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The precision of international market sampling for North Sea herring and its influence on assessment.

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Abstract

Market sampling is a key source of data for catch-at-age-based assessment. Little has been documented about the influence of potential error in these data on the precision of assessments and the management information they produce. This paper presents the results of a study of the precision of North Sea herring fish market sampling carried out by the UK, Denmark and the Netherlands. Data from eight years of market sampling were analysed to obtain the precision of estimated numbers-at-age in the catch. The market sample data was then used to estimate 1000 realisations of the international catch-at-age and mean weights-at-age in the catch. Three methods of estimating the variability of missing catch data were used and three options for the catch-at-age matrices were computed. These base datasets were utilised to obtain 1000 assessments conditional on the ICA (Integrated Catch-at-age Analysis) model. From the outcome of these assessments the influence of the market sampling programmes on the management of the stock are presented as 95% confidence intervals on the main management parameters (recruitment, SSB, F0-1 and F2-6). In addition, the influence of missing data is estimated. The implications of our conclusions on the requirements from a market sampling programme are discussed.

Introduction

The catch at age matrix forms a major part of the assessment of many fish stocks. For stocks with international shares of catch the sampling schemes are often diverse and the task of assembling the catch at age matrix is a complex and time consuming process. The influence of this data on the assessment is rather poorly studied. To the knowledge of the authors, there are no comprehensive studies of the precision of international market sampling programmes and their implications for fisheries management advice. The papers published on this issue either deal either with the potential effects of theoretical uncertainty in basic data on the advice provided (Pope and Gray 1983; Pope 1988; Pelletier and Gros 1994; Coggins and Quinn 1998), or on the estimation techniques and results of the analysis of uncertainty in the basic data itself (Tanaka 1953; Johnston et al. 1975; Pope and Knights 1975; Kimura 1977; Sparre et al. 1977; Gavaris and Gavaris 1983; Smith and Maguire 1983; ICES 1994; Reinert and Lewy 1998). In this paper, we present an attempt to combine these two approaches. This paper describes the analysis of catch at age data on North Sea herring from 1991 to 1998 inclusive and their use in the assessment. We wanted to combine results from different sampling programs to arrive at total international estimates of catch numbers at age and their associated variances, we could have follow two routes:

1. attempt to combine the raw sampling data, calculate appropriate age-length keys (ALK) and raise the sampling data to the total international landings. In this way the variances of the procedure could be directly calculated (Gavaris and Gavaris 1983; Smith and Maguire 1983) or obtained from bootstrap analysis. A pre-requisite for this approach is that the sampling procedures (strata) are harmonized so

that samples can be freely exchanged. This harmonisation is difficult to obtain from data already collected independently by different countries with different sampling and data storage methods.

2. use bootstrap or jackknife techniques to generate an a certain number of realisations of national age compositions and weights at age. Then combine these national realisations as an assessment working group would have done with the data for a single year, delivering a number of realisations of the international age composition. These are then fed into an stock assessment program to arrive at bootstrapped stock estimates. This approach has been followed in this study.

We present first the results from studies of national market sampling programmes for estimating catch at age of North Sea herring for the period 1991 to 1998. Market sample data from the major fishing countries for these species have been collated at minimum aggregation level and used to generate 1000 national and then international replicates for use in bootstrapped assessments, whereby the assessment procedure was kept the same as used in the most recent ICES working group (ICES 2000).

Materials and methods

Three sets of national data were used to provide 1000 replicate market sampling for three nations, Netherlands, Denmark and Scotland. The sampling methods are different for each nation, and consequentially the methods for deriving the 1000 replicates were also different. These are described by nation below. Data from the Norwegian market sampling program on North Sea herring was kindly made available by IMR Bergen. However, it was found that the implementation of the bootstrap method for these data was difficult due to sparse coverage and a need for complex fillin rules, similar to the Scottish data (see below). However, this requires intimate knowledge of the fishery which was not available to the authors. Therefore, the Norwegian herring market sample data have not been used in the analysis presented here. The implications of this and the implications of other missing data are included in these studies by examining different methods for allocation of un-sampled catch. The results from this part of the investigation indicate that this is not a major problem (see below).

The methodology for each national analysis is different, and are described below.

National analysis of The Netherlands data

The method followed a generic method developed at CEFAS UK. The process of manually allocating unsampled catches to sampled strata has not been taken into account, so the re-sampling process only operated on the already existing temporal and spatial stratification. Bootstrapping the catch at age data was carried out at the vessel level using SAS code to replicate the raising calculations carried out by the Market sampling system as closely as possible. The market samples were stratified by quarter, fleet and area. The original data were extracted from the database which holds length and biological sample data, along with combined and raised processed data. Firstly, using the sample number and vessel codes in the database, two lists were formed: the boat-trips from which age samples and length samples had been taken. Each list was sampled with replacement to form a new list – the *bootstrap*. The *bootstrap* length and age samples were then comprised of the data from the boat-trips included in the new lists. Catch-at-age and weight-at-age estimates were calculated from the bootstrap length and age samples. This bootstrap procedure was repeated 1000 times for each period of interest.

The algorithm for the bootstrap procedure used is as follows:

Set-up:

- read in original length, age and weight data.
- create a list of unique identifiers for sampling units – here used vessel code and sample number.

- calculate values that will not change with each bootstrap sample – commercial weight totals and numbers of samples.

Bootstrap loop which is repeated for a 1000 iterations.
- set seed for random number generator.
- form bootstrap length sample by resampling length data.
- calculate length distributions (LD) and analytical variance due to length sampling for bootstrap length sample using appropriate stratification and length groups (5cm cod, 2cm plaice).
- set seed for random number generator.
- form bootstrap age sample by resampling age data.
- calculate age-length key (ALK) and analytical variance due to ageing for bootstrap age sample using appropriate stratification and length groups.
- calculate age-length distribution (ALD) and analytical variance from LD and ALK.
- calculate mean length within each length group and parameter for length-weight relationship.
- calculate mean weight-at-age from ALD and length-weight relationship.
- append the estimates from this iteration to the output file.

National analysis of Danish data

The Danish sampling procedure was changed in 1998. Until that time, practically all fish were aged and the raising of biological samples to total catch was made without considering length information, even though it exists. From 1998 only a part of the length-measured fish was aged such that the raising of samples includes length distributions and age-length keys for calculation of catch at age. This approach has been used for all years in the bootstrapping exercise for a more consistent approach. Even though it has been tried to mimic what has been done historically to produce catch at age data for ICES working groups, the catch at age numbers produce are probably slightly different.

The ICES herring assessment working group divides the total assessment area into smaller areas (IVaE, IVaW, IVb, IVc and IIIa) for storage of catch and sampling data. These areas were used in the stratification of the Danish catches as well. However, due to the large variation in the industrial herring catches, area IVb was divided further into sub-areas for this type of landings.

North Sea Herring landed for human consumption and for industrial purposes are sampled differently and are treated at two independent "species".

Human consumption herring are sampled from landings where the fishing grounds are known. Landings are not split up on size classes, such that the stratification includes the variables sub-area, year and quarter. Similar stratification is available for the official landings statistics. A number of strata with relatively small catches has not been sampled, and the same procedure, as used for cod and plaice, of copying samples from area was used. In cases of missing samples, samples representing area IIIaN were copied from a IIIaN sample in an earlier or later quarter, if possible, and only taken from a neighboring area if there were no IIIaN samples in the actual half-year. For other areas, samples were taken from a neighboring area within the same quarter. If there were no bordering areas, data were copied from another quarter within the half-year.

The amount of industrial catches of herring are determined from the total industrial landings and samples of the landings for species composition. The Ministry of Fishery makes this sampling and the split of total industrial landing on species. This process is not included in the bootstrap exercise, and the catch weight of industrial herring by quarter and area are considered exact, as for landings for human consumption. Both the Ministry of Fishery and DIFRES takes samples of industrial landings for the construction of catch at age data. Such samples do include all species as well, but these samples are all analyzed by DIFRES. All samples taken have approximately the same total weight and are assumed randomly sampled within the industrial fishery. A simple aggregation of the herrings sampled in a stratum does thereby represents the total industrial fishery targeting different species, both with respect to the proportion of herring in catch, and the size distribution of herring. The same procedure, as for human consumption herring, was applied when sampling had not covered all strata.

