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REPORT OF THE

STUDY GROUP ON STOCK-RECRUITMENT RELATIONSHIPS FOR NORTH SEA AUTUMN-SPAWNING HERRING

Lowestoft, UK
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1 INTRODUCTION

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1.2 Terms of reference

At the 86 th Annual Science Conference in 1997, it was decided (C. Res. 1997/2:35) that a Study Group on Stock-recruitment Relationships for North Sea Autumn-spawning herring will meet in Lowestoft, UK from 26–28 May 1998 to:

a) establish the data series of recruitments and SSB for as long a period as possible,
b) investigate the performance of different stock-recruitment models,
c) propose standard models to be used for different purposes.

1.3 Overview

Data and assessment

The first term of reference was to revise data to get a best possible set of stock - recruitment pairs for a long period as possible. It became clear well before the meeting that a complete revision of input data for an assessment far back in time would be out of reach, both because this would be a major task, and also because in some cases original data would no longer be accessible.

For some of the early years, there were large discrepancies between SOP's (sum of products of catch numbers and individual catch weights at age) and the reported landings. This was taken as an indication that some of the early input data for the VPA might be unreliable. Before the meeting, an attempt was made to revise the catch numbers at age to give SOP's equal to the reported landings (Needle and Patterson, WD #1). During the meeting, it was realised however, that the the main cause of the SOP-discrepancies might relate to the weights at age rather than to the catch numbers. For all years prior to 1984, the Working Group used standard weights at age both in the catch and in the stock. A brief literature search revealed support for the hypothesis that growth rates, and consequently weight at age, may have increased over this period. It was considered less likely that the standard weights would have been the basis for converting landings to catches in numbers. Consequently, it was decided to use catches in numbers as reported in previous Working Group reports as basis for a revised assessment. For the present purpose, weights in the catch are irrelevant. However, the likely changes in growth rates would affect weights in the stock as well, and thus the estimates of SSB. Therefore, an attempt was made to adjust the weights in the stock. The details are described in Section 2. This adjustment only included the years prior to 1960. Revisions of the weights for the rest of the years prior to 1984, where standard weights were used in previous assessments, would also be appropriate.

It is likely that also maturity at age would be affected by changes in the growth rate. The Study Group was not in the position to evaluate this. Furthermore, there are indications that the effective fecundity (actual number of fertile eggs released) is not directly proportional to the SSB, but rather to the $SSB^{4/3}$. The effect of this on the perception of the stock-recruitment relation is described in Section 2.1.4.

Finally, it was realised that catches from Division IIIa were only included after 1980. Since these catches, as far as they are from the North Sea autumn-spawners, mainly have been on juveniles, the recruitments as estimated by the VPA will be biased in the earlier years. The Study Group was not in the position to include more catches from Division IIIa. A comparison between recruitment at age 2 and at age 0 is included in Section 2.1.3, to illustrate the possible impact of such an amendment, indicates that some of the apparent difference in stock - recruitment dynamics before and after the collapse in the late 1970'ies may be artificial, due to lack of adequate catch data on juveniles before 1980.

The stock - recruitment estimates presented in this report are believed to represent an improvement compared to previous ones. The estimates of parameters on a Beverton-Holt function did not change very much compared to the values arrived at by the WG. Including the period just after World War II in addtion gives suggestion of how the stock may behave at low exploitation rates. The results indicate that the SSB may become markedly larger than that experienced in more recent years. Using revised weights, based on a hypothesis of density dependence will tend to lower the average SSB at zero exploitation.

In the process, problems have been revealed that imply that the present estimates still can be improved, which will affect both the recruitment and the SSB estimates. The experience by this Study Group clearly indicates that such improvements will have a substantial impact on the perception of the stock-recruitment relations for the stock, not the least on how the stock can be expected to behave at low exploitation rates. With the present emphasis on the precautionary approach, these estimates become increasingly important for giving realistic advise. An additional argument for putting effort into amending the data is that this is one of the best stocks for studying stock - recruitment relations in general, because of the long time series, the wide range of SSB's, and the fact that this is a very well-studied stock.

Methodology

In Section 3, some approaches to describing the relation between stock and recruitment are discussed. This includes both the conventional parametric stock-recruitment functions, and some recent attempts to find alternative ways of describing those features of the relation that may be essential for specific purposes.

For the parametric models (Section 3.1), it is pointed out that these very often will be overparameterised, i.e., there is often not sufficient information to estimate both a representative recruitment level at high SSB's and the curvature at low SSB's. North Sea herring may be one of few exceptions to this, because of the wide range of SSB's which includes the region close to the origin, and the relatively low year-to-year variation in recruitment at given SSB-levles. Even for this stock, however, the problem should not be under-rated. Bayesian parameter estimates are also discusssed, which indicate that a Ricker curve may be slightly more likely than a Beverton-Holt curve. The difference, both in posterior probability and in the actual ordinate values, is small, however.

Some alternatives to parametric curves are presented in Sections 3.2, 3.4 and 4.1. This includes smoothing and kernel functions, and a recent attempt to estimate the slope of the curve at a specific SSB-level, assuming only convexity of the stock-recruitment relation. Non-parametric alternatives to stock-recruitment functions is a rapidly developing field which seems very promising, but the properties of such approaches are still not sufficiently well understood to enable this Study Group to recommend one approach over others.

The Study Group also attempted to look into the question of how to model time trends in the recruitment from other causes than variations in the SSB (Section 3.3). Time did not allow a thorough discussion of this problem, but some examples of possible approaches are described. The North Sea herring is one of the stocks where the recruitment, in addition to the effect of the SSB, may have been influenced by variable external conditions. Thus, in the 1970'es, the recruitment was generally poorer than one would expect from the SSB, while it was better in the early 1980'es. Periodic variations induced by a good recruitment in one year leading to an elevated SSB some years later was only discussed briefly. For the North Sea herring, this is hardly a major problem.

Some general points relating to the use of stock-recruitment in medium term predictions and calulation of long term equilibria, reflecting the common experience with the use of such predictions in general and for North Sea herring in particular, are made in Sections 4.2 and 4.3.

Proposals

The Study Group did not conclude by recommending a certain standard model for the stock-recruitment relationship for North Sea herring. Rather, it would point out some areas where further investigations should be done. The main emphasis at this brief meeting was to reveal areas where further research would be expected to be rewarding, and to evaluate the possible impact of such research on the perception of the stock-recruitment relationship. The main areas include:

- Review the stock- and catch weights for the entire period 1947 - 1983, and the use of such revised weights for forecasting purposes.
- Review maturity at age for the period for which a constant maturity at age is presently assumed.
- The use of fecundity-weight relationships to enable calculation of effective fecundity for use in stock-recruitment analyses.
- If at all possible, include catches of North Sea herring from Skagerak and Kattegat for the period 1947 - 1980.

The Study Group also noted that if revision of catch and stock weights, and maturity at age confirm that growth and maturity may be density dependent, this should be taken into account in long term calculations of yield and stock size.

North Sea herring is one of the stocks that is considered for a comprehensive assessment by the Comprehensive Assessment Evaluation WG, and the present Study Group would suggest this as a suitable forum for following up the tasks noted above.

On theoretical grounds, the Study Group would prefer the use of non-parametric methods to model the stock dynamics at low levels of stock size. The relative performance of parametric and non-parametric methods applied to North Sea herring has not yet been explored, but for this stock (which has many observations at low stock size) perceptions of stock dynamics at low stock size would *a priori* be expected to be rather robust to the choice of estimating model.

2 DATA SERIES OF SSB-RECRUITMENT PAIRS

2.1 Revisions of input data for assessment

2.1.1 The SOP problem

In order to understand fully the population dynamics of the North Sea herring stock, it is necessary to include the immediate post-war years in the analysis. This was a time of high spawning-stock biomass as the peacetime fishery re-commenced, which therefore comprises a valuable contrast to the more recent low biomass situation. Consequently, the 1960–1997 time-series of North Sea herring from the latest Working Group report (ICES 1998a) was augmented with hindcast data for 1947–1959 from an early herring Working Group report (ICES 1977).

Before being used in historical reconstruction, the validity and utility of these early data must be quantified. This can be done via the sum-of-products (SOP) for a given year in the stock, which is a useful measure of the consistency of the sampling program used in the generation of the data; it is given by $SOP_y = \Sigma_i C_{i,y}W_{i,y}$, where $C_{i,y}$ is the catch numbers at age i in year y and $W_{i,y}$ is the mean weight of an individual fish of age i and year y. The historical data can then be evaluated by calculation of the ratio of SOP_y to landed weight L_y. Ideally, this ratio should be close to 1.0, although small deviations are to be expected and indeed are best ignored (Lewy & Lassen 1997).

The results of the SOP analysis for North Sea herring 1947–1997 data are given in Table 2.1.1.1, and are illustrated in Figure 2.1.1.1. It is clear that the observed SOP discrepancies, particularly for the years prior to 1968, are not the expected minor deviations, but large effects which may impinge significantly on the value of the time-series in historical reconstruction. In particular there is a clear positive trend from 1947 to 1970; in other words, over that period SOP was consistently larger than landings, although the difference reduced progressively. The option of wholesale SOP corrections on catch numbers-at-age was explored by Needle & Patterson (WD #1), but was thought by the Study Group to be neither informative nor justifiable.

There were three potential sources of error in these early data, namely the catch numbers-at-age, the estimated landed weight, and the mean catch weights-at-age; and it is difficult to state definitively where the principal problem lies. Certainly participants at early Working Group meetings were aware of potential failings in the extant sampling programs, although it is not clear that SOPs were ever calculated (for a review, see Needle and Patterson WD #1). However, it is instructive to note that a standard set of mean weights-at-age was used to generate the data from 1947–1959 that were reported in ICES (1977). The literature suggests that Working Group attention focussed on landings and catch numbers-at-age, and while a re-examination of these data would be appropriate, the Study Group decided they were reliable in the absence of evidence to the contrary. In contrast, it would appear that early Working Group members did not generally bring estimates of mean weights-at-age to their meetings, which may explain why standard mean weights-at-age were used for so long: these weights were derived by von Bertalanffy growth-curve parameters of uncertain lineage, but may be assumed to have been determined towards the end of the period under consideration. Burd (1978) noted that estimates of adult biomass of North

Sea herring in 1947, given in the herring Working Group report of 1975 (ICES 1975), made no allowance for the change in growth rate, since mean weights-at-age of the stocks during 1970–1971 were used for the period 1947–1975. The problem addressed by the Study Group is therefore not new.

It seems reasonable to hypothesise that herring became progressively larger between 1947 and 1959, since an over-estimation of weight in those early years would indeed give rise to the observed large yet steadily reducing SOP discrepancies: the weight increase may have been due to a rise in density-dependent growth as stock size declined.

2.1.2 Revised Stock Weights (Years 1947–1959)

According to the historic SOP problems identified and detailed in Section 2.1.1, an attempt was made to retrieve weight at age data from sources in available literature for the period 1947 to 1959, which has been identified as especially problematic. To investigate the possibility of changing mean weights-at-age, a number of secondary sources were obtained giving mean weight-at-age distributions for herring in various areas of the North Sea for specific years. While a full enumeration of such distributions for all areas, seasons and years must await detailed analysis of primary sources (specifically, research survey log books and reports), much can be learned from those data that could be obtained in the time available.

The principal sources found were:

- Mean lengths in Belgian herring catches in various areas of the southern and Central North Sea, compiled in Annales Biologiques by Ch. Gilis (1947 - 59).

- Mean lengths of herring (ages 2, 3 and 4 winter rings only) in the Buchan area (Saville, 1978). A review of this information showed that lengths at age of fish were (a) consistently higher in the Buchan area, and (b) appeared to increase with time. The Study group ascribed the time-trend to a density-dependence. In order to fill-in missing observations for the Buchan area, a simple model of density-dependent growth was used, similar to that used by Patterson (1997). The model assumes different lengths at age 1 and asymptotic lengths in the two areas, but assumes a common, density-dependent growth rate in the whole stock.

The model was formulated to fit to observations of lengths L at age a, in area j and in year y in terms of a Ford growth parameter K, area-specific asymptotic length $L_{\infty j}$ and area-specific initial length (at age 1) $L_{1,j}$.

The structural model used was:

$$\hat{L}_{a+1,y+1,j} = L_{\infty j}(1-K_y) + K_y \hat{L}_{a,y,j} \qquad (1)$$

in which

$$K_y = K_0 exp(aB_y/B_{max}) \qquad (2)$$

where K_0 represents the conventional Ford growth constant (without density dependence) and B_y represents the abundance in weight of fish aged two winter rings and older, as estimated by conventional VPA. B_{max} is the highest observed value of B. B_y are calculated conventionally from VPA estimates of abundance using weights-at-age derived from (1) using a conventional length-weight relationship, and iterating when fitting the model.

The model was fitted by minimising log residuals of fitted and observed lengths, giving equal weight to the Belgian and Scottish fisheries in the Buchan area. The quantity minimised was:

$$1/n_{\text{Buchan}}\, S(\ln(L_{a,y,Buchan}/\hat{L}_{a,y,Buchan}))^2$$

$$+1/n_{\text{Belgium}}\, S(\ln(L_{a,y,Belgium}/\hat{L}_{a,y,Belgium}))^2 \qquad (3)$$

where predicted lengths are calculated from (1), beginning with lengths at age 1 in the two areas which are also model parameters.

Observed and fitted values are given in Figures 2.1.2.1 and 2.1.2.2. Conversion from length to weight was made using length-weight regression parameters estimated for herring in Scottish catches in August (See Table 2.1.2.3)

This model provided fitted estimates of weights at age for the Buchan and Belgian fisheries. A combined-weight at age data set for the entire stock was calculated simply by averaging these.

Fitted values, parameter estimates and subsequent estimates of weights at age in the stock are given in Tables 2.1.2.2 and 2.1.2.3.

Taking these estimated weights as catch weights, the resultant SOP discrepancies for the period 1947 - 1959 are shown in Table 2.1.2.4 and in Figure 2.1.1.1. It is not clear from this preliminary investigation whether herring were or were not lighter in those early years. However, it is clear that herring growth and weights did change over that period, so the assumption on constant weight-at-age distribution is flawed.

Some additional light is shed on the problem by basing the SOP calculation for the years 1960–1997 on *stock* weights-at-age, rather than catch weights-at-age. The catch weights-at-age for 1947–1959 discussed above are derived from catches on spawning aggregations, and were primarily intended as a proxy for stock weights-at-age. Thus it may be hypothesised that the SOP discrepancy might be reasonably consistent for the whole 1947–1997 period *if* the SOPs are based on stock weights-at-age, and this is included in Figure 2.1.1.1. This suggests that the continuance of the work on the revision of stock and catch weights-at-age would indeed be worthwhile.

2.1.3 Fishing areas omitted in early catch statistics

It should be noted that there is some inconsitency in the inclusion or otherwise of the fisheries in the Skagerrak (Division IIIa) and the eastern English Channel (Division VIId) in the analyses. In current catch statistics (ICES 1998a) these areas are considered jointly with the North Sea (Sub-Area IV) only for the years 1980 and onwards. This will lower the estimates of stock numbers in the VPA for the earlier years, in particular at ages 0–1, which dominates these catches. Interestingly, the results of smoothing the recruitment estimates described in Sections 3.2 and 3.3 (see Figures 3.2.1.2 and 3.3.1.2) suggest that two separate stock-recruitment relationships can be applied to the herring dataset, with the split between them occurring in that same year. The combination of the adjustment of mean weights-at-age (thus reducing overall spawning stock biomass) and the inclusion of early Skagerrak data in particular (thus increasing recruitment estimates) would potentially have the effect of reducing the distinction between the two relationships by shifting the earlier curve upwards and leftwards. Hence the problem may be one of two datasets grounded in different assumptions, rather than two different stock-recruitment relationships.

A more consistent recruitment estimate would be achieved by treating age-2 as the recruiting age for the whole North Sea, in which case the Skagerrak catches (which come from an industrial fishery largely on age-1 fish) are effectively removed from the analysis for the entire time-period. Doing so, and transferring the recruitment to age 0 via a straightforward multiplier, produces the alternative recruitment time-series in Figure 2.2.1, and the stock-recruitment plot in Figure 2.1.3.1, from which it can be seen that only one stock-recruitment relationship should be fitted to these data. This approach is not satisfactory, however, since there are important fisheries on 0- and 1- ringers, and recruitment estimates at age 0 are necessary to address the impact of these fisheries on the stock in predictions and evaluation of management regimes. Further work on this problem would therefore be beneficial.

2.1.4 Fecundity, body size and egg production

When fitting stock-recruit relationships, spawning stock biomass is usually used as a proxy for potential egg production. SSB is generally calculated as:

$$SSB = \sum_a N_a w_a \pi_a$$

where a is age, N_a is numbers-at-age, w_a is mean-weight-at-age, and π_a is proportion mature-at-age. However, this formula will not accurately reflect total egg production unless fecundity (eggs-per-fish in a mature fish) is directly proportional to weight. In particular, if the stock's length composition changes with time and SSB, there is liable to be bias in fitting stock-recruit relationships, and errors in setting biological reference points; see e.g., Rothschild and Fogarty (1989) for a fuller discussion.

For herring, there is strong evidence that fecundity f is not directly proportional to weight. Almatar and Bailey (1989) and Baxter (1959) fitted relationships of the form $\log f = a + b \log l$ to samples collected from a range of areas in and around the North Sea and in different years. If fecundity were proportional to weight, we would expect b to be around 3. Although the 14 estimated slopes b varied from one sample to another, all but one exceed 3.4. The authors did not specifically test for slopes different from 3, the standard errors associated with each estimate are very small (where reported) and there is little doubt that the average slope is significantly greater than 3. The mean and median slope estimates are both 4.1. (Note that there has not been time to properly scrutinize the estimates, and the average figure is thus indicative only).

Bridger (1961) and Burd and Howlett (1974) fitted fecundity-weight relationships of the form $f = c + dw$. Bridger's data appear quite linear, with a non-zero intercept so that fecundity is zero for fish below a certain weight. In the limited time available, we could not find any comparisons of goodness-of-fit between log-log and linear models.

There are significant and substantial differences between the intercepts in the fitted log-log regressions, depending on the area and year sampled. Kelly and Stevenson (1985) and Messieh *et al.* (1985) have reported significant density-dependent effects on fecundity for Northwest Atlantic herring, but Almatar and Bailey did not find evidence of any systematic link between stock size and fecundity-at-length for their samples, which were from 1972–74 and 1983–84. The authors suggest that there is insufficient contrast in stock size between these two periods to allow significant effects to be found. There are too few samples to allow a time-series of fecundity relationships to be constructed. Given the differences in fecundity-at-length between samples from different areas, changes in the spatial distribution of the stock over time may represent a further confounding factor.

To see the likely effects of using fecundity rather than weight in determining egg production, the group explored the effect of replacing SSB by

$$\sum_a N_a f(w_a) \pi_a \propto \sum_a N_a w_a^{1.3} \pi_a = RELEGG$$

when fitting the stock-recruit function. Obviously, if fecundity is used in place of weight, spawner-per-recruit calculations need to be redone in terms of lifetime fecundity-per-recruit.

Of course, there are other factors besides fecundity that can affect how many viable larvae are produced: examples are atresia, egg size, spawning time, relation of egg size to larval viability and sex ratio. Egg size appears to be less nonlinearly dependent on adult weight than fecundity is, and Bailey and Almatar (1989) found little evidence of variations in egg size between years. Nevertheless, it is possible that such factors may distort RELEGG as a measure of larval viability, but RELEGG (or an improved measure based on more rigorous analyses) does incorporate the most important determinants: maturity-at-age, weight-at-age, and fecundity-with-weight.

The illustrate the effect of using RELEGG as an alternative to SSB as measure of fecundity, an assessment run was made in addition to the standard run described in Section 2.2, where the stock weights at age $w(a)$ were substituted by $w^{1.3}$. A plot comparing the two measures of fecundity is shown in Figure 2.1.4.1.

2.1.5 Comments to the data revision

Analysis of stock-recruitment relationships can only be considered to be preliminary until a consistent and viable stock dataset had been achieved. The first choice to be made in this context is between inclusion or exclusion of the 1947–1959 data. If these data are to be excluded, then much information will be lost about herring population dynamics when stock sizes are high. If the path of inclusion is to be followed, then some effort *must* be expended to increase knowledge of the true mean weights-at-age for the 1947–1983 period when standard weights at age were used. By this argument, the early data should be included and the weights-at-age should be adjusted by whatever good information is available. While some of this work has been done in the Study Group, and the mean weights-at-age discussed above are an improvement on those used in ICES (1977), additional analyses of primary sources should be a priority. Contemporaneous to this should be a re-assessment of the Division IIIa fishery to determine if the omission of catches from that area before 1974 is detrimental to subsequent analyses.

It should also be noted that spawning stock biomass calculated from numbers at age is heavily dependent on the assumed stock weights-at-age and maturity ogive. For some stocks, size at first maturity has been shown to be more constant or consistent over time than age at first maturity (for example, see Garrod 1988, Skagen 1989). Hubold (1978) suggested that, for herring, the percentage mature-at-age is strongly correlated with size. Given the clear changes in mean length-at-age over the period 1947–59, and possibly also for the period 1960–80, it would be prudent to investigate this problem further and try to improve the time-series of maturity-at-age used in calculating SSB. We have modelled the changes in length-at-age over time to derive a more realistic set of stock weights-at-age over time. A similar model could provide a way of modelling maturity-at-size, from which maturity-at-age could be derived.

