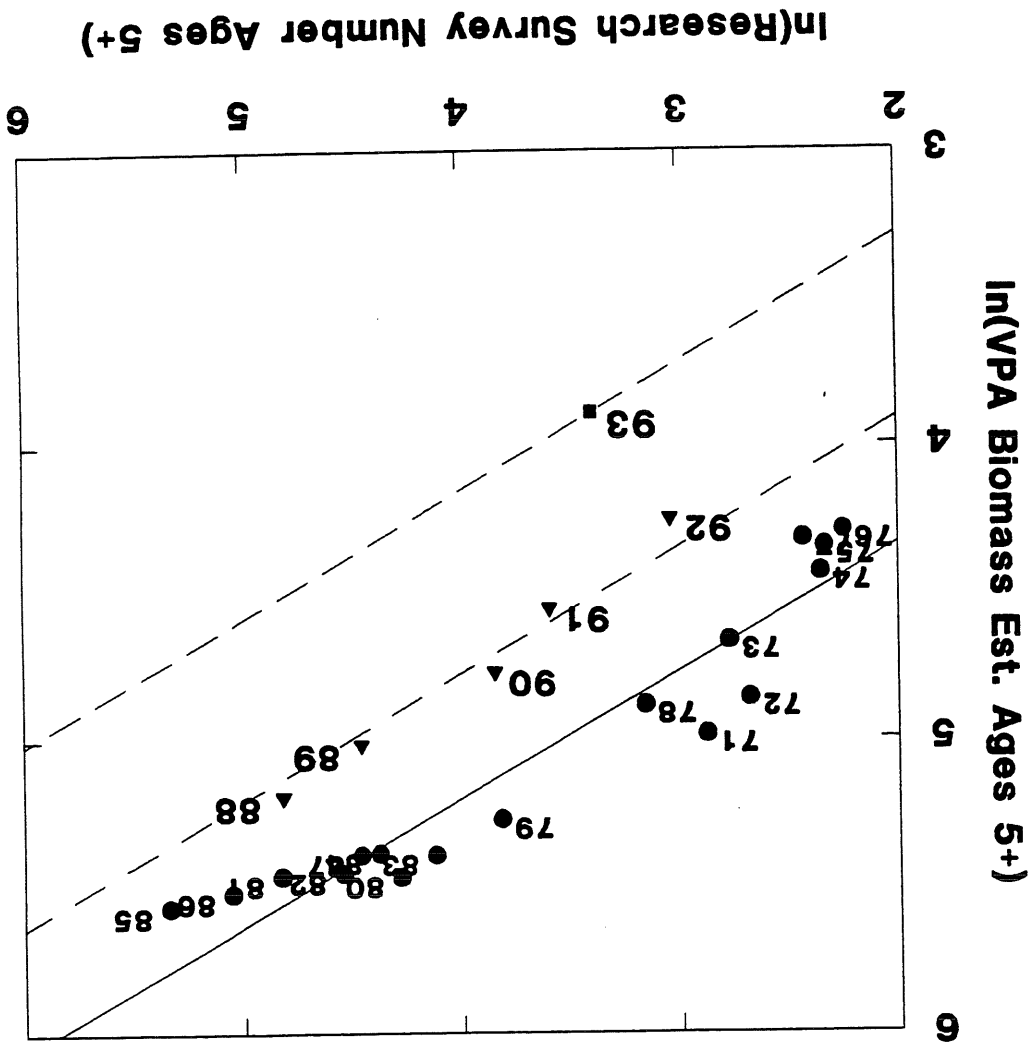
Figure 6.8.1d

Figure 6.8.3
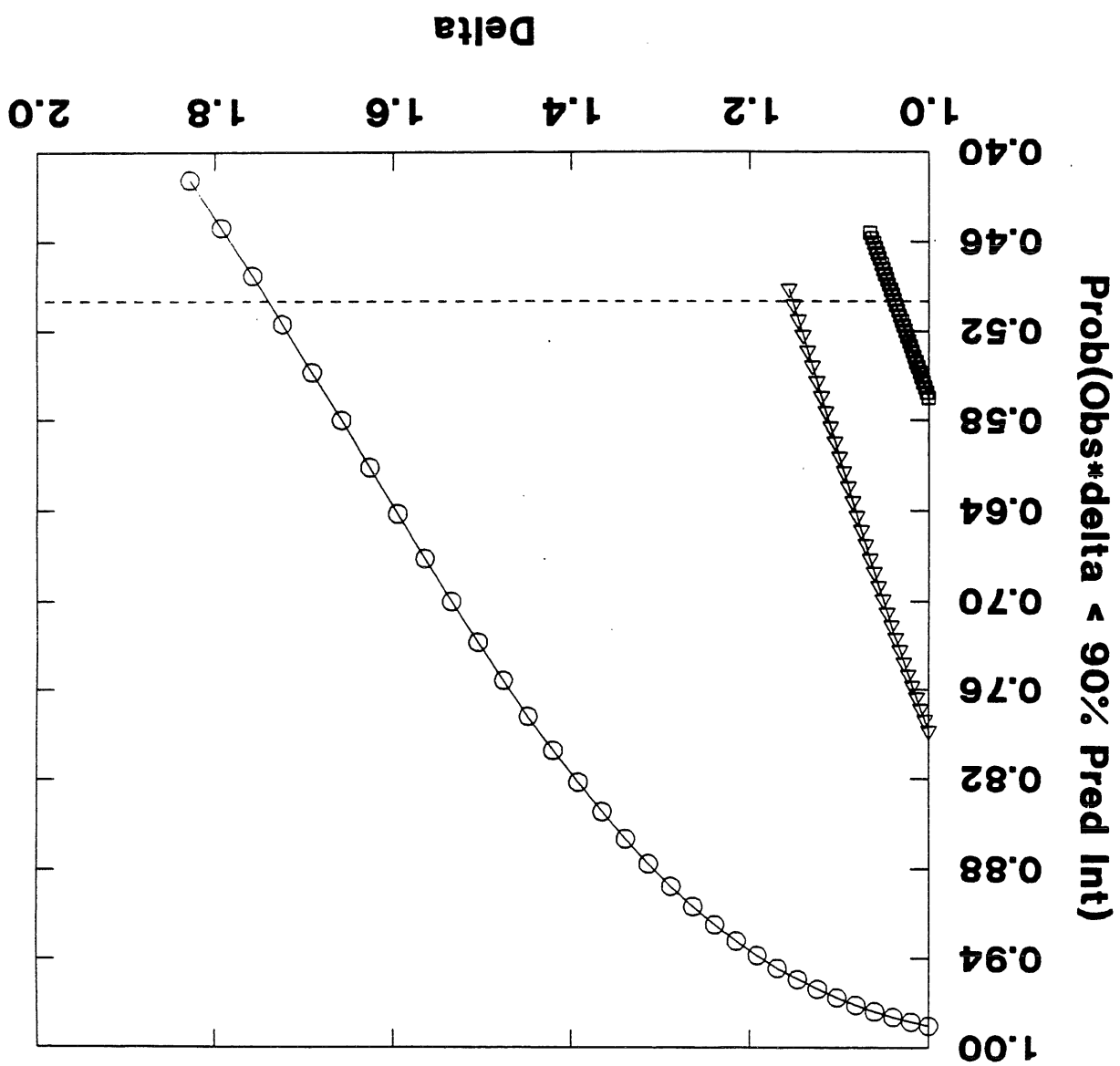
Figure 7.1.1 Comparison of methods.
Gulf of Maine Cod.

Recruitment

Fishing mortality

Figure 7.1.1 Cont.

Exploited biomass

Spawning stock biomass
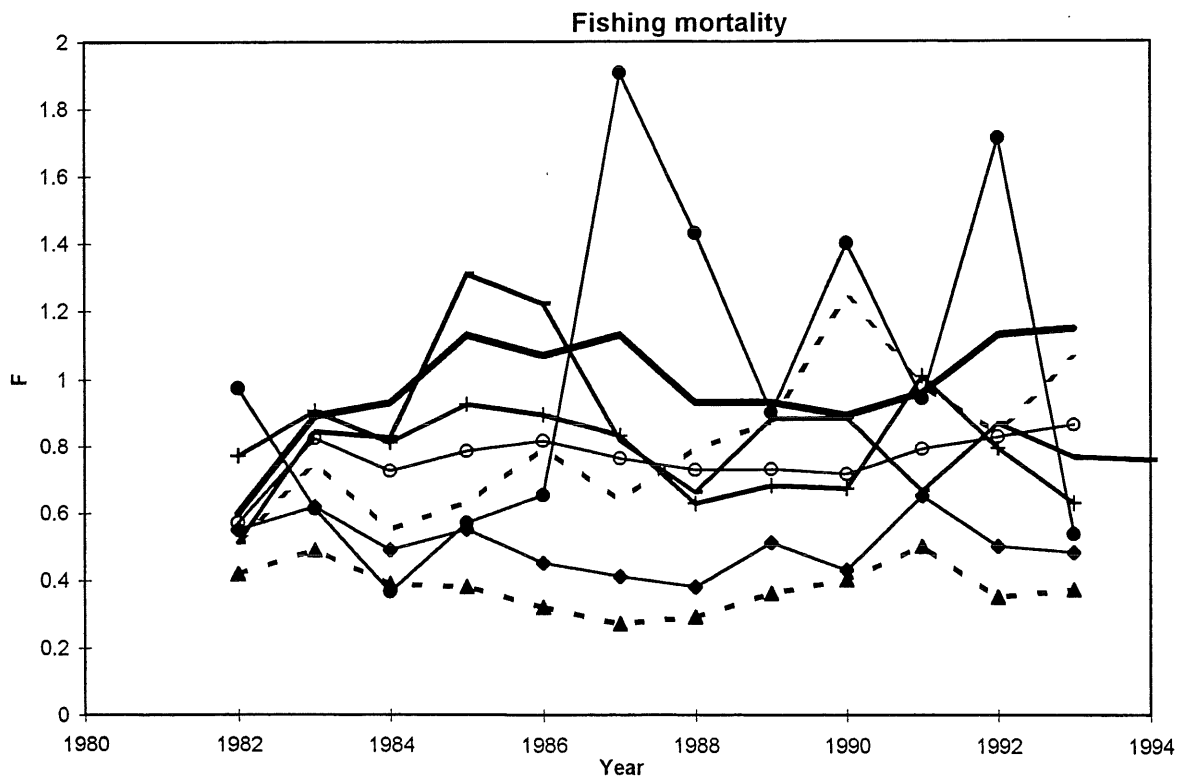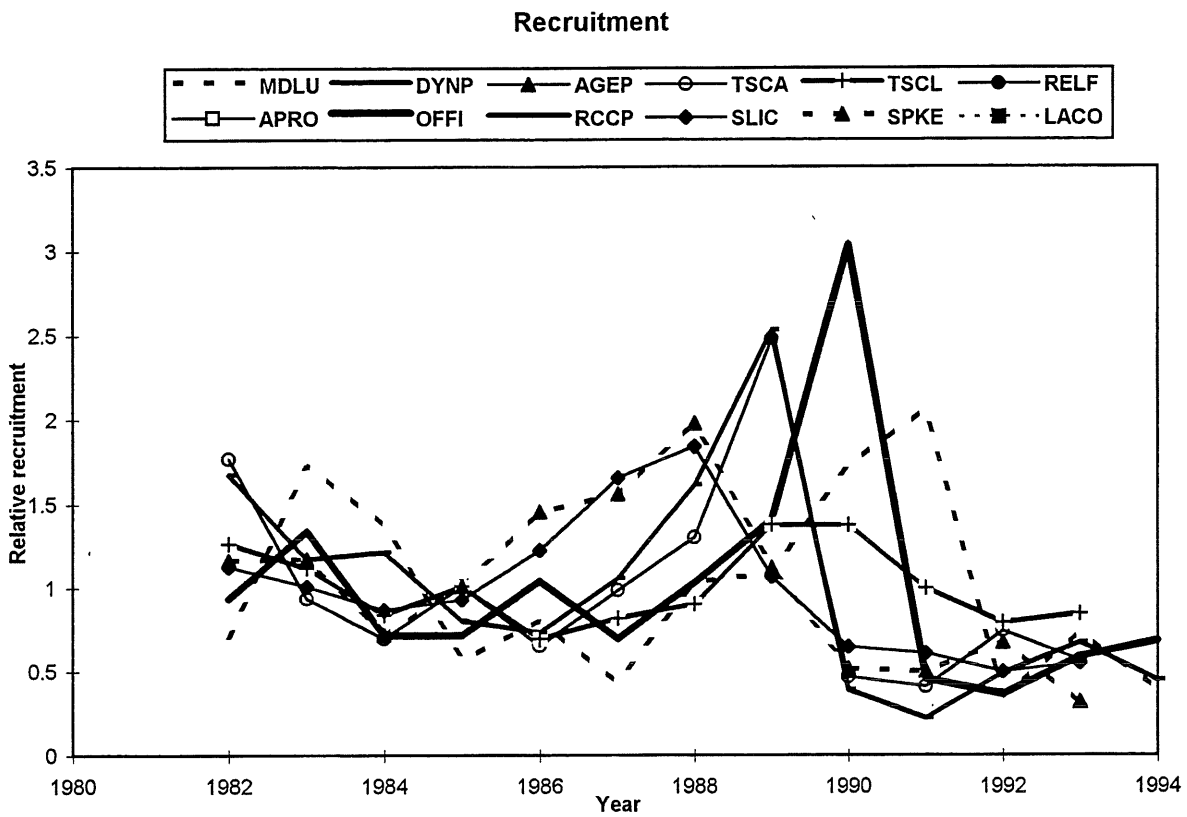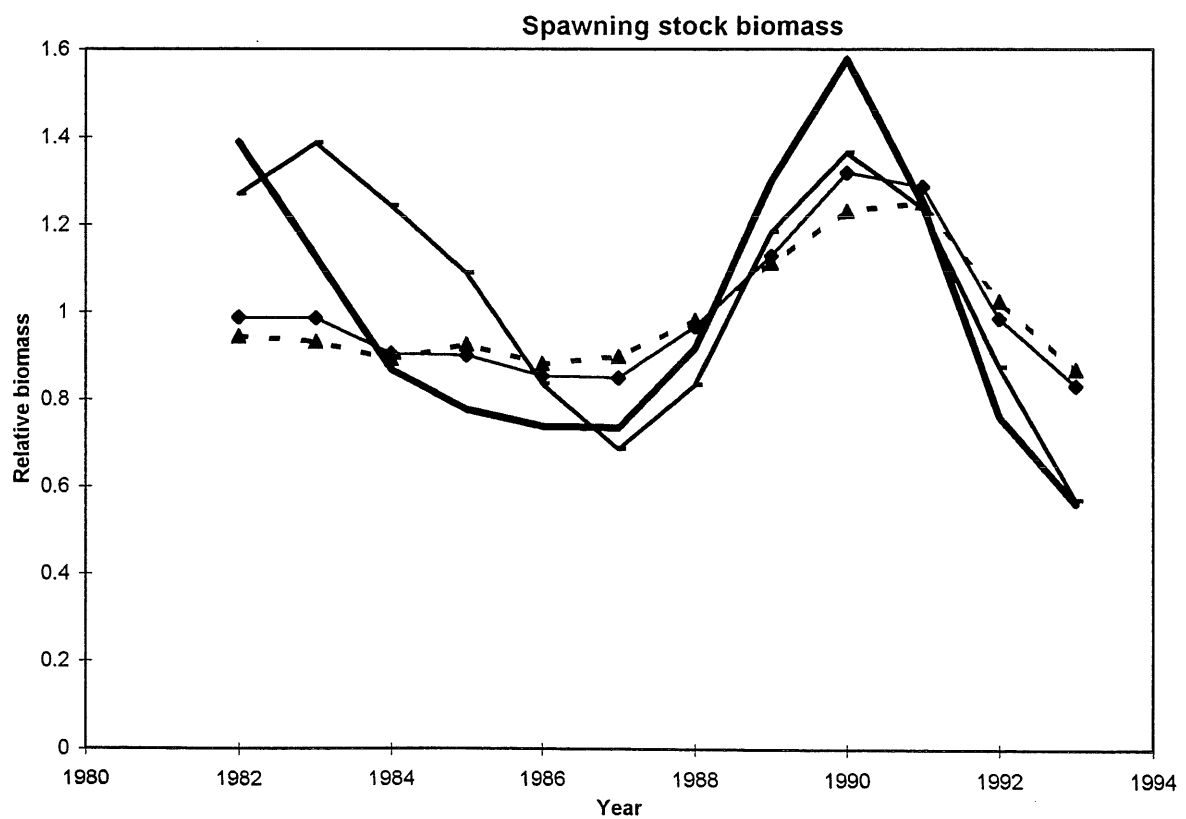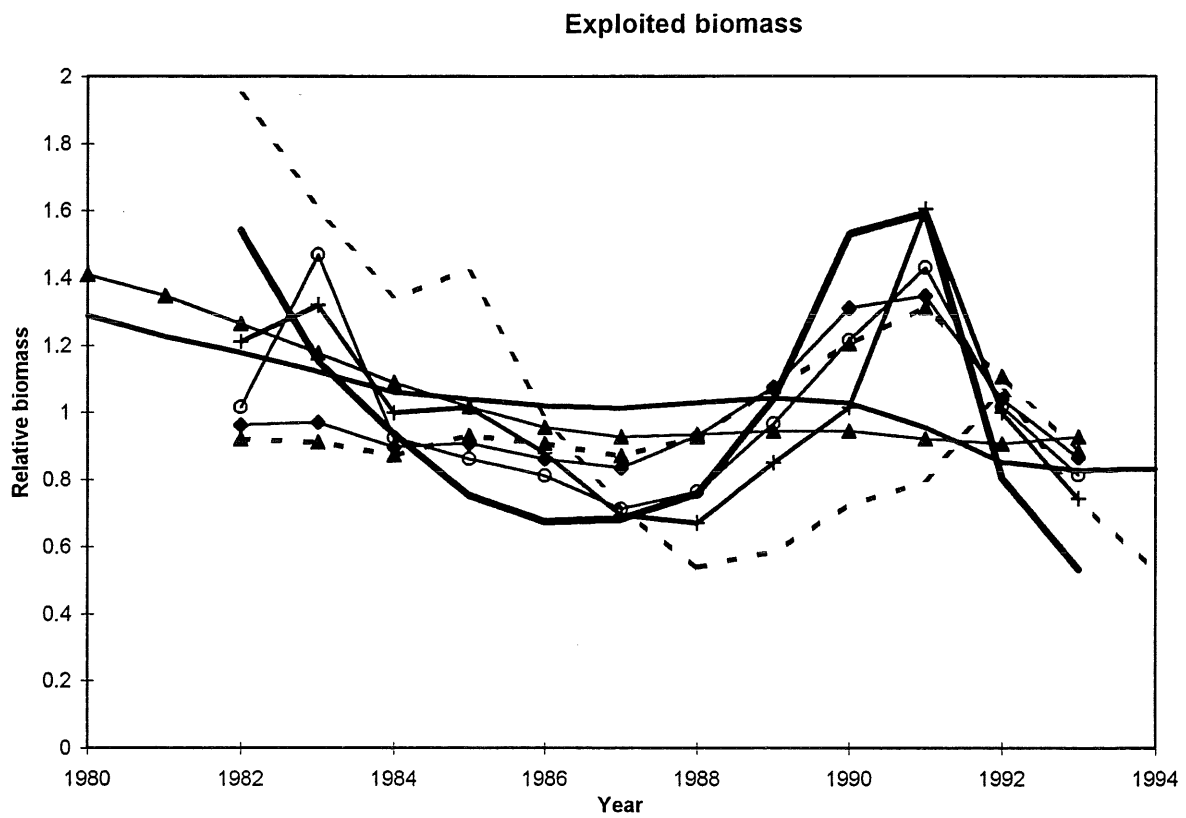
Figure 7.1.2 Comparison of methods.
Icelandic Haddock.