The preprocessing of data used for calculation of catch at age includes (using combinations of year, quarter, district and size class as strata):

1. Convert landings and samples weights to live fish weight
2. Ensure that at least one sample per stratum has been taken in all principal sampling districts. In cases of missing data, copy sampling data from the geographically nearest sampling district (and rename district name and create a new unique sample id.).
3. Move landings from the non-sampled district to the nearest sampled district stratum and sum landings. Do not include landings from ports in other countries.
4. Raise all the landings allocated to a district, such that they sum up to the total national landings weight. Do this raising by sea-area and quarter.

The data set for bootstrapping has now at least one sample for all strata (catch area, "district", year, quarter and size class), and the sum of all strata landings is equivalent to the total national landings. Each sample has measurement of individual fish, such that a length distribution, an age-length key, and a mean weight at age can be calculated.

Catch at age data normally produced to the ICES assessment split herring catches into two stocks (North Sea autumn spawners, and Baltic Sea spring spawners). This separation is based on additional data on number of vertebra and otolith structure, and has not been included in this study.

<u>Bootstrapping of the raising of samples to total landings</u>
The raising of samples to total catch weight includes the following steps (all steps are default done by stratum; human consumption and industrial herring: catch area, year and quarter):

1. Take a simple random sample of the available biological samples with replacement. The number of samples taken is equal to the number of available biological samples in the stratum. Calculate total weight of samples within a stratum from the individual sample weights actually selected.
2. Option a. For each of the resampled biological samples, take a random sample of the individual fish with replacement, of a size equal to the number of fishes within the sample. Re-calculate total weight of samples within a stratum from the individual fish weights (required) in the samples.
3. Calculate raising factor from strata sample total weight and total catch weight.
4. Create a length distribution as a simple sum of sampled fish. Raise length distributions by raising factors
5. Option b. Calculate proportion at age and mean weight at age for each length group from fishes included in the selected samples
5. Option c. Calculate proportion at age and mean weight at age for each length group from all available sample with a stratum.
6. Combine length distribution and proportion at age per length group to calculate catch at age, and mean weight and length at age.
7. Sum catches at age from all size classes and districts (cod and plaice only). Calculate mean weight and mean length, using catch at age numbers as weighting factor.
8. Output catch numbers, mean weight and mean length by catch area, quarter and age

The relatively few samples, in some case just one sample, per stratum makes bootstrapping of just samples pointless. Therefore resampling was extended with the resampling of individual fish, within a resampled biological sample (option a). This requires weight of individual fishes to calculate sample weight which were available for cod and plaice 1991-1998, and for human consumption herring 1991-1997. For these groups, the age information of just the resampled fish was used (option b).

The sampling level for industrial herrings 1991-1998 was reasonable high and there was no resampling done of individual fishes. This was furthermore impossible, as the fish were worked up by length group, and not individually. Age distribution was estimated from the resampled biological samples (option b).

The change in sampling methods from 1998 made it necessary to use the full set of available length-age information (option c) to convert length distribution into ages. It would of course have been possible to make a qualified guess on age for a fish length without a resampled age information. However, to simplify the programming the full set of age information was used for 1998.

National analysis of Scottish data

The data collected is aggregated to monthly based region and gear length distributions with age length keys. These data are collected from multiple samples, however as the data is combined before entry into the database, it is no longer possible to separate the individual samples at age and the data is treated as a series of length samples with associated age sampling. The total landings for the fleet are collected as a census by region, gear and month. The data can be thought of as estimates of 'data cells' where each cell is has a landing, and a length distribution and may have an age length key. The catch-numbers (N_{armg}) and catch-biomass (W_{armg}) at age are calculated as:

$$N_{armg} = \sum_{l} n_{lrmg} p_{larmg} * L_{rmg} / \sum_{l} n_{lrmg} w_{lrm}$$

$$W_{armg} = \sum_{l} n_{lrmg} p_{larmg} w_{lrm} * L_{rmg} / \sum_{l} n_{lrmg} w_{lrm}$$

where n_{lrmg} is the number sampled at length (l) by region (r), month (m) and gear (g), p_{larmg} is the proportion at age (a) for each length by region, month and gear. (for herring this is independent of gear), L_{rmg} is the landings by weight by region, month and gear, w_{lrmg} is the weight of an individual fish at length by region, month, derived from long weight length relationships (region and month dependant for herring, monthly for cod)

The p_{larmg} are calculated from the number of fish aged at each length. Both p and on occasion n may be missing for a particular month, region and gear. In this case the p are 'filled in' from another region, gear or adjacent month. These fill-in sequences are provided as a standard from the sampling program.

Three main methods were applied to try to estimate the precision of the Scottish market sampling scheme;
1. a simple jackknife (Efron and Tibshirani 1993) procedure with the use of fill-in rules for missing data,
2. a grouped bootstrap (Efron and Tibshirani 1993) where monthly and gear categories were combined to give a number of samples by region and quarter, these were then bootstrapped by group,
3. a weighted jackknife similar to the simple jackknife but weighing the probability of a data-cell being removed according to estimates of the probability of sampling the cell based on 8 years data.

In practice only the first method was used, the second method gave high CVs for all ages as would be expected. The third method provided smaller CVs but relied upon the calculation of the effective sample size, it is unclear how to calculate this factor for such a weighted resampling method, it was thought preferable to be conservative and assume that the simple jackknife would gave adequate results.

For all procedures the following initial set up was carried out
1. Obtain total catch for commercial catch per data cell L
2. Obtain a length frequency distribution per data cell LF
3. Obtain an age length key for those cells for which it was available ALK
4. Obtain a list of links between length keys to age length keys, for all data cells, using fill-in rules as required
5. Select data cells for removal randomly without replacement; for simple jackknife select with equal probability;
6. Create new data set with selected samples removed
7. Find new fill-ins for data cells without length or age length keys
8. Calculate the mean weight W of fish for each data cell using standard monthly, region dependent length weight relationship and length frequency LF.
9. Calculate the total number of fish N for each data cell from the total catch L and the mean weight W

10. Calculate the number at age N_a for each data cell using the total N, the length frequency LF and the age length key ALK
11. Calculate the mean weight at age for each data cell using the length frequency LF, weight at length W_l and the age length key ALK
12. Calculate the total numbers at age by summing the numbers at age per data cell
13. Calculate the total biomass at age by summing the numbers * mean weight at age per data cell

Following 1000 replications
1. Check that 1000 values have similar mean to original data
2. Calculate CV from mean and variance of 1000 replicates.
3. Correct the Jackknife estimates of CV for number of data cells and removed samples (Efron and Tibshirani, 1993)
4. For Jackknife inflate catch number at age of each replicate by scaling the replicates about the mean and setting the small number of negative observations (<1%) to zero.

The sampling, the procedure attempts to estimate data cells organised by month, area and gear. As the sampling is only partial, inevitably it is not possible to fill all of the cells where landings are reported in the year. In some cases no data is available at all, in others length keys only are available and age length key data must be supplied. The current method used is to assign length or more usually age/length key data from another cell. This process is in effect a step-wise spatial temporal based model, estimated by nearest neighbour method. The nearest neighbour is selected with a sequence of assignments from previous or following month based on the most similar areas. The presence of data in the same area gear cell is checked in previous and subsequent months, then in sequence (1^{st}, 2^{nd},3^{rd} etc.), until an alternative is found. (See Table 1 and Figure 1).

Analysis of internationally combined market data

The 1000 bootstrap replicates of mean weight and catch at age from Denmark, The Netherlands and Scotland were combined into 1000 replicates of international catch data. This fully sampled component constitutes on average 66% of the North Sea herring landings over this period. In addition to this fraction of the catch the area misreported data from VIa_{north}, is allocated to Scottish fleet and unsampled catches from English German and French fleets are usually raised by Netherlands samples in the Working Group, this increases the proportion of the catch covered by the sampling to 75% of the total. The major missing components are the remaining unallocated landings and the Norwegian catch discussed above. The bootstrapped components both underestimate and overestimate numbers at age because landings are both added and subtracted due to area misreporting, discards and catches of Baltic Spring Spawning herring in the North Sea.
To carry out the assessment the catch estimated from the bootstrap replicates had to be scaled to the WG catch. Three methods were used for this purpose:

Scn Scaling to WG numbers at age by year and age dependant multiplicative factors.

