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Notes on the stock-dynamics and assessments of the Icelandic cod.

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ABSTRACT

This paper briefly reviews the estimation of some biological parameters required for the assessment of the Icelandic cod. These parameters are then used to assess the cod stock and to evaluate some of the stock-dynamics in relation to the utilization of the stock. In particular, the maturity and mean weights at age are redefined along with partial fishing mortalities in order to compute the spawning stock at the time of spawning. The spawning stock is corrected for immigration and the stock-recruitment relationship is investigated. There are indications that the stock-recruitment relationship is becoming important to present recruitment and this has consequences for management advice.

CONTENTS

1. Introduction

This paper deals with the stock-dynamics of the Icelandic cod, in relation to long-term management as well as a short-term assessment. Biological data is reviewed with an emphasis on assessing the stock and evaluating the longer-term effects of harvesting the stock.

The paper describes the methodology and results concerning the current state of the stock. Some of the results given here are summarized in Anon (1992a and 1992b).

The estimate of natural mortality is reviewed, and estimation of both sexual maturity and mean weights at age are defined in such a fashion as to make both relate to the spawning stock at the time of spawning.

Finally, it is shown that there is a (weak) relationship between spawning stock biomass and recruitment for this stock. This has major implications for management since the effect of only a slight indication of a S-R relationship yields considerably stronger statements concerning reduction of fishing effort than does the Y/R curve alone.

2. Basic data and analyses

2.1 Tagging data

Tagging results show considerable migration of the '73 year class from Greenland into Icelandic waters in 1980 and 1981. Similarly, the 1984 year class migrated from Greenland to Iceland in 1990 and 1991. A fairly large drift of larvae from the spawning grounds off Southwest Iceland to East Greenland had been noted in both 1973 and 1984 (Anon. 1973 and Vilhjálmsson and Magnússon 1984). It is believed that the drift returns to Icelandic waters for spawning, and that the fish that return stay in Icelandic waters (Anon. 1971).

The tagging data are only used to determine the years in which considerable migration may occur. An estimation procedure is described later in this paper where migration estimation is included in the assessment.

The magnitude and effect of the migrations is best seen in Fig. 1. The figure shows the catches in numbers at age from three cohorts. The 1980 and 1983 cohorts are "typical" in the sense that the catches at age have been mostly from age groups 4-6 in recent years and there tends to be a very sharp drop in the catches after age 7. For the 1973 year class, however, the decrease from age 7 to age 8 is very slight. Given the weight increase, this resulted in a very substantial increase in the biomass from what would have been expected in the area without the migration.

The tag return data for the 1984 year class tagged in Greenland waters yielded 11 returns in Icelandic waters in 1990 and 23 returns in 1991, indicating a migration of this year class into Icelandic waters at least in 1990 and potentially also in 1991.

It is quite well known (Anon 1971) that cod of many, if not most, year classes migrate from Greenland to Iceland. The magnitude of these is not easy to estimate, however, and hence estimation is confined to the years where external information indicates that the migration is considerable.

2.2 0-group data

Surveys of 0-group cod have been conducted since 1970. The data are not explicitly used except as an indicator of larval drift to East Greenland, along with later tag returns. The surveys are summarised in Vilhjálmsson and Friðgeirsson (1976) and Helgason and Sveinbjörnsson (1987). Later indices are given in Magnússon *et al* (1987, 1988 and 1989) and Magnússon and Sveinbjörnsson (1990 and 1991). These indices are summarised in Table 17.

2.3 Catch in numbers at age

Catches (C_{ayf}) in numbers at age (a) were made available by fleets (f) and years (y) (Schopka, pers. comm.) for the years 1980-1991. The "fleets" (or "metiers") are defined by the gear, season and area combinations. The three basic gears are: long lines, bottom trawl and gillnets. Due to sparseness of data and less importance in terms of the magnitude of the catches, each of these classes contains some related gears. For example, handlines are included with the long lines and pelagic trawl is included with the bottom trawl.

Aggregated data from these and earlier years are obtained from Anon. (1992a) and Anon. (1976).

Total catch at age (aggregated across fleets) was used as VPA input, as described in the assessment section, and seasonal data were used to estimate the fishing mortalities for January-May separately, as described in the spawning stock section. The data are further described in Tables 1 and 2.

2.4 Groundfish survey data

In the following, the Icelandic groundfish survey data (Pálsson *et al* 1989) is used to consider the magnitude of the natural mortality. The basic data is age-disaggregated (Pálsson and Stefánsson, 1991) and indices are computed using the Gamma-Bernoulli (Γ-B) model of Stefánsson (1991).

Specifically, the analysis is done for each age group seperately and also for each of the two regions (N and SW) separately. Since the northern region (N) contains the juvenile grounds and few samples of ages 1 and 2 group cod are obtained in the south, only the northern data is used for those two age groups, resulting in indices SUR1 and SUR2 which will later in the paper be related to the stock size of 3-group cod. Abundance indices for ages 3-14 are obtained for each of the two regions, resulting in the series SUR.N and SUR.S.

Within each analysis, the probability of zero at a given location is estimated as is the expected number of fish given a positive number. Each response is modelled using a statistical square effect and a year effect. This differs from Stefánsson (1991), where stations were used as factors. Specific models need to be considered in more detail and the effects of using other terms in the model need to be evaluated. Such terms include the time of day, depth within statistical square etc.

The analysis thus results in indices, U_{ayf}, for ages (a) from 3 to 14 and year (y) from 1985 to 1991. The "fleets", f, run from 1 to 4 and the first two fleets only have indices for age 3. The resulting indices are given in Tables 3a-d in the order used for tuning purposes.

2.5 Commercial CPUE data

Commercial trawler CPUE data is analyzed using multiplicative models (Gavaris, 1980) as described in Stefánsson (1988) to yield indices of abundance, U_{ayf}. The analysis takes into account catchability changes in the fleet due to vessel renewal and region shifting, but not changes in the spatial distribution of the resource or changes within vessels in the fleet.

These indices are based on trawler log books from the each part of the year (January-May and June-December) for tows in the two basic regions (northern+eastern and southern). The basic data is aggregated somewhat before the analysis. The analysis uses a log-linear model which describes the log-catch in terms of the (logged) towing time, year, month, vessel and statistical square. The year effect is then exponentiated and age-disaggregated using otolith samples taken on board the same vessel class in the same seasons.

The years 1979-1984 and 1985-1991 are analysed separately. Due to lack of otolith samples, only the northern region could be used for the first time period. Thus, the analysis resulted in CPUE data for 6 "fleets":

	Jan-May	June-Dec
North 1985-1991	TRWL.winter.n	TRWL.fall.n
South 1985-1991	TRWL.winter.s	TRWL.fall.s
North 1979-1984	TRWL0.winter.n	TRWL0.fall.n

The resulting indices are given in Tables 4a-f.

3. Assessment theory

3.1 Background

As noted above, migrations from Greenland into the Icelandic cod stock can have major effects and hence these need to be taken into account in the assessments. Since the Laurec-Shepherd and XSA methods have not been developed to account for migration, an ADAPT-type of method (Gavaris, 1988; Stefánsson, 1988) has been used for assessing the Icelandic cod stock. The term "VPA" in the following will be used, although "tuned cohort analysis" would be more appropriate.

3.2 Estimation procedure

The approach taken is a simple statistical model, where CPUE in numbers per fleet, year and age group (U_{ayf}) is assumed to be related to abundance:

$$\ln U_{ayf} = \alpha_{af} + \beta_{af} \ln N_{ay} \qquad (1)$$

The CPUE values can be from commercial fleets or surveys. As described above, for the Icelandic cod, these are from the bottom trawl fleet, with indices calculated as in Stefánsson (1988), and from a groundfish survey (Pálsson *et al* 1989), with indices calculated as in Stefánsson (1991).

Given the results of a VPA, and coefficients, (α_{af} and β_{af}), predicted values $\hat{U}_{ayf}$ can be computed. The assessment method used was described in detail by Stefánsson (1988). Basically, for any given set of terminal fishing mortalities and coefficients, the sum

$$SSE = \sum_{ayf} w_{ayf} \left[\ln U_{ayf} - \ln \hat{U}_{ayf} \right]^2 \qquad (2)$$

can be computed. The weights, w_{ayf}, are constants defined in such a fashion as to make the terms of similar magnitude and to ensure that no single fleet or age group dominates the estimation. The estimation procedure now simply chooses coefficients and terminal fishing mortalities to minimize the sum of squares.

It should be noted that the weights are not estimated e.g. based on the minimum possible SSE obtainable for a given age group, since this can potentially lead to one age group dominating the criterion.

Formally, the entire set of last-year (terminal) fishing mortalities can be estimated. However, this will in some cases result in selection patterns that are badly determined and not in accordance with what is expected from the gears used. Therefore, the simplification is made that the selection in the latest year is fixed equal to the average selection in some years prior to the last one. As will be seen from the output, the year 1988 is somewhat abnormal in terms of very high fishing mortalities. If a short, recent, period is chosen for the average selection pattern, some danger exists that 1988 may weigh too heavily in the average (although care is taken to average selection patterns as opposed to the average of unscaled fishing mortalities). For this reason the rather long-term average across the previous 10 years has been chosen. In this specific assessment, using the longer-term average also gives a marginally better fit than is obtained by a short-term average of 3 years.

Similarly, in principle the fishing mortalities on the oldest age groups can be estimated, but these are always badly determined. Therefore, the fishing mortality on the oldest ages is set as the average of some (5) younger age groups, as is customary. Thus the minimization is reduced to estimating a single fishing mortality along with the coefficients, which are determined from a simple linear regression for a given fishing mortality.

To estimate migration, one needs a way of incorporating these into the VPA and an estimation method. For given migrations, P_{ay}, it is easy to modify the usual VPA equations so that

$$N_{a+1,y+1} = N_{ay} e^{-Z_{ay}} + P_{ay}. \qquad (3)$$

Hence it is assumed that migrations are fixed, unknown, numbers, and the migrations appear at the beginning of a year. When a backwards VPA is performed, these numbers are simply subtracted after the stock size has been computed for the beginning of a year, before continuing to the previous year.

To estimate these unknown quantities, the view is limited to the years and ages where migration is known to have occurred in quantity. For the Icelandic cod, this leads to the estimation of at most four parameters to account for migration during the period 1970-1992. For any given value of these, the above estimation procedure allows computation of the SSE. Thus, the migration can be estimated simply by minimising the SSE.

4. Stock estimates

Since the primary purpose of this paper is to investigate the stock-dynamics of the Icelandic cod stock in relation to longer-term management, a long-term assessment must be used to investigate the possible relationship between spawning stock biomass and recruitment. The existence of such a relationship (even a subtle one) will have considerable effects on long-term advice for the stock.

An assessment was conducted, using catch-at-age data since 1955 (Table 1), survey data since 1985 (Tables 3a-d) and commercial CPUE data since 1979 (Tables 4a-f).

In this assessment, a natural mortality of 0.2 has been used for all ages and years. This will be verified in the next section.

Although the assessment method described here is a "statistical" one, in that it assumes lognormal errors in the CPUE and survey data and therefore uses least-squares to estimate the parameters, there is considerable flexibility in how the method is applied. This flexibility is obtained by varying the weights used for the different fleets and age groups and different assumptions in the type of model relating the CPUE (U) to the stock.

The effects of different weights are sufficient to warrant some consideration. For the younger age groups in the survey of the northern grounds, the 1984 year class is consistently estimated to be of similar magnitude at age as the 1983 year class (less than 30% difference). For the southern region, however, there is a considerable difference in that the magnitudes are similar for ages 3-5 but for ages 6-8 the index for the 1984 year class is roughly double that of the 1983 year class. Thus, varying the weights on these two survey indices will lead to estimates of migration in 1990 from zero to fairly high numbers.

The choice of weights, therefore, is crucial. The approach taken here is based on considering both the perceived quality of the two data sets and the perceived built-in variances in the two sets. Firstly, the 3-group is eliminated from the commercial CPUE series since the variances in this series are much higher than in any other, and the effects of e.g. mesh size changes can be quite drastic for this age group. Ages 4-7 are the most prominent ones in the trawl catches and these are therefore given most of the weight among the CPUE series.

In spite of what appear to be very accurate measurements in the some of the commercial CPUE series, it is not felt reasonable to let this series have more weight than the survey, on the crucial age groups. This is partly due to the fact that if slightly longer time series are used, catchability changes become evident. Hence the CPUE series are not allowed to dominate the SSE.

Similarly, ages 1-3 in the surveys are severely downweighted.

It should also be noted that the presence and absence of a migration in the terminal year is very related (inversely) to the terminal fishing mortality. If a given combination of weights yields positive migration, then the fishing mortality estimate will tend to be lower.

The commercial trawler CPUE data were separated into the two periods, 1985-1991 and 1979-1984. The reason for extending the CPUE series was to incorporate information to allow estimation of the migration in 1980 and 1981. For migration to be estimable with this assessment method, some SSE-values must be available for migration years, to reflect the effect of the migrations on the CPUE. In order to minimize the effect of catchability changes, the series has been split into the two segments. Effectively, the first series is only used to estimate the migration, since the backwards VPA has converged long before reaching 1984.

The terminal fishing mortality (unweighted average over ages 5-10) is found to be 0.87 and the migration of the 1973 year class is estimated as 38 million in 1980. The migration of the 1984 year class is estimated at 32 million in 1990. The 1981 and 1991 migrations are estimated as zero. The primary purpose of this paper is not an annual assessment, and a finer coordination of the various data sets would belong in such a paper. In the assessments in Anon (1992a and 1992b), fewer fleets were used, but considerable effort was placed on the fine coordination of the data sets available at the time. In Anon (1992a and 1992b) the terminal fishing mortality was estimated as 0.80 and migration estimates were at 37+7 million for the 1973 year class and 24 million for the 1984 year class.

For the fleets used in this paper, the difference between the minimum SSE obtainable (10.14) and the SSE obtained by using the earlier assessments (10.25) is neglible. In spite of the increased information, there is thus no reason to change the former assessment. Therefore, the VPA input assumptions of migration ond terminal fishing mortalities in Anon (1992a and 1992b) are used in what follows (apart from potential rounding differences and differences between using cohort analysis vs VPA), but it should be noted that a more accurate assessment can probably be made, by further scrutinizing the information in this paper. However, this is unlikely to have any effect on the conclusions concerning the longer-term management of the stock.

Assessment results are described in Tables 5 and 6. Standardized log-catchability residuals, i.e.

$$\left\{\ln(U/N)-\mu\right\}/\sigma \qquad (4)$$

are given in Table 7. These are shown for comparability with other works and it should be noted that these do not reflect the deviations in (2). The reason for model (2) is that simple tests indicate that β_{af} in (1) are different from each other and from the constant 1.

5. Biological parameters

The biological parameters which need to be estimated and/or assumed for each age and year are: mean weight, natural mortality and sexual maturity. Basic data needed for the assessments includes these data and catch in numbers at age per year. The following subsections describe the estimation used to obtain these numbers.

5.1 Natural mortality

5.1.1 History Effort data has been used (Jónsson, 1960) to estimate the natural mortality (M) to be around 0.2 for all ages and years. This value has been used without much scrutiny, in particular since it has been found that basic long- and short-term conclusions for management do not depend heavily on the value of this parameter for this stock (Anon 1986). This refers to (1) catch predictions a few years ahead and (2) conclusions on the ideal direction for fishing mortalities to go (down!) based on the yield-per-recruit curve.

The above studies did not consider whether M might vary with time or age. In this context it must be noted that the fisheries start catching 3-group cod in very small numbers, but most of the catches are directed at older ages, with age groups 4-6 being most prominent in the catches-at-age in numbers.

5.1.2 Estimation Natural mortality is known to be hard to estimate and hence the following is merely an attempt to verify whether there is reason to abandon the classical value of 0.2.

The age-disaggregated survey indices in Table 1 are the basic data for this analysis. These indices have been rearranged and expanded to include all available indices in Tables 8-9. It should be noted that indices for all ages within a region are based on integrating over the same areas, so they are on the same scale.

It has been believed (Schopka, pers. comm) that cod of age one and two are not fully recruited to the groundfish survey. This is easily seen in Tables 8-9, where the indices tend to increase from age 1 to age 2 and from age 2 to age 3. For these age groups, therefore, the positive change in catchability is clearly greater than the negative change in index due to total mortality.

At age 3, the cod is hardly recruited at all to the trawl fishery, mainly due to the large mesh-size used by the bottom trawl fleet. In fact, the fishing mortality is estimated by the VPA (using M=0.2) to be about 0.05, or much less than any reasonable level of natural mortality. At this age, the cod is on the other hand believed to have become fully available to the survey. The three year old cod are, however, likely to have somewhat higher escapement than older cod (Godö, 1989). This can result in a seemingly lower mortality than observed by comparing indices from the groundfish survey, but the effect will be ignored.

For the northern region, indices of 3-group cod are always larger than those of 4-group cod. For the southern region, however, the 4-group indices are always higher than the 3-group. This is in accordance with the observation that maturity at age (Table 10) of the 4-group is three times that of the 3-group and the southern area contains most of the spawning population.

Combining the indices for the two regions by simple addition and computing

$$\overline{\log\left[\frac{U_{3y}}{U_{4y}}\right]}, \qquad (5)$$

results in an overall estimate of Z=0.27, which is in reasonable correspondence with the VPA estimate of 0.25.

The 3-group is caught in very low numbers and therefore the Z-value changes considerably for this age group if tuning is performed with different M values (Z goes from 0.15 to 0.35 as M is varied from 0.1 to 0.3). Since the VPA Z-value of 0.25 corresponds to M=0.2 and the survey indicates this Z-value to be appropriate, the value M=0.2 will be used throughout this paper.

There is little in the biology of the cod to indicate differential M by age for three year olds and older. The possibility of increasing M at ages after spawning does exist, but cannot be tested with the available data.

Year-to-year variations are even harder to assess, since these are confounded with the variability in the survey. The six individual Z_{3y}-estimates lie between the two extremes of -0.002 and 0.61, with the remaining four values between 0.12 and 0.41.

In light of the above, a natural mortality of 0.2 on ages 3 and older will be used in all years, throughout this paper.

5.2 Proportion mature

Apart from general biological interest, the only reason for computing the sexual maturity at age is to obtain a spawning stock biomass, and the only real reason for wanting a spawning stock biomass is in relation to recruitment. It follows that the proportion mature should be defined and computed in such a fashion as to relate to the spawning stock biomass at the time of spawning.