Recruitment

Fishing mortality

Figure 7.1.2 Cont.

Exploited biomass

Spawning stock biomass
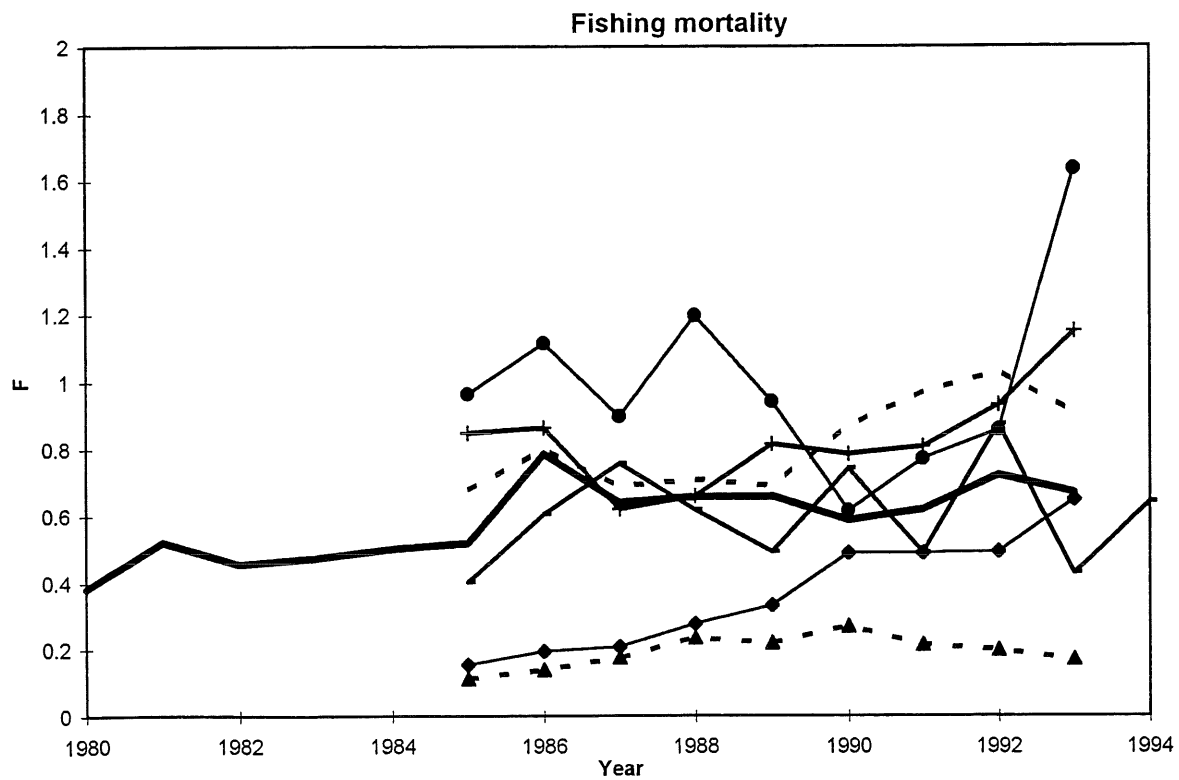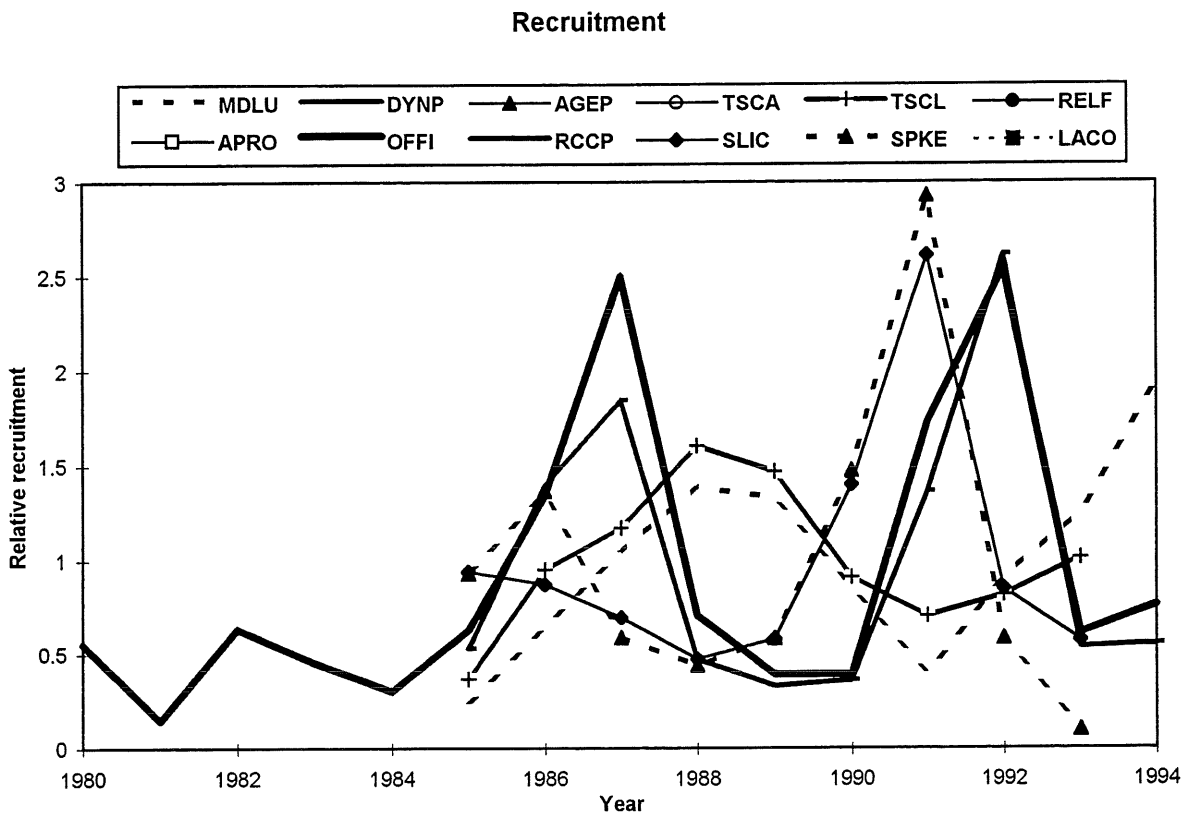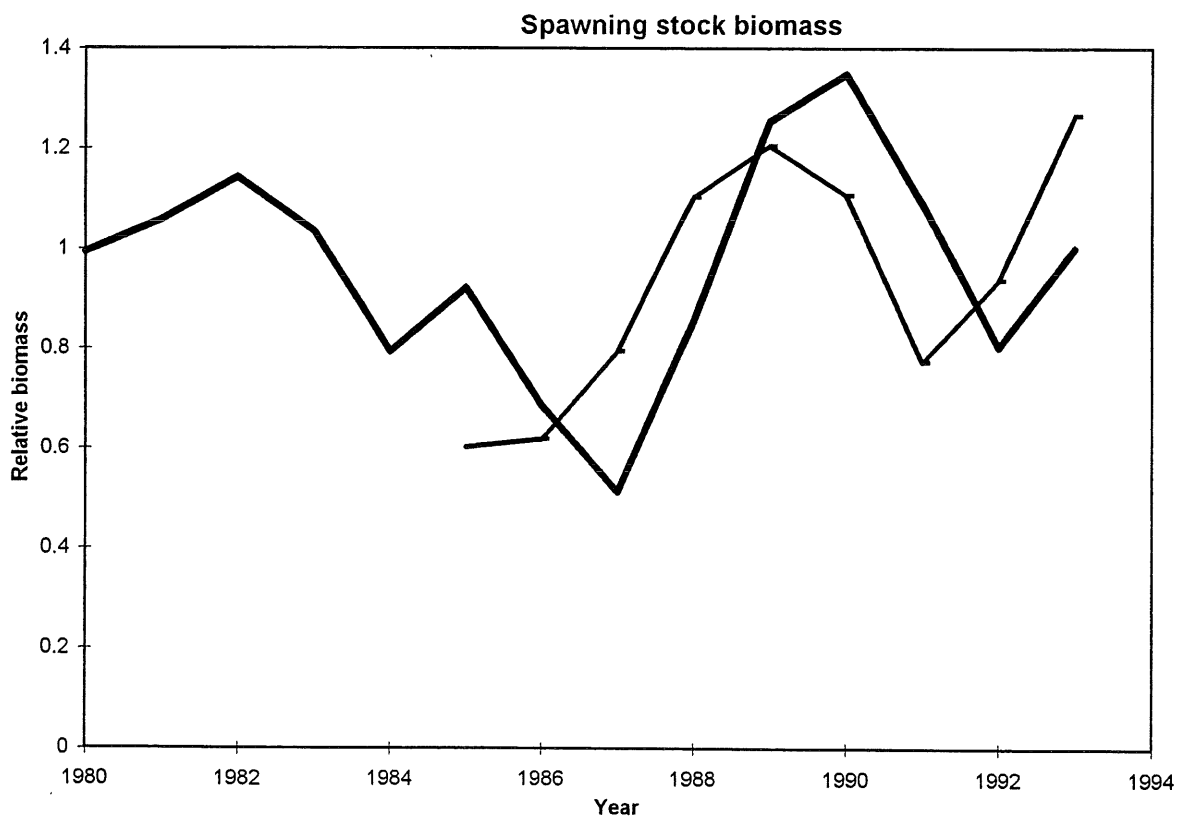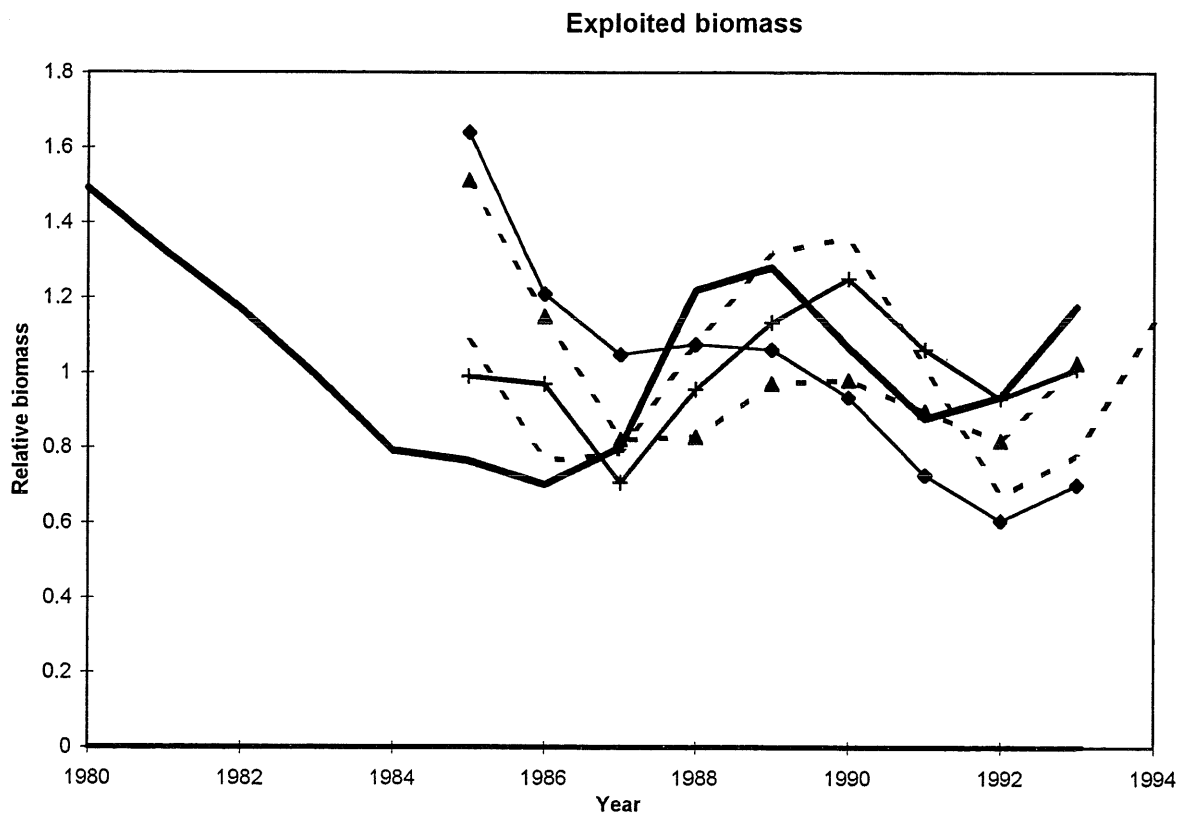
Figure 7.1.3 Comparison of methods.
Icelandic Cod.

Recruitment

Fishing mortality

Figure 7.1.3 Cont.

Exploited biomass

Spawning stock biomass

178
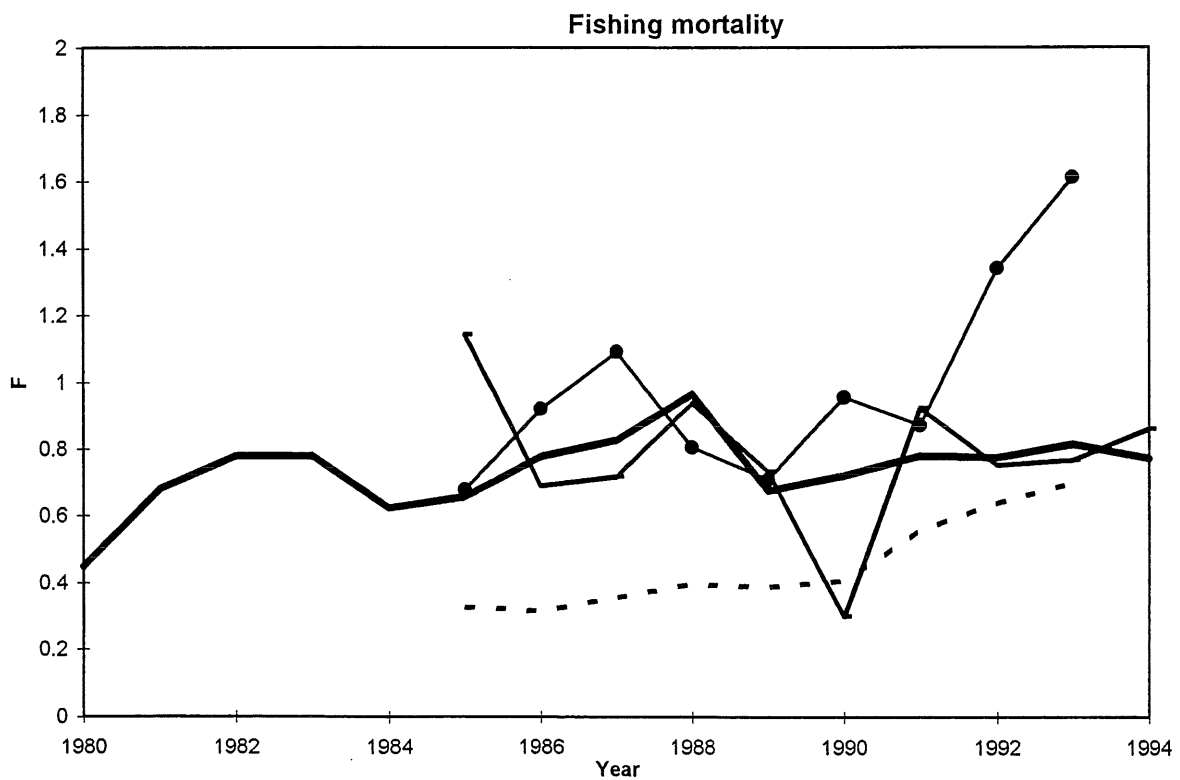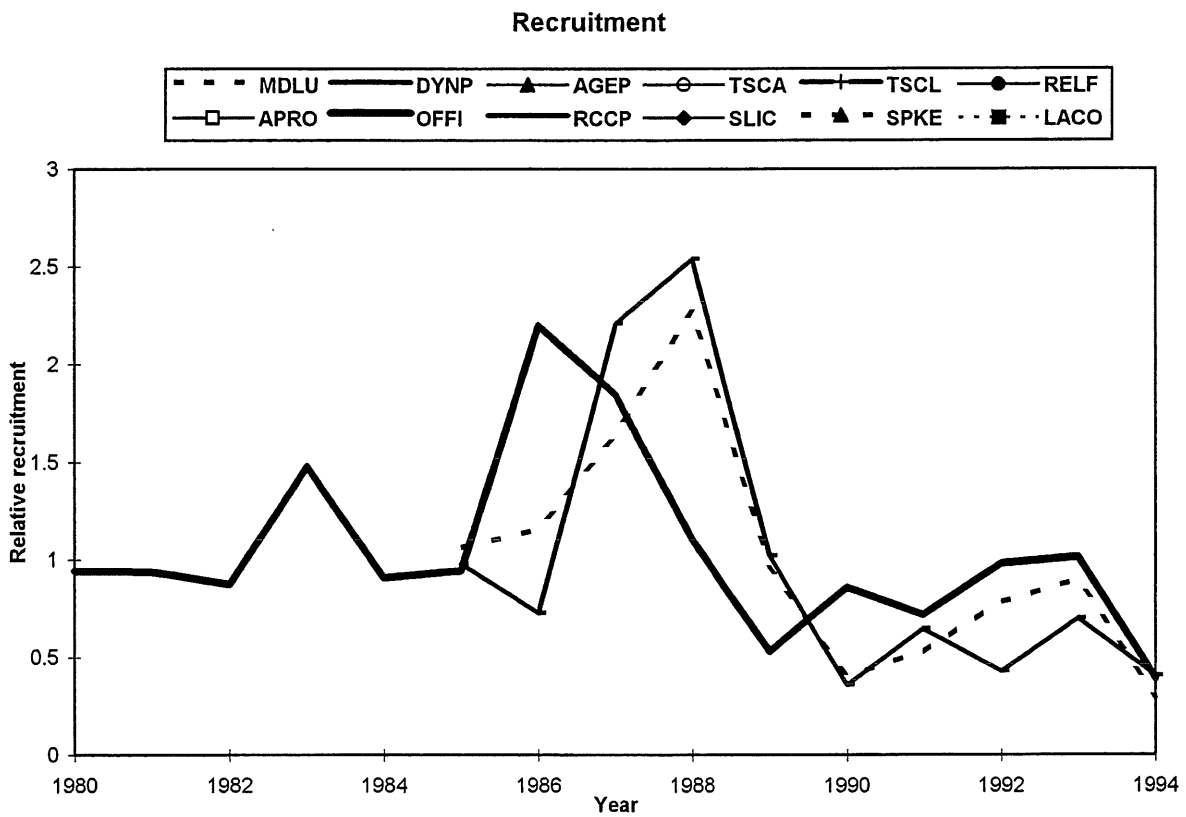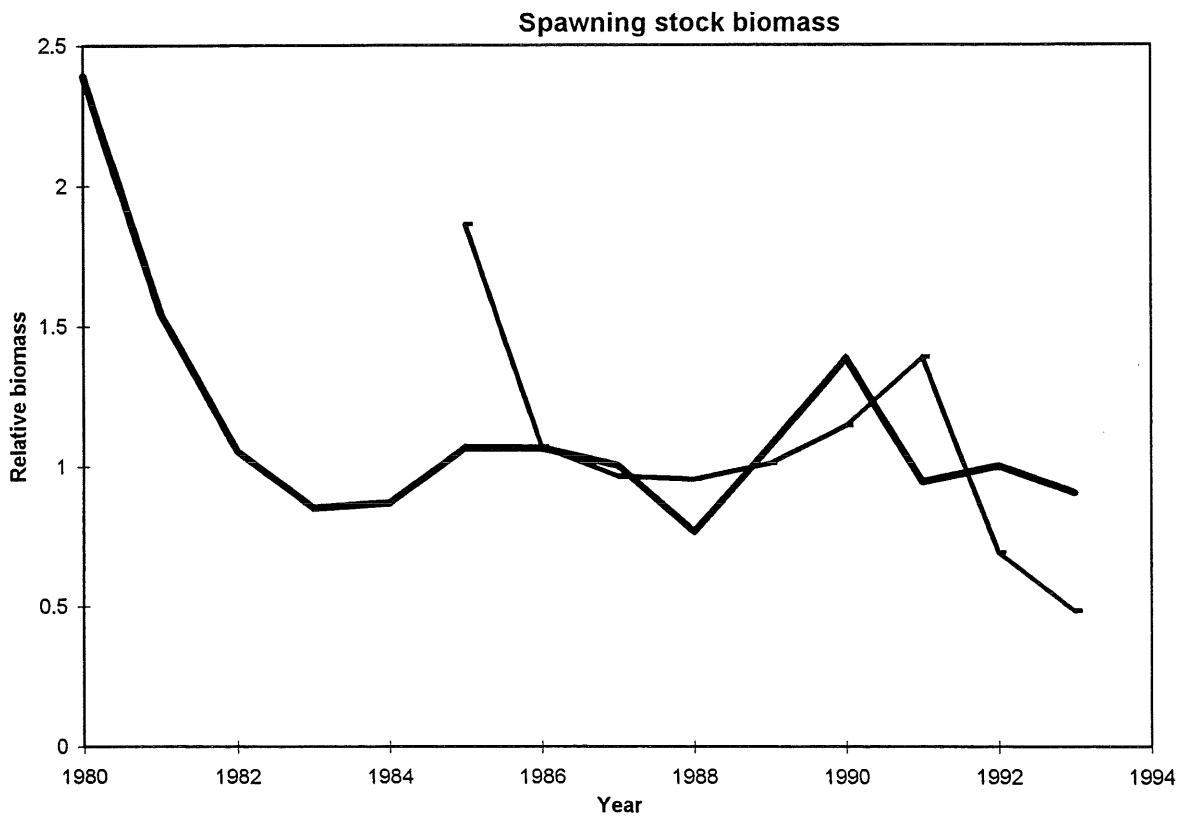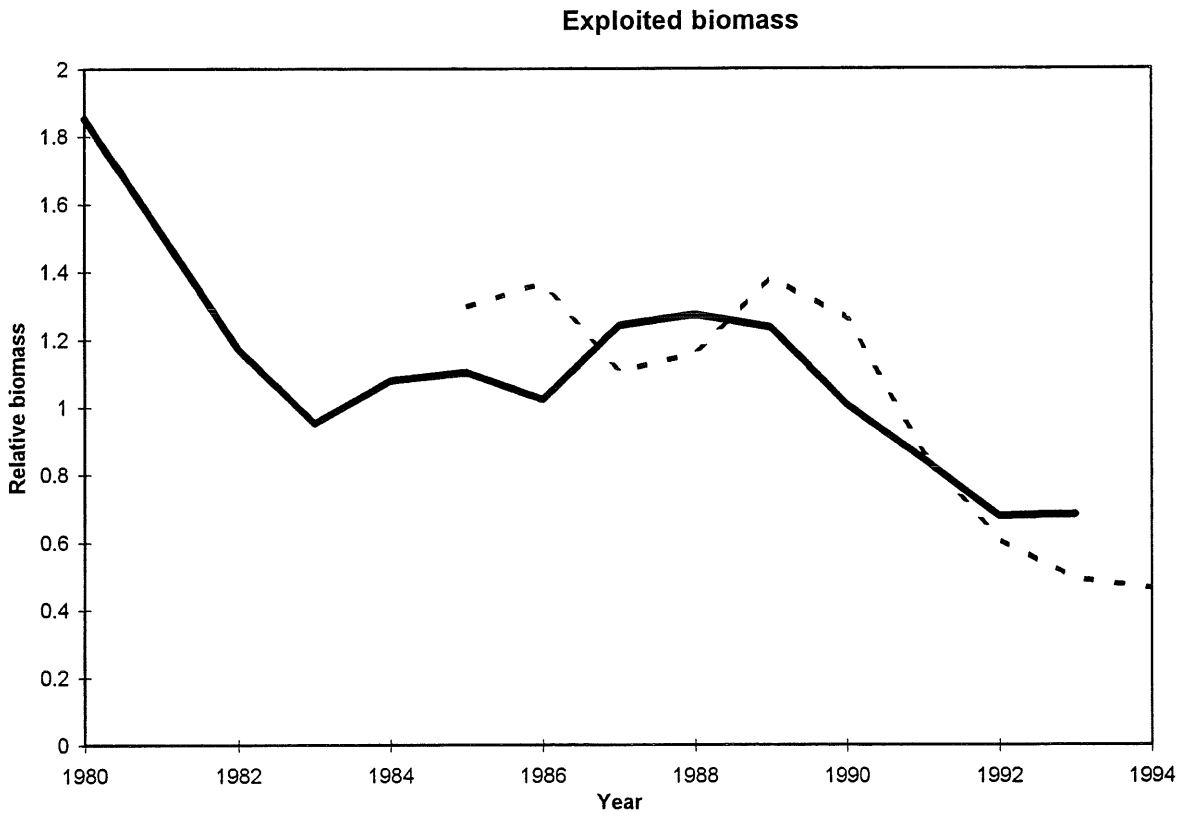
Figure 7.1.4 Comparison of methods.
"Clean" simulated tuna.