Scb Scaled to landings biomass, retaining bootstrap age structure but scaling with year dependant biomass scaling factors.

Miss Difference between WG catch and mean bootstrapped replicated catch (positive or negative as necessary) was estimated. This missing catch at age by year was used to scale a simulated sampling scheme with the same CV and correlation at age as the Danish sampling scheme (but with uncorrelated with the Danish estimates).

Assessment of herring

The assessments carried out to study the effects of estimates of landings have been done using models, indices and procedures of the ICES Herring Assessment Working group (ICES 2000). The Integrated Catch at Age (ICA) model was used to assess the state of the stock (Patterson 1998).

Deterministic catch-numbers at age were available for the year range 1960 to 1990 (ICES 2000a, section 2.2) and bootstrapped numbers at age for the period 1991-1998. Also the bootstrapped mean weight at age was available for 1991-1998. All other data was the same as used in the assessment working group.
Survey indices:

- MIK 0-wr index. Available and used since 1977 as a recruitment index (ICES 2000a, section 2.3)
- Acoustic 2-9+ wr index. Available since 1989 (ICES 2000a, section 2.4)
- IBTS 1-5+ wr index. Separated into a 1 wr index (used since 1979) and a 2-5+ wr index (used since 1983). (ICES 2000a, section 2.3 and 2.6)
- Multiplicative larvae abundance index (MLAI). Available since 1973, used since 1979 as an SSB index (ICES 2000a, section 2.5).

Data from 2000 assessment were used for all other input parameters such as natural mortality, spawning proportions and proportion of mortality prior to spawning. Assessment of the stock was carried out by fitting the integrated catch-at-age model (ICA) including a separable constraint over a eight-year period(Patterson and Melvin 1996). Input parameters and model setup for the ICA assessments were taken from the 1999 assessment WG (ICES 1999). All catch data (within the separable period) where weighted with a weight of one. Each of the separate survey indices where also weighted with a weight of one, because errors were assumed to be correlated by age for both the acoustic survey and the IBTS (2-5+) index. The stock-recruitment model was weighted by 0.1 as in WG assessment, in order to prevent bias in the assessment due to this model component.

Results

The bootstrapped catch at age of North Sea herring 1991 to 1998 scaled to biomass (Scb – see above) are shown plotted with WG estimates of catch at age in Figure 2. This set shows the greatest deviation from the WG catch, for the other methods the mean catch at age is equal to the WG catch at age..

Catch at age distributions.

Histograms of the bootstrap estimates of catch at age, scaled to the total international landings, are shown in Figures 3 &4 for two arbitrarily chosen example years (1991-1998)**.** Superimposed on each histogram is a normal distribution with the same mean and variance as the data. These allow a visual inspection of how well normal distributions fit the data. The histograms show some departures from the normal distribution, mainly for the 0- and 1-ringers (industrial fishery) and for the older fish (due to the lack of data).
Overall, the normal distribution appears to be reasonable description of the data. This may be a result of the many stages of combining data involved in producing the international estimates. A plot of log variance log mean catch is shown in Figure 5.

Uncertainty and precision

The CV of catch numbers at age for the national and combined data set are presented in Figure 6. CV of the international catch numbers follow the same pattern as observed for the national data, with relatively higher CV on the very young and older age groups. As expected, the international CV are lower than the national CV. For both cod and plaice the CV of the most fished age groups are less than 5%,
The CV of the combined mean weight at are generally less than 20% for most age groups and about 5% for the dominant age groups The underlying correlation of catch numbers-at-age was estimated using the numbers-at-age obtained from the resampling of the market sampling data. The patterns of positive and negative correlation were similar across the years within a species and the mean correlation coefficients between estimates of catch numbers-at-age are given in the Table 2 The correlation between estimates at age is positive for ages 3 to 8 for herring. It appears from this analysis, that the process is dominated by groups of fish at older ages being landed together in groups, so the presence of a group of ages increases or decreases together. It is important that this type of correlation within the estimates of catch are dealt with correctly within the assessment and that the process inducing the correlation structure is understood.

Implications of uncertainty for stock assessment and management advice

North Sea herring management is based on SSB, F adult and F juvenile, with short term projections dependant on estimates of recruitment. The median and 95% intervals of these four parameters for the last few years of the assessment are shown for all three methods of combining the catch at age data in Figure 6 (juvenile 7a and adult fishing mortality 7b), Figure 8 (recruitment) and Figure 9 (SSB)
The Coefficient of variation on fishing mortality in the final year is 4% and 8% for adult and juvenile mortality respectively (Erreur! Source du renvoi introuvable.). The CV on recruitment is 4% and 2% for SSB due to the precision of the catch estimation. However, it must be remembered that these CVs are conditional on the estimate of total landings.
The differences in the assessment carried out in 1999 [ICES, 1999] and the median of the analysis presented here are small. For the terminal year (1998) the SSB is different by less than 3%, however, the difference in F was 13% and the difference in recruitment 16%. In all cases these differences are very small in the context of the intervals on the assessment from the analysis of historic uncertainty [Figure 2.8.13 in \ ICES, 1999]. It should be noted that for the analysis carried out here the model assumptions were different. The software used at the ICES WG was a special version of ICA which allowed two periods of separable constraint for juveniles (ages 0 & 1 wr) but only one for adults, (ages 2-8 wr). Here only the standard ICA was available in a form to allow multiple assessments and it was used with two separable periods for all ages. For SSB the difference was well inside the 95% intervals from the market samples, however, the differences in F and recruitment were just outside these intervals. This indicates that the model assumptions may be more important in estimating values for F and recent recruitment than the influence of the market sampling data for this stock.

Comparison of errors contributed by market sampling to uncertainty in the assessment for herring.

The contributions of the market sample data to the overall precision of the assessment may be estimated by comparing the coefficient of variation (CV) from the catch variation alone using the bootstrapped assessments with the estimates of historic uncertainty from the assessment carried out in the Herring Assessment WG in 1999. Three main parameters can be compared: spawning stock biomass (SSB) F adult, ($F_{2\text{-}6}$) and recruitment. In all cases the comparison is limited to the estimates made using data up to 1998 and for the years 1991 to 1998 the period over which bootstrap data is available for catch. The CV on the parameters estimated by variance – covariance method in ICA can be compared to the contribution due to the market sampling (see Table 3). The 95% intervals for the same parameters estimated from 1000 estimates can be compared in Figure 10 for F2-6 Figure 11 for SSB and Figure 12 for Recruitment.

The results for herring suggest that for this assessment the variability in SSB and Recruitment contributed by the market sampling is negligible with a CV of between one eighth to one thirtieth of the CV indicted by the historic uncertainty. The CV of the estimates of $F_{2\text{-}6}$ suggest an interval of between half and one fifth if the historic CV is contributed by the market sampling programme. The relatively small contribution of the market sampling variability to the overall precision of the assessment may be the result of a rather well sampled fishery and specific to assessments which use market sampling only to construct the catch at age matrix and do not use commercial CPUE tuning indices.

DISCUSSION

The international sampling programmes appear to be delivering estimates of catch at age that are rather precise, with CV's of 6% for herring for the best estimated ages rising to about 30% at the older ages. While the precision of the best estimated ages is good, the current scheme is delivering much poorer CVs on older ages. Care must be taken to ensure that the importance of estimating both old and young year classes is fully understood. Based on the analysis of the histograms of the numbers at age, the normal distribution appears to be reasonable description of the catch at age data. However, this may be a result of the many stages of combining data involved in producing the international estimates and assumes independence among the national programmes. Negative correlations are observed between estimates of younger age classes, and positive correlations are found between estimates of older ages for the three species examined. The positive correlations at older ages are thought to be a property of the population distributions and the fisheries, older fish are caught and sampled in groups. In addition there is negative correlation between estimation of most of the old ages and most of the young ages. It is thought that this results from the above mentioned correlation in the estimates of older ages and the national raising procedures to total national catch. The mechanisms used to raise age structures to total catch result in a pattern of negative correlation between younger ages and all older ages.

The results of the analyses reported here are conditional on an accurate catch census, and do not yet include bootstrapped CPUE indices from commercial fleets (which are part of the market sampling programmes) because they are not used in herring assessment. These studies are suggesting that for the data sets examined the current levels of market sampling cause only small amounts of variability in assessment outputs for North Sea herring.