2.2 Assessment with Extended Time-period

A new assessment calculation was made using ICES historic age-disaggregated catch numbers and stock weights (as described in Sections 2.1.1 and 2.1.2) for the period 1947 - 1997, and the herring assessment model (implemented with ICA version 1.4) as used by ICES (1998a). In this model, populations in years before 1992 are fitted using a conventional VPA calculation. The following changes have been made to the input data:

1. The age range was reduced to ages 0 to 8+ rather than the conventional 0 to 9+. This was required because of missing information about older fish in the early years of the analysis, and has resulted in a small change in estimates of fishing mortality in 1997 compared with the Working Group assessment.

2. Weights at age in the stock and in the catches were replaced with the values given in Table 2.1.2.3 for the years 1947 to 1959.

By introducing these new weights at age, SOP discrepancies were reduced in most years from 1947 to 1959. Although these now lie mostly around 70–80 % in this time period, this was not a major concern since the main use of this information was to calculate spawning stock biomasses predicated on VPA estimates of abundance in number. In years where better data are available stock weights exceed catch weights by about 15 %, and SOP discrepancies of a similar magnitude may indicate that a similar relationship existed in the past.

The effect of long-term changes in selection has not been investigated at present.

Pending further investigation, the Study Group considered that the use of the new stock values was an improvement over existing estimates.

The Beverton-Holt stock recruit function parameters as estimated by the ICA (as R = a*SSB/(b+SSB)) are:

a) $6.199 * 10^7$ (95 % C.L. $4.8* 10^7$ to $13.6* 10^7$)

b) $4.28 * 10^5$ (95 % C.L. $2.45* 10^5$ to $23.8* 10^5$)

Variance of log stock-recruit function residuals: 0.3897

Details of the model fit are given in Table 2.2.1. A summary of SSB and recruitment estimates is plotted in Figures 2.2.1 and 2.2.2. The new model fit indicates that a rapid decline in stock size ocurred when the fishery re-opened after 1947. The spawning stock is estimated as having been at a level of some 5 Million t, declining thereafter to 1 Million t in 1958. These levels of stock size are considerably higher than those estimated in the period from 1960 to 1997 (Maximum 2.1 Million t). In the early period, recruitments were in the range 28 to 65 billion fish, except for the extremely abundant 1957 year class.

3 STOCK - RECRUITMENT MODELS

In order to put the stock-recruitment modelling for the North Sea herring in a somewhat broader perspective, the Study Group discussed several approaches to modelling this relation. Some of these are discussed in this section. Others, that are more directed towards estimating specific reference points, are discussed in Section 4.

3.1 Parametric models

3.1.1 Nonlinear regression

The common practise has hitherto been to estimate parameters in some stock - recruitment function by nonlinear minimisation of the sum of squares of log residuals. Often, this is done with sets of data where the effect of SSB on the recruitment is not very prominent, compared to the variability in the recruitment. A simple Monte-Carlo simulation of the parameter estimation, using artificial data with known parameters to investigate how well one can expect to estimate such parameters, was presented (Skagen WD #2).

Recruitment data were generated with random SSB's and a Beverton - Holt stock - recruitment relation not unlike the one assumed for North Sea herring, and a lognormal variance of the recruitment residuals. Attempts were made to estimate the parameters using various ranges of SSB's, various numbers of stock - recruitment pairs and various values for the variance of the residuals. In addition, estimates were made for F_{MSY}, MSY and for F_{crash}, using artificial SSB and yield per recruit data similar to those for North Sea herring.

This excercise showed a very tight linear relationship between the estimated parameters in the Beverton-Holt function in most cases, indicating that this model is overparameterized as a representation of the data. The exception was when the range of SSB extended close to the origin, and the variance was moderate. Given this, the estimate of F_{crash} becomes highly uncertain. The estimate of F_{MSY} was quite robust.

In more general terms, this study illustrates that it is not possible to estimate both the level and the curvature of a stock - recruitment relation, unless there are sufficient information about both in the data. If this is not the case, the range of parameter estimates will generally represent a family of almost straight lines at a level corresponding to the average recruitment and a slope which is mainly determined by the noise in the data. Accordingly, this restricts the use of parametric stock - recruitment functions to applications using the average recruitment, and to some extent the trend in the recruitment over the observed range of SSB's. In particular, parametric functions are rarely suited for evaluating the stock - recruitment relation close to the origin. The North Sea herring may to some extent be an exception in this respect, because the observed range of SSB's extends close to the origin, and the year-to- year variations in the recruitment are relatively small.

3.1.2 Bayes estimates

A working paper by Lewy and Nielsen (WD #3) was presented applying a Bayesian approach for estimation of the probability distribution of the stock-recruitment parameters and predicted recruitment using a Deriso/Schnute class of models. The model is

$$R = \alpha S (1 - \beta \gamma S)^{\frac{1}{\gamma}}$$

where R denotes the recruitment, S the spawning stock biomass, and α, β and γ are parameters.

The recruitment models are flexible in the sense that both the standard Beverton and Holt and the Ricker models are included.

The idea behind Bayes principle is that the parameters in a model are considered as stochastic variables for which the so called posterior distribution given the observations can be found. In order to find this posterior distribution of the parameters in the Deriso/Schnute model two type of distribution must be specified: The distribution of the observed recruitment for given spawning stock biomass and the so called prior distribution of the parameters included in the Deriso/Schnute model. The recruitment is assumed to be lognormal distributed. With respect to the positive parameters α and β the prior distributions are assumed to be uniform distributed on the positive axis. The distribution of γ, which determines the shape of the stock-recruitment curve, was restricted to be uniform in the interval (-10,1) The posterior distributions of the parameters were simulated by Markov Chain Monte Carlo, MCMC, using the AD Model Builder program. For selected values of spawning stock biomass the distribution of predicted recruitment was simulated. From this distribution the confidence limits of the predictions were calculated.

The advantage of Bayesian approach compared to the maximum likelihood is that one gets exact estimates of the uncertainties in contrast to approximate ML values. The drawback of the Bayesian method is the subjectivity with respect to the choice of priors. However, simulations with other prior distributions indicated that the results were not sensitive to the choice of prior distributions.

The residual variance was not estimated using the Bayesian approach, which would have been an improvement of the method.

Considering stock-recruitment relationships the correlation between estimated parameters are often very high. In the case of North sea herring the correlation between the parameters α and β, describing the reproductivity at low biomass and the scale parameter, is rather high, about 0.8, indicating that the model is overparameterised., The shape parameter γ is not correlated to the other two parameters.

Using the revised Stock-Recruitment pairs, and a prior for g uniform on the interval (-10,0), the parameter estimates were:

a: 127.2
b: 0.001358
g: - 0.5786

Posterior distributions of the parameters are shown in Figure 3.1.2.1. The estimated stock-recruitment function is intermediate between the Beverton-Holt and the Ricker types, but is almost constant in most of the observed interval of biomass. The estimated parameter is probably sensitive to changes of the few recruitment values generated by large biomasses.

The residuals indicate that some autoregression may exist.

3.2 Nonparametric regression function estimation

Given the inherent uncertainty in the specification of a parametric stock - recruitment relationship, a nonparametric approach to function fitting is often preferable and more enlightening.

3.2.1 Locally weighted regression

Robust locally weighted regression is a method for smoothing a scatterplot, (y_i, x_i), i = 1, 2,..., n, in which the fitted value at x_k is the value of a polynomial fit to the data using weighted least squares, where the weight for (y_i, x_i) is large if x_i is close to x_k and small if it is not. A robust fitting procedure guards against deviant points distorting the smoothed points.

A way of smoothing two-dimensional scatterplots, using either robust or non-robust locally weighted regression, is given in Cleveland(1979). The method consists essentially in substituting the ordinate y_i, for each x_i, with the fitted value $\hat{y}_i$ of a d th degree polynomial fit obtained considering only the r nearest neighbours of x_i; in the fit, weights are used which decrease according to the distance of a point x_k from x_i. In the robust version further weights are introduced which are inversely related to the residuals of the above regression, and a second weighted fit is carried out; in this way suspect outliers are allowed to give only a little (or null, in the most extreme situations) contribution to the resulting smoothed plot.

The procedure can be iterated a number of times, each iteration being based on the results of the previous fit and on newly calculated robustness weights.

In practice the specification of the components for this method is rather arbitrary but Cleveland(1979) discusses the relevant aspects and draws the following conclusions:

a) The choice of d = 1 seems appropriate in most cases.

b) A suitable starting value for the proportion f of points on which to base the local fit is f = 0.5, although some other value should also be considered, with larger values giving more smoothed results, possibly distorting the actual pattern of the dependence between the ordinate and abscissa. However, an accurate choice of f seems to be a critical issue only in situations in which the resulting smoothed graph is to be used as the only possible description of the unknown form of the dependence of Y on X. On the other hand, when a smoothed version of a plot is required essentially to pick up a pattern, as in most graphical diagnostic procedures for the validation of a fitted model, an *exact* choice of f seems hardly relevant.

c) Convenient weight functions appear to be the bisquare defined by:

$B(x) = (1 - x^2)^2$; for $|x| < 1$

$= 0$; for $|x| \geq 1$

or the *tricube* function defined by

$T(x) = (1 - |x|^3)^3$; for $|x| < 1$

$= 0$; for $|x| \geq 1$

d) A formal stopping rule is not needed in practice. In most situations a small number of iterations is enough.

The method of summarising the scatterplot is appropriate when Y is the response or dependent variable and X is the explanatory variable. In cases in which neither variable can be designated as the response, the scatterplot can be summarised by plotting the smoothed points of Y given X and the smoothed points of X given Y. The smoothed points ($\hat{y}_i$, x_i) portray the location of the distribution of Y given $X = x_i$.

The results of applying robust locally weighted regression to the North Sea herring stock - recruitment pairs presented in ICES (1994) for the years 1947–93 are presented below. A sequence of smoothed recruits was estimated for the years 1947–93 using a robust locally weighted regression and plotted in the time domain give the graph in Figure 3.2.1.1. Plotting the nonparametric (depicted by the *dotted line*) estimates in 2-dimensions as the level of recruitment versus spawning stock biomass, together with the perception from XSA (depicted as a *circle*) reported in ICES (1994), produces the graph shown in Figure 3.2.1.2 and an obvious anomaly in the stock - recruitment plot; namely, a period of successful recruitment following the collapse of the fishery.

Further applications of the locally weighted regression to stock - recruitment pairs for North Sea stocks are presented in O'Brien *et al.* (1995).

3.3 Modelling time trends

The investigation of stock-recruitment relationships can result in functional models that are appealing when depicted in 2-dimensions as the level of recruitment versus spawning stock biomass. Translation of a fitted functional model to the third dimension of time may produce an estimated sequence of recruits which bears little resemblance to the time series of recruits used to estimate the 2-dimensional functional model. This may result from mis-specification of modelling assumptions when adopting a parametric model or the model used may have excluded important biological or environmental information which might account for any temporal effects. The functional form assumed might be inappropriate, and unaccounted for temporal changes in the form of the stock-recruitment relationship might be present.

In an attempt to detect time trends and autocorrelation, nonparametric hybrid estimators can be used as part of graphical diagnostic procedures. These are applied in the recruitment-time domain rather than in the R-S domain.

3.3.1 Hybrid estimators

The estimation of a regression function $m(t) = E(y|t)$, given observations at a fixed set of points, is a recurrent theme of data analysis. Typically, m(t) does not have a specified functional form and one may wish to have an estimation technique applicable for an arbitrary m(t). The term $E(y|t)$ denotes the expectation of a variable y conditional on a variable t. The conditioned variable in our case will denote time in years.

A variety of estimators has been proposed for m(.). The estimator

$$m_n(x) = \sum_{j=0}^{N}\left(\sum_{i=1}^{n} y_i \int_{s_{i-1}}^{s_i} \varphi_j(u)du\right)\varphi_j(x)$$

was originally proposed in Rutkowski(1982). The y_i are measurements of the unknown regression function m(.) made at points t_i such that $t_1 \leq t_2 \leq \ldots \leq t_n$. Assume that m(.) has compact support [c, d] where $t_i \in [c, d]$, $c < d$. Consider the transformation $x = 2\,t/(d - c) - (c + d)/(d - c)$ mapping [c, d] to [-1, 1], and let x_i be the transformed values of t_i and x be the transformed value of $t \in [c, d]$.

The estimators depend on two smoothing parameters which must be supplied *a priori*, the bandwidth and the truncation point N for the orthonormal expansion. The φ_j are chosen to be orthonormal polynomials. Given the values of the smoothing parameters, the algorithm of Azari and Müller(1995) will perform the efficient computation of smoothed points $\hat{y}_i$; for i = 1, 2,... n. A grid search algorithm may be employed to select suitable values of the smoothing parameters.

The smoothed points ($\hat{y}_i$, x_i) portray the location of the distribution of Y given $X = x_i$ and this may be transformed to portray the location of the distribution of Y given $T = t_i$. The smoothed points can be plotted by joining successive points by straight lines or by symbols at the points ($\hat{y}_i$, t_i). When the smoothed points are superimposed on a scatterplot, the first method provides greater visual discrimination with the points of the scatterplot but using lines raises the danger of an inappropriate interpolation. One possible approach is to use symbols initially when the data are being analysed; then if a particular plot is needed for further use the lines can be used if the initial plot indicates that linear interpolation would not lead to a distortion.

This class of hybrid orthogonal polynomial kernel estimators for nonparametric regression can be considered as an orthogonal series estimator based on orthogonal expansions on varying intervals, or as a kernel estimator with varying kernels [Azari *et al.*(1992)]. Silverman(1984) demonstrated the equivalent kernel interpretation of smoothing splines, while Lejeune(1985) and Müller(1987) presented similar results for the weighted local least squares method. The work of Azari et al.(1992) gives the equivalent kernel interpretation for orthogonal polynomial estimators, thus completing the picture where the kernel approach serves as a unifying principle, linking the other nonparametric curve estimation methods.

North Sea herring

The result of applying the hybrid estimator to the North Sea herring stock, using SSB and recruitment data from ICES (1994), is as follows.

A sequence of smoothed recruits was estimated for the years 1947–93 using a hybrid estimator and plotted in the time domain to give the graph in Figure 3.3.1.1 which is similar to the earlier Figure 3.2.1.1 but the hybrid estimator now exhibits a peak during the earlier part of the time series. Plotting the nonparametric (depicted by the *dotted line*) estimates in 2-dimensions as the level of recruitment versus spawning stock biomass, together with the perception from XSA (depicted as a *circle*) reported in ICES (1994), produces the graph shown in Figure 3.3.1.2 and clearly identifies the period of successful recruitment following the collapse of the fishery.

3.3.2 Autocorrelation

Conditional on the spawning stock biomass, stock - recruitment models typically assume no effect of previous levels of recruitment on the present ones. Verifying that the hypothesis is, indeed, correct and, if not, with modifying it to take into account lagged time effects should be a necessary pre-requisite to formal model building.

In the presence of autocorrelation, typically, a parametric stock - recruitment model such as a Ricker or a Beverton-Holt curve is proposed and an autoregressive model of some order (typically, one) is assumed for the residuals [ICES (1996)]. For North Sea herring, such a Beverton-Holt has been fitted in the past but for other stocks this may not, however, capture the nature of the autocorrelation and the following alternative has been proposed.

Schnute and Richards (1995) in their formulation of a stochastic catch-age model assigned process error to recruitment through the following formulation:

$$R_t = R^{1-\gamma} R_{t-1}^{\gamma} e^{\sigma_1 \delta_t}$$

(1)

leading to recruitment equations derived from the log-normal autoregressive process

$$\ln R_t = \ln R + \gamma (\ln R_{t-1} - \ln R) + \sigma_1 \delta_t$$

(2)

with parameters (R, γ, σ_1), where *noise* is introduced by the independent standard normal variates δ_t. The equation (2) implies that ln R_t has the following conditional means and variances:

$E[\ln R_t \mid R_{t-1}] = (1 - \gamma) \ln R + \gamma \ln R_{t-1}$

$var[\ln R_t \mid R_{t-1}] = \sigma_1^2$

and unconditional means and variances:

$E[\ln R_t] = \ln R$

$var[\ln R_t] = \sigma_1^2 / (1 - \gamma^2)$

When $\gamma = 0$, ln R_t is obviously independent of R_{t-1} and follows a normal distribution with mean ln R and variance σ_1^2. When $\gamma = 1$, equation (2) corresponds to a random walk with finite conditional first-order and second-order moments but infinite unconditional variance. The equation (2) provides a simple process for generating correlated recruitments; the nonstationary case $\gamma = 1$ allows recruitments to drift toward high or low levels over long time periods.

3.3.3 Stationary time series models

There are occassions when stock and recruitment data may neither yield information on the relationship between stock and recruitment at low spawning stock biomass nor indicate the level of spawning stock biomass at which recruitment would be expected to start to show a decline. This is not the case for North Sea herring but can be seen in other stocks such as North Sea plaice [O'Brien(1997 c)]; Irish Sea plaice and sole[O'Brien(1997a,b]; and North Sea sandeel [O'Brien et al.(1997d)]. For these later four stocks, recruitment can be modelled as a stationary univariate time series apparently independent of the perceived spawning stock biomass using the class of *autoregressive integrated moving-average* (ARIMA) models.

Box and Jenkins(1976) give a paradigm for fitting ARIMA models, which is to iterate through the following steps:

(a) model identification;
(b) estimation of model parameters; and
(c) diagnostic checking.

These steps are repeated until a satisfactory model is found. Initial model identification is achieved through the interaction of theory and practice leading to the fit of a tentative model. Diagnostic checks are applied with the object of uncovering possible lack of fit and diagnosing the cause. If any inadequacy is found, the iterative cycle of identification, estimation and diagnostic checking is repeated until a suitable representation is found. It is important, however, that in practice one employs the *smallest possible* number of parameters for adequate representation of a time series. The role played by this principle of *parsimony* in the use of parameters is central to good modelling practice.

3.3.4 State classification

Besides fitting parametric and nonparametric stock - recruitment functions, a classification of stock status based on stock - recruitment pairs can be considered.

Rothschild and Mullen(1985) consider a 2 x 2 classification that utilizes the median stock size and the median recruitment to partition the Stock - recruitment data of a single species into four regions or *states*:

S_1 = low stock/low recruitment;
S_2 = low stock/high recruitment;
S_3 = high stock/high recruitment; and
S_4 = high stock/low recruitment.

Depending on the quality and quantity of data available, the nonparametric classification would enable the probability of transition from one state to another state to be estimated; i.e., to answer the question: if in a particular year, a stock - recruitment datum is in a particular state, how likely is it to stay in the same state, or to move to another state? Furthermore, probability transition matrices might be used to gain insight into the short-term behaviour of the relationship between stock and recruitment. For some species there might appear to be no evidence that the transitions among states are not random, whilst for others, future transitions may appear to be dependent upon present states. Steady-state probabilities might be calculated to indicate how representative the data are of the theoretical distribution based upon the probability transition matrix; and expected first-passage times calculated to indicate how long it should take to return to a particular state given that the species is in that particular state.

For this type of nonparametric classification, it is easy to envisage implementing such a scheme as a useful management tool. However, its application may necessitate the substitution of the 2 x 2 classification by an m x n classification where the choice of m and n might be dependent upon the characteristics of the species under investigation.

3.4 Uncertainty

Fishery systems are stochastic, errors are made when sampling, our knowledge and ability to model is imperfect and implementation of management following an assessment is subject to error. Rosenberg and Restrepo (1996) identified and categorised the different sources of error.

Measurement error: The error in sampled quantities such as catch or biological characteristics (e.g., growth or maturity)

Process Noise: The underlying stochasticity in the population dynamics such as the variability in recruitment

Model mis-specification: The mis-specification of model structure.

Estimation Error: The inaccuracy and imprecision in the estimated population parameters such as stock abundance or fishing mortality rate. Can result from any of the above uncertainties but is also related to the information content of the data. For example the estimated slope at the origin in a stock recruitment relationship will be poorly determined if data are not available for low stock sizes.

Implementation Deviation: Results from variability in the resulting implementation of a management policy, i.e., inability to exactly achieve a target harvest strategy.

Implementation deviance and model estimation error can cause the perceived and actual states of the system to diverge.

Spawning stock biomass and recruit series are not observations but are estimated via a VPA calibration procedure. They will therefore include uncertainty of due to types of error listed above.

Common practice in ICES (Cook 1998, Gabriel 1994) when estimating reference points is to perform a Monte Carlo Simulation of mean or steady state vectors (i.e., the weight, maturity natural mortality and selectivity at age) and to bootstrap the stock-recruit pairs. Detailed case studies (ICES 1997a, ICES 1998b) have shown, however, that bootstrapping stock-recruit data may not produce the correct level of uncertainty in the simulated distribution of reference points. Estimates of uncertainty obtained from a combined bootstrapped/Monte Carlo assessment are in many case less than those obtained by current working group practice. Combining a bootstrap of the catch-at-age analysis procedure with a Monte Carlo can allow the uncertainty in measurement, processes, modelling and lack of knowledge to be better captured (Powers and Restrepo, 1993).