When a fish goes from stage I (immature) to other stages (II-IV), it is assumed to enter the mature portion of the population once and for all. Thus, it can be assumed that if proportions mature in the stock are computed on a monthly basis, this proportion should be a nondecreasing function for any given cohort. Since the interest lies in the spawning stock, the proportion mature used in VPA tables should be based on the proportion mature at spawning time.

Using data throughout the year will inevitably bias the proportion, and in some cases this can be substantial. For example, some anchovy mature in the fall of their first year (Anon. 1991b), but it is quite clear that this 0-group did not take part in spawning its own cohort, and should not enter the spawning stock of that year. As a general rule, if maturity stages are correctly classified, the proportions mature late in a year are a reflection of what will spawn in the following year but not of what spawned in that year (assuming spawning in spring or summer).

5.2.1 A simple analysis The problem may or may not be serious for any given stock. To investigate this with regard to the Icelandic cod, all samples for the years 1975-1991 are combined. Fig. 2. gives the average proportion mature by age in months. It is quite clear that for any given age, the proportion mature is lowest during the summer months. There is also an indication that the proportion is at its highest in fall.

Since spawning takes place in March-April, it follows that using all samples during a year will lead to a downward bias if summer fishing is dominant and to an upwards bias if catches (and samples) in fall dominate.

The reason for the drop in summer can be either that the mature stock has been considerably reduced by fishing or that maturity stages are incorrectly determined. The latter explanation is known to account for some of the problems, since it can be very hard to distinguish between maturity stages IV (post-spawners) and I (immature) in late summer, even for experienced readers.

5.2.2 Remedial measures Correcting the incorrect classification is difficult, but not inconceivable. A simple model can be written down, where it is assumed that the proportion is strictly increasing throughout the year, and the monthly probability of misclassification is estimated. This, however, is confounded by the possibility that heavy fishing on the mature stock may reduce the proportion in reality, so it is not attempted here, but it would seem an appropriate area for future research.

Since the maturity stage for the Icelandic cod is easier to determine during the first half of the year, data from this time period seems appropriate. Further, spawning tends to be at its peak in April (Jónsson, 1982) and therefore data from January through May will be used in this paper.

This leaves the question of specifically which data from the first season should be used. Catchabilities are very different in the Northern and Southern regions, and e.g. the bottom trawl has low catchability in the southern region during the spawning season. The approach taken here is to assume that the catches in the different gears and areas appropriately reflect the stock composition with regard to maturity at age. Hence, the maturity at age is based on samples in each gear/region combination, weighted together with catch.

5.2.3 Alternatives The proportions mature have classically been computed by year and age group. The question should be raised whether this is totally appropriate, since it is quite possible that the variance in the proportion mature each year dominates the changes between years. If this is the case, then a single proportion should be used for all years. As an example, if maturity for a given age is determined for 500 fish, of which 250 are estimated mature, then the confidence interval is ±4%, which may or may not be tolerable. This matter needs further investigation.

5.2.4 Results The available data on maturity and mean weights at age is only available on an annual basis from 1973 onwards. Stock-recruit considerations need to take into account long time series, and catch at age data are available from 1955. Hence the maturity at age for earlier years is computed as the average across the years 1973-1991.

The maturity data based on samples in January-May and January-December are given in Tables 10 and 11, respectively. The data seem to indicate an upwards trend in recent years. This fact needs further investigation, since it may be due to biological reasons as well as changes in fleet composition.

5.3 Weight at age

Weight-at-age in the spawning stock is essential for assessment purposes, if there is any concern with potential stock-recruitment relationships. The fact that mean weigths at age in the catches are needed to compute the catches at age and mean weights-at-age in the fishable stock are also of interest will not be further considered in this paper.

In order to obtain reasonable estimates of the mean weights in the spawning stock, data from the period January-May have been used, since the center of this period coincides roughly with the peak of the spawning. As for the maturity computations, it is assumed that the catches in the different gears and areas appropriately reflect the stock composition with regard to mean weight at age. Unfortunately, the specific weights-at-age of mature fish have not been available, so weights of all fish sampled in the season have been used.

For the "fishable" stock (the 4+ group), weight samples taken throughout the year have been used.

For short-term predictions, it is essential to take into account potential changes in mean weights at age due to environmental conditions. This paper will not deal with short-term predictions and hence the relationship with the capelin stock size can be ignored (Steinarsson and Stefánsson, 1991; Magnússon and Pálsson 1989).

For long-term predictions, fluctuating environmental conditions can be ignored, but it is essential to take into account potential changes due to density-dependent growth. These have been investigated for this stock (Steinarsson and Stefánsson, 1991 and Anon. 1991c) and no obvious density-dependent relationships were found concerning growth. These results apply to stock sizes in the range observed during the period 1970-1990 and of course care must be taken when extrapolating to very large stock sizes.

As described in the maturity section above, mean weights at age are not available on an annual basis before 1973, and hence the average across the years 1973-1991 is used as the constant (in time) mean weight at age for the years 1955-1972. The weight-at-age data based on January-May and January-December are described in Tables 12 and 13, respectively.

6. Estimation of spawning stock at the time of spawning

Since the spawning stock at the time of spawning is of primary interest, and there is considerable fishing on the spawning grounds, it may be important to account for these catches when computing the spawning stock biomass.

For Icelandic cod, the catch of older fish is mainly taken during the January-May season (Table 2). In fact, when the fishing mortalities are computed by season, about 80% of the fishing mortalities on the oldest age groups appear during these first months (Table 14). Most of these catches are taken in gillnets, and e.g. in 1991 those catches were almost all taken in March and April, roughly equally in the two months.

The center of the spawning period is April, so it would seem reasonable to discount the spawning stock by 3 months of the (roughly) 80% of F which are taken in the first 5 months, i.e. to use about 0.6*0.8 as the fraction of F to use before spawning, for the oldest age groups. The resulting fractions of fishing mortalities to be used for each age group are given in Table 14.

As described earlier, the maturity-at-age and weights-at-age are also computed in such a fashion as to reflect the situation at the time of spawning.

There are very few measurements of the stock size and recruitment at the high end of the stock size. The VPA from 1955 to 1991 gives recruitment for 1952-1988 and spawning stock biomasses for 1955-1991. Since the stock was known to be large in the early years, the series has been extended here by taking the average spawning stock biomass over 1955-1959 and assuming that constant to apply for the years 1952-1955.

7. Recruitment prediction

The above mentioned VPA only yields recruitment estimates up to and including the 1988 year class. A few more pieces of information are available on recent year classes. Exact estimates of these year classes are not required. Hence a simple method is used to estimate each one in order to obtain more points for the stock-recruitment analysis. The estimation is based on the relationship between the northern indices and 3-group stock numbers from the "tuning".

From Fig. 3, the (inverted) fitted equation connecting the age 3 VPA stock size to the one group index is:

$$N = e^{(\ln(U)+1.89)/1.31}$$

and for the two group index, the relationship is

$$N = e^{(\ln(U)+1.22)/1.48}$$

The 3-group index relation to stock size is:

$$N = e^{(\ln(U)-0.38)/1.25}$$

and the 4-group relationship is:

$$N = e^{(\ln(U)+0.06)/1.33}$$

The 1987 year class is estimated at 159 million from the VPA. Available survey indices (1-5), except the 2-group index, indicate this year class to be smaller (Fig. 3). The 4-group index of 596.84 indicates this year class to be 128 million, the three-group index of 637.90 gives 129 million while the two-group index of 655.36 gives 182 million. Using also the 1-group index of 56.58 giving 92 million results in an inverse-variance weighted mean of 147 million.

The 1988 year class is estimated from the VPA at 200 million. This estimate is next to useless, however, due to the exceedingly low catches of 3-group cod. The 1-4-group indices yield 85.20, 416.92, 542.98 and 448.78 respectively and these result in predictions of 126 , 134 , 114 and 103 million. The inverse variance weighted mean gives 121 million.

For the 1989 year class, there is a 3-group survey index of 852.37, a 2-group estimate of 544.66 and a 1-group index of 120.81. These indices all give predictions of about 160 million, with the weighted mean estimate of 162 million.

For the 1990 year class, there is a 2-group index of 616.26 and a 1-group index of 76.28. The 2-group index results in a prediction of about 175 million, the 1-group gives 116 million resulting in an overall weighted mean of 163 million.

For the 1991 year class, the 1-group index gives 11.66. The above relationship gives a prediction which is far below the historical minimum and therefore the historical minimum of 86 million is used.

8. Stock-recruitment

8.1 Data

The VPA described above gives estimates which include estimated migration of the 1973 and 1984 year classes from Greenland into Icelandic waters in 1980, 1981, 1990 and 1991 (where the 1981 and 1991 migrations were estimated as zero).

As described in the earlier sections, the SSB and recruit series have been extended to include the years 1952-1991.

An attempt has been made to appropriately account for migrations in these figures. In particular, the VPA, as described above, removes the migrations from the spawning stock biomass in the years before the migrations appear in Icelandic waters. A different approach is needed for the recruits, since recruitment at Greenland comes to some extent from Iceland. A first attempt at estimating the total recruitment from the spawning stock biomass at Iceland is done by performing a simple VPA without migration, but based on the same terminal fishing mortalitites as estimated above. This gives the same result as does backcalculating the immigrant numbers to age 3 using only natural mortality.

The resulting spawning stock biomass and recruitment series are given in Fig. 4. In the recruitment figure, horizontal lines indicate poor and good recruitment (defined here as below 150 million and above 250 million, respectively). Also shown are smoothed versions of the recruitment series, with different robust smoothers which effectively have a different span. The scales on the recruitment graphs are different, but there seems to be an overall decline in recruitment, and there also seems to be something looking like cyclic behaviour in the series.

8.2 Data analytic approach

Although the stock-recruitment data in Fig. 5 initially look like a random scatter of points, one immediate item is of some concern. This is the fact that the probability of poor (below 150 million) recruitment is 45% when the spawning stock biomass is below 500 thousand tonnes, but this probability is much smaller - only 17% - when the biomass is above 500 thousand tonnes. It would, therefore, seem that the data does contain some information about the increased likelihood of poor recruitment at lower SSB-values. A χ^2-statistic can be computed on a more formal contingency table:

	Spawning stock biomass Below median	Above median	Total Total
Recruitment			
< median	14	6	20
> median	6	14	20
Total	20	20	40

The statistic yields a highly significant result (χ^2=6.4; P=0.01).

Naturally there are some caveats to this. Notably, most of the low SSB-R data points come from recent years and it is quite possible that recent environmental changes have had the effect of reducing both the spawning stock biomass and recruitment.

Techniques exist for estimating relationships from noisy data. For example, the lowess(), supsmu() and ace() functions of Splus (Anon. 1991d; Becker *et al.* 1988; Cleveland 1979; Chambers *et al.* 1983; Friedman 1984; Breiman and Friedman 1984) can be applied to the spawning stock biomass and recruit data. Further, the GLIM package (Baker and Nelder 1978 and Aitkin *et al.* 1989) and the glm() function of Splus can be used to fit generalized linear models (Chambers and Hastie 1991). Finally, the gam() function will fit generalized additive models (Hastie and Tibshirani 1986 and 1990).

The results of these methods tend to indicate a slight decline in recruitment when the SSB is reduced, but the signal is not at all clear. Fig. 5 presents the results from fitting a generalized additive model with two degrees of freedom.

8.3 Models and significance

As indicated in Shepherd (1982), formal statistical test- and fitting procedures are not totally appropriate for the type of data used here. Rather than proceed completely *ad hoc* by assuming a specific stock-recruitment relationship, a few models will be fitted to the data and one of these will be selected.

Several functions exist for describing the theoretical relationship between spawning stock biomass and recruitment. The most common ones include the Ricker function (Ricker, 1975):

$$R = \alpha S e^{-S/K}, \qquad (6)$$

and the Beverton-Holt relationship (Beverton and Holt, 1957):

$$R = \frac{\alpha S}{1+S/K}. \qquad (7)$$

It should be noted that the "usual" method of fitting the Ricker form, by regressing $log(R/S)$ on $log(S)$ (e.g. Parrish and MacCall, 1978) is not a valid procedure, since this will inevitably indicate a relationship if the spawning stock biomass has a wide enough range, even if recruitment is fully random.

Shepherd (1982) gives the functional form,

$$R = \frac{\alpha S}{1+(S/K)^{\gamma}}, \qquad (8)$$

which can approximate the Ricker function and also give the Beverton-Holt recruitment function.

An alternative functional form (Schnute 1984) can be written as

$$R = \frac{\alpha S}{(1+S/\gamma K)^{\gamma}}, \qquad (9)$$

This form reduces to the Beverton-Holt formula when $\gamma \rightarrow 1$ and to the Ricker function when $\gamma \rightarrow \infty$. It would seem, therefore, that there is little reason to argue about which function is "correct", since each of the last two functions can imitate the behaviour of both the others in a parametric fashion.

Formally, the function in (9) can be estimated by nonlinear regression (possibly with the assumption of a gamma density of recruitment), but this is unlikely to work and it is somewhat suspect to put this data into a completely black box estimation procedure. This leaves two approaches, both of which have some validity. Firstly, it is easy to assume a few parameter values, which pass through the point cloud and test the effect of assuming each of these curves. Secondly, it is feasible to transform the equation to a linear form, as has been done with the Beverton-Holt formula by Pope (1991). Given a linear relationship, excellent methods exist for the analysis of the data.

For a given value of γ, eq. (9) can be linearized by using the transformation

$$R'=R^{-1/\gamma}, \tag{10}$$

in which case eq. (9) becomes

$$R'=aS_1+bS_2 \tag{11}$$

where the two variables, S_1 and S_2 are defined by

$$S_1=S^{-1/\gamma} \tag{12}$$

and

$$S_2=S^{(1-\gamma)}. \tag{13}$$

and the parameters are related through $a=\alpha^{-1/\gamma}$, $b=\alpha^{-1/\gamma}/\gamma K$. When $\gamma=1$, the transform becomes the simple inverse transform of Pope (1991) for linearizing the Beverton-Holt relationship.

A slightly *ad-hoc* way of "fitting" the above curve is to try different values of γ and compute the (multiple) regressions of R' on S_1 and S_2. Each such regression gives an SSE-value (based on deviations between R and the fitted value, both on a log-scale) which indicates the goodness-of-fit. The best fitting regression is then an indication of an adequate γ, if coefficients make sense.

Estimation is restricted to values of γ greater than 1. The value of SSE is minimized at $\gamma=1.5$, which is very close to the Beverton-Holt S/R-curve (Fig. 6). In the following, therefore, the Beverton-Holt approach is taken and the values of α and K are estimated by a simple linear regression of $1/R$ on $1/S$.

9. Yield potential

9.1 A simple approach

Before applying fancy models, it is easy to consider the trend in biomass given no fishing on a year class. Using obvious notation, the year class biomass is in this case simply given by

$$B_a=R\,W_a\,e^{-\sum_{a'<a} M_{a'}}.$$

The total year class biomass depends on the recruitment. In order to compute average recruitment for varying values of natural mortality, a complete assessment needs to be made for each value of M. It is therefore easier to compute the biomasses per recruit, since this does not require the recruit information.

Plots of such biomasses per recruit for different values of natural mortality (M=0.1,0.2 and 0.3) and mean weights are given in fig 7. It should be noted that under all assumptions considered, the biomass is at a maximum after age 6, and under the assumption that $M\leq0.2$, the maximum does not occur until by age 8 or older. It would seem, therefore, that the current harvesting regime, which takes the largest number of fish at the ages 4-6 can be improved upon considerably.

9.2 Yield per recruit

The usual yield-per-recruit plots are given in fig 9. These are based on the average weights-at-age and maturity for the time period 1983-1991, and the average fishing pattern for the same period (Fig. 8 and Table 15).

For comparative purposes, the same plots, but based on data for the time period 1973-1982 (Fig. 8 and and Table 16) are given in Fig. 10. Data from this period indicate a higher yield potential.

It is noted that firstly, assuming average recruitment of 204 million, one would expect an average yield of 304 thousand tonnes at F=0.8, where Y/R= 1568 *g*. Further, there is not much incentive to reduce fishing from a level of 0.8 to F_{max}=0.34, since this will only change the expected yield per recruit from 1568 *g* to 1720 *g*, i.e. give a 10% increase. It will be seen later that both of these conclusions change drastically when a stock-recruitment relationship is taken into account.

Taking a simple-minded approach, it is be noted that for low stock-levels (SSB<500), the average recruitment is about 194 million, whereas for higher values it is 218 million. Although this may not seem a large difference, it does indicate that when the population is at a low, the potential yield is expected to increase by some 12% by moving the stock to larger levels due only to the recruitment change. Thus, the overall perception immediately changes: instead of merely expecting a 10% increase in yield, the expected overall change is from 304 thousand tonnes to 374 thousand tonnes, i.e. an increase of 23%.

9.3 Theory

As indicated in Shepherd (1982), given the S-R relationship and regular Y/R and S/R curves, it is feasible to compute the expected absolute yield for a given fishing mortality.

Basically, the Y/R curve gives Y/R as a function, f, of F and similarly, one obtains S/R as a function, g, of F. Since the S-R relationship is of a given (fitted) form:

$$R = \alpha \frac{S}{\left[1+S/\gamma K\right]^{\gamma}}$$

it follows that R/S is of a related form, involving only the spawning stock biomass, and similarly for the inverse:

$$S/R = \frac{\left[1+S/\gamma K\right]^{\gamma}}{\alpha}$$

This inverse must (under steady-state) be equal to g(F) and this equation can be solved to obtain S as a (numerical) function of F via

$$\frac{1+S/K\gamma}{\alpha} = g(F),$$

so that

$$S = \gamma K \left[\left[\alpha g(F)\right]^{1/\gamma} - 1 \right]$$

To compute the absolute yield, note that Y/R is given as is S/R, so that

$$Y = (Y/R)R = (Y/R)\frac{\alpha S}{\left[1+S/\gamma K\right]}.$$

This quantity can be readily computed for given values of the parameters, as part of the standard yield-recruit computations.

9.4 Results

The relevant curves are given in figs. 11-12. It is seen that with increasing F there is considerably more lost total yield when the S/R relationship is taken into account, than would seem to be the case based on the regular Y/R results in figs 9-10.

In particular, it is seen that the increase in expected yield goes from 246 thousand tonnes to 333 thousand tonnes by decreasing fishing mortality from 0.8 to Fmax=0.28, i.e. the expected yield increases by 35%. It should be noted that the estimate of Fmax is reduced slightly by including the stock-recruitment information, from the traditional Y/R curve analysis.