The relationship between the mean and variance of the numbers-at-age is fundamental to any future statistical modelling of catch numbers-at-age; as is the assumption of independence between numbers-at-age. The underlying relationship between mean-variance of catch numbers-at-age was investigated by considering the mean and variance of the numbers-at-age obtained from the resampling of the market sampling data and compared to the power relationship:

$$\text{variance}\{\text{bootstrapped numbers-at-age}\} = e^{a} \,.\, \text{mean}\{\text{bootstrapped numbers-at-age}\}^{b}$$

Relationships between mean and variance are observed for herring, slopes on the log variance-mean relationships are 1.7 for herring. Assessment models generally do not take this into account; changes to models or to weighting practices that would include these mean-variance relationships would be helpful. The apparent proportionality for the variance-mean relationship will facilitate the development of appropriate statistical models of catch-at-age that do not assume a log-normal distribution for catch-at-age.

While the precision of this well-sampled fisheriy appears to be rather good, no attempt has been made to check whether the international sampling is representative. It is particularly important if sampling methods are changed that care is taken to ensure that sampling covers the whole fishery.

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3.2 Results

Table 1 Scottish neighbour sequences for herring areas (see: Figure 1)

Area	Area Neighbour
1	2, 8 ,3
2	1, 3, 8
3	4, 2, 1
4	3, 5, 6
5	4, 11, 6
6	5, 4, 11
7	1, 9, 8
8	9, 2, 1
9	8, 7, 1
10	9, 13, 7
11	5, 12, 6
12	11, 6, 14
13	10, 9, 7
14	12, 6, 11

Table 2 Mean correlation coefficient for North Sea herring catch at age from 1991-1998, for combined Danish, Dutch and Scottish bootstrapped estimates.

	0	1	2	3	4	5	6	7	8	9+
0	1.00	-0.29	-0.07	-0.06	-0.05	-0.02	0.01	-0.01	0.00	0.00
1		1.00	-0.22	-0.10	-0.07	-0.05	-0.03	-0.04	0.00	0.00
2			1.00	0.02	-0.37	-0.34	-0.30	-0.29	-0.26	-0.31
3				1.00	-0.02	-0.24	-0.31	-0.21	-0.17	-0.23
4					1.00	0.19	0.06	0.02	0.00	-0.04
5						1.00	0.29	0.20	0.08	0.06
6							1.00	0.22	0.15	0.31
7								1.00	0.18	0.37
8									1.00	0.22
9+										1.00

Table 3 Comparison of Estimated Coeficient of Variation (CV) for management parameters $F_{2\text{-}6}$, SSB and Recuitment for 1991 to 1998. Estimated from 1999 assessment using ICA estimates of historic uncertainty and estimates of the contribution of the markert sampling variability from bootstraped assessments.

		1991	1992	1993	1994	1995	1996	1997	1998
F2-6	As Hist Unc	41%	41%	40%	41%	43%	40%	42%	45%
	Market	3%	3%	9%	8%	18%	9%	7%	8%
SSB	As Hist Unc	128%	182%	136%	203%	39%	27%	20%	23%
	Market	3%	4%	4%	8%	3%	3%	3%	4%
Recruits	As Hist Unc	175%	293%	138%	71%	47%	40%	38%	40%
	Market	5%	3%	3%	3%	4%	4%	6%	4%

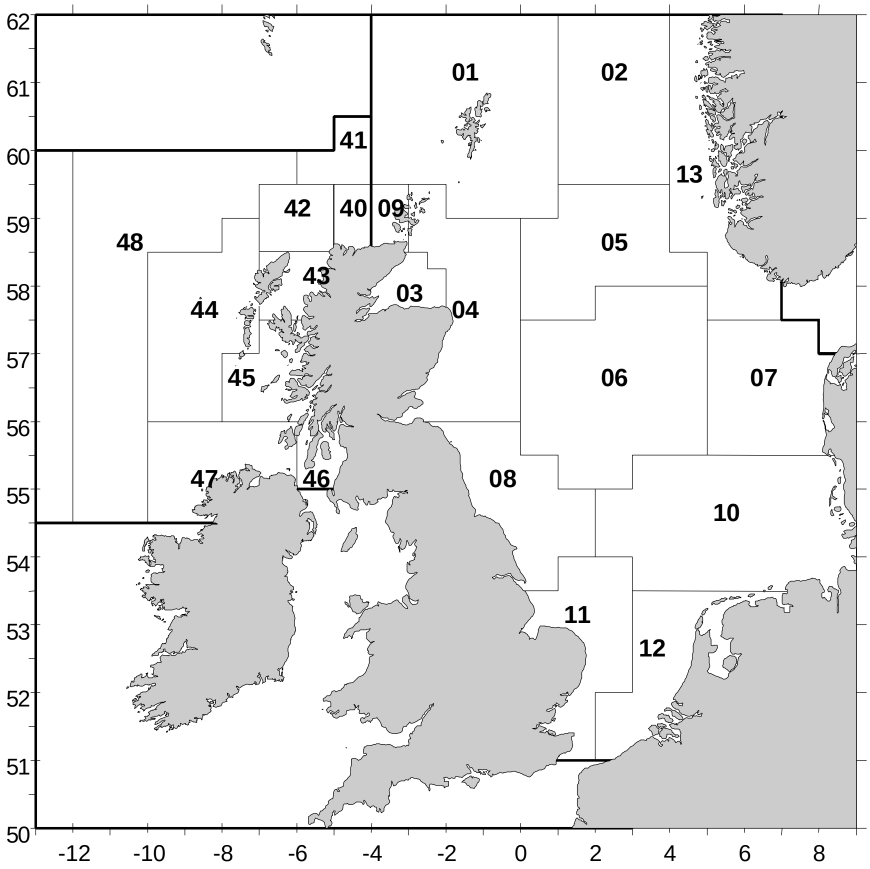

Figure 1 Scottish herring sampling areas.

