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REPORT OF THE WORKSHOP ON SAMPLING STRATEGIES FOR AGE AND MATURITY

Copenhagen, 3-9 February 1994

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1.1 Participants

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An address list of participants i given in Appendix B.

1.2 Terms of Reference

It was decided at the 1993 Statutory meeting (C.Res 1993/2:17) that a Workshop on Sampling Strategies for Age and Maturity Data should be held at ICES Headquarters from 3-9 February 1994 to:

a) evaluate sampling strategies for age and maturity data with various levels of stratification by length (including purely random sampling) and advise on their usefulness;

b) advise on how maturity-at-age data should be derived from length-stratified sample data;

c) advise on the usefulness of applying smoothing to age-length keys;

d) prepare guidelines for conducting age-reading workshops.

1.3 Structure of the report

Terms of reference a) - c) all relate to the accuracy of assessments and the ability to detect changes in population parameters. Section 2 of the report contains some theoretical and practical concerns which relate the sampling strategy to how the data must be analyzed, relating in particular to a) and b). Section 3 of the report presents models which can be applied to the analyses of age-length-maturity samples. This is relevant to item c), but goes considerably further. Section 4 is in a fashion an extension of the terms of reference, investigating the effects of various sampling variations and biases on population parameters such as recruitment and spawning stock biomass. Section 5 deals with item d), which is of a different nature from the other items.

A listing of earlier reports of the ICES Working Group on the Methods of Fish Stock Assessment (and related meetings) is given, together with subjects dealt with, in Appendix C.

1.4 Working Papers

Working papers were presented on all of the topics. These, along with other documents available to the meeting, are presented in Appendix A.

1.5 Notation

Notation used in the report is in line with the following table:

$\bar{l}_a, \mu_a$	Sample and population mean length at age a.
$s_{a,} \sigma_a$	Sample and population standard deviation of length at age a.
$p_{a,} \pi_a$	Sample and population proportion of fish at age a.
K_{la}	Number of fish read as being of age a and length l (the **age-length table** or **distribution**).
K'_{la}	The revised age-length table, based on combining the age readings and length distributions.
$K_{.a}$	Number of age-read fish of age a.
$L_{l.}$	Number of age-read fish of length l.
K_l	Number of length measured fish in length class l.
$p_a^{(mature)}$	Proportion mature at age.
$N, \hat{N}$	Stock numbers and estimates of stock numbers.

Subscripts of a and l etc. are used as appropriate.

2 SAMPLING STRATEGIES

2.1 Introduction

The topic of sampling strategies is a very wide one and only a few aspects are considered in this report. The primary emphasis here is on sampling strategies appropriate for commercial samples (port sampling) or on board research vessels for the purpose of obtaining information on the length composition, age composition, maturity at age and mean length or weight at age. Before deciding on sampling strategies for, and the appropriate precision of, catch-at-age data, it is necessary to consider what the data are to be used for. Possible purposes include:

1. To be combined with the catch at age data of other fleets and/or the catch at age data of other countries into the total International catch at age data;

2. To be used in the construction of catch per unit effort at age data for a fleet;

3. To be used to provide fine structure catch at age data by fleet and subarea/season for defining partial F's in technical interactions models, c.f. use in North Sea ABC model.

Of these uses 1 will certainly be the least exacting and 3 probably the most. It is, therefore, important not to optimise sampling just for the first purpose unless it is very clear that no other purposes exist or will exist. Appropriate precision for purpose 1 has been most researched (see for example Pope (1972) which gives approximate formulas for CV's of population estimates in terms of the CV's of inputs).

Appropriate precision for purpose 2 has been less well considered. Pope and Gray (1983) present simulations of the precision of the TAC estimation process under varying levels of precision of major inputs for a fishery tuned to only 1 fleet. Pope (1983) derives some formulas relating the precision of TAC estimates to the precision of inputs. Again these are for the situation of a single tuning fleet. Indications from these studies suggested that individual fleet data used for tuning should be about as precise as the total international catch at age data. This condition might be relaxed for multiple fleet tuning but extra precision would seem appropriate for fleets or surveys used in tuning.

The use of port samples for age to break fleet fishing mortalities, F, into partial F by age, region and season seems likely to be even more exacting but guidelines for target precision and how to achieve it seem to be totally lacking. The fact that this exercise was possible for the North Sea fisheries would indicate that there was a healthy degree of redundancy in the data, collected for other purposes. Such geographic breakdowns of catch at age data are an area where length sampling may be particularly helpful since individual length samples are cheaper to acquire than individual age samples and in many cases there would be fewer problems assuming that age at length was more consistent between regions than length distributions.

Note, however, that concern has been raised about research vessel sampling (e.g., Gudmundsdóttir *et al.*, 1988) in that, if length stratified sampling for age is used, a situation is quite likely to arise in which the age samples predominantly come from only a part of the areal stratum. If the need arises later to analyse the data with different areal strata, there may not be any data in important areas and the number of samples per length group is no longer constant. On the other hand, if sampling at sea is done randomly (e.g. by sampling every nth fish from a conveyor belt when possible), then reallocation of areas is feasible and easy. The same applies if commercial data are sampled for catches (at sea) as opposed to landings (in port).

It follows from this that it is important to consider the purpose behind the sampling and also to consider the possible uses that might be made of the data at later stages.

Some practical constraints on sampling

Sampling of commercial catch at age data is often carried out by port-based staff, who may not have received training in subjects such as random sampling or bias. They will often be presented with landings to sample which have already been stratified in preparation for the market. Sampling catches at random may in fact be quite a difficult task to perform. A stratified system of sampling is likely to be more robust to human error than a random sampling scheme would be if the possibility of using simple rules which guarantee some of the required randomness does not exist.

Optimisation of sampling

Several papers have been written on optimal sampling strategies for age and length (e.g., Tanaka, 1953; Gulland, 1955; Pope and Knights, 1975; Lai, 1987; Kimura, 1977; and Schweigert and Sibert, 1983).

Optimal allocations are seldom startlingly better than the suboptimal solutions that pragmatic schemes generate. In any case allocations of otoliths which would have been optimal for last year's age distribution may not be for this year's. Furthermore, an optimal allocation means that some specific goal function has been optimised and it follows that other goal functions will not be optimised for that particular strategy. A strategy should therefore be tested for its performance in various settings. Thus, the primary aim with age sampling may be to obtain indices of numbers at age from a research vessel survey, but if the same samples are used to compute maturity at age, then it must be verified that this secondary aspect is also dealt with adequately.

2.2 Sampling Strategies in Current Use

It is not possible to fully describe all of the various stratified strategies for sampling national landings here. Length measurements are usually sampled at random from some specified sampling unit (eg. a box on the market or the catch from one haul or vessel) and the Workshop therefore considered only the different approaches to the sampling of age, sex, maturity and individual fish weight attributes rather than exploring in detail the overall schemes in operation (port census, incomplete census, random etc.). Similarly, aspects of survey design, such as fixed versus random sites have not been considered here since they have been reported elsewhere (eg. Anon 1992a)

Examples of current national sampling strategies for commercial landings and research surveys are given in Table 2.2.1.

2.3 The Effect of Length Stratification of Sampling

2.3.1 Bias in age compositions estimated from raised age-length distributions

When age compositions are estimated by raising a length-stratified age-length key by a randomly sampled length frequency distribution, they are not biased (Cochran 1977; Gudmundsdóttir *et al.*, 1988).

Biased estimates were obtained in simulations by Armstrong and Ilardia (1986), with the explanation that cells in the age length key with low probabilities of age given length will be unlikely to receive an otolith if the number of fish aged per length stratum is small. This zero will be carried over to the raised age-length distribution, inducing a bias in estimates of both mean length and age composition. This is not actually a source of bias (Nicholson, WP K3), since these results will be balanced by those infrequent occasions when otoliths do fall in the cell, resulting in a wildly different estimate. Since the distribution of estimates will be of a majority of, for example, below average results and a minority of very well above-average results that might in practice be rejected, this might be considered to be a source of effective bias. In practice such 'biases' are likely to be small, and were not observed by Gudmundsdóttir *et al.* (1988).

2.3.2 Bias in mean lengths at age estimated from raised age/length distributions

When length distributions within an age group are generated by raising a length-stratified age/length key by a randomly sampled length frequency distribution, the estimated mean lengths at age are biased. This has been demonstrated by Nicholson and Armstrong (1974), Armstrong and Ilardia (1986) and Gudmundsdóttir *et al.* (1988). These demonstrations relied on simulations which were supported by heuristic arguments by Armstrong and Ilardia (1986) and Gudmundsdóttir *et al.* (1988).

Gudmundsdóttir *et al.* (1988) exploited a simple 2 x 2 length-age distribution. This was developed by Nicholson (WP K3) to show that

- the bias decreases as both the length and age-length sample sizes increase.
- if the size of the length samples is small, the bias increases with the size of the age-length sample.
- if the size of the age-length sample is small, the bias increases with the size of the length sample.

Although based on a simplistic model, these results are compatible with those of Armstrong and Ilardia (1986) obtained by simulating samples from a cod population with 16 age groups and 110 length groups. Bias was greatest when the length distribution was based on an infinite sample size with only one fish aged per length group.

2.3.3 Effect of length stratification on estimates of proportion mature at age

Maturity-at-age estimates determined from samples collected using a length-stratified sampling scheme will be subject to bias if the number of fish in each length group is not taken into account (Halliday, 1987; Morgan and Hoenig, 1993, and WP M3; Trippel *et al.*, WP M4). This source of bias can easily be removed by accounting for the effect of length on the probability of being mature at a given age, the distribution of a given age across length classes, and the length frequency of the population. This length frequency may be based on the entire population as a whole or maturities at age collected in a subarea might be weighted by the length frequency of that subpopulation (see Section 3.2.2).

Comparisons of weighted and unweighted estimates of proportion mature at age show that the differences between estimates can be large and that these differences are not consistent in magnitude or direction across ages or for a given age across years. In general, most of the comparisons between estimates showed differences of from 5 to 10% with the largest difference being 49% (Morgan and Hoenig, 1993; Trippel *et al.*, WP M4). Differences between estimates of age at 50% maturity produced from weighted and unweighted estimates of proportion mature at age seem to be smaller. Estimates of SSB using weighted and unweighted proportions mature at age differed from nearly 0 to almost 9% for two substocks examined by Morgan and Hoenig (WP M3).

3 DATA ANALYTICAL METHODS FOR THE ANALYSIS OF AGE, LENGTH AND MATURITY DATA

3.1 Using Generalized Linear Models for the Computation of Catch in Numbers at Age

A fairly common problem in fisheries involves the lack or inadequacy of data when computing catch in numbers at age (Johannesson and Stefánsson, WP K2). Typically, mean lengths at age, weights at age and proportions or numbers at age will be required for several *data cells*. Such cells will correspond to different seasons, gears or areas. Given the nature of the data involved, it is difficult and in some cases impossible to obtain enough data for a given cell to be able to estimate the required quantities for that cell alone. It then becomes necessary to draw on information in other data cells in order to estimate the required numbers for the cell of interest. The most common example of this problem occurs when age readings are not available for a certain area or gear.

The same situation occurs when attempts are made to use historical data to age-disaggregate catches using different data cells from those used in the original data collection scheme. Two data sets were used for testing the use of models for smoothing age-length data when computing catch in number at age.

3.1.1 Icelandic data sets

The first data set used for comparing the different methods consists of length measurements, age readings and landings data for Icelandic cod for the year 1992.

The data cells are made up of two regions, three seasons (4 month periods) and three gear classes (hooks, gillnets and trawls), giving at most 18 data cells. The sample sizes for each cell were:

Number of age-readings:

	Season 1		Season 2		Season 3	
	Region 1	Region 2	Region 1	Region 2	Region 1	Region 2
Gear 1	225	334	200	681	122	191
Gear 2	2,831	200	510	0	287	0
Gear 3	393	1,372	1,026	1,708	195	1,590

Number of length measurements:

	Season 1		Season 2		Season 3	
	Region 1	Region 2	Region 1	Region 2	Region 1	Region 2
Gear 1	2,140	540	3,145	3,943	7,474	2,596
Gear 2	10,588	1,132	1,807	481	861	0
Gear 3	4,976	1,372	4,403	32,092	1,526	33,032

Tonnes landed:

	Season 1		Season 2		Season 3	
	Region 1	Region 2	Region 1	Region 2	Region 1	Region 2
Gear 1	225	334	200	681	122	191
Gear 2	2,831	200	510	0	287	0
Gear 3	393	1,372	1,026	1,708	195	1,590

3.1.2 Basic methodology

Two models were considered, a **base model** with no smoothing involved, where empty length groups in the ALK were omitted and **generalized linear models** which in effect smooth the entire ALD.

The **base model** is given by using the age-length key along with the length distribution, based on each data cell separately to give the catch at age in numbers for each data cell. In particular, the proportion at age is given by

$$p_a = \frac{K'_{.a}}{K'_{..}} = \frac{\sum_l K'_{la}}{\sum_{la'} K'_{la'}}$$

where

$$K'_{la} = \frac{K_{la}}{K_{l.}} L_l$$

is the revised age-length table and the *key* is defined as the length-at-age matrix

$$\frac{K_{la}}{K_{l.}}$$

Since this is undefined when there are no age readings in a length group with length measurements, the method must be modified if there are such length groups. The base approach varies but here the length measurements corresponding to an empty length group in the key are simply omitted.

In this simple base model, the mean length at age is computed from the formula:

$$\bar{l}_a = \frac{\sum_l l K'_{la}}{K'_{.a}} = \frac{\sum_l l K'_{la}}{\sum_l K'_{la}}$$

In the case of the Icelandic data sets, measurements of weights at age (or length) have historically been scarce. Hence the approach used is to use a cell-specific length-weight relationship along with the length distribution to obtain the mean weight of fish in the samples:

$$\bar{w} = \frac{\sum_l \alpha l^{\beta} L_l}{\sum_l L_l}$$

This number is used to derive the total numbers from total landings.

In the case of missing data in a cell, the base model smears the landings data into other data cells in proportion to the landings in those cells. That is, if data are missing for a given gear and region combination in one season, then the landings are smeared to the other seasons for the same gear and region.

Generalized linear models were used to describe the data in the age-length distribution, which is fully described by the probability distribution of length at age and the proportion at age. Since the measured length at age is discrete, the density is taken to be a discrete equivalent of gaussian distribution, obtained by evaluating the continuous distribution at the discrete points and scaling this so that the density sums to one.

Thus the modelling is reduced to modelling the mean and standard deviation of length at age along with the proportion at age. This needs to be done for each data cell and since some cells may be empty, the model is designed in such a fashion as to allow data, e.g., for gillnets in one season to aid in predicting the mean length etc. for gillnets in another season. When applying this approach, model testing needs to be performed to decide on an appropriate model for the data set at hand. This is usually done by testing the significance of model terms and comparing predicted and observed values.

For simulation purposes, a single procedure needs to be defined for the selection of a model based on an arbitrary data set. The model used for simulation was fixed and is described in the following.

The mean length at age a of fish caught by gear g in region r in season s is denoted by $\bar{l}_{arsg}$, which is assumed to be gamma distributed.

$$\mu_{asrg} = E\{l_{asrg}\}$$

denotes the expected value of these numbers and the model estimated was:

$$\ln(\mu_{arsg}) = \alpha + ns(a,3) + \beta_r + \gamma_g + \delta_s + \xi_r \ln(a)$$

Here, *ns(a,3)* denotes the *natural cubic spline* function (Hastie and Tibshirani, 1990). Regression weights were the sample sizes (K_{asrg}).

The variance of length at age, S_a^2, is also assumed to come from a gamma distribution. The model used here is:

$$\ln(\sigma^2_{arsg}) = \alpha + ns(a,2) + \beta_r + \gamma_g + \delta_s + \xi_r \ln(a)$$

where $\sigma^2_{asrg} = E\{s^2_{asrg}\}$. As before, the regression weights were the sample sizes.

The sample proportion at age within a *cell*:

$$p_{asrg} = K_{.asrg}/K_{..srg},$$

might be assumed to correspond to a multinomial distribution. However, assuming a Poisson distribution of $K_{.asrg}$ produces identical estimates (Chambers and Hastie, 1992). The model to be estimated is given by:

$$\ln(\kappa_{asrg}) = \alpha + \beta_a + \delta_r + \phi_g + ns_r(a,3) + ns_g(a,3) + ns_s(a$$

where $\kappa_{asrg} = E\{K_{.asrg}\}$.

By fitting the model, a revised age-length table is obtained. These do not contain any missing entries and can be used to obtain any of the quantities of interest.

3.1.3 Simulation method

Simulations were performed to compare the standard method to the smoothing technique. For this purpose, sub-samples of data were taken without replacement and the two methods were used on each sub-sample. A given subsample thus results in vectors of catches in numbers, mean length at age etc. Repeated subsampling results in a sequence of such vectors.

The population being sampled is the full available collection of otolith and length samples. The sampling unit in the sub-sampling is as a single such otolith or length sample. It should be noted that since no stratification is used in the sub-sampling, certain cells will sometimes be void of data although there are considerable numbers in other cells.

Because of computing time limitations only 100 simulations were done for each sub-sample size (20%, 40% or 60% of original sample collection).

3.1.4 Results

Figures 3.1.1 and 3.1.2 show the observed and predicted proportions and mean length at age, where each plot corresponds to one data cell.

Figures 3.1.3 and 3.1.4 show the bias and CV from the various simulations. Each point in the figures corresponds to 100 simulations.

The CV is defined in the usual fashion, i.e. as $100*s/\bar{x}$ where s and $\bar{x}$ are computed on the basis of 100 simulations. The bias estimates presented represent only the change in bias due to reduced sample sizes. This quantity is defined as the difference between the estimate obtained from the sub-sample and the full sample for each method.

In many cases, improvement is seen in bias and CV by using the model approach. But further improvements could be made; here only one year is used to predict smooth keys and an alternative approach would be to take data available back in time on the year classes appearing in the ALDs (see Section 3.1.5).

3.1.5 Smoothing of ALD for Faroe saithe

The data set analysed contained all otolith samples taken from the trawl fishery for Faroe saithe for the period 1978-1992. The samples were all taken randomly.

The data were grouped into years and quarters and for each quarter t_j the relative frequency $p_{YC}(t_j)$, the mean length $m_{YC}(t_j)$ and the length standard deviation $s_{YC}(t_j)$ for each year class *(YC)* were computed. These key parameters were then fitted with GLM models. First an attempt was made to fit the mean length to a *von Bertanlanffy* growth curve for each year class:

$$\mu_{YC}(t) = L_{YC}\left(1 - e^{-k_{YC}(t - YC)}\right)$$

This worked when only looking at a single year class, but created problems when trying to take all year classes into account, since the model cannot be translated into a simple linear model. Instead the logarithm of the mean length was fitted with a linear model containing two 3-knot natural spline terms to smooth out the curve, while accounting for gamma-distributed errors:

$$ln\ (\mu_{YC}(t)) = \alpha_{YC} + ns(t - YC,3) + ns(t -$$

and this succeeded very well. The plots are shown in Figure 3.1.5. Next the length standard deviation was fitted with a very simple model:

$$s_{YC}(t) = \alpha_{YC} + \beta \cdot m_{YC}(t),$$

ie the observed standard deviation $s_{YC}(t)$ is linearly related to the observed mean length $\mu_{YC}(t)$. This model too worked very well for the Faroe saithe samples. The plots are shown in Figure 3.1.6.

The relative frequency of a year class fluctuates very much with time and it was difficult to fit a model to it. The fluctuations in the relative frequencies of a year class were smoothed using a linear model containing a term for the age group, a term for the year class and a 5-knot natural spline term on age, specific to the year class, to smooth out the fluctuations, while assuming a Poisson distribution for the counts:

$$ln(\pi_{YC}(t)) = \alpha_a + \beta_{YC} + ns(t - YC,\ 5)_{YC}$$

$$where \qquad a = trunc(t - YC).$$

Other models with additional smoothing terms were also tried, but it seemed that these only picked up the noise contained in the sample data. Since the relative frequency of a year class fluctuates so widely in the otolith quency of a year class fluctuates so widely in the otolith samples some kind of smoothing must be applied and this is one way of doing it. The relative frequencies $\pi_{YC}(t)$ for the year classes must then be scaled, so that they sum up to 1 at any time t.

The plots for the smoothed relative frequencies of the year classes along with the original ones are shown in Figure 3.1.7 and 3.1.8. Figure 3.1.8 shows the smoothed and the original relative frequencies of the age groups for each quarter in the period 1991-1992. All the parameters in the models were tested and found to be highly significant.

3.1.6 Summary

From Section 3.1.4 on Icelandic cod it is seen that smoothing of ALDs can lead to better stock estimates and that GLM models are a useful tool for doing so. The models should be kept as simple as possible, since complicated models often tend to pick up the noise contained in the data. The simulations of the Icelandic cod indicate that there is little difference between using observed length distributions with smoothed ALDs, on the one hand, and smoothed length distributions with smoothed ALDs on the other. Since the number of length-measured fish is usually very high, smoothing of the length distributions is not a priority.

In the Section 3.1.5 on Faroe saithe it is seen that examination of historical ALDs is worthwhile. Unfortunately the Faroe saithe data set only contained the ALDs and no supplementary length data or the total catch data, so it was not possible to compute any stock estimates to evaluate the effect of smoothing.

When smoothing ALDs using historical data it is relatively easy to find an appropriate model for the mean length and standard deviation of a year class, whereas it is harder to model the relative frequency of an age class in the stock.

Although smoothing of ALDs cannot be recommended as a default procedure, the Workshop came to the conclusion that these techniques should be explored for more stocks in the future.

If models for ALDs are to be used, then such models have to be carefully assessed and verified, for example by using simulation.

3.2 Analysis of Maturity Data

3.2.1 The Barents Sea haddock data set

The haddock data set available to the meeting consisted of data from 5 surveys (1989-1993) in the Barents Sea. Each survey was conducted in the period mid-January to mid-March with some variation within this time period. The data consist of swept area estimates (length distributions with 5 cm length intervals) and of subsamples (stratified in the same 5 cm groups) with readings of age, sex and maturity. All stations used to estimate the length frequency distributions are fixed stations on a regular grid. Most of the age readings come from these, but a few were collected at other trawl stations (mainly trawls made in support of the acoustic survey). The sampling deatils are given in the text table below.

Year	Total no. of Stations	No. of age readings
1989	315	1704
1990	292	1801
1991	343	1380
1992	361	1786
1993	433	1521
Total	1744	8192

The survey is divided into 4 regions (A, B, C, and D). Each region is further divided into strata. Region A is divided into 8 strata, B into 5, C into 4 and D into 18 strata. The survey area is 108,280 nm^2. In each region the length distribution was estimated as mean relative densities of fish in each 5 cm length group multiplied by the area of the stratum and then summed over the strata in the region. This data set was used for the analysis presented in Sections 3.2.2, 3.2.3 and 3.3.

3.2.2 Region weighted vs unweighted

If one assumes that the proportion of mature fish may change within a survey area and that the change is somehow related to fish densities on a local scale (or possibly to the abundance within a stratum) this should be accounted for. The haddock data set was used in 2 ways. The first used the age, sex and maturity data in a straightforward manner. In the second, each observation was given a weight according to the abundance estimate of that particular length group in the same stratum.

For each region the following quantities were computed:

(1) The unweighted estimate of population numbers obtained by multiplying the abundance estimate in the length group by the appropriate proportion

$$\hat{N}_{lasm} = \hat{N}_l \cdot \frac{K_{lasm}}{K_l}$$

where

$$\frac{K_{lasm}}{K_l} = P_{lasm}$$

based on the age-length-sex-maturity sample above

(2) The region-weighted estimate

$$\hat{N}_{lasm} = \hat{N}_l \cdot P^{(W)}_{lasm}$$

where each age reading was given a weight

$$w_l^{(t)} = \frac{\hat{N}_l^{(t)}}{K_l^{(t)}}$$

before the proportions were calculated. $\hat{N}_l^{(t)}$ is the estimated length frequency from a single stratum t and $K_l^{(2)}$ is the number of age readings in the same stratum. The sum of weights then adds up to N (region by region).

For both methods the N's could easily be summed over one or more of the subscripts and then used to calculate proportions.

For both methods the proportions mature at age and length were plotted agains length (length group) and age.

$$p_l\,(mature) = \frac{\hat{N}_l(mature)}{\hat{N}_l}$$

$$p_a(mature) = \frac{\hat{N}_a(mature)}{\hat{N}_a}$$

The plots are shown in Figures 3.2.1-10. The results shown are summed over all the regions. Some variation can be seen, but the results are similar. Region by region plots hinted at a larger variation between the unweighted and the region-weighted method, but a higher level of "noise" masked any conclusive comparison at that level. The results are inconclusive as to whether the proportions mature (at age or length) are changing across the survey area. But it should be pointed out that in cases where population parameters are dependent on abundance on a local scale one could introduce bias when using straightforward estimators.

3.2.3 Proportions mature at age from proportions mature at length: a caution

In view of the variability inherent in proportions mature at age and the fact that maturity is often thought to depend largely on length, it is quite tempting to estimate only proportion mature at length (possibly as a smoothed function). After this is obtained, an age-length distribution could be used to obtain the proportion mature at age. This procedure is described in the following equations for the proportion mature at length, the estimated population numbers mature at age and the proportion mature at age, respectively:

$$p_l\,(mature) = \frac{\hat{N}_l(mature)}{\hat{N}_l}$$

$$\hat{N}_a(mature) = \sum_l p_l\,(mature) \cdot \hat{N}_{al}$$

$$p_a(mature) = \frac{\hat{N}_a(mature)}{\hat{N}_a}$$

Figures 3.2.1-15 show the comparisons between the proportion mature at age estimated using a maturity-age-length key (dotted line) and the proportion mature at age estimated using the proportion mature at length only (solid line). It is clear that the proportions mature at age estimated on the basis of maturity at length is biased. In all cases examined, the proportion mature at older ages was lower when estimated using the proportion mature at length than when estimated on an age-length basis. There was also a tendency for the opposite to occur at younger ages. This is a result of the proportion mature at age being a function of both age and length. This is not properly accounted for when proportion mature is based on length and not on a combination of age and length. Since there was a bias in the estimates of proportion mature at age produced from the length-based method, no attempt was made to smooth the estimates of proportion mature at length and then apply them to the age-length distribution.