Stock projections are made by a Monte Carlo simulation of the steady state vectors (with CVs estimated from data in the recent period) for a given stock recruit model and multiplier on the selectivity vector (Reeves and Cook, 1994). The choice of recruitment model will of course be of great importance in determining the outcome of the projections and careful consideration of the sources of errors listed above needs to be done.

4 MODEL CHOICE FOR SPECIFIC PURPOSES

4.1 Biological reference points representing limits to exploitation

The group discussed ways of estimating two BRPs that can be used as limits to fishing mortality. The first BRP is F_{crash}, the fishing mortality that would drive the population to extinction; the second is the fishing mortality that will drive the stock to a specified biomass such as MBAL. F_{crash} is estimated from g_0, the slope-at-origin of the stock-recruit relationship. Bravington introduced a working paper (WD #4) that describes problems with existing methods of estimating g_0, and develops a new method ("CONCR") specifically designed to make inferences about g_0. In particular, parametric stock-recruit models (see Section 3.1.1) are liable to give untrustworthy estimates of g_0, because they are not designed for this purpose; parametric models are meant to give reasonable fits away from the origin, and to be mathematically convenient. Different mathematical forms can give almost identical fits away from the origin, yet lead to very different estimates of slope-at-origin. Specifying a particular mathematical form is therefore a somewhat arbitrary process that nevertheless has major implication for slope-at-origin.

There are alternatives to parametric models. The g_{loss} method fits a smoother through the stock-recruit data (Section 3.2), then estimates g_0 as the slope of a linear extrapolation from the left endpoint of the smooth fit to the origin. Lower confidence intervals are obtained by bootstrapping. While the g_{loss} approach does not rely on arbitrary choices about functional form, there are problems with using it to make inferences about g_0 (O'Brien 1997d). Some of the problems are to do with implementation: how to organize the bootstrap, how much smoothing to use, etc. There are also some more fundamental problems. For example, the fitted smoother-plus-extrapolation may not be concave; or a high proportion of the fitted curves in the bootstrap resamples may be biologically implausible; should the g_{loss} estimates from these resamples be used when constructing the bootstrap distribution?

CONCR is also a nonparametric method based on smoothing, but is designed to avoid the above difficulties. CONCR assumes only that the stock-recruit relationship is concave, smooth, and passes through the origin. Concavity is a biologically reasonable assumption for most stocks, though it relies on having a "stock" measure that is highly correlated with egg production. If g_0 is very small, then it is impossible to find any concave curves that fit the data well. On the other hand, if g_0 is large, it is always possible to find a reasonable-looking smooth concave fit, by "bending the curve downwards" to the left of the lowest observed stock size. Smoothness is also biologically reasonable, although the precise extent of smoothing is not easy to specify *a priori*. Fortunately, CONCR is much less sensitive to degree of smoothing than conventional smoothers like g_{loss}. If very little smoothing is used, g_{loss} will almost interpolate the data. However, the concavity requirement means that CONCR can never do this, however little smoothing is used. The fitted curve from CONCR does not change much as smoothing is reduced, but eventually numerical problems are encountered when too little smoothing is used.

By experimenting with different values of slope-at-origin, and finding the best-fitting concave curve at each slope-of-origin that is considered, a likelihood profile can be constructed describing goodness-of-fit as a function of g_0. This profile can then be used to find lower confidence limits for g_0. However, it is not reasonable to try to find point estimates or upper confidence intervals; there is not enough information content in stock-recruit data to permit this unless one is prepared to make a parametric assumption.

It is also possible to investigate fishing mortalities that will drive stocks to a specified biomass, e.g., F_{MBAL}. This requires inferences about R_{MBAL}, the height of the stock-recruit curve at MBAL. It is in principle easier to make inferences about R_{MBAL} than about g_0, and indeed CONCR can be adapted to provide point estimates of R_{MBAL} as well as lower confidence limits. Since MBAL will normally fall within or close to the range of observed stock sizes, inferences about R_{MBAL} ought to be similar whatever method is used, provided that the method is statistically defensible and the fit to the data is plausible.

Whatever method is used to make inferences about limiting fishing mortalities, spawner-per-recruit curves are needed (or fecundity-per-recruit, as appropriate). If there is evidence of density-dependent growth (as seems to be the case with North Sea herring as dicussed in Section 2.1), then these spawner-per-recruit curves need to be "tuned" to match the conditions of the stock in the long term limit. In other words, if F_{crash} is being considered, the spawner-per-recruit curve needs to be generated using the weights-at-age that are predicted when stock sizes are very low. When F_{MBAL} is being considered, the weights-at-age should correspond to those expected when SSB is equal to MBAL.

The group considered that CONCR is very promising, although its behaviour is not fully understood yet and some further work is required to investigate e.g., sensitivity to points with high stock sizes. If no data is available for stock sizes 'near' the origin, then CONCR will suggest a biological reference point that appears quite conservative. This is arguably a fair reflection of the low information content in such datasets; when little information is available, the precautionary approach is to play it safe. It was pointed out that, for herring, there is relatively good information on how recruitment declines with low stock sizes; therefore, relative to other stocks, one would expect comparatively little difference between different approaches to making inferences about g_0 for North Sea herring. CONCR may be of most value with other stocks where the data are not as informative.

4.2 Equilibrium reference points

Biological reference points related to long term steady state can be derived from steady state vectors for selection, natural mortality, growth and maturity alone (F0.1, Fmax) or from the equilibrium between SSB produced by each recruit and the number of recruits produced by each unit SSB (FMSY). Traditionally, both the SSB per recruit and the stock-recruitment relation have been taken as deterministic functions, and the equilibrium determined as a critical point in the stock-recruitment dynamics.

Recruitment variation, however, can mean that equilibrium reference points underestimate properties such as fishing mortality or spawner per recrtuit. Recruitment variability has been included in non-equilibrium and transitional reference points (Mace et al, 1996, Powers, 1996, Ehrhardt and Legault, 1997) by allowing the age specific abundances to incorporate variations in year-class strength. Uncertainty in weight and maturity at age has also been included (ICES 1997b) by running a projection for a given F multplier until the distributions of SSB and recruitment no longer vary over time (i.e., are stationary) and using the probability distributions obtained. Alternatively, a distribution of SSB's can be transferred by the stochastic stock-recruitment relationship, and the distribution of SSB' s transferred to a distribution of recruitments until convergence (ICES 1997b). When applying stochastic relations between SSB and recruitment, the equilibrium is represented by a stationary bivariate distribution of SSB's and recruitments. From such distributions, the long term risk of undesirable events, e.g., SSB falling below some limit, can be derived.

When using stock-recruitment models, in particular for evaluating the risk of unwanted future events, it is important to distinguish the uncertainty due to error in the model specification and parameters from the natural variations in the recruitment. Primarily, the intention is to outline the distributions associated with the natural variations. The other sources of error will render these distributions uncertain.

4.3 Medium term simulations

Such simulations, covering the transition period where both the initial state of the stock and the future recruitment are influential, has become increasingly important for evaluating management measures, not the least in relation to the precautionary approach.

Such simulations are in principle done as Monte-Carlo stock projections with specified rules for catch or F- constraints, where at least a stochastic stock-recruitment relationship is included. One may also include variations in growth and maturity as stochastic elements, with or without models relating these to the current state of the stock. The initial state may be treated as stochastic, according to the estimated distribution of the state variables for the stock. Including uncertainty in future management may be done by models of management behavior, but it may be more realistic to just explore the robustness to management misbehavior. Finally, updated assessments may be simulated for each year, which should then include updating the stock-recruitment relation.

With regard to stock-recruitment relationships in this context, a few points may be made.

1. The assumed stock-recruitment should render the residuals uncorrelated to the state of the stock, since these residuals are simulated by random numbers generated without regard to the state of the stock. This can be introduced as a constraint in the parameter estimation, but it is probably wiser to take such correlations as an indication that a better stock - recruitment function should be found.

2. Whatever stock-recruitment function is used, it is not advisable to apply it outside the range where it is supported by data. In particular, if the range of SSB's is not very broad, the usual models may be over-parameterised, and it is not possible to distinguish models with widely different properties outside this range.

3. Time trends pose special problems, which could only be adressed superficially by this Study Group. For some stocks, there clearly has been periods where the recruitment has been poorer (or better) than expected for a whole range of years. In the case of North Sea herring, there seems to have been a period with poor recruitment in the 1970'ies and one with very good recruitment in the 1980'ies, although this may to some extent be explained by inadequate data (see Section 2.1.3). For some stocks, it may be possible to relate such peroids to environmental changes, in temperature, currents, nutrition, or in migrating routes and competition between species. It is still hard to find examples where such influences can be modelled to the extent that they can be included in simulation models. It may be relevant, however, to issue warnings that a management regime will have to be revised in periods of poor (or good) recruitment.

4. When estimating parameters in a stock recruitment function, some distribution is assumed for the residuals. If chosen properly, this distribution will be a fair representation of the natural variations in recruitment in most years. It is not self-evident, however, that the tails of this distribution will represent the unusual year-classes properly. For some stocks, a small number of outstanding year classes actually dominate the stock dynamics, and since these outstanding year-classess are rare, there is hardly data to evaluate their statistical properties. In other stocks, like North Sea herring, where such outstanding year classes have not been experienced, incuding them in simulations will have a profound influence on the perception of the future stock dynamics. A possible measure may be to truncate the distribution at some percentage of the largest recruitment residual observed.

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6 WORKING DOCUMENTS FOR THE STUDY GROUP ON STOCK-RECRUITMENT RELATIONSHIPS OF THE NORTH SEA HERRING

WD #1: Needle, C. L. & K. R. Patterson. SOP errors in herring assessments: causes, remedies and implications..

WD #2: Skagen, D.W. How reliable are estimates of stock-recruit function parameters?

WD#3: Lewy,.P & Nielsen, A. A Bayesian approach for estimation of stock-recruitment parameters and associated precision of predicted recruitment using a Deriso/Schnute model.

WD #4: Bravington, M.V. A minimally-subjective method for lower confidence intervals on the slope-at-origin of stock-recruitment relationships.

Table 2.1.1.1. Estimated SOP discrepancies for the total North Sea herring stock from 1947–1997. All data are in tonnes. Data from 1947–1959 are taken unchanged from ICES (1977); data from 1960–1997 are taken from ICES (1997).

Year	SOP	Landings	L/SOP	Year	SOP	Landings	L/SOP
1947	1057746.8	581760	0.55	1973	463442	484000	1.04
1948	842263.9	502100	0.60	1974	266296.8	275100	1.03
1949	894786.2	508500	0.57	1975	292242.5	312800	1.07
1950	764388.1	491700	0.64	1976	166577.6	174800	1.05
1951	917191.6	600400	0.65	1977	55104.7	46000	0.83
1952	923854.1	664400	0.72	1978	13367.6	11000	0.82
1953	889549.3	698500	0.79	1979	25241.5	25100	0.99
1954	994356.3	762900	0.77	1980	77390.2	70764	0.91
1955	862084.8	806400	0.94	1981	176293	174879	0.99
1956	860355.5	675200	0.78	1982	269181.35	275079	1.02
1957	794311.1	682900	0.86	1983	417046.05	387202	0.93
1958	789316.7	670500	0.85	1984	451915.45	428631	0.95
1959	1125537.3	784500	0.70	1985	639454.3	613780	0.96
1960	823638.1	696200	0.85	1986	763649.2	671488	0.88
1961	790606.9	696700	0.88	1987	805787.1	792058	0.98
1962	734871.2	627800	0.85	1988	1033429.2	887686	0.86
1963	615876	716000	1.16	1989	814286.6	787899	0.97
1964	928369.6	871200	0.94	1990	678775.95	645229	0.95
1965	1343636.9	1168800	0.87	1991	671060.4	658008	0.98
1966	958788.1	895500	0.93	1992	713484.2	716799	1.00
1967	817683.9	695500	0.85	1993	688146.8	671397	0.98
1968	900935.5	717800	0.80	1994	596601.3	568234	0.95
1969	528853.6	546700	1.03	1995	649130.1	639146	0.98
1970	543766.5	563100	1.04	1996	306725.5	306157	1.00
1971	558968.4	520100	0.93	1997	247962.1	247909	1.00
1972	457564	497500	1.09				

Table 2.1.2.1. Historic values of mean lengths at age reported in Belgian fisheries, operating mainly in the Southern and Central North Sea (Gilis, 1947-59), and mean lengths reported by Saville (1977) for fisheries in the Buchan area.

a. Belgian Fishery

Rings	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959
1						207.0		217.0			221.3	225.8	217.0
2	227.8	230.9	233.0	238.0	242.0	239.0	242.0	242.0	247.0	223.0	246.9	241.8	237.5
3	245.7	248.2	249.0	248.0	259.0	255.0	261.0	260.0	262.0	238.0	264.6	262.6	264.0
4	257.2	255.9	261.0	258.0	266.0	268.0	272.0	275.0	276.0	260.0	280.4	273.6	279.0
5	265.0	264.9	267.0	266.0	272.0	271.0	279.0	289.0	287.0	272.0	288.3	291.3	287.0
6	272.7	269.8	273.0	273.0	279.0	276.0	282.0	287.0	292.0	283.0	293.0	292.8	292.5
7		273.1	275.0	279.0	282.0	279.0	286.0	290.0	294.0	289.0	297.4	299.0	294.5
8		272.7	279.0	282.0	278.0	281.0	289.0	296.0	296.0	295.0	300.1	307.3	300.5
9		274.8	282.0	283.0	285.0		292.0	298.0	299.0	295.0	302.8	300.7	304.5

b. Buchan Fishery

Rings	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959
1													
2	255.5	247.1	240.0	247.8	254.8	260.0	257.0	260.6	257.8	259.8	267.5	260.7	257.0
3	264.6	264.3	246.1	252.4	265.6	273.2	272.7	277.9	277.3	276.2	272.7	272.8	271.2
4	272.2	270.5	265.8	261.3	267.8	281.4	283.0	285.9	290.2	288.8	285.6	283.9	287.5
5													
6													
7													
8													
9													

Table 2.1.2.2. Calculation of density-dependent growth coefficient, K.
N: VPA-estimated population abundance, ages 2+, as used in the density-dependent growth model.

	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959
N	38.4061	31.7102	31.252	23.23351	18.04535	17.61369	15.41113	14.6365	14.26366	12.72668	12.21924	9.07868	20.69329
exp(alpha.N/Nmax)	1.288554	1.225558	1.219873	1.157207	1.123908	1.12445	1.10828	1.102559	1.093765	1.087397	1.083324	1.063532	1.133267
K	0.854094	0.812339	0.80857	0.767033	0.744962	0.745321	0.734603	0.730811	0.724982	0.720761	0.718061	0.704942	0.751165
B 2+	6735.085	5403.477	5279.939	3878.913	3103.256	3116.063	2731.264	2593.765	2381.029	2225.902	2126.204	1636.351	3323.566
exp(alpha.B/Bmax)	1.288554	1.225558	1.219873	1.157207	1.123908	1.12445	1.10828	1.102559	1.093765	1.087397	1.083324	1.063532	1.133267

N max: 38.4061
B max: 6735.085

MODEL PARAMETERS

			Variance
	alpha	-0.25352	0.000811
	Loo Belgium	309.3632	
	Loo Scotland	316.6418	
VB	K	0.411234	
	L1 Belgium	217.812	
	L1 Scotland	235.9793	

Table 2.1.2.3. Calculation of Weight at Age 1947 - 1959

Fitted Values for Length at Age: Belgium

	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959
1	217.812	217.812	217.812	217.812	217.812	217.812	217.812	217.812	217.812	217.812	217.812	217.812	217.812
2	231.1699	231.1699	234.9926	235.3377	239.1404	241.1611	241.1282	242.1094	242.4566	242.9902	243.3767	243.6238	244.8249
3	242.5787	242.5787	245.8437	249.2294	252.5832	257.0499	258.5307	259.2375	260.2134	260.8571	261.5241	261.9808	263.0207
4	252.3229	252.3229	255.1116	258.0033	263.2386	267.0642	270.373	272.0215	272.7308	273.7305	274.4019	275.0118	275.9614
5	260.6454	260.6454	263.0272	265.497	269.9684	275.0021	277.8369	280.7209	282.0735	282.8054	283.6805	284.2588	285.1475
6	267.7536	267.7536	269.7879	271.8973	275.7163	280.0156	283.7532	286.2039	288.4311	289.5786	290.2214	290.9215	291.6661
7	273.8247	273.8247	275.5621	277.3638	280.6256	284.2976	287.4898	290.55	292.4381	294.1878	295.1033	295.6182	296.3628
8	279.01	279.01	280.4939	282.0327	284.8186	287.9548	290.6813	293.2949	295.6143	297.0928	298.4254	299.1237	299.6738
9	283.4387	283.4387	284.7061	286.0204	288.3998	291.0784	293.4071	295.6394	297.6203	299.3955	300.5192	301.5092	302.1449

Fitted Values for Length at Age: Scotland

	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959
1	235.9793	235.9793	235.9793	235.9793	235.9793	235.9793	235.9793	235.9793	235.9793	235.9793	235.9793	235.9793	235.9793
2	247.7484	247.7484	251.1165	251.4205	254.7709	256.5513	256.5223	257.3868	257.6927	258.1629	258.5034	258.7211	259.7794
3	257.8003	257.8003	260.677	263.66	266.6149	270.5504	271.8551	272.4778	273.3376	273.9048	274.4925	274.8948	275.8111
4	266.3856	266.3856	268.8426	271.3903	276.003	279.3737	282.2889	283.7413	284.3663	285.247	285.8386	286.376	287.2126
5	273.7183	273.7183	275.8168	277.9928	281.9324	286.3674	288.8651	291.406	292.5978	293.2426	294.0137	294.5232	295.3062
6	279.9811	279.9811	281.7734	283.6319	286.9967	290.7846	294.0777	296.2369	298.1992	299.2103	299.7766	300.3934	301.0495
7	285.3301	285.3301	286.8609	288.4482	291.3221	294.5574	297.3699	300.0661	301.7297	303.2713	304.0779	304.5316	305.1876
8	289.8986	289.8986	291.2061	292.5618	295.0164	297.7796	300.1818	302.4846	304.5281	305.8308	307.0049	307.6201	308.1048
9	293.8006	293.8006	294.9173	296.0752	298.1717	300.5317	302.5834	304.5502	306.2956	307.8596	308.8497	309.7219	310.2821

Residuals- Belgium

Average:		1947	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959
0.000386	1						0.002592		1.4E-05			0.000257	0.001281	1.4E-05
	2	0.000216	1.36E-06	7.25E-05	0.000127	0.000141	8.1E-05	1.3E-05	2.04E-07	0.000345	0.00737	0.000204	5.65E-05	0.000923
	3	0.000163	0.000525	0.000163	2.45E-05	0.000629	6.41E-05	9.04E-05	8.63E-06	4.68E-05	0.008409	0.000139	5.57E-06	1.38E-05
	4	0.000366	0.000198	0.000521	1.59E-10	0.000109	1.22E-05	3.6E-05	0.000119	0.000142	0.002648	0.000464	2.65E-05	0.00012
	5	0.000275	0.000262	0.000225	3.58E-06	5.62E-05	0.000215	1.75E-05	0.000845	0.0003	0.001518	0.000255	0.00059	4.19E-05
	6	0.000335	5.8E-05	0.00014	1.64E-05	0.00014	0.000209	3.84E-05	7.72E-06	0.000151	0.000528	9.08E-05	3.93E-05	8.15E-06
	7		7.02E-06	4.17E-06	3.46E-05	2.39E-05	0.000354	2.7E-05	3.59E-06	2.84E-05	0.000317	5.88E-05	0.000129	3.98E-05
	8		0.000523	2.85E-05	1.34E-08	0.000587	0.000598	3.36E-05	8.43E-05	1.7E-06	5E-05	3.23E-05	0.000733	7.58E-06
	9		0.000958	9.12E-05	0.000113	0.000141		2.31E-05	6.33E-05	2.14E-05	0.000219	5.47E-05	7.83E-06	6.03E-05

Residuals- Scotland

Average:		1947	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959
0.000425	1													
	2	0.000949	6.87E-06	0.00205	0.00021	1.3E-08	0.000178	3.46E-06	0.000154	1.73E-07	4E-05	0.00117	5.81E-05	0.000116
	3	0.000678	0.00062	0.003311	0.001905	1.45E-05	9.5E-05	9.63E-06	0.000388	0.000207	6.96E-05	4.29E-05	5.85E-05	0.000284
	4	0.000466	0.000235	0.00013	0.001436	0.00091	5.22E-05	6.33E-06	5.74E-05	0.000412	0.000153	6.97E-07	7.54E-05	1E-06
	5													
	6													
	7													
	8													
	9													

Combined Lengths at Age

Weighting to Northern Area

	0.5	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**
1	226.8956	226.8956	226.8956	226.8956	226.8956	226.8956	226.8956	226.8956	226.8956	226.8956	226.8956	226.8956	226.8956
2	239.4591	239.4591	243.0546	243.3791	246.9557	248.8562	248.8252	249.7481	250.0747	250.5766	250.94	251.1725	252.3021
3	250.1895	250.1895	253.2604	256.4447	259.599	263.8001	265.1929	265.8577	266.7755	267.3809	268.0083	268.4378	269.4159
4	259.3543	259.3543	261.9771	264.6968	269.6208	273.2189	276.3309	277.8814	278.5486	279.4888	280.1203	280.6939	281.587
5	267.1819	267.1819	269.422	271.7449	275.9504	280.6848	283.351	286.0635	287.3356	288.024	288.8471	289.391	290.2268
6	273.8674	273.8674	275.7806	277.7646	281.3565	285.4001	288.9154	291.2204	293.3152	294.3945	294.999	295.6574	296.3578
7	279.5774	279.5774	281.2115	282.906	285.9739	289.4275	292.4299	295.3081	297.0839	298.7295	299.5906	300.0749	300.7752
8	284.4543	284.4543	285.85	287.2973	289.9175	292.8672	295.4315	297.8898	300.0712	301.4618	302.7151	303.3719	303.8893
9	288.6197	288.6197	289.8117	291.0478	293.2857	295.8051	297.9952	300.0948	301.958	303.6276	304.6844	305.6155	306.2135

Conversion to weights (by W = 0.00667* L(cm)^3.0904) =
Estimated stock weights at age

	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959
1	103.3	103.3	103.3	103.3	103.3	103.3	103.3	103.3	103.3	103.3	103.3	103.3	103.3
2	122.0	122.0	127.8	128.3	134.2	137.5	137.4	139.0	139.5	140.4	141.0	141.4	143.4
3	139.7	139.7	145.1	150.8	156.6	164.6	167.3	168.6	170.4	171.6	172.9	173.7	175.7
4	156.2	156.2	161.1	166.3	176.1	183.5	190.0	193.3	194.7	196.8	198.2	199.4	201.4
5	171.2	171.2	175.7	180.4	189.2	199.4	205.3	211.4	214.4	215.9	217.9	219.1	221.1
6	184.8	184.8	188.8	193.0	200.9	209.9	218.0	223.4	228.4	231.1	232.5	234.1	235.8
7	197.0	197.0	200.5	204.3	211.2	219.2	226.3	233.3	237.6	241.7	243.9	245.1	246.9
8	207.8	207.8	210.9	214.3	220.4	227.4	233.6	239.6	245.1	248.6	251.8	253.5	254.9
9	217.3	217.3	220.1	223.0	228.4	234.5	239.9	245.2	249.9	254.2	256.9	259.4	260.9

Table 2.1.2.4. Estimated SOP discrepancies for the total North Sea herring stock from 1947–1997 with adjusted mean catch weights-at-age. Data from 1947–1959 are derived in Section 2.1.2; data from 1960–1997 are taken from ICES (1997).