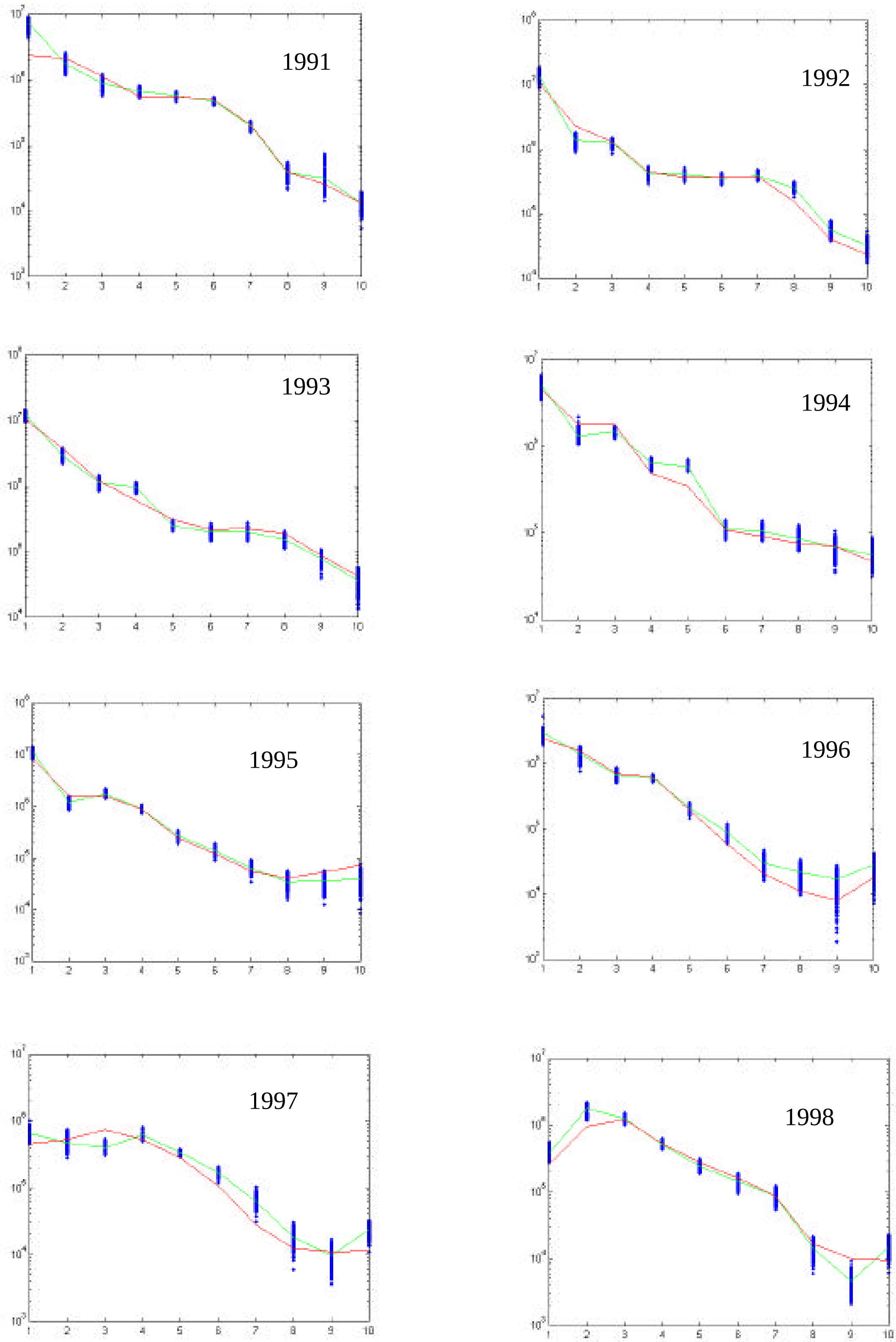

Figure 2. North Sea herring catch in number at age (wr+1) from 1991 to 1998, showing WG catch (red), boostrap mean catch (green) and boostrap values (blue) for catch scaled to biomass of landings (Scb). For other methods (Scn and Miss) mean numbers at age for WG are equal to mean numbers at age in the bootstrap.

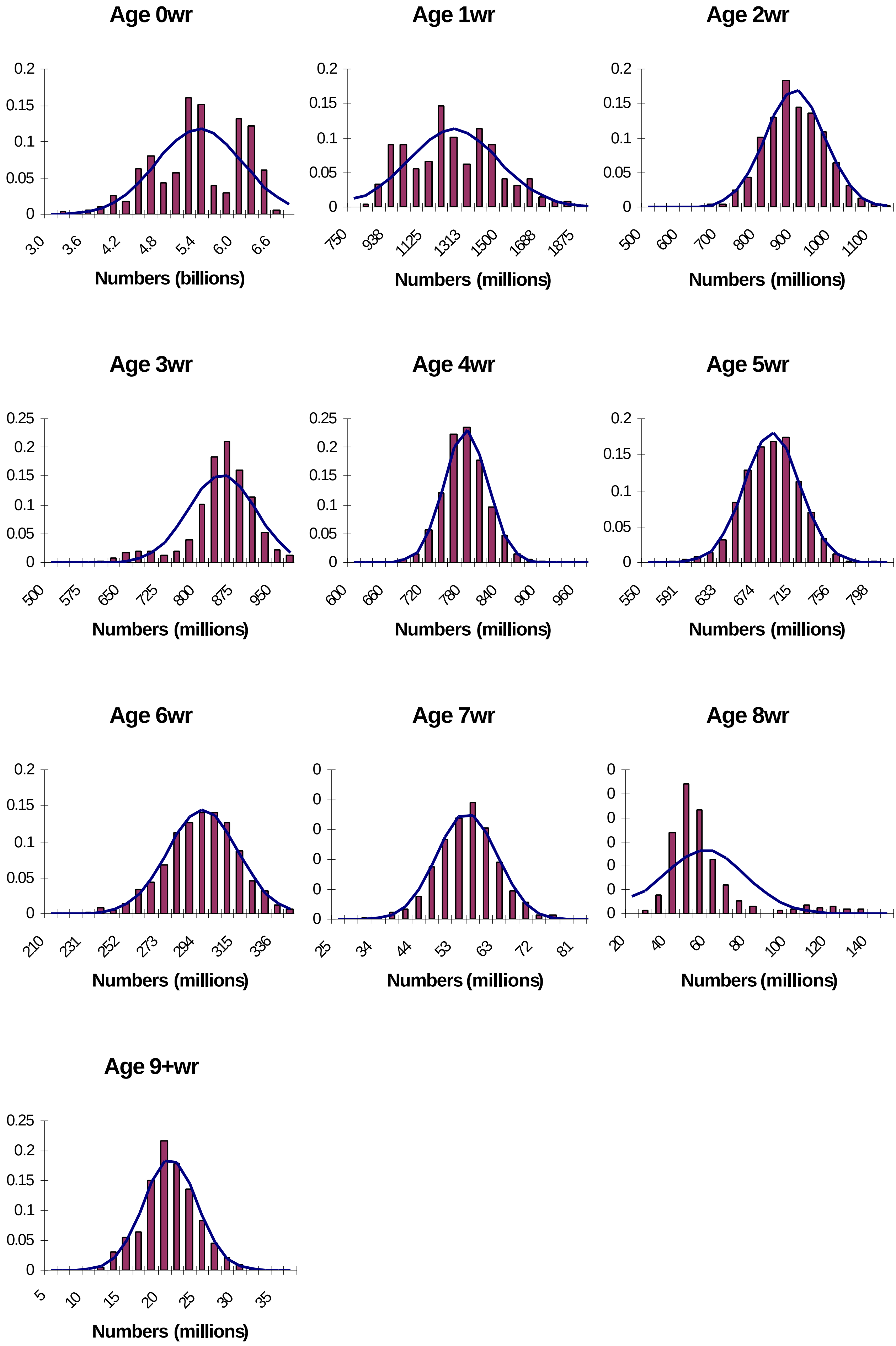

Figure 3. Histograms of international catch at age (wr) from 1991. Lines show a norrnal distribution with same mean and variance.