The biased estimates produced in this example indicate that caution should be used if proportions mature at age are to be estimated in this fashion. The estimates from the two methods should first be compared and if a bias is found then only estimates of proportion mature at age from an age-length-maturity key should be used. In view of this and considering the points made in Section 2.3.3 any *ad hoc* procedures should be viewed with caution and not used without considerable testing.

3.3 Smoothing Applied to Maturity Proportions at Length and Age

Instead of simply raising the observed proportions of mature fish in each age group from a length-stratified sample by a randomly sampled length-frequency distribution (c.f. Section 2.3.3), the proportions can be smoothed by fitting some appropriate statistical model. This may increase the precision of the estimated numbers mature, especially if the number of fish in each age/length/sex category is small. Other advantages include the additional insight provided by the model, the ability to test for spatial and temporal effects, and if these are found to be negligible, a stable maturity profile for subsequent SSB computations.

Using the haddock data from area D, described in Section 3.2.1, a logistic model of the form

$$\log\left(\frac{\pi_{yla}}{1-\pi_{yla}}\right) = Y_y + S_3(a) + \beta \bullet l$$

was developed where π_{yla} is the probability of maturity for a fish in year y in length group l and age a; Y_y is the y'th year effect; and $S_3(.)$ is a smoothing spline with 3 degrees of freedom applied to age. The number of fish in a year-length-group-age-sex category is n_{ylas}; r_{ylas} is the corresponding number mature and is assumed to be distributed as $B(n_{ylas}, \pi_{yla})$.

Alternative forms of model such as complementary log-log were assessed, but the logistic was found to be preferable. Additional terms such as sex and interactions between length group and age, between year and length group and between year and age were tested, found not to be statistically significant, and omitted. A smoothing spline was also fitted to length and its non-linear component found to be significant. However, examination of the fitted smoother showed that it was very strongly by a few fish in the largest length group. The length effect was therefore restricted to a linear term.

Table 3.3.1 gives the number of occupied cells by age and year - providing some indication of the data available for fitting the model. Table 3.3.2 gives the average number of fish per cell by age and year - providing some indication of the precision in the data. Table 3.3.3 gives the analysis of deviance for the fitted model, demonstrating a significant difference between years and the need for the non-linear component in the smoothers of the effects of length group and age. The residual deviance shows no evidence of lack of fit compared with a chi-squared distribution with 251 degrees of freedom. This suggests that the assumed binomial distribution is adequate, even though the maturity data were pooled across tows taken in different parts of the survey area (c.f. Pennington and Vølstad, 1994).

Figure 3.3.1 shows the observed maturity proportions plotted against length group together with the fitted maturity ogives by age and year.

Figure 3.3.2 shows the trends in the computed proportions mature by each age group raised to the population length distribution for the traditional non-parametric method and using the model.

To give some idea of the relative precision of the two procedures, Table 3.3.4 gives the estimated proportions mature with their standard errors by length and age for the 1993 data. As would be expected, the proportions predicted by the model vary more smoothly as a function of length within age, and have the advantage of providing estimates for empty cells. The standard errors for the model are mostly smaller, with the exception of those cases where the observed proportion in a length-age cell is 0 or 1, for which the estimated standard error is identically zero. This value is usually associated with cells sampled by one fish.

Assuming that the fitted model is appropriate, there are several benefits in smoothing maturity at length data.

Although sex was not significant in the model (tested at any stage in the model development), it may still have an effect if growth rates differ. Figure 3.3.3 shows the predicted population proportions mature estimated separately for males and females plotted against age. For these data there are some small differences.

4 SOURCES OF VARIABILITY AND BIAS

4.1 Background

In this section, various sources of variation and bias are considered in relation to the understanding of the resources, in particular in relation to recruitment and spawning stock biomass estimation. The basic numbers behind age-structured stock estimates are the catch-numbers at age, weight-at-age and proportion mature at age. All of these numbers need to be known with some accuracy in order to get a handle on e.g. changes in SSB. Naturally, the age readings need to be well-established (Section 5) before these numbers can be computed.

In several circumstances it may be desirable to obtain smoothed values based on a table of numbers by age and year. Examples of this and possible solutions are shown in this section. Such analyses also yield estimates of the variability inherent in the data. It should be noted that for maturity and weight data, a preferred approach would be the one given in Section 3.3 where raw data, rather than annual aggregates, are used.

4.1.1 Catch-at-age in numbers

Pope (1972 and WP S1) shows how CV-measures for catch-at-age data can be translated into measures of variability in stock estimates and this is used in Section 4.2 to indicate how different sampling strategies may affect the precision of recruitment estimates. Similar formulae for the SSB are developed and used in Section 4.3. Such CV-measures may be obtained from knowledge of the sampling scheme (Flatman, 1990) or by the following modelling method.

Catches-at-age in numbers for Icelandic cod are given in Anon (1993a). Simple ANOVA-type models for such data have been suggested, e.g. by Shepherd and Nicholson (1986), and can be taken of the form:

$$\ln C_{ay} = \alpha + \beta_a + \gamma_y + \delta_{y-a}$$

ie by assuming that log-catches in numbers at age are log-normally distributed with expected values which depend on age, year and year class.

Although this model contains parameters which are not estimatable, the fitted values can be estimated and used to obtain residuals. These residuals, squared and averaged, provide the basis for estimates of the CV of the catch numbers at age data.

If the base model is fitted to the entire range (3-14) of ages, CV estimates are quite high as indicated in the text table. If, however, only ages 4-10 are used, the estimated CV values are considerably lower. This phenomenon needs further investigation both with this and other stocks. In particular, the question arises as to whether the seemingly high CV values might lead to problems in VPA procedures.

CV of catch-at-age data

Age	Using ages 3-14	Using ages 4-10
3	37	
4	32	26
5	21	11
6	26	17
7	28	14
8	21	9
9	27	15
10	22	16
11	29	
12	37	
13	44	
14	62	

In simulations and other computations, the CV values in the right-hand column were used for the respective ages but CV values from the left-hand column were used for ages 3 and 11-14.

4.1.2 Weight-at-age

Weight-at-age, although an important and sometimes a major issue (see eg. Anon. 1992b) was not dealt with in great detail by the Workshop. Some models were considered, however, for obtaining CV values at age and tested on Icelandic cod data. The same model as for the catch in numbers at age was taken, i.e. the log-weights were assumed to come from a Gaussian distribution and to have expected values of the form:

$$\ln w_{ay} = \alpha + \beta_a + \gamma_y + \delta_{y-a}$$

Resulting CV estimates were all around 10%, which was used where such numbers were needed.

4.1.3 Maturity at age

As with the catch in numbers and weight at age data, a simple model for proportions can be used to derive estimates of the CV at age. Given the highly variable nature of estimates of proportions, annual estimates of such numbers can be expected to fluctuate considerably due to sampling variation, which is compounded by cluster sampling effects, as described e.g. in Pennington and Vølstad (1994).

A smoothing procedure should take account of the variability involved and allow for the possibility of year effects and year class effects. The following model was used for Icelandic cod and was fitted using the glim procedure in Splus, assuming equal sample sizes in each age group and year:

$$P_{ay}^{(mature)} = \frac{1}{1 + e^{a + \beta_a + \gamma_y + \delta_{y-a}}}$$

Input data for the model are given in Table 4.1.1 and results in Tables 4.1.2 and 4.1.2. Since the effective sample size behind each proportion is not known, test statistics are no longer valid. However, F statistics are likely to provide a better insight into whether terms are needed or not, rather than the usual χ^2-statistic, which increases in proportion to the unknown sample size.

As above, residuals from the model were simply squared and averaged in order to obtain the variances required to obtain CV estimates at age.

Age	p	CV(p)
3	.029	56
4	.084	38
5	.228	18
6	.451	7
7	.703	6
8	.860	4
9	.936	3
10	.968	4
11	.978	6
12	1	0
13	1	0
14	1	0

Not all factors that introduce variability or bias in the estimation of proportion mature at age were dealt with in this Workshop. Many of these additional factors have a biological basis and highlight the requirement of a good base of knowledge on the reproductive biology and dynamics of each stock. Addressing these issues will assist those designing sampling strategies for the accumulation of appropriate data for the estimation of proportion mature at age.

These factors have in part been identified in earlier work and include:

1) *Accurate identification of mature fish.* Comparison of results of visual and histological examination of gonads suggest that during research vessel surveys young immature fish may be misclassified as mature (Annand, 1993). This could lead to positive bias in the estimation of proportion mature at age ranging from 10-30% (Trippel *et al.*, WP M4). Further consideration and confirmation of accurate identification of maturity at sea is recommended for sampling times both during spawning and other periods (see Morrison, 1990).

2) *Rates of maturity dependent on sex.* This tends to be more apparent for haddock than cod (Trippel *et al.*, WP M4) and is especially important for the sexually dimorphic flatfishes (Morgan, pers comm.). Note, however, that no sex effect was seen in the analyses of Barents Sea haddock in Section 3. Sex ratio is also important on an age-specific basis as females commonly outlive males. Appropriate calculation of sex ratios to generate female spawning stock biomass is required. It is recommended that sex be considered for inclusion in the maturity-age-length key.

3) *Time of year when maturity data are sampled.* Ideally, maturity sampling should be conducted before fish migrate or assemble for spawning but when signs of gametogenesis are pronounced in the gonads (Pawson, WP M1). Sampling of fish from the spawning aggregation could introduce positive bias in the proportion mature (see, however, Section 4.5). The effect of sampling during spawning on the estimation of the proportion mature may be variable if a survey period remains fixed from year to year, yet spawning time of a stock varies annually. Sampling after the spawning season to examine if all cohort members participated in spawning would help to address the question of effective spawning stock biomass.

4) *Sampling of a cohort.* Net selectivity is commonly associated with the capture of a greater proportion of the larger *vs.* the smaller members of a cohort. These larger members tend to achieve sexual maturity earlier in life than slow-growing cohort members (Trippel *et al.*, 1994). Hence, a greater proportion mature at age would be estimated than occurs naturally in the population and this bias is especially pronounced in the younger, recruiting age groups. Commercial samples from large-mesh gear are particularly suspect for maturity ogive construction.

5) *Age at 50% maturity.* The utility of this value should be viewed with caution. Earlier work has shown that very similar estimates of A_{50} can be obtained for different distributions of the proportion mature at age (Trippel and Harvey, 1991).

4.2 Effects of Precision of Catch-at-Age Data on Recruitment Estimates

The effect of precision of catch at age data on VPA outputs is addressed in Pope (1972) and a summary is given in Pope (WP 51). This shows that the CV of F is approximately equal to the CV of the catch at age data and CVs of population estimates are a weighted average of the CV's of catch at age on older ages.

Using cohort analysis it is seen that:

$$Var(N_a) = Var(C_a)*exp(M) + Var(N_{a+1})*exp(2M).$$

Hence it is possible to build up a series solution for N_a as:

$$N_a = C_a*exp(M/2) + C_{a+1}*exp(3M/2) + C_{a+2}*exp(5M/2) + etc.$$

which can be used directly, e.g. in a spreadsheet, to compute the variances recursively. Alternatively, this can be used to generate a series for $Var(N_a)$ as:

$$Var(N_a) = Var(C_a)*exp(M) + Var(C_{a+1})*exp(3M) + Var(C_{a+2})*exp(5M) etc.$$

If for simplicity CV is written in ratio rather than % terms, eg.:

$$CV(C_a)^2 = \frac{Var(C_a)}{C_a^2}$$

then

$$Var(N_a) = C_a^2 * CV^2(C_a) * exp(M) + C^2_{a+1} * exp(3M) + C^2_{a+2} * exp(5M) + etc.,$$

which can be used to investigate the effects of different catch at age CVs.

Catch at age and associated CV data were available for Irish Sea cod and plaice stocks, based on samples taken in a single quarter, and these have been used with the above relationship to simulate the effect of the pattern of CV at age on the variance of recruitment estimates.

A function of the form

$$CV(C_a) = rmsCV_{target}[(2.0001-K)^{-1} + |a_o - a|]/c$$

where

$$C = \sqrt{\Sigma_a[(2.0001 - K)^{-1} + |a_o - a|]}$$

was used to generate different patterns of CVs of estimated catches-at-age. rms CV_{target} is the target root mean square of the CVs at age, providing a constraint on the average quality of the catch-at-age estimates. The parameters K and a_0 determine the shape of the generated CV-at-age pattern: a_0 establishes a focus of low CVs at a_0, K determines how steeply the CVs at age increase as a moves away from a_0 (for K = 1 the pattern is flat, becoming steepest for K = 2). Some example patterns for different values of K and a_0 are shown in Figures 4.2.1a and b.

Table 4.2.1 gives the results for Irish Sea cod when K = 1 and a_0 = 2 with a target rms CV of 0.55 (that obtained with the current sampling scheme). Figure 4.2.2 shows the surface of realised CVs of estimated recruitment as a function of K and a_0. We see that moving away from a flat CV-at-age pattern results in a lower CV for estimated recruitment provided that the focus is towards younger age groups. A small shift in the emphasis of sampling effort towards ages 6 or older predicts a higher realised CV for estimated recruitment. Results for Irish Sea plaice, where catch numbers at age are more evenly spread across age groups are shown in Figure 4.2.3. Here the surface is flatter, but the conclusions are similar to those of cod.

4.3 Variability and Bias in SSB Estimation

The SSB can be written as:

$$S = \Sigma_a P_a W_a N_a$$

from which an approximate variance formula can be derived. This is done by assuming independence of the various quantities involved and using the appropriate formula for the variance of a product:

$$V(XY) \approx E[X]^2 V(Y) + E[Y]^2 V(X)$$

to obtain:

$$V(S) = \sum_A V(p_a w_a N_a) \cong \sum_a (p_a w_a N_a)^2 * \left(\frac{V(p_a)}{p_a^2} + \frac{V(w_a)}{w_a^2} + \frac{V(N_a)}{N_a^2} \right).$$

Estimates of the variances of weight at age and proportion mature at age can be obtained from fitting GLMs to the respective VPA input tables, where such data exist on an annual basis. Estimates of the variances of stock in numbers at age can be obtained from the formulae in Pope (1972), if the primary interest is in historic stock sizes, where the effect of the terminal-year tuning is diminished.

The above formula can be used to investigate which components of the variance of SSB are likely to dominate the total. Similarly, the above formula can be differentiated with respect to e.g. the CV of stock numbers for a particular age group:

$$\frac{d[V(S)]}{d[CV(N_a)]} \approx 2(p_a w_a N_a)\ CV(N_a)$$

which gives an indication of how much the variance in SSB may be likely to be reduced by changing the CV of individual components.

In particular, the formula for V(S) can be used to illustrate the likely effect of changes in sampling strategy on the variance of spawning stock biomass estimates.

Pope's cohort approximation was used to derive population numbers from the catch-at-age data for Irish Sea cod and plaice, and weight at age and proportion mature were taken from Anon. (1993b) in order to calculate SSB. The variances of population numbers at age were calculated as above, and CVs derived from them. For the purposes of this exercise, the CVs of weight at age and maturity at age were ignored. CV surfaces for cod and plaice SSB estimates were calculated in the same manner as the recruit CV surfaces, and the results are given in Figures 4.3.1 and 4.3.2.

The slope of the surface for cod reflects the high fishing mortality on this stock (and hence the low population numbers at older ages) in comparison with the much flatter surface given by the plaice data. Again, a modest move away from a constant CV across ages towards a pattern focussed on ages 2 to 4 (cod) and 3 to 5 (plaice) would appear to benefit overall CV on the SSBs, although the improvement for plaice is small at such low CV levels.

For comparison with Section 4.2.3, the results for Iceland cod are presented in Figures 4.3.3 and 4.3.4, with and without estimates of maturity proportion CVs. These CVs were computed as described in Section 4.1.

The interpretation of the above analysis is worthy of some consideration. In particular, there are several items to be noted concerning the maturity at age, due to the high degree of variability in such numbers. If maturity at age is estimated annually, then the level of variability can be considerable. If, however, the maturity at age does not change in time and is only estimated as a mean level based on several years' data, then the corresponding variances will be much smaller.

The following table illustrates the likely quality of estimates of SSB in relation to the possible behaviour of true proportions and the net effect of different sampling/analysis schemes.

		Actual proportions in SSB		
		Stable	Smooth	Varying
Model or sampling used	**Annual sampling**	Very variable	Variable	Good
	Smoothed annual	Variable	Good	Biased
	Fixed average	Good	Biased	Very biased

For the terminal year, variability in the tuning data is likely to dominate other effects. Since the stock sizes in the terminal year may depend on surveys which can result in a survey effect on all age groups, it may be reasonable, e.g. for simulation purposes, to assume that a single terminal fishing mortality is estimated and that the selection pattern is known. This will allow the estimation of the variance of the SSB using an approach similar to the one above. The results of such an analysis should be compared to results from a simulation where the estimation procedure is simulated along with other potential errors.

A simulation was performed during the meeting to illustrate this effect. Icelandic cod was used as an example. The terminal fishing mortality was assumed to follow a lognormal distribution with CV=0.2, and the selection pattern in the final year was assumed to be known. Proportions mature at age were then generated in the following way,:

$\hat{p}$ Proportions assumed to be fixed and known equal to the fitted model.

$\bar{p}$ Proportions assumed to be equal to the long-term average.

$\tilde{p}$ Gamma distributed porportions (truncated to be below 1), using same CV as above and expected value equal to $\hat{p}$.

p Observed proportions mature used unmodified.

The results from 200 simulations are summarized below:

	CV in 1975	CV in 1993
$\hat{p}$	0	.16
$\bar{p}$	0	.18
$\tilde{p}$	0.09	.20
p	0	.17

Thus, assuming this variability in the proportions at age implies that the CV of SSB in earlier years may be about 9%, whereas, if this variability is ignored, the convergent nature of the VPA indicates that the historic stock estimate is known perfectly.

It should be noted that the model used to estimate the CV values of maturity at age included year effects. These year effects may in some cases be due to measurement errors rather than true variability in the population. In this case, the year effects should not be assumed to be fixed and known, but random. This increases the CV of SSB in 1975 from 9% in the above table to 16%.

Although the above computations might indicate that the SSB is known with a low CV, this does not take into account e.g. assumptions of constant selectivity (or otherwise) on the oldest age groups, nor is the uncertainty in the estimate of natural mortality taken into account.

4.4 Sensitivity of SSB to Growth and Maturity Estimates

It is usually recognized that estimated mean weights at age in the sea and maturity ratios could influence the historical perception of the SSB as well as evaluations of the stock recruitment relationship. A simple assessment model was used to investigate the sensitivity of SSB to over- and underestimates of growth rates and maturity ogives.

Growth and maturity functions were fitted to mean weights and maturity at age. Changes in the parameters of the functions were used to generate a set of SSB estimates. These estimates were then tested through simple correlations against the original baseline SSB. Thus, lower coherence indicates influence from the changed parameter values.

Growth was fitted to a von Bertalanffy alias:

$W_t = W_\infty (1\text{-exp}[-K^{(t-t_o)}]^3$, W_t = weight at age t
W_∞ = asymptotic weight
K = growth coefficient
t_o = theoretical growth onset

and the maturity fitted to a simplified logistic curve:

$P_t = 1/(1+Xi(t-a_{0.5}))$ P_t = proportion mature at age t
Xi = steepness or maturity rate
$a_{0.5}$ = age at 50% maturity

Two fish stocks were investigated. All input data (catches, weights, proportions, fishing mortalities) for the Icelandic cod (Anon., 1993a) stock were disaggregated by year and age. A spreadsheet model (incl. Pope´s cohort approximation) provided SSB estimates at the time of spawning from 1975 to 1992. Data on the Irish Sea cod stock were taken from Anon. (1993b) and covered the same time period. Maturity ogives were not disaggregated by years. Spawning was assumed to take place on 1 January. For both stocks the fitted growth and maturity functions used in this analysis did not include year effects and are consequently identical between years.

Subsequent to the fitting, the growth parameters K and W_∞ and the maturity parameters Xi and $a_{0.5}$ were varied sequentially by +/- 20%. The derived SSB estimates were then correlated to the baseline SSB.

Results from the manipulations of growth parameters are illustrated in Figures 4.4.1 and 4.4.2. Little effect on the SSB estimates is deserved although the differences in mean weight at age are conspicuous. The change in W_∞ is only a scale change and thus the correlation stays constant. Varying the K parameter seems to have a minor effect.

Figures 4.4.3 and 4.4.4 illustrate noticeable impacts on the SSB correlations due to varied age at maturity. The effect of a knife-edge maturity can be recognized for the Icelandic cod stock. Simulations on the Irish Sea cod do not reveal similar differences in the correlations. This might be due to the smaller age range and the symmetrical maturity ogive.

This exercise was carried out to find tools to illuminate the effects on SSB of erroneous estimates of mean weights and maturity proportions. Obviously further exploration is needed to draw general conclusions. A prerequisite is the development of a statistic that performs better than the correlation coefficient.

4.5 Effects of maturity-dependent catchability on survey indices and estimates of age-specific maturity

In working papers presented at the Workshop (Pawson, WP M1; Thorasinsson and Stefánsson, WP,M2) a potential source of error in groundfish survey indices used for tuning assessments was pointed out. The hypothesis is that mature fish are less catchable than immature fish during the spawning season and therefore less visible to groundfish surveys carried out during that period. Differences in catchability may be due to bottom type influencing relative trawl performance between spawning and non-spawning areas, or due to the effects of spawning behaviour.

A simple model relating catchability to maturity was presented (WP M2) in order to clarify and further develop the idea and to allow the computation of annual age-specific correction factors for groundfish survey indices prior to tuning. The effect postulated in the model is an interaction effect: its operation requires both a sizeable change in catchability at maturity in the survey and substantial temporal changes in maturity at age in the stock. The model was applied to data on Icelandic cod.

If proportions mature at age in the Icelandic cod stock have increased substantially in the last few years, as independent data derived from commercial catches suggest, then the most recent groundfish survey indices may underestimate stock numbers. Rough estimates of the relative ratios of catchability of immature to mature cod in the Icelandic groundfish survey (ϱ_a), required by the model, were presented. These were obtained by dividing the age-specific odds ratios for maturity in the age-specific commercial data by those derived from groundfish survey data. The preliminary results suggest that $\varrho_a \geq 1$ for all values of a and, that it increases substantially with age. This suggests that corrections of groundfish survey indices may be needed. This result is preliminary, and the authors stress a variety of problems in the data and analysis.

The Icelandic cod maturity estimates derived from commercial data are in need of revision (see Section 4.3) and thus cannot be considered reliable at this stage (see also Section 4.1.3, item (3)). If these are found to overestimate proportions mature at age in recent years, then correction of groundfish survey indices will have little effect and current SSB estimates are upwardly biased.

The separate groundfish survey indices for immature and mature Icelandic cod were computed using a length-based key and not an age-and-length-based key. This has been shown to lead to a downward bias in maturity at age estimates for the oldest fish (see Section 3.2.3) and could contribute to the increasing trend in ϱ_a with age. Improved estimates will be prepared and presented at the 1994 ICES Statutory Meeting.

If it is true that mature fish are inherently less catchable on surveys conducted during the spawning season, then there would be a downward bias in maturity at age estimates derived from such surveys. This bias would be difficult to detect without independent maturity-at-age data, e.g. commercial data or other survey data. Reliable estimation of maturity at age may require the use of surveys conducted outside the spawning season.

5 AGEING READING WORKSHOPS AND EXCHANGES OF AGEING STRUCTURES

5.1 Objective

The objective of ageing structure workshops and exchanges is to minimize between-reader bias and variability in the precision of age determinations (their reproducibility), either between or within age reading laboratories. It is critical that the accuracy of the age readings (their proximity to the actual age) determined through carefully planned and executed validation studies prior to any workshop or exchange. The importance of validating the method used to determine the age separately for each species under study has been discussed e.g.in Beamish and McFarlane (1983). This aspect of the age determination process is not discussed herein.

5.2 Control (Reference) Collections

Control collections are sets of age structures from which random subsets are re-aged at regular intervals by experienced readers and used as training tools for new readers. [The expression "control collection" is used instead of "reference collection" to stress the fact that the actual ages of the fish in the collection are not known]. They are instruments for achieving formal quality control in the age reading process, and their use is important for providing means of testing the precision of age determinations either within laboratories or during exchanges and workshops. The collections evolve slowly with the periodic addition of new structures to reflect the changing state of the stock and by the deletion of structures damaged or no longer representative. The benefits of utilizing these collections are many:

Historical consistency - The criteria for interpreting age structures are transmitted in a cultural manner. With a control collection acting as a reference, subtle shifts accompanying changes of responsibilities of jurisdictions can be detected. Past interpretations that are found to be incorrect in the light of new data can be found and corrected.

Demonstrable consistency - Stock assessments can give rise to contentious disagreements. Without control collections, the age data will sooner or later be contested and there will be no way of proving their consistency.

Improved age reading personnel management - The use of control collections facilitates the management of age reading teams because it can provide early signs of divergence and measurable quantities to resolve differences of perception. An evaluation that is perceived to be fair is more likely to elicit positive adjustments between readers.

Support for resource reallocation - Age reading is a costly activity. The benefits of ageing certain difficult stocks may not justify the costs. On the other hand, more resources can be allocated to ageing a stock to compensate for the variability of age readings. Cost/benefit analyses can be performed on the basis of control collection data to support such decisions.

Deblurring of age-length keys - With certain extra assumptions, control collection data can be used to compensate statistically for the effect of age reading errors (Richards *et al.*, 1992). This would improve mainly the recruitment estimates for stocks with high recruitment variability (Bradford, 1991).

5.3 Routine Quality Control

Analyses of age data prepared at individual laboratories should be undertaken on a routine basis and should be performed very shortly after the structures are aged. Typically these analyses are conducted during the data archiving process. They include developing ALKs with associated statistics such as mean length at age of the sample data, minimum and maximum lengths at each age, and CVs. The ALKs may be viewed for obvious outliers and statistics compared with data from earlier time periods, either previous years to examine changes in mean length at age, or data from the previous survey or quarter of the year to examine whether age groups are 'growing' through a year.