Year	Total	Landings	L/SOP	Year	Total	Landings	L/SOP
1947	811177.35	581760	0.7172	1973	463442	484000	1.0444
1948	642141.07	502100	0.7819	1974	266296.8	275100	1.0331
1949	707959.27	508500	0.7183	1975	292242.5	312800	1.07032
1950	627134.83	491700	0.7840	1976	166577.6	174800	1.0494
1951	809139.97	600400	0.7420	1977	55104.7	46000	0.8348
1952	873405.26	664400	0.7607	1978	13367.6	11000	0.8229
1953	884408.1	698500	0.7898	1979	25241.5	25100	0.9944
1954	1022788.1	762900	0.7459	1980	77390.2	70764	0.9144
1955	960424.78	806400	0.8396	1981	176293	174879	0.9920
1956	945220.1	675200	0.7143	1982	269181.35	275079	1.0219
1957	867417.73	682900	0.7873	1983	417046.05	387202	0.9284
1958	1010527.7	670500	0.6635	1984	451915.45	428631	0.9485
1959	1277136	784500	0.6143	1985	639454.3	613780	0.9598
1960	823638.1	696200	0.8453	1986	763649.2	671488	0.8793
1961	790606.9	696700	0.8812	1987	805787.1	792058	0.9830
1962	734871.2	627800	0.8543	1988	1033429.2	887686	0.8590
1963	615876	716000	1.1626	1989	814286.6	787899	0.9676
1964	928369.6	871200	0.9384	1990	678775.95	645229	0.9506
1965	1343636.9	1168800	0.8699	1991	671060.4	658008	0.9805
1966	958788.1	895500	0.9340	1992	713484.2	716799	1.0046
1967	817683.9	695500	0.8506	1993	688146.8	671397	0.9757
1968	900935.5	717800	0.7967	1994	596601.3	568234	0.9525
1969	528853.6	546700	1.0337	1995	649130.1	639146	0.9846
1970	543766.5	563100	1.0356	1996	306725.5	306157	0.9981
1971	558968.4	520100	0.9305	1997	247962.1	247909	0.9998
1972	457564	497500	1.0873				

Table 2.2.1

Output Generated by ICA Version 1.4

SOP correction not applied

Catch in Number

AGE	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961
0	0.	0.	0.	0.	0.	0.	150.	219.	164.	96.	279.	97.	0.	195.	1269.
1	0.	3.	0.	0.	462.	722.	1023.	1451.	2072.	1697.	1483.	4279.	1609.	2393.	336.
2	494.	247.	478.	535.	660.	1346.	1322.	1493.	1931.	1860.	1644.	1029.	4934.	1142.	1889.
3	415.	672.	644.	1039.	959.	576.	1003.	1111.	1032.	1221.	736.	999.	488.	1967.	480.
4	638.	328.	396.	617.	1255.	610.	474.	591.	479.	516.	644.	322.	497.	166.	1456.
5	526.	601.	287.	290.	630.	652.	386.	361.	337.	249.	344.	461.	233.	168.	124.
6	756.	487.	652.	254.	262.	464.	473.	330.	232.	194.	207.	147.	249.	113.	158.
7	431.	400.	462.	331.	142.	236.	278.	379.	120.	104.	147.	73.	120.	126.	61.
8	1311.	917.	1037.	597.	445.	554.	392.	511.	215.	292.	253.	118.	301.	271.	144.

x 10 ^ 6

Catch in Number

AGE	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976
0	142.	443.	497.	157.	375.	645.	839.	112.	898.	684.	750.	289.	996.	264.	238.
1	2147.	1262.	2972.	3209.	1383.	1674.	2425.	2503.	1196.	4379.	3341.	2368.	846.	2461.	127.
2	270.	2961.	1548.	2218.	2570.	1172.	1795.	1883.	2003.	1147.	1441.	1344.	773.	542.	902.
3	797.	177.	2243.	1325.	741.	1365.	1494.	296.	884.	663.	344.	659.	362.	260.	117.
4	335.	158.	148.	2039.	450.	372.	621.	133.	125.	208.	131.	150.	126.	141.	52.
5	1082.	81.	149.	145.	890.	298.	157.	191.	50.	27.	33.	59.	56.	57.	35.
6	127.	230.	95.	152.	45.	393.	145.	50.	61.	31.	5.	31.	22.	16.	6.
7	145.	22.	256.	118.	65.	68.	163.	43.	8.	27.	0.	4.	5.	9.	4.
8	173.	93.	84.	49.	332.	254.	106.	53.	24.	13.	2.	2.	3.	5.	1.

x 10 ^ 6

Table 2.2.1 (Cont'd)

Catch in Number

AGE	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
0	257.	130.	542.	1263.	9520.	11957.	13297.	6973.	4211.	3725.	8229.	3165.	3058.	1303.	2387.
1	144.	169.	159.	245.	872.	1116.	2449.	1818.	3253.	4801.	6836.	7867.	3146.	3020.	2139.
2	45.	5.	34.	134.	284.	299.	574.	1146.	1326.	1267.	2137.	2233.	1594.	899.	1133.
3	186.	6.	10.	92.	57.	230.	216.	441.	1182.	841.	668.	1091.	1364.	779.	557.
4	11.	5.	10.	32.	40.	34.	105.	202.	369.	466.	467.	384.	809.	861.	549.
5	7.	0.	2.	22.	29.	14.	26.	81.	125.	130.	246.	256.	212.	388.	501.
6	4.	0.	0.	2.	23.	7.	23.	23.	44.	62.	75.	128.	124.	80.	205.
7	2.	0.	1.	1.	19.	8.	13.	25.	20.	21.	24.	38.	61.	54.	39.
8	1.	1.	1.	1.	7.	5.	23.	30.	29.	28.	16.	24.	28.	41.	39.

x 10 ^ 6

Catch in Number

AGE	1992	1993	1994	1995	1996	1997
0	10331.	10265.	4499.	8426.	2429.	457.
1	2303.	3827.	1785.	1635.	1608.	527.
2	1285.	1176.	1783.	1573.	709.	680.
3	443.	609.	489.	898.	629.	496.
4	362.	306.	348.	242.	196.	259.
5	361.	216.	109.	121.	59.	94.
6	376.	226.	92.	55.	20.	25.
7	152.	188.	76.	41.	11.	12.
8	63.	13.	117.	126.	26.	2.

x 10 ^ 6

Table 2.2.1 (Cont'd)

Predicted Catch in Number

AGE	1992	1993	1994	1995	1996	1997
0	8940.0	9288.2	5754.7	9004.3	1630.9	676.8
1	1752.8	3204.3	2734.4	1941.9	1027.7	852.6
2	1204.0	1377.9	2073.3	1992.8	670.3	675.5
3	581.6	693.4	638.1	1079.4	558.4	307.7
4	437.5	284.6	269.7	279.2	252.7	190.5
5	391.2	210.7	108.7	116.1	63.8	84.9
6	356.7	200.4	85.8	49.9	28.4	22.7
7	141.0	181.4	81.0	39.0	12.1	10.1

x 10 ^ 6

Weights at age in the catches (Kg)

AGE	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961
0	0.01500	0.01500	0.01500	0.01500	0.01500	0.01500	0.01500	0.01500	0.01500	0.01500	0.01500	0.01500	0.01500	0.01500	0.01500
1	0.05000	0.05000	0.05000	0.05000	0.05000	0.05000	0.05000	0.05000	0.05000	0.05000	0.05000	0.05000	0.05000	0.05000	0.05000
2	0.12204	0.12204	0.12779	0.12832	0.13424	0.13746	0.13740	0.13898	0.13955	0.14041	0.14104	0.14145	0.14342	0.12600	0.12600
3	0.13975	0.13975	0.14511	0.15083	0.15663	0.16460	0.16730	0.16860	0.17041	0.17160	0.17285	0.17371	0.17567	0.17600	0.17600
4	0.15618	0.15618	0.16111	0.16634	0.17609	0.18345	0.18999	0.19330	0.19474	0.19678	0.19815	0.19941	0.20138	0.21100	0.21100
5	0.17121	0.17121	0.17569	0.18041	0.18918	0.19939	0.20530	0.21144	0.21435	0.21595	0.21786	0.21913	0.22109	0.24300	0.24300
6	0.18480	0.18480	0.18882	0.19305	0.20087	0.20992	0.21802	0.22344	0.22844	0.23105	0.23252	0.23413	0.23585	0.25100	0.25100
7	0.19697	0.19697	0.20055	0.20431	0.21123	0.21921	0.22632	0.23327	0.23764	0.24173	0.24389	0.24511	0.24688	0.26700	0.26700
8	0.21255	0.21255	0.21553	0.21865	0.22437	0.23093	0.23674	0.24240	0.24750	0.25141	0.25438	0.25645	0.25790	0.27100	0.27100

Table 2.2.1 (Cont'd)

Weights at age in the catches (Kg)

AGE	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976
0	0.01500	0.01500	0.01500	0.01500	0.01500	0.01500	0.01500	0.01500	0.01500	0.01500	0.01500	0.01500	0.01500	0.01500	0.01500
1	0.05000	0.05000	0.05000	0.05000	0.05000	0.05000	0.05000	0.05000	0.05000	0.05000	0.05000	0.05000	0.05000	0.05000	0.05000
2	0.12600	0.12600	0.12600	0.12600	0.12600	0.12600	0.12600	0.12600	0.12600	0.12600	0.12600	0.12600	0.12600	0.12600	0.12600
3	0.17600	0.17600	0.17600	0.17600	0.17600	0.17600	0.17600	0.17600	0.17600	0.17600	0.17600	0.17600	0.17600	0.17600	0.17600
4	0.21100	0.21100	0.21100	0.21100	0.21100	0.21100	0.21100	0.21100	0.21100	0.21100	0.21100	0.21100	0.21100	0.21100	0.21100
5	0.24300	0.24300	0.24300	0.24300	0.24300	0.24300	0.24300	0.24300	0.24300	0.24300	0.24300	0.24300	0.24300	0.24300	0.24300
6	0.25100	0.25100	0.25100	0.25100	0.25100	0.25100	0.25100	0.25100	0.25100	0.25100	0.25100	0.25100	0.25100	0.25100	0.25100
7	0.26700	0.26700	0.26700	0.26700	0.26700	0.26700	0.26700	0.26700	0.26700	0.26700	0.26700	0.26700	0.26700	0.26700	0.26700
8	0.27100	0.27100	0.27100	0.27100	0.27100	0.27100	0.27100	0.27100	0.27100	0.27100	0.27100	0.27100	0.27100	0.27100	0.27100

Weights at age in the catches (Kg)

AGE	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
0	0.01500	0.01500	0.01500	0.01500	0.00700	0.01000	0.01000	0.01000	0.00900	0.00600	0.01100	0.01100	0.01700	0.01900	0.01700
1	0.05000	0.05000	0.05000	0.05000	0.04900	0.05900	0.05900	0.05900	0.03600	0.06700	0.03500	0.05500	0.04300	0.05500	0.05800
2	0.12600	0.12600	0.12600	0.12600	0.11800	0.11800	0.11800	0.11800	0.12800	0.12100	0.09900	0.11100	0.11500	0.11400	0.13000
3	0.17600	0.17600	0.17600	0.17600	0.14200	0.14900	0.14900	0.14900	0.16400	0.15300	0.15000	0.14500	0.15300	0.14900	0.16600
4	0.21100	0.21100	0.21100	0.21100	0.18900	0.17900	0.17900	0.17900	0.19400	0.18200	0.18000	0.17400	0.17300	0.17700	0.18400
5	0.24300	0.24300	0.24300	0.24300	0.21100	0.21700	0.21700	0.21700	0.21100	0.20800	0.21100	0.19700	0.20800	0.19300	0.20300
6	0.25100	0.25100	0.25100	0.25100	0.22200	0.23800	0.23800	0.23800	0.22000	0.22100	0.23400	0.21600	0.23100	0.22900	0.21700
7	0.26700	0.26700	0.26700	0.26700	0.26700	0.26500	0.26500	0.26500	0.25800	0.23800	0.25800	0.23700	0.24700	0.23600	0.23500
8	0.27100	0.27100	0.27100	0.27100	0.27100	0.27450	0.27450	0.27450	0.28100	0.25700	0.28800	0.25800	0.26200	0.26850	0.26500

Table 2.2.1 (Cont'd)

Weights at age in the catches (Kg)

AGE	1992	1993	1994	1995	1996	1997
0	0.01000	0.01000	0.00600	0.00900	0.01600	0.01600
1	0.05300	0.03300	0.05600	0.04800	0.01000	0.03200
2	0.10200	0.11500	0.13000	0.13600	0.12300	0.10100
3	0.17500	0.14500	0.15900	0.16700	0.16000	0.14400
4	0.18900	0.18900	0.18100	0.19600	0.19200	0.19100
5	0.20700	0.20400	0.21400	0.20000	0.20700	0.22500
6	0.22300	0.22800	0.24000	0.24700	0.21100	0.22700
7	0.23700	0.24400	0.25500	0.24900	0.25200	0.22600
8	0.26800	0.28300	0.27700	0.28250	0.26750	0.25950

Weights at age in the stock (Kg)

AGE	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961
0	0.01500	0.01500	0.01500	0.01500	0.01500	0.01500	0.01500	0.01500	0.01500	0.01500	0.01500	0.01500	0.01500	0.01500	0.01500
1	0.05000	0.05000	0.05000	0.05000	0.05000	0.05000	0.05000	0.05000	0.05000	0.05000	0.05000	0.05000	0.05000	0.05000	0.05000
2	0.12204	0.12204	0.12779	0.12832	0.13424	0.13746	0.13740	0.13898	0.13955	0.14041	0.14104	0.14145	0.14342	0.15500	0.15500
3	0.13975	0.13975	0.14511	0.15083	0.15663	0.16460	0.16730	0.16860	0.17041	0.17160	0.17285	0.17371	0.17567	0.18700	0.18700
4	0.15618	0.15618	0.16111	0.16634	0.17609	0.18345	0.18999	0.19330	0.19474	0.19678	0.19815	0.19941	0.20138	0.22300	0.22300
5	0.17121	0.17121	0.17569	0.18041	0.18918	0.19939	0.20530	0.21144	0.21435	0.21595	0.21786	0.21913	0.22109	0.23900	0.23900
6	0.18480	0.18480	0.18882	0.19305	0.20087	0.20992	0.21802	0.22344	0.22844	0.23105	0.23252	0.23413	0.23585	0.27600	0.27600
7	0.19697	0.19697	0.20055	0.20431	0.21123	0.21921	0.22632	0.23327	0.23764	0.24173	0.24389	0.24511	0.24688	0.29900	0.29900
8	0.21255	0.21255	0.21553	0.21865	0.22437	0.23093	0.23674	0.24240	0.24750	0.25141	0.25438	0.25645	0.25790	0.30900	0.30900

Weights at age in the stock (Kg)

AGE	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976
0	0.01500	0.01500	0.01500	0.01500	0.01500	0.01500	0.01500	0.01500	0.01500	0.01500	0.01500	0.01500	0.01500	0.01500	0.01500
1	0.05000	0.05000	0.05000	0.05000	0.05000	0.05000	0.05000	0.05000	0.05000	0.05000	0.05000	0.05000	0.05000	0.05000	0.05000
2	0.15500	0.15500	0.15500	0.15500	0.15500	0.15500	0.15500	0.15500	0.15500	0.15500	0.15500	0.15500	0.15500	0.15500	0.15500
3	0.18700	0.18700	0.18700	0.18700	0.18700	0.18700	0.18700	0.18700	0.18700	0.18700	0.18700	0.18700	0.18700	0.18700	0.18700
4	0.22300	0.22300	0.22300	0.22300	0.22300	0.22300	0.22300	0.22300	0.22300	0.22300	0.22300	0.22300	0.22300	0.22300	0.22300
5	0.23900	0.23900	0.23900	0.23900	0.23900	0.23900	0.23900	0.23900	0.23900	0.23900	0.23900	0.23900	0.23900	0.23900	0.23900
6	0.27600	0.27600	0.27600	0.27600	0.27600	0.27600	0.27600	0.27600	0.27600	0.27600	0.27600	0.27600	0.27600	0.27600	0.27600
7	0.29900	0.29900	0.29900	0.29900	0.29900	0.29900	0.29900	0.29900	0.29900	0.29900	0.29900	0.29900	0.29900	0.29900	0.29900
8	0.30900	0.30900	0.30900	0.30900	0.30900	0.30900	0.30900	0.30900	0.30900	0.30900	0.30900	0.30900	0.30900	0.30900	0.30900

Table 2.2.1 (Cont'd)

Weights at age in the stock (Kg)

AGE	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
0	0.01500	0.01500	0.01500	0.01500	0.01500	0.01500	0.01500	0.01300	0.01000	0.00700	0.00600	0.00800	0.01200	0.01500	0.01400
1	0.05000	0.05000	0.05000	0.05000	0.05000	0.05000	0.05000	0.05400	0.06400	0.06400	0.05700	0.04800	0.05300	0.06000	0.06900
2	0.15500	0.15500	0.15500	0.15500	0.15500	0.15500	0.15500	0.15000	0.14700	0.14000	0.13400	0.13200	0.13600	0.14800	0.14800
3	0.18700	0.18700	0.18700	0.18700	0.18700	0.18700	0.18700	0.18900	0.19000	0.18900	0.17900	0.17500	0.17600	0.18700	0.19800
4	0.22300	0.22300	0.22300	0.22300	0.22300	0.22300	0.22300	0.22500	0.22500	0.22400	0.22000	0.21500	0.21100	0.21400	0.21700
5	0.23900	0.23900	0.23900	0.23900	0.23900	0.23900	0.23900	0.24200	0.24500	0.24800	0.24500	0.24700	0.24200	0.24100	0.23700
6	0.27600	0.27600	0.27600	0.27600	0.27600	0.27600	0.27600	0.27000	0.27200	0.26700	0.27100	0.27200	0.27000	0.26700	0.25700
7	0.29900	0.29900	0.29900	0.29900	0.29900	0.29900	0.29900	0.29900	0.29500	0.29100	0.28300	0.28300	0.28200	0.28200	0.27600
8	0.30900	0.30900	0.30900	0.30900	0.30900	0.30900	0.30900	0.31100	0.32400	0.33000	0.32550	0.32300	0.31350	0.31500	0.30550