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References

Aitkin, M., Anderson, D, Francis, B., and Hinde, J. 1989. Statistical modelling in GLIM. Clarendon Press, Oxford. 375 pp.

Anon. 1971. Report of the North-Western Working Group, 1970. ICES C.M. 1971/F:2 (mimeo).

Anon. 1973. Preliminary report on the International 0-group Fish Survey in Faroe, Iceland and East Greenland in July-August 1973. ICES C.M. 1973/F:9.

Anon. 1976. Report of the North-Western Working Group. ICES C.M. 1976/F:6. (mimeo)

Anon. 1986. Report of the Working Group on Methods of Fish Stock Assessments. ICES C.M. 1986/Assess:10. (mimeo)

Anon. 1991a. State of stocks and environmental conditions in Icelandic waters 1991. Fishing prospects 1991/1992. (In Icelandic with English summary). Marine Research Institute, Reykjavík, Iceland, Report no. 25 (mimeo).

Anon. 1991b. Report of the Working Group on the Assessment of the Stocks of Sardine, Horse Mackerel, Anchovy. ICES C.M. 1991/Assess:22

Anon. 1991c. Report of the Multispecies Assessment Working Group. ICES C.M. 1991/Assess:7. (mimeo)

Anon. 1991d. S-plus user's manual. Statistical Sciences, Inc. Seattle, Washington, USA.

Anon. 1992a. State of stocks and environmental conditions in Icelandic waters 1992. Fishing prospects 1992/1993. (In Icelandic with English summary). Marine Research Institute, Reykjavík, Iceland, Report no. 25 (mimeo).

Anon. 1992b. Report of the NorthWestern Working Group. ICES C.M. 1992/Assess:14.

Baker, R. J., and Nelder, J. A. 1978. The GLIM system, release 3. Oxford: Numerical Algorithms group.

Becker, R. A., Chambers, J. M. and Wilks, A. R. 1988. The New S language. A programming environment for data analysis and graphics. Wadsworth & Brooks/Cole Advanced Books & Software. Pacific Grove, California.

Beverton, R. J. H. and Holt, S. J. 1957. On the dynamics of exploited fish populations. Fishery Investigations II/XIX.

Breiman, L. and Friedman, J. H. 1985. Estimating optimal transformations for multiple regression and correlation. (with discussion). Journal of the American Statistical Association 80, 580-619.

Chambers, J. M., Cleveland, W. S., Kleiner, B. and Tukey, P. A. 1983. Graphical Methods for Data Analysis. Wadsworth, Belmont, California.

Chambers, J. M. and Hastie, T. J. 1991. Statistical models in S. Wadsworth and Brooks. Pacific Grove CA. 608 pp.

Cleveland, W. S. 1979. Robust locally weighted regression and smoothing scatterplots. Journal of the American Statistical Association 74, 829-836.

Friedman, J. H. 1984. A Variable Span Smoother. Tech. Rep. No. 5, Laboratory for Computational Statistics, Dept. of Statistics, Stanford Univ., California.

Gavaris, S. 1980. Use of a multiplicative model to estimate catch rate and effort from commercial catches. Can. J. Fish. Aquat. Sci. 37:2272-2275.

Gavaris, S. 1988. An adaptive framework for the estimation of population size. CAFSAC Research Document 88/29.

Godö 1989. Escape of fish under the fishing line of a Norwegian sampling trawl and its influence on survey results. J. Cons. int. Explor. Mer, 45: 269-276.

Hastie, T. and Tibshirani, R. 1986. Generalized additive models, Statist. Sci. vol. 1. pp. 297-318.

Hastie, T. and Tibshirani, R. 1990. Generalized additive models, Chapman and Hall. London.

Helgason, V. and Sveinbjörnsson, S. Revised indices of cod abundance in 0-group surveys in the Iceland-East Greenland area in 1970-1986. ICES C.M. 1987/G:59. mimeo.

Jónsson, J. 1960. On the mortality in the Icelandic cod stock during the years 1930-1959.

Jónsson, E. 1982. A survey of the spawning and reproduction of the Icelandic cod. Rit Fiskideildar, VI (2).

Magnússon, J. V., Sveinbjörnsson, S. and Helgason, V. 1987. Report on the 0-group fish survey in Iceland and East Greenland waters, Aug.-Sep. 1987. ICES C.M. 1987/G:60. mimeo.

Magnússon, J. V., Sveinbjörnsson, S. and Helgason, V. 1988. Report on the 0-group fish survey in Iceland and East Greenland waters, August 1988. ICES C.M. 1988/G:69. mimeo.

Magnússon, J. V., Sveinbjörnsson, S. and Helgason, V. 1989. Report on the 0-group fish survey in Iceland and East Greenland waters, Aug.-Sep. 1989. ICES C.M. 1989/G:52. mimeo.

Magnússon, J. V. and Sveinbjörnsson, S. 1990. Report on the 0-group fish survey in Iceland and East Greenland waters, Aug.-Sep. 1990. ICES C.M. 1990/G:68. mimeo.

Magnússon, J. V. and Sveinbjörnsson, S. 1991. Report on the 0-group fish survey in Iceland and East Greenland waters, Aug.-Sep. 1991. ICES C.M. 1991/G:80. mimeo.

Magnússon, K. G. and Pálsson, Ó. K. 1989. Trophic ecological relationships of Icelandic cod. Rapp. P.-v. Réun. Cons. int. Explor. Mer, 188: 206-224.

Parrish, R. H. and MacCall, A. D. 1978. Climatic variation and exploitation in the Pacific mackerel fishery. Fish Bull. 167. State of California, Resources Agency, Dept. of Fish and Game.

Pálsson, Ó. K., Jónsson, E., Schopka, S. A., Stefánsson, G. and Steinarsson, B. Æ. 1989. Icelandic groundfish survey data used to improve precision in stock assessments. J. Northw. Atl. Fish. Sci. 9:53-72.

Pálsson, Ó. K. and Stefánsson, G. 1991. Spatial distributions of Icelandic cod in March 1985-1991. ICES C.M. 1991/G:63.

Pope, J. G. 1991: Recruitment research for fisheries management: is there a simple approach ? ICES C.M. 1991/Mini:8.

Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. Bull. Fish. Res. Bd. Can. 191.

Schnute, J. A general theory for analysis of catch and effort data. Can. J. Fish. Aquat. Sci. 42:414-429.

Shepherd, J. G. 1982. A versatile new stock-recruitment relationship for fisheries, and the construction of sustainable yield curves. J. Cons. int. Explor. Mer 40(1) 67-75.

Stefánsson, G. 1988. A statistical analysis of Icelandic trawler reports, 1973-1987. ICES C.M. 1988/D:13.

Stefánsson, G. 1991. Analysis of groundfish survey data: Combining the GLM and delta approaches. ICES C.M. 1991/D:9. (mimeo)

Steinarsson, B. Æ. and Stefánsson, G. 1991. An attempt to explain cod growth variability. ICES C.M.1991/G:42. mimeo.

Vilhjálmsson, H. and Friðgeirsson, E. 1976. A review of 0-group surveys in the Iceland-East Greenland area in the years 1970-1975. ICES Coop. Res. Rep. 54.

Vilhjálmsson, H. and Magnússon, J. V. 1984. Report on the 0-group fish survey in Icelandic and East Greenland waters, August 1984. ICES C.M. 1984/H:66. mimeo.

Table 1. Icelandic cod. Catch at age in numbers, 1955-1991. Totals across all fleets.

	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971
3	3.981	6.318	15.967	25.694	20.329	13.434	14.665	12.309	14.884	16.284	22.039	16.957	27.444	11.514	9.828	9.645	13.060
4	24.277	16.112	23.354	30.535	44.478	30.544	19.971	28.867	29.298	28.590	30.535	30.039	25.937	49.731	23.168	45.711	35.856
5	33.115	28.249	17.250	16.012	22.953	29.000	19.680	19.718	22.390	20.312	21.562	19.791	24.063	22.280	43.262	22.880	45.577
6	25.328	22.879	18.212	11.501	6.693	12.105	18.826	15.786	11.586	10.882	11.002	12.338	11.953	16.072	16.968	26.038	21.135
7	9.749	14.945	12.627	15.304	4.760	8.681	7.617	12.424	17.508	7.482	9.050	6.196	7.807	17.478	12.826	15.469	17.340
8	4.545	4.551	12.927	14.876	7.561	5.967	6.502	4.243	8.295	17.182	6.228	7.118	2.838	5.657	17.411	12.652	10.924
9	5.757	3.433	3.734	7.466	11.698	6.512	3.633	7.852	2.640	5.169	11.670	2.305	4.142	1.728	1.881	14.165	6.001
10	18.172	1.983	2.197	1.982	7.221	12.136	2.962	2.614	6.063	1.763	1.694	5.862	1.279	3.169	0.578	0.563	4.210
11	2.548	14.391	1.327	1.492	0.979	3.661	6.181	1.866	1.410	3.315	0.974	0.526	2.017	0.526	0.498	0.187	0.237
12	1.380	1.475	8.020	6.001	0.981	0.911	1.230	3.007	0.946	0.768	0.587	0.281	0.095	0.598	0.101	0.148	0.069
13	2.083	1.679	0.531	1.192	0.223	0.221	0.090	0.386	1.396	0.463	0.131	0.374	0.040	0.057	0.063	0.025	0.038
14	0.186	0.980	0.740	0.663	1.203	0.219	0.126	0.068	0.204	0.969	0.246	0.054	0.153	0.053	0.029	0.016	0.020

	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
3	8.973	36.538	14.846	29.301	23.578	2.614	5.999	7.186	4.348	2.118	3.285	3.554	6.750	6.457	20.642	11.002	6.713
4	29.574	25.542	61.826	29.489	39.790	42.659	16.287	28.427	28.530	13.297	20.812	10.910	31.553	24.552	20.330	62.130	39.323
5	30.918	27.391	21.824	44.138	21.092	32.465	43.931	13.772	32.500	39.195	24.462	24.305	19.420	35.392	26.644	27.192	55.895
6	22.855	17.045	14.413	12.088	24.395	12.162	17.626	34.443	15.119	23.247	28.351	18.944	15.326	18.267	30.839	15.127	18.663
7	11.097	12.721	8.974	9.628	5.803	13.017	8.729	14.130	27.090	12.710	14.012	17.382	8.082	8.711	11.413	15.695	6.399
8	9.784	3.685	6.216	3.691	5.343	2.809	4.119	4.426	7.847	26.455	7.666	8.381	7.336	4.201	4.441	4.159	5.877
9	10.538	4.718	1.647	2.051	1.297	1.773	0.978	1.432	2.228	4.804	11.517	2.054	2.680	2.264	1.771	1.463	1.345
10	3.938	5.809	2.530	0.752	0.633	0.421	0.348	0.350	0.646	1.677	1.912	2.733	0.512	1.063	0.805	0.592	0.455
11	1.242	1.134	1.765	0.891	0.205	0.086	0.119	0.168	0.246	0.582	0.327	0.514	0.538	0.217	0.392	0.253	0.305
12	0.119	0.282	0.334	0.416	0.155	0.024	0.048	0.043	0.099	0.228	0.094	0.215	0.195	0.233	0.103	0.142	0.157
13	0.031	0.007	0.062	0.060	0.065	0.006	0.015	0.024	0.025	0.053	0.043	0.064	0.090	0.102	0.076	0.046	0.114
14	0.001	0.001	0.028	0.046	0.029	0.002	0.027	0.004	0.004	0.068	0.011	0.037	0.036	0.038	0.044	0.058	0.025

	1989	1990	1991
3	2.605	5.785	8.705
4	27.983	12.313	25.652
5	50.059	27.179	15.832
6	31.455	44.534	21.961
7	6.010	17.037	25.489
8	1.915	2.573	6.438
9	0.881	0.609	0.915
10	0.225	0.322	0.246
11	0.107	0.118	0.127
12	0.086	0.050	0.063
13	0.038	0.015	0.011
14	0.005	0.020	0.012

Table 2. Icelandic cod. Seasonal catches at age in numbers. January-May and June-December, 1980-1990. For each age, the upper line indicates the catch at age in the first part of the year.

Age	80	81	82	83	84	85	86	87	88	89	90	Average
2	0.035	0.000	0.010	0.000	0.005	0.000	0.010	0.031	0.000	0.000	0.000	0.008
2	0.072	0.046	0.001	0.043	0.071	0.000	0.511	0.349	0.316	0.120	0.099	0.148
3	0.918	0.454	0.079	0.100	0.278	2.396	2.804	2.197	0.669	0.102	0.385	0.944
3	3.231	2.021	3.207	3.453	6.472	4.060	17.837	8.804	6.041	2.487	5.675	5.753
4	9.275	5.694	2.276	2.072	5.632	8.731	4.744	22.306	16.015	8.679	2.398	7.984
4	18.925	9.162	18.535	8.840	25.922	15.821	15.588	39.823	23.307	19.359	10.053	18.667
5	14.439	19.856	6.589	9.086	7.195	12.844	11.187	7.726	26.302	24.754	11.331	13.755
5	18.480	23.389	17.874	15.221	12.227	22.546	15.458	19.466	29.593	25.406	15.796	19.587
6	5.649	13.047	13.740	9.008	7.469	6.812	17.612	7.355	7.240	20.087	20.196	11.656
6	9.506	12.190	14.612	9.937	7.856	10.825	13.225	7.774	11.422	11.431	23.319	12.009
7	19.172	7.192	8.079	10.080	4.870	4.512	7.937	9.614	4.307	4.609	12.070	8.404
7	8.035	6.163	5.933	7.303	3.212	4.200	3.474	6.081	2.091	1.414	4.769	4.789
8	6.540	18.216	5.747	6.253	5.019	2.543	3.577	3.296	4.546	1.545	2.195	5.407
8	1.422	8.872	1.920	2.127	2.317	1.659	0.864	0.862	1.331	0.375	0.376	2.011
9	2.085	3.642	10.001	1.734	2.068	1.521	1.254	1.140	1.134	0.780	0.540	2.354
9	0.182	1.341	1.517	0.321	0.612	0.743	0.518	0.323	0.210	0.102	0.067	0.540
10	0.622	1.277	1.687	2.394	0.420	0.743	0.695	0.480	0.384	0.188	0.297	0.835
10	0.026	0.518	0.227	0.339	0.092	0.321	0.111	0.113	0.071	0.036	0.024	0.171
11	0.231	0.443	0.258	0.445	0.381	0.145	0.288	0.240	0.191	0.081	0.085	0.253
11	0.026	0.119	0.070	0.069	0.157	0.073	0.103	0.014	0.112	0.028	0.032	0.073
12	0.094	0.184	0.068	0.124	0.164	0.145	0.098	0.142	0.123	0.078	0.045	0.115
12	0.007	0.026	0.025	0.091	0.030	0.087	0.004	0.000	0.035	0.010	0.005	0.029
13	0.017	0.091	0.039	0.025	0.068	0.064	0.067	0.046	0.114	0.035	0.014	0.053
13	0.007	0.037	0.004	0.039	0.022	0.038	0.008	0.000	0.000	0.003	0.001	0.014
14	0.001	0.058	0.010	0.018	0.029	0.022	0.040	0.041	0.019	0.004	0.017	0.024
14	0.003	0.002	0.001	0.018	0.009	0.016	0.004	0.016	0.007	0.002	0.003	0.007
15	0.003	0.031	0.007	0.012	0.009	0.000	0.020	0.022	0.007	0.012	0.000	0.011
15	0.000	0.000	0.005	0.001	0.000	0.000	0.010	0.009	0.000	0.004	0.000	0.003

Tables 3a-d. Groundfish survey indices.

	87	88	89	90	91	92
3	363.81	293.93	64.63	56.58	85.2	120.82

	86	87	88	89	90	91	92
3	1539.74	1866.34	807.64	220.83	655.37	416.92	544.66

	85	86	87	88	89	90	91	92
3	624.88	2158.38	2649.60	1699.76	486.73	637.90	542.99	852.37
4	843.77	323.28	1553.59	1984.68	1367.31	301.79	596.84	448.79
5	1205.60	353.91	414.88	1391.06	1013.89	421.16	257.44	353.68
6	313.26	490.91	202.85	114.14	398.40	372.99	245.00	131.18
7	256.20	81.14	191.59	116.68	30.85	155.27	185.69	60.13
8	65.43	30.59	24.21	145.84	13.61	8.87	30.00	25.79
9	54.82	6.67	12.22	5.33	14.43	4.22	9.00	6.77
10	26.02	9.81	3.33	2.96	1.28	5.11	1.80	0.93
11	0.51	3.12	4.09	1.49	1.48	1.38	1.58	NA
12	0.74	0.54	1.24	5.55	0.99	51.68	NA	1.90
13	0.18	0.27	0.64	0.48	NA	0.30	0.34	0.60
14	0.17	0.13	0.67	0.46	0.48	0.84	0.41	NA

	85	86	87	88	89	90	91	92
3	27.69	62.08	69.73	30.29	14.12	29.57	17.93	45.92
4	55.31	28.73	94.80	95.49	98.03	28.05	72.42	48.13
5	78.84	43.08	25.15	113.99	170.98	143.49	51.71	46.06
6	65.49	56.47	28.67	27.44	136.52	229.63	102.67	23.91
7	31.66	35.17	28.57	18.59	23.68	69.44	175.62	45.77
8	22.60	11.14	11.65	16.45	6.87	8.90	24.99	48.43
9	7.25	6.20	2.23	4.37	3.22	3.87	3.77	8.87
10	4.21	3.69	1.20	1.68	1.74	1.90	1.69	1.40
11	0.51	1.44	1.00	0.60	0.88	0.54	0.41	0.22
12	0.95	0.57	1.17	0.71	0.57	NA	NA	NA
13	0.35	0.43	0.61	0.18	0.27	0.18	0.42	NA
14	0.09	0.58	0.27	0.18	NA	NA	NA	NA

Table 4a. Commercial trawl CPUE indices. Winter. Northern region.

	85	86	87	88	89	90	91
3	NA	0.02	0.01	NA	NA	NA	NA
4	0.05	0.04	0.28	0.12	0.07	0.01	0.04
5	0.16	0.11	0.11	0.27	0.29	0.09	0.05
6	0.11	0.15	0.07	0.07	0.16	0.18	0.10
7	0.04	0.05	0.05	0.03	0.02	0.08	0.14
8	0.01	0.01	0.01	0.02	NA	0.01	0.02
9	0.01	NA	NA	NA	NA	NA	NA

Table 4b. Commercial trawl CPUE indices. Fall. Northern region.