5.4 Workshop or Exchange: Which is Appropriate?

In order to maintain consistency between experienced age readers, the most economical approach is to conduct regular age structure exchanges and hold workshops only if 1) the results of the exchanges indicate substantial bias or disagreements between readers, or 2) new information on the life history of the species becomes available.

Workshops should be held when new responsibilities are assigned, either in the form of new species, with inexperienced staff, or when the results of stock assessment research indicate inconsistencies in the data, or with new, inexperienced staff. In the cases of new responsibilities or inexperienced staff, it is important to hold workshops first in order to develop appropriate ageing criteria for a species or to provide inexperienced staff with adequate training to age a species independently. Once criteria are developed or staff are provided with appropriate background, regular exchanges of age structures are necessary to maintain adequate levels of precision between readers. Exchanges should be held at least every 2 years.

5.5 Conducting Workshops

Once it has been determined that a workshop should be conducted, specific procedures and criteria should be followed to ensure its success. These criteria are the following:

1. Each workshop should begin with a review of the biology of the species, specifically examining the results of the latest research on life history parameters and stock status. A review of when and how the ageing technique was validated should also be carried out at this point.

2. Next, a review of sample processing methods should be conducted. Indeed, the workshop may be held to introduce a new sample processing technique to experienced age readers, to determine whether or not ages obtained from the new method are consistent with the previous technique, and to decide if the new technique is superior to the old. Processing methods, both in terms of equipment and technique, should be standardized between ageing laboratories as much as possible.

3. A discussion of the age determination criteria used for the species should be held to define and communicate those criteria to all participants. This is critical and the workshop should not proceed until it is clear that all participants know and understand the criteria. The criteria must include the determination of birth year (ring counts vs. time of spawning, etc.), and this must be consistent between readers.

4. Independent age readings should follow with each participant ageing a minimum of 50-100 samples.

5. Once all readers have completed their initial readings, analyses of the data should be accomplished immediately as described in Section 5.7. At a minimum, bias graphs and pairwise bias tests should be prepared. If only expert readers are participating in the workshop, it is appropriate to use the mode of the readings as the source of comparison. If the workshop is comprised of both experts and inexperienced readers, the mode of the readings of the expert agers should be used.

6. Once the data have been analyzed, a review of the samples in which disagreements were found should be undertaken. A resolution of discrepancies between readers and a discussion of how the ageing criteria were applied to the samples used in the initial independent readings is probably the most important part of any workshop.

7. A second independent reading of a different set of samples will provide the basis for determining how well the discussion of the disagreements and criteria was applied.

8. A more complete data analysis should be performed once the second independent readings are complete. The convener(s) should then determine whether additional discussion involving all participants or a subset of those with inadequate levels of precision is appropriate.

5.6 Conducting Exchanges

Age structure exchanges should only be conducted between experienced readers with the primary objective of maintaining the consistency obtained through past workshops. Structure exchanges may be "seeded" with samples from control collections to determine levels of accuracy achieved by the participants. The following guidelines will provide the basis for standardized conduct of exchanges.

1. Provide individuals participating in the exchanges unprocessed age structures if possible. This is generally easy for exchanges with only two participants since each can utilize a single otolith from each fish

and process the structures in a familiar way. Likewise, if scale samples are exchanged, each participant should be provided with a small number of unprocessed scales. In the case of whole otolith or embedded otolith exchanges, or where there are multiple participants, extreme care should be taken by all to ensure that samples are not damaged either in transport or during age reading. Samples that are damaged should be eliminated from all analyses.

2. Once samples are exchanged, independent readings should be conducted. Laboratories with more than one individual ageing the species should treat the readings from each individual in confidence. This will provide the basis for examining between-reader bias both within the laboratory and with the others participating in the exchange. Samples collected in areas from which the participants are not familiar should not be included in any exchange.

3. Once age reading is complete, the data should be forwarded to a separate source (e.g. supervisors) to ensure that the readings between participants remain completely independent.

4. Once all data have been exchanged, analyses of the between-reader bias should be conducted following the criteria developed in the following section of this report.

5. The most important component of the exchanges comes once the data have been evaluated and disagreements located. Age readers must confer with one another to discuss differences and come to consensus agreement. If image analysis systems are available and applicable, annotated images, sent via electronic exchange or hardcopy, may be useful in identifying where differences in interpretation have occurred.

If the results of the exchange indicate an unacceptably low level of agreement between readers, or if a consensus cannot be reached on disagreements, further workshops should be recommended.

5.7 Analytical Methods

This section presents a set of statistical tools that can be useful in the analysis of data from age reading workshops or exchanges. This set is by no means exhaustive or optimal, but should provide a reasonable basis that will be refined and expanded with experience.

5.7.1 Testing for Between-reader Bias

The minimal requirement for age reading consistency is the absence of bias among readers and through time. The hypothesis of absence of bias between two readers can be tested in three ways: parametrically with a simple paired t-test, with Bowker's test of symmetry (Bowker 1948), or non-parametrically with a one-sample Wilcoxon rank sum test.

For example, it was noted in the assessment of whiting in Sub-area IV (Anon. 1994) that otolith exchanges have demonstrated serious inconsistencies in age determinations. The application of inter-reader bias tests to the data from one of these exchanges involving 10 readers ageing a set of 115 otoliths provides a formal confirmation of this statement:

Readers

Readers	1	2	3	4	5	6	7	8	9	10
1		-	-	*	**	*	**	**	**	**
2	-		-	*	**	**	**	**	**	**
3	-	**		**	**	*	**	*	**	**
4	**	**	**		**	**	-	**	**	**
5	**	**	**	**		**	**	*	**	-
6	**	**	-	**	**		**	-	**	-
7	**	**	**	*	**	**		**	**	**
8	**	**	**	**	**	-	**		**	**
9	**	**	**	**	**	**	**	**		**
10	**	**	**	**	-	-	**	**	**	

Bowker's symmetry test

t-test and Wilcoxon test (1)

- : no sign of bias ($p > 0.05$)
* : possibility of bias ($0.01 < p < 0.05$)
** : certainty of bias ($p < 0.01$)

(1) both tests give identical classifications

These results clearly emphasize the need for an age reading workshop for this stock. No other statistical test or measure assuming the absence of bias need be applied to these data. A plot of mean length at age (Figures 5.7.1 a and b) can sometimes serve to diagnose individual reader tendencies.

Inter-reader bias tests can also serve as inter-methods tests when two preparation methods are used on hard parts from the same fish. The blue whiting otolith reading workshop held in the Faroe Islands (Anon. 1993d) involved whole and sectioned otoliths from the same fish. The age determinations of the four readers present at the workshop can be compared between the two preparation methods showing that reader 3 seems less familiar with both preparation methods than the others but that the two methods can be used without bias:

Reader	1	2	3	4
t-test	-	-	**	-
Wilcoxon	-	-	**	-
Bowker's	-	-	*	-

- : no sign of bias ($p > 0.05$)
* : possibility of bias ($0.01 < p < 0.05$)
** : certainty of bias ($p < 0.01$)

Note that in the examples presented here, and in all those considered, the t-test and the Wilcoxon rank sum test always give the same classifications. Bowker's test is usually less powerful, however, except when asymmetry doesn't cause bias, for example when a small number of large negative errors is compensated by a large number of small positive errors or when negative and positive errors are associated with different ages.

5.7.2 Measurement agreement between unbiased age readers

A minimal requirement for a group of readers is that they are unbiased. When this is the case, groups of readers, stocks, or preparation methods can be compared for levels of agreement. Low levels of agreement will cause the cohorts of a stock to be confused, larger cohorts "leaking" into smaller adjacent ones, thus reducing the perceived recruitment variability. Three measures of agreement are considered here: the average percent age error (APE) (Beamish and Fournier, 1981), the coefficient of variation (CV) (Chang, 1982) and the chance-corrected observer-agreement measure (kappa) (O'Connell and Dobson 1984; Schouten 1982). The two first measures are relative estimates of variability, the third is a true measure of inter-reader agreement, corrected for the level of agreement that would be expected even if the readers were assigning ages at random (for the same common age distribution).

As an example, the results from a Swedish workshop on cod age reading in 1992 were reviewed. The 100 otolith sample was collected during International Bottom Trawl surveys conducted in the Kattegat in September 1992. Of the seven readers participating in the workshop, two were considered to be experts. It was first determined that these two experts were unbiased ($p=0.4$). All the other readers were biased among themselves and with the experts except for one trainee. The agreement measures calculated for the experts were: APE = 9.9 %, CV = 14.1%, kappa = 0.73.

Another example is provided by a plaice otolith comparative reading exercise held in Lowestoft, involving three local expert readers. Based on data which consisted of a subsample of 50 otoliths chosen at random among those used in the exercise, only two of the readers were unbiased. The agreement measures for those two readers were computed as: APE = 0.7%, CV = 1%, kappa = 0.96.

5.7.3 Testing for group membership

Each member of an unbiased group of age readers can be tested for membership in that group. A reader could be unbiased with respect to the rest of a group without ever agreeing with the others. On the other hand, a pair of readers could agree very well without agreeing too well with the rest of the group. For example, in the case where some otoliths are read by three readers and every triplet of readings contains two identical readings and one dissenting one, if the readers are interchangeable, only about one third of the dissentions should belong to any given reader. Significantly more dissentions would indicate a lack of agreement with the others while significantly less would indicate membership of a tighter subgroup. Both situations can be detected by calculating the likelihood of a reader's choices among all the observed readings. This likelihood which is normally distributed under the hypothesis that the members of the group are interchangeable can be compared with its expected value. Likelihood values that are too small (with a probability $p > 0.975$) indicate members of a group that do not agree often enough with the rest, while likelihood values that are too large ($p < 0.025$) indicate membership of a tight subgroup.

For example, the unbiased trainee in the Swedish workshop mentioned in Section 5.7.2 scored $p = 0.54$ when compared with the expert readers, indicating a level of agreement very close to the expected value.

Another example is given by a herring otolith exchange programme organized by the RIVO institute in IJmuiden in 1992 (Anon. 1993c). The age bias plots (Campana *et al.*, WP A3) in Figures 5.7.2 (for all readers against the mode) and 5.7.3a to g (for each reader against the mode) help visualize the problems within this group of readers. Of the seven readers involved, only three were found to be unbiased. When compared for group membership, they scored respectively $p = 0.25$, 0.12 and 0.95, indicating that they form a rather homogeneous group compared to most of the other groups of readers considered which showed extreme values in both directions. As a matter of fact, the presence of a single disagreeing reader in a group (a biased reader for example) will make the rest of the group look like a tight subgroup.

Note that this membership test does not require the absence of bias but that the tests described in Section 5.7.1 should be used first since they are more powerful when there is bias.

5.7.4 Estimating dispersion parameters

The probability models and the maximum likelihood methods described in Richards *et al.* (1992) can be used to estimate the reading dispersion rates of the readers in a homogeneous group. If the dispersion rates of readers are known, it is then possible to correct for the effect of ageing dispersion on age distribution estimates (Richards *et al.* 1992). For the three herring otolith readers of the preceding section, the dispersion seems to be symmetrical and to span seven ages with probabilities: 0.001, 0.006, 0.038, 0.91, 0.038, 0.006, 0.001. These are the probabilities defining the multinomial distribution of the possible age readings for a given otolith.

6 CONCLUSIONS AND RECOMMENDATIONS

The conclusion and recommendations of the Workshop are given below, referenced to the relevant section of the report.

1. **Sampling strategies** (Section 2.3.2)

Mean lengths at age estimated from length-stratified samples are biased, but the bias should be small with balanced sampling of length and age.

2. **Analytical methods** (Section 3.3)

Modelling maturity on age and length (combined) produces smoother and less variable estimates of proportions mature compared with using observed proportions of maturity at age and length.

3. **Sources of variability and bias** (Section 4.2)

Allocation of sampling effort for the purpose of effective focusing on the precision of estimated catches at age may improve the quality of estimated recruitment and SSBs.

More work is necessary to verify these conclusions, e.g. by estimating recruitment by VPA with simulated catches at age with different CVs.

4. **Data Analytical Methods for the Analysis of Age, Length and Maturity Data** (Section 3)

Spatial variability on maturity at age should be examined when constructing maturity ogives.

5. **Data Analytical Methods for the Analysis of Age, Length and Maturity Data** (Section 3)

Bias can be introduced if the proportion mature at length is first estimated and then used with an age-length distribution to produce proportions mature at age instead of accounting for age-dependency of maturity.

6. **Sampling Strategies** (Section 2)

Estimating proportions mature at age from length stratified samples introduces a bias unless appropriately corrected.

7. **Data Analytical Methods for the Analysis of Age, Length and Maturity Data** (Section 3)

A good understanding of the reproductive biology and dynamics of each stock is critical to the achievement of accurate estimates of proportion mature.

8. **Sources of Variability and Bias** (Section 4)

Ideally, maturity sampling should be conducted before fish migrate or assemble for spawning but when signs of gametogenesis are clearly distinguishable in the gonads.

9. **Sources of Variability and Bias** (Section 4)

Differences in catchability between spawning and non-spawning fish may adversely affect the accuracy of parameter estimates from surveys conducted during the spawning season.

10. **Sources of Variability and Bias** (Section 4)

Generalised linear models of annual at-age data (proportion mature, catch in numbers or mean weights) could and should be used to obtain information on the relative accuracy of the data for each age group.

11. **Age-Reading Workshops and Exchanges of Ageing Structures** (Section 5)

In order to minimise variability between readers ageing the same species/stock, it is important that regular ageing structure exchanges are conducted. If analyses of data from the exchanges indicate significant bias between readers, formal age reading workshops should be held.

12. **Age-Reading Workshops and Exchanges of Ageing Structures** (Section 5)

Valid statistical tests and measures should be used to quantify the conclusions of ageing structure exchanges and age reading workshops. They can also help in the construction and maintenance of age reading control collections. Plots of age bias and mean age at length can also help diagnose age reading problems.

13. **Age-Reading Workshops and Exchanges of Ageing Structures** (Section 5)

Both exchanges and age reading workshops should follow the standard procedures described in this report to ensure that results are consistent between laboratories and species.

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Table 2.2.1 Summary of national sampling strategies for fish attributes within the basic sampling unit.

	Commercial landings:				*Surveys:*			
Country	*Age*	*Sex*	*Maturity*	*Individual Weight*	*Age*	*Sex*	*Maturity*	*Individual Weight*
Canada /1 - (Pelagics and Gadoids)	SR	-	-	SR	SE	SE	SE	SE
Canada /1 - (Flounders)	SR	-	-	-	SNE	SNE	SNE	SNE
Canada /2	SE	-	-	-	SE	SE	SE	SE
England/Wales	SNE	SNE	-	-	SE	SE	SE	SE
Faroe Islands	R	-	-	R	R	R	R	R
Greenland	SE	SE	SE	SE	SE	SE	SE	SE
Iceland	SR	SR	SR	SR	SR	SR	SR	SR
Norway - (Demersals)	SE	SE	SE	SE	SE	SE	SE	SE
Norway - (Pelagics)	SR	SR	SR	SR	SR	SR	SR	SR
Spain	SE	R	R	R	SE	R	R	R
Sweden								
USA	SE	-	-	-	SE	SE	SE	SE

Canada/1 = NAFO SubDiv 2-3
Canada/2 = NAFO Subdiv 4-5Zc

R	Random
SR	Stratified random
SE	Stratified - equal numbers per length group
SNE	Stratified - unequal numbers per length group
-	Not usually sampled

NB : The strategy shown against each country is that which generally applies; it is not restrictive.

Table 3.3.1 Barents Sea Haddock.
Number of observations by age and year.

age	1989	1990	1991	1992	1993
1	4	1	3	4	4
2	5	7	7	10	8
3	6	5	8	9	9
4	9	7	8	9	11
5	9	7	4	3	8
6	10	10	5	3	2
7	5	11	7	3	5
8	0	6	9	4	3
9	0	1	0	7	0
10	0	0	0	0	3
11	0	0	0	0	1

Table 3.3.2 Barents Sea Haddock.
Average number of fish per cell by age and year.

age	1989	1990	1991	1992	1993
1	1.5	5	5	4.5	6.2
2	2.8	19	32.7	23.5	11.5
3	6.5	5.4	17.1	29	35.7
4	9.9	4.9	4.4	15	24.6
5	13.4	8.6	3.8	3.3	5.8
6	8.1	6.3	2.8	2	1.5
7	2	5.8	2.6	1.7	1.2
8	0	1.8	2.4	2.2	1
9	0	1	0	2	0
10	0	0	0	0	1.7
11	0	0	0	0	1

Table 3.3.4. Comparison of nonparametric and model predictions of proportions mature by age and length. Barents Sea Haddock 1993

age	Length group	Number females	Number males	Prop.mature males	se.m	Prop.mature females	se.f	Prop.mature continued	se.comb	Prop.mature model	se.model
4	7	1	1	0	0	0	0	0	0	0.02	0.007
4	8	12	16	0.062	0.061	0.167	0.108	0.107	0.058	0.039	0.011
4	9	49	44	0	0	0.163	0.053	0.086	0.029	0.074	0.015
4	10	44	49	0.102	0.043	0.295	0.069	0.194	0.041	0.138	0.024
4	11	21	31	0.355	0.086	0.333	0.103	0.346	0.066	0.241	0.042
4	12	0	3	0.333	0.272	NA	NA	0.333	0.272	0.388	0.068
5	9	0	1	0	0	NA	NA	0	0	0.14	0.035
5	10	3	4	0	0	0	0	0	0	0.245	0.044
5	11	8	16	0.125	0.083	0.125	0.117	0.125	0.068	0.392	0.054
5	12	4	9	0.222	0.139	0.75	0.217	0.385	0.135	0.562	0.064
5	13	0	1	1	0	NA	NA	1	0	0.718	0.065
6	12	1	2	1	0	1	0	1	0	0.856	0.035
7	12	2	1	1	0	1	0	1	0	0.95	0.019
7	13	0	1	1	0	NA	NA	1	0	0.974	0.01
7	14	1	1	1	0	1	0	1	0	0.987	0.006
8	13	1	1	1	0	1	0	1	0	0.988	0.007
8	15	1	0	NA	NA	1	0	1	0	0.997	0.002

Table 4.1.1 Proportion mature at age for Icelandic cod.

Year	3	4	5	6	7	8	9	10	11	12	13	14
1975	0.01	0.09	0.30	0.51	0.83	0.95	0.99	1.00	1.00	1	1	1
1976	0.03	0.11	0.37	0.56	0.67	0.93	0.99	1.00	1.00	1	1	1
1977	0.00	0.04	0.19	0.55	0.84	0.96	0.99	1.00	1.00	1	1	1
1978	0.02	0.08	0.21	0.47	0.86	0.96	0.98	1.00	1.00	1	1	1
1979	0.04	0.05	0.20	0.49	0.74	0.90	0.98	0.93	1.00	1	1	1
1980	0.02	0.05	0.17	0.46	0.74	0.85	0.97	0.98	1.00	1	1	1
1981	0.00	0.02	0.09	0.26	0.57	0.81	0.91	0.95	1.00	1	1	1
1982	0.01	0.06	0.17	0.26	0.53	0.81	0.93	0.95	1.00	1	1	1
1983	0.00	0.04	0.16	0.33	0.51	0.71	0.86	0.98	1.00	1	1	1
1984	0.01	0.05	0.20	0.41	0.65	0.81	0.93	0.99	1.00	1	1	1
1985	0.04	0.11	0.20	0.49	0.70	0.88	0.91	1.00	1.00	1	1	1
1986	0.01	0.07	0.23	0.46	0.72	0.81	0.96	0.97	0.98	1	1	1
1987	0.02	0.04	0.14	0.46	0.67	0.84	0.93	1.00	1.00	1	1	1
1988	0.04	0.06	0.22	0.35	0.61	0.78	0.84	0.95	0.98	1	1	1
1989	0.04	0.12	0.25	0.49	0.76	0.84	0.89	0.97	1.00	1	1	1
1990	0.04	0.08	0.26	0.48	0.73	0.87	0.96	0.99	1.00	1	1	1
1991	0.09	0.19	0.26	0.46	0.68	0.86	0.85	0.77	0.65	1	1	1
1992	0.11	0.25	0.48	0.62	0.84	0.92	0.97	1.00	1.00	1	1	1
Mean	0.03	0.08	0.23	0.45	0.70	0.86	0.94	0.97	0.98	1	1	1
Standard deviation	0.03	0.06	0.09	0.1	0.1	0.07	0.05	0.05	0.08	0	0	0

Table 4.1.2 Analysis of Deviance Table for binomial model of proportion mature for Icelandic cod. F-statistics to be used with caution due to incorrect degrees of freedom (see text).

Binomial model

Response: resp

Terms added sequentially (first to last)

	Df	Deviance Resid.	Df	Resid. Dev	F Value	Pr(F)
NULL			215	163.5		
a	11	155.5266	204	8.0	828.5	0.0000
y	17		187	4.8	11.1	0.0000
ycl	27		160	2.7	4.5	0.0000

Table 4.1.3 Fitted values from binomial model with age, year and yearclass effects.

Year	3	4	5	6	7	8	9	10	11	12	13	14
1975	0.01	0.09	0.30	0.47	0.85	0.96	0.99	1.00	1.00	1	1	1
1976	0.02	0.06	0.30	0.60	0.75	0.94	0.99	1.00	1.00	1	1	1
1977	0.02	0.06	0.20	0.59	0.83	0.90	0.98	0.99	1.00	1	1	1
1978	0.01	0.07	0.25	0.50	0.85	0.94	0.96	1.99	1.00	1	1	1
1979	0.01	0.05	0.19	0.48	0.73	0.93	0.97	0.98	0.99	1	1	1
1980	0.02	0.04	0.16	0.45	0.75	0.88	0.97	0.99	0.99	1	1	1
1981	0.01	0.03	0.09	0.24	0.57	0.81	0.91	0.97	0.98	1	1	1
1982	0.01	0.04	0.14	0.28	0.56	0.82	0.93	0.96	0.99	1	1	1
1983	0.01	0.03	0.12	0.32	0.52	0.76	0.91	0.96	0.97	1	1	1
1984	0.02	0.04	0.18	0.40	0.71	0.83	0.92	0.97	0.98	1	1	1
1985	0.03	0.08	0.18	0.49	0.74	0.90	0.94	0.97	0.99	1	1	1
1986	0.03	0.09	0.23	0.38	0.72	0.87	0.95	0.97	0.98	1	1	1
1987	0.03	0.10	0.22	0.43	0.61	0.85	0.93	0.97	0.97	1	1	1
1988	0.03	0.07	0.21	0.37	0.60	0.73	0.90	0.95	0.97	1	1	1
1989	0.04	0.13	0.29	0.52	0.71	0.84	0.89	0.96	0.97	1	1	1
1990	0.07	0.12	0.32	0.51	0.73	0.84	0.91	0.93	0.97	1	1	1
1991	0.05	0.11	0.20	0.41	0.60	0.78	0.85	0.91	0.91	1	1	1
1992	0.11	0.29	0.53	0.64	0.83	0.90	0.95	0.97	0.97	1	1	1
Mean	0.03	0.08	0.23	0.45	0.70	0.86	0.94	0.97	0.98	1	1	1
Standard deviation	0.03	0.06	0.10	0.11	0.10	0.07	0.04	0.02	0.02	0	0	0

Table 4.2.1

Irish Sea cod example

C (base for target rms) =	0.102
K=	1.00
M =	0.2
Base age =	2

AGE	Catch number	Observed CV	(CV)^2	CV patterns : K = 2	K
1	1296	0.62	0.38	0.55	0.20
2	64588	0.12	0.01	0.55	0.10
3	31631	0.08	0.01	0.55	0.20
4	5241	0.14	0.02	0.55	0.30
5	2155	0.19	0.04	0.55	0.41
6	425	0.36	0.13	0.55	0.51
7	403	0.34	0.12	0.55	0.61
8	210	0.53	0.28	0.55	0.71
9	51	1.00	1.00	0.55	0.81
10	30	1.00	1.00	0.55	0.91
Var(pop)		1.32E+08		3.17E+09	2.08E+08
Root mean square CV		**0.55**			**0.55**

Fig 3.1.1 Estimated proportion at age for the 1992 data (18 cells)