Weights at age in the stock (Kg)

AGE	1992	1993	1994	1995	1996	1997
0	0.01200	0.00900	0.00800	0.00600	0.00400	0.00400
1	0.07100	0.07000	0.06400	0.05500	0.04900	0.04400
2	0.13800	0.13200	0.12800	0.12900	0.12300	0.11800
3	0.18500	0.18600	0.17700	0.19300	0.18100	0.18100
4	0.21500	0.21300	0.20700	0.22300	0.22700	0.24000
5	0.23500	0.23900	0.22300	0.23500	0.23700	0.25800
6	0.26400	0.27400	0.26500	0.27200	0.25500	0.26900
7	0.27800	0.29100	0.28600	0.29200	0.27000	0.27600
8	0.31400	0.32250	0.32350	0.32600	0.31400	0.31450

Natural Mortality (per year)

AGE	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961
0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
1	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
2	0.3000	0.3000	0.3000	0.3000	0.3000	0.3000	0.3000	0.3000	0.3000	0.3000	0.3000	0.3000	0.3000	0.3000	0.3000
3	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000
4	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000
5	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000
6	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000
7	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000
8	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000

Table 2.2.1 (Cont'd)

Natural Mortality (per year)

AGE	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976
0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
1	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
2	0.3000	0.3000	0.3000	0.3000	0.3000	0.3000	0.3000	0.3000	0.3000	0.3000	0.3000	0.3000	0.3000	0.3000	0.3000
3	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000
4	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000
5	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000
6	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000
7	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000
8	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000

Natural Mortality (per year)

AGE	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
1	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
2	0.3000	0.3000	0.3000	0.3000	0.3000	0.3000	0.3000	0.3000	0.3000	0.3000	0.3000	0.3000	0.3000	0.3000	0.3000
3	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000
4	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000
5	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000
6	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000
7	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000
8	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000

Natural Mortality (per year)

AGE	1992	1993	1994	1995	1996	1997
0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
1	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
2	0.3000	0.3000	0.3000	0.3000	0.3000	0.3000
3	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000
4	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000
5	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000
6	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000
7	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000
8	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000

Table 2.2.1 (Cont'd)

Proportion of fish spawning

AGE	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961
0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
3	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
4	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
5	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
6	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
7	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
8	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

Proportion of fish spawning

AGE	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976
0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.8200	0.8200	0.8200	0.8200	0.8200
3	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
4	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
5	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
6	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
7	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
8	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

Proportion of fish spawning

AGE	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2	0.8200	0.8200	0.8200	0.8200	0.8200	0.8200	0.8200	0.8200	0.7000	0.7500	0.6300	0.6600	0.7900	0.7300	0.6400
3	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9000	0.9400	0.9700	0.9700
4	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
5	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
6	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
7	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
8	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

Table 2.2.1 (Cont'd)

Proportion of fish spawning

AGE	1992	1993	1994	1995	1996	1997
0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2	0.5100	0.4700	0.7200	0.7300	0.6100	0.6500
3	1.0000	0.6300	0.8600	0.9500	0.9800	0.9400
4	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
5	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
6	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
7	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
8	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

INDICES OF SPAWNING BIOMASS

MLAI < 10 mm

	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
1	2.07	3.41	4.61	3.26	6.68	12.65	17.99	27.99	42.35	22.76	40.08	72.10	85.88	112.60	56.04

MLAI < 10 mm

	1992	1993	1994	1995	1996
1	11.73	25.08	15.74	25.87	45.88

Table 2.2.1 (Cont'd)

AGE-STRUCTURED INDICES

AC089: acoustic survey 2-8+

AGE	1989	1990	1991	1992	1993	1994	1995	1996	1997
2	3726.0	2971.0	2834.0	4179.0	3710.0	3280.0	3799.0	4550.6	6363.0
3	3751.0	3530.0	1501.0	1633.0	1885.0	957.0	2056.0	2823.1	3287.0
4	1612.0	3370.0	2102.0	1397.0	909.0	429.0	656.0	1087.3	1696.0
5	488.0	1349.0	1984.0	1510.0	795.0	363.0	272.0	310.9	692.0
6	281.0	395.0	748.0	1311.0	788.0	321.0	175.0	98.7	259.0
7	120.0	211.0	262.0	474.0	546.0	328.0	135.0	82.8	79.0
8	66.0	177.0	168.0	318.0	294.0	352.0	194.0	338.9	236.0

x 10 ^ 3

IBTSA: 2-5+

AGE	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
2	109.0	161.0	716.0	661.0	838.0	4100.0	775.0	580.0	794.0	377.0	762.0	1090.0	1285.0	195.0	391.0
3	42.0	75.0	256.0	235.0	117.0	783.0	411.0	322.0	283.0	181.0	236.0	199.0	152.0	46.0	85.0
4	14.0	32.0	26.0	57.0	56.0	55.0	86.0	271.0	250.0	63.0	45.0	64.0	46.0	14.0	26.0
5	34.0	7.0	36.0	17.0	44.0	26.0	10.0	70.0	170.0	102.0	64.0	40.0	9.0	9.0	18.0

IBTSA: 2-5+

AGE	1998
2	743.0
3	90.0
4	20.0
5	19.0

Table 2.2.1 (Cont'd)

IBTSY: 1-wr

AGE	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
1	172.0	312.0	431.0	772.0	1260.0	1440.0	2080.0	2540.0	3680.0	4530.0	2310.0	1020.0	1160.0	1160.0	2940.0

IBTSY: 1-wr

AGE	1994	1995	1996	1997	1998
1	1667.0	1186.0	1729.0	4192.0	2054.0

MIK: MIK 0-wr

AGE	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
0	17.10	13.10	52.10	101.10	76.70	133.90	91.80	115.00	181.30	177.40	270.90	168.90	71.40	25.90	69.90

MIK: MIK 0-wr

AGE	1992	1993	1994	1995	1996	1997	1998
0	200.70	190.10	101.70	127.00	106.50	148.10	53.10

Fishing Mortality (per year)

AGE	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961
0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0039	0.0077	0.0053	0.0055	0.0034	0.0047	0.0000	0.0245	0.0185
1	0.0000	0.0002	0.0000	0.0000	0.0444	0.0753	0.0978	0.1081	0.2193	0.1586	0.2559	0.1498	0.2348	0.2629	0.1226
2	0.1142	0.0448	0.0652	0.1259	0.1978	0.3040	0.3347	0.3540	0.3600	0.5787	0.4037	0.5208	0.4635	0.4722	0.6441
3	0.1894	0.2376	0.1666	0.2079	0.3686	0.2820	0.4172	0.5610	0.4748	0.4357	0.5132	0.4939	0.5414	0.3625	0.3974
4	0.1482	0.2129	0.2037	0.2258	0.3930	0.4019	0.3739	0.4401	0.4771	0.4382	0.4098	0.4198	0.4642	0.3371	0.4732
5	0.1186	0.1819	0.2603	0.2019	0.3366	0.3237	0.4244	0.4808	0.4275	0.4317	0.5196	0.5116	0.5407	0.2491	0.4019
6	0.2026	0.1378	0.2730	0.3431	0.2528	0.3940	0.3655	0.6886	0.5749	0.4161	0.6860	0.3877	0.5086	0.4838	0.3484
7	0.1367	0.1411	0.1681	0.1937	0.2924	0.3373	0.3851	0.4945	0.5082	0.4881	0.5642	0.4878	0.5548	0.4626	0.4685
8	0.1367	0.1411	0.1681	0.1937	0.2924	0.3373	0.3851	0.4945	0.5082	0.4881	0.5642	0.4878	0.5548	0.4626	0.4685

Table 2.2.1 (Cont'd)

Fishing Mortality (per year)

AGE	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976
0	0.0048	0.0148	0.0126	0.0072	0.0215	0.0257	0.0348	0.0082	0.0351	0.0340	0.0581	0.0470	0.0735	0.1690	0.1477
1	0.0894	0.1237	0.3079	0.2459	0.1855	0.2984	0.3006	0.3289	0.2680	0.6022	0.5789	0.6704	0.4619	0.6704	0.2721
2	0.2345	0.2963	0.3876	0.7730	0.5911	0.4229	1.3313	0.7858	0.9719	0.8824	0.8123	1.0251	1.0158	1.3884	1.2466
3	0.6800	0.2534	0.4100	0.7344	0.7037	0.8019	1.8824	0.9207	1.2736	1.2111	0.8011	1.3345	0.9805	1.4392	1.8445
4	0.5063	0.2574	0.3304	0.7686	0.5653	0.9111	1.0622	0.8915	1.3696	1.2488	0.7934	0.9868	0.9956	1.4092	1.4208
5	0.6854	0.1932	0.3640	0.5487	0.8156	0.8087	1.1827	1.0286	0.9183	1.1958	0.5732	0.9338	1.1825	1.8995	1.8129
6	0.8154	0.2638	0.3247	0.6802	0.2914	0.9538	1.1038	1.5708	1.0081	4.4049	0.6459	1.5582	1.0253	1.2628	1.1197
7	0.5492	0.2835	0.4645	0.7404	0.6154	0.8163	1.3128	1.0677	1.1057	1.8319	0.9119	1.3403	1.1376	1.6229	1.4469
8	0.5492	0.2835	0.4645	0.7404	0.6154	0.8163	1.3128	1.0677	1.1057	1.8319	0.9119	1.3403	1.1376	1.6229	1.4469

Fishing Mortality (per year)

AGE	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
0	0.0921	0.0470	0.0828	0.1261	0.4828	0.3340	0.3985	0.2285	0.0857	0.0621	0.1633	0.1233	0.1286	0.0605	0.1108
1	0.2996	0.1874	0.1726	0.1119	0.2865	0.2256	0.2514	0.2044	0.3877	0.3179	0.3735	0.5896	0.4247	0.4448	0.3180
2	0.2524	0.0245	0.0877	0.3812	0.3196	0.2618	0.3032	0.3139	0.4022	0.4686	0.4103	0.3573	0.4094	0.3690	0.5575
3	1.1009	0.0485	0.0672	0.3803	0.2939	0.4977	0.3266	0.4319	0.6693	0.5182	0.5221	0.4068	0.4129	0.3848	0.4402
4	0.8743	0.0658	0.1081	0.3011	0.2647	0.2692	0.4221	0.5426	0.7446	0.5790	0.5807	0.6158	0.5694	0.4724	0.4871
5	0.6351	0.0441	0.0321	0.3157	0.4206	0.1303	0.3084	0.5928	0.6762	0.5640	0.6109	0.6467	0.7314	0.5212	0.4918
6	1.1300	0.0286	0.0338	0.0403	0.5591	0.1487	0.2788	0.4217	0.6549	0.7602	0.6569	0.6632	0.6653	0.6007	0.5117
7	0.8260	0.1209	0.1369	0.3086	0.4592	0.3354	0.4047	0.4977	0.7274	0.6551	0.6591	0.7377	0.6834	0.6154	0.5905
8	0.8260	0.1209	0.1369	0.3086	0.4592	0.3354	0.4047	0.4977	0.7274	0.6551	0.6591	0.7377	0.6834	0.6154	0.5905

Fishing Mortality (per year)

AGE	1992	1993	1994	1995	1996	1997
0	0.2398	0.2780	0.2700	0.3033	0.0441	0.0247
1	0.2628	0.3047	0.2959	0.3325	0.1183	0.0661
2	0.5520	0.6399	0.6214	0.6982	0.3229	0.1804
3	0.6817	0.7903	0.7674	0.8622	0.4584	0.2561
4	0.7059	0.8184	0.7946	0.8929	0.4725	0.2640
5	0.6802	0.7886	0.7657	0.8604	0.4553	0.2544
6	0.6907	0.8007	0.7775	0.8737	0.4613	0.2578
7	0.7059	0.8184	0.7946	0.8929	0.4725	0.2640
8	0.7059	0.8184	0.7946	0.8929	0.4725	0.2640

Table 2.2.1 (Cont'd)

Population Abundance (1 January)

AGE	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961
0	64.77	38.56	31.31	45.55	42.52	46.83	60.57	44.79	49.37	27.81	131.09	32.60	43.56	12.71	109.20
1	17.71	23.83	14.19	11.52	16.76	15.64	17.23	22.19	16.35	18.07	10.17	48.06	11.94	16.03	4.56
2	5.28	6.52	8.76	5.22	4.24	5.90	5.34	5.75	7.33	4.83	5.67	2.90	15.22	3.47	4.53
3	2.65	3.49	4.62	6.08	3.41	2.58	3.22	2.83	2.99	3.79	2.01	2.81	1.28	7.09	1.60
4	4.86	1.79	2.25	3.20	4.05	1.93	1.59	1.74	1.32	1.52	2.01	0.98	1.40	0.61	4.04
5	4.94	3.79	1.31	1.66	2.31	2.47	1.17	0.99	1.01	0.74	0.89	1.20	0.58	0.80	0.39
6	4.32	3.97	2.86	0.91	1.23	1.49	1.62	0.69	0.55	0.60	0.44	0.48	0.65	0.31	0.56
7	3.54	3.19	3.13	1.97	0.59	0.86	0.91	1.02	0.31	0.28	0.36	0.20	0.29	0.36	0.17
8	10.76	7.31	7.03	3.55	1.84	2.03	1.29	1.37	0.56	0.79	0.61	0.32	0.74	0.76	0.40

x 10 ^ 9

Population Abundance (1 January)

AGE	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976
0	46.39	47.73	62.85	34.86	27.83	40.22	38.72	21.58	41.07	32.28	20.94	9.93	22.09	2.65	2.71
1	39.43	16.98	17.30	22.83	12.73	10.02	14.42	13.76	7.88	14.59	11.48	7.27	3.49	7.55	0.82
2	1.48	13.27	5.52	4.68	6.57	3.89	2.73	3.93	3.64	2.22	2.94	2.37	1.37	0.81	1.42
3	1.76	0.87	7.31	2.78	1.60	2.69	1.89	0.54	1.33	1.02	0.68	0.97	0.63	0.37	0.15
4	0.88	0.73	0.55	3.97	1.09	0.65	0.99	0.24	0.17	0.30	0.25	0.25	0.21	0.19	0.07
5	2.28	0.48	0.51	0.36	1.67	0.56	0.24	0.31	0.09	0.04	0.08	0.10	0.08	0.07	0.04
6	0.24	1.04	0.36	0.32	0.19	0.67	0.23	0.07	0.10	0.03	0.01	0.04	0.04	0.02	0.01
7	0.36	0.10	0.72	0.23	0.15	0.13	0.23	0.07	0.01	0.03	0.00	0.01	0.01	0.01	0.01
8	0.43	0.39	0.24	0.10	0.75	0.48	0.15	0.08	0.04	0.02	0.00	0.00	0.00	0.01	0.00

x 10 ^ 9

Population Abundance (1 January)

AGE	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
0	4.58	4.46	10.71	16.69	37.82	64.83	61.97	53.01	80.50	97.37	85.27	42.73	39.68	34.96	35.66
1	0.86	1.54	1.57	3.63	5.41	8.58	17.08	15.31	15.52	27.18	33.67	26.64	13.90	12.84	12.11
2	0.23	0.23	0.47	0.48	1.19	1.49	2.52	4.89	4.59	3.87	7.28	8.52	5.44	3.34	3.03
3	0.30	0.13	0.17	0.32	0.25	0.64	0.85	1.38	2.64	2.27	1.80	3.58	4.42	2.67	1.71
4	0.02	0.08	0.10	0.13	0.18	0.15	0.32	0.50	0.73	1.11	1.11	0.87	1.95	2.39	1.49
5	0.02	0.01	0.07	0.08	0.09	0.12	0.10	0.19	0.26	0.31	0.56	0.56	0.43	1.00	1.35
6	0.01	0.01	0.01	0.06	0.06	0.05	0.10	0.07	0.09	0.12	0.16	0.28	0.27	0.19	0.54
7	0.00	0.00	0.01	0.01	0.05	0.03	0.04	0.07	0.04	0.04	0.05	0.08	0.13	0.12	0.09
8	0.00	0.00	0.01	0.00	0.02	0.02	0.07	0.08	0.06	0.06	0.04	0.05	0.06	0.09	0.09

x 10 ^ 9

Table 2.2.1 (Cont'd)

Population Abundance (1 January)

AGE	1992	1993	1994	1995	1996	1997	1998
0	65.05	59.18	37.64	53.11	59.56	43.88	20.85
1	11.74	18.83	16.49	10.57	14.43	20.97	15.75
2	3.24	3.32	5.11	4.51	2.79	4.72	7.22
3	1.28	1.38	1.30	2.03	1.66	1.50	2.92
4	0.90	0.53	0.51	0.49	0.70	0.86	0.95
5	0.83	0.40	0.21	0.21	0.18	0.40	0.60
6	0.75	0.38	0.17	0.09	0.08	0.10	0.28
7	0.29	0.34	0.15	0.07	0.03	0.05	0.07
8	0.13	0.02	0.22	0.22	0.07	0.01	0.04

x 10 ^ 9

Weighting factors for the catches in number

AGE	1992	1993	1994	1995	1996	1997
0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
1	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
2	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
3	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
4	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
5	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
6	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
7	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

Predicted SSB Index Values

MLAI < 10 mm

	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
1	1717.	2382.	4313.	5241.	8426.	12055.	20163.	34835.	36317.	37060.	43078.	57883.	65276.	58895.	47153.

x 10 ^ -3

Table 2.2.1 (Cont'd)

MLAI < 10 mm

	1992	1993	1994	1995	1996
1	32712.	19204.	24857.	25554.	23366.

x 10 ^ -3

Predicted Age-Structured Index Values

ACO89: acoustic survey 2-8+ Predicted

AGE	1989	1990	1991	1992	1993	1994	1995	1996	1997
2	5647.4	3551.4	2898.5	3113.2	3040.1	4722.1	3999.5	3039.1	5556.5
3	5699.5	3503.1	2176.1	1428.7	1449.1	1377.5	2047.8	2092.2	2103.8
4	2685.8	3478.0	2147.5	1153.7	638.7	625.0	568.7	1020.8	1402.8
5	623.3	1637.9	2251.7	1245.2	571.1	304.4	285.8	310.9	753.1
6	447.8	323.9	982.4	1240.2	593.1	262.4	134.0	151.3	220.9
7	228.7	228.2	172.3	510.4	558.8	257.7	109.1	67.3	102.5
8	176.6	285.2	282.6	377.9	66.4	619.6	586.6	240.8	32.1

x 10 ^ 3

IBTSA: 2-5+ Predicted

AGE	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
2	347.2	672.1	624.5	522.7	989.0	1166.4	738.9	456.7	403.8	432.7	438.7	676.0	591.6	383.3	659.6
3	75.3	120.2	223.8	196.1	154.8	312.8	386.0	234.5	149.1	108.5	115.2	108.5	167.9	144.5	133.3
4	18.5	28.7	40.8	63.0	63.0	49.3	110.9	137.8	85.6	50.5	29.3	28.4	26.9	40.4	50.9
5	11.9	15.0	16.7	19.8	29.6	35.0	31.9	51.7	76.8	72.3	41.0	27.0	20.9	13.8	21.3

Table 2.2.1 (Cont'd)

IBTSA: 2-5+ Predicted

AGE	1998
2	1009.9
3	259.9
4	56.0
5	37.8

IBTSY: 1-wr Predicted

AGE	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
1	175.6	409.8	598.0	956.1	1895.7	1709.1	1693.5	2992.6	3680.7	2835.4	1509.5	1390.8	1332.9	1301.8	2076.1

IBTSY: 1-wr Predicted

AGE	1994	1995	1996	1997	1998
1	1820.2	1161.8	1628.4	2382.1	1789.3

MIK: MIK 0-wr Predicted

AGE	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
0	11.57	11.33	27.09	41.96	90.96	158.84	150.63	131.61	203.47	246.84	213.45	107.49	99.75	88.64	89.85

MIK: MIK 0-wr Predicted

AGE	1992	1993	1994	1995	1996	1997	1998
0	161.27	146.03	92.98	130.64	151.33	111.76	53.10

Table 2.2.1 (Cont'd)

Fitted Selection Pattern

AGE	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961
0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0105	0.0176	0.0111	0.0125	0.0082	0.0112	0.0000	0.0726	0.0392
1	0.0000	0.0011	0.0000	0.0000	0.1130	0.1874	0.2617	0.2457	0.4597	0.3619	0.6246	0.3568	0.5058	0.7800	0.2590
2	0.7707	0.2102	0.3199	0.5574	0.5034	0.7564	0.8950	0.8045	0.7546	1.3205	0.9853	1.2405	0.9985	1.4009	1.3611
3	1.2786	1.1163	0.8180	0.9207	0.9380	0.7016	1.1156	1.2748	0.9951	0.9942	1.2525	1.1764	1.1663	1.0754	0.8397
4	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
5	0.8001	0.8545	1.2779	0.8941	0.8566	0.8053	1.1350	1.0925	0.8961	0.9851	1.2682	1.2186	1.1648	0.7392	0.8492
6	1.3675	0.6472	1.3406	1.5193	0.6433	0.9804	0.9775	1.5648	1.2050	0.9494	1.6742	0.9236	1.0958	1.4354	0.7362
7	0.9229	0.6626	0.8254	0.8578	0.7442	0.8391	1.0299	1.1236	1.0653	1.1138	1.3769	1.1619	1.1953	1.3723	0.9899
8	0.9229	0.6626	0.8254	0.8578	0.7442	0.8391	1.0299	1.1236	1.0653	1.1138	1.3769	1.1619	1.1953	1.3723	0.9899