	85	86	87	88	89	90	91
3	0.02	0.08	0.03	0.01	0.01	0.03	0.02
4	0.10	0.07	0.17	0.09	0.08	0.05	0.09
5	0.14	0.08	0.09	0.15	0.16	0.08	0.06
6	0.05	0.07	0.03	0.07	0.09	0.14	0.07
7	0.02	0.02	0.02	0.01	0.02	0.02	0.06
8	NA	NA	NA	NA	NA	NA	0.01

Table 4c. Commercial trawl CPUE indices. Winter. Southern region.

	85	86	87	88	89	90	91
3	NA	NA	0.01	0.01	NA	NA	NA
4	0.03	NA	0.07	0.05	0.03	NA	0.02
5	0.05	0.01	0.02	0.09	0.11	0.02	0.02
6	0.02	0.02	0.05	0.04	0.11	0.09	0.04
7	0.02	NA	0.03	0.02	0.01	0.06	0.10
8	0.02	0.01	0.01	0.01	0.01	0.01	0.03
9	0.01	0.01	0.01	NA	NA	NA	0.01
10	0.01	0.01	0.01	NA	NA	NA	NA

Table 4d. Commercial trawl CPUE indices. Fall. Southern region.

	85	86	87	88	89	90	91
3	0.02	0.13	0.05	0.02	NA	NA	0.02
4	0.05	0.09	0.20	0.07	0.02	0.01	0.02
5	0.06	0.10	0.08	0.10	0.05	0.04	0.02
6	0.03	0.06	0.01	0.03	0.05	0.08	0.04
7	0.01	0.01	NA	0.01	0.01	0.04	0.06
8	0.01	0.01	NA	0.01	NA	0.01	0.03
9	0.01	NA	NA	NA	NA	NA	0.01

Table 4e. Commercial trawl CPUE indices. Winter. Northern region.

	79	80	81	82	83	84
3	0.01	NA	NA	NA	NA	NA
4	0.08	0.05	0.03	0.01	0.01	0.05
5	0.06	0.09	0.14	0.04	0.07	0.07
6	0.11	0.03	0.08	0.12	0.07	0.06
7	0.03	0.09	0.04	0.06	0.07	0.04
8	NA	0.02	0.05	0.02	0.02	0.02
9	NA	NA	0.01	0.02	NA	0.01
10	NA	NA	NA	NA	0.01	NA

Table 4f. Commercial trawl CPUE indices. Fall. Northern region.

	79	80	81	82	83	84
3	0.05	0.02	0.01	0.02	0.01	0.02
4	0.13	0.09	0.07	0.09	0.03	0.15
5	0.05	0.09	0.14	0.08	0.07	0.08
6	0.09	0.06	0.06	0.07	0.06	0.05
7	0.02	0.06	0.03	0.03	0.05	0.02
8	NA	0.01	0.04	0.01	0.01	0.01
9	NA	NA	0.01	0.01	NA	NA

Table 5. Icelandic cod. Fishing mortalities at age. The averages across age groups are taken in an unweighted fashion across ages 5-10. The "Mature F" is the fishing mortality inflicted on the spawning stock, viewed as a unit age class.

	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73
3	0.030	0.035	0.104	0.115	0.076	0.102	0.089	0.100	0.106	0.064	0.100	0.071	0.097	0.076	0.044	0.059	0.084	0.075	0.143
4	0.148	0.165	0.176	0.296	0.299	0.156	0.217	0.252	0.364	0.304	0.163	0.192	0.148	0.255	0.216	0.291	0.321	0.279	0.318
5	0.165	0.257	0.267	0.175	0.380	0.325	0.143	0.346	0.317	0.465	0.396	0.151	0.232	0.183	0.369	0.344	0.530	0.509	0.452
6	0.261	0.165	0.262	0.286	0.103	0.353	0.363	0.163	0.351	0.250	0.497	0.415	0.128	0.240	0.207	0.397	0.622	0.560	0.592
7	0.392	0.243	0.129	0.367	0.183	0.188	0.394	0.435	0.274	0.404	0.341	0.584	0.507	0.280	0.306	0.296	0.505	0.806	0.713
8	0.280	0.319	0.342	0.220	0.312	0.368	0.210	0.398	0.589	0.475	0.705	0.494	0.587	0.877	0.499	0.565	0.352	0.603	0.698
9	0.282	0.354	0.473	0.340	0.270	0.485	0.402	0.423	0.464	0.941	0.701	0,621	0.606	0,900	0.845	1.032	0.580	0.688	0.669
10	0.390	0.147	0.404	0.498	0.650	0.498	0.426	0.572	0.686	0.658	0.983	0.977	0.876	1.504	0.906	0.664	1.067	0.995	1.098
11	0.333	0.619	0.139	0.533	0.494	0.837	0.514	0.526	0.709	1.075	0.988	1.005	1.190	1.215	1.114	0.875	0.663	1.160	0.915
12	0.224	0.328	0.874	1.733	0.834	1.292	0.771	0.509	0.559	1.161	0.540	0.901	0.482	1.759	0.812	1.359	0.994	0.859	0.935
13	0.356	0.468	0.187	0.292	0.237	0.443	0.383	0.590	0.472	0.595	0.611	0.816	0.293	0.604	0.964	0.476	2.378	2.729	0.103
14	0.311	0.373	0.403	0.603	0.466	0.654	0.451	0.503	0.580	0.817	0.755	0.802	0.672	1.143	0.857	0.829	1.006	1.172	0.736
Average	0.295	0.247	0.313	0.314	0.316	0.370	0.323	0.389	0.447	0.532	0.604	0.540	0.489	0.664	0.522	0.550	0.609	0.694	0.704
Mature F	0.276	0.261	0.252	0.301	0.267	0.342	0.293	0.317	0.374	0.433	0.447	0.355	0.257	0.299	0.331	0.431	0.491	0.596	0.568

	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91
3	0.101	0.130	0.082	0.020	0.030	0.033	0.034	0.016	0.027	0.017	0.055	0.050	0.070	0.041	0.043	0.034	0.041	0.049
4	0.382	0.299	0.262	0.210	0.168	0.194	0.175	0.137	0.220	0.119	0.210	0.286	0.222	0.311	0.204	0.255	0.223	0.255
5	0.495	0.520	0.362	0.354	0.347	0.210	0.356	0.387	0.399	0.432	0.321	0.385	0.579	0.520	0.513	0.435	0.424	0.492
6	0.458	0.568	0.617	0.367	0.331	0.506	0.375	0.468	0.540	0.622	0.539	0.570	0.693	0.785	0.849	0.618	0.615	0.720
7	0.734	0.641	0.595	0.812	0.493	0.486	0.439	0.631	0.579	0.768	0.597	0.684	0.883	0.972	0.957	0.747	0.835	0.878
8	0.969	0.785	0.940	0.655	0.662	0.502	0.552	0.839	1.042	0.852	0.904	0.731	0.945	0.998	1.393	0.882	0.870	0.898
9	0.802	1.077	0.717	1.001	0.500	0.508	0.512	0.800	1.201	0.917	0.745	0.808	0.809	1.003	1.130	0.809	0.798	0.898
10	0.979	1.158	1.307	0.537	0.532	0.333	0.453	0.954	0.907	1.118	0.611	0.768	0.776	0.710	1.067	0.559	0.811	0.898
11	1.354	1.253	1.297	0.593	0.282	0.534	0.415	0.998	0.479	0.663	0.683	0.574	0.735	0.598	1.052	0.794	0.654	0.898
12	0.772	1.756	0.758	0.478	0.402	0.155	0.710	0.872	0.412	0.679	0.572	0.730	0.596	0.655	0.969	1.026	1.176	0.898
13	0.537	0.295	2.451	0.055	0.632	1.392	0.127	1.127	0.387	0.552	0.687	0.681	0.560	0.588	2.375	0.661	0.480	0.898
14	0.902	1.054	1.245	0.553	0.568	0.571	0.462	0.932	0.738	0.797	0.701	0.715	0.737	0.759	1.331	0.788	0.798	0.898
Average	0.739	0.791	0.756	0.621	0.477	0.424	0.448	0.680	0.778	0.785	0.620	0.658	0.781	0.832	0.985	0.675	0.725	0.797
Mature F	0.566	0.551	0.443	0.464	0.349	0.172	0.333	0.653	0.641	0.605	0.518	0.511	0.669	0.639	0.617	0.385	0.605	0.578

Table 6. Icelandic cod. Stock size in numbers at age, SSB in '000 t and fishable (4+) stock in '000 t, as obtained from tuned VPA.

	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77
3	148	203	179	261	308	153	191	143	164	292	257	273	329	174	255	187	179	137	303	171	265	331	145
4	195	117	160	132	190	233	113	143	106	121	224	190	208	244	132	200	144	134	104	215	126	191	249
5	240	138	81	110	80	115	163	75	91	60	73	156	128	147	155	87	122	86	83	62	120	77	120
6	122	166	87	51	76	45	68	116	43	54	31	40	110	83	100	88	50	59	42	43	31	59	44
7	33	77	116	55	31	56	26	39	81	25	35	15	22	79	54	67	48	22	28	19	22	14	26
8	21	18	49	83	31	21	38	14	21	50	14	20	7	11	49	32	41	24	8	11	8	10	6
9	26	13	11	29	55	19	12	25	8	9	26	6	10	3	4	24	15	23	11	3	3	3	3
10	62	16	7	6	17	34	9	7	13	4	3	10	2	5	1	1	7	7	10	4	1	1	1
11	10	34	11	4	3	7	17	5	3	6	2	1	3	1	1	0	1	2	2	3	1	0	0
12	8	6	15	8	2	1	3	8	2	1	2	1	0	1	0	0	0	0	1	1	1	0	0
13	8	5	3	5	1	1	0	1	4	1	0	1	0	0	0	0	0	0	0	0	0	0	0
14	1	4	3	2	3	1	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0
SSB	1441	1366	1265	1128	995	866	795	760	709	587	459	415	478	595	694	685	616	479	439	333	343	287	322
Fishable	2806	2530	2272	2047	1874	1857	1651	1587	1434	1249	1215	1240	1384	1652	1632	1640	1442	1201	1013	1053	1003	946	1175

	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92
3	224	248	145	145	135	229	141	145	336	299	175	86	159	200	NA
4	116	178	197	115	116	108	184	109	113	257	235	137	68	125	156
5	166	80	120	135	82	77	78	122	67	74	154	157	87	45	79
6	69	96	53	69	75	45	41	46	68	31	36	75	107	47	22
7	25	41	84	30	35	36	20	19	22	28	11	13	33	47	18
8	9	12	20	51	13	16	14	9	8	7	9	4	5	12	16
9	3	4	6	10	18	4	6	5	4	3	2	2	1	2	4
10	1	1	2	3	4	4	1	2	2	1	1	1	1	0	1
11	1	0	1	1	1	1	1	1	1	1	1	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SSB	380	454	608	391	267	214	220	270	270	254	193	281	347	350	NA
Fishable	1199	1255	1554	1238	988	776	840	843	837	1033	1037	990	829	739	723

Table 7. Icelandic cod. Standardised log-catchability residuals.

Standardized catchabilities. Fleet:
SUR1

	1987	1988	1989	1990	1991	1992	Mean	Var	c/Var	Wts
3	0.73	1.22	0.01	-1.12	-0.85	NA	-0.29	0.44	0.11	0.02

Standardized catchabilities. Fleet:
SUR2

	1986	1987	1988	1989	1990	1991	1992	Mean	Var	c/Var	Wts
3	0.47	1.22	0.49	-0.94	0.21	-1.45	NA	1.33	0.17	0.30	0.05

Standardized catchabilities. Fleet:
SUR.N

	1985	1986	1987	1988	1989	1990	1991	1992	Mean	Var	c/Var	Wts
3	-0.53	0.35	1.06	1.27	0.07	-0.69	-1.54	NA	1.70	0.21	0.24	0.10
4	0.77	-1.33	0.25	0.96	1.31	-0.40	-0.25	-1.31	1.68	0.22	0.22	0.20
5	1.64	-0.55	-0.35	1.34	0.16	-0.86	-0.24	-1.14	1.82	0.08	0.62	1.00
6	0.82	1.03	0.75	-1.66	0.02	-1.35	0.00	0.39	1.66	0.09	0.54	1.00
7	1.61	-0.54	0.49	1.16	-1.29	-0.17	-0.48	-0.78	1.64	0.34	0.15	0.20
8	0.85	0.00	-0.18	1.95	-0.01	-0.97	-0.53	-1.11	1.34	0.58	0.09	0.10
9	1.58	-1.09	0.24	-0.73	1.02	-0.23	0.41	-1.20	1.40	0.48	0.10	0.10
10	1.59	0.55	-0.70	-0.10	-0.95	0.99	-0.05	-1.33	1.42	0.44	0.11	0.10
11	-0.26	0.32	0.55	0.21	0.57	0.44	0.56	-2.38	0.56	5.80	0.01	0.01
12	-0.41	-0.29	-0.10	0.46	0.09	1.62	-1.90	0.53	1.63	8.94	0.01	0.01
13	-0.49	-0.22	0.40	0.19	-2.16	0.49	0.91	0.88	0.82	4.94	0.01	0.01
14	-0.37	-0.56	0.22	0.31	1.07	0.75	0.66	-2.07	1.51	4.73	0.01	0.01

Standardized catchabilities. Fleet:
SUR.SW

	1985	1986	1987	1988	1989	1990	1991	1992	Mean	Var	c/Var	Wts
3	0.41	0.30	1.08	0.09	-0.09	0.32	-2.11	NA	-1.78	0.09	0.56	0.20
4	0.55	-1.52	-0.40	-0.12	1.57	-0.08	0.94	-0.93	-0.86	0.11	0.45	0.20
5	-0.37	-0.37	-1.68	-0.08	0.70	1.55	0.83	-0.58	-0.26	0.24	0.21	0.20
6	0.21	-1.04	-0.76	-1.23	0.80	1.19	1.25	-0.42	0.25	0.18	0.27	0.20
7	-0.39	-0.38	-1.63	-0.41	-0.01	0.27	1.80	0.75	0.63	0.14	0.36	0.20
8	0.96	-1.43	-0.86	-0.16	-0.17	-0.35	0.26	1.75	0.69	0.06	0.80	0.20
9	-0.40	-0.16	-2.05	0.17	-0.05	1.42	0.50	0.57	0.62	0.14	0.36	0.10
10	-0.42	-0.05	-2.14	-0.10	0.65	0.62	1.17	0.28	0.83	0.18	0.28	0.10
11	-1.35	0.07	-0.09	-0.86	2.04	0.39	0.10	-0.31	0.52	0.19	0.26	0.10
12	0.63	0.67	0.79	0.70	0.81	-1.16	-1.27	-1.18	-1.75	14.47	0.00	0.00
13	0.00	0.14	0.50	-0.07	0.28	0.40	1.06	-2.31	0.43	6.03	0.01	0.00
14	0.69	1.11	0.93	0.97	-0.83	-1.11	-1.01	-0.75	-2.85	17.67	0.00	0.00

Standardized catchabilities. Fleet:
TRWL.winter.n

	1985	1986	1987	1988	1989	1990	1991	Mean	Var	c/Var	Wts
3	0.57	1.43	0.90	-0.51	-0.50	-1.45	-0.44	-11.60	1.87	0.03	0.00
4	0.17	-0.31	1.52	0.35	0.45	-1.74	-0.45	-7.85	0.44	0.11	0.05
5	-0.50	0.46	0.38	0.96	1.18	-1.25	-1.22	-6.55	0.05	1.08	0.50
6	1.07	0.49	0.73	-0.69	0.19	-1.89	0.09	-6.20	0.01	4.39	0.50
7	-0.14	0.71	-0.99	0.27	-1.60	0.49	1.27	-6.17	0.06	0.81	0.50
8	-0.42	0.17	-0.71	1.30	-1.65	0.58	0.73	-6.69	0.16	0.31	0.15
9	0.80	-1.49	0.07	1.14	NA	-0.85	0.33	-7.14	0.32	0.16	0.05
10	-0.89	-0.01	-1.35	0.91	NA	0.09	1.25	-7.06	0.94	0.05	0.00

Standardized catchabilities. Fleet:
TRWL.fall.n

	1985	1986	1987	1988	1989	1990	1991	Mean	Var	c/Var	Wts
3	0.31	1.57	-0.38	-1.26	-0.85	0.95	-0.33	-9.07	0.20	0.25	0.00
4	1.40	-0.11	0.11	-1.90	-0.29	0.37	0.42	-7.36	0.07	0.68	0.50
5	0.16	0.63	0.76	-1.11	-0.62	-1.21	1.39	-6.81	0.02	3.28	0.50
6	-0.61	-0.94	-0.82	1.82	-0.38	0.17	0.76	-6.66	0.05	0.97	0.50
7	-0.62	0.15	-0.96	0.92	0.99	-1.40	0.93	-6.97	0.06	0.88	0.50
8	0.12	0.40	-1.18	0.38	0.95	-1.59	0.93	-7.69	0.15	0.32	0.15
9	0.25	0.08	0.69	-0.55	0.18	-1.89	1.24	-7.97	0.58	0.09	0.05
10	-0.84	-0.16	-1.00	-0.49	1.39	-0.31	1.41	-8.45	1.01	0.05	0.00

Standardized catchabilities. Fleet:
TRWL.fall.s

	1985	1986	1987	1988	1989	1990	1991	Mean	Var	c/Var	Wts
3	0.20	1.46	0.59	0.19	-1.09	-1.49	0.13	-9.11	0.71	0.07	0.00
4	0.49	1.28	1.21	-0.24	-1.10	-0.91	-0.74	-8.01	0.51	0.10	0.15
5	-0.57	1.56	1.06	-0.02	-1.38	-0.39	-0.26	-7.37	0.28	0.18	0.15
6	0.00	0.49	-1.97	0.81	-0.44	0.10	1.01	-7.27	0.09	0.53	0.15
7	-1.76	-0.61	NA	0.55	0.33	0.72	0.78	-7.09	0.18	0.27	0.15
8	-0.52	-1.03	NA	0.08	-0.42	0.02	1.87	-6.86	0.17	0.29	0.10
9	0.07	-1.78	NA	0.07	0.39	-0.03	1.29	-6.44	0.61	0.08	0.05
10	-0.31	-1.84	NA	0.56	0.06	0.60	0.93	-6.21	0.22	0.23	0.05