Recruitment

Legend: MDLU, DYNP, AGEP, TSCA, TSCL, RELF, APRO, Simulated, RCCP, SLIC, SPKE, LACO

Fishing mortality
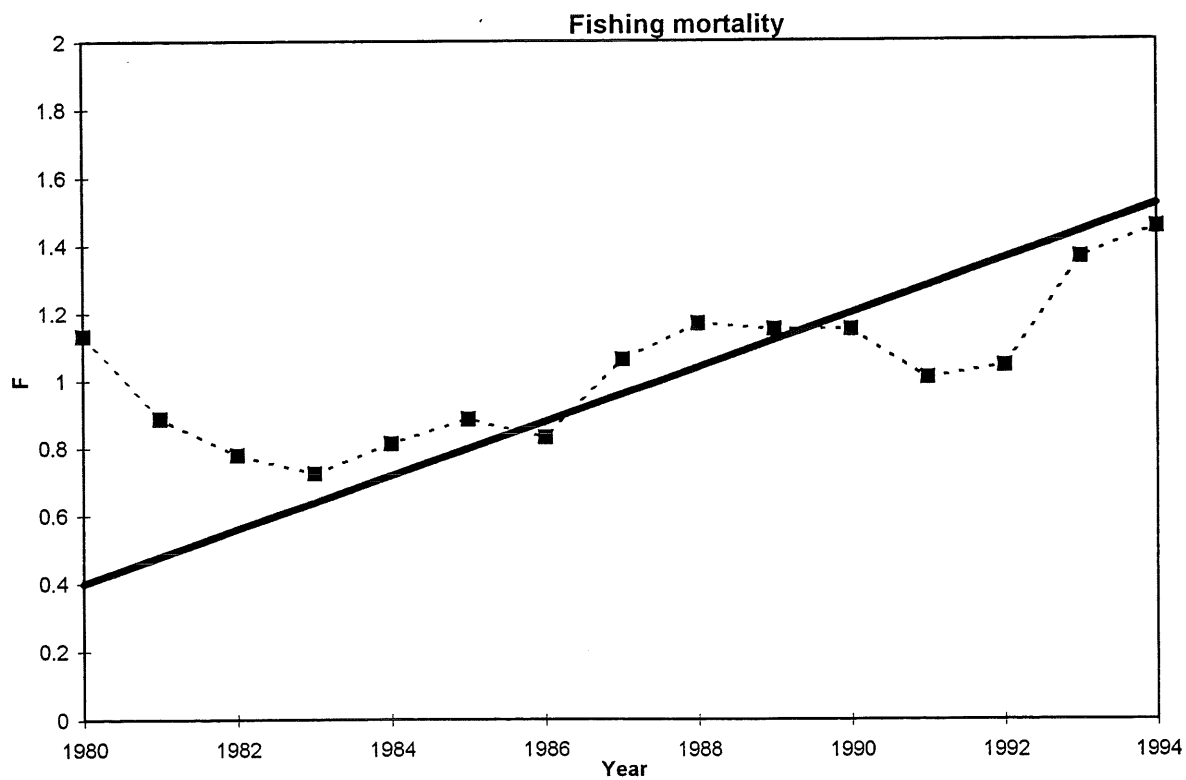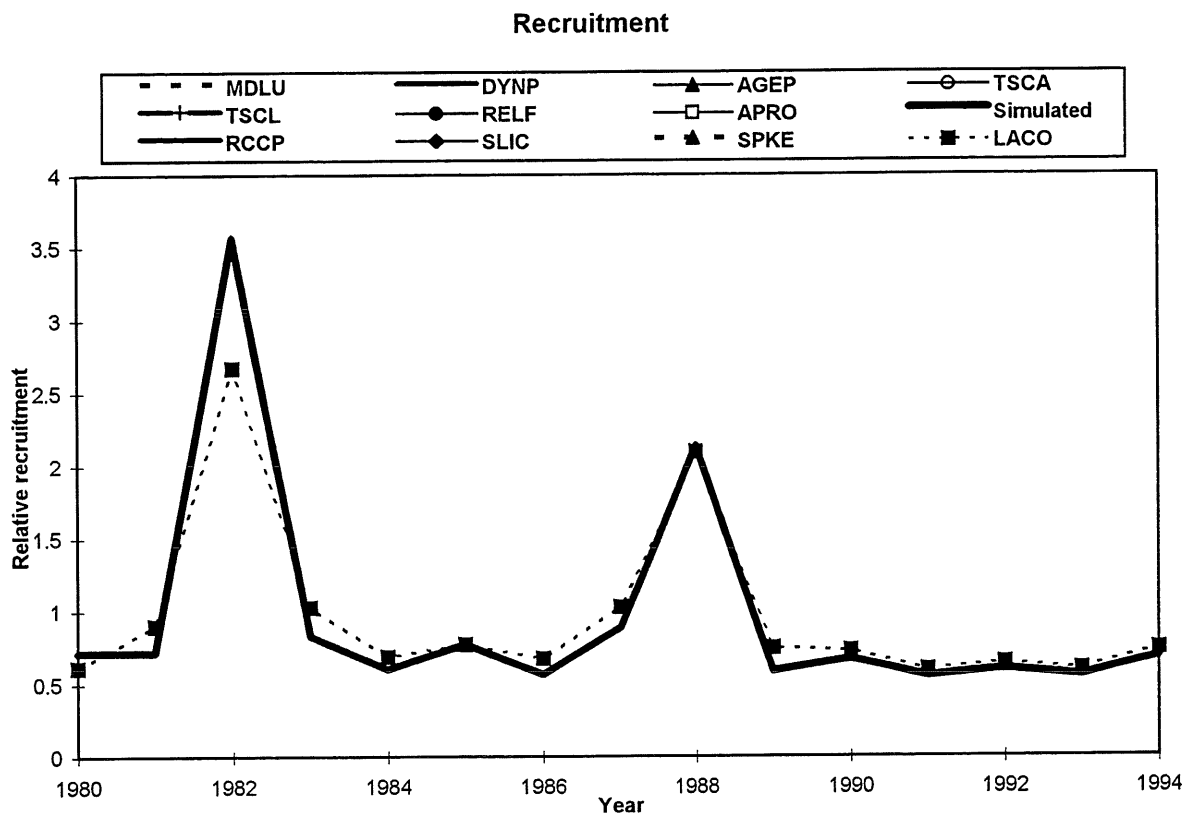
Figure 7.1.5 Comparison of methods.
North Sea Haddock.

Recruitment

- - - MDLU	———DYNP	—▲—AGEP	—⊖—TSCA	—+—TSCL	—●—RELF
—□—APRO	——OFFI	——RCCP	—◆—SLIC	- ▲ - SPKE	··■··LACO

Fishing mortality

Spawning stock biomass
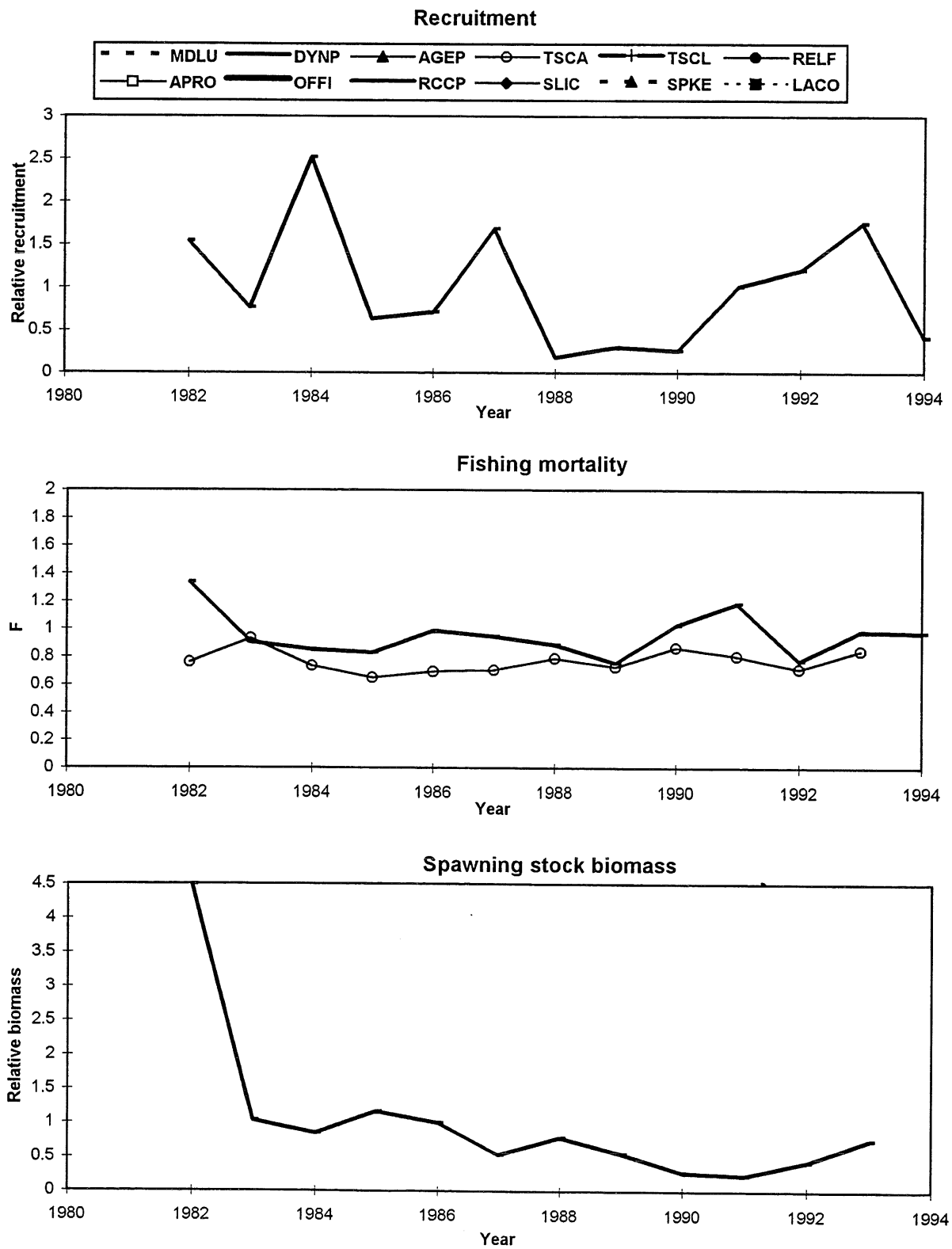
Figure 7.1.6 Comparison of methods.
Southern Gulf cod
4T 4Vn (Nov-May).

Recruitment

Fishing mortality

Spawning stock biomass

181
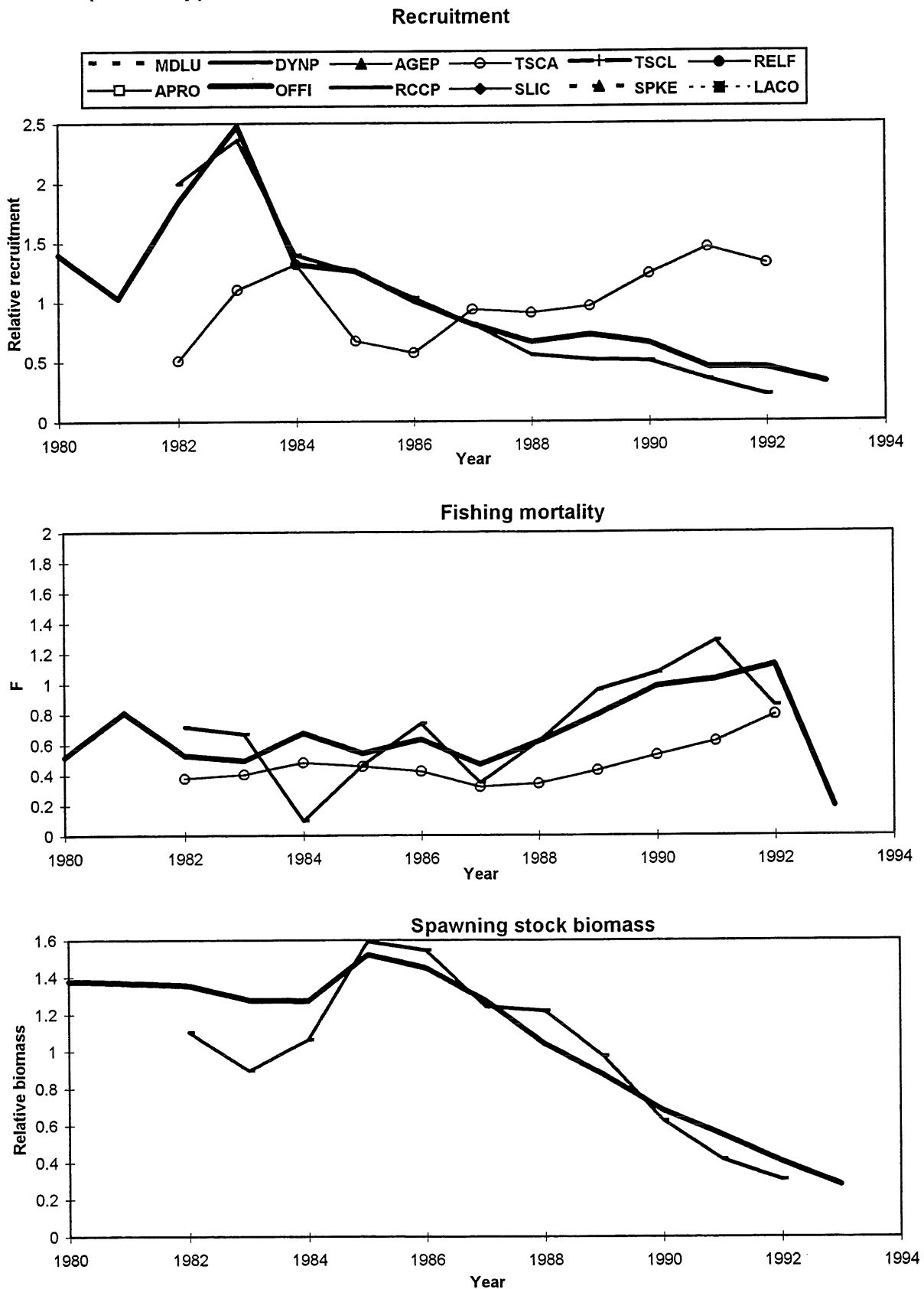
Figure 7.1.7 Comparison of methods.
Canadian Redfish.