Fitted Selection Pattern

AGE	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976
0	0.0096	0.0574	0.0381	0.0093	0.0380	0.0282	0.0328	0.0092	0.0256	0.0272	0.0732	0.0476	0.0739	0.1199	0.1040
1	0.1765	0.4807	0.9319	0.3199	0.3281	0.3275	0.2829	0.3690	0.1957	0.4822	0.7297	0.6794	0.4639	0.4757	0.1915
2	0.4631	1.1512	1.1733	1.0056	1.0457	0.4642	1.2533	0.8815	0.7096	0.7066	1.0238	1.0388	1.0203	0.9852	0.8774
3	1.3431	0.9843	1.2411	0.9555	1.2450	0.8801	1.7721	1.0328	0.9299	0.9699	1.0097	1.3524	0.9849	1.0213	1.2982
4	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
5	1.3538	0.7504	1.1018	0.7139	1.4428	0.8876	1.1134	1.1538	0.6705	0.9575	0.7225	0.9463	1.1877	1.3479	1.2760
6	1.6105	1.0247	0.9829	0.8849	0.5155	1.0468	1.0391	1.7619	0.7361	3.5273	0.8140	1.5791	1.0298	0.8961	0.7881
7	1.0847	1.1014	1.4061	0.9633	1.0886	0.8959	1.2359	1.1976	0.8074	1.4670	1.1494	1.3582	1.1426	1.1516	1.0184
8	1.0847	1.1014	1.4061	0.9633	1.0886	0.8959	1.2359	1.1976	0.8074	1.4670	1.1494	1.3582	1.1426	1.1516	1.0184

Fitted Selection Pattern

AGE	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
0	0.1054	0.7139	0.7660	0.4189	1.8244	1.2407	0.9440	0.4211	0.1151	0.1072	0.2812	0.2002	0.2258	0.1280	0.2275
1	0.3427	2.8459	1.5965	0.3718	1.0823	0.8380	0.5955	0.3766	0.5206	0.5491	0.6431	0.9575	0.7459	0.9416	0.6528
2	0.2887	0.3715	0.8113	1.2660	1.2077	0.9724	0.7183	0.5785	0.5401	0.8093	0.7065	0.5802	0.7190	0.7810	1.1445
3	1.2592	0.7371	0.6214	1.2630	1.1106	1.8487	0.7737	0.7959	0.8989	0.8951	0.8991	0.6606	0.7251	0.8146	0.9037
4	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
5	0.7264	0.6705	0.2969	1.0485	1.5890	0.4841	0.7306	1.0925	0.9081	0.9741	1.0519	1.0503	1.2844	1.1031	1.0096
6	1.2924	0.4337	0.3128	0.1338	2.1124	0.5523	0.6605	0.7771	0.8795	1.3129	1.1311	1.0769	1.1684	1.2715	1.0505
7	0.9447	1.8368	1.2661	1.0250	1.7349	1.2459	0.9587	0.9173	0.9768	1.1315	1.1349	1.1980	1.2001	1.3025	1.2123
8	0.9447	1.8368	1.2661	1.0250	1.7349	1.2459	0.9587	0.9173	0.9768	1.1315	1.1349	1.1980	1.2001	1.3025	1.2123

Table 2.2.1 (Cont'd)

Fitted Selection Pattern

AGE	1992	1993	1994	1995	1996	1997
0	0.3397	0.3397	0.3397	0.3397	0.0934	0.0934
1	0.3724	0.3724	0.3724	0.3724	0.2505	0.2505
2	0.7819	0.7819	0.7819	0.7819	0.6834	0.6834
3	0.9657	0.9657	0.9657	0.9657	0.9703	0.9703
4	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
5	0.9636	0.9636	0.9636	0.9636	0.9637	0.9637
6	0.9785	0.9785	0.9785	0.9785	0.9764	0.9764
7	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
8	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

Table 2.2.1 (Continued)

STOCK SUMMARY

Year	Recruits Age 0 thousands	Total Biomass tonnes	Spawning Biomass tonnes	Landings tonnes	Yield /SSB ratio	Mean F Ages 2- 6	SoP (%)
1947	64767680	8261099	5346690	581760	0.1088	0.1546	71
1948	38564220	6899320	4243087	502100	0.1183	0.1630	78
1949	31309270	6246303	4090144	508500	0.1243	0.1938	71
1950	45547340	5034866	2974674	491700	0.1653	0.2209	78
1951	42518960	4511591	2218173	600400	0.2707	0.3098	76
1952	46828770	4536729	2187243	664400	0.3038	0.3411	79
1953	60569000	4447689	1851705	698500	0.3772	0.3832	84
1954	44791570	4326686	1651151	762900	0.4620	0.5049	80
1955	49368210	3905134	1531516	806400	0.5265	0.4628	94
1956	27805890	3513349	1399759	675200	0.4824	0.4601	78
1957	131088370	4557190	1340159	682900	0.5096	0.5065	86
1958	32599190	4492115	1025219	670500	0.6540	0.4668	85
1959	43563770	4486172	1995028	784500	0.3932	0.5037	65
1960	12705670	3610396	1775315	696200	0.3922	0.3809	84
1961	109197030	4194403	1490005	696700	0.4676	0.4530	88
1962	46390220	4274127	987284	627800	0.6359	0.5843	85
1963	47730140	4499433	2063031	716000	0.3471	0.2528	116
1964	62846580	4663637	1902369	871200	0.4580	0.3634	93
1965	34857110	4069156	1291109	1168800	0.9053	0.7010	95
1966	27826910	3341675	1306575	895500	0.6854	0.5934	93
1967	40220100	2858771	966323	695500	0.7197	0.7797	85
1968	38715210	2534029	427523	717800	1.6790	1.3125	79
1969	21583700	1910956	430039	546700	1.2713	1.0395	103
1970	41071250	1925036	378218	563100	1.4888	1.1083	103
1971	32278210	1848646	265610	520100	1.9581	1.7886	93
1972	20938070	1548790	287051	497500	1.7331	0.7252	108
1973	9932350	1153455	232065	484000	2.0856	1.1677	104
1974	22094900	915679	162483	275100	1.6931	1.0399	103
1975	2647050	682774	80346	312800	3.8931	1.4798	107
1976	2711290	361060	81743	174800	2.1384	1.4889	104
1977	4581940	215080	49849	46000	0.9228	0.7986	83
1978	4461970	229115	66612	11000	0.1651	0.0423	82
1979	10713480	388637	112600	25100	0.2229	0.0658	99
1980	16685270	634498	133791	70764	0.5289	0.2837	91
1981	37820220	1166175	203611	174879	0.8589	0.3716	99
1982	64827120	1844533	279492	275079	0.9842	0.2616	102
1983	61972200	2491035	440514	387202	0.8790	0.3278	92
1984	53008900	2731544	714495	428631	0.5999	0.4606	94
1985	80503640	3261992	741311	613780	0.8280	0.6295	95
1986	97374820	3785752	754705	671488	0.8897	0.5780	87
1987	85272860	4178809	862146	792058	0.9187	0.5562	98

Table 2.2.1 (Continued)

1988	42728330	3810225	1119575	887686	0.7929	0.5380	85
1989	39676480	3370734	1245172	787899	0.6328	0.5577	96
1990	34960080	3155715	1136883	645229	0.5675	0.4696	95
1991	35662340	2955832	933905	658008	0.7046	0.4976	98
1992	65045380	3006407	675833	716799	1.0606	0.6621	100
1993	59183940	2966093	421934	671397	1.5912	0.7676	102
1994	37643280	2553200	530107	568234	1.0719	0.7453	95
1995	53114580	2150496	543235	639146	1.1766	0.8375	98
1996	59564310	1844297	501875	306157	0.6100	0.4341	99
1997	43879640	2277628	726379	247909	0.3413	0.2425	101

No of years for separable analysis : 6
Age range in the analysis : 0 . . . 8
Year range in the analysis : 1947 . . . 1997
Number of indices of SSB : 1
Number of age-structured indices : 4
Stock-recruit relationship to be fitted.
Parameters to estimate : 49
Number of observations : 287

Two selection vectors to be fitted.
Selection assumed constant up to and including : 1995
Abrupt change in selection specified.

PARAMETER ESTIMATES

Parm. No.		Maximum Likelh. Estimate	CV (%)	Lower 95% CL	Upper 95% CL	-s.e.	+s.e.	Mean of Param. Distrib.
Separable model : F by year								
1	1992	0.7059	13	0.5426	0.9182	0.6173	0.8073	0.7123
2	1993	0.8184	13	0.6338	1.0566	0.7183	0.9323	0.8253
3	1994	0.7946	13	0.6122	1.0313	0.6956	0.9077	0.8017
4	1995	0.8929	14	0.6776	1.1766	0.7756	1.0279	0.9018
5	1996	0.4725	19	0.3243	0.6883	0.3899	0.5725	0.4813
6	1997	0.2640	20	0.1768	0.3942	0.2152	0.3239	0.2696
Separable Model: Selection (S1) by age 1992 1995								
7	0	0.3397	17	0.2411	0.4787	0.2852	0.4047	0.3450
8	1	0.3724	17	0.2632	0.5268	0.3120	0.4444	0.3782
9	2	0.7819	16	0.5696	1.0734	0.6653	0.9191	0.7922
10	3	0.9657	15	0.7168	1.3009	0.8295	1.1242	0.9769
	4	1.0000	Fixed : Reference Age					
11	5	0.9636	14	0.7306	1.2709	0.8367	1.1098	0.9733
12	6	0.9785	13	0.7539	1.2700	0.8566	1.1177	0.9872
	7	1.0000	Fixed : Last true age					

Table 2.2.1 (Continued)

Separable Model: Selection (S2) by age from 1996 to 1997

13	0	0.0934	30	0.0511	0.1706	0.0687	0.1270	0.0979
14	1	0.2505	29	0.1392	0.4507	0.1856	0.3380	0.2620
15	2	0.6834	28	0.3905	1.1960	0.5137	0.9093	0.7118
16	3	0.9703	15	0.7183	1.3106	0.8323	1.1311	0.9817
	4	1.0000		Fixed : Reference Age				
17	5	0.9637	14	0.7287	1.2744	0.8356	1.1114	0.9735
18	6	0.9764	13	0.7501	1.2708	0.8535	1.1169	0.9852
	7	1.0000		Fixed : Last true age				

Separable model: Populations in year 1997

19	0	43879645	19	30091158	63986347	36197563	53192069	44699876
20	1	20966766	17	14975667	29354638	17659058	24894039	21278077
21	2	4715062	15	3457402	6430207	4024795	5523713	4774502
22	3	1496052	16	1089215	2054848	1272400	1759015	1515794
23	4	860823	16	621766	1191793	729170	1016247	872763
24	5	396324	17	281555	557874	332883	471855	402400
25	6	104868	19	71397	154029	86190	127593	106905
26	7	45830	21	29808	70463	36799	57077	46947

Separable model: Populations at age

27	1992	290933	28	165456	511567	218141	388015	303248
28	1993	338880	21	220346	521179	272062	422108	347152
29	1994	154220	19	104342	227941	126348	188241	157315
30	1995	68950	19	46742	101710	56546	84076	70320
31	1996	33723	21	22142	51362	27208	41797	34509

Recruitment in year 1998

32	1997	20849126	30	11526857	37710717	15408951	28209969	21824296

SSB Index catchabilities

MLAI < 10 mm

Power model fitted. Slopes (Q) and exponents (K) at age

33	1	Q	3.098	13	2.555	4.329	2.907	3.804	3.356
34	1	K	.8385E-05	13	.1619E-04	.2742E-04	.1842E-04	.2410E-04	.2253E-04

Age-structured index catchabilities

ACO89: acoustic survey 2-8+

Linear model fitted. Slopes at age :

35	2	Q	1.535	26	1.191	3.351	1.535	2.601	2.069
36	3	Q	1.807	26	1.402	3.953	1.807	3.067	2.438
37	4	Q	1.991	26	1.543	4.371	1.991	3.387	2.690
38	5	Q	2.309	26	1.786	5.101	2.309	3.944	3.128
39	6	Q	2.564	27	1.974	5.747	2.564	4.423	3.495
40	7	Q	2.733	28	2.083	6.309	2.733	4.810	3.773
41	8	Q	4.564	27	3.512	10.24	4.564	7.881	6.225

Table 2.2.1 (Continued)

IBTSA: 2-5+

Linear model fitted. Slopes at age :

42	2	Q	.1485E-03	15	.1286E-03	.2317E-03	.1485E-03	.2006E-03	.1746E-03
43	3	Q	.9434E-04	15	.8163E-04	.1473E-03	.9434E-04	.1275E-03	.1109E-03
44	4	Q	.6184E-04	15	.5347E-04	.9679E-04	.6184E-04	.8370E-04	.7277E-04
45	5	Q	.4001E-04	15	.3454E-04	.6298E-04	.4001E-04	.5437E-04	.4719E-04

IBTSY: 1-wr

Linear model fitted. Slopes at age :

46	1	Q	.1298E-03	6	.1214E-03	.1596E-03	.1298E-03	.1493E-03	.1395E-03

MIK: MIK 0-wr

Linear model fitted. Slopes at age :

47	0	Q	.2895E-05	6	.2714E-05	.3531E-05	.2895E-05	.3311E-05	.3103E-05

Parameters of the stock-recruit relationship

48	1	a	.6199E+08	26	.4806E+08	.1359E+09	.6199E+08	.1053E+09	.8370E+08
49	1	b	.4280E+06	57	.2453E+06	.2381E+07	.4280E+06	.1365E+07	.9040E+06

RESIDUALS ABOUT THE MODEL FIT

Separable Model Residuals

Age	1992	1993	1994	1995	1996	1997
0	0.1446	0.1000	-0.2462	-0.0663	0.3983	-0.3924
1	0.2730	0.1775	-0.4264	-0.1721	0.4478	-0.4813
2	0.0651	-0.1582	-0.1507	-0.2367	0.0556	0.0071
3	-0.2729	-0.1298	-0.2659	-0.1841	0.1196	0.4770
4	-0.1908	0.0707	0.2538	-0.1434	-0.2547	0.3053
5	-0.0817	0.0230	0.0025	0.0407	-0.0738	0.1040
6	0.0517	0.1204	0.0672	0.1054	-0.3295	0.0793
7	0.0777	0.0355	-0.0583	0.0492	-0.0979	0.1257

Table 2.2.1 (Continued)

SPAWNING BIOMASS INDEX RESIDUALS

MLAI < 10 mm

	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
1	0.187	0.359	0.067	-0.475	-0.232	0.048	-0.114	-0.219	0.154	-0.488	-0.072	0.220	0.274	0.648	0.173

MLAI < 10 mm

	1992	1993	1994	1995	1996
1	-1.026	0.267	-0.457	0.012	0.675

AGE-STRUCTURED INDEX RESIDUALS

AC089: acoustic survey 2-8+

Age	1989	1990	1991	1992	1993	1994	1995	1996	1997
2	-0.416	-0.178	-0.022	0.294	0.199	-0.364	-0.051	0.404	0.136
3	-0.418	0.008	-0.371	0.134	0.263	-0.364	0.004	0.300	0.446
4	-0.510	-0.032	-0.021	0.191	0.353	-0.376	0.143	0.063	0.190
5	-0.245	-0.194	-0.127	0.193	0.331	0.176	-0.049	0.000	-0.085
6	-0.466	0.199	-0.273	0.055	0.284	0.202	0.267	-0.427	0.159
7	-0.645	-0.078	0.419	-0.074	-0.023	0.241	0.213	0.208	-0.261
8	-0.984	-0.477	-0.520	-0.172	1.488	-0.565	-1.106	0.342	1.996

IBTSA: 2-5+

Age	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
2	-1.158	-1.429	0.137	0.235	-0.166	1.257	0.048	0.239	0.676	-0.138	0.552	0.478	0.776	-0.676	-0.523
3	-0.583	-0.472	0.135	0.181	-0.280	0.918	0.063	0.317	0.641	0.512	0.717	0.607	-0.099	-1.144	-0.450
4	-0.280	0.108	-0.450	-0.100	-0.117	0.109	-0.254	0.676	1.072	0.222	0.429	0.813	0.535	-1.061	-0.671
5	1.048	-0.761	0.770	-0.155	0.395	-0.296	-1.160	0.303	0.795	0.344	0.446	0.392	-0.842	-0.425	-0.167

Table 2.2.1 (Continued)

IBTSA: 2-5+

Age	1998
2	-0.307
3	-1.060
4	-1.030
5	-0.688

IBTSY: 1-wr

Age	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
1	-0.0206	-0.2727	-0.3276	-0.2139	-0.4085	-0.1713	0.2056	-0.1640	-0.0002	0.4685	0.4255	-0.3101	-0.1389	-0.1153	0.3479

IBTSY: 1-wr

Age	1994	1995	1996	1997	1998
1	-0.0879	0.0206	0.0599	0.5652	0.1379

MIK: MIK 0-wr

Age	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
0	0.391	0.145	0.654	0.879	-0.171	-0.171	-0.495	-0.135	-0.115	-0.330	0.238	0.452	-0.334	-1.230	-0.251

Table 2.2.1 (Continued)

MIK: MIK 0-wr

Age	1992	1993	1994	1995	1996	1997	1998
0	0.219	0.264	0.090	-0.028	-0.351	0.282	0.000

PARAMETERS OF THE DISTRIBUTION OF ln(CATCHES AT AGE)

```
 Separable model fitted from 1992  to 1997
 Variance                            0.1296
Skewness test stat.                 -0.3340
Kurtosis test statistic             -0.2234
Partial chi-square                   0.1661
Significance in fit                  0.0000
Degrees of freedom                       23
```

PARAMETERS OF DISTRIBUTIONS OF THE SSB INDICES

DISTRIBUTION STATISTICS FOR   MLAI < 10 mm

Power catchability relationship assumed
Last age is a plus-group

```
 Variance                            0.1743
Skewness test stat.                 -1.0729
Kurtosis test statistic              0.3742
Partial chi-square                   1.1458
Significance in fit                  0.0000
Number of observations                   20
Degrees of freedom                       18
Weight in the analysis               1.0000
```

PARAMETERS OF THE DISTRIBUTION OF THE AGE-STRUCTURED INDICES

Table 2.2.1 (Continued)

DISTRIBUTION STATISTICS FOR ACO89: acoustic survey 2-8+

Linear catchability relationship assumed

Age	2	3	4	5	6	7	8
Variance	0.0116	0.0147	0.0112	0.0054	0.0131	0.0146	0.1670
Skewness test stat.	-0.1720	-0.1798	-0.9318	0.5364	-0.8005	-0.8943	1.0970
Kurtosis test statisti	-0.7288	-0.8568	-0.3350	-0.6411	-0.8009	-0.0619	-0.3605
Partial chi-square	0.0061	0.0080	0.0064	0.0032	0.0083	0.0097	0.1187
Significance in fit	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Number of observations	9	9	9	9	9	9	9
Degrees of freedom	8	8	8	8	8	8	8
Weight in the analysis	0.1429	0.1429	0.1429	0.1429	0.1429	0.1429	0.1429

DISTRIBUTION STATISTICS FOR IBTSA: 2-5+

Linear catchability relationship assumed

Age	2	3	4	5
Variance	0.1260	0.0973	0.0969	0.1078
Skewness test stat.	-0.5945	-0.6045	-0.1855	-0.2559
Kurtosis test statisti	-0.2816	-0.7068	-0.6223	-0.8950
Partial chi-square	0.2959	0.2874	0.3730	0.5181
Significance in fit	0.0000	0.0000	0.0000	0.0000
Number of observations	16	16	16	16
Degrees of freedom	15	15	15	15
Weight in the analysis	0.2500	0.2500	0.2500	0.2500

DISTRIBUTION STATISTICS FOR IBTSY: 1-wr

Linear catchability relationship assumed

Age	1
Variance	0.0786
Skewness test stat.	1.0579
Kurtosis test statisti	-0.6256
Partial chi-square	0.2022
Significance in fit	0.0000
Number of observations	20
Degrees of freedom	19
Weight in the analysis	1.0000

Table 2.2.1 (Continued)

DISTRIBUTION STATISTICS FOR MIK: MIK 0-wr

Linear catchability relationship assumed

Age	0
Variance	0.1951
Skewness test stat.	-1.0291
Kurtosis test statisti	1.2186
Partial chi-square	0.9915
Significance in fit	0.0000
Number of observations	22
Degrees of freedom	21
Weight in the analysis	1.0000