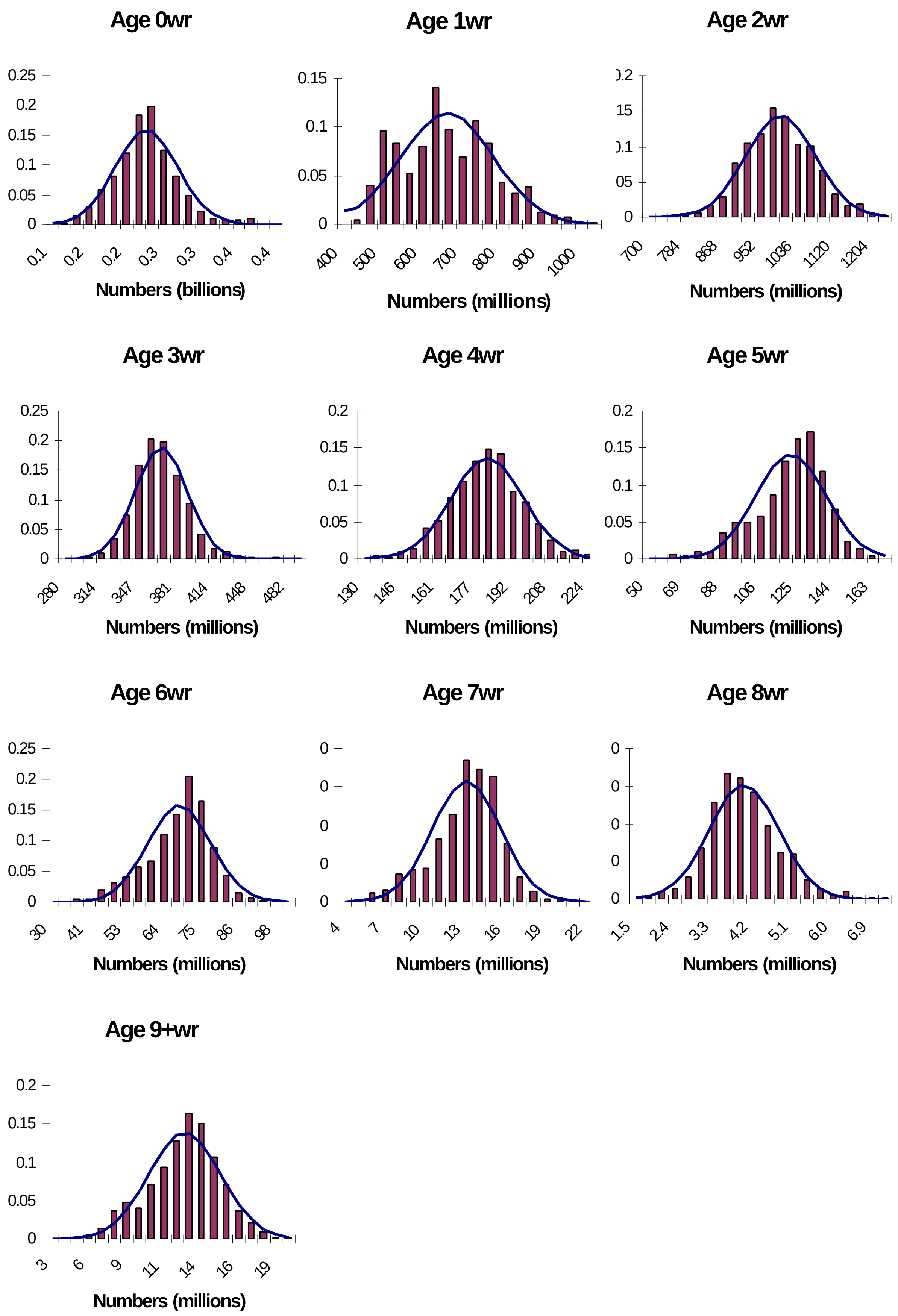

Figure 4. Histograms of international catch at age (wr) from 1998. Lines show a nornal distribution with same mean and variance.

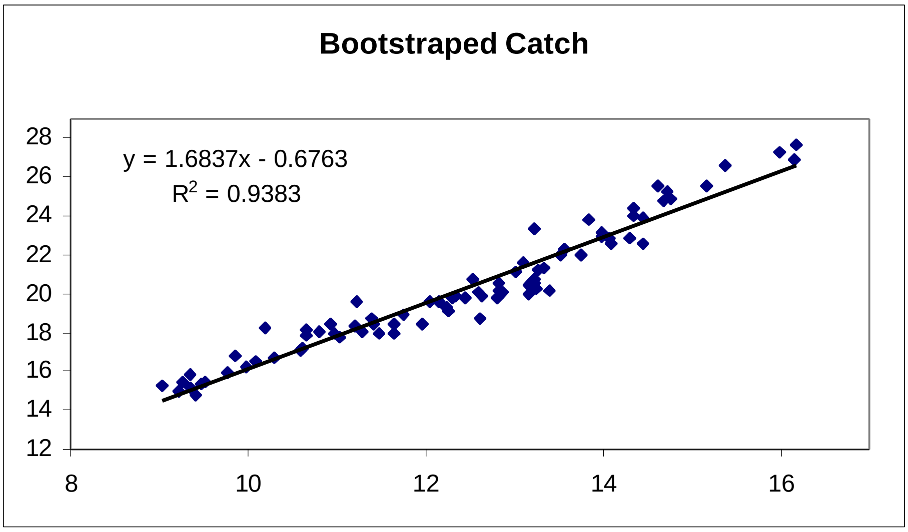

Figure 5 North Sea herring log(Mean)-log(Variance) plots of combined Danish, Dutch and Scottish bootstrapped estimates (ages 1-9). All years combined.

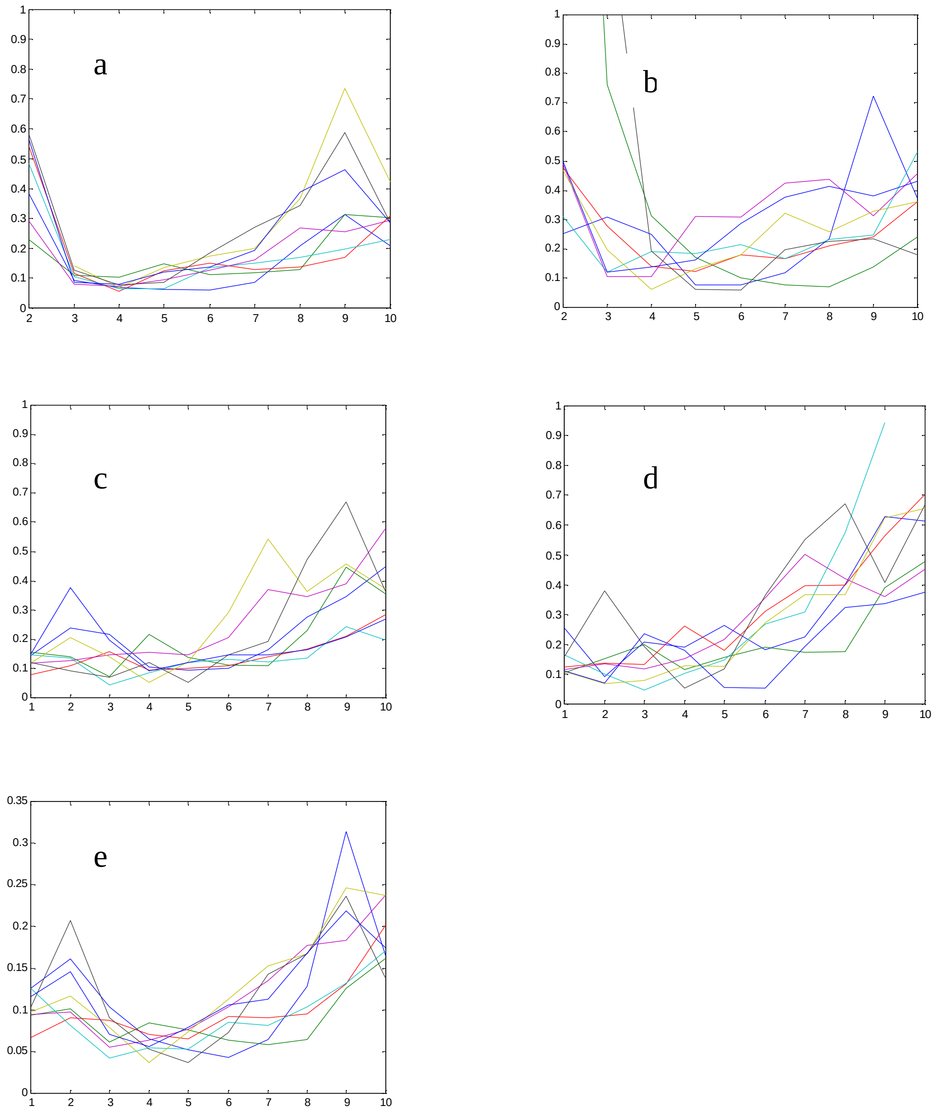

Figure 6 National CVs for North Sea herring catch at age (wr+1) for a) Netherlands, b) Scotland, c) Denmark in ICES area VI, d) Denmark in ICES area III. CVs at age for North Sea herring for 75% of combined international catch (e).

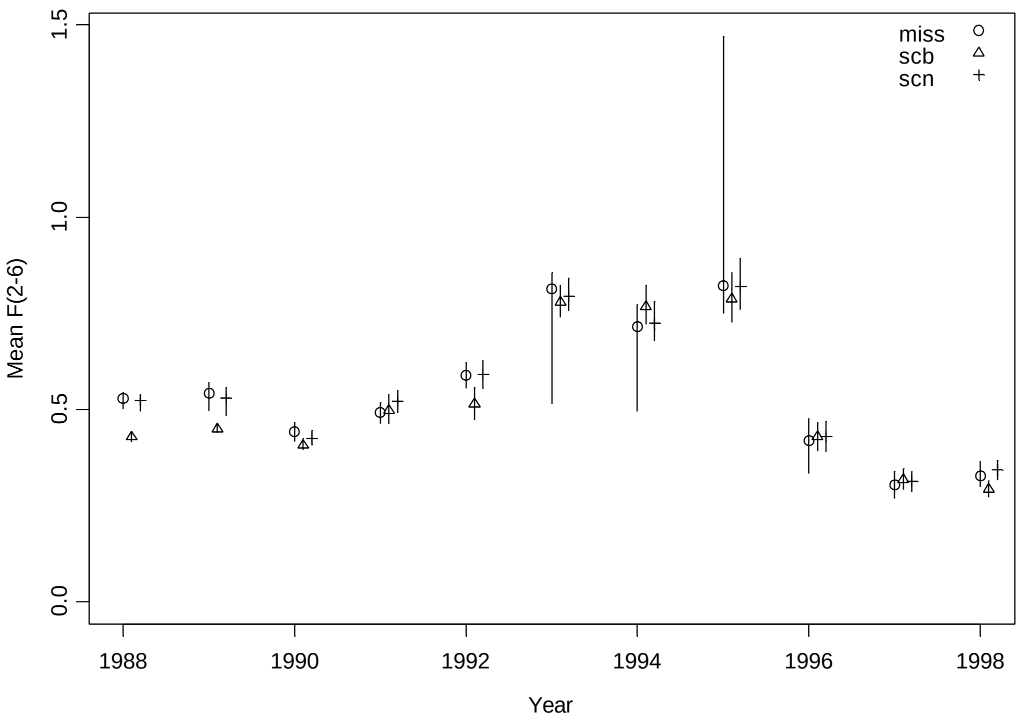

Figure 7a Estimated median and 95% intervals on estimated mean adult F (ages 2-6 wr) from 1988 to 1998 conditional on total landings and boostraped estimates of catch at age 1991-1998.

