

THE RELATIONSHIP BETWEEN SPAWNING STOCK AND RECRUITMENT FOR
ATLANTIC COD STOCKS

by

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ABSTRACT

The relationship between spawning stock biomass and recruitment in Atlantic cod stocks is investigated by ranking the SSB values according to size and applying a moving average of ten points. The resulting averages are plotted against the average recruitment produced by the respective SSBs. The plot in most cases resembles a Beverton and Holt or Ricker type of relationship, showing substantial reduction in mean recruitment at low levels of SSB even though the relationship is not forced towards the origin. Applying a moving average of ten years to the time series of data shows how SSB and recruitment relationships have developed. For some stocks the apparent relationship might be explained by medium- or long-term variation in the recruitment caused by environmental conditions. Considering all the available data, there is nevertheless substantial evidence of reduced recruitment at low levels of SSB for the cod.

INTRODUCTION

The nature of the relationship between SSB (spawning stock biomass) and recruitment is fundamental in the population dynamics of fish stocks. Most stock and recruitment plots show a wide scatter of points and a large part of the variation is evidently caused by environmental or ecological factors.. This does not exclude an influence of the spawning stock size, but in many cases it makes a such relationship difficult to see in a plot. Another cause of the scatter may be the lack of data on fecundity, but these are non-existent or at best difficult to obtain and in most cases the size of the SSB will be the only parameter available over longer periods.

In spite of the problems in defining the relationship with recruitment, the SSB has probably been the most important factor in management advice for long-living species. Frequently, the advice from ACFM (ICES Advisory Committee on Fishery Management) is to avoid fishing at exploitation levels which leads to reduction in SSB. The current policy of ACFM is to define MBAL (minimum biologically acceptable level) for all stocks and to give firm recommendations about management measures if SSB falls below this level. Although there are no clear guide-lines on how to estimate MBAL, it is defined as a level of SSB where there is danger of reduced recruitment. The policy of ACFM reflects a strong belief among scientists that the size of SSB is important for sustaining the stocks.

3112 / h 5305

The importance of SSB in management advice has spurred the activity among scientists to explore the relationship between SSB and recruitment. In particular, Dr. R. A. Myers and associates have put in a large effort, collecting and exploring virtually all existing time series of SSB and recruitment (see e.g. Myers et al. 1995). One conclusion of these studies must be that there is no universal solution to the problem of finding an SSB and recruitment relationship and to defining MBAL.

The present paper deals with the Atlantic cod stocks. A method for visualising the SSB and recruitment relationship is proposed. Further, the validity of the apparent relationships is discussed.

MATERIALS AND METHODS

Data on SSB and recruitment for Atlantic cod stocks were collected from recent reports of ICES assessment working groups for Northeast Atlantic stocks and from the data collected by Dr. R. A. Myers for Northwest Atlantic stocks. Of the 23 stocks, data from 20 were used in the analysis. For the remaining three the time series available (10-14 years) was considered too short.

The basic method used is to apply a moving average to the data, i.e. taking moving average values of SSB and plotting these against the corresponding values of recruitment. The SSB values were ranked according to size before the moving average was applied. Figure 1 shows how the scatter plot for Northeast Arctic cod changes as more points are included in the average. A moving average of ten points was adopted as standard, for no other reason than that this seemed to give a desirable smoothing of the data.

In using moving average the weight given to each observed point is not the same, the values towards the extremes of the series being used less than the medium ones. On the other hand, in a visual presentation the points near the highest and lowest level of SSB, are very important for the overall impression of the pattern. The plots are probably easiest interpreted by considering that each point represents a selected part of the data. For instance, if the plot shows a descending tendency on the left-hand side, it simply means that if the ten lowest observed values of SSB gives the lowest value of recruitment, replacing the lowest SSB with a higher value and thereby increasing the average SSB, gives a higher average recruitment.