ANALYSIS OF VARIANCE

Unweighted Statistics

Variance

	SSQ	Data	Parameters	d.f.	Variance
Total for model	68.6206	287	49	238	0.2883
Catches at age	2.2029	48	31	17	0.1296
SSB Indices					
MLAI < 10 mm	3.1378	20	2	18	0.1743
Aged Indices					
AC089: acoustic survey 2-8+	13.3030	63	7	56	0.2376
IBTSA: 2-5+	25.6817	64	4	60	0.4280
IBTSY: 1-wr	1.4937	20	1	19	0.0786
MIK: MIK 0-wr	4.0974	22	1	21	0.1951
Stock-recruit model	18.7040	50	2	48	0.3897

Weighted Statistics

Variance

	SSQ	Data	Parameters	d.f.	Variance
Total for model	12.9956	287	49	238	0.0546

Table 2.2.1 (Continued)

Catches at age	2.2029	48	31	17	0.1296
SSB Indices					
MLAI < 10 mm	3.1378	20	2	18	0.1743
Aged Indices					
AC089: acoustic survey 2-8+	0.2715	63	7	56	0.0048
IBTSA: 2-5+	1.6051	64	4	60	0.0268
IBTSY: 1-wr	1.4937	20	1	19	0.0786
MIK: MIK 0-wr	4.0974	22	1	21	0.1951
Stock-recruit model	0.1870	50	2	48	0.0039

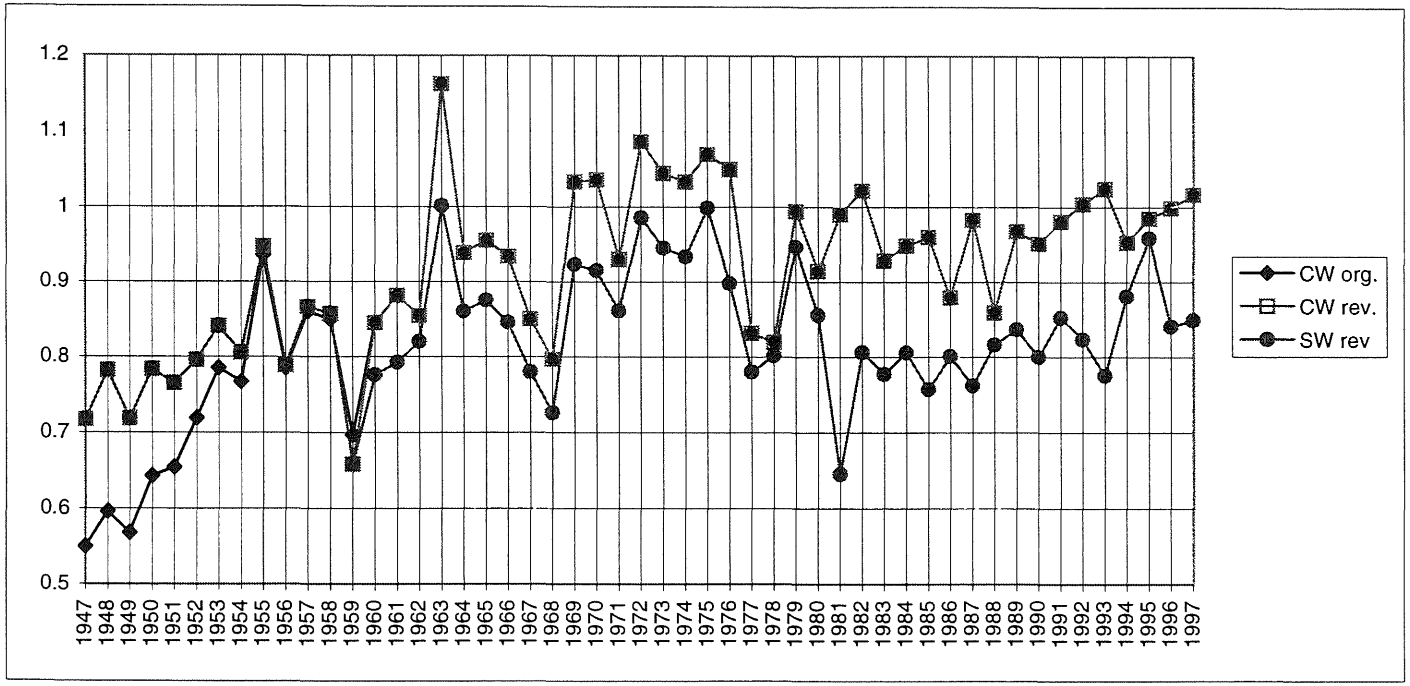


Figure 2.1.1.1. SOP-deviations (Landings/SOP) using different sets of weights at age:

CW org: Catch weights as used by previous Working Groups

CW rev: Catch weights revised for 1947 - 1959

SW rev: Stock weights, with revised data for 1947 - 1959

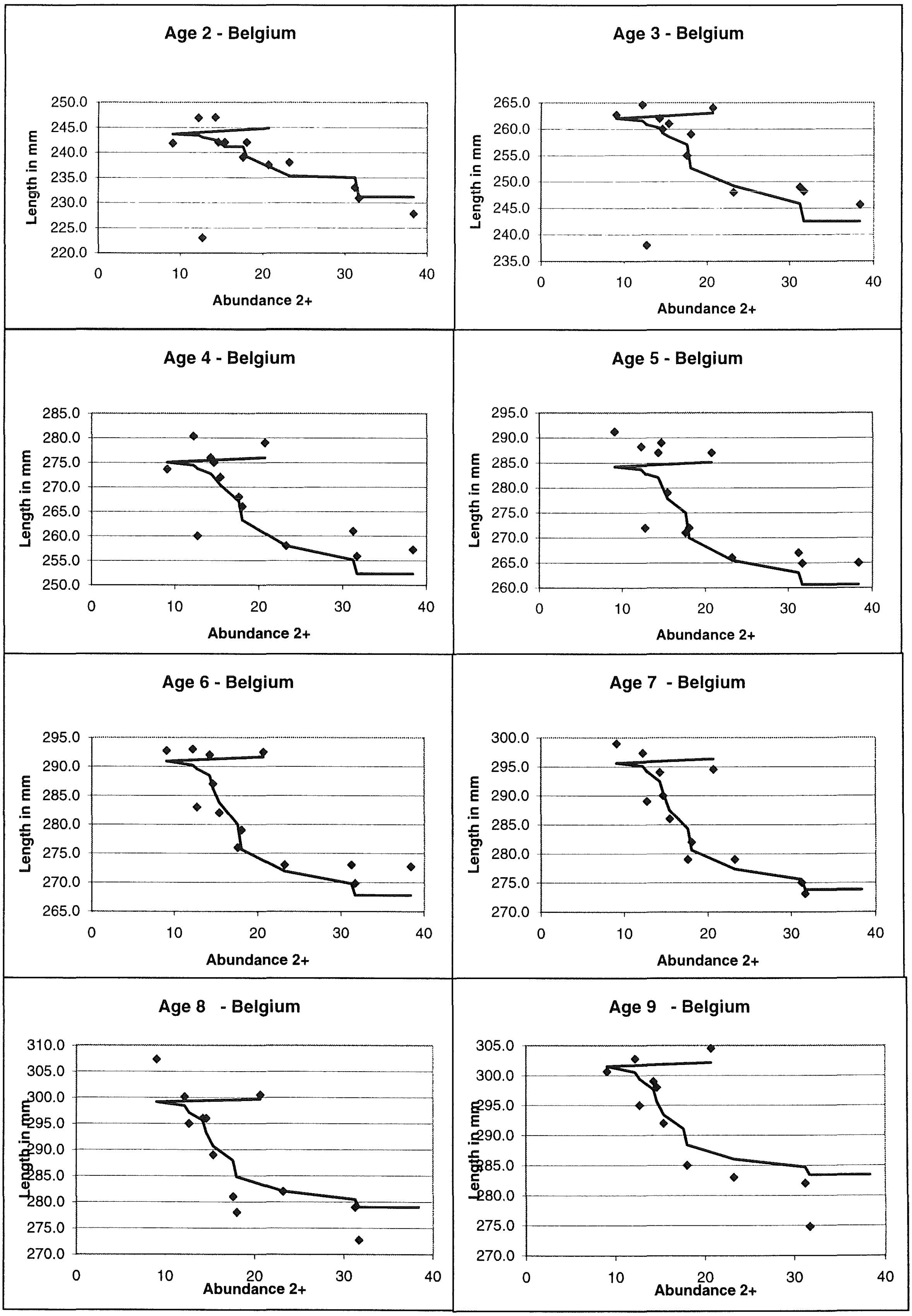
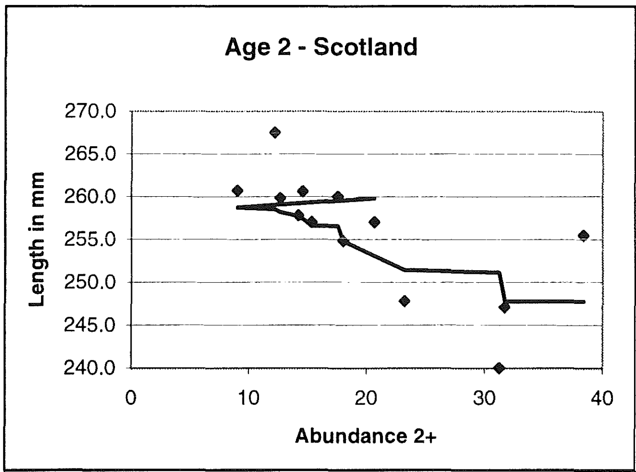


Figure 2.1.2.1. Observed and fitted lengths at age for fish measured in Belgian catches (Gilis, 1947-59) using the growth model described in Section 2.1.2.

F-2121.XLS



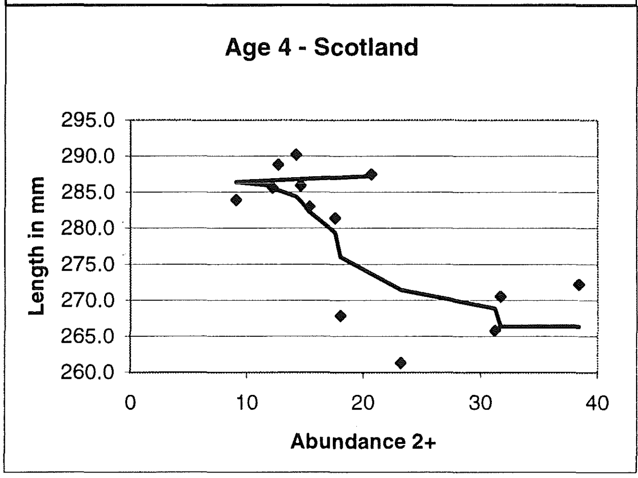


Figure 2.1.2.2. Observed and fitted lengths at age for fish measured in Scottish catches (Saville, 1978; Burd 1978) using the growth model described in Section 2.1.2.

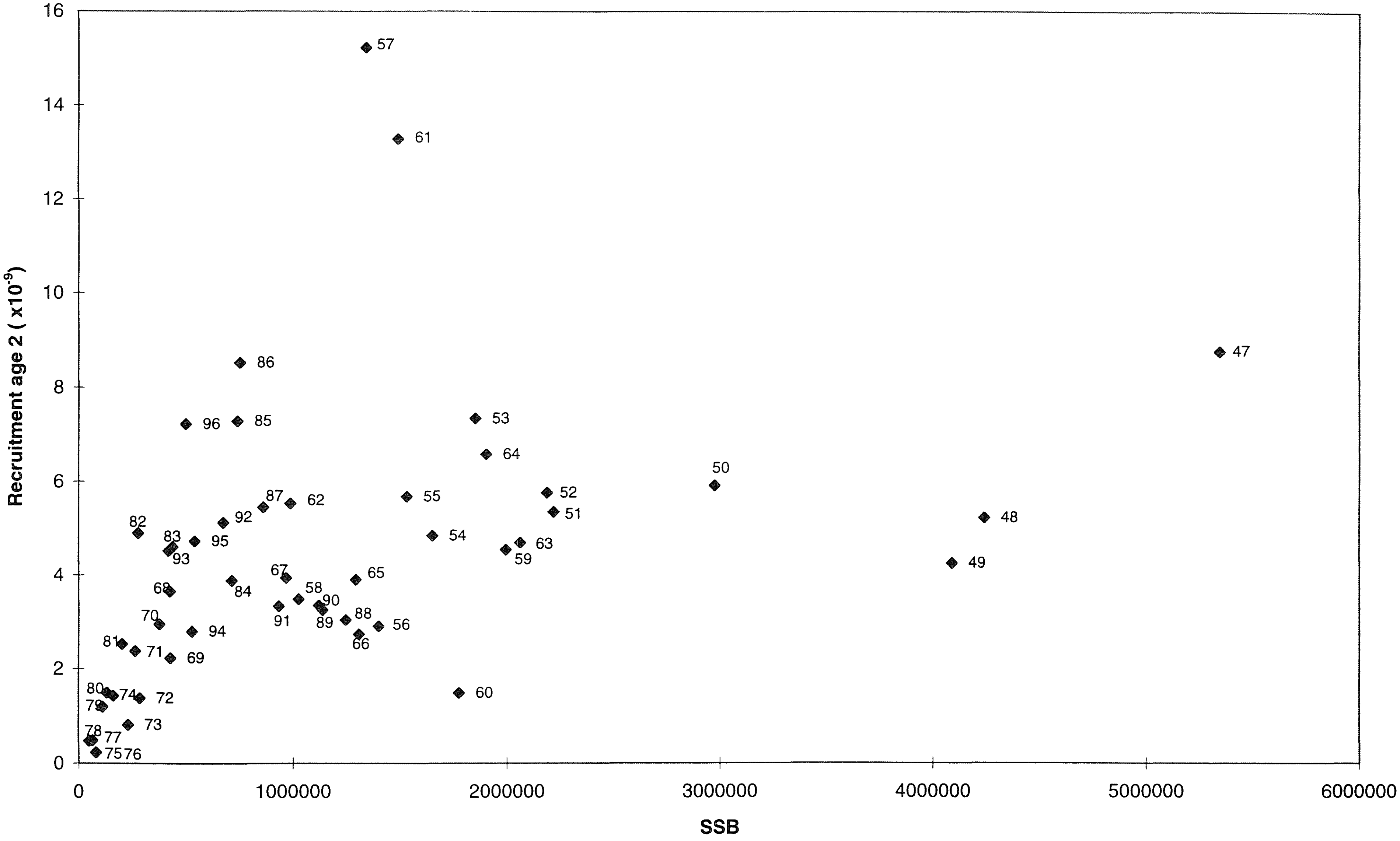


Figure 2.1.3.1 Stock - recruitment pairs when the recruitment is taken at age 2. Data from ICA assessment for the period 1947 to 1997, using revised weights in the stock for 1947 - 1959.

Figure 2.1.4.1

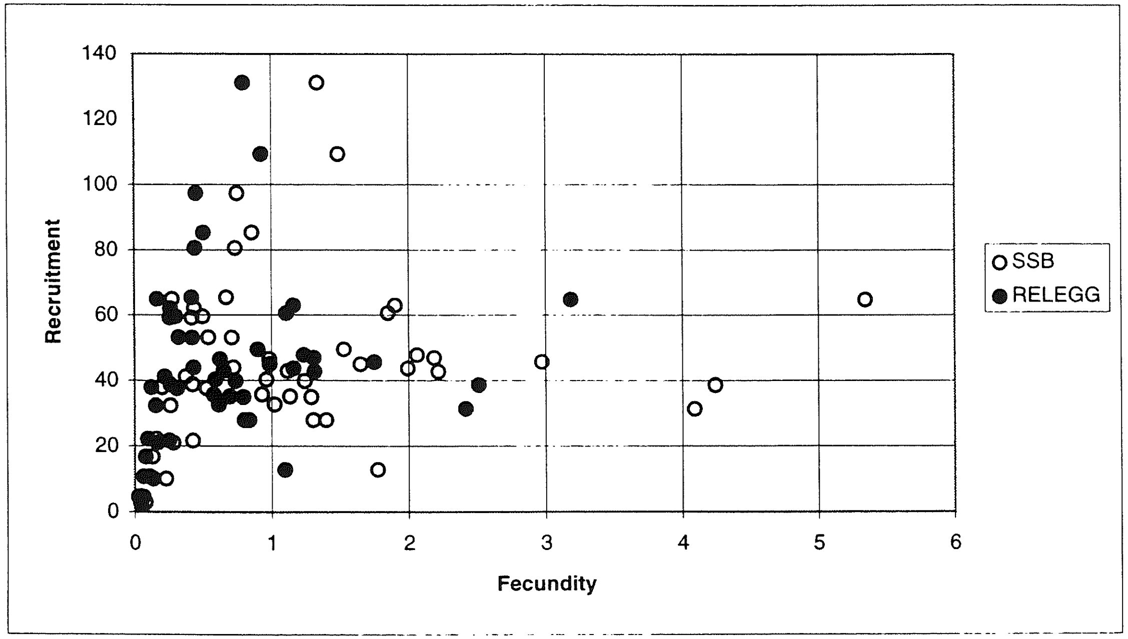


Figure 2.1.4.1 Stock fecundity - recruitment pairs comparing SSB and RELEGG as measures of the total fecundity of the stock. Fecundity is SSB in million tonnes, and RELEGG in artificial units. Data from ICA assessment for the period 1947 to 1997, using revised weights in the stock for 1947 - 1959.

Figure 2.2.1

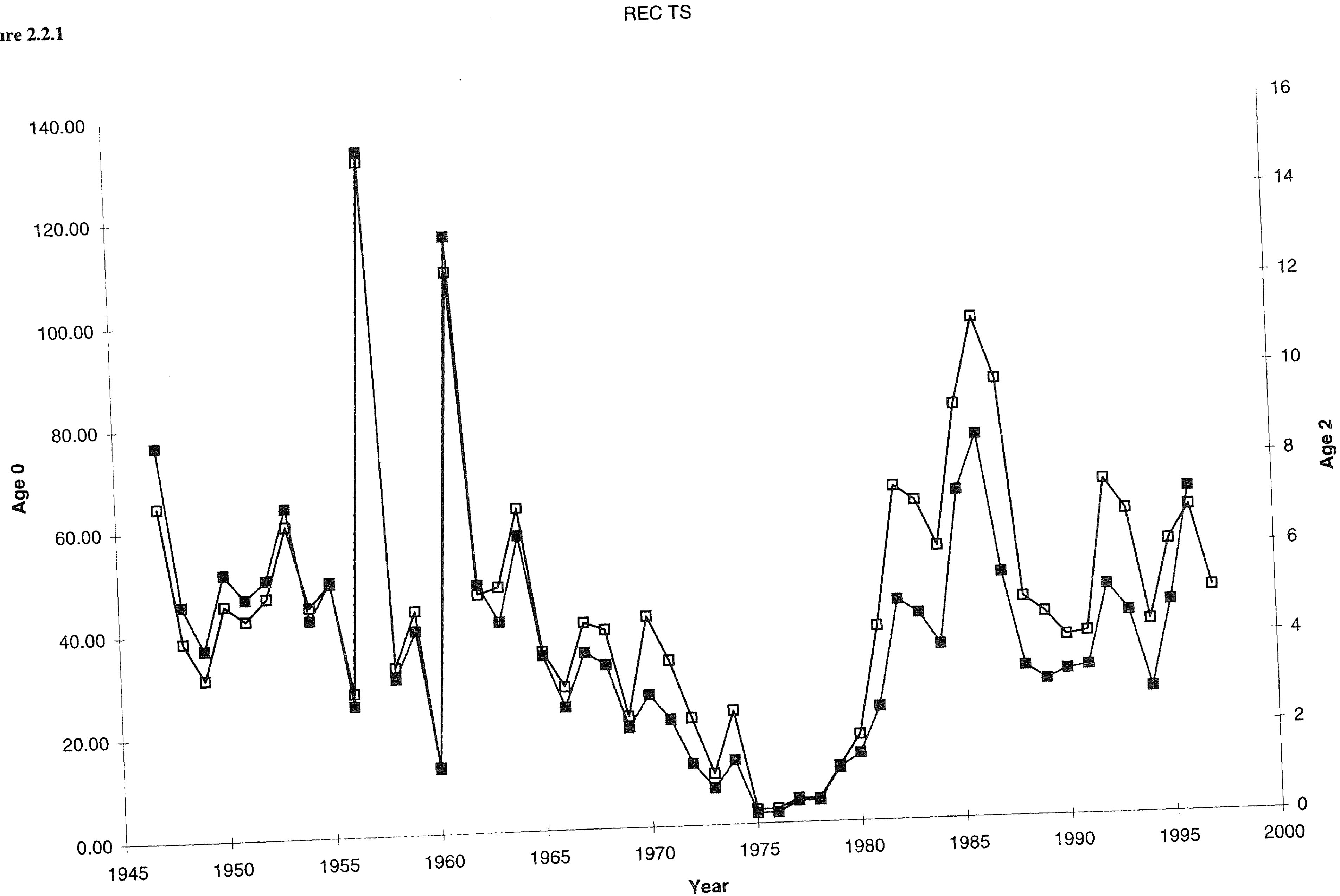


Figure 2.2.1 Recruitment estimates at age 0 (n squares) and age 2 (filled squares) from ICA asse ent for the period 1947 to 1997, using revised weights in the stock for 1947 - 1959.