Standardized catchabilities. Fleet:
TRWL.winter.s

	1985	1986	1987	1988	1989	1990	1991	Mean	Var	c/Var	Wts
3	NA	-0.16	0.65	1.19	NA	-1.44	-0.24	-11.23	1.33	0.04	0.00
4	0.63	-1.03	0.74	0.63	0.56	-1.79	0.25	-9.22	1.82	0.03	0.05
5	0.40	-1.82	-0.16	0.88	1.17	-0.58	0.12	-8.02	0.45	0.11	0.05
6	-0.98	-1.70	0.99	0.43	0.95	0.10	0.21	-7.17	0.45	0.11	0.05
7	-0.18	-2.08	0.04	0.67	0.03	0.69	0.84	-6.86	0.76	0.07	0.05
8	0.24	-0.61	-0.26	-1.61	-0.14	1.02	1.36	-6.46	0.13	0.38	0.05
9	0.20	-1.02	1.00	-1.06	NA	-0.39	1.28	-6.00	0.08	0.60	0.05
10	0.03	1.13	0.43	-0.79	NA	-1.54	0.74	-5.77	0.36	0.14	0.05

Standardized catchabilities. Fleet:
TRWLO.winter.n

	1979	1980	1981	1982	1983	1984	Mean	Var	c/Var	Wts
3	1.27	0.90	-0.94	-0.90	-0.81	0.49	-11.89	2.88	0.02	0.00
4	1.37	0.24	0.23	-1.11	-1.23	0.50	-8.51	0.36	0.14	0.15
5	-0.32	-0.04	1.13	-1.74	0.71	0.26	-7.14	0.07	0.73	0.40
6	-0.16	-1.87	-0.03	0.80	0.76	0.50	-6.72	0.13	0.38	0.20
7	-1.58	-0.56	-0.31	0.56	0.91	0.97	-6.63	0.13	0.38	0.20
8	-1.84	-0.16	-0.14	0.64	0.62	0.88	-6.87	0.36	0.14	0.20
9	-0.72	-1.32	-0.54	0.74	0.61	1.23	-7.08	0.09	0.58	0.20
10	-1.56	-0.92	0.59	0.75	0.84	0.30	-7.48	0.74	0.07	0.05

Standardized catchabilities. Fleet:
TRWLO.fall.n

	1979	1980	1981	1982	1983	1984	Mean	Var	c/Var	Wts
3	0.92	0.40	-0.56	0.23	-1.75	0.77	-9.21	0.42	0.12	0.00
4	0.54	-0.67	0.00	0.89	-1.64	0.88	-7.45	0.14	0.36	0.20
5	-1.77	-0.59	0.80	0.66	0.32	0.58	-7.04	0.04	1.22	0.50
6	-0.73	0.76	-0.99	-0.94	1.30	0.59	-6.85	0.03	1.75	0.50
7	-1.80	-0.41	0.44	0.10	0.88	0.79	-7.06	0.22	0.23	0.15
8	-1.87	-0.41	0.58	0.50	0.49	0.72	-7.57	0.72	0.07	0.05
9	-0.83	-1.62	0.80	0.68	0.27	0.71	-8.03	0.55	0.09	0.05
10	NA	0.45	1.38	0.09	-1.14	-0.77	-8.32	0.27	0.18	0.05

Table 8. Northern region indices. From groundfish survey in years 1985-1991.

	Age							
Year class	1	2	3	4	5	6	7	8
77								65.43
78							256.20	30.59
79						313.25	81.14	24.21
80					1205.59	490.90	191.59	145.83
81				843.77	353.91	202.84	116.68	13.61
82			624.87	323.27	414.88	114.13	30.84	8.87
83		1539.73	2158.37	1553.59	1391.06	398.40	155.26	30.00
84	363.80	1866.34	2649.6	1984.68	1013.88	372.99	185.69	25.79
85	293.93	807.64	1699.76	1367.31	421.16	244.99	60.13	
86	64.62	220.83	486.72	301.78	257.44	131.17		
87	56.58	655.36	637.90	596.84	353.67			
88	85.20	416.92	542.98	448.78				
89	120.81	544.66	852.37					
90	76.28	616.26						
91	11.66							

Table 9. Southern region indices. From groundfish survey in years 1985-1991.

	Age							
Year class	1	2	3	4	5	6	7	8
77								22.59
78							31.66	11.13
79						65.49	35.17	11.65
80					78.83	56.47	28.56	16.45
81				55.31	43.08	28.67	18.59	6.87
82			27.68	28.73	25.14	27.44	23.67	8.89
83		15.40	62.08	94.80	113.99	136.51	69.43	24.99
84	8.68	29.35	69.72	95.49	170.98	229.63	175.62	48.42
85	11.88	11.43	30.28	98.03	143.48	102.67	45.77	
86	4.93	3.26	14.11	28.05	51.70	23.91		
87	14.17	18.95	29.56	72.42	46.06			
88	15.17	8.16	17.93	48.13				
89	19.08	14.32	45.91					
90	12.08	24.27						
91	6.51							

Table 10. Icelandic cod. Estimated sexual maturity at age in the stock, based on weighted samples from all commercial gears, January-May. The average over the years 1973-1991 is used for the years 1955-1972.

	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91
3	0.02	0.03	0.01	0.01	0.05	NA	0.05	NA	0.06	NA	0.02	NA	NA	0.03	NA	0.02	0.04	0.04	NA	0.06
4	0.07	0.07	0.09	0.11	0.06	0.05	0.05	0.02	0.02	0.03	0.05	0.09	0.04	0.06	0.05	0.05	0.02	0.12	0.07	0.21
5	0.24	0.41	0.28	0.34	0.28	0.21	0.18	0.19	0.16	0.08	0.13	0.17	0.19	0.20	0.24	0.24	0.21	0.25	0.30	0.54
6	0.51	0.61	0.58	0.54	0.50	0.61	0.44	0.53	0.48	0.29	0.23	0.34	0.42	0.55	0.54	0.58	0.48	0.49	0.63	0.78
7	0.76	0.84	0.79	0.86	0.63	0.88	0.88	0.79	0.81	0.66	0.54	0.51	0.66	0.77	0.76	0.81	0.69	0.76	0.82	0.89
8	0.90	0.94	0.93	0.95	0.94	0.96	0.96	0.93	0.92	0.89	0.85	0.72	0.78	0.90	0.89	0.94	0.83	0.84	0.91	0.94
9	0.95	0.98	0.96	0.99	0.99	0.99	0.98	0.98	0.98	0.95	0.96	0.86	0.86	0.94	0.98	0.95	0.93	0.89	0.95	0.84
10	0.98	1.00	0.99	1.00	1.00	1.00	1.00	0.92	0.98	0.96	0.97	0.98	0.95	1.00	0.96	1.00	0.95	0.97	0.99	1.00
11	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	1.00	0.98	0.97	1.00	0.99	0.98	0.97	1.00	1.00	1.00
12	0.98	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.96	1.00	1.00	1.00	0.95	1.00	1.00	1.00	0.82	0.92	1.00	1.00
13	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.86	1.00	1.00
14	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Table 11. Icelandic cod. Sexual maturity at age based on weighted samples from all commercial gears, January-December. The average over the years 1973-1991 is used for the years 1955-1972.

	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91
3	0.03	0.04	0.04	0.01	0.03	NA	0.02	0.04	0.02	NA	0.01	NA	0.01	0.04	0.01	0.02	0.04	0.04	0.04	0.09
4	0.08	0.07	0.11	0.09	0.11	0.04	0.08	0.05	0.05	0.02	0.06	0.04	0.05	0.11	0.07	0.04	0.06	0.12	0.08	0.19
5	0.22	0.26	0.27	0.30	0.37	0.19	0.21	0.20	0.17	0.09	0.17	0.16	0.20	0.20	0.23	0.14	0.22	0.25	0.26	0.26
6	0.45	0.51	0.61	0.51	0.56	0.55	0.47	0.49	0.46	0.26	0.26	0.33	0.41	0.49	0.46	0.46	0.35	0.49	0.48	0.46
7	0.70	0.78	0.80	0.83	0.67	0.84	0.86	0.74	0.74	0.57	0.53	0.51	0.65	0.70	0.72	0.67	0.61	0.76	0.73	0.68
8	0.86	0.94	0.93	0.95	0.93	0.96	0.96	0.90	0.85	0.81	0.81	0.71	0.81	0.88	0.81	0.84	0.78	0.84	0.87	0.86
9	0.94	0.98	0.97	0.99	0.99	0.99	0.98	0.98	0.97	0.91	0.93	0.86	0.93	0.91	0.96	0.93	0.84	0.89	0.96	0.85
10	0.97	0.99	0.99	1.00	1.00	1.00	1.00	0.93	0.98	0.95	0.95	0.98	0.99	1.00	0.97	1.00	0.95	0.97	0.99	0.77
11	0.98	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.98	1.00	0.98	1.00	1.00	0.65
12	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
13	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
14	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Table 12. Icelandic cod. Stock mean weights at age in grammes. Based on samples taken from commercial catches in January-May. The average over the years 1973-1991 is used for the years 1955-1972.

	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
3	1070	999	1046	978	1217	960	1031	1141	1333	967	996	891	1002	1131	1182	1289	1218	1012	813	1122
4	1638	1580	1850	1855	1604	1723	1671	1647	1680	1513	1626	1472	1479	1597	1762	1811	1604	1542	1330	1771
5	2551	3488	2772	3292	2516	2729	2863	2532	2708	2101	2095	2139	2257	2285	2681	2735	2499	2423	2132	2228
6	3735	4441	4596	4165	4380	4108	3920	4027	3875	3225	3006	2918	3476	3524	3562	4202	3566	3743	3187	3037
7	5117	5585	5859	5893	5407	5957	5976	5664	5446	4520	4339	4130	4480	5010	4824	5110	5161	5298	4691	3882
8	6503	6844	7209	7153	6985	6696	6946	6951	7106	5851	5571	5553	5887	6195	6457	6497	6238	6910	6627	5885
9	7832	7002	7820	7905	8752	7618	9204	8234	8120	7661	6801	7007	7660	7800	7843	7802	7302	7725	8915	7644
10	9384	6917	7874	8753	10143	9669	10833	9500	10737	9084	9259	7770	9920	9225	9419	10220	8647	9397	10362	10562
11	11074	7632	8301	8745	11829	12578	12920	12921	12628	10833	11550	10817	11035	11336	10674	11197	10184	11953	12093	11185
12	12543	7899	9886	9788	11518	13884	12863	13028	17528	12401	13445	13176	14531	13277	13660	10620	11504	9529	15453	14334
13	14415	13982	11221	10081	13916	17026	19104	13308	15939	11724	17138	14175	15378	15325	13812	15893	14159	12195	15337	14178
14	17158	14000	14363	9876	15367	24652	21183	18930	25212	14326	16554	18543	16394	18932	18479	16514	10952	14270	17257	20195

Table 13. Icelandic cod. Catch mean weights at age in grammes. Based on samples taken from commercial catches in January-December. The average over the years 1973-1991 is used for the years 1955-1972.

	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
3	1255	1030	1050	1100	1350	1259	1289	1408	1392	1180	1006	1095	1288	1407	1459	1316	1438	1186	1290	1310
4	1783	1420	1710	1770	1780	1911	1833	1956	1862	1651	1550	1599	1725	1971	1961	1956	1805	1813	1704	1897
5	2579	2470	2430	2780	2650	2856	2929	2642	2733	2260	2246	2275	2596	2576	2844	2686	2576	2590	2383	2473
6	3623	3600	3820	3760	4100	4069	3955	3999	3768	3293	3104	3021	3581	3650	3593	3894	3519	3915	3034	3155
7	4898	4900	5240	5450	5070	5777	5726	5548	5259	4483	4258	4096	4371	4976	4635	4716	4930	5210	4624	3784
8	6301	6110	6660	6690	6730	6636	6806	6754	6981	5821	5386	5481	5798	6372	6155	6257	6001	6892	6521	5671
9	7684	6670	7150	7570	8250	7685	9041	8299	8037	7739	6682	7049	7456	8207	7503	7368	7144	8035	8888	7230
10	9345	6750	7760	8580	9610	9730	10865	9312	10731	9422	9141	8128	9851	10320	9084	9243	8822	9831	10592	9780
11	10921	7430	8190	8810	11540	11703	13068	13130	12301	11374	11963	11009	11052	12197	10356	10697	9977	11986	10993	9723
12	12767	7950	9780	9780	11430	14394	11982	13418	17281	12784	14226	13972	14338	14683	15283	10622	11732	10003	14570	14337
13	14521	10170	12380	10090	14060	17456	19062	13540	14893	12514	17287	15882	15273	16175	14540	15894	14156	12611	15732	14178
14	17235	17000	14700	11000	16180	24116	21284	20072	19069	19069	16590	18498	16660	19050	15017	12592	13042	16045	17290	20195

Table 14. Icelandic cod. Percentage of catches taken in each of the two seasons (January-May vs June-December) and estimated fractions of fishing mortalities taken in January-March.

Age	Jan-May	June-December	Partial F
2	0.05	0.95	0.031
3	0.14	0.86	0.085
4	0.30	0.70	0.180
5	0.41	0.59	0.248
6	0.49	0.51	0.296
7	0.64	0.36	0.382
8	0.73	0.27	0.437
9	0.81	0.19	0.477
10	0.83	0.17	0.477
11	0.78	0.22	0.477
12	0.80	0.20	0.477
13	0.79	0.21	0.477
14	0.77	0.23	0.477
15	0.79	0.21	0.477

Table 15. Input parameters for yield computations based on the years 1983-1991.

	fatage	m	m.wt	sexmat
3	0.06	0.2	1073.33	0.02
4	0.31	0.2	1596.44	0.08
5	0.62	0.2	2375.44	0.26
6	0.90	0.2	3468.33	0.53
7	1.10	0.2	4731.78	0.74
8	1.13	0.2	6249.89	0.86
9	1.13	0.2	7744.22	0.91
10	1.13	0.2	9502.44	0.98
11	1.13	0.2	11163.78	0.99
12	1.13	0.2	12898.22	0.97
13	1.13	0.2	14494.67	0.98
14	1.13	0.2	16837.33	1.00

Table 16. Input parameters for yield computations based on the years 1973-1982.

	fatage	m	m.wt	sexmat
3	0.10	0.2	1066.8	0.02
4	0.37	0.2	1674.9	0.05
5	0.61	0.2	2709.6	0.23
6	0.76	0.2	3974.3	0.48
7	0.96	0.2	5464.6	0.77
8	1.22	0.2	6731.2	0.93
9	1.22	0.2	7911.7	0.98
10	1.22	0.2	9276.9	0.98
11	1.22	0.2	10993.7	1.00
12	1.22	0.2	12224.0	1.00
13	1.22	0.2	14343.9	1.00
14	1.22	0.2	17446.3	1.00

Table 17. Icelandic cod. 0-group indices, 1970-1991 and mean lengths.

Year	Index	Mean length
70	873	55.7
71	283	40.4
72	79	43.7
73	1191	61.0
74	54	46.0
75	130	42.4
76	2743	52.6
77	435	44.5
78	552	50.2
79	370	36.0
80	558	49.3
81	78	55.9
82	10	44.6
83	153	55.2
84	1772	56.1
85	812	54.0
86	50	52.2
87	81	48.4
88	20	48.7
89	42	51.2
90	37	53.3
91	6	41.6

Fig. 1. Icelandic cod. Catch in numbers at age
for three yearclasses.