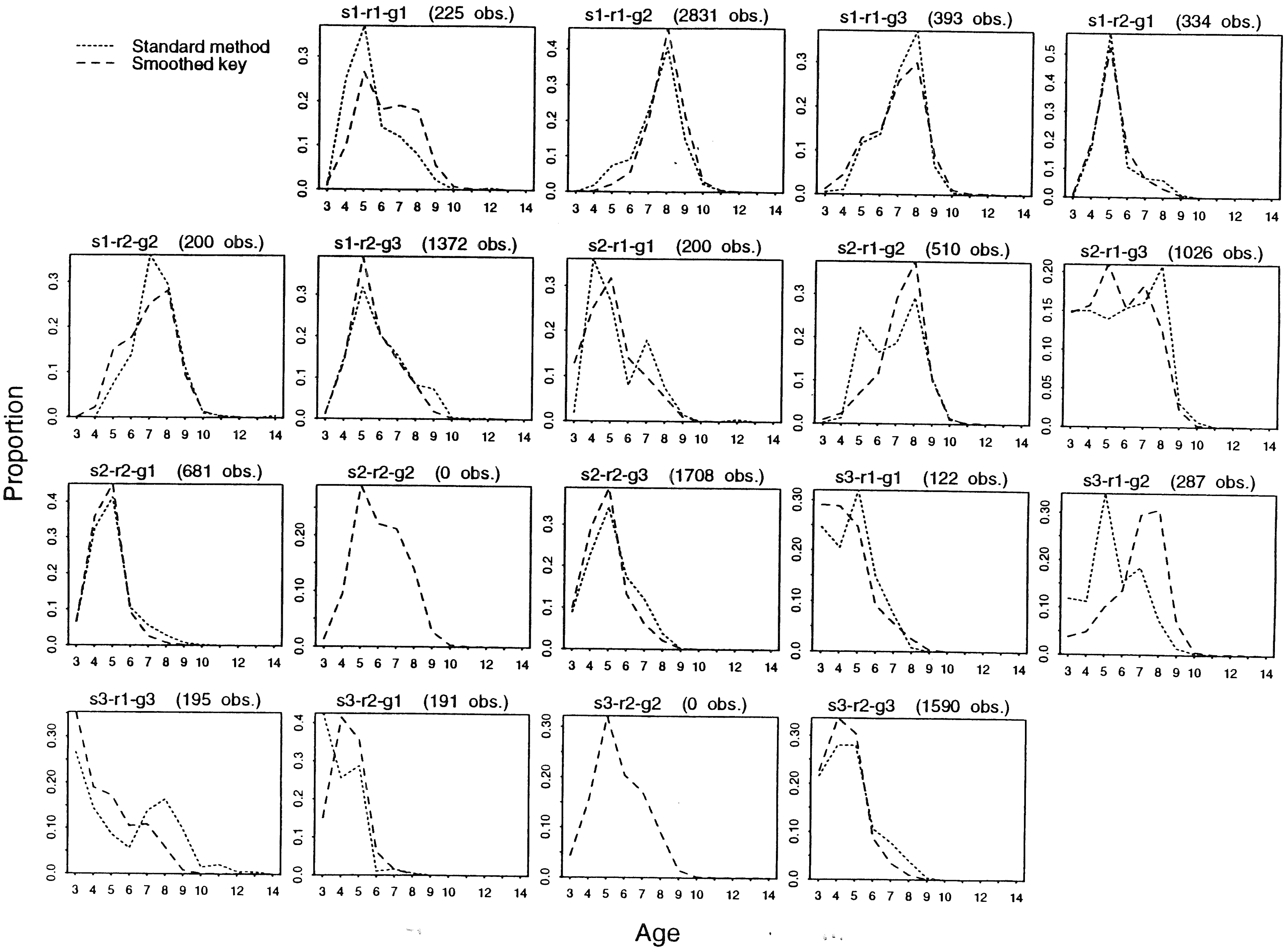


Fig 3.1.2 Estimated mean length at age for the 1992 data (18 cells)

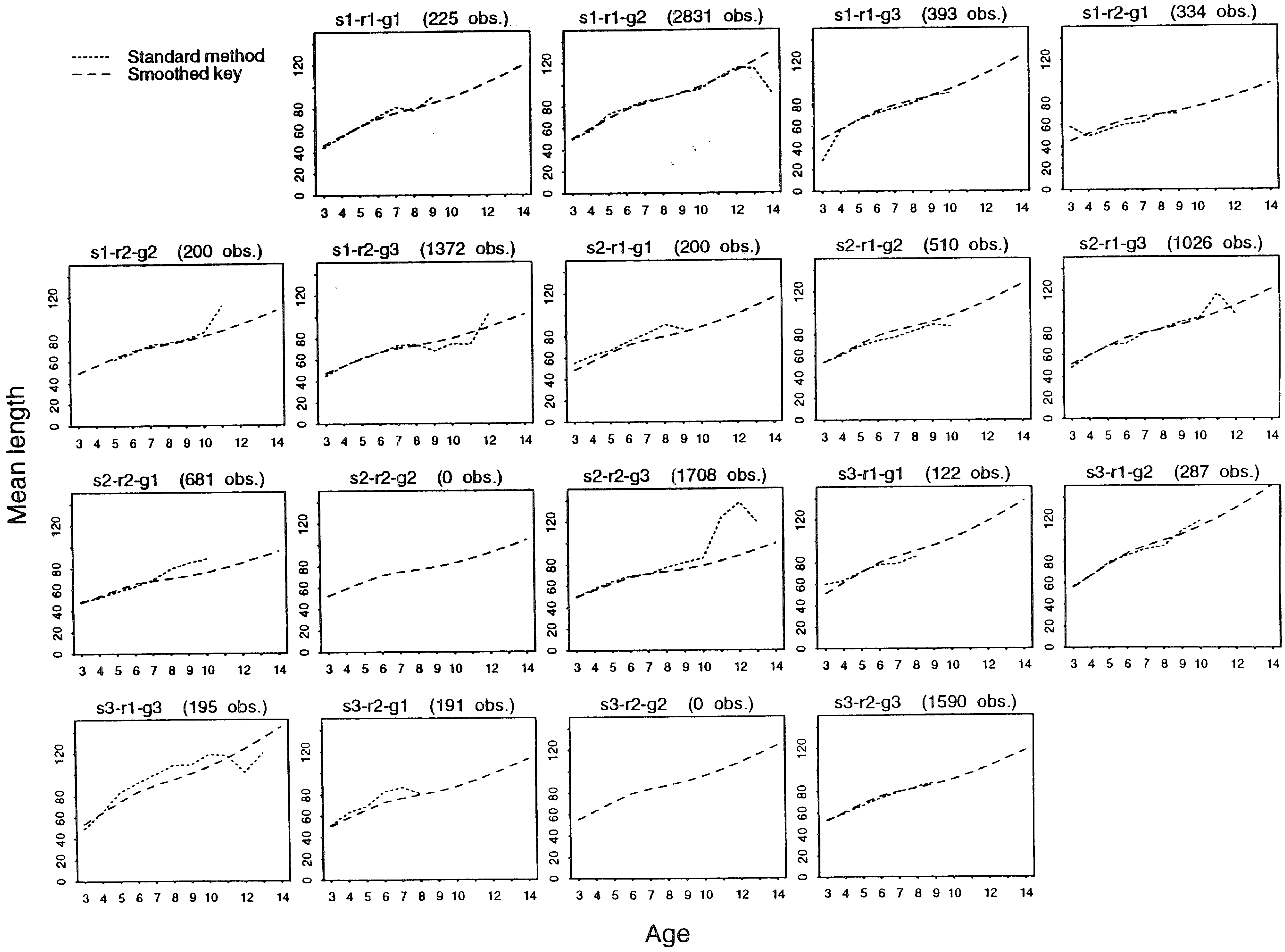


Fig 3.1.3 Bias in catch-in-number from simulations plotted vs. sample size for the 1992 data

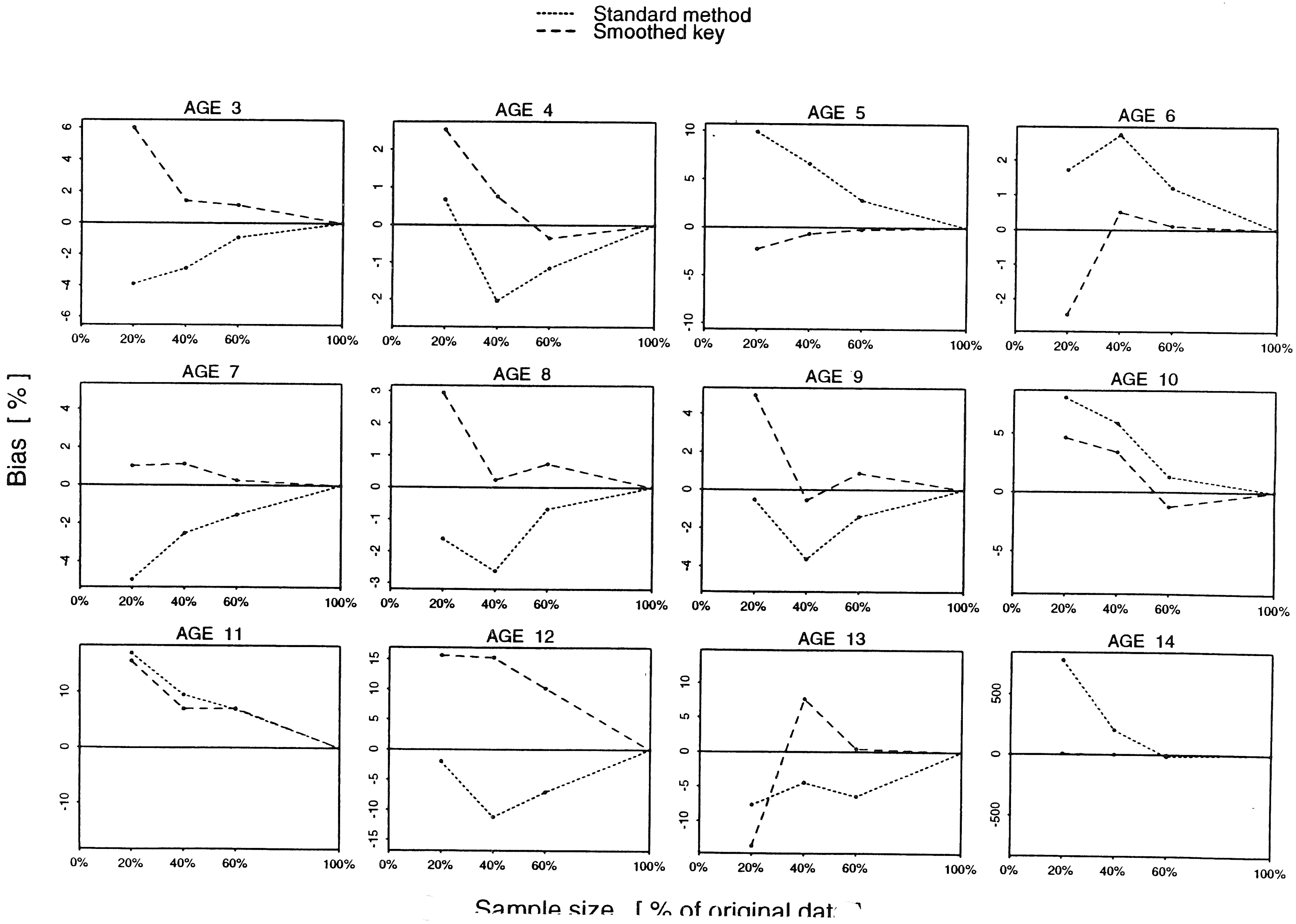
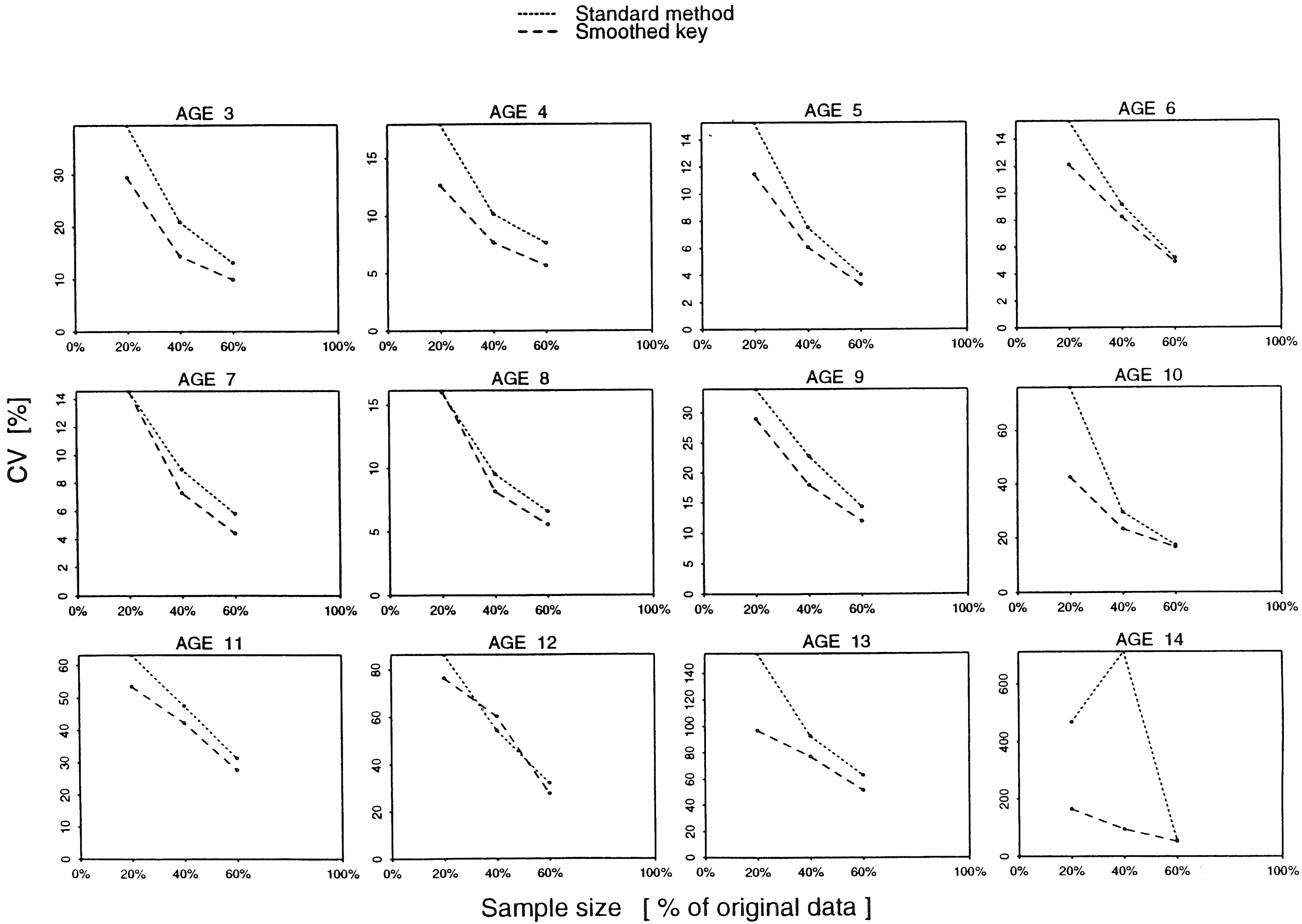


Fig 3.1.4 CV of catch-in-number from simulations plotted vs. sample size for the 1992 data



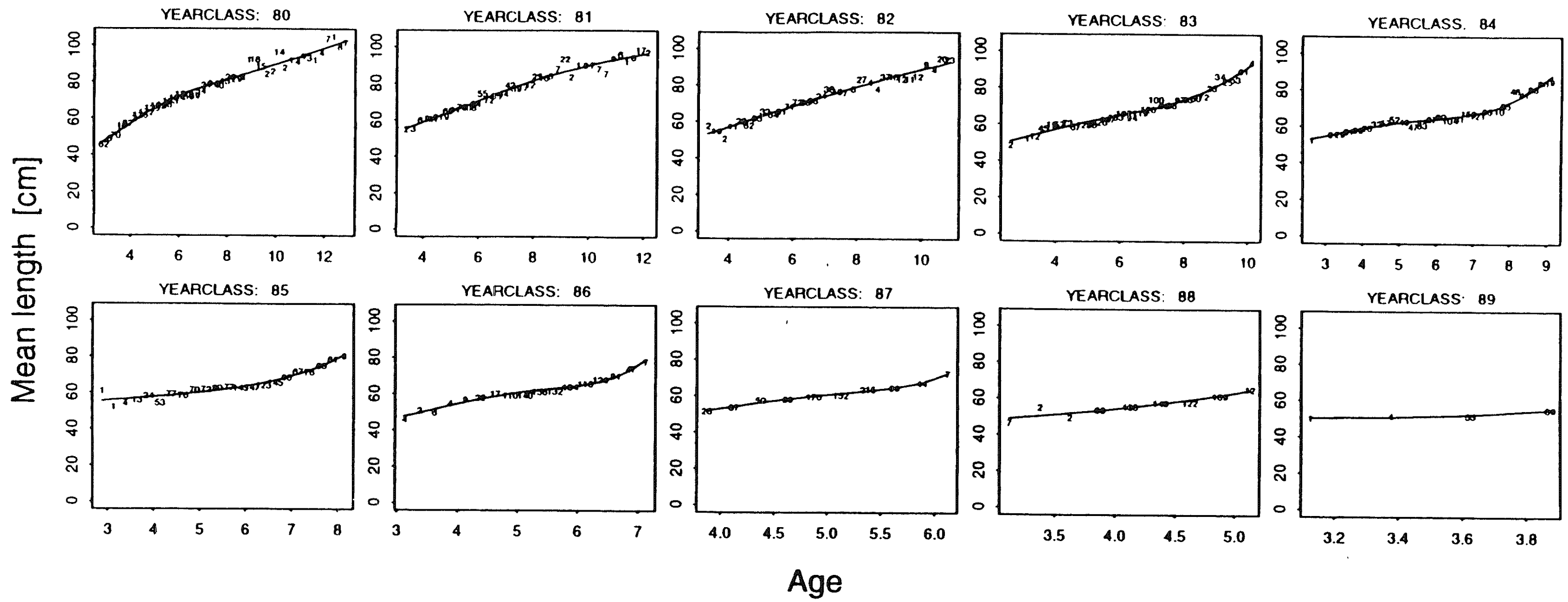


Figure 3.1.5 Smoothing of mean length for the Faroe saithe ALD's (numbers = No. observations).

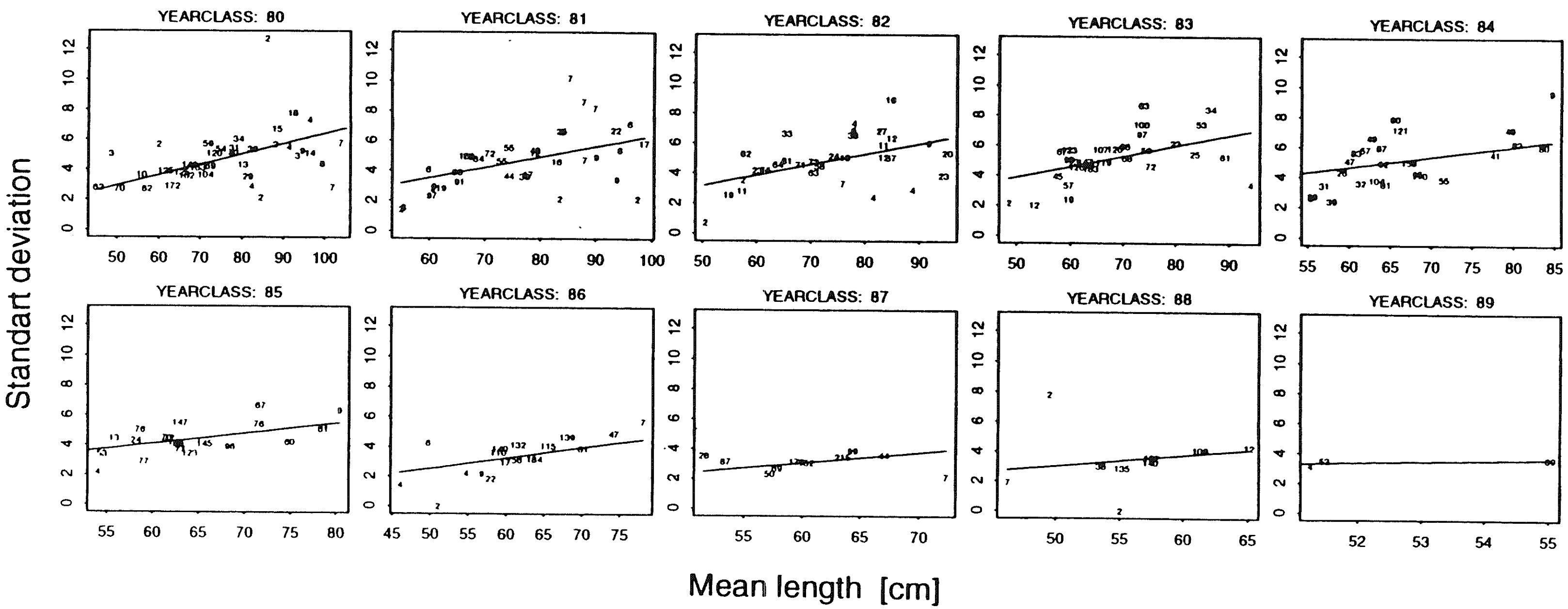


Figure 3.1.6 Smoothing of the length standard deviations for the Faroe saithe ALD's (numbers = No. obervations).

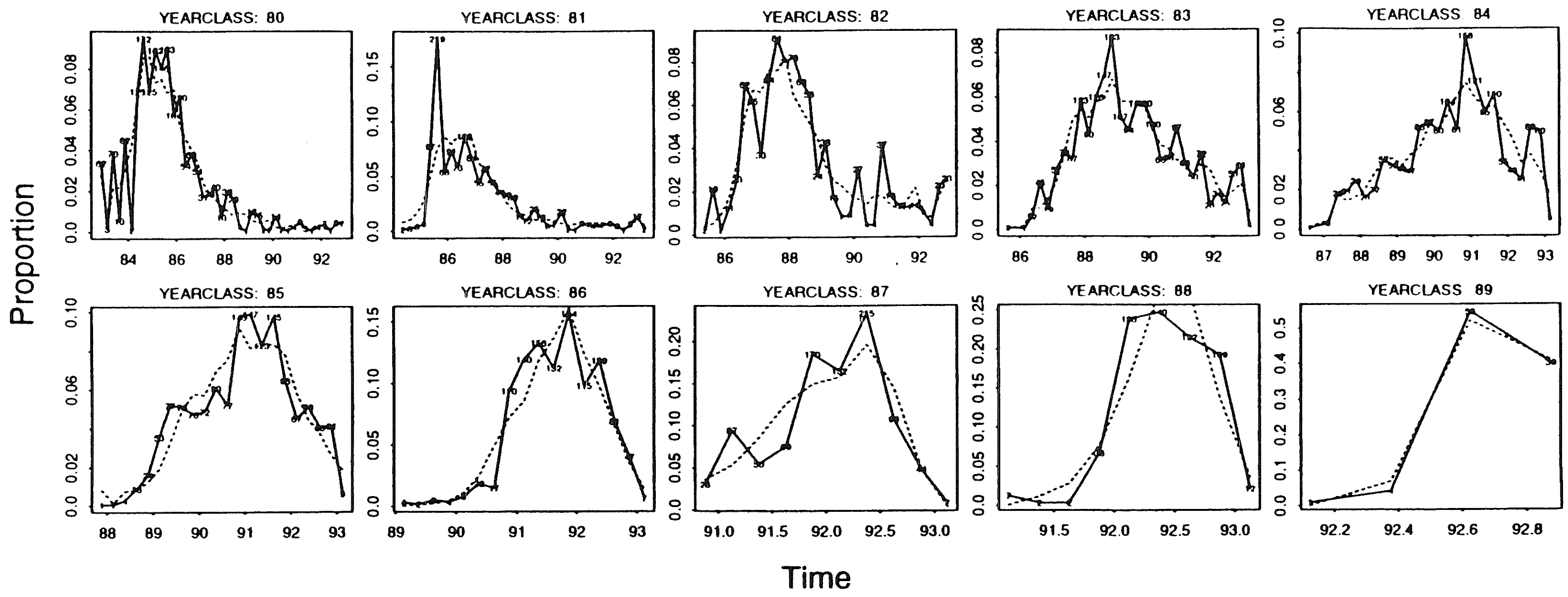


Figure 3.1.7 Smoothing of the relative frequency of a year class in the ALD's for Faroe saithe (numbers = No. observations).

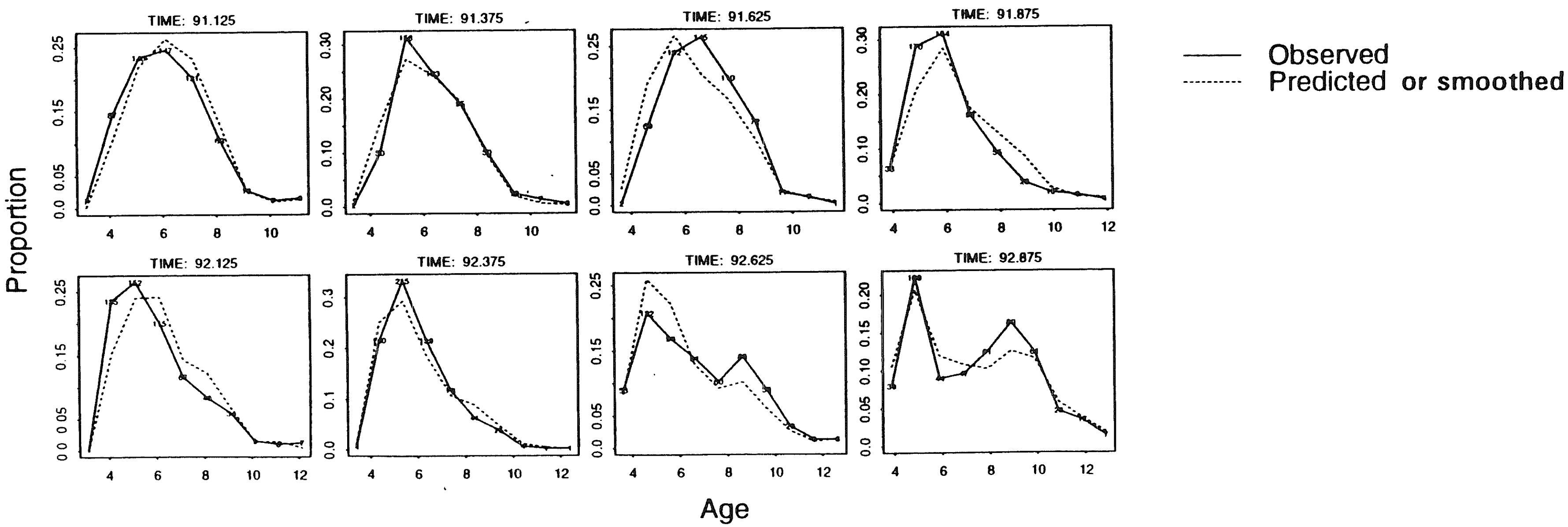


Figure 3.1.8 Smoothed and observed values of the relative frequency of the age groups for each quarter in 1991 and 1992 from the Faroe saithe ALD's (number = No. observations).