Recruitment

Fishing mortality

Exploited biomass
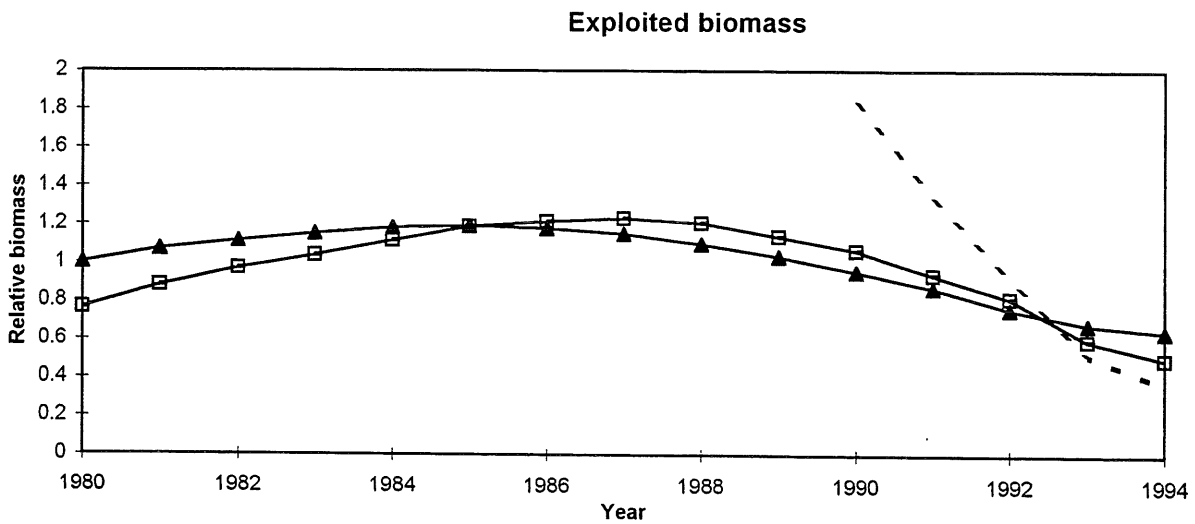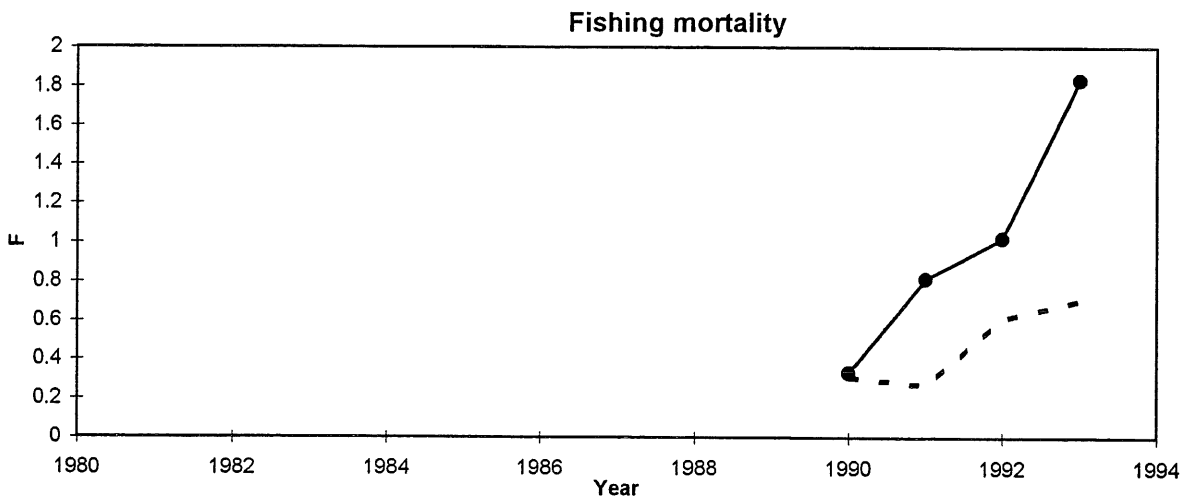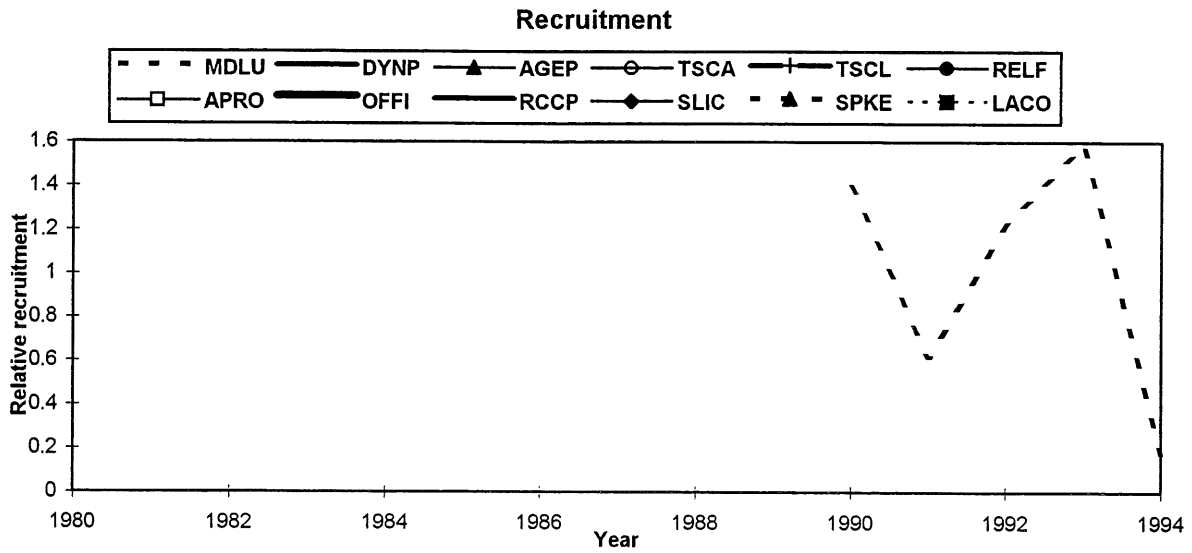
Figure 7.1.8 Comparison of methods.
Icelandic data on *S. marinus.*

Recruitment

Fishing mortality

Figure 7.1.8 Cont.

Exploited biomass
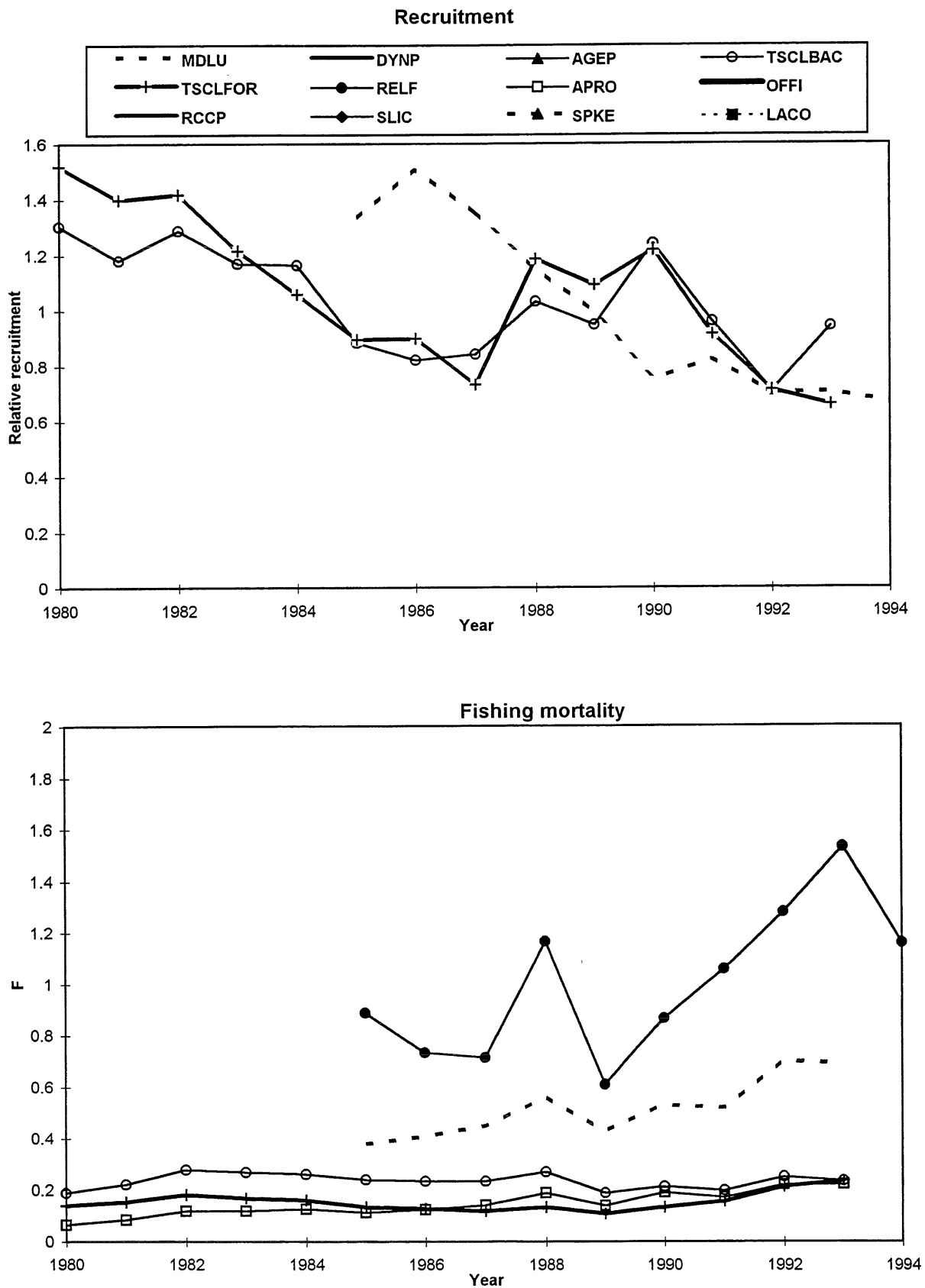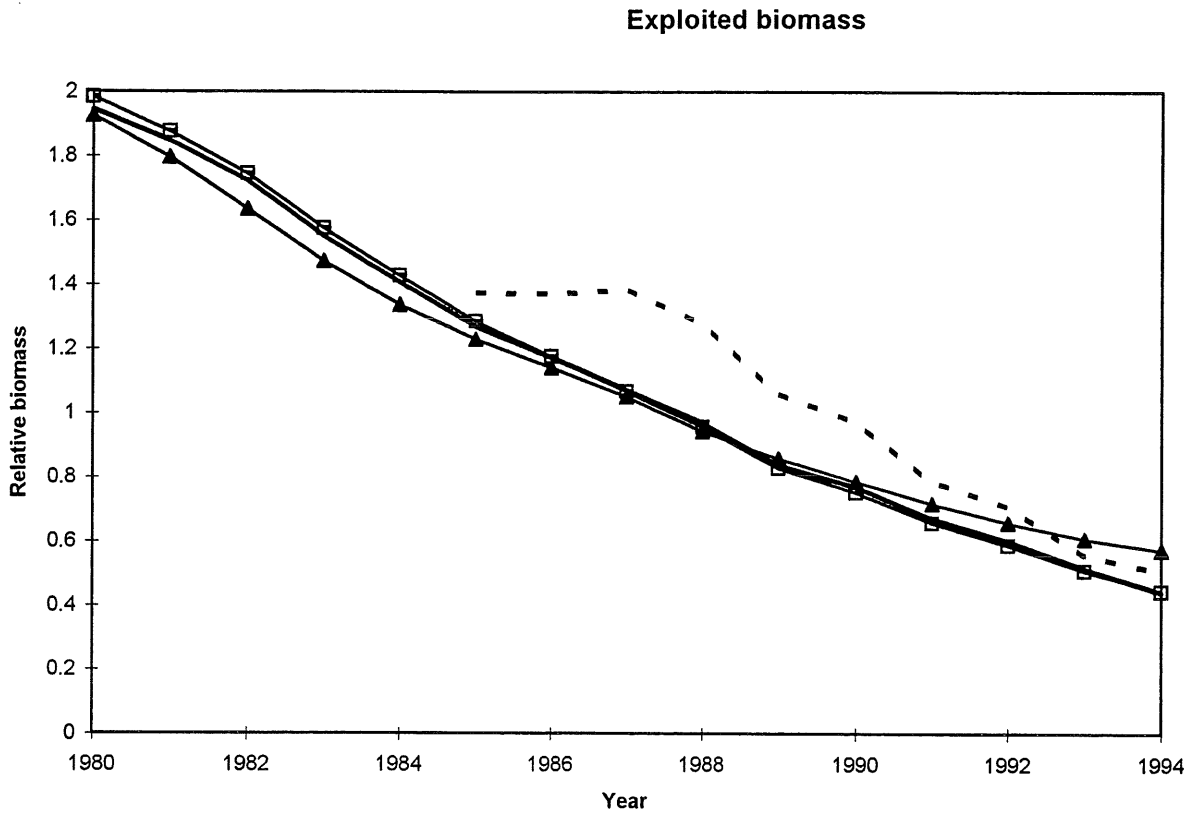
Figure 7.1.9 Comparison of methods.
Pacific Ocean Pearch.
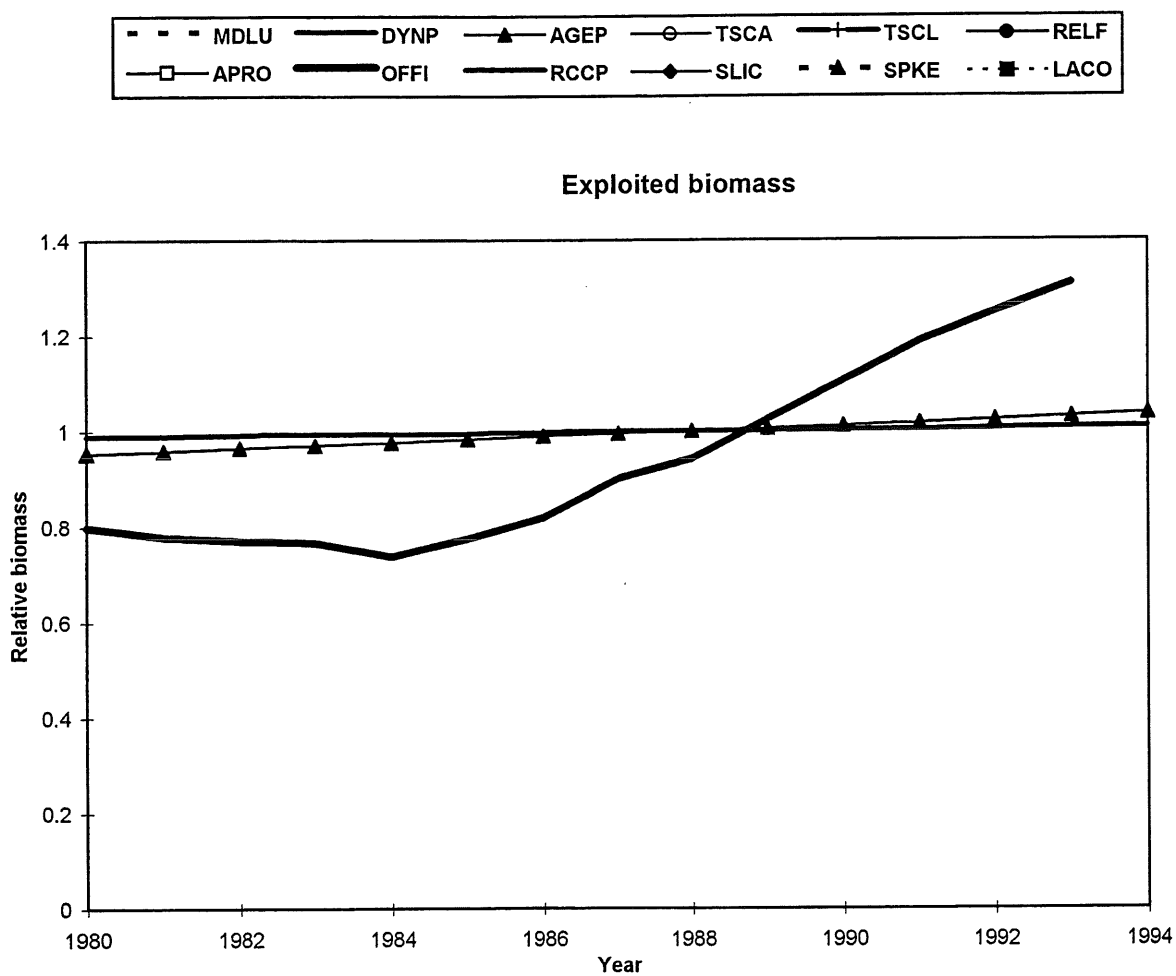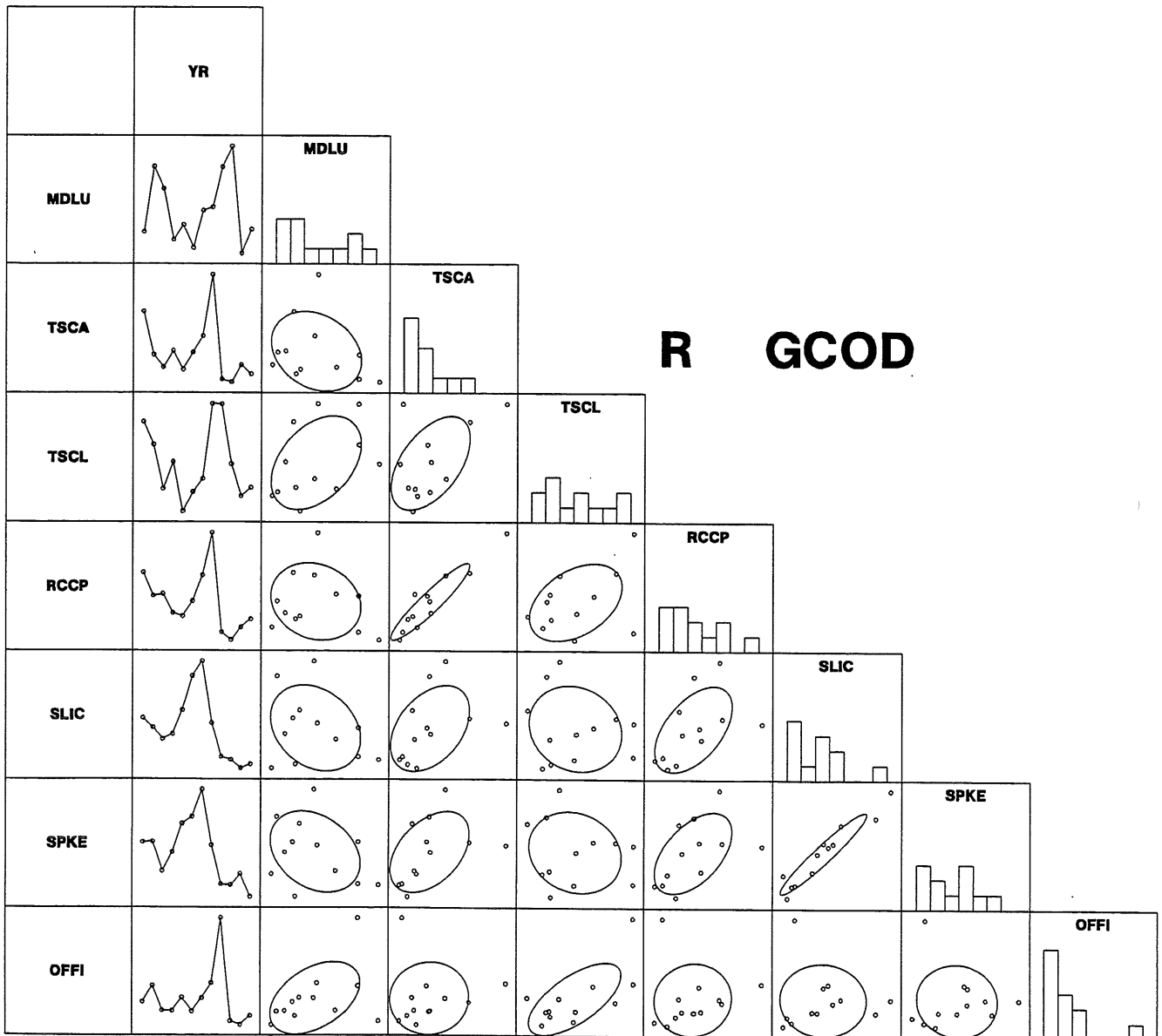
Exploited biomass