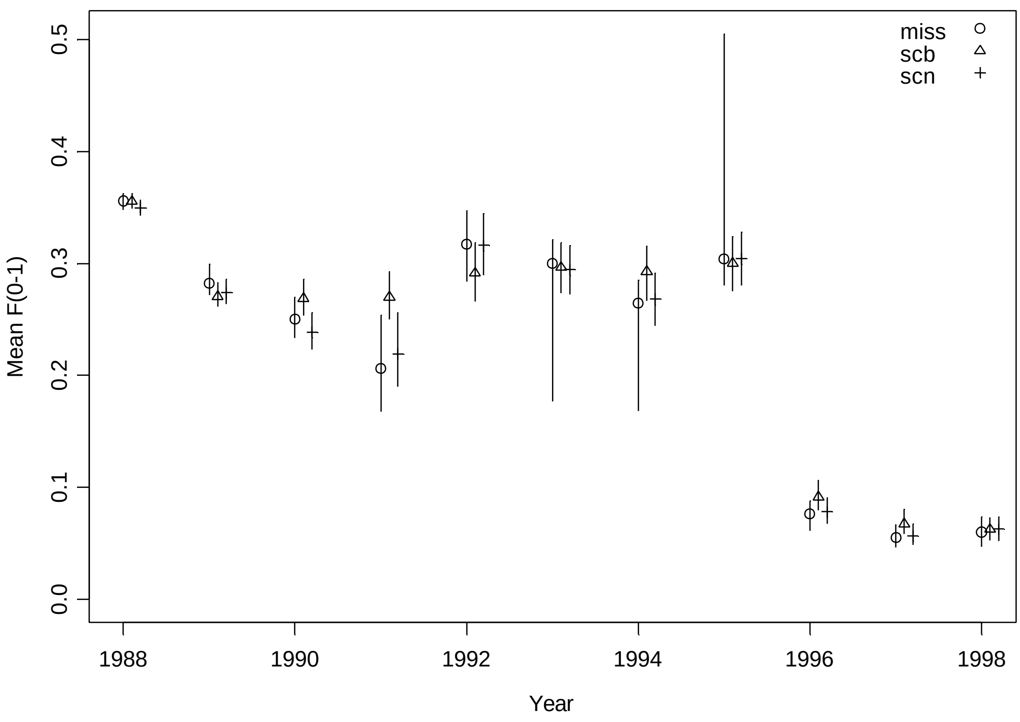

Figure 7b Estimated median and 95% intervals on estimated mean juvenile F (ages 0-1 wr) from 1988 to 1998 conditional on total landings and boostraped estimates of catch at age 1991-1998.

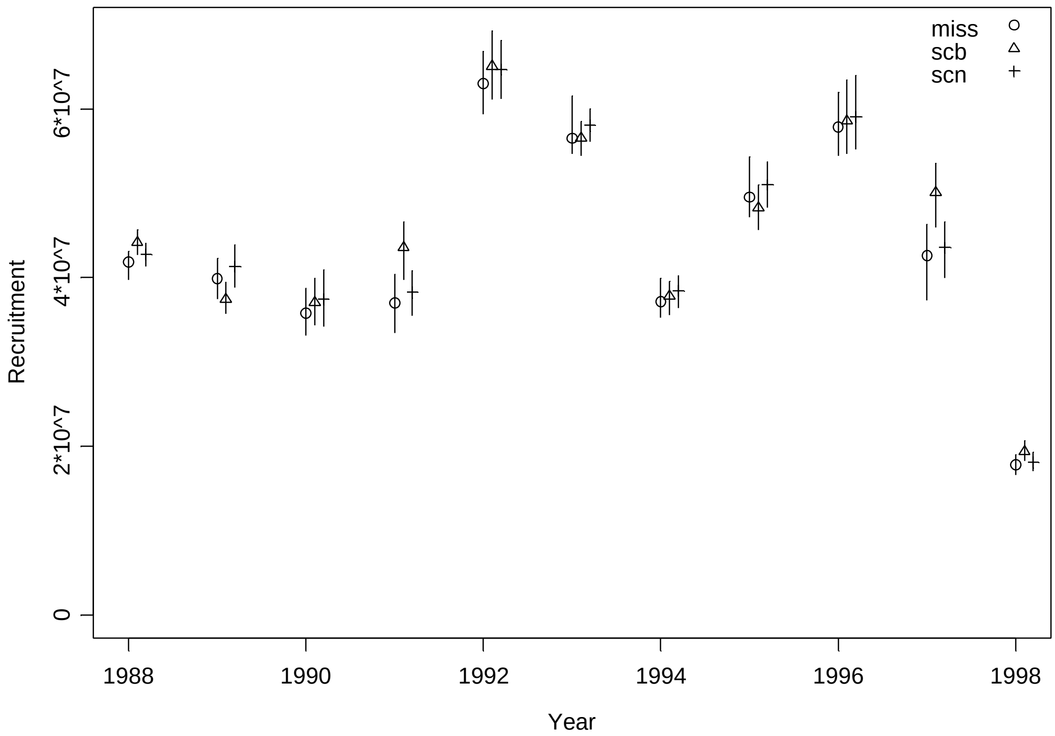

Figure 8 Estimated median and 95% intervals on North Sea hering recruitment 1988 to 1998 conditional on landings and bootstrapped estimated catch at age 1991-1998.

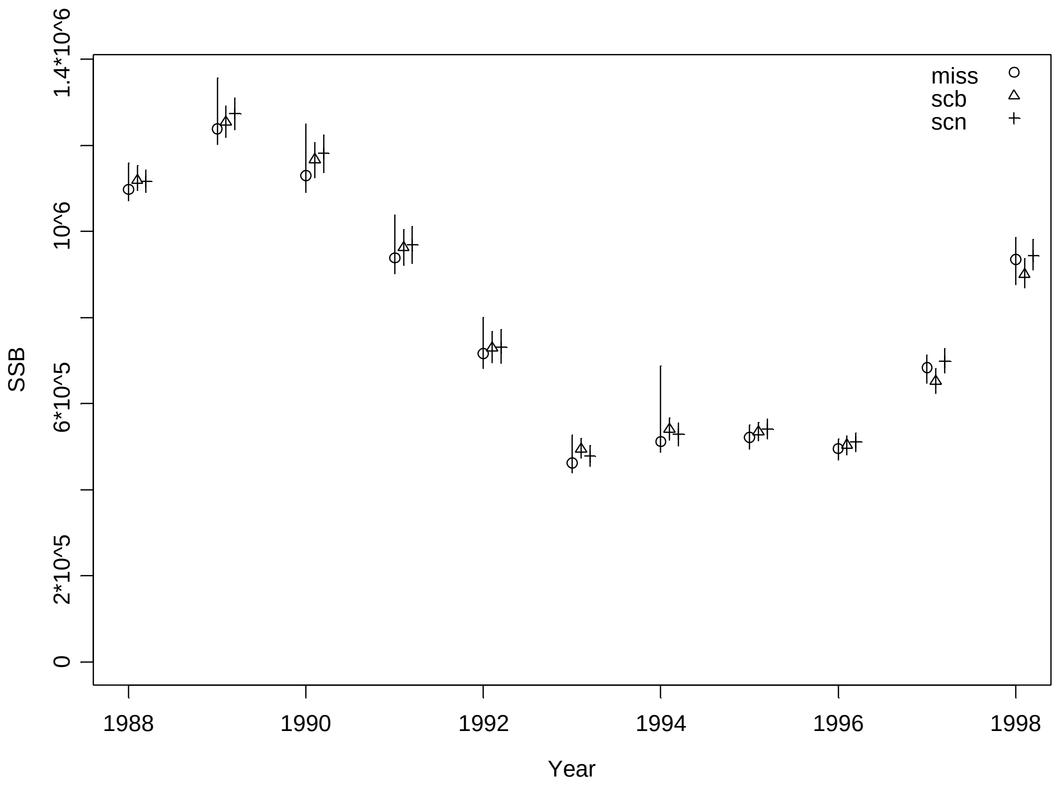

Figure 9 Estimated median and 95% intervals on North Sea hering spawning stock biomass (SSB) 1988 to 1998 conditional on landings and bootstrapped estimated catch at age 1991-1998.