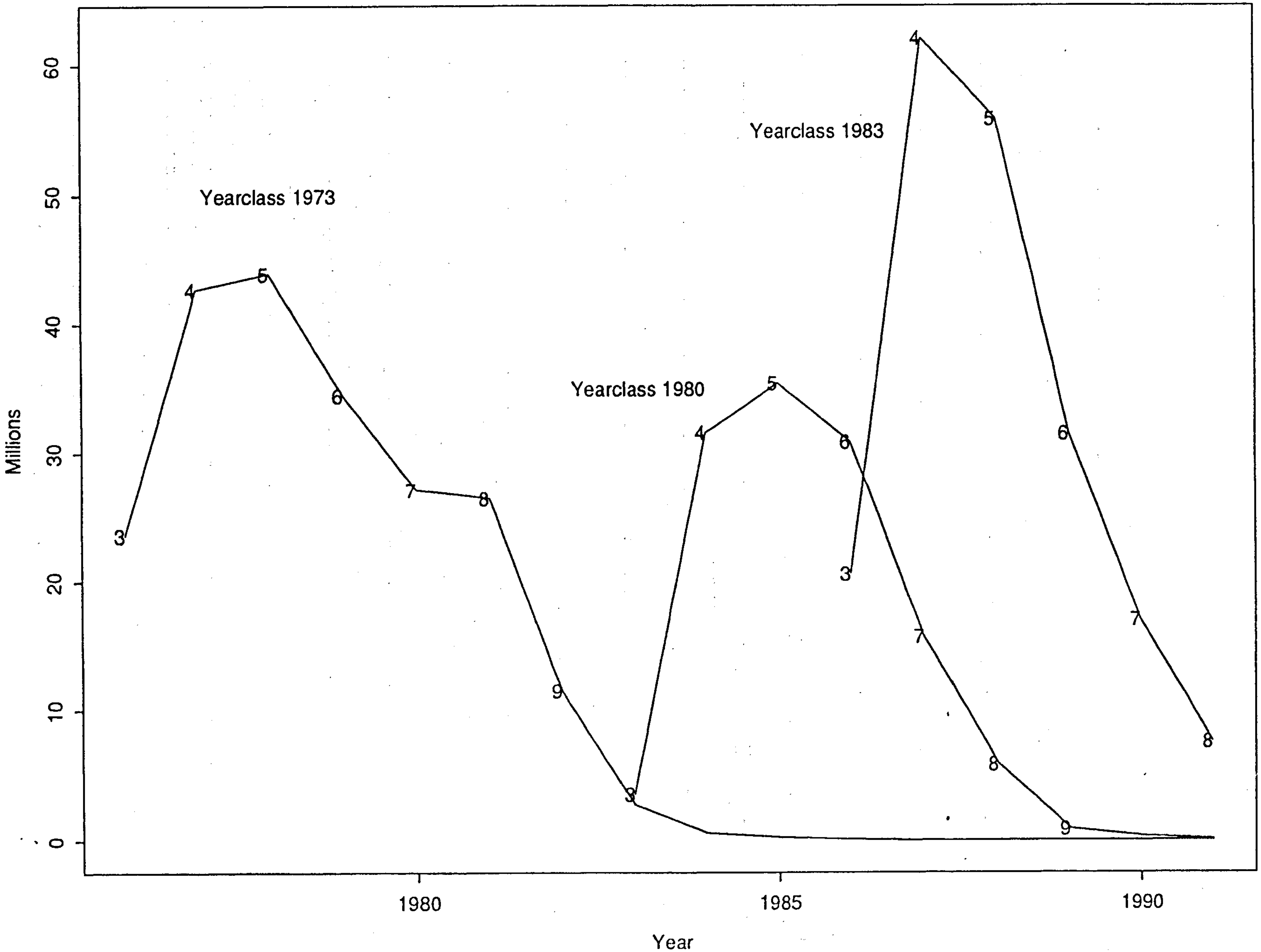
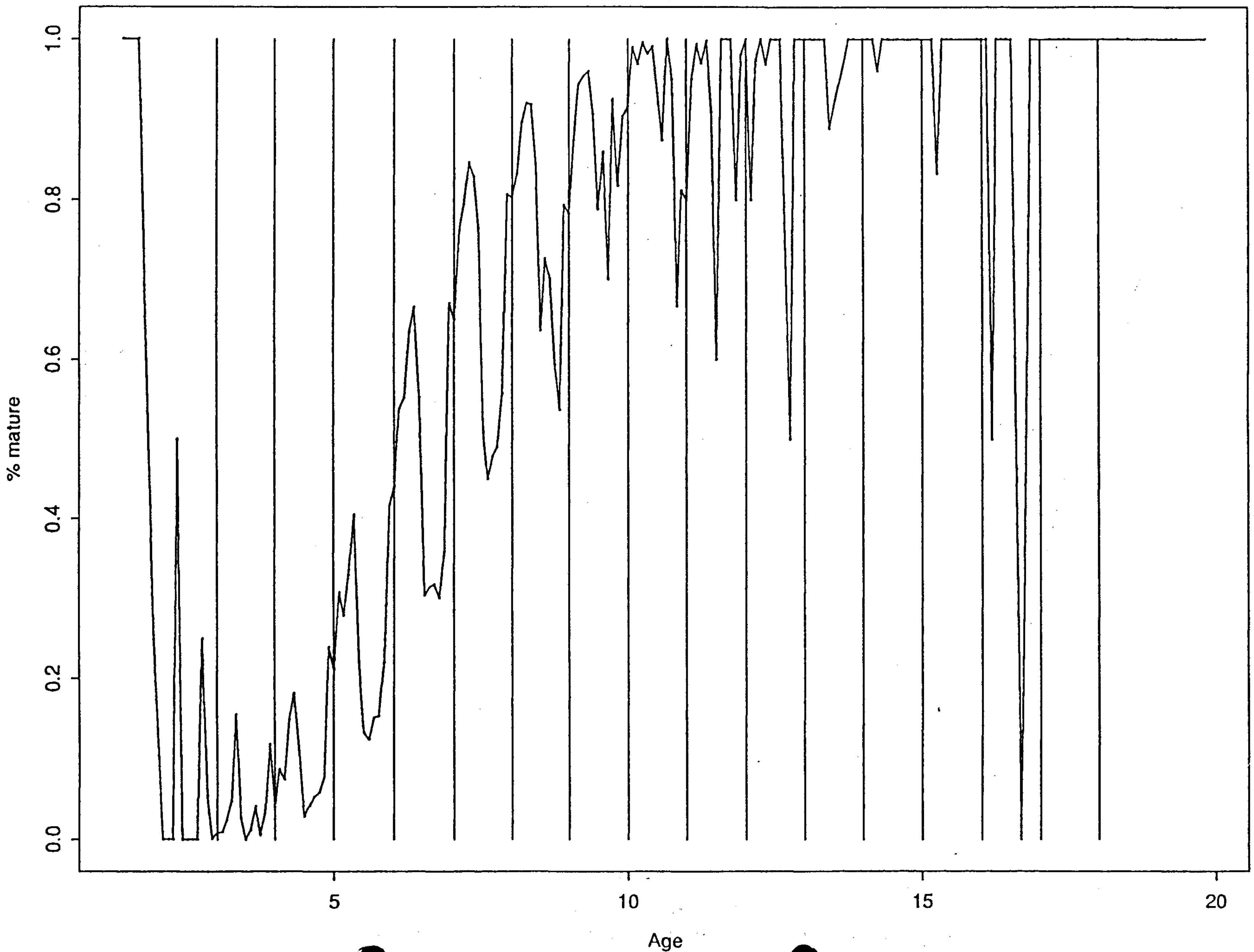
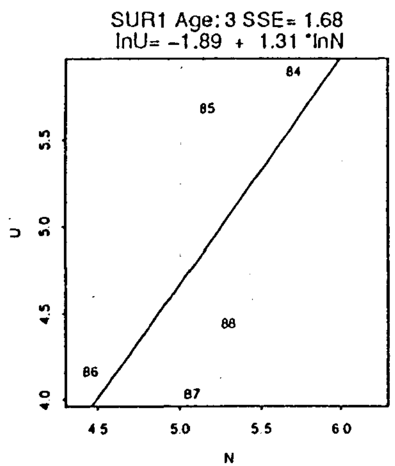
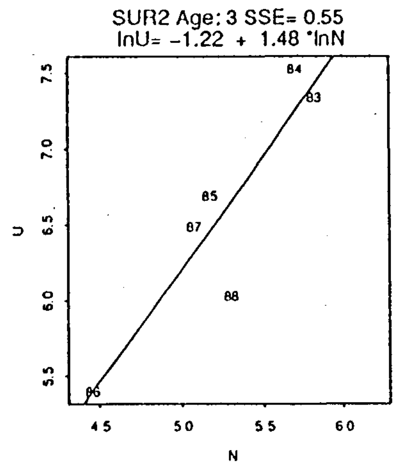


Fig. 2. Maturity of cod by month. Average 1975–1990.
All commercial gear combined.







Stations in southern (X) and northern (O) regions in groundfish survey

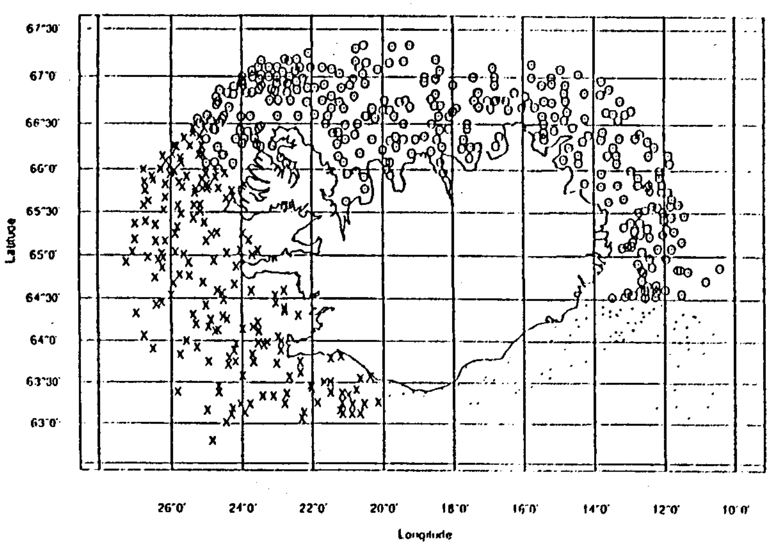


Figure 3. Catch per unit effort (U) from different "fleets":

SUR1	Survey, northern region, 1-group
SUR2	Survey, northern region, 2-group
SUR.N	Survey, northern region, ages 3-14
SUR.SW	Survey, southern region, ages 3-14
TRWL.winter.n	Commercial trawler CPUE, winter (jan-may), northern region
TRWL.fall.n	Commercial trawler CPUE, fall (june-dec), northern region
TRWL.winter.s	Commercial trawler CPUE, winter (jan-may), southern region
TRWL.fall.s	Commercial trawler CPUE, fall (june-dec), southern region
TRWLO.winter.n	Commercial trawler CPUE, winter (jan-may), northern region
TRWLO.fall.n	Commercial trawler CPUE, fall (june-dec), northern region

Fig. 3 (cont.)

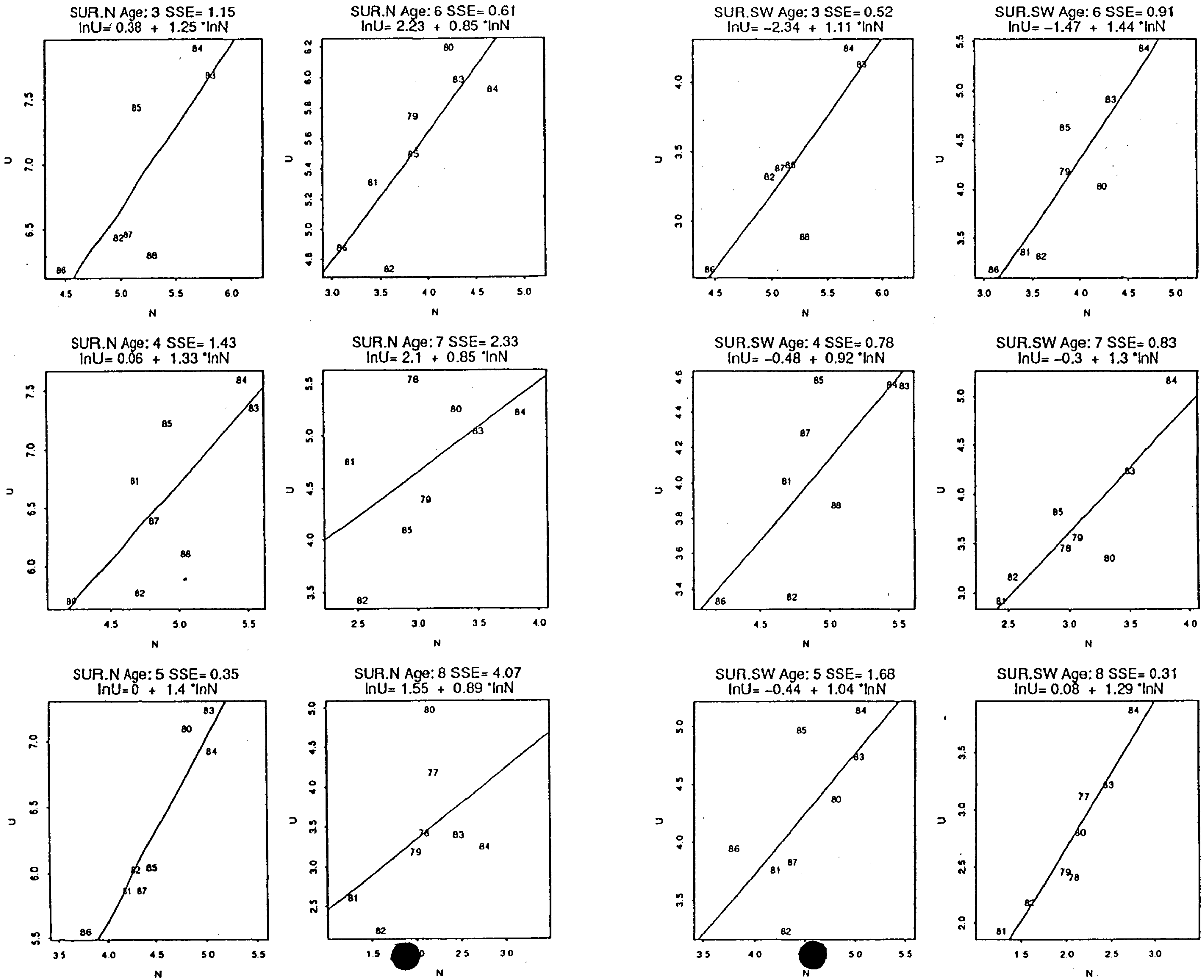

SUR.N Age: 3 SSE= 1.15
lnU= 0.38 + 1.25 *lnN
SUR.N Age: 6 SSE= 0.61
lnU= 2.23 + 0.85 *lnN
SUR.SW Age: 3 SSE= 0.52
lnU= -2.34 + 1.11 *lnN
SUR.SW Age: 6 SSE= 0.91
lnU= -1.47 + 1.44 *lnN
SUR.N Age: 4 SSE= 1.43
lnU= 0.06 + 1.33 *lnN
SUR.N Age: 7 SSE= 2.33
lnU= 2.1 + 0.85 *lnN
SUR.SW Age: 4 SSE= 0.78
lnU= -0.48 + 0.92 *lnN
SUR.SW Age: 7 SSE= 0.83
lnU= -0.3 + 1.3 *lnN
SUR.N Age: 5 SSE= 0.35
lnU= 0 + 1.4 *lnN
SUR.N Age: 8 SSE= 4.07
lnU= 1.55 + 0.89 *lnN
SUR.SW Age: 5 SSE= 1.68
lnU= -0.44 + 1.04 *lnN
SUR.SW Age: 8 SSE= 0.31
lnU= 0.08 + 1.29 *lnN
U
N

Fig. 3 (cont.)

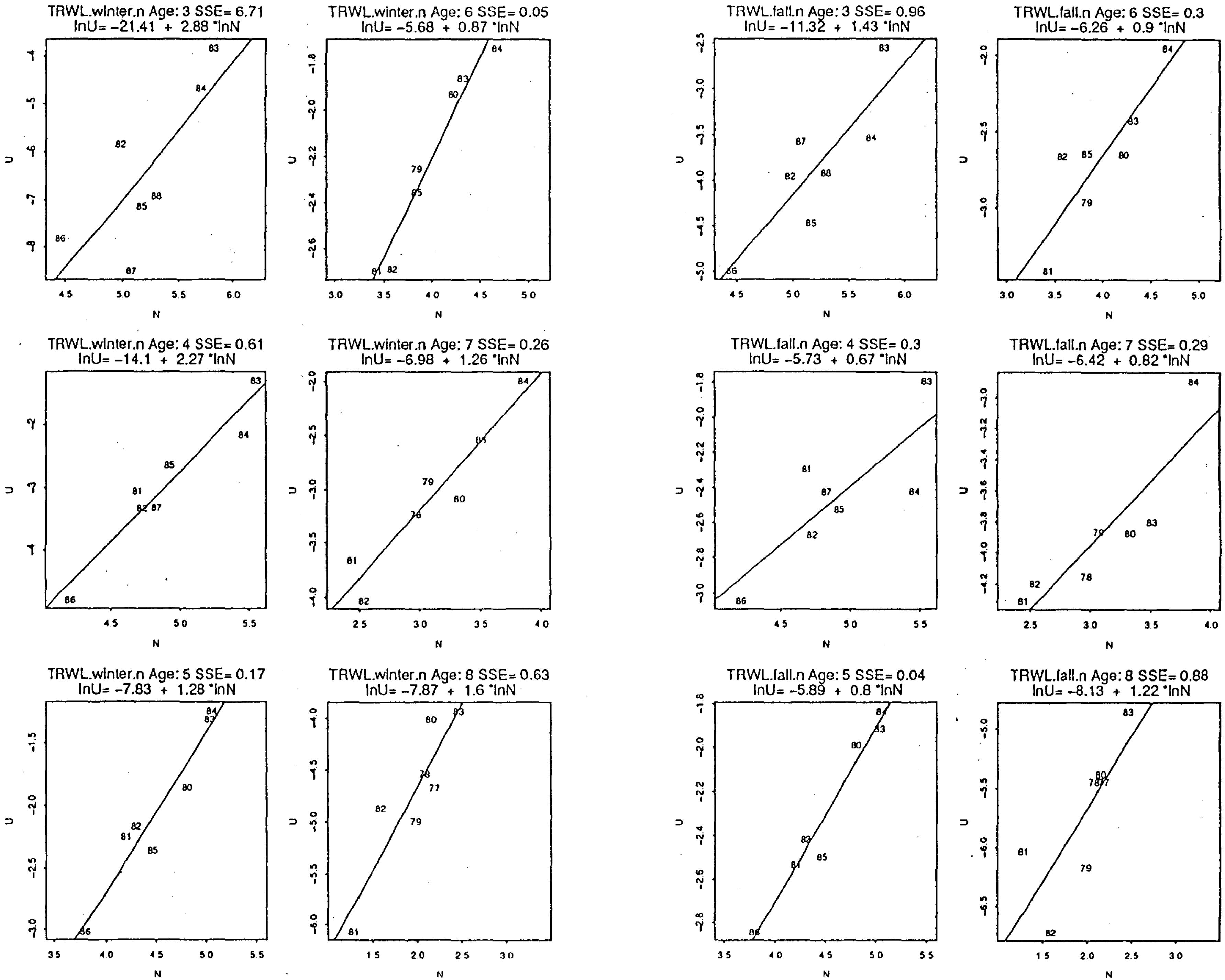

TRWL.winter.n Age: 3 SSE= 6.71
lnU= -21.41 + 2.88 *lnN
TRWL.winter.n Age: 6 SSE= 0.05
lnU= -5.68 + 0.87 *lnN
TRWL.fall.n Age: 3 SSE= 0.96
lnU= -11.32 + 1.43 *lnN
TRWL.fall.n Age: 6 SSE= 0.3
lnU= -6.26 + 0.9 *lnN
TRWL.winter.n Age: 4 SSE= 0.61
lnU= -14.1 + 2.27 *lnN
TRWL.winter.n Age: 7 SSE= 0.26
lnU= -6.98 + 1.26 *lnN
TRWL.fall.n Age: 4 SSE= 0.3
lnU= -5.73 + 0.67 *lnN
TRWL.fall.n Age: 7 SSE= 0.29
lnU= -6.42 + 0.82 *lnN
TRWL.winter.n Age: 5 SSE= 0.17
lnU= -7.83 + 1.28 *lnN
TRWL.winter.n Age: 8 SSE= 0.63
lnU= -7.87 + 1.6 *lnN
TRWL.fall.n Age: 5 SSE= 0.04
lnU= -5.89 + 0.8 *lnN
TRWL.fall.n Age: 8 SSE= 0.88
lnU= -8.13 + 1.22 *lnN
U
N

Fig. 3 (cont.)