Figure 2.2.2

Age 0

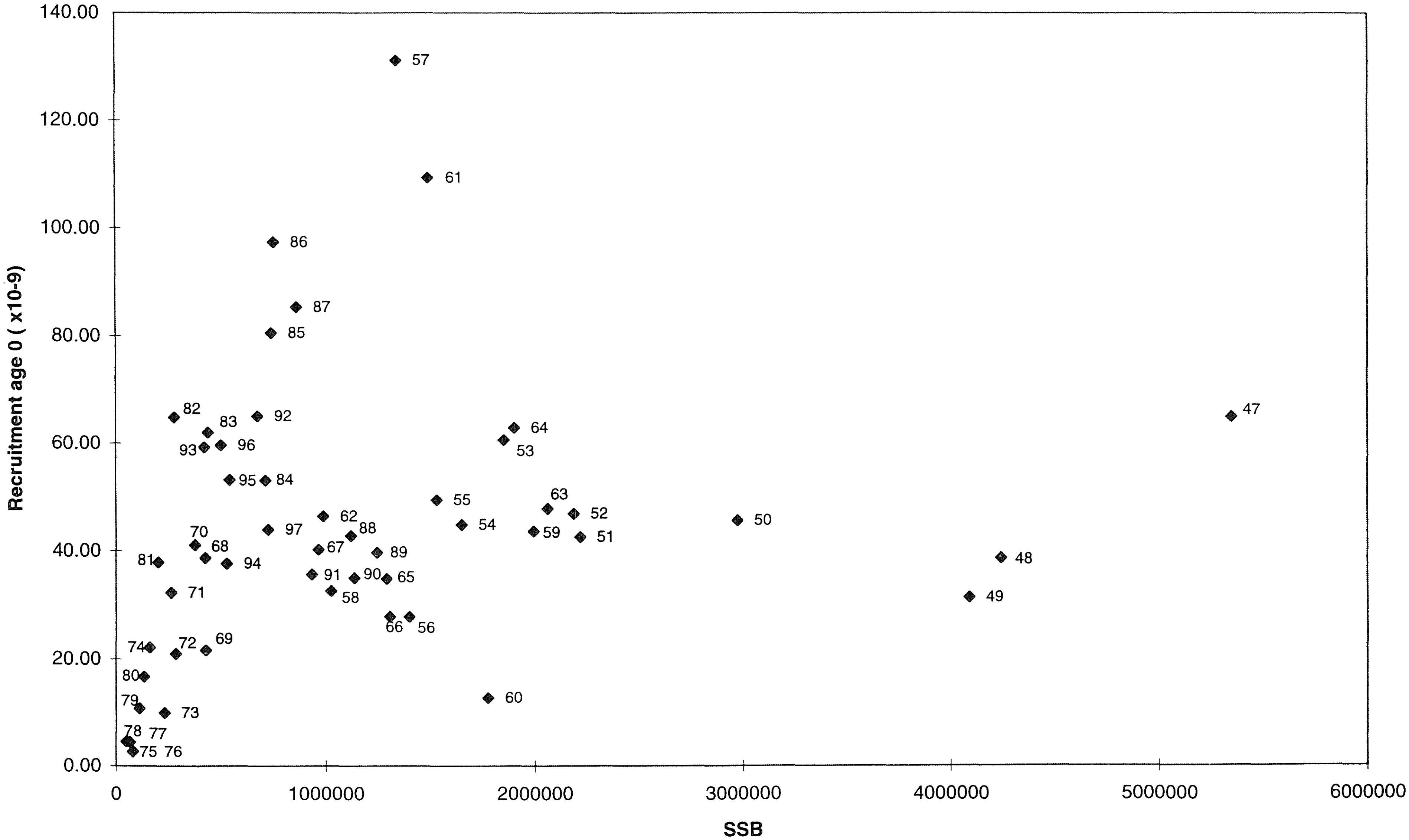
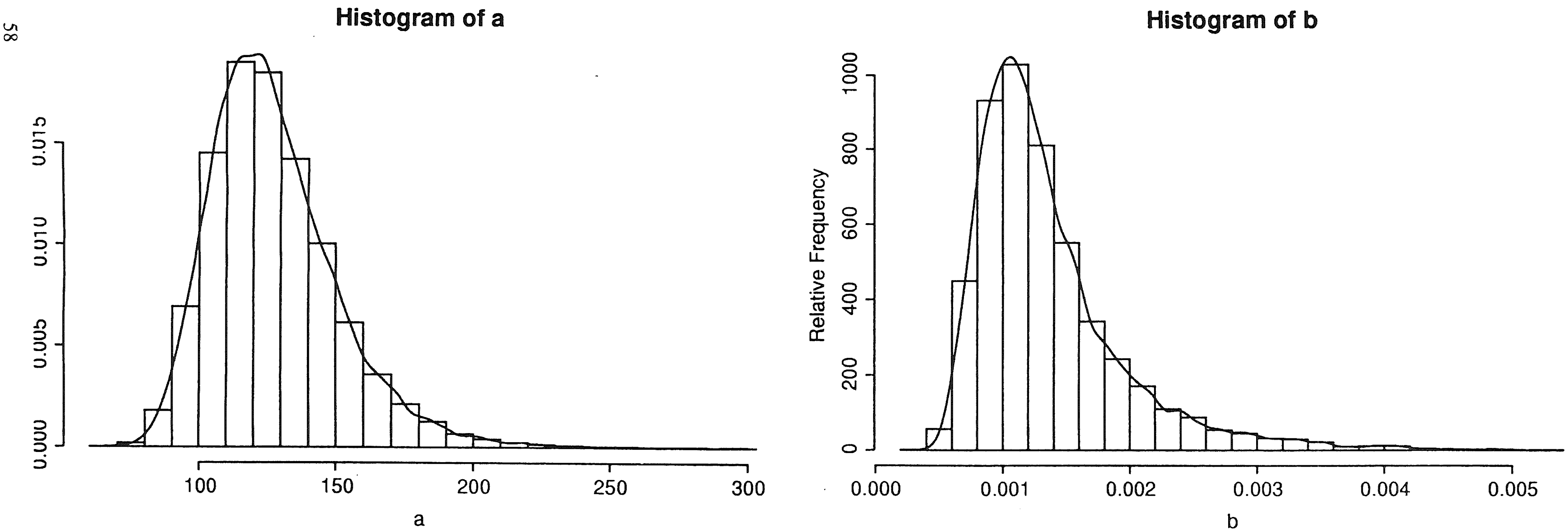


Figure 2.2.2 Stock - recruitment pairs with recruitment estimated at age 0 from ICA assessment for the period 1947 to 1997, using revised weights in the stock for 1947 - 1959.



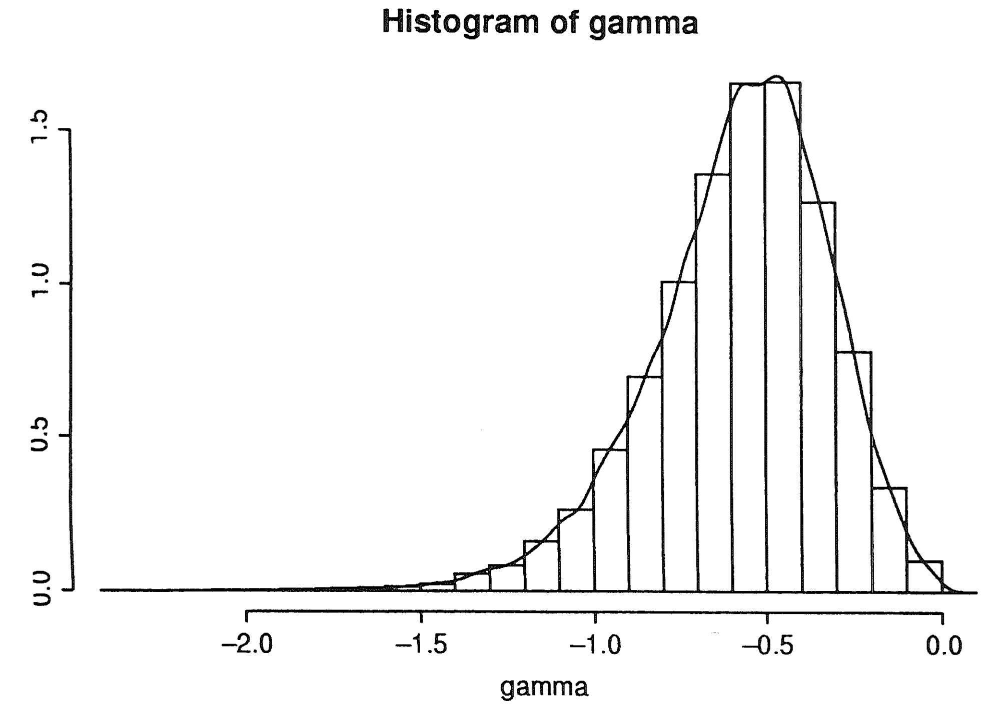


Figure 3.1.2.1 Bayesian posterior distributions of parameters in the Deriso-Schnute stock - recruitment function. SSB and recruitment data from ICA assessment for the period 1947 to 1997, using revised weights in the stock for 1947 - 1959.

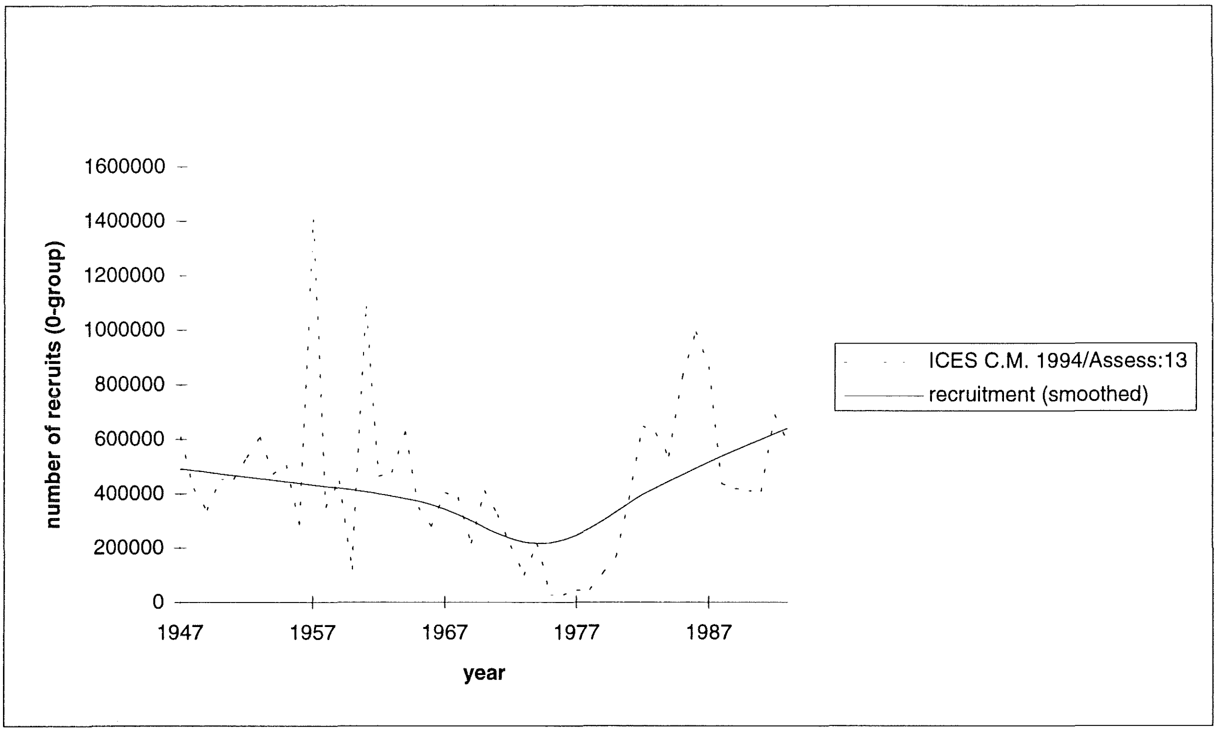


Figure 3.2.1.1. Time domain plot of North Sea herring recruitment as reported in Anon.(1994); together with a robust locally weighted regression smoother.

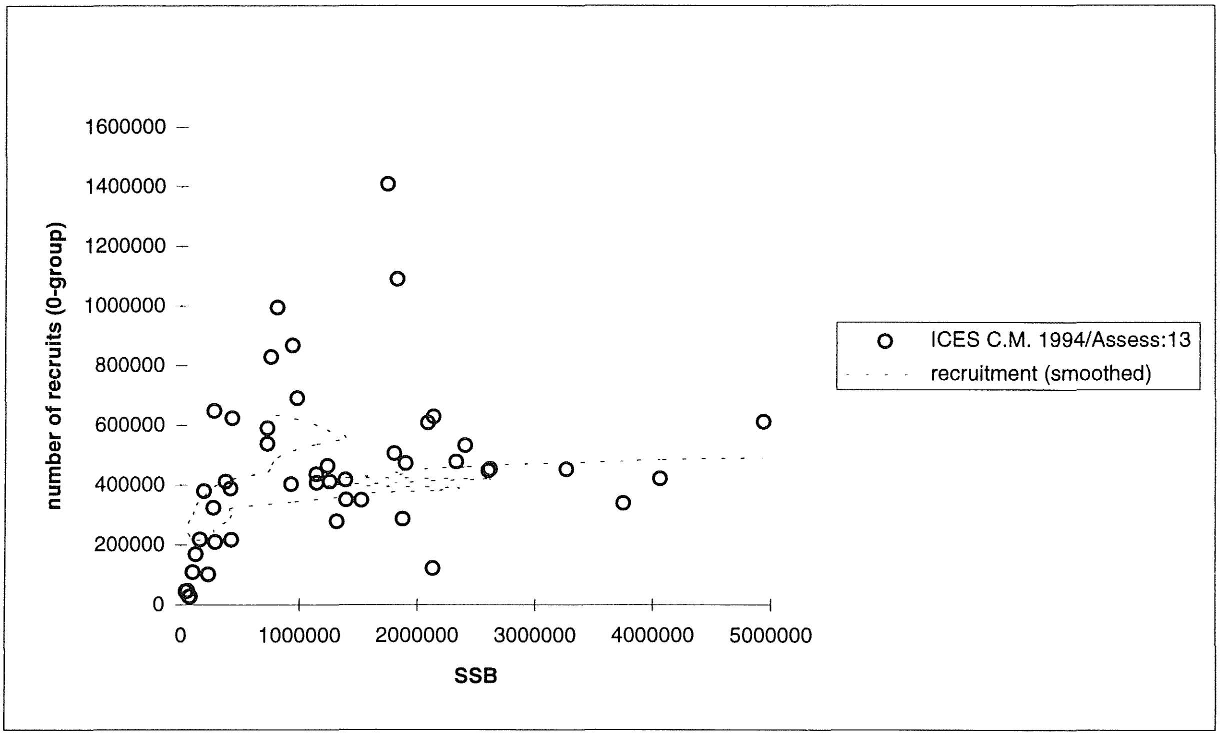


Figure 3.2.1.2. North Sea herring S-R pairs as reported in Anon.(1994); together with the nonparametric smoothed estimates of recruitment depicted in the figure 3.2.1.1.

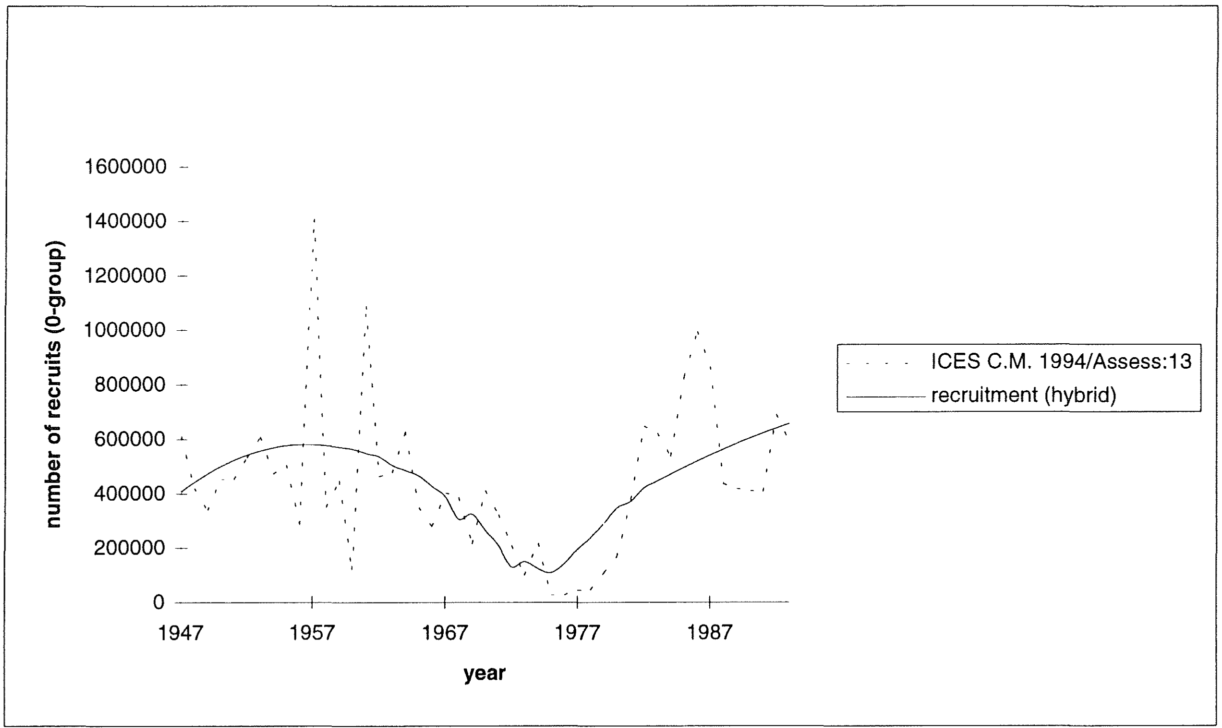


Figure 3.3.1.1. Time domain plot of North Sea herring recruitment as reported in Anon.(1994); together with a hybrid estimator.

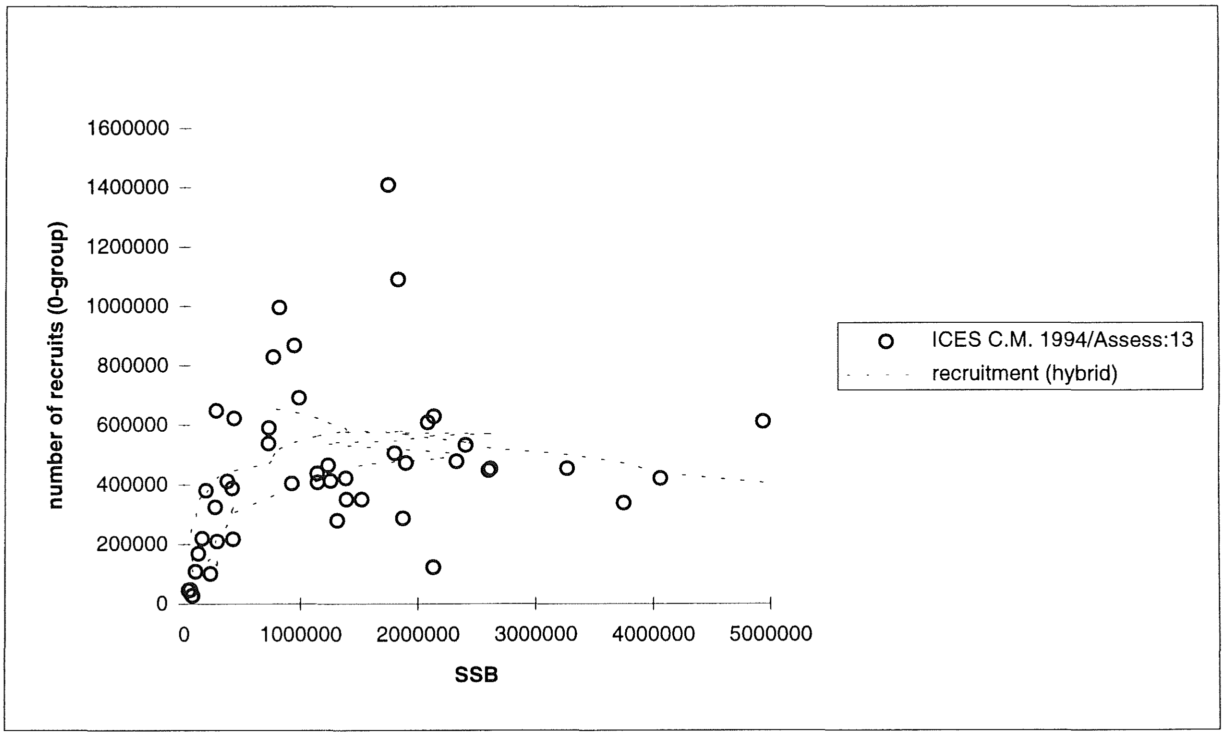


Figure 3.3.1.2. North Sea herring S-R pairs as reported in Anon.(1994); together with the nonparametric smoothed estimates of recruitment depicted in the figure 3.3.1.1.