Figure 7.2.1a

Figure 7.2.1b

Figure 7.2.1c

R ICOD

OFFI

RCCP

MDLU

YR

OFFI

RCCP

MDLU

OFFI

Figure 7.2.a

EB ICOD

OFFI

RCCP

MDLU

YR

OFFI

RCCP

MDLU
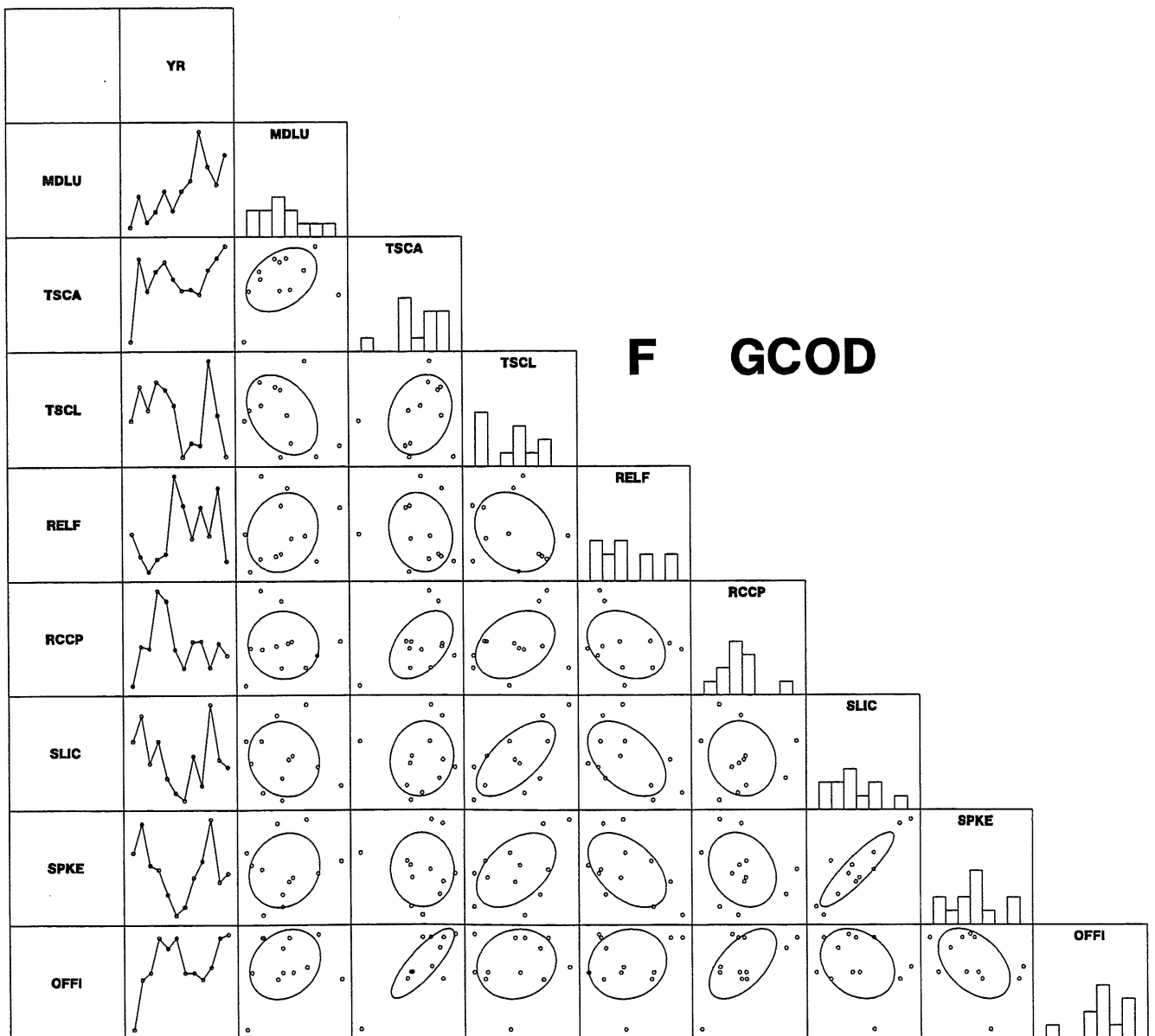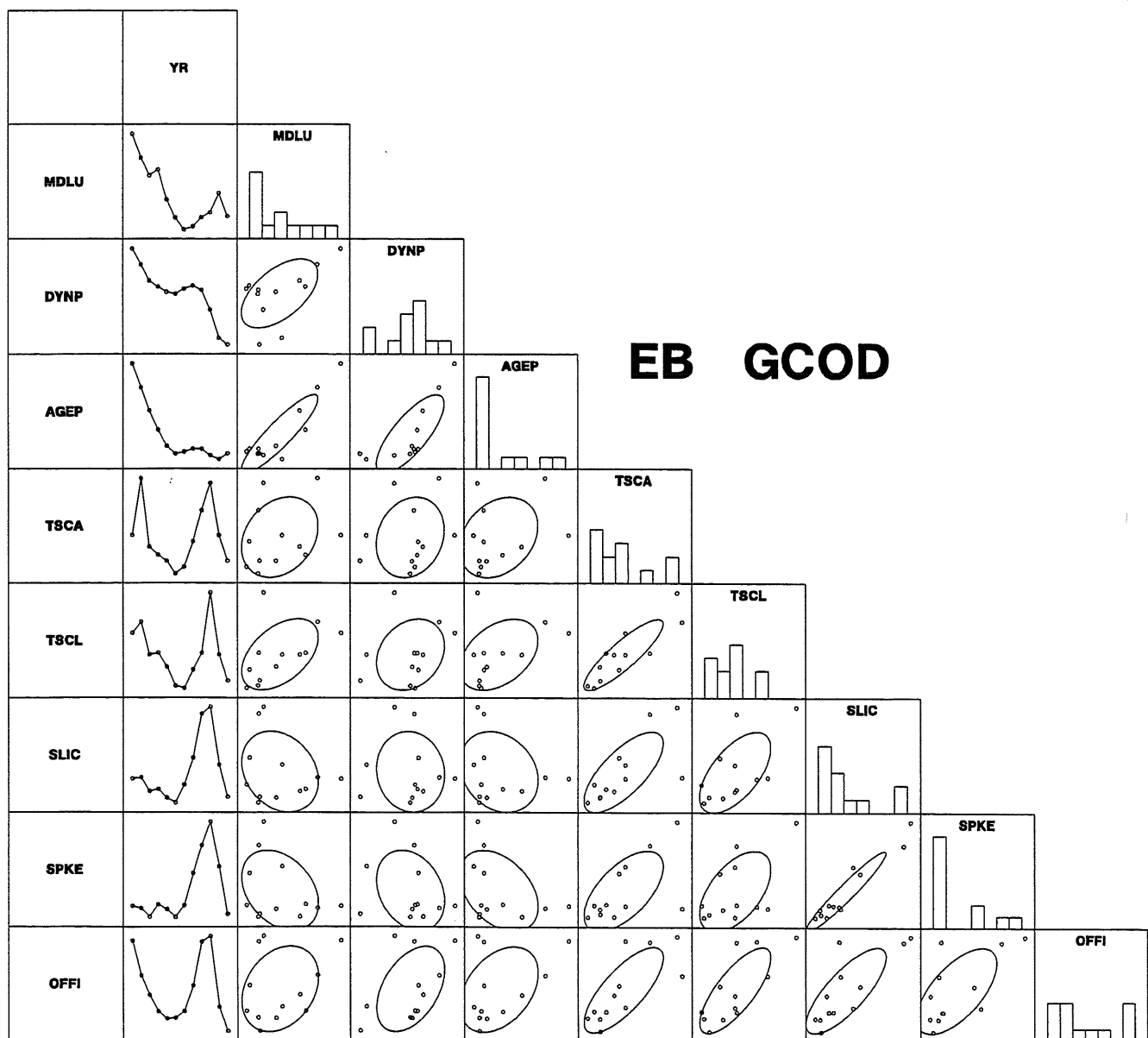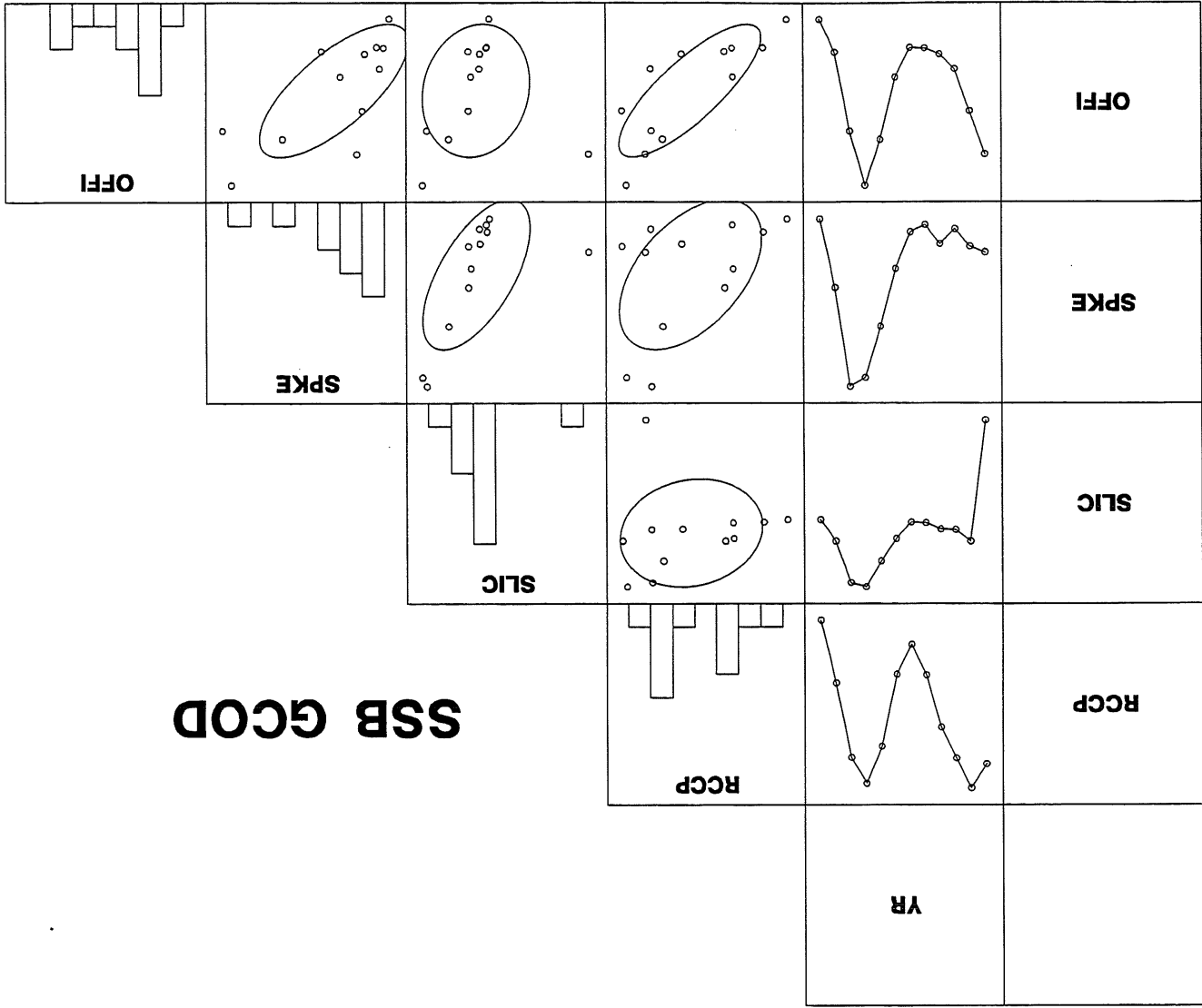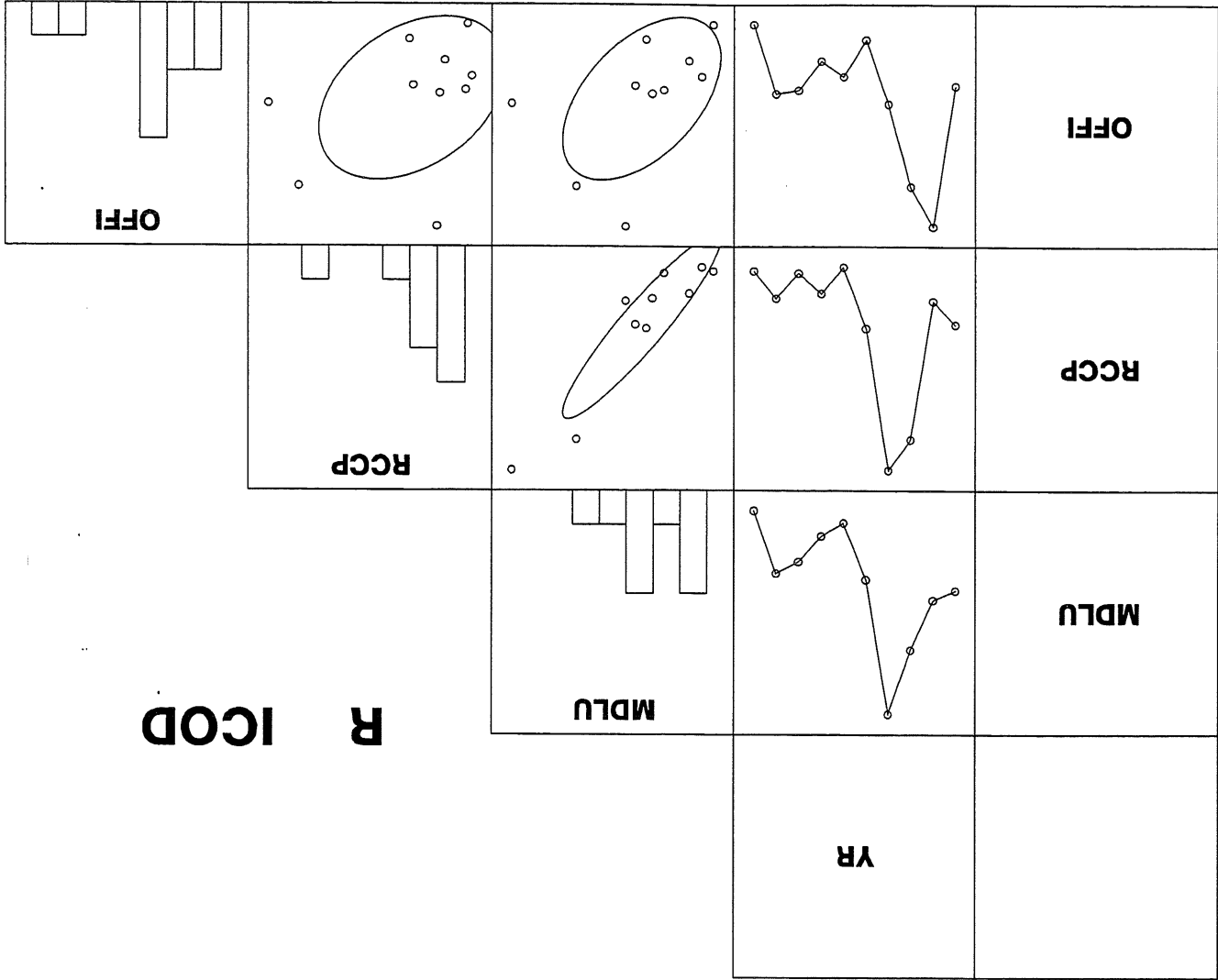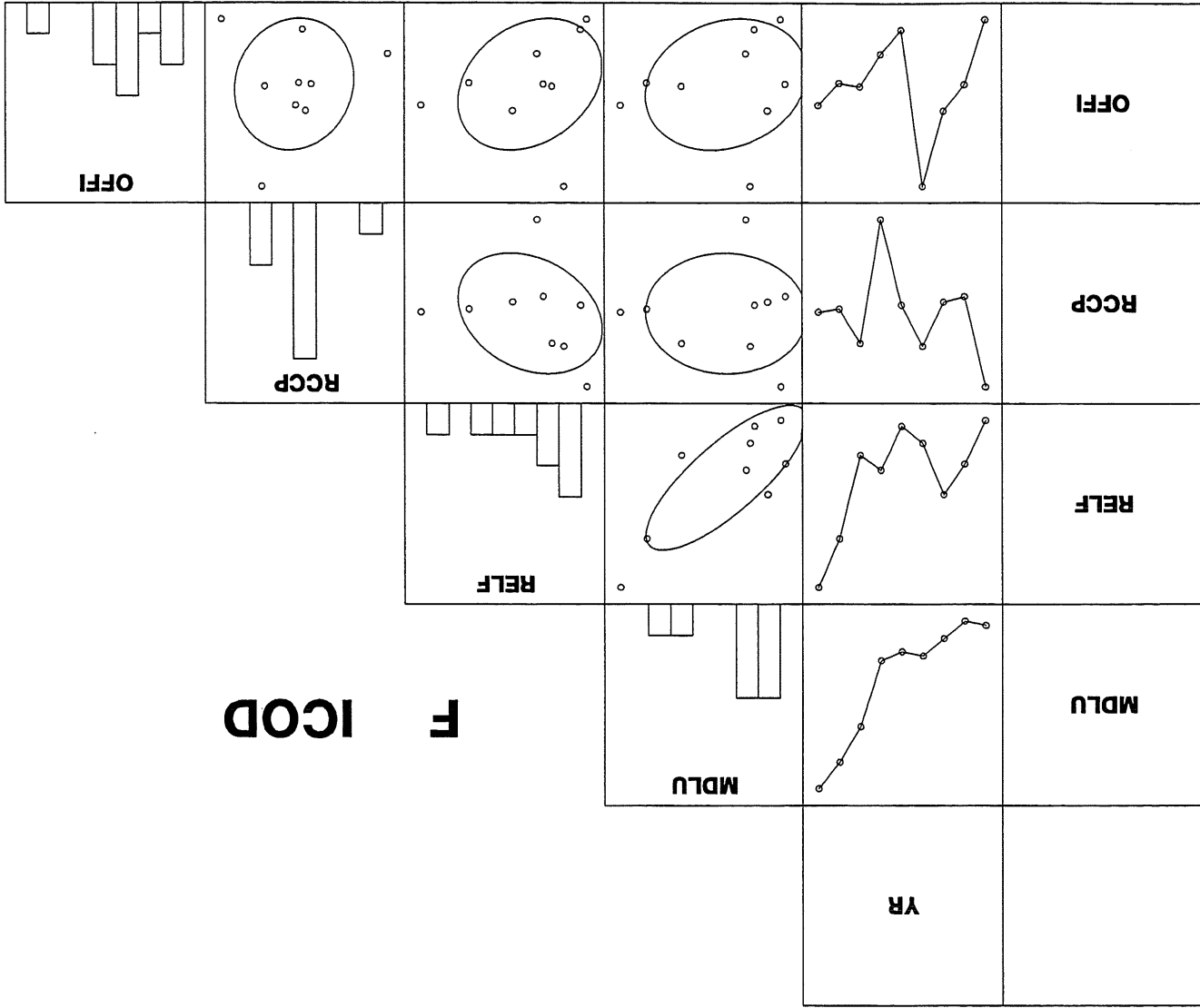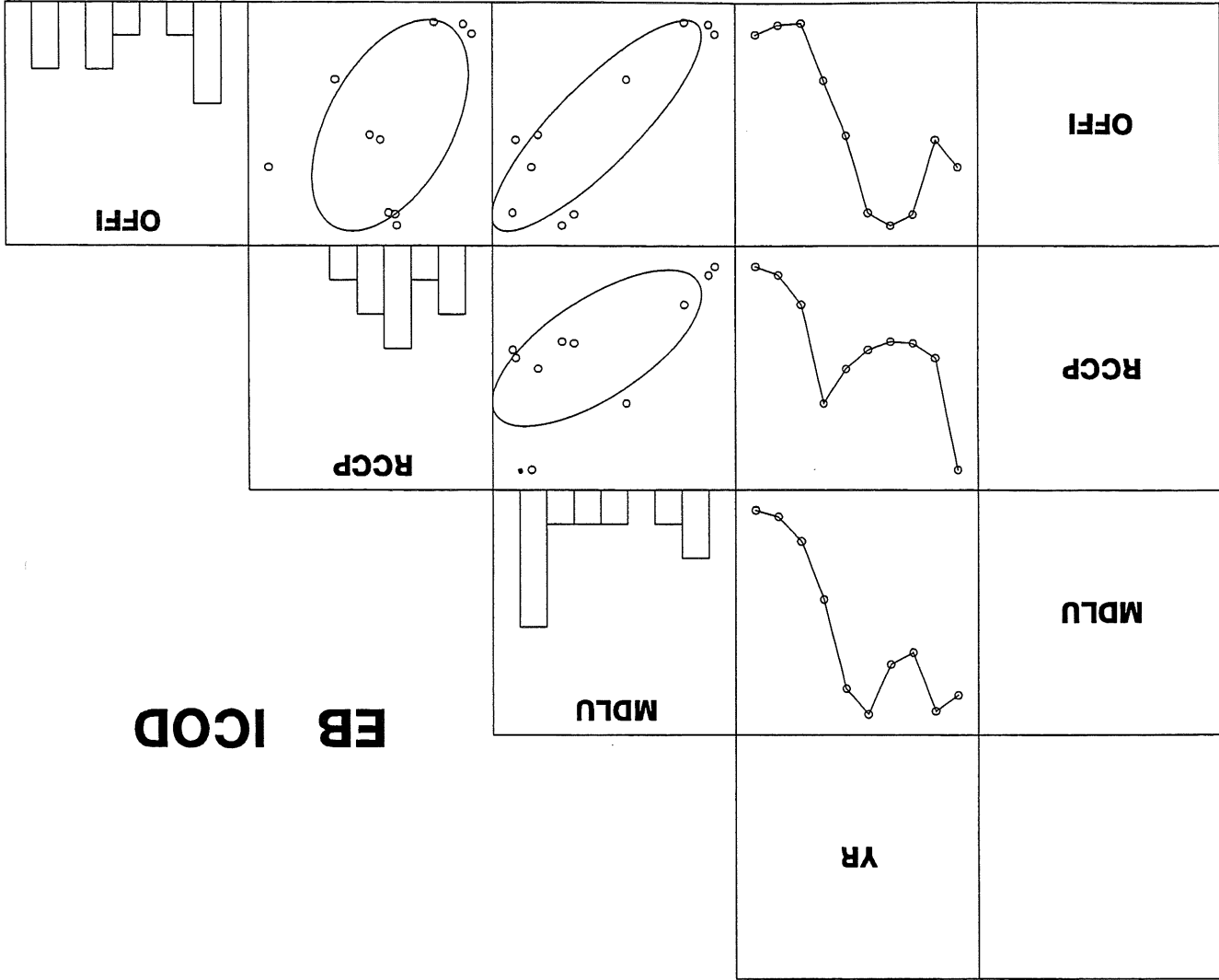
Figure 7.2.2.c