Fig. 3.2.1 : Prop. mature 1989
Haddock

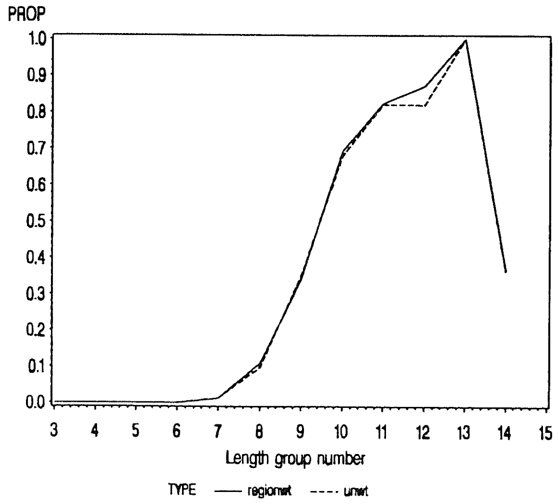


Fig. 3.2.2 : Prop. mature 1990
Haddock

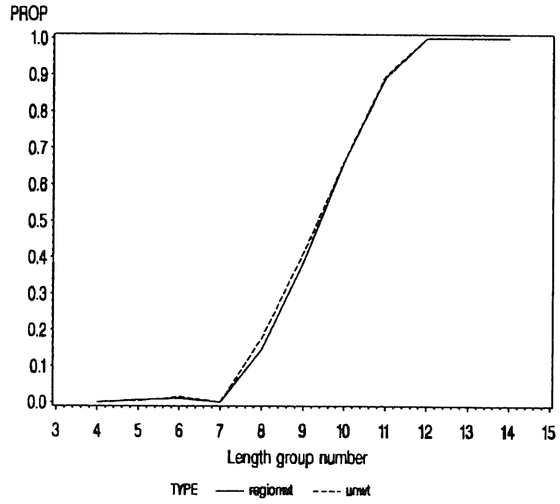


Fig. 3.2.3 : Prop. mature 1991
Haddock

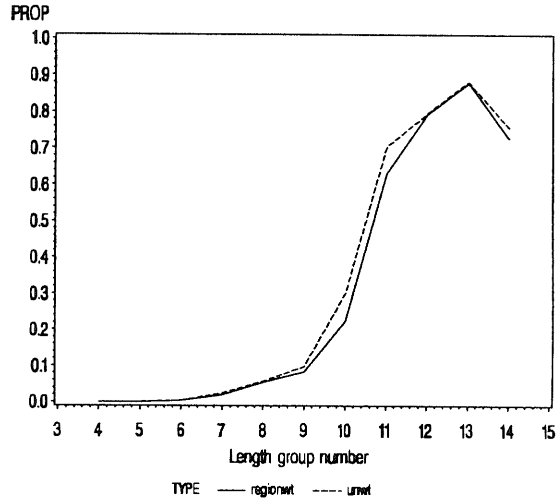


Fig. 3.2.4 : Prop. mature 1992
Haddock

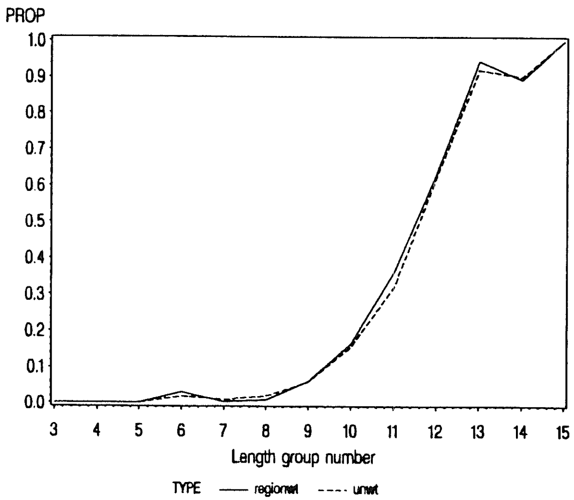


Fig. 3.2.5 : Prop. mature 1993
Haddock

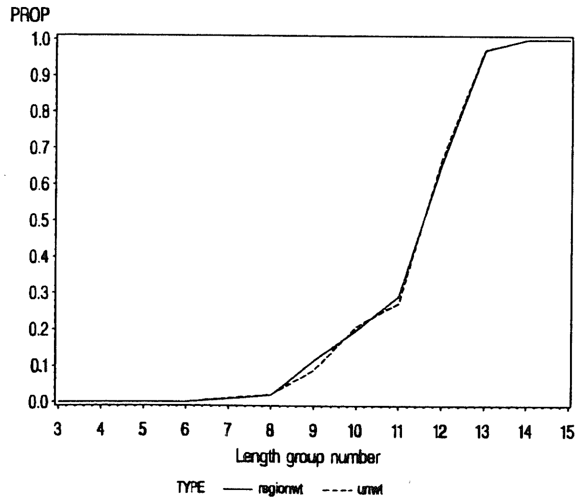


Fig. 3.2.6 : Prop. mature 1989
Haddock

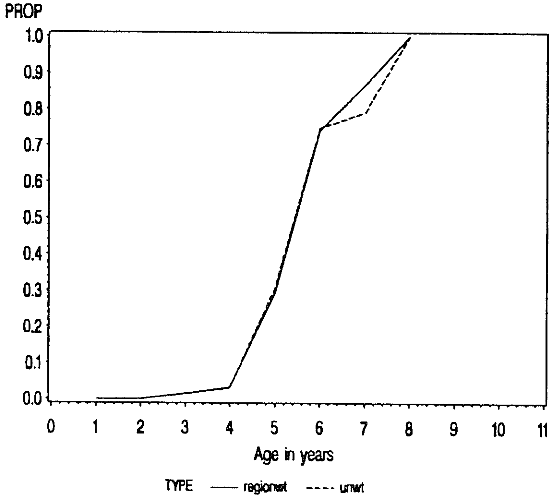


Fig. 3.2.7 : Prop. mature 1990
Haddock

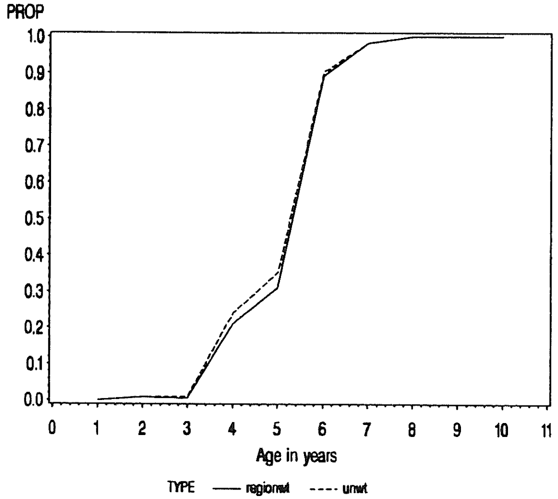


Fig. 3.2.8 : Prop. mature 1991
Haddock

Fig. 3.2.9 : Prop. mature 1992
Haddock

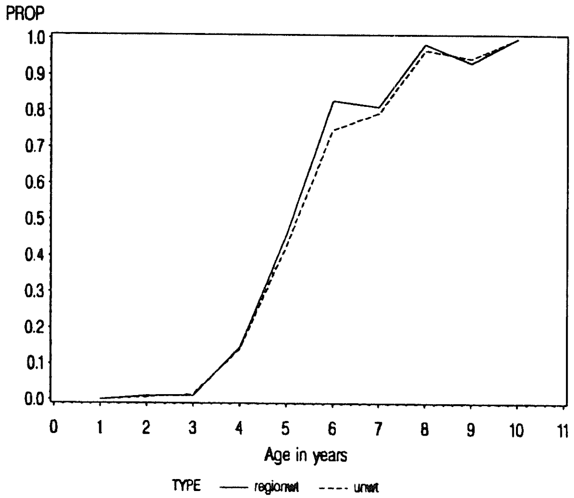


Fig. 3.2.10 : Prop. mature 1993
Haddock

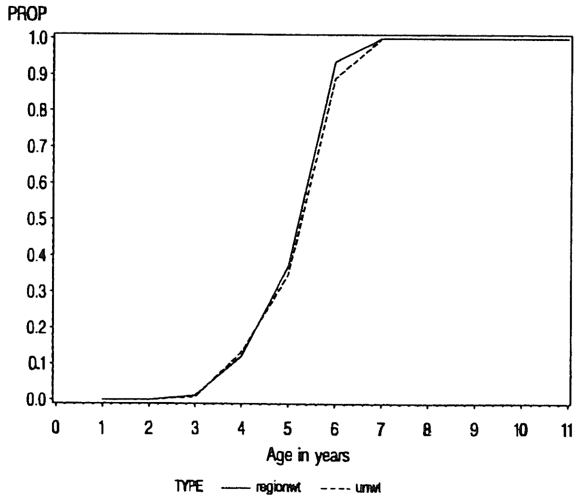


Fig. 3.2.11: Prop. mature 1989 (length applied vs not)

Haddock region weighted

Fig. 3.2.12: Prop. mature 1990 (length applied vs not)

Haddock region weighted

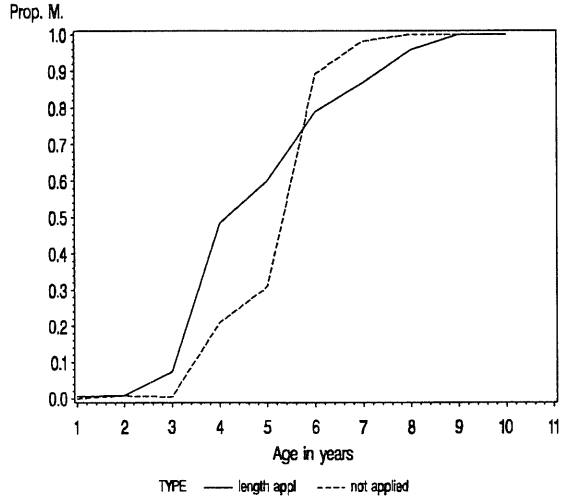


Fig. 3.2.13: Prop. mature 1991 (length applied vs not)

Haddock region weighted

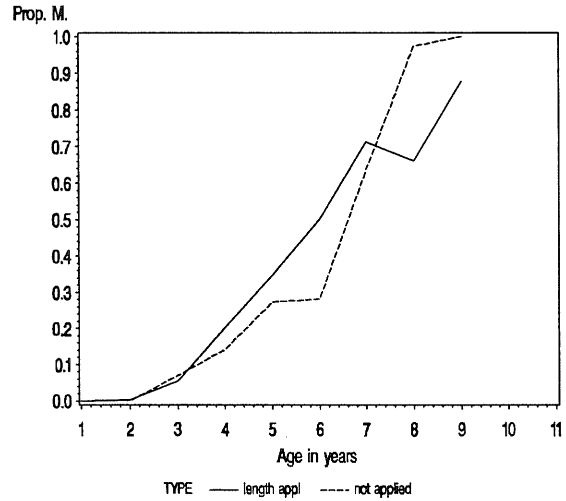


Fig. 3.2.14: Prop. mature 1992 (length applied vs not)

Haddock region weighted

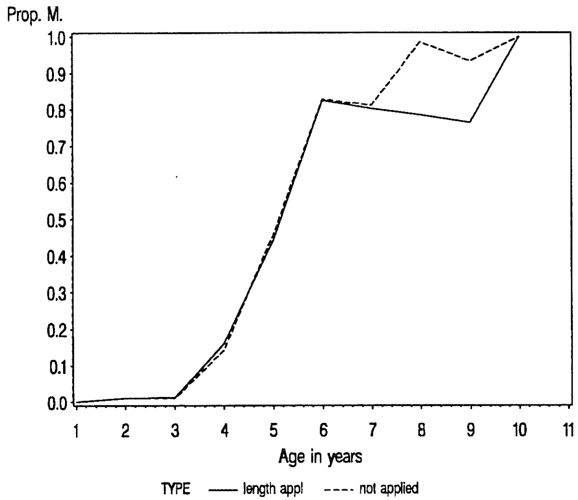


Fig. 3.2.15: Prop. mature 1993 (length applied vs not)

Haddock region weighted

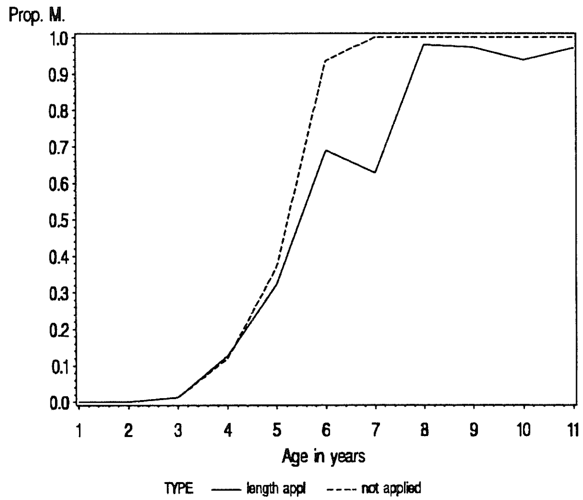
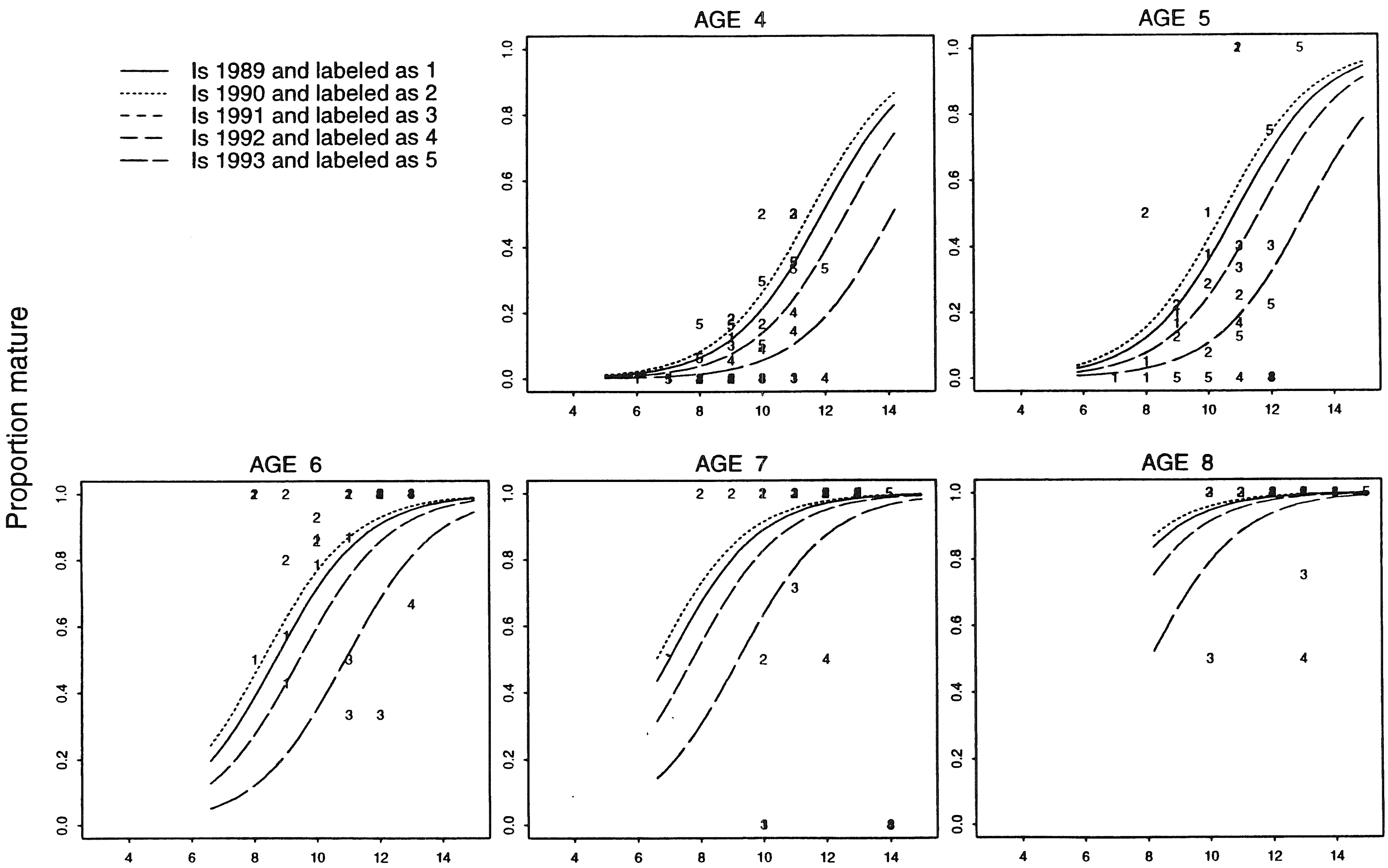


Fig 3.3.1 Barent Sea Haddock, Area D (observed and predicted proportions)



Length group [5 cm groups, 1 = 0 to 5 cm, 2 = 6 to 10 cm, ...]

Fig 3.3.2 Barent Sea Haddock, Area D

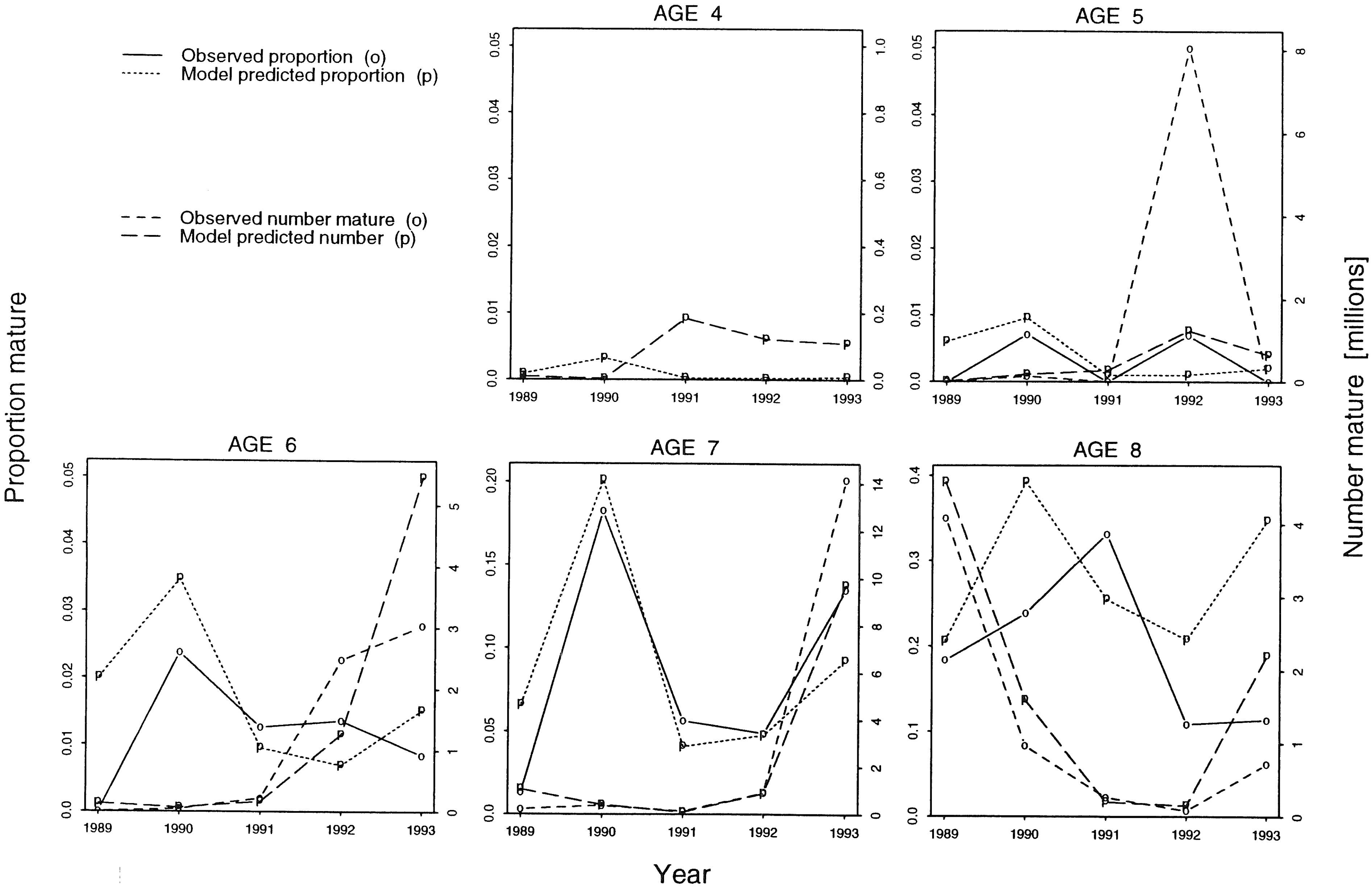


Fig 3.3.3 Barent Sea Haddock, Area D

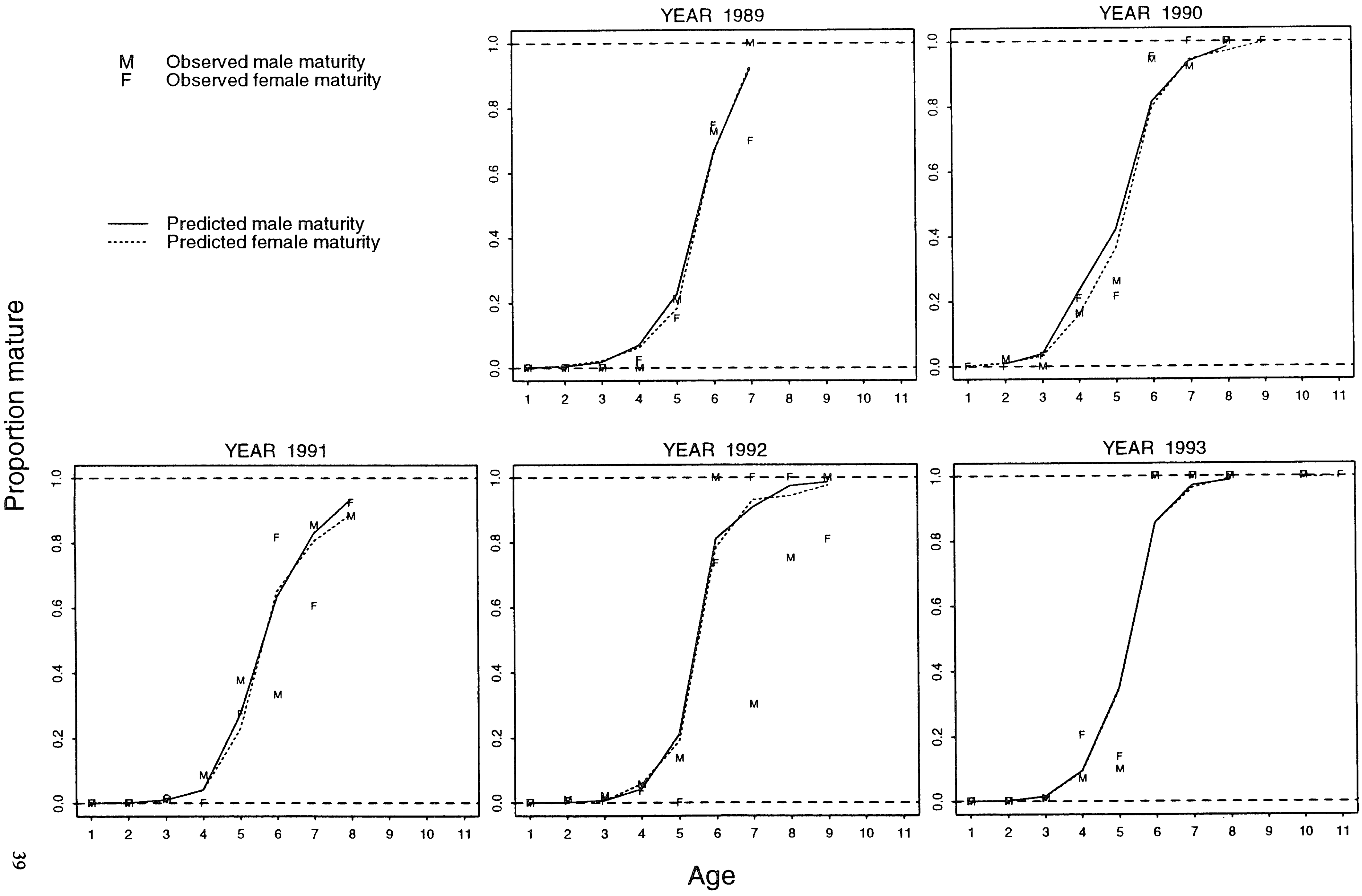
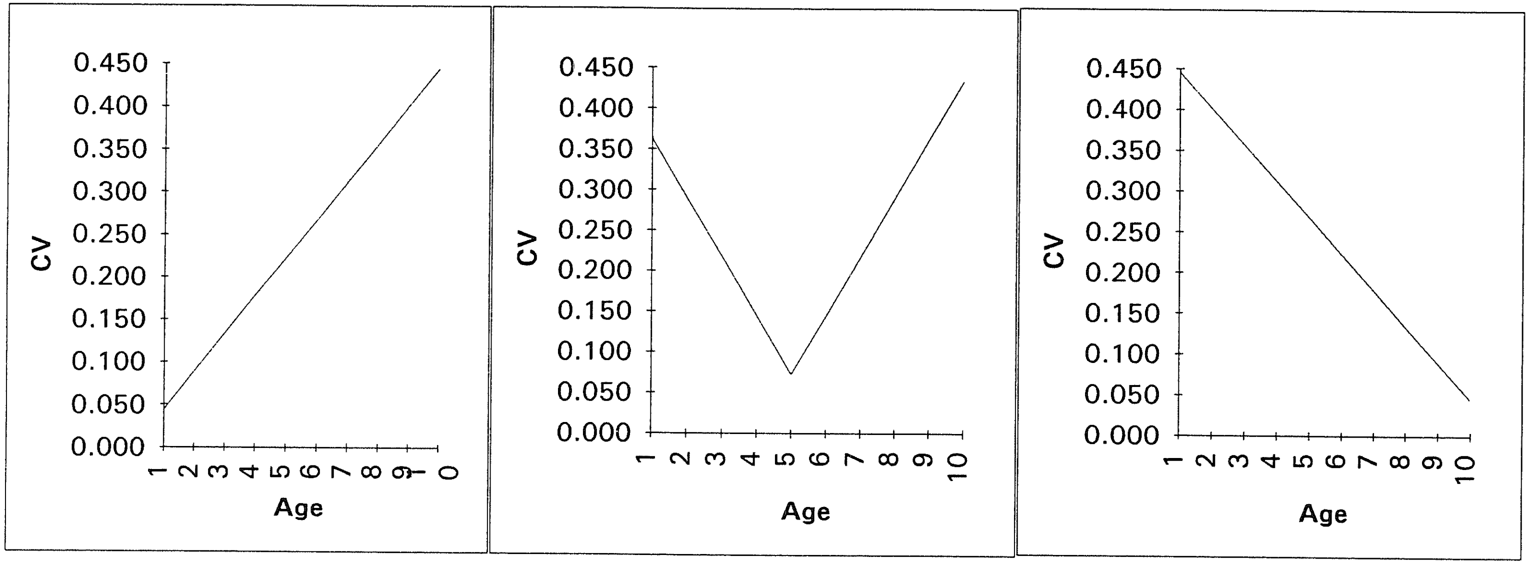