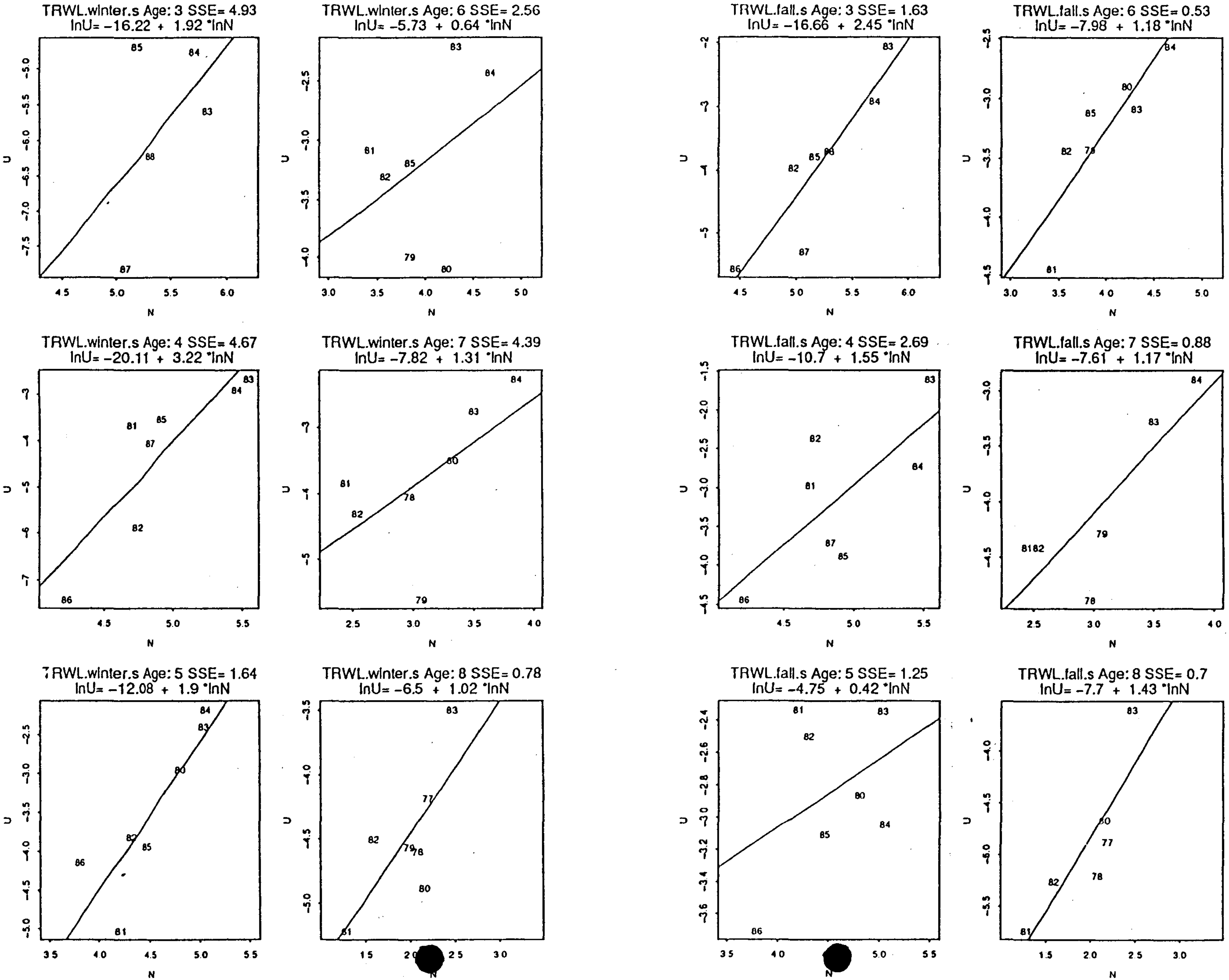

TRWL.winter.s Age: 3 SSE= 4.93
lnU= -16.22 + 1.92 *lnN
TRWL.winter.s Age: 6 SSE= 2.56
lnU= -5.73 + 0.64 *lnN
TRWL.fall.s Age: 3 SSE= 1.63
lnU= -16.66 + 2.45 *lnN
TRWL.fall.s Age: 6 SSE= 0.53
lnU= -7.98 + 1.18 *lnN
TRWL.winter.s Age: 4 SSE= 4.67
lnU= -20.11 + 3.22 *lnN
TRWL.winter.s Age: 7 SSE= 4.39
lnU= -7.82 + 1.31 *lnN
TRWL.fall.s Age: 4 SSE= 2.69
lnU= -10.7 + 1.55 *lnN
TRWL.fall.s Age: 7 SSE= 0.88
lnU= -7.61 + 1.17 *lnN
TRWL.winter.s Age: 5 SSE= 1.64
lnU= -12.08 + 1.9 *lnN
TRWL.winter.s Age: 8 SSE= 0.78
lnU= -6.5 + 1.02 *lnN
TRWL.fall.s Age: 5 SSE= 1.25
lnU= -4.75 + 0.42 *lnN
TRWL.fall.s Age: 8 SSE= 0.7
lnU= -7.7 + 1.43 *lnN
U
N

Fig. 3 (cont.)

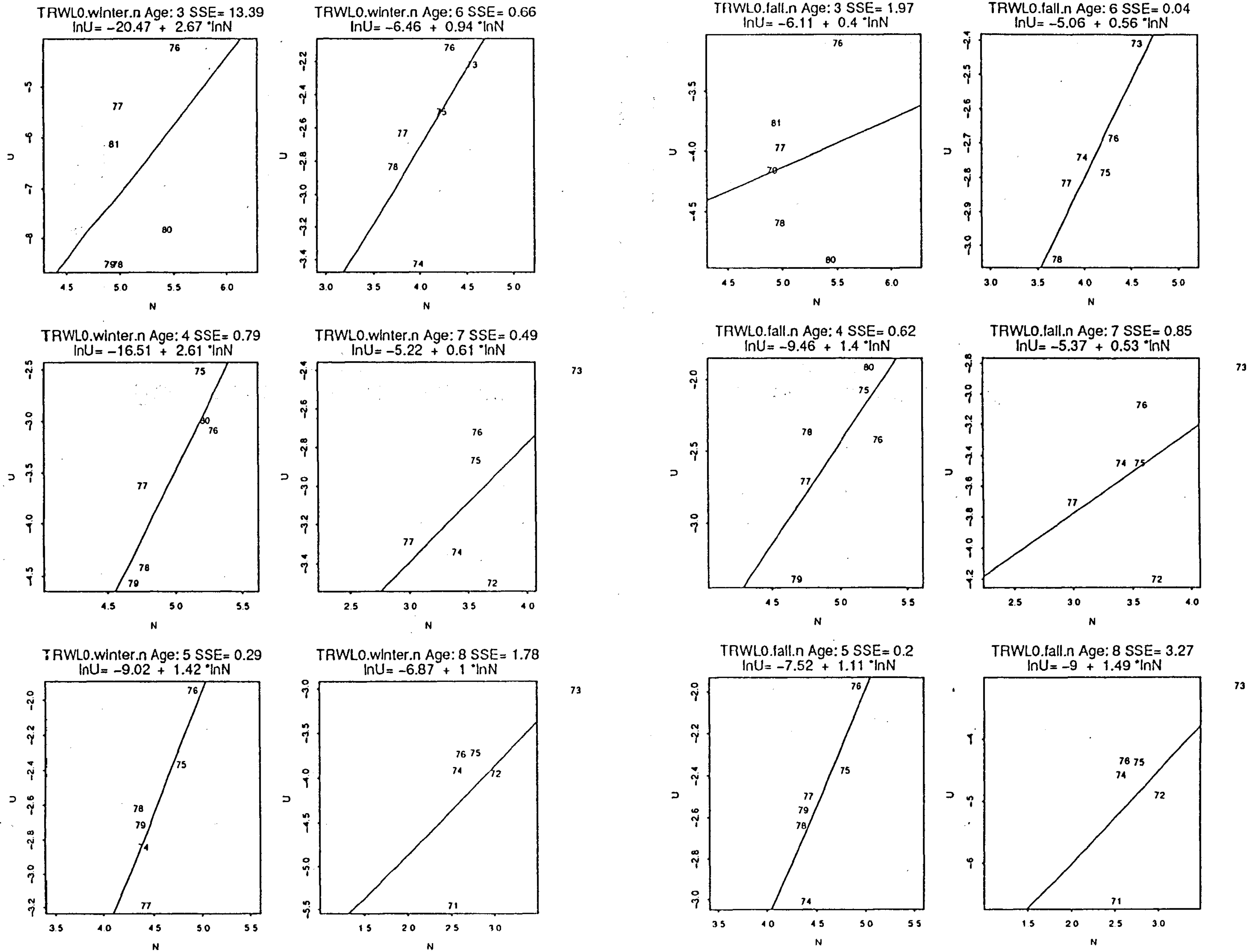

TRWL0.winter.n Age: 3 SSE= 13.39
lnU= -20.47 + 2.67 *lnN
TRWL0.winter.n Age: 6 SSE= 0.66
lnU= -6.46 + 0.94 *lnN
TRWL0.fall.n Age: 3 SSE= 1.97
lnU= -6.11 + 0.4 *lnN
TRWL0.fall.n Age: 6 SSE= 0.04
lnU= -5.06 + 0.56 *lnN
TRWL0.winter.n Age: 4 SSE= 0.79
lnU= -16.51 + 2.61 *lnN
TRWL0.winter.n Age: 7 SSE= 0.49
lnU= -5.22 + 0.61 *lnN
TRWL0.fall.n Age: 4 SSE= 0.62
lnU= -9.46 + 1.4 *lnN
TRWL0.fall.n Age: 7 SSE= 0.85
lnU= -5.37 + 0.53 *lnN
TRWL0.winter.n Age: 5 SSE= 0.29
lnU= -9.02 + 1.42 *lnN
TRWL0.winter.n Age: 8 SSE= 1.78
lnU= -6.87 + 1 *lnN
TRWL0.fall.n Age: 5 SSE= 0.2
lnU= -7.52 + 1.11 *lnN
TRWL0.fall.n Age: 8 SSE= 3.27
lnU= -9 + 1.49 *lnN
U
N

Fig. 4. SSB time series

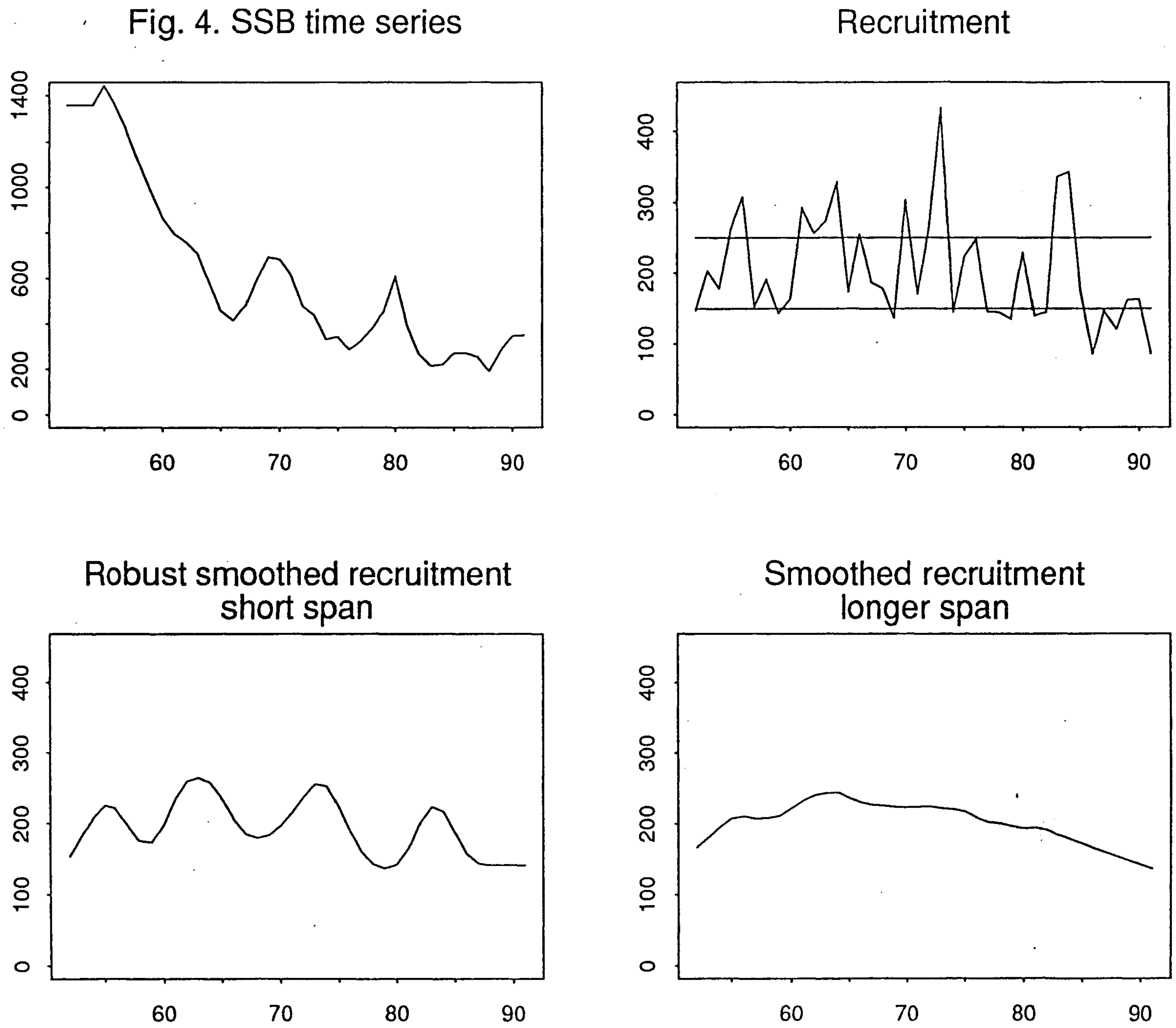


Fig 5. Stock–recruitment data along with curve (X) fitted using a GAM

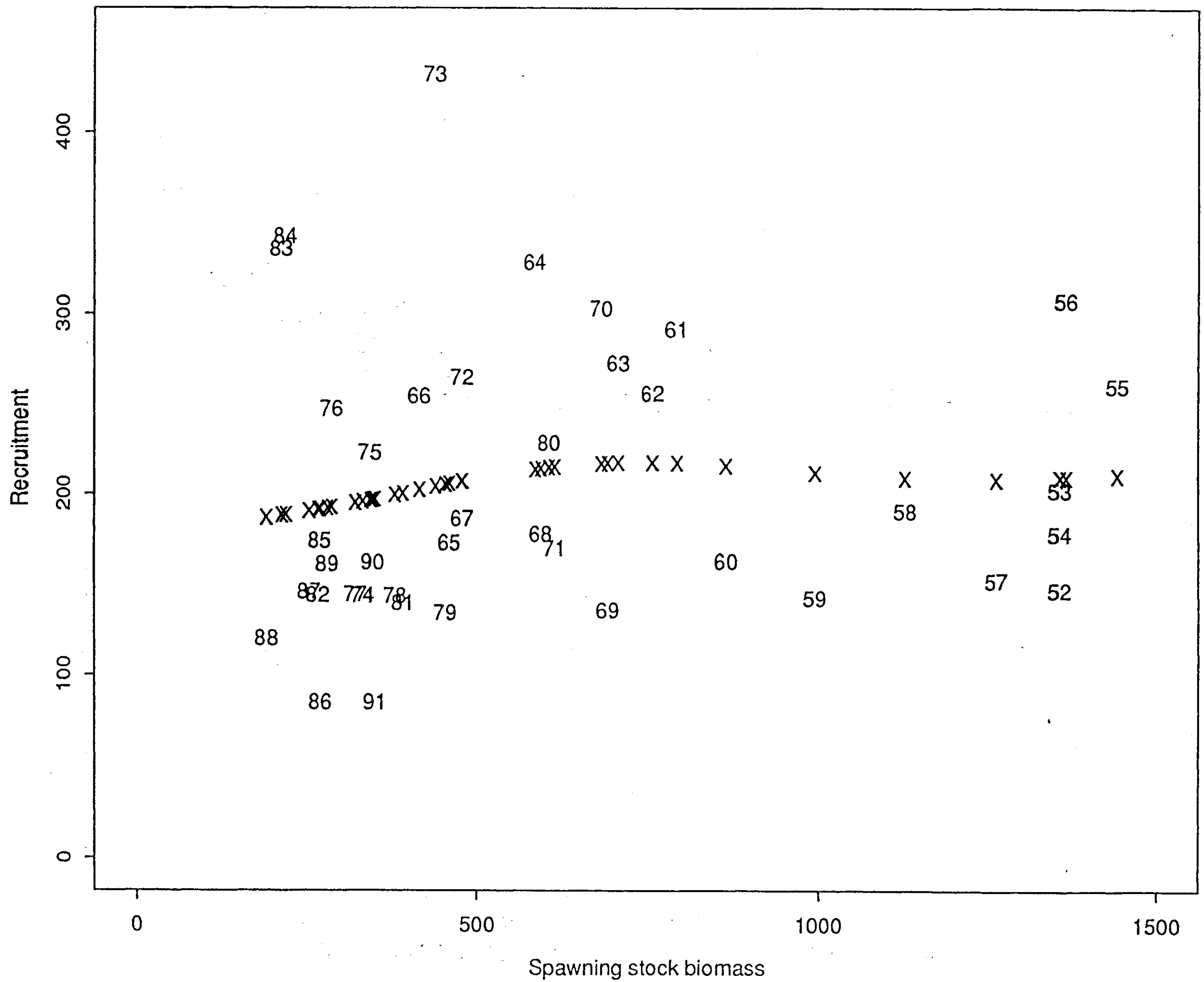
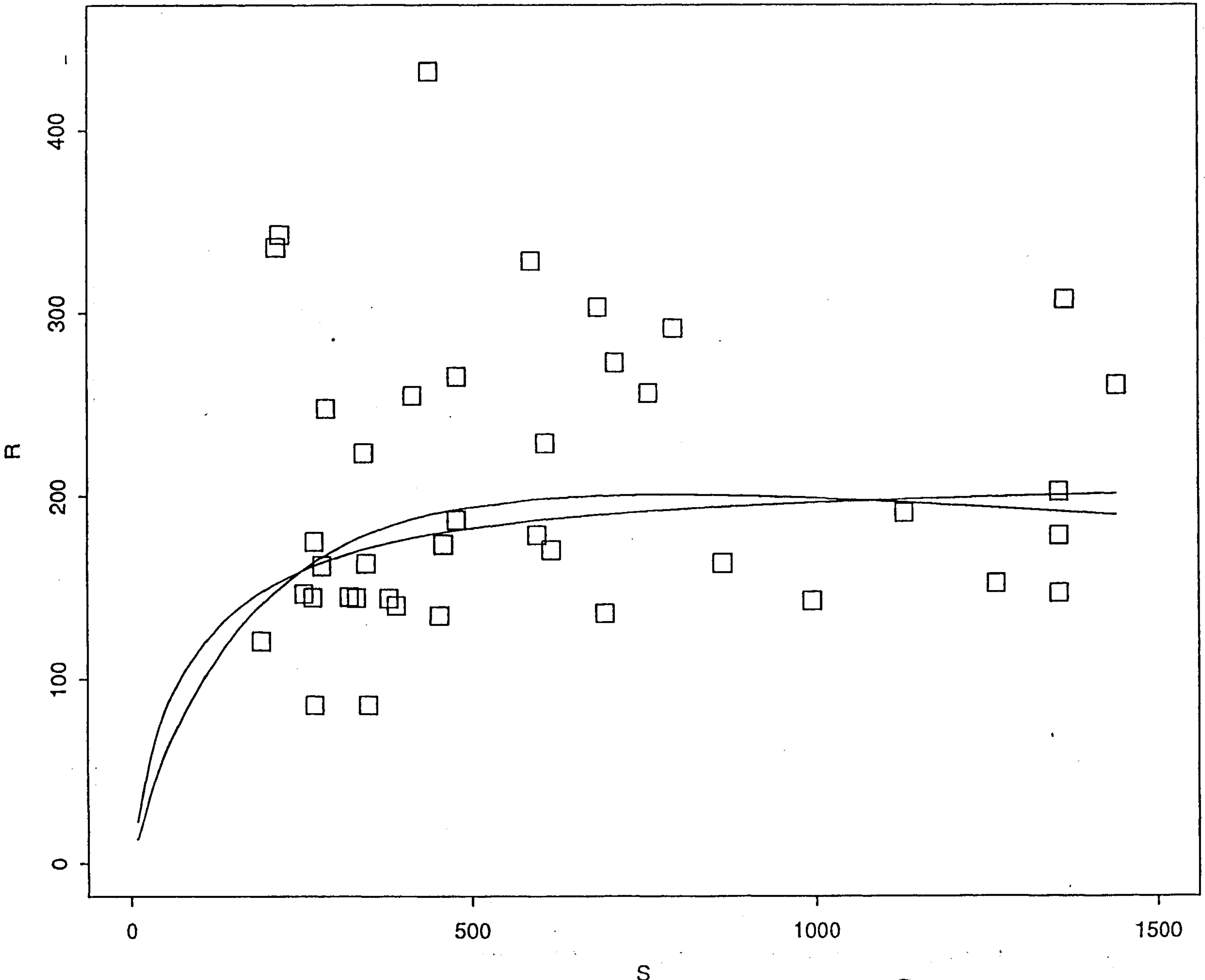