Figure 7.2.3.a

Figure 7.2.3.b

F IHAD

CTUN R

OFFI

LACO

YR

LACO

OFFI

Figure 7.2.4a

FUCTN F

OFFI

LACO

OFFI

LACO

YR

OFFI

Figure 7.2.4b

Figure 7.2.5a

R 4HAD

RCCP

YR

RCCP

RCCP

RCCP

RCCP

YR

SSB 4HAD

Figure 7.2.5c

641.0L

Figure 7.2.6a

RCCP

EB 4COD

YR

RCCP

Figure 7.2.6c

F CRED

RELF

MDLU

RELF

MDLU

YR

RELF

Figure 7.2.7b

Figure 7.2.7c

APRO

APRO

AGEP

APRO

AGEP

YR

EB CRED

Figure 7.2.7d

APRO

RELF

TSCL

TSCA

MDLU

YR

APRO

RELF

TSCL

TSCA

MDLU
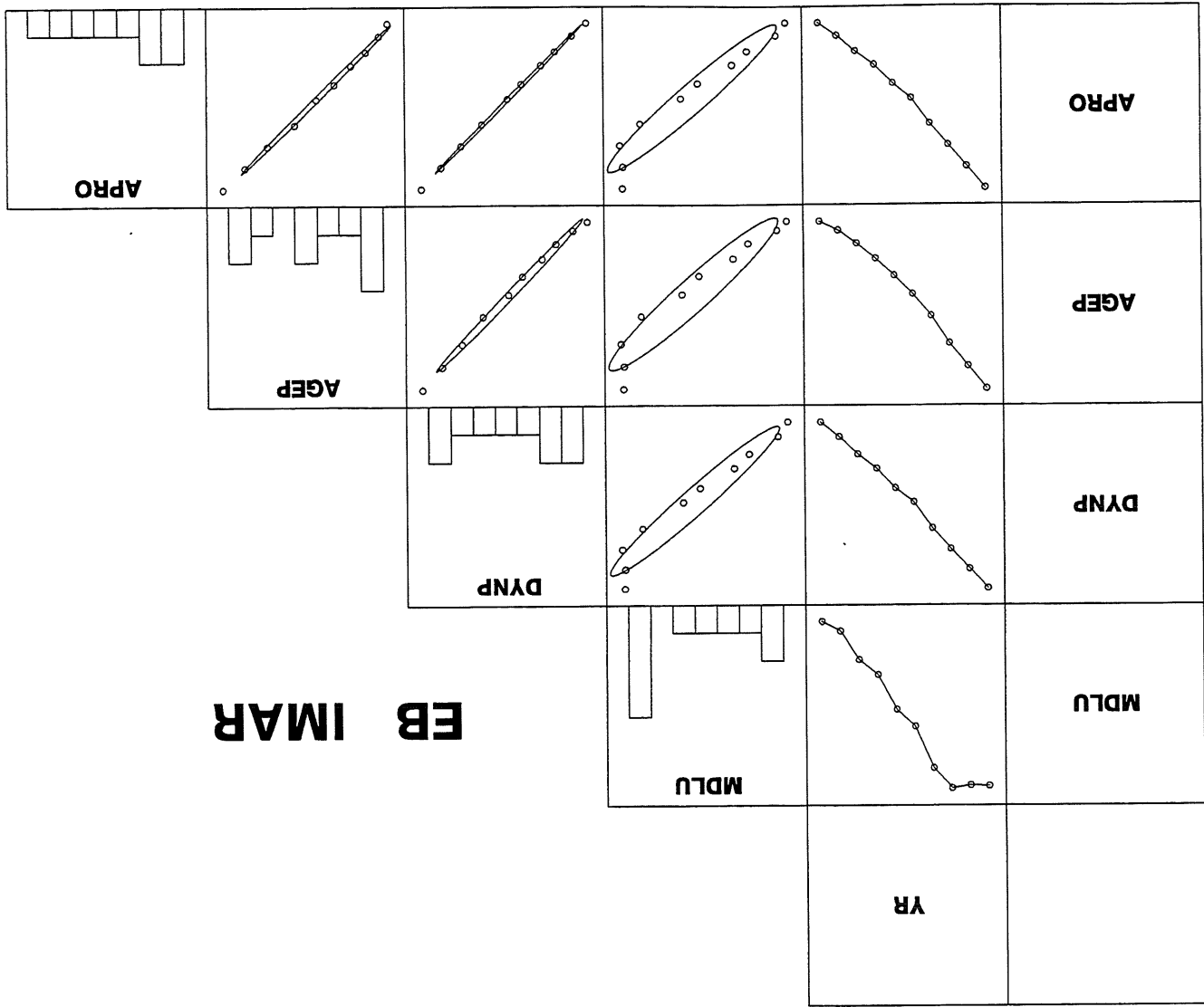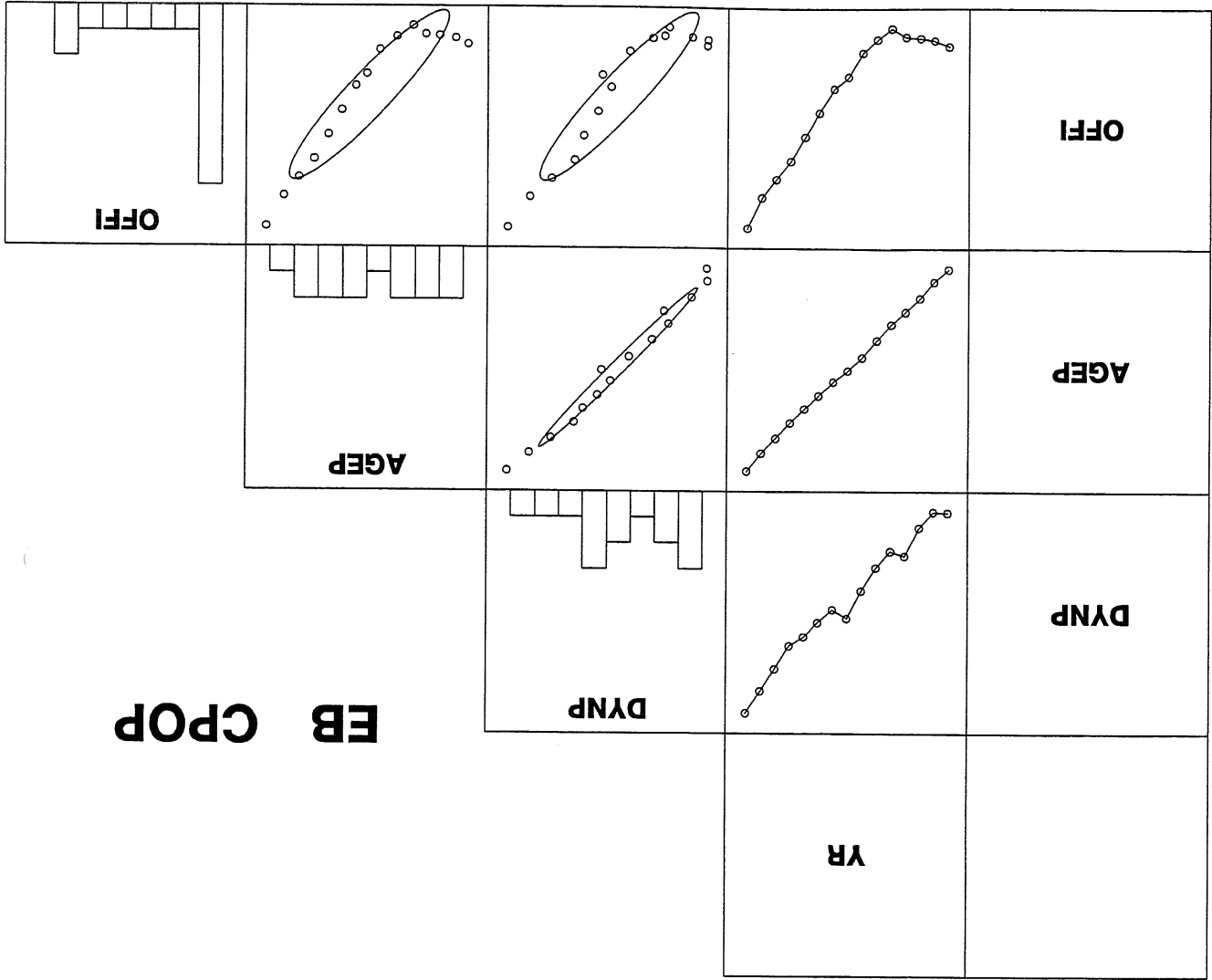
IMAR F