Figure 4.2.1a

CV pattern for selected parameters in the objective function

K = 1



Base age = 1

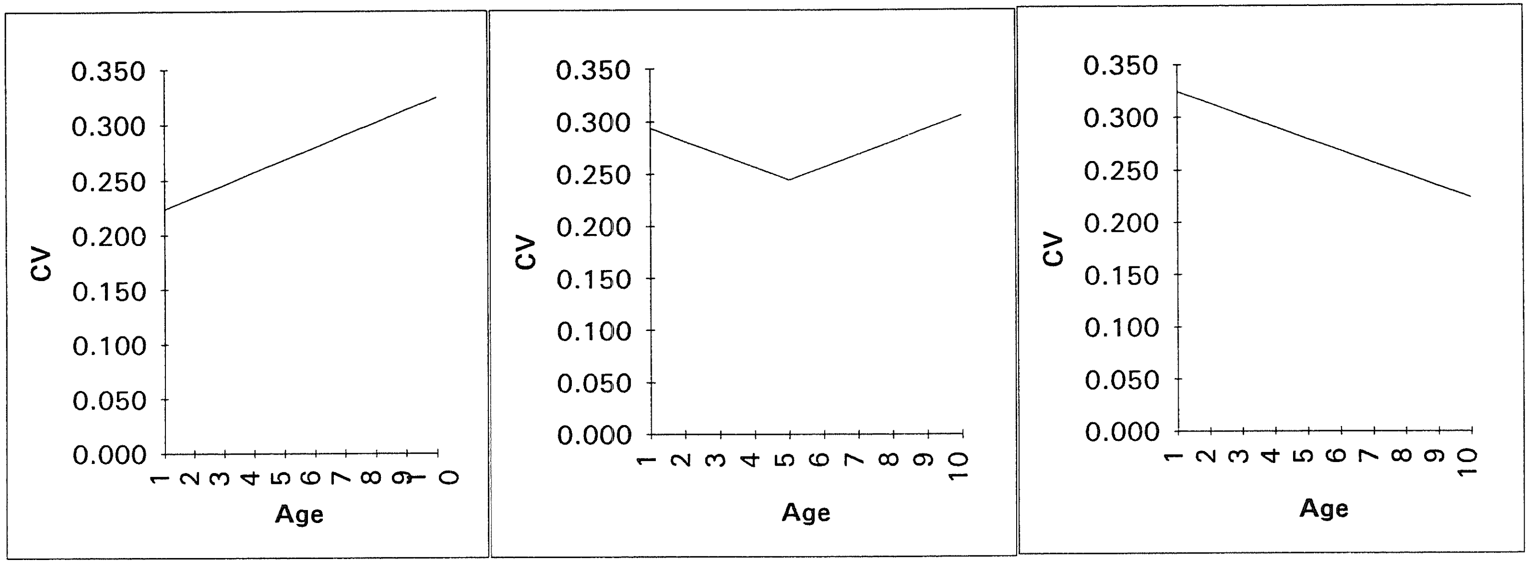
Base age = 5

Base age = 10

Figure 4.2.1b

CV pattern for selected parameters in the objective function

K=1.95



Base age = 1 Base age = 5 Base age = 10

Figure 4.2.2

Cod: recruitment CV surface

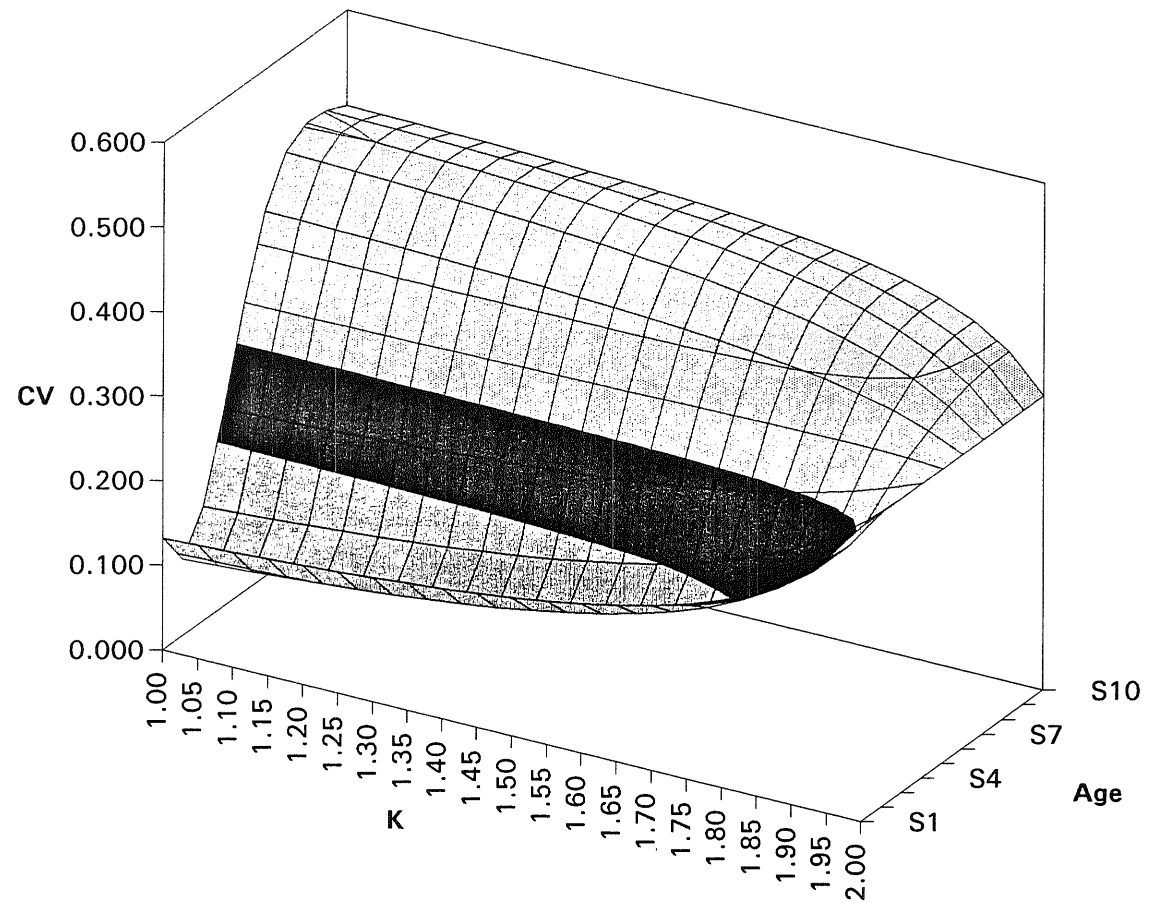
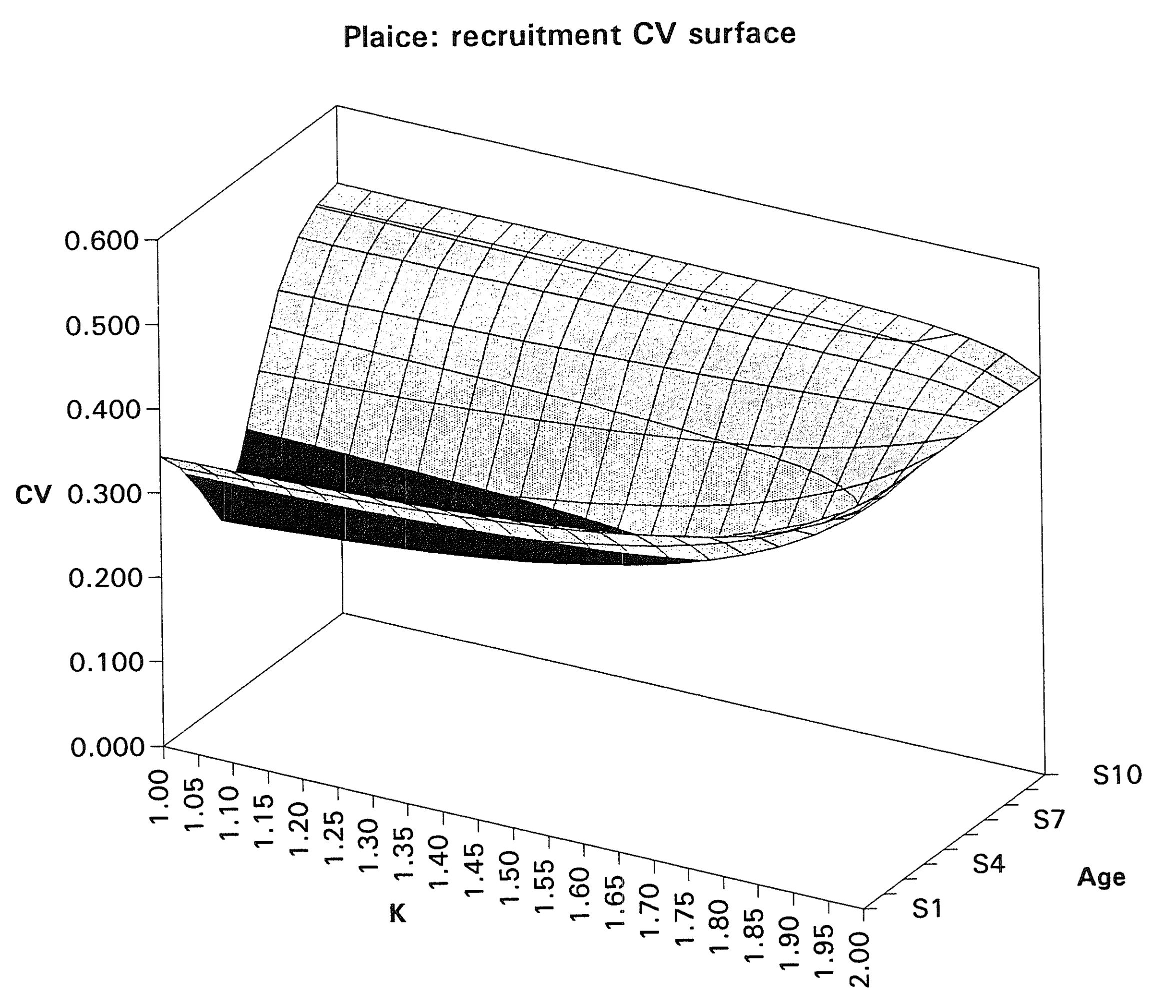


Figure 4.2.3



Plaice: recruitment CV surface
CV
0.000
0.100
0.200
0.300
0.400
0.500
0.600
K
1.00
1.05
1.10
1.15
1.20
1.25
1.30
1.35
1.40
1.45
1.50
1.55
1.60
1.65
1.70
1.75
1.80
1.85
1.90
1.95
2.00
Age
S1
S4
S7
S10

Figure 4.3.1

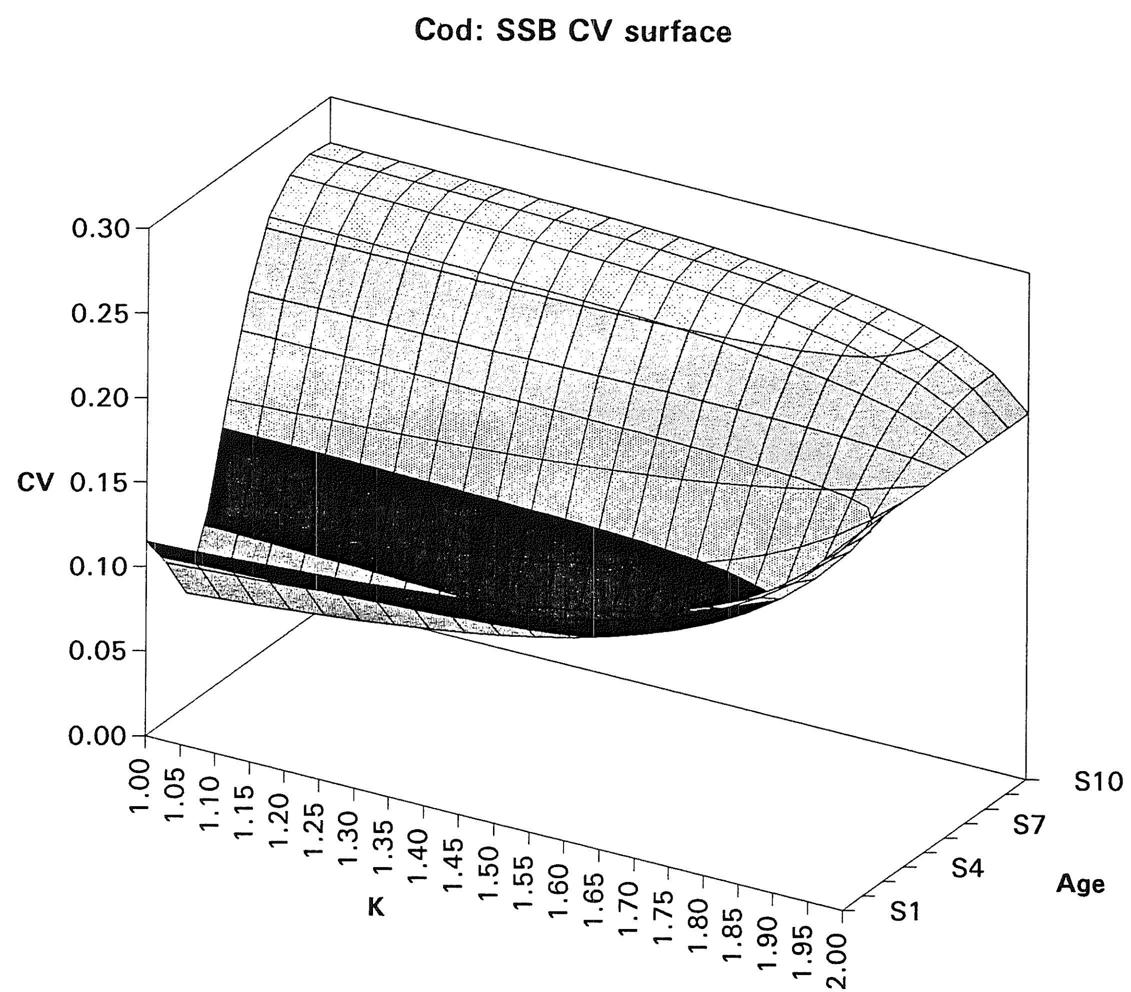

Cod: SSB CV surface
CV
0.30
0.25
0.20
0.15
0.10
0.05
0.00
K
1.00
1.05
1.10
1.15
1.20
1.25
1.30
1.35
1.40
1.45
1.50
1.55
1.60
1.65
1.70
1.75
1.80
1.85
1.90
1.95
2.00
Age
S1
S4
S7
S10

Figure 4.3.2

Plaice: SSB CV surface

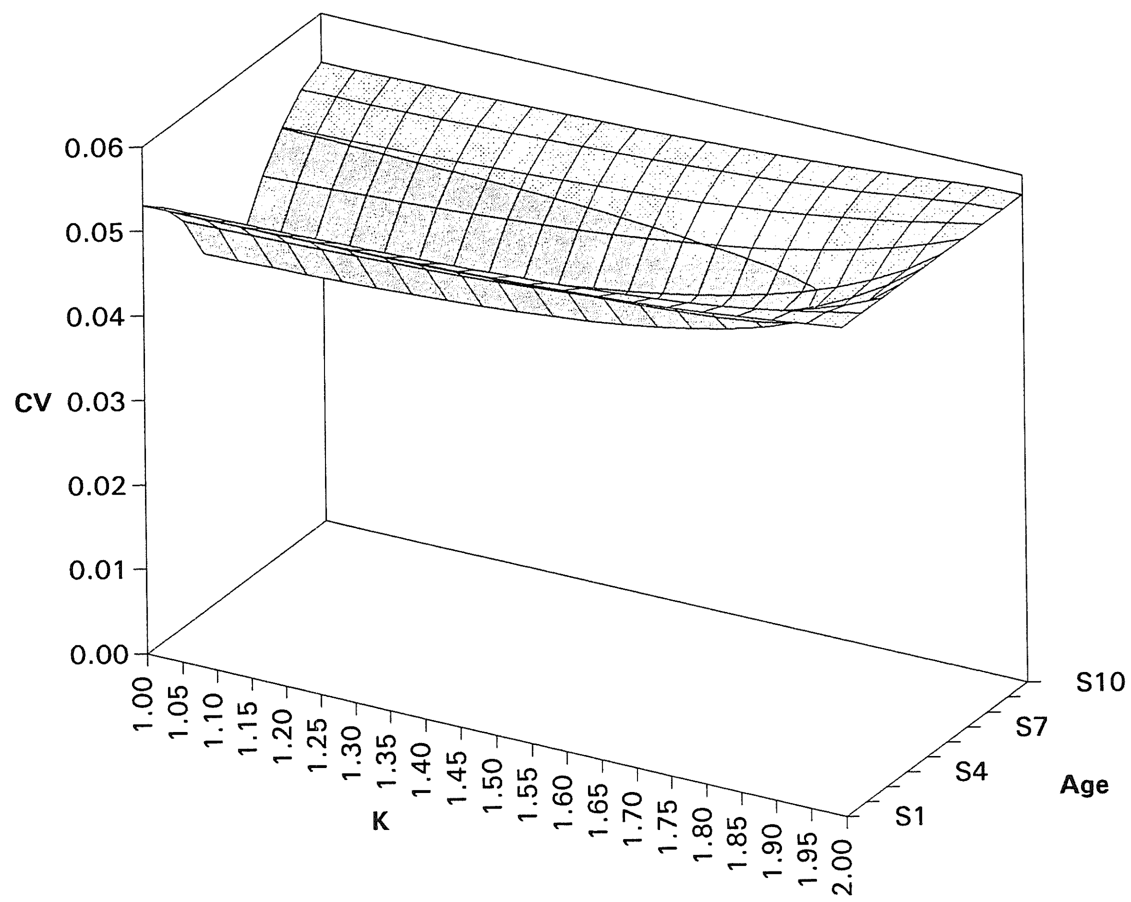


Figure 4.3.3

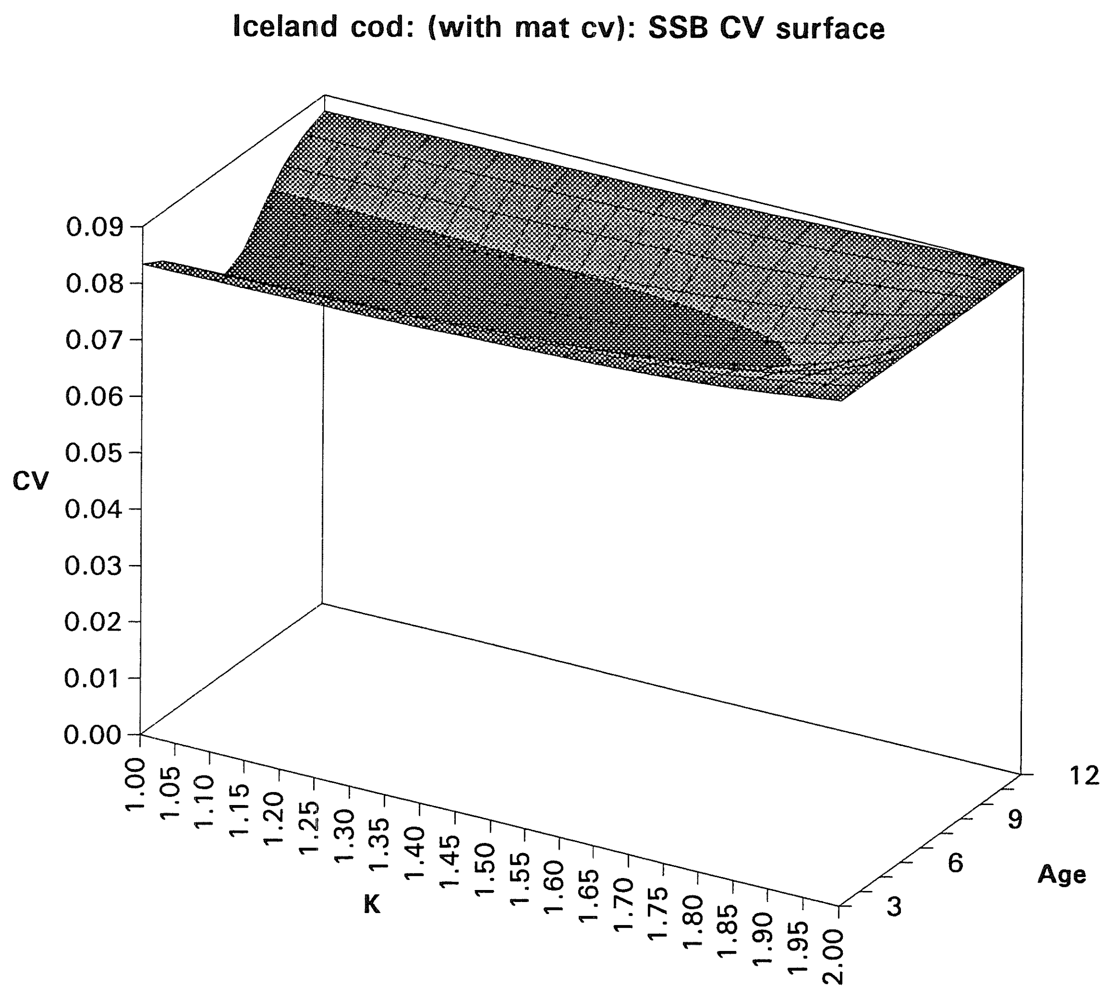

Iceland cod: (with mat cv): SSB CV surface
CV
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
K
1.00
1.05
1.10
1.15
1.20
1.25
1.30
1.35
1.40
1.45
1.50
1.55
1.60
1.65
1.70
1.75
1.80
1.85
1.90
1.95
2.00
Age
3
6
9
12

Figure 4.3.4

Iceland cod: (no mat cv): SSB CV surface

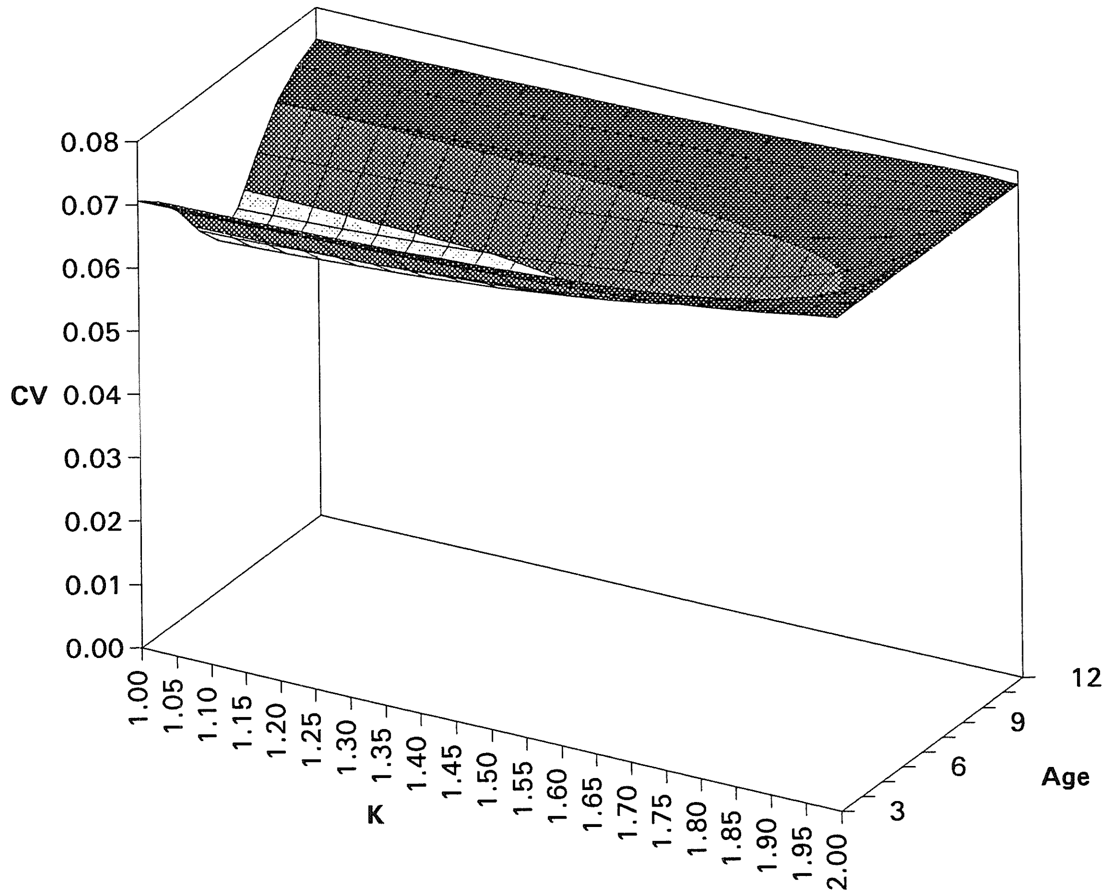
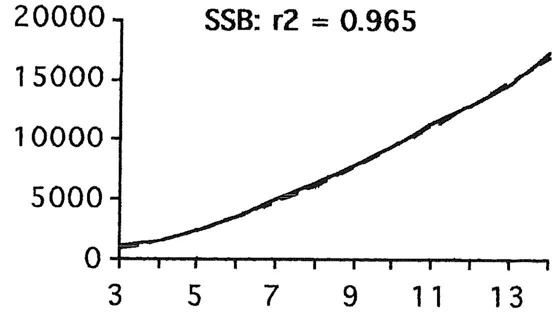
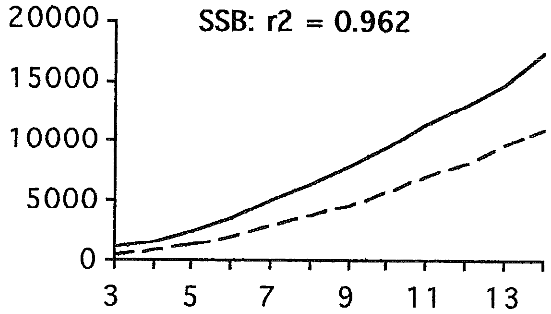


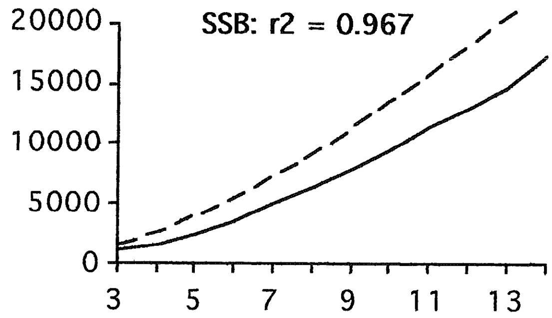
Figure 4.4.1 Icelandic cod: Effects on correlation between baseline SSB and SSB estimates derived from changes in the parameters of a fitted growth curve. Solid lines indicate baseline mean weights at age. Dashed lines indicate changes in the fitted Bertalanffy function. x-accis denotes weight in grammes, y-accis age. Winf = asymptotic weight. K = Bertalanffy growth coefficient.