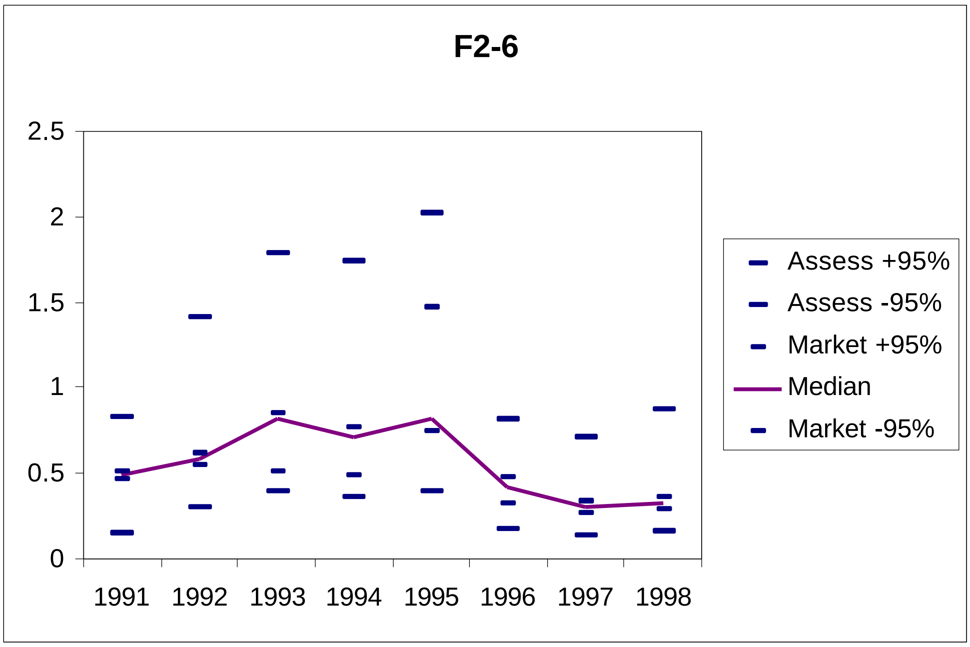

Figure 10 Median $F_{2\text{-}6}$ for herring 1991 to 1998 with 95% intervals estimated by variance – covariance historic uncertainty from the ICA assessment (Assess +-95%) and the contribution of market sampling data estimated by bootstrap assessments (Market +-95%).

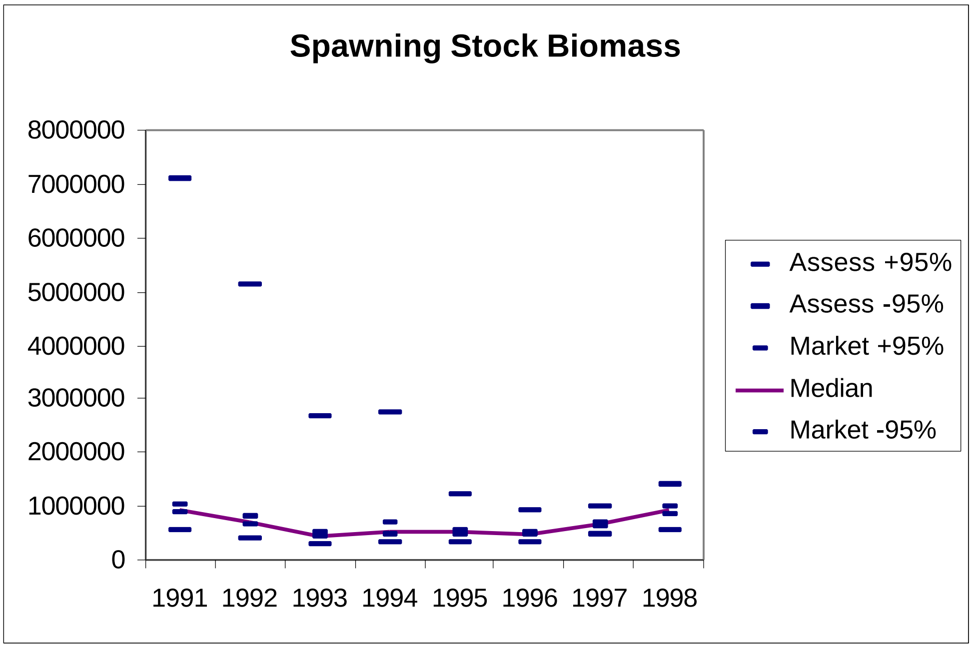

Figure 11 Median Spawning Stock Biomass for herring 1991 to 1998 with 95% intervals estimated by variance – covariance historic uncertainty from the ICA assessment (Assess +-95%) and the contribution of market sampling data estimated by bootstrap assessments (Market +-95%).

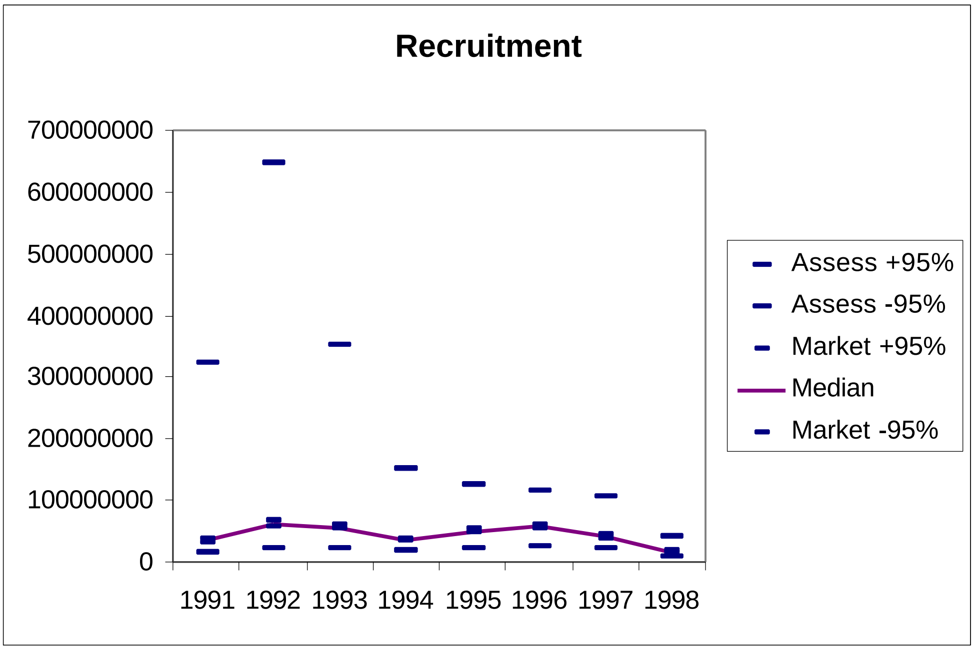

Figure 12 Median Estimates of recruitment (0wr) for herring 1991 to 1998 with 95% intervals estimated by variance – covariance historic uncertainty from the ICA assessment (Assess +-95%) and the contribution of market sampling data estimated by bootstrap assessments (Market +-95%).