Figure 7.2.8b

EB IMAR

APRO

AGEP

DYNP

MDLU

YR
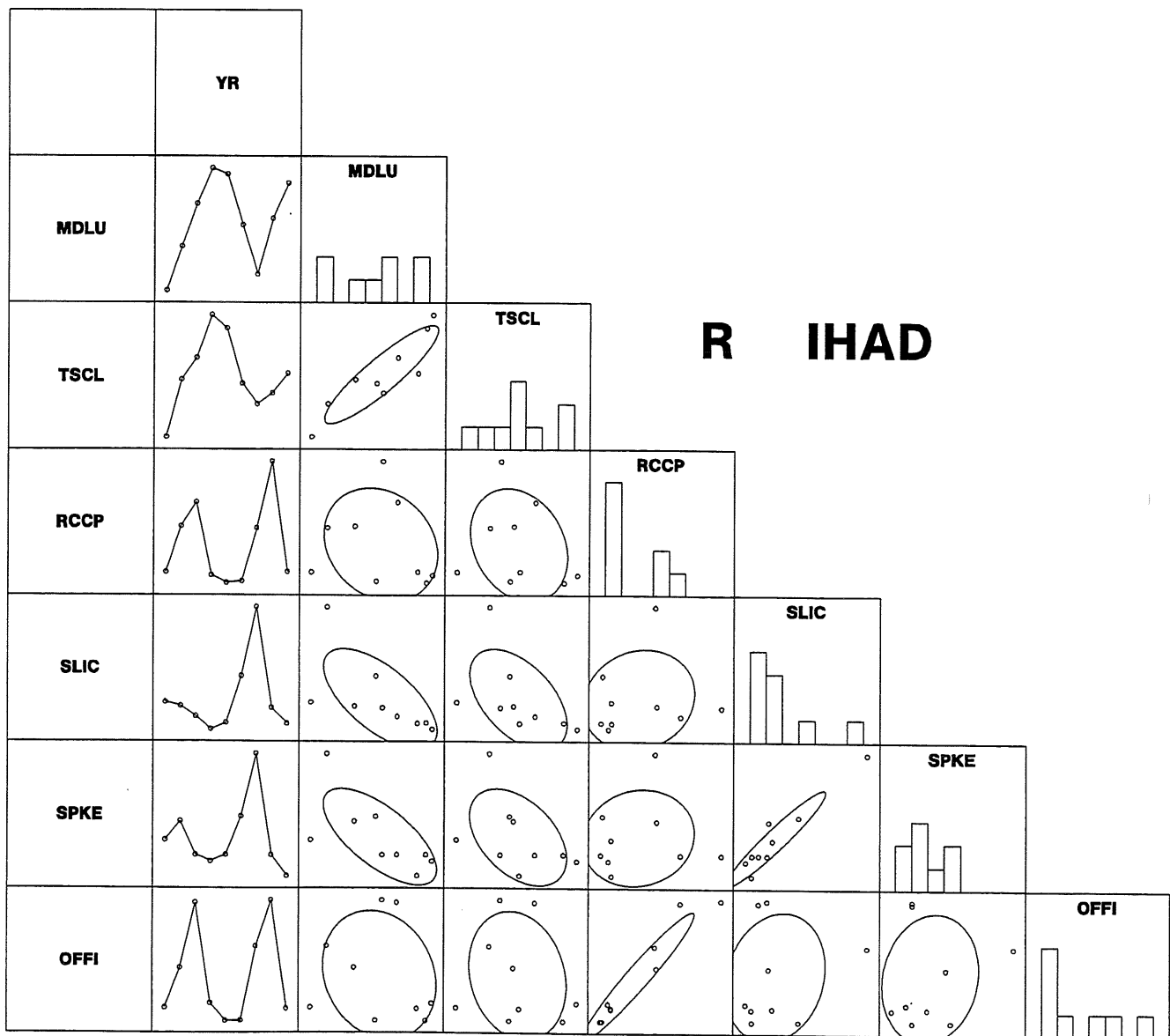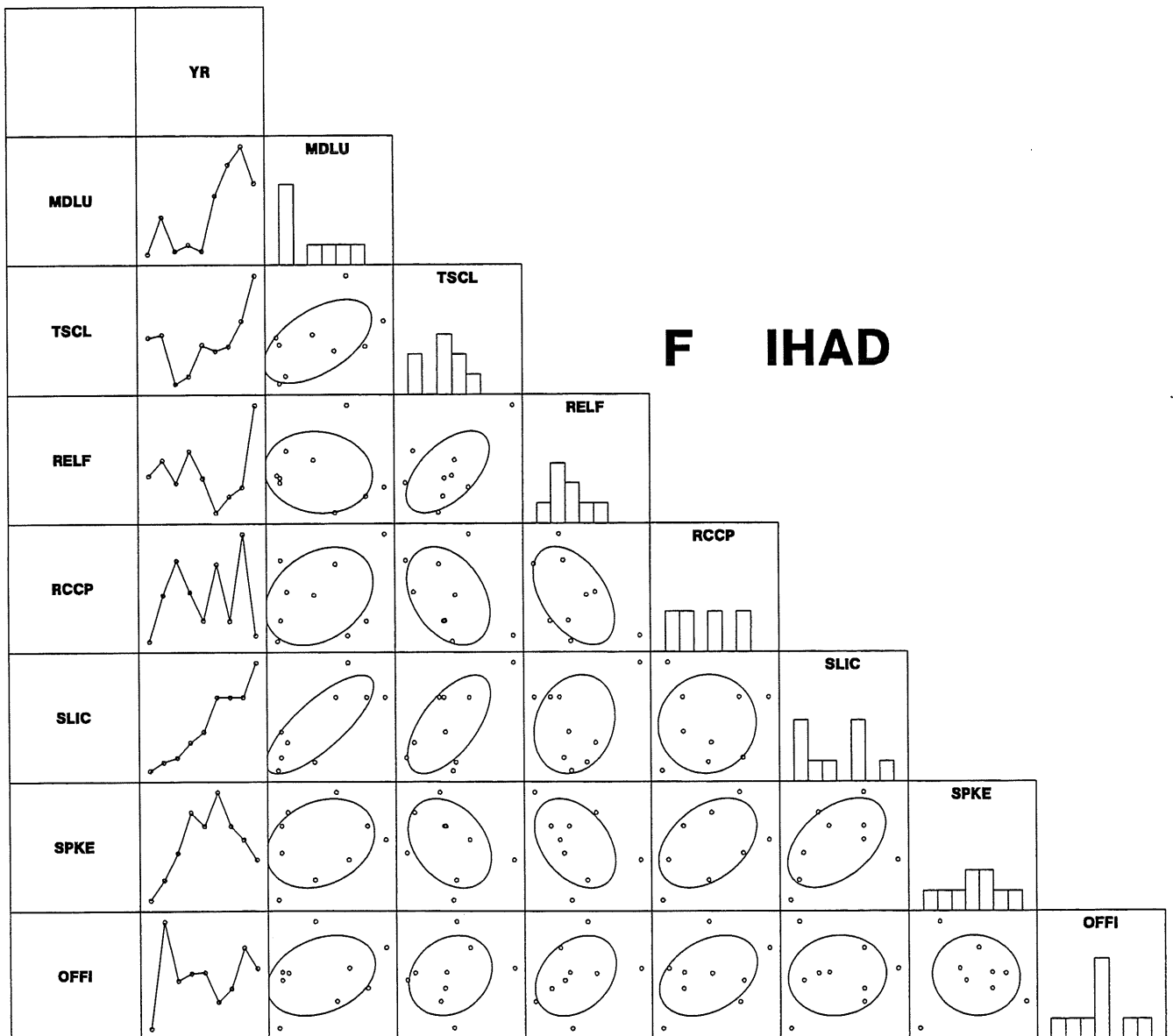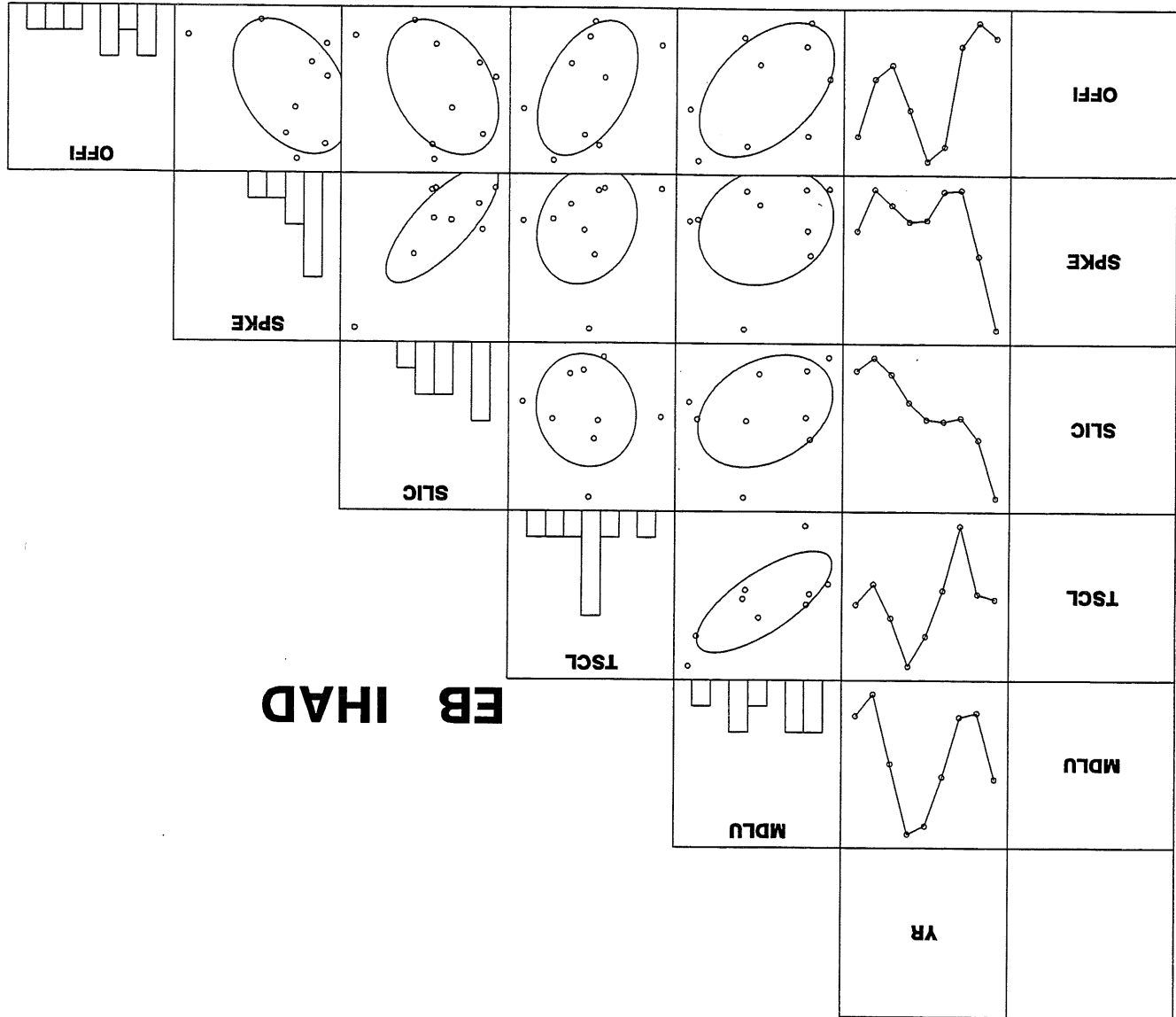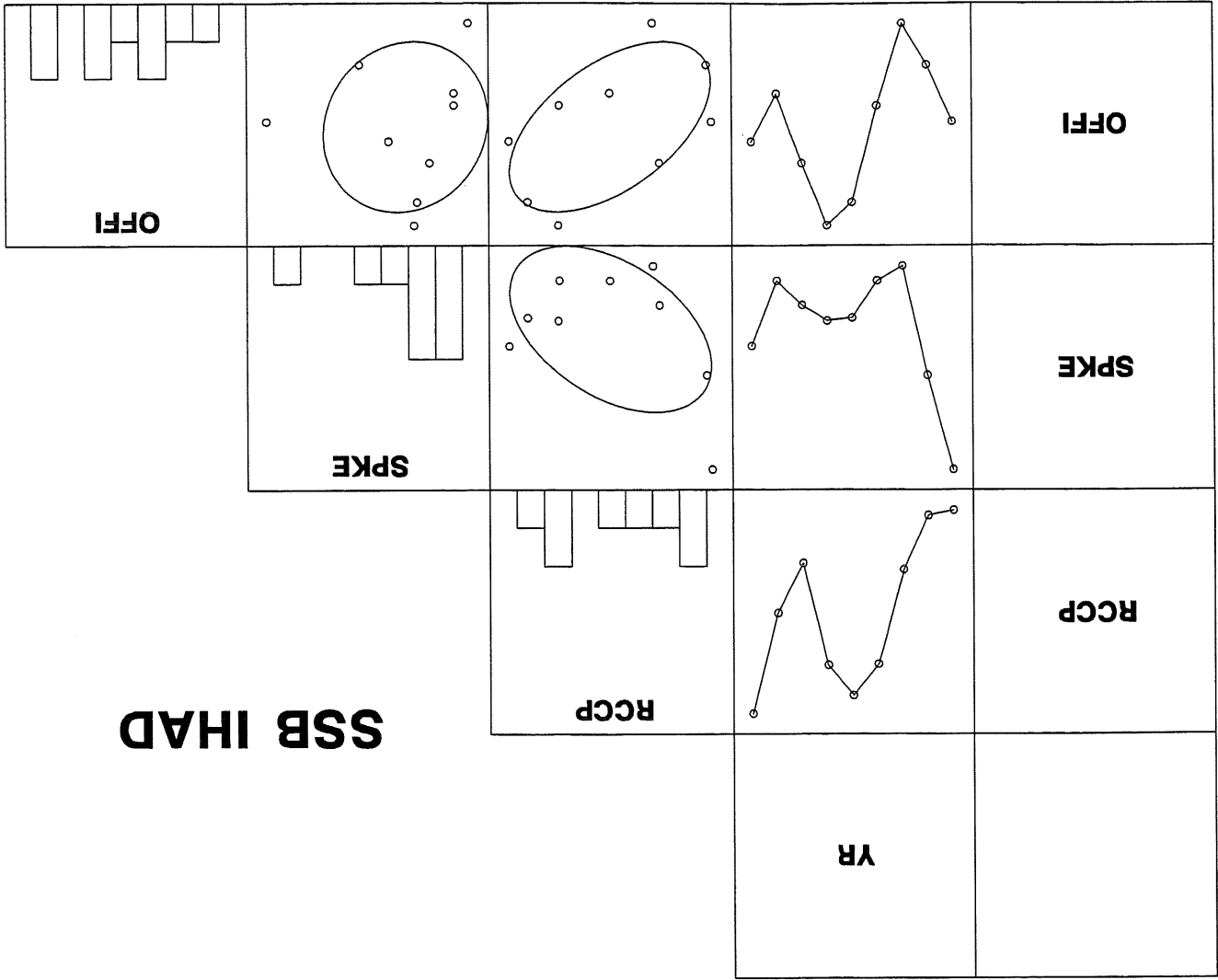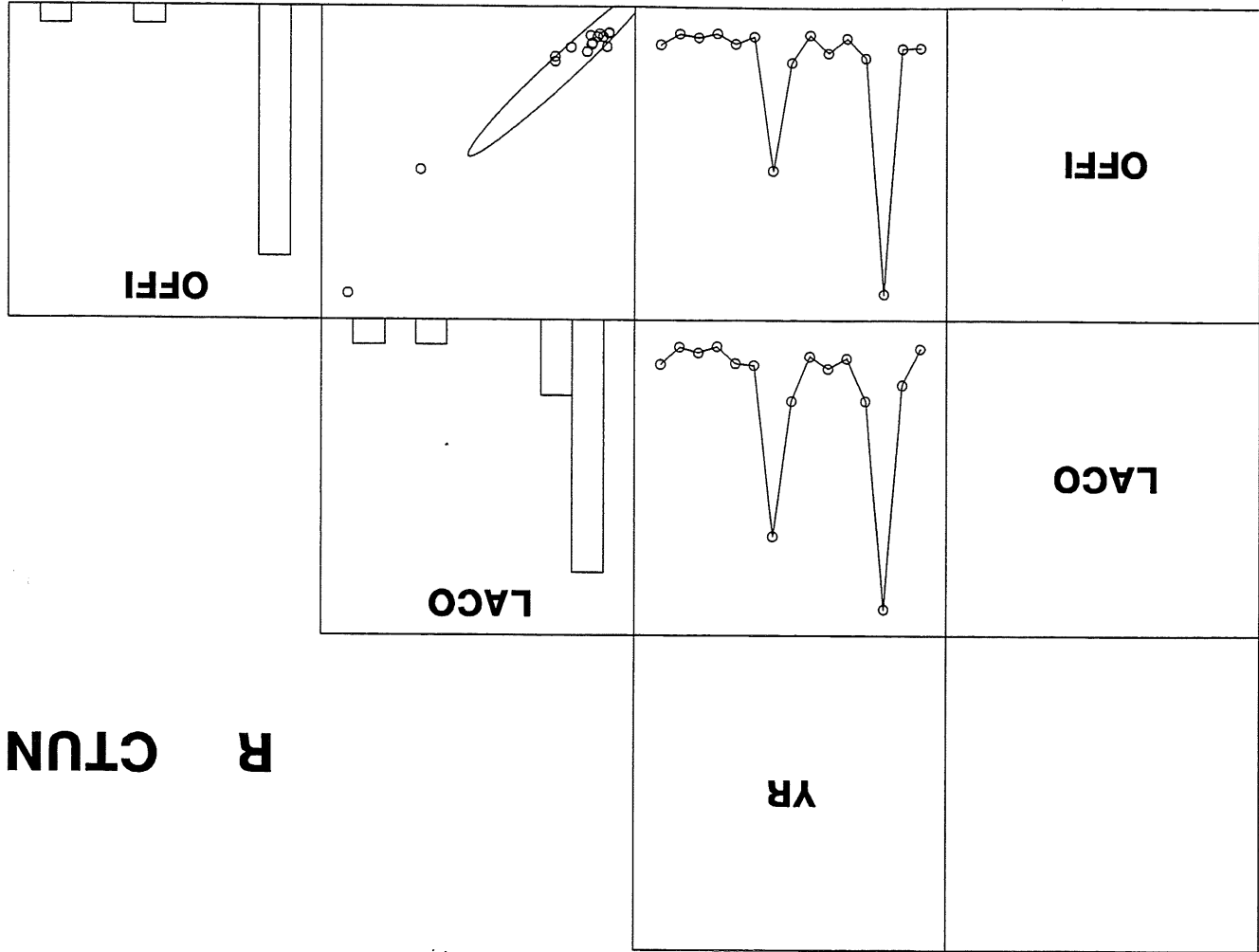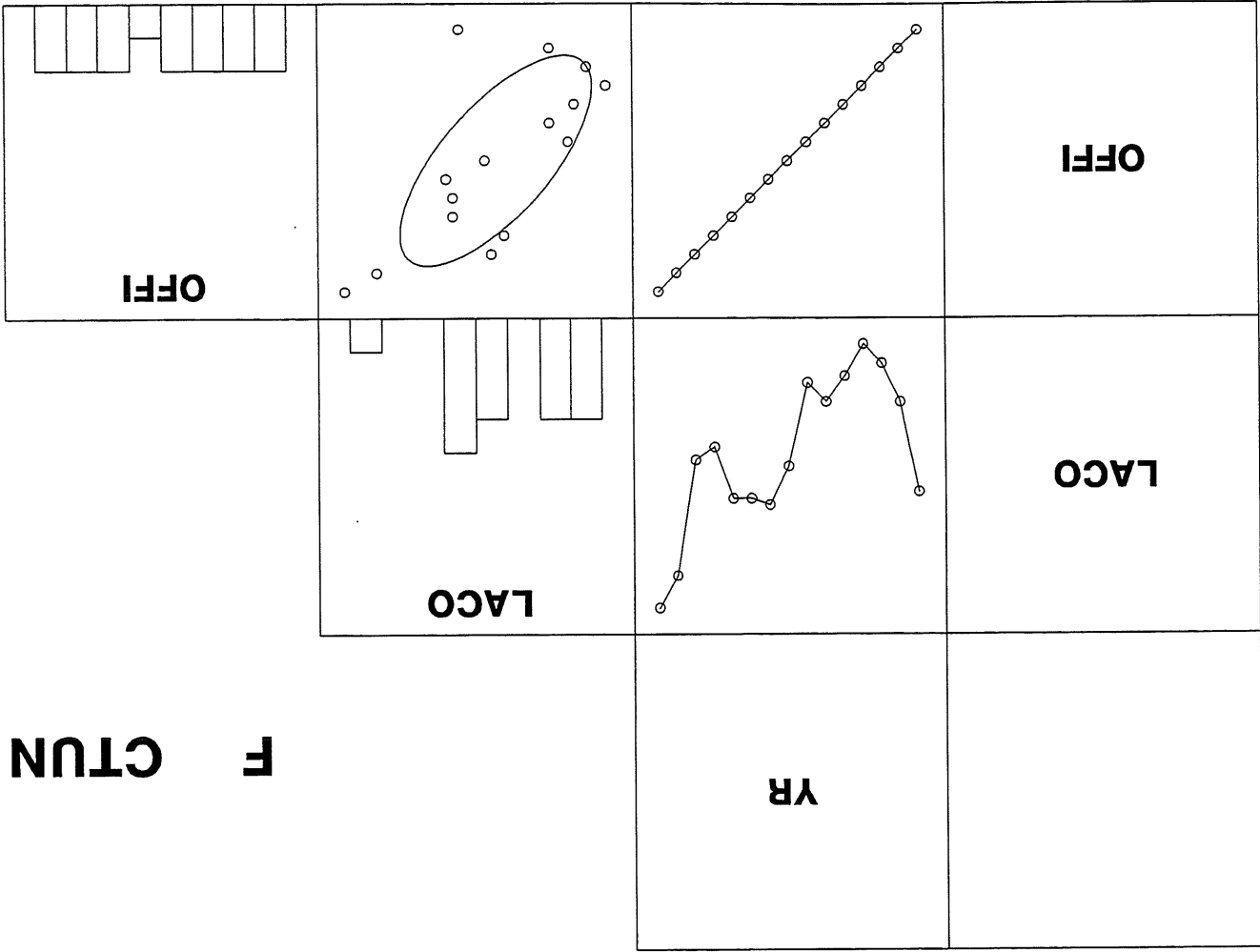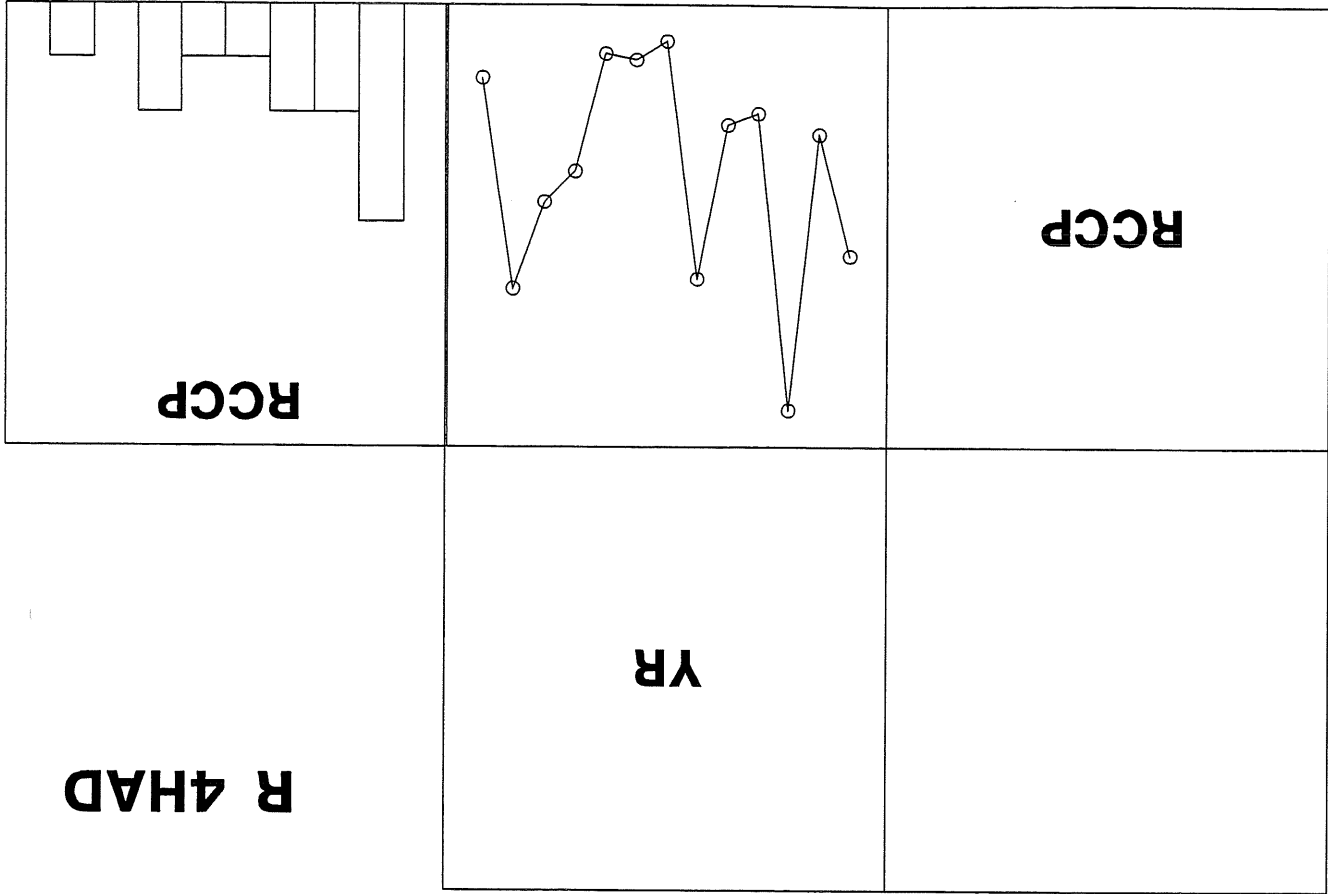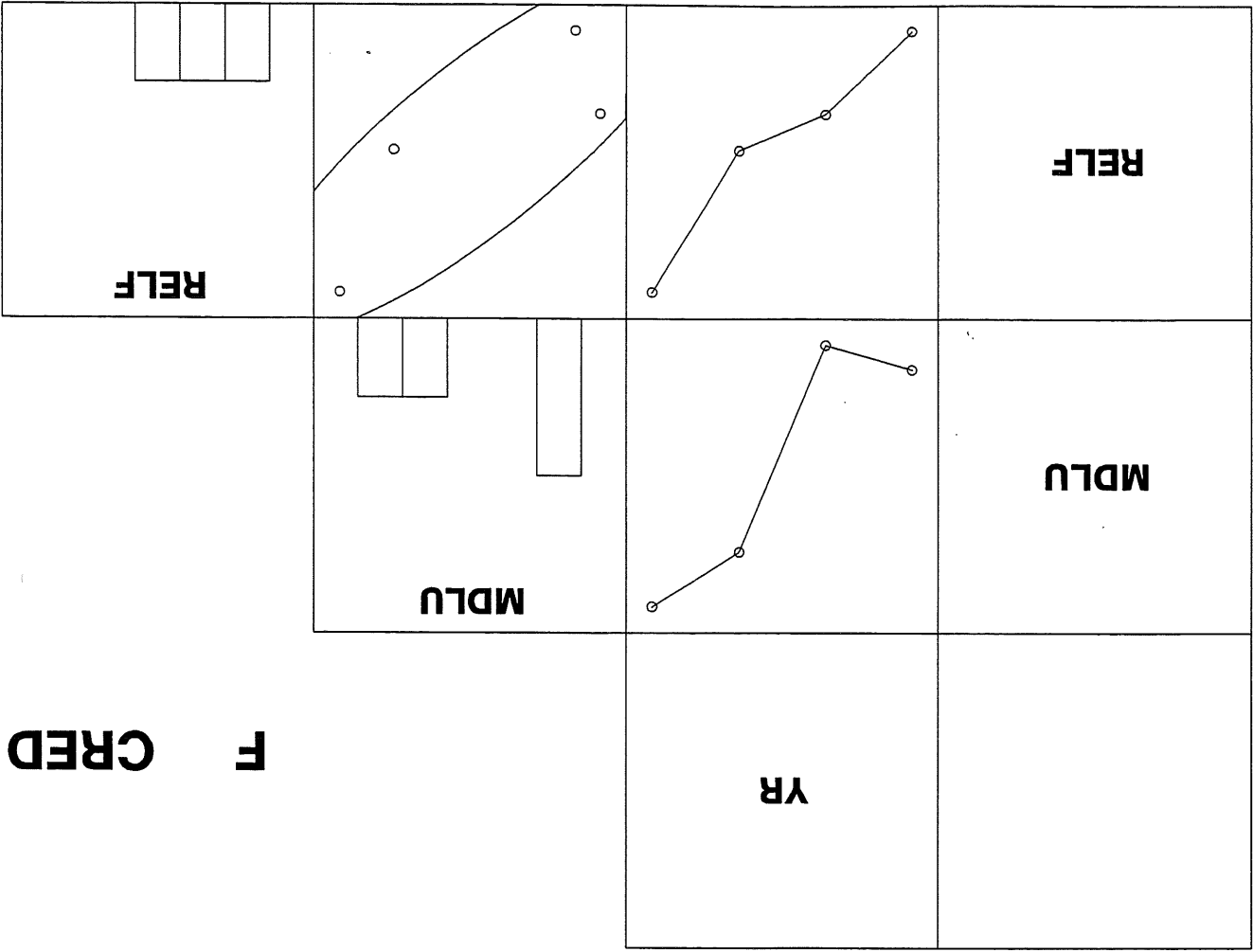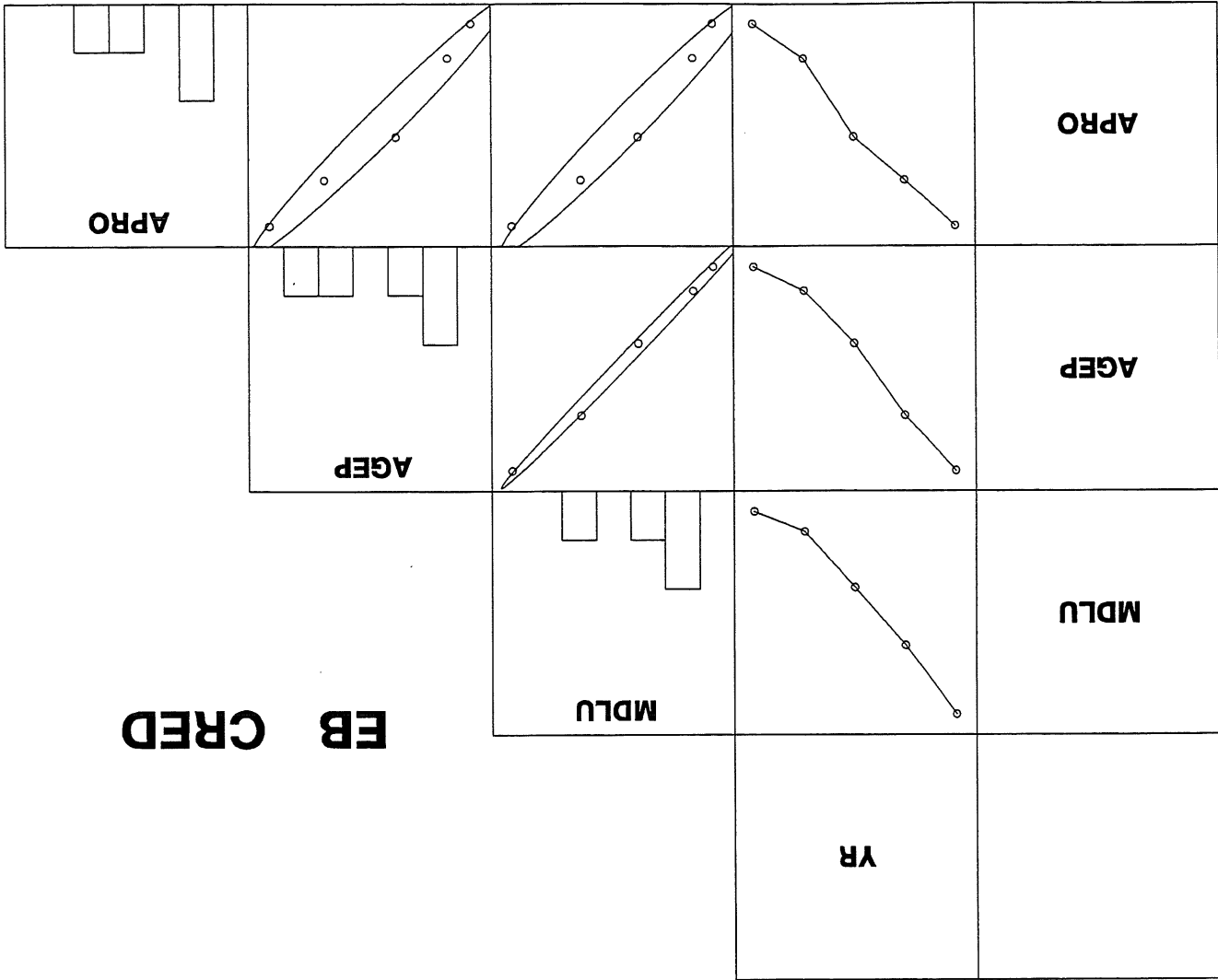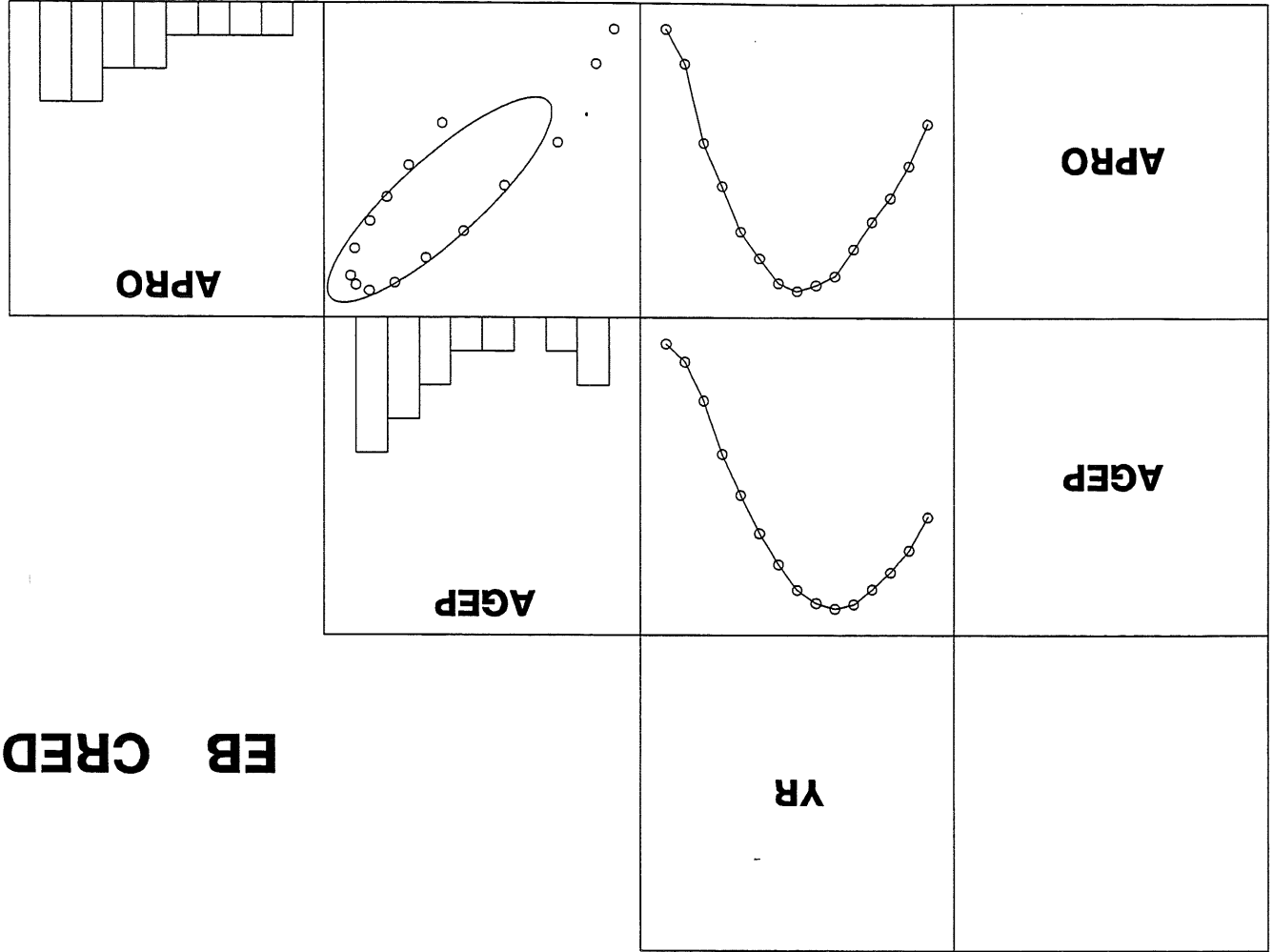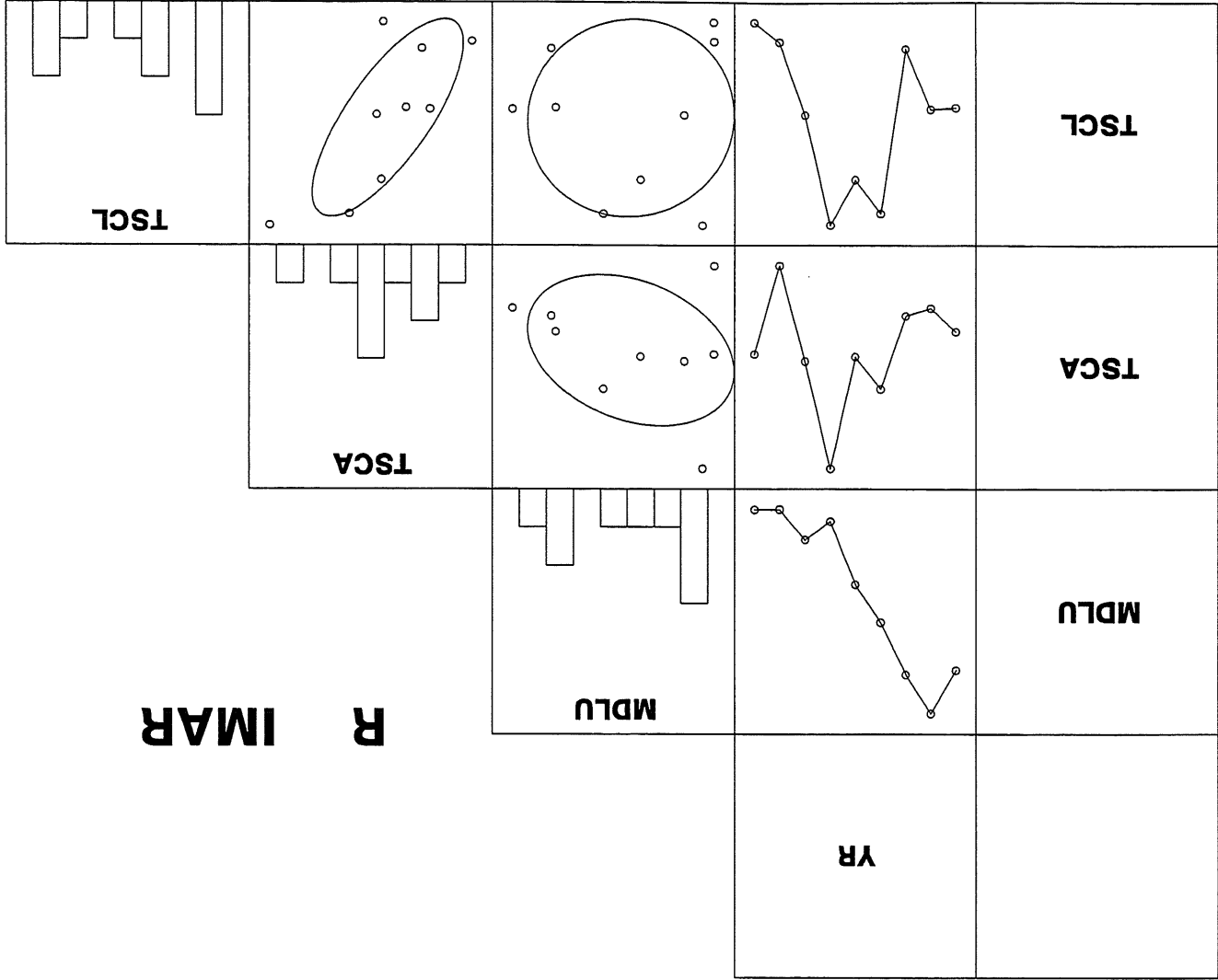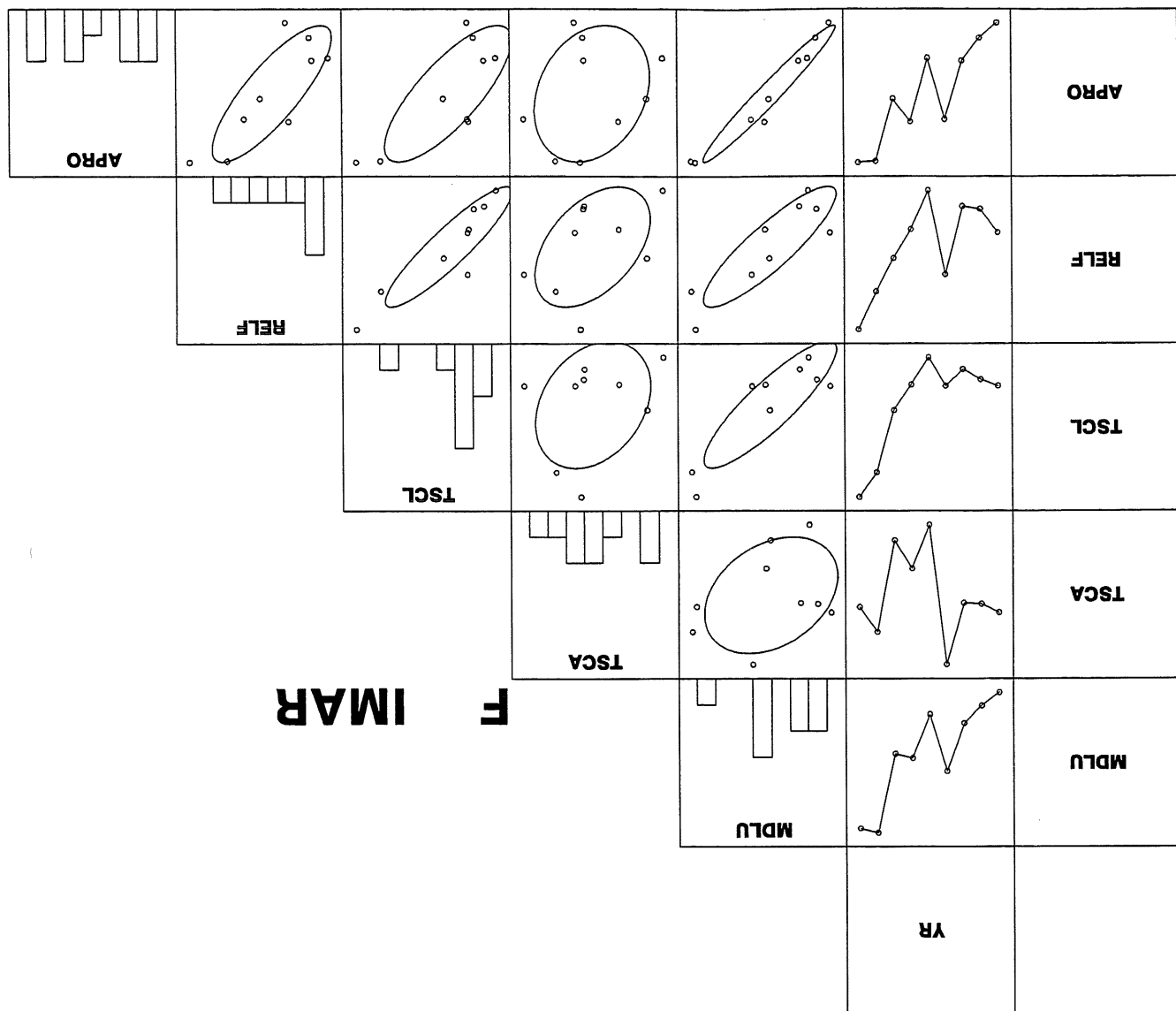
Figure 7.2.8c

Figure 7.2.9

APPENDIX A

This notation is used in this report as a standard. Other symbols or usages may be defined in the text.

Indices

y = year
a = age
l = length
f = fleet

Variables

Subgroups are identified by subscripts, e.g. N_{rec}, N_{juv} etc.
Indexes are put in parenthesis, e.g. N(y,a), or may appear as subscripts (N_{ya}) if this does not cause confusion.

N = number of fish in population
R = number of recruits
B = biomass
P = net production (biomass)
C = catch in numbers
Y = catch in weight (yield)
U = abundance index
q = catchability (U=q*N)
F = fishing mortality rate
s_a = Age component of separable F
f_y = Year component of separable F
M = natural mortality rate
Z = total mortality rate
H = hidden mortality rate
W = mean individual weight (W_c and W_s for weight in catch and stock if necessary)

L_∞ : l at infinity
k : v. Bertalanffy's K
p(a,l): Bivariate distribution of age and length in the population
p(a | l): Distribution of age for each given length
p(l | a): Distribution of length for each given age.

ε : Error term

Symbols:

‾ :average
' : alternative value
* : reference value
^ : estimate
Σ : sum