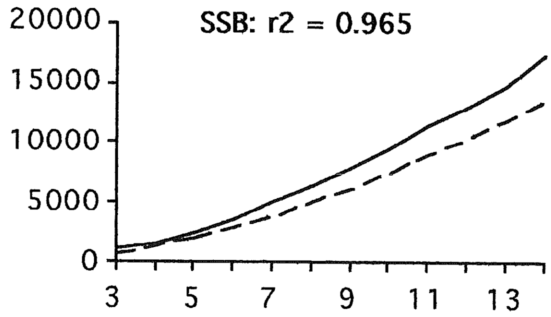
a) fitted growth curve. Winf=76024 gram, K=0.060



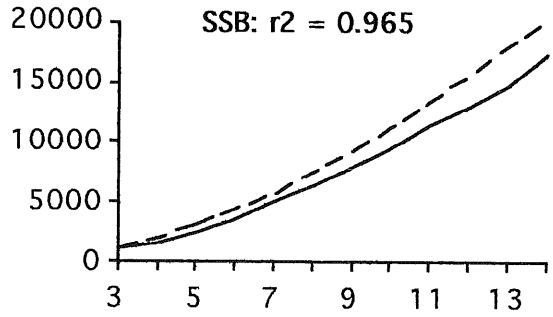
b) 20% decrease in growth rate. K=0.048



c) 20% increase in growth rate. K=0.072

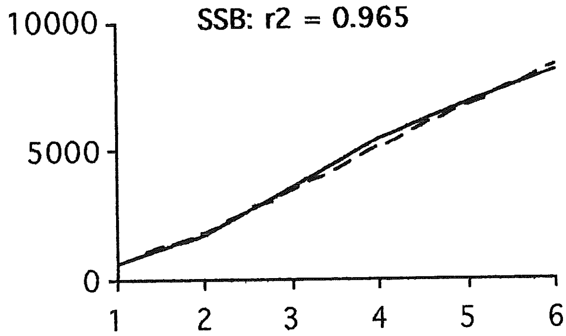


d) 20% decrease in asymptote. Winf=60819

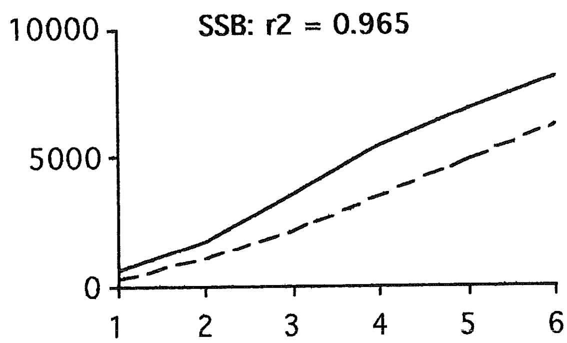


e) 20% increase in asymptote. Winf=91228

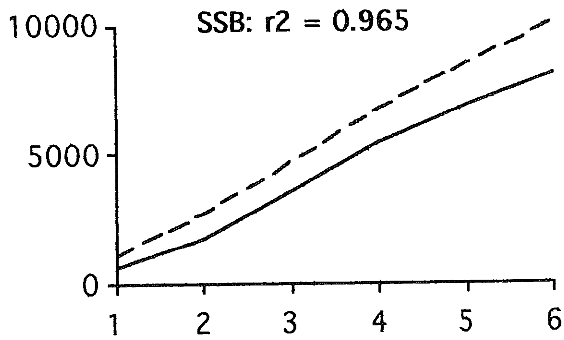
Figure 4.4.2 Irish Sea cod: Effects on correlation between baseline SSB and SSB estimates derived from changes in the parameters of a fitted growth curve. Solid lines indicate baseline mean weights at age. Dashed lines indicate changes in the fitted Bertalanffy function. x-accis denotes weight in grammes, y-accis age. Winf = asymptotic weight. K = Bertalanffy growth coefficient.



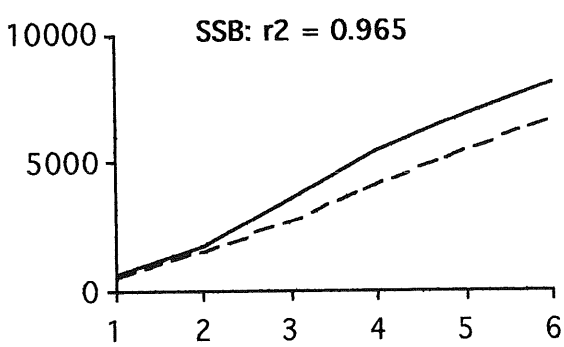
a) fitted growth curve. Winf=15748 gram, K=0.243



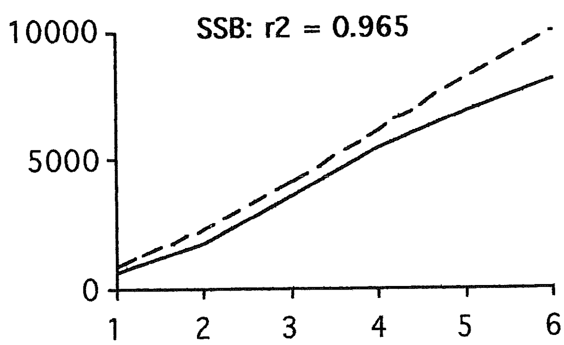
b) 20% decrease in growth rate. K=0.195



c) 20% increase in growth rate. K=0.292

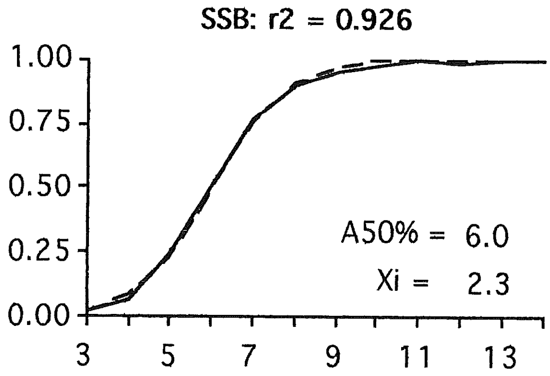


d) 20% decrease in asymptote. Winf=12598

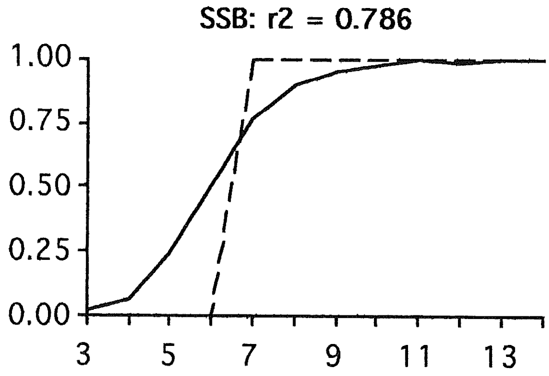


e) 20% increase in asymptote. Winf=18897

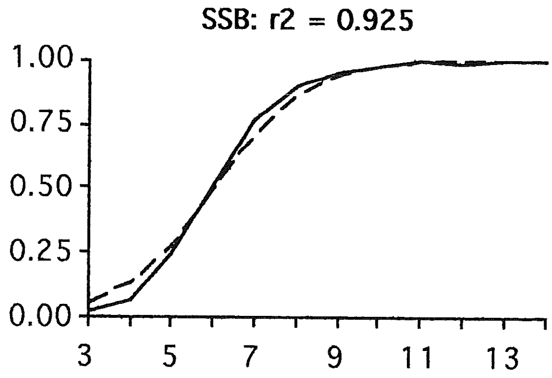
Figure 4.4.3 Icelandic cod: Effects on correlation between baseline SSB and SSB estimates derived from changes in the parameters of a fitted maturity ogive. Solid lines indicate baseline maturity at age. Dashed lines indicate changes in the fitted logistic function. x-accis denotes proportions, y-accis age. A50% = age at 50% maturity, Xi = steepness multiplyer.



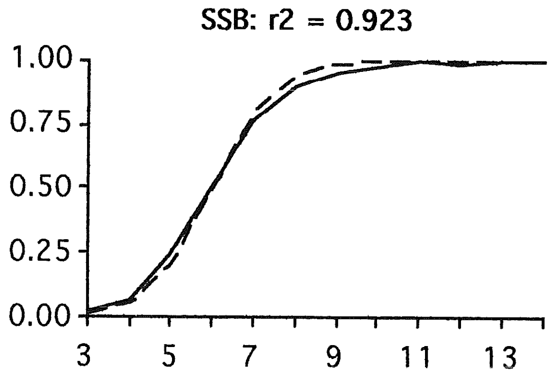
a) fitted logistic curve. A50% = 6.0, Xi = 2.3



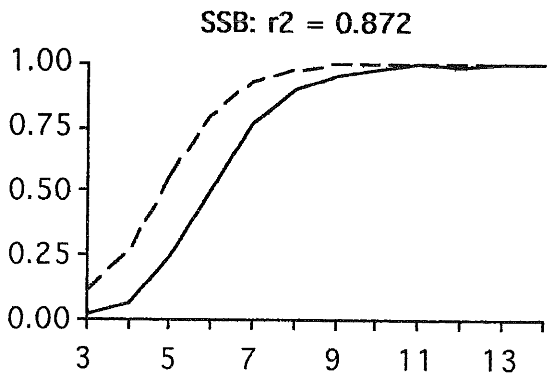
b) knife-edge maturity at age 7



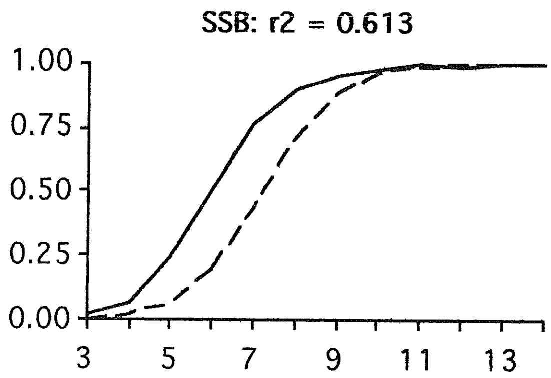
c) 20% decrease in maturity rate. Xi=1.9



d) 20% increase in maturity rate. Xi=2.8

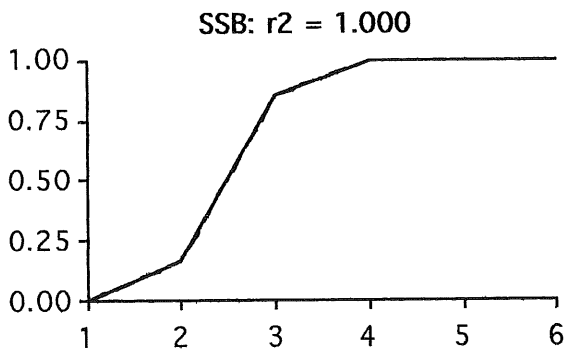


e) 20% decrease in age at maturity. A50%=4.8

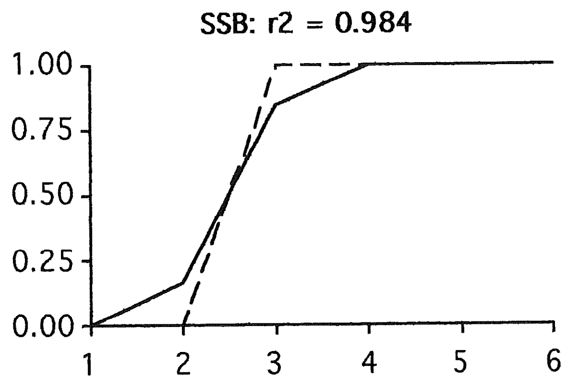


f) 20% increase in age at maturity. A50%=7.2

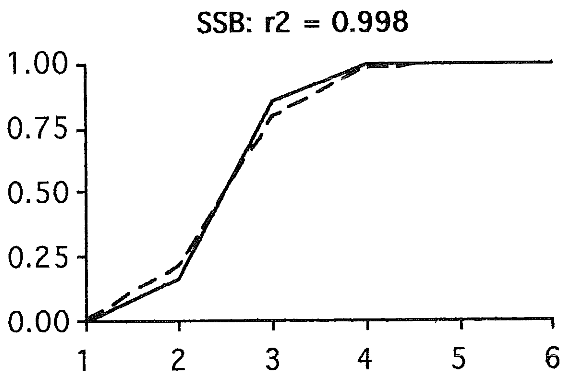
Figure 4.4.4 Irish Sea cod: Effects on correlation between baseline SSB and SSB estimates derived from changes in the parameters of a fitted maturity ogive. Solid lines indicate baseline maturity at age. Dashed lines indicate changes in the fitted logistic function. x-accis denotes proportions, y-accis age. A50% = age at 50% maturity, Xi = steepness multiplyer.



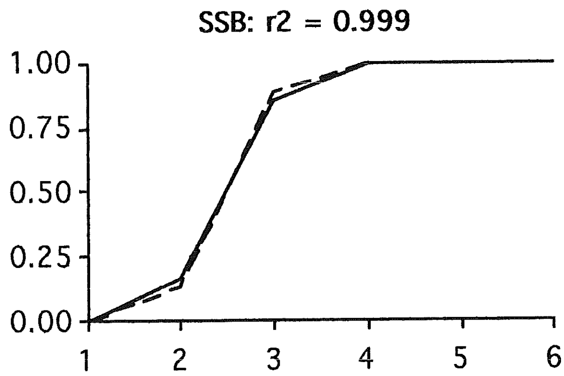
a) fitted logistic curve. A50%=2.5, Xi=6.7



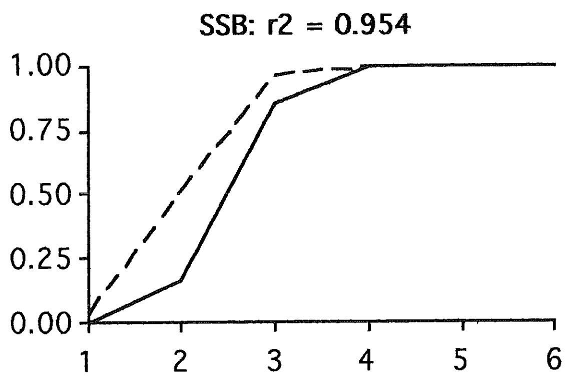
b) knife-edge maturity at age 3



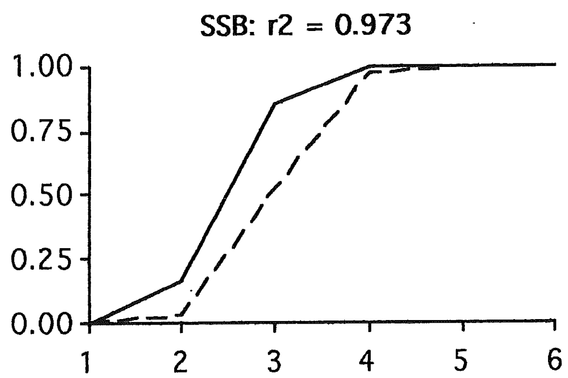
c) 20% decrease in maturity rate. Xi=5.3



d) 20% increase in maturity rate. Xi=8.0



e) 20% decrease in age at maturity. A50%=2.0



f) 20% increase in age at maturity. A50%=3.0

Figure 5.7.1a

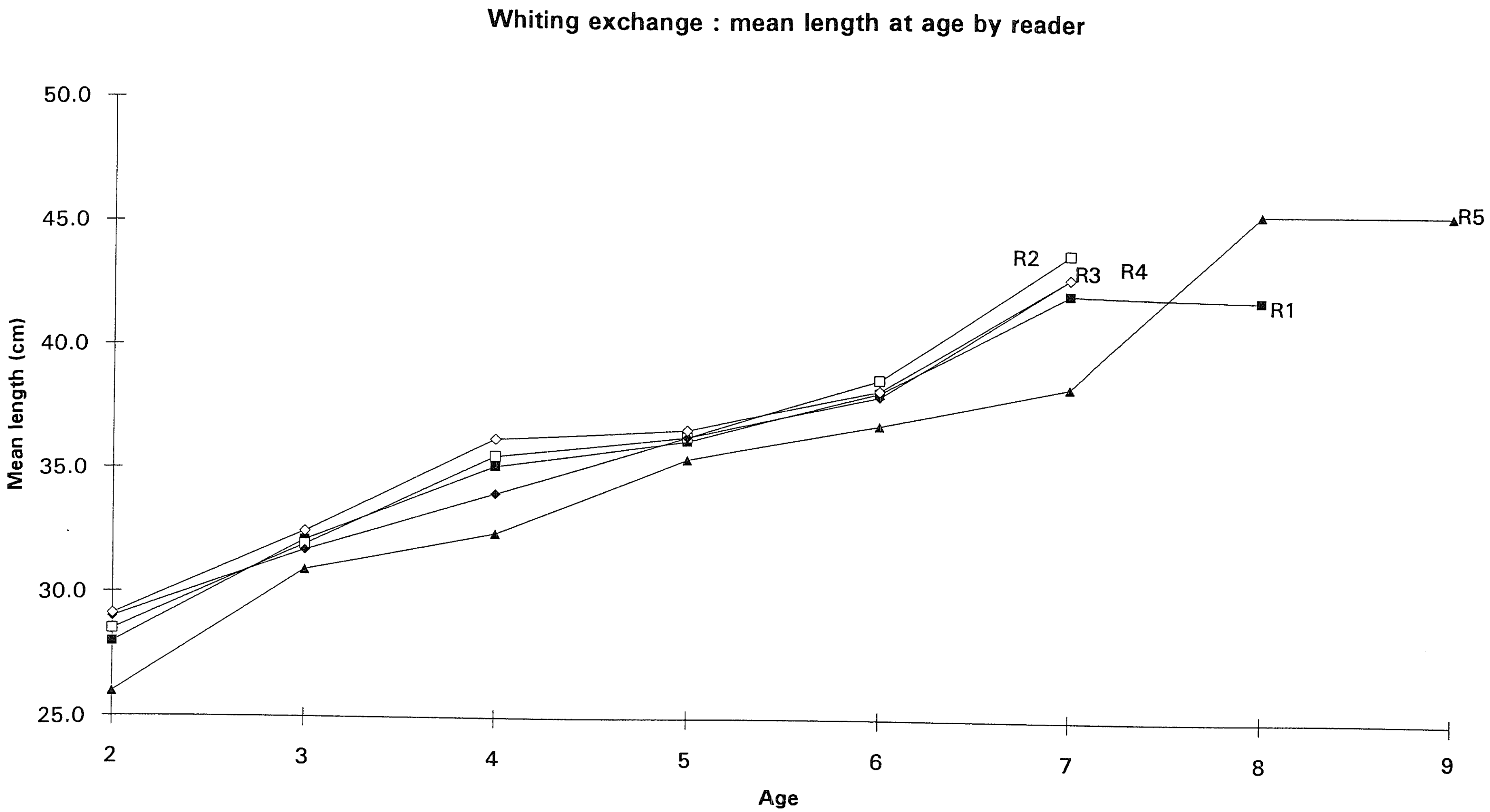
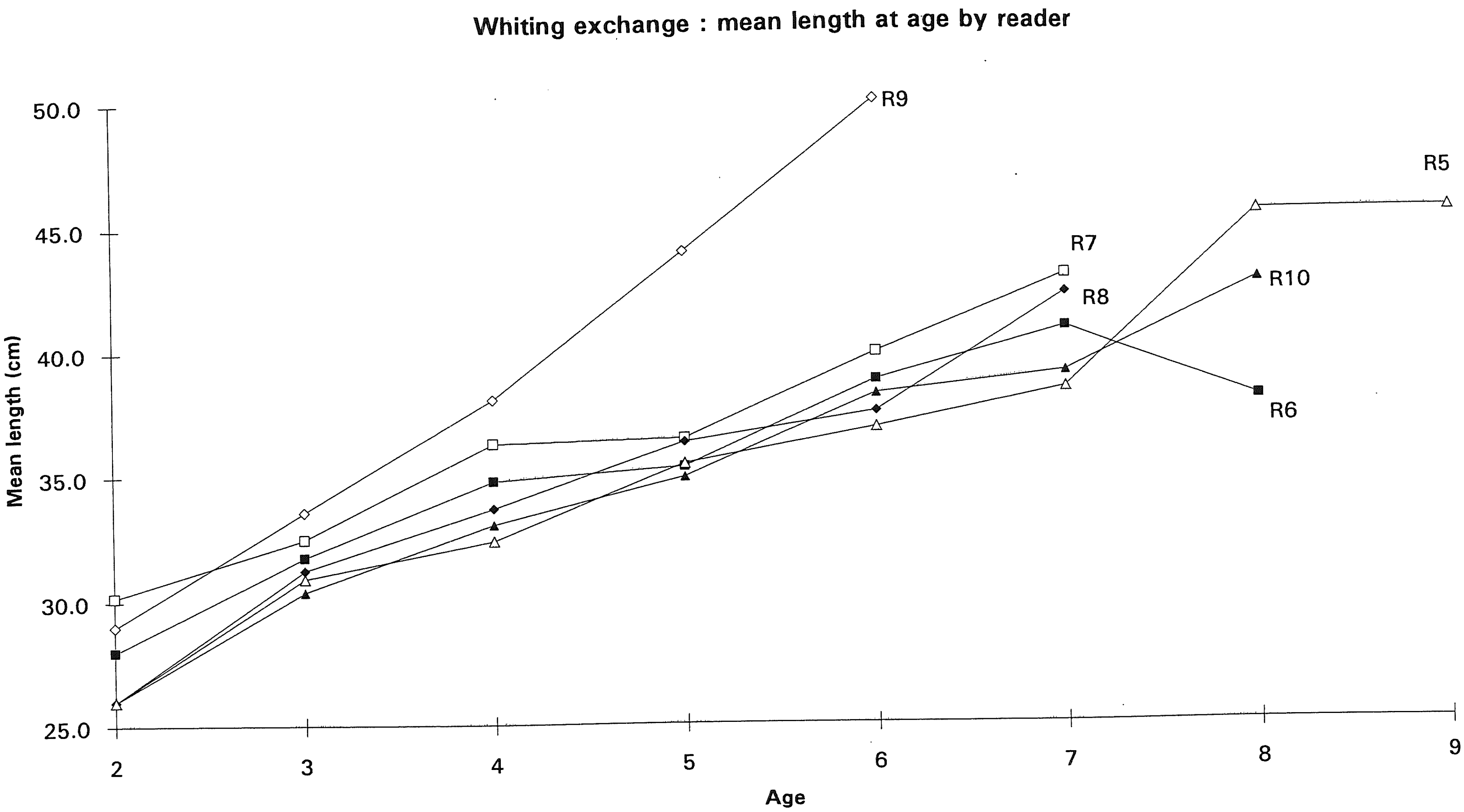

Whiting exchange : mean length at age by reader
Mean length (cm)
50.0
45.0
40.0
35.0
30.0
25.0
Age
2
3
4
5
6
7
8
9
R1
R2
R3
R4
R5

Figure 5.7.1b



Whiting exchange : mean length at age by reader
Mean length (cm)
50.0
45.0
40.0
35.0
30.0
25.0
Age
2
3
4
5
6
7
8
9
R9
R5
R7
R10
R8
R6