Fig. 6. Stock–recruitment plot with sample curves
(Beverton–Holt and best fit)



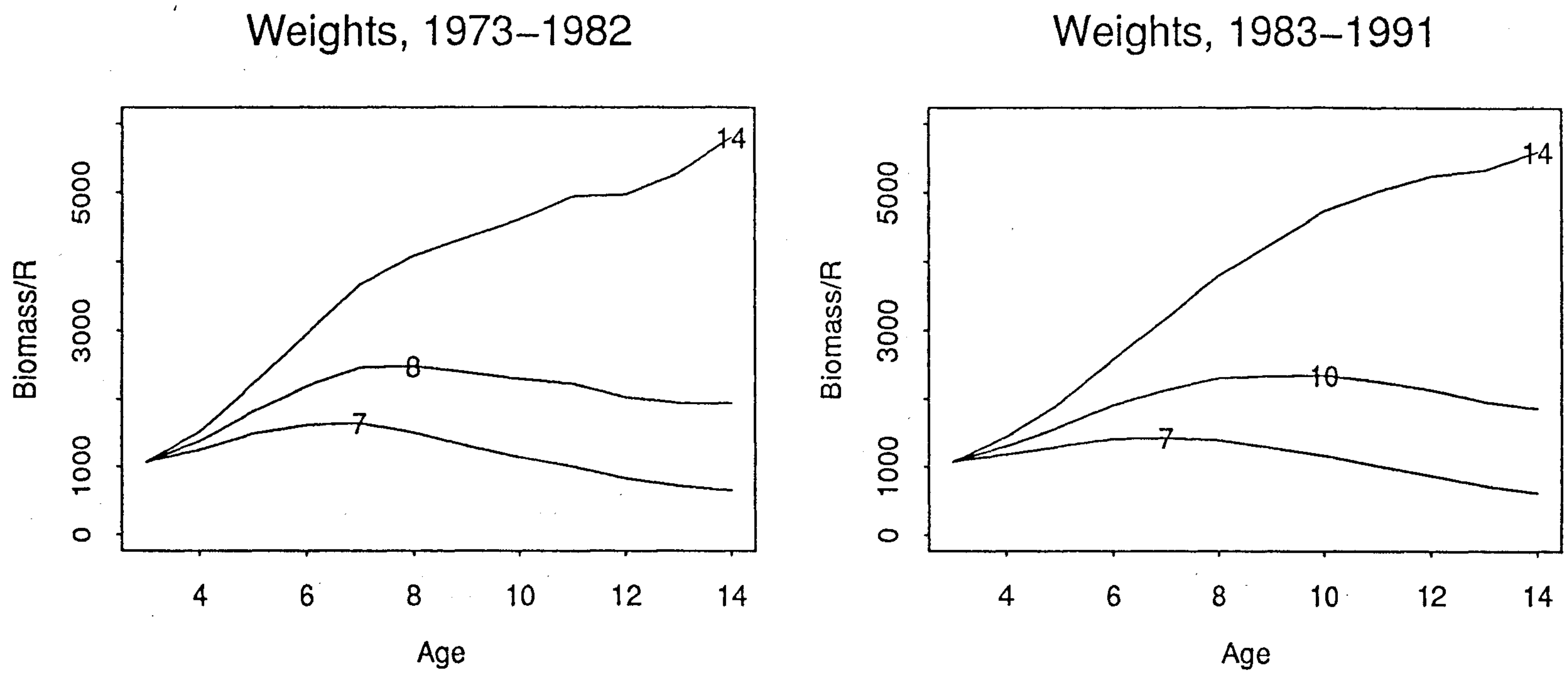


Fig. 7. Biomass per recruit
for different mean weights
and natural mortalitites,
in an unexploited yearclass

Fig. 8. Parameters 73–82 (–*–)
and 83–91 (–––)

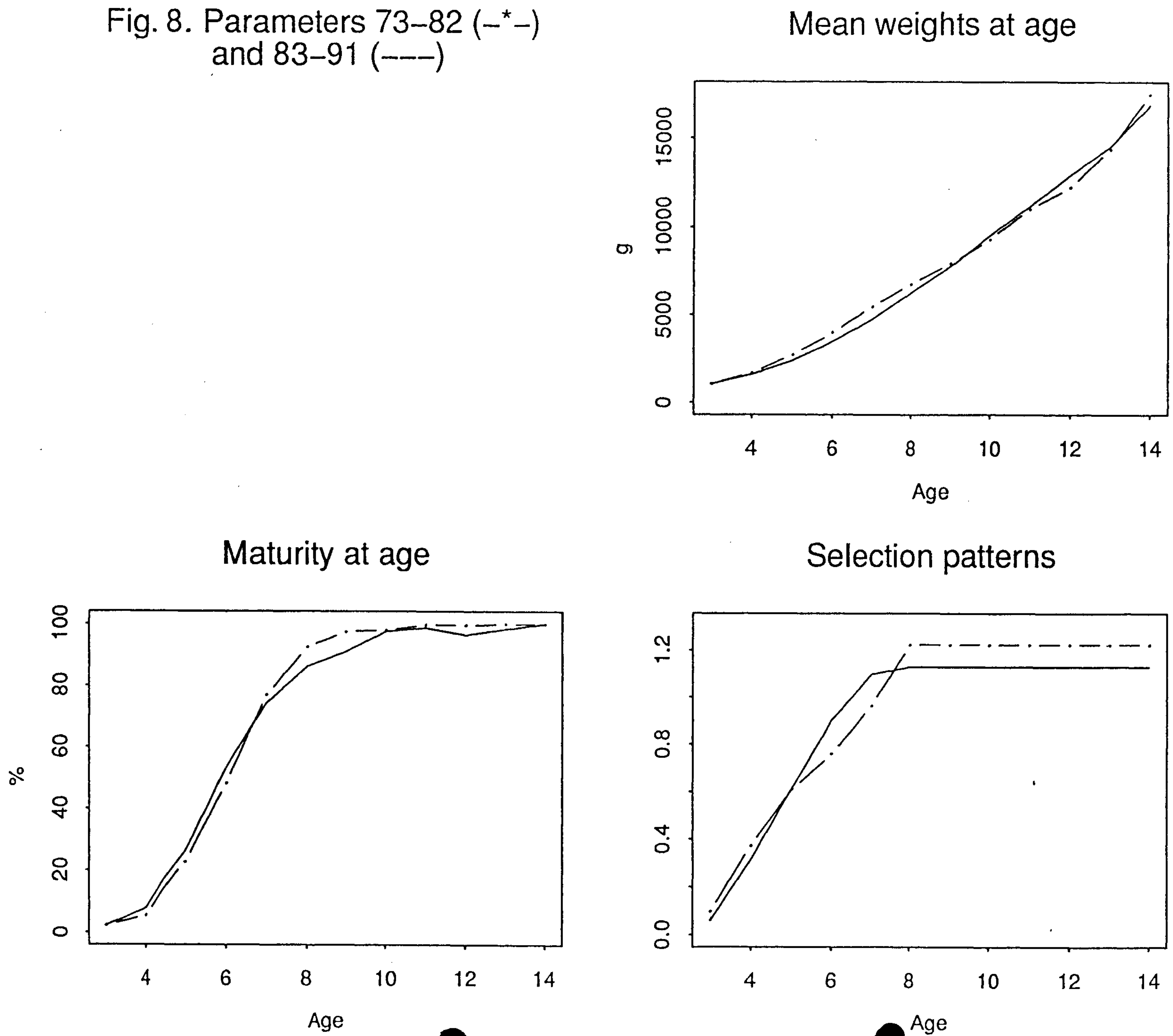
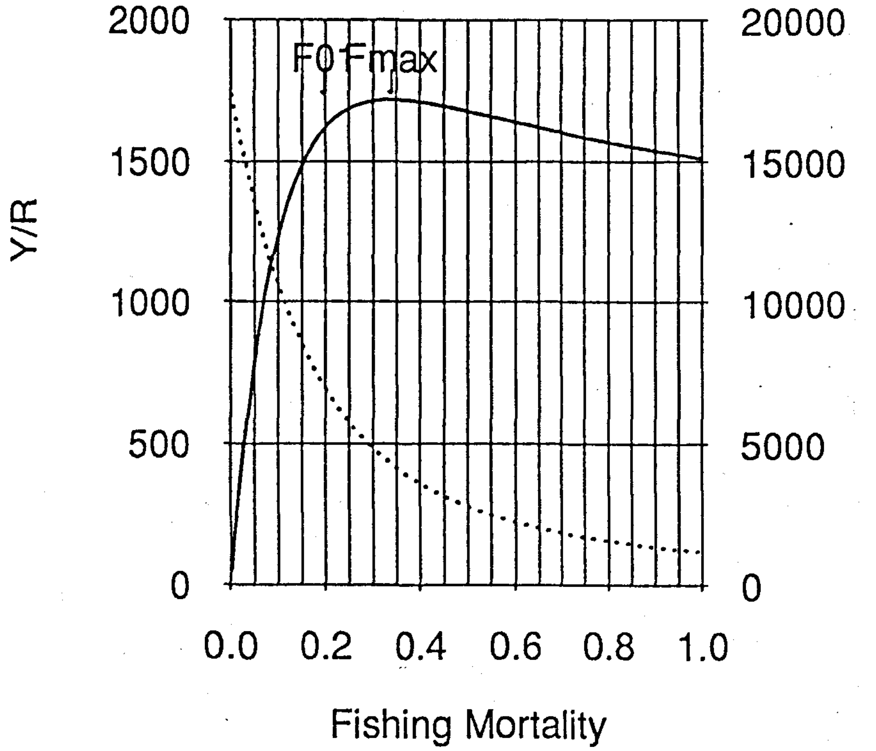
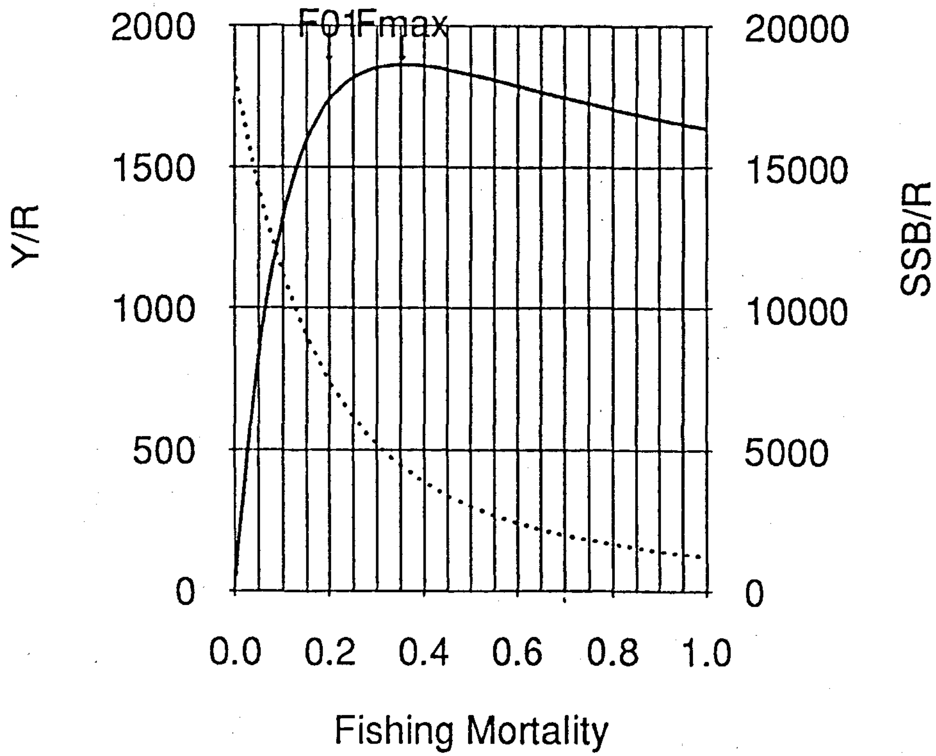


Fig. 9. Cod Input data 1983–1991
Long–term yield and SSB



F01= 0.2 Y01= 1614.14 Fmax= 0.34

Fig. 10. Cod Data 1973–1982
Long– yield and SSB



F01= 0.2 Y01= 1738.49 Fmax= 0.35

Fig. 11. Expected yield. B–H model
Data from 1983–1991 and 1973–1982

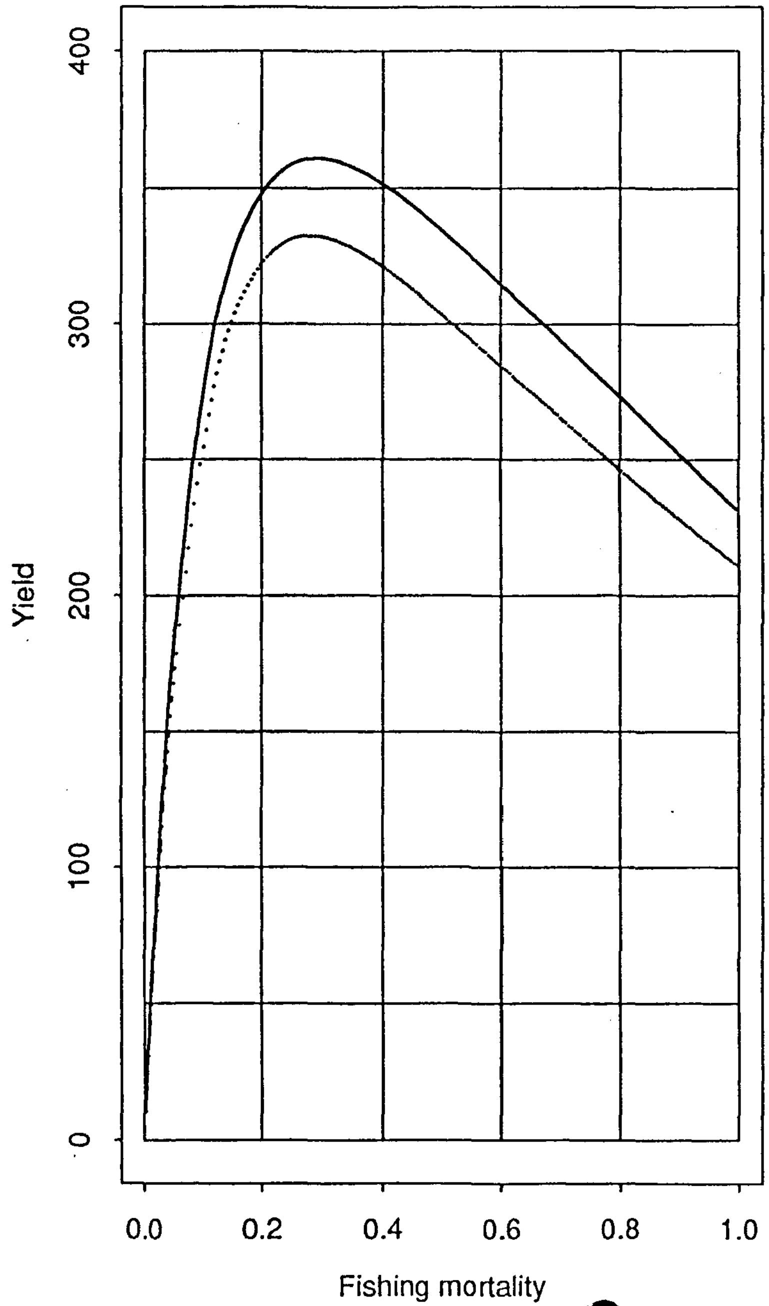


Fig. 12. Expected yield. g=1.5 model
Data from 1983–1991 and 1973–1982