Figure 5.7.2

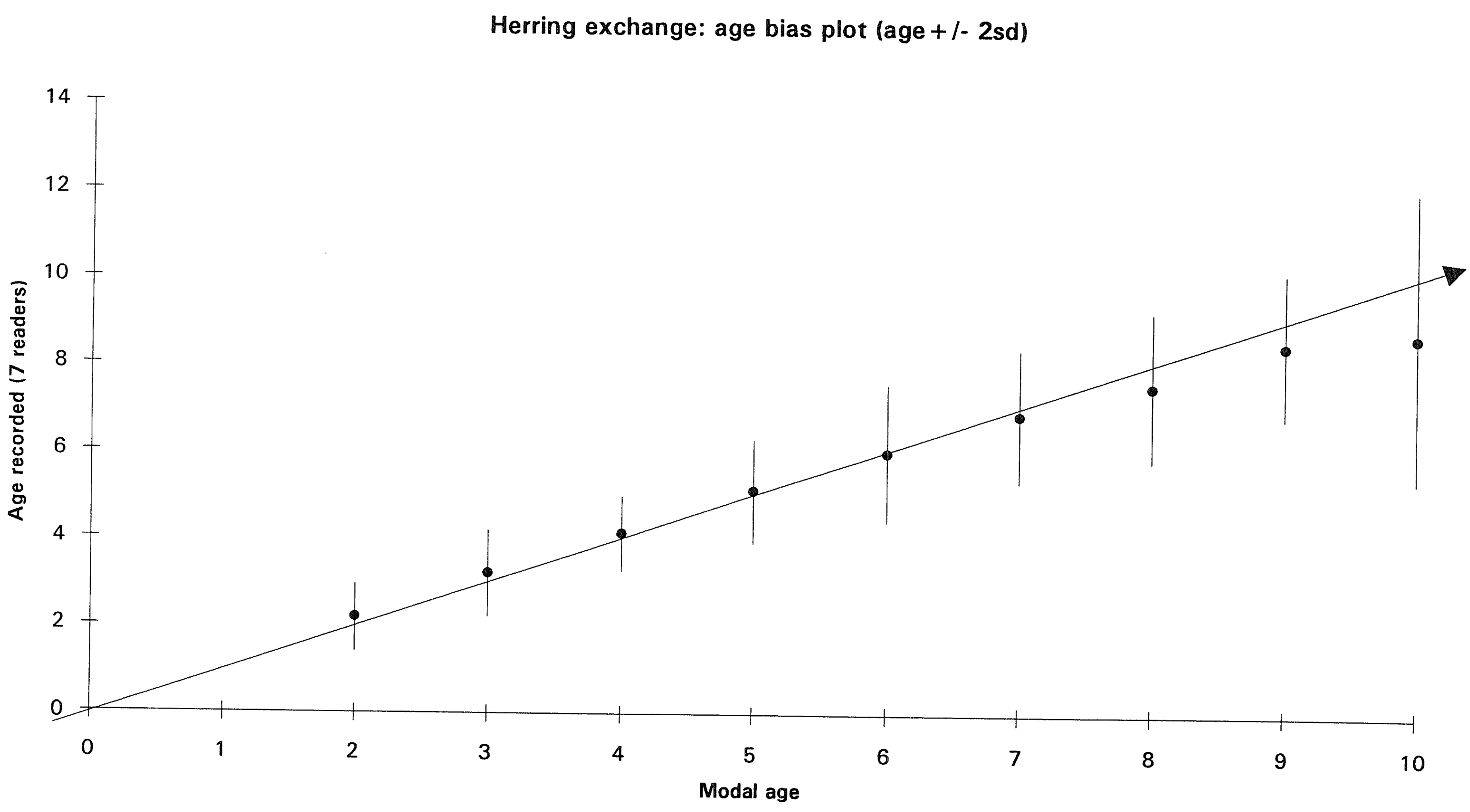

Herring exchange: age bias plot (age+/- 2sd)
Age recorded (7 readers)
0
2
4
6
8
10
12
14
0
1
2
3
4
5
6
7
8
9
10
Modal age

Figure 5.7.3a

Herring exchange: age bias plot (age+/- 2sd)
Age recorded (reader 1)
0
2
4
6
8
10
12
Modal age
0
1
2
3
4
5
6
7
8
9
10

Figure 5.7.3b

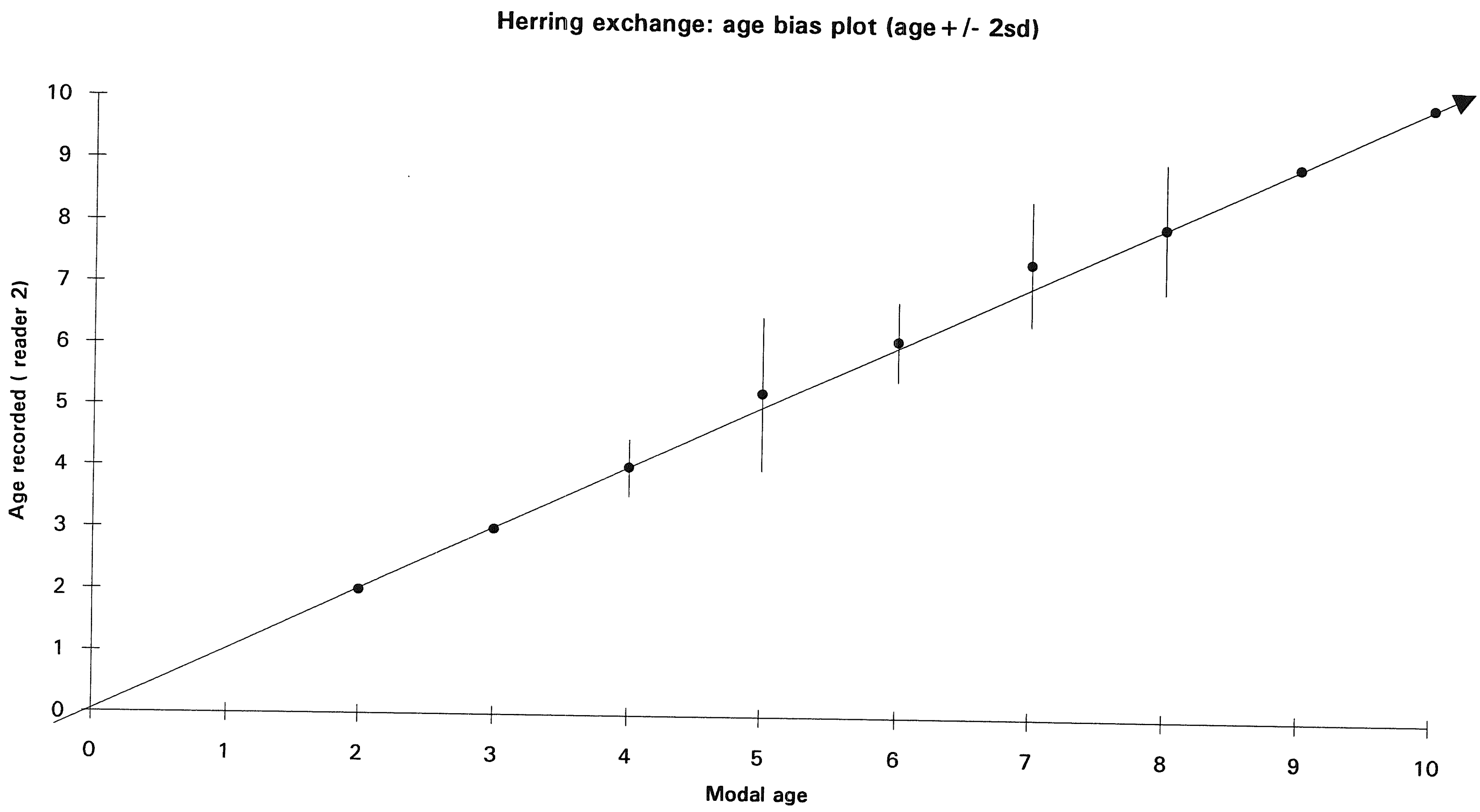

Herring exchange: age bias plot (age +/- 2sd)
Age recorded (reader 2)
0
1
2
3
4
5
6
7
8
9
10
Modal age

Figure 5.7.3c


Herring exchange: age bias plot (age+/- 2sd)
Age recorded (reader 3)
Modal age
0
1
2
3
4
5
6
7
8
9
10

Figure 5.7.3d

Herring exchange: age bias plot (age+/- 2sd)

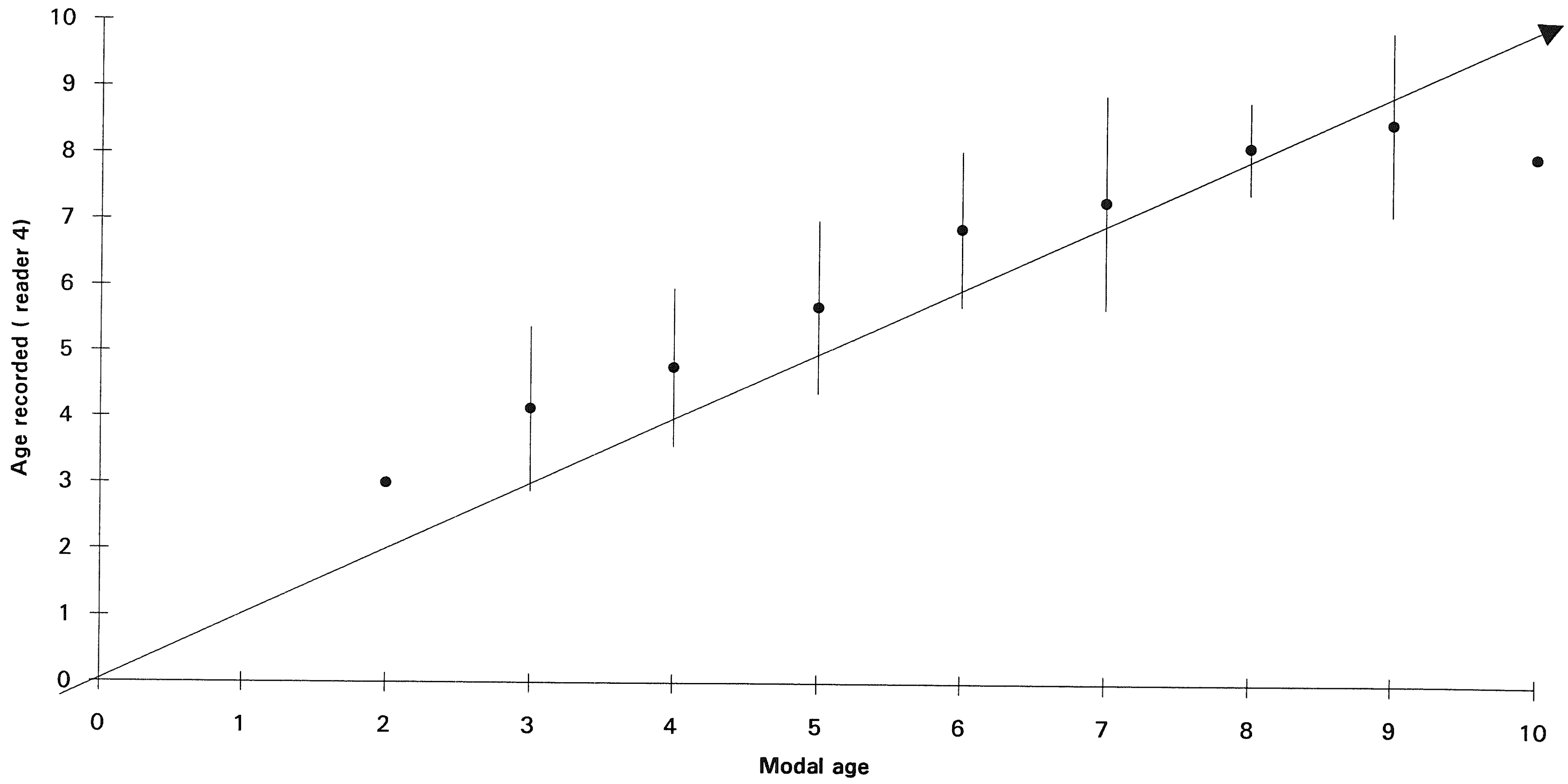


Figure 5.7.3e

Herring exchange: age bias plot (age +/- 2sd)

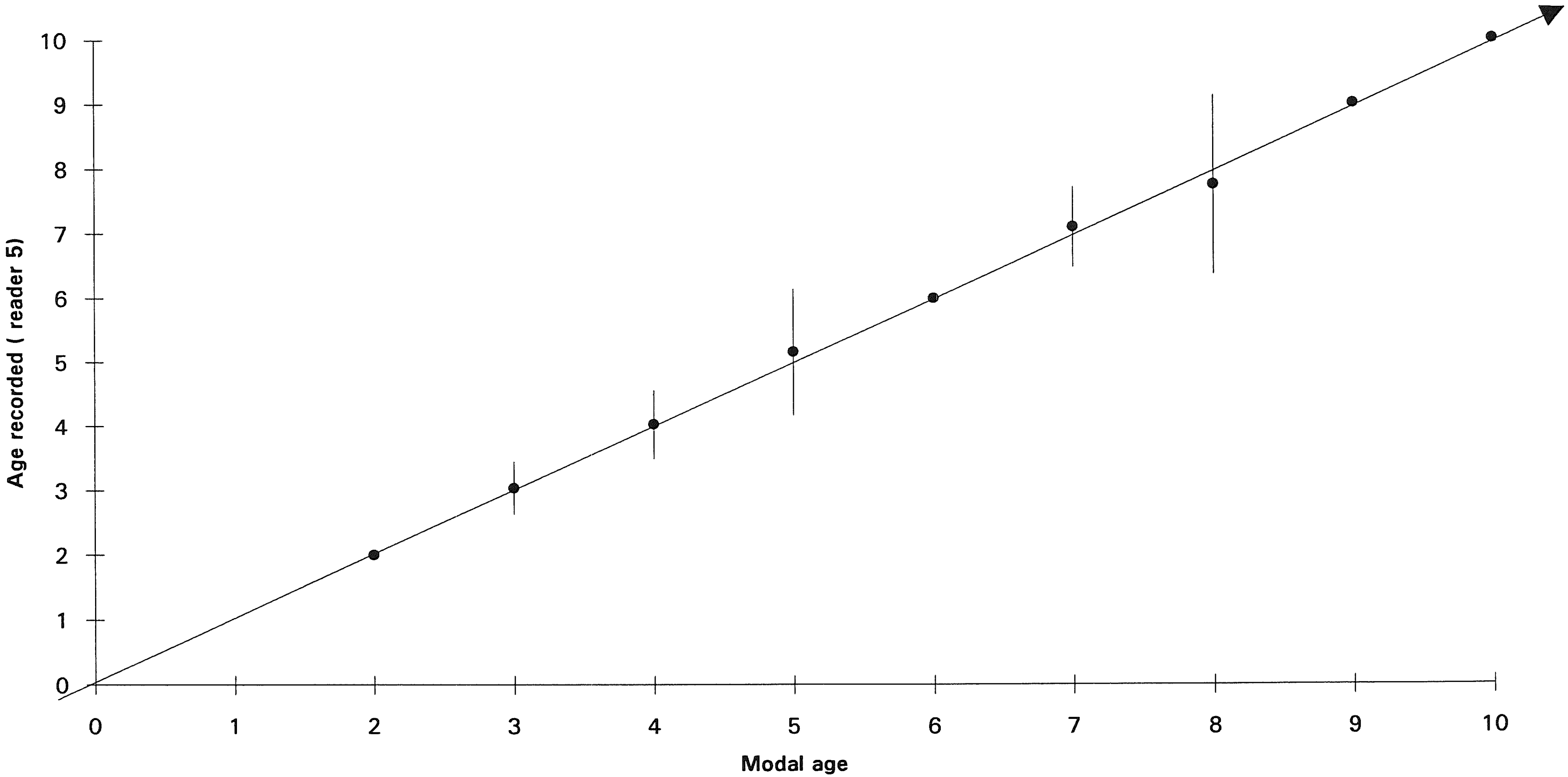
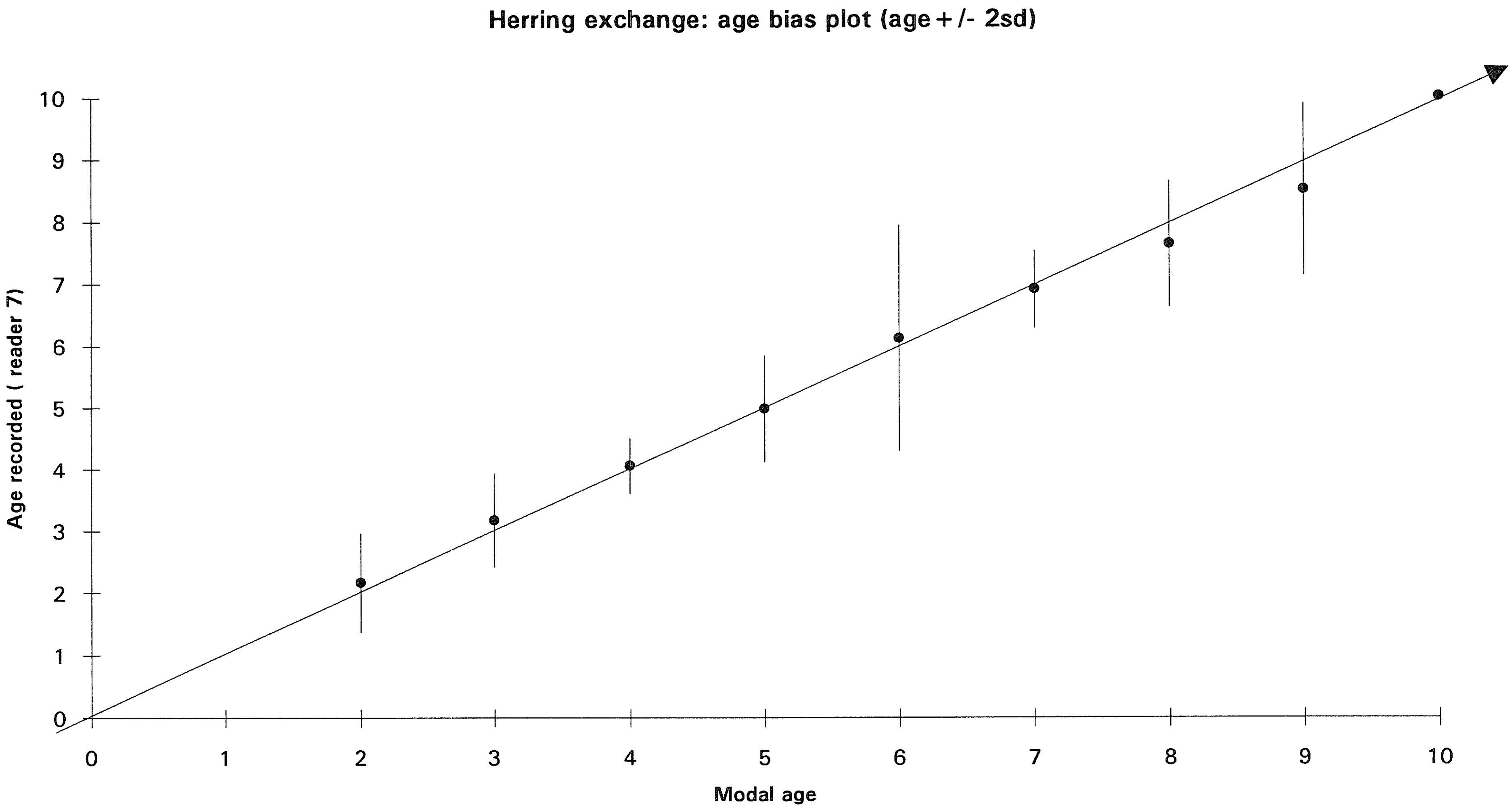


Figure 5.7.3f


Herring exchange: age bias plot (age+/- 2sd)
Age recorded (reader 6)
0
1
2
3
4
5
6
7
8
9
10
Modal age
0
1
2
3
4
5
6
7
8
9
10

Figure 5.7.3g



Herring exchange: age bias plot (age+/- 2sd)
Age recorded (reader 7)
10
9
8
7
6
5
4
3
2
1
0
0
1
2
3
4
5
6
7
8
9
10
Modal age

Workshop on Sampling Strategies for Age and Maturity

Copenhagen, 3-9 February 1994

APPENDIX A

WORKING PAPERS PRESENTED

S1: A bonfire of variances: a personal and perhaps pragmatic view of sampling catch-at-age data by J.G. Pope.

S2; The accuracy of age composition of optimum sample size by R. Oeberts.

S3: Sampling and stratification of age and maturity data in Greenland by G. Bech.

K1: Smoothing of ALKs with Bezier curves by J.M. Gråstein.

K2: Using generalized linear models for the computation of catch in numbers at age by G. Johannesson and G. Stefánsson.

K3: A note on biases originating from length stratified sampling by M. Nicholson.

M1: Population maturity ogives by M. Pawson.

M2: The potential effects of rapid shifts in several maturity rates on assessments of the Icelandic cod stock by K. Thorarinsson and G. Stefánsson.

M3: Maturity of age from length stratified sampling by M.J. Morgan and J.M. Hoenig.

M4: Alternative methods of estimating maturity ogives: options, limitations of sampling, and statistical-biological implications by E.A. Trippel, J. Hunt, S.J. Smith, and C. Annand.

A1: Comparison of otolith readings by G. Eltink.

A2: Statistical tools for the control of age reading variability by P. Gagnon.

A3: Graphical and statistical methods for age comparison by S.E. Campana, C.M. Annand, and J.I. McMilland.

A4: Testing for differences between two age determination methods: tests of symmetry by J.M. Hoenig, M.J. Morgan, and C.A. Brown.

cont'd.

APPENDIX A (cont'd.)

RELATED DOCUMENTS, AVAILABLE TO THE MEETING

Corten, A. 1993. Results of a comparative age reading experiment on herring from the North Sea and adjacent waters. ICES, Doc. C.M.1993/H:16.

Hayes, D.B. 1993. A statistical method for evaluating differences between age-length keys with application to Georges Bank haddock, *Melanogrammus aeglefinus*. Fish. Bull. U.S. 91: 550-557.

Jakobsen, I. and K. Nedreaas. 1986. A model simulating the effect of sampling strategy on stock assessment of gadoids in Sub-areas I and II. ICES, Doc. C.M.1986/G:69.

Kimura, D.K. and J.J. Lyons. 1991. Between-reader bias and variability in the age-determination process. Fish. Bull. U.S. 89: 53-60.

Large, P.A. 1994. Examination of stock parameters - maturity at age. Mimeo SSWS 94.

Nicolajsen, Á. and J.M. Grástein. 1993. What is the most cost-effective procedure for sampling landings from a commercial fishery? ICES, C.M.1993/D:41.

Workshop on Ssampling Strategies for Age and Maturity

Copenhagen, 3-9 February 1994

APPENDIX B

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APPENDIX C

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

SUMMARY OF TOPICS

Topic		1981	1983	1984	1985	1987	1988	1989	1991	1992	1993	1994
1.	Application of separable VPA	-	M	r	-	-	-	-	m	-	-	-
2.	Simpler methods of assessment	-	-	M	M	i	-	-	i	-	m	-
3.	Measures of overall fishing mortality	-	-	-	-	-	-	-	i	-	-	-
4.	Use of CPUE effort and survey data in assessments	M	M	r	r	M	M	m	i	-	i	-
5.	Need for two-sex assessment	-	-	-	-	-	-	-	-	-	-	m
6.	Computation and use of yield per recruit	-	M	m	i	-	-	-	-	-	-	-
7.	Inclusion of discards in assessments	-	-	-	-	-	-	-	-	-	-	-
8.	Methods for estimation of of recruitment	-	-	M	r	M	-	-	-	-	M	-
9.	Denisty dependence growth, mortality, etc.	-	-	-	-	-	-	-	-	-	-	-
10.	Linear models in relation to assessments	-	-	M	-	m	-	-	-	-	-	m
11.	Effect of age-dependent natural mortality	-	-	-	M	-	-	-	-	-	-	-
12	Stock-production models	-	-	-	-	M	-	-	-	-	-	-
13	Utilizaiton of research survey data	-	-	-	-	M	M	m	i	M	m	-
14	Use of less reliable fishery statistics	-	-	-	-	m	-	i	i	-	i	-
15	Construction of survey and CPUE indices from disaggregated data	-	-	-	-	-	-	M	i	-	-	-
16	Implications of timing of WG meetings	-	-	-	-	-	-	m	-	-	-	-
17	Testing of age-balanced methods of analysis	-	-	-	-	-	M	m	M	-	-	-
18	Effects of management measures on CPUE	-	-	-	-	-	-	-	m	-	-	-
19	Evaluation and development of diagnostics	-	-	-	-	-	-	-	M	-	-	-
20	Application of length-based methods	-	-	-	-	-	-	-	m	-	-	-
21	Extension of time series of stock and recruitment	-	-	-	-	-	-	-	m	-	-	-
22	Problems with weight and maturity at-age	-	-	-	-	-	-	-	-	-	-	M
23	Evaluation of uncertainty and risk	-	-	-	-	-	-	-	-	-	M	-
24	Shrinkage	-	-	-	-	-	-	-	-	-	M	-
25	Stock-recruitment relationships	-	-	-	-	-	-	-	-	-	M	-
26	Retrospective analysis	-	-	-	-	-	-	-	-	-	m	-
27	Minimum Biologically Acceptable Levels (MBALs)	-	-	-	-	-	-	-	-	-	M	-
28	Ageing problems	-	-	-	-	-	-	-	-	-	-	M

[1] See List of Meetings on page .

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

cont'd.

APPENDIX C (cont'd.)

M93-104

DATES, LOCATIONS AND REPORTS OF PREVIOUS MEETINGS OF THE ICES WORKING GROUP ON THE METHODS OF FISH STOCKS ASSESSMENT (AND ASSOCIATED MEETINGS)

DATE	PLACE	REPORT TITLE	CITATION: CM PAPER	CITATION: CO-OPERATIVE RESEARCH REPORT
1981	Copenhagen	ICES WG on Use of Effort Data in Assessments	1981/G:5	129(1984)
1983	Copenhagen	ICES WG on Methods of Fish Stock Assessments	1983/Assess 17	129(1984)
1984	Copenhagen	ICES WG on Methods of Fish Stock Assessment	1984/Assess 19	133(1985)
1985	Copenhagen	ICES WG on Methods of Fish Stock Assessment	1986/Assess 10	157(1988)
1987	Copenhagen	ICES WG on Methods of Fish Stock Assessment	1987/Assess 24	111(1993)
1988	Reykjavik	ICES Workshop on Methods of Fish Stock Assessment	1988/Assess 26	111(1993)
1989	Nantes	ICES WG on Methods of Fish Stock Assessment	1990/Assess 15	111(1993)
1991	St John's	ICES WG on Methods of Fisk Stock Assessment	1991/Assess 24	
1992	Woods Hole	ICES Workshop on the Analysis of Trawl Survey Data	1992/D:6	
1993	Copenhagen	ICES WG on Methods of Fish Stock Assessment	1993/Assess:12	
1994	Copenhagen	ICES Workshop on Sampling Strategies for Age and Maturity date	1994/D:1	