The relationship between SSB and recruitment has usually been expressed as a single curve. The two most commonly used curves have been those proposed by Beverton and Holt (1957) and Ricker (1954). These were estimated from the original data for each stock by a least sum of squares fit.

One effect of using moving average is that some of the "noise" in the plot caused by environmental factors is removed. However, in addition to environmental noise, the plots are obviously affected by estimation errors which may cause substantial displacement in some cases. In general sampling tended to be more sparse in earlier years, data on changes in maturity may be entirely lacking, and discarding practices may have changed affecting the recruitment estimates from the VPA. Comparing recent and historical levels of SSB and recruitment in a stock might therefore be misleading.

The age of recruitment is normally defined as the age when the fish enter the fishery and for cod it varies between 0 and 3 years. This reflects the large differences in growth and age at maturity between the cod stocks, with generally faster growth and earlier maturity in the southernmost stocks. A number of factors are involved in deciding the year class strength. Some concern only the very early stages, but others, like cannibalism, will also affect juvenile fish. Thus, for stocks recruiting at age 0 or 1 cannibalism may still represent an important part of the mortality, but for stocks recruiting at age 3 cannibalism will usually no longer be important. Possible estimation errors and differences in biology should be considered when comparison between the SSB and recruitment patterns in different stocks are made.

RESULTS

Figure 2a-e shows the SSB and recruitment plots for all stocks with the fitted Beverton and Holt (1957) and Ricker (1954) curves. Although lower recruitment at low SSB levels are clearly seen in a few of the plots, the evidence of an SSB and recruitment relationship of a type represented by either of the two curves is far from convincing in many cases. The curves logically starts at the origin, but the ascending slope appears to be poorly estimated for most of the stocks. Since the left-hand side of the curve is most crucial to the management considerations, this is clearly unfortunate.

One pattern seems to emerge from the plots: The occurrence of very poor year classes tends to be more frequent for lower levels of SSB. Nevertheless, there are some examples of good year classes produced by small SSBs. Thus, to the extent that there is a relationship, it seems often to be of a type where recruitment on the average suffers at low SSBs rather than a limitation of the maximum recruitment potential in a single year.

Figure 3a-e shows the same plots after ranking the SSB values and applying a moving average of ten points. The Beverton and Holt and Ricker curves are the same as in Figure 2. In most of the stocks the points shows a descending trend as SSB is decreasing and the fit to one or both curves is generally good, considering the wide scatter of the original data points. This is probably not surprising because the curves are fitted from the same original data the moving averages are calculated from. However, it is worth noting that the descending tendency indicated at low SSBs, in contrast to the fitted curves, is not a result of forcing any relationship towards the origin.

The relationships indicated by the plots in Figure 3 are of different types. Some are close to the "normal" Beverton and Holt type or Ricker type, others indicate a nearly linear relationship between SSB and recruitment and in some cases there is hardly indication of any relationship. The overall impression, however, is that there is substantial evidence of poorer recruitment at low levels of SSB.

The size of the SSB is decided mainly by two factors: Previous recruitment and the exploitation rate. For some stocks recruitment seems to follow more or less periodical patterns which may be linked to climatic changes (Northeast Arctic cod, inflow of Atlantic water), ecological factors (North Sea cod, the "gadoid outburst") or environmental factors (Eastern Baltic cod, oxygen deficiency). Such periods of poor recruitment are likely to reduce future levels of SSB. Furthermore, many stocks have suffered an increasing rate of exploitation up to recent years. A result of this is that even if recruitment were stable in the

long term, the level of SSB would be reduced. How can these factors affect the SSB and recruitment plot?

In order to explore this, the time trajectory of SSB and recruitment for each stock, applying a moving average of ten years, are plotted in Figure 4a-e. The resulting patterns differ greatly, but four basic patterns, labelled A-D; can be identified. Pattern A can be exemplified by North Sea cod. After a period of declining SSB, but stable recruitment, both recruitment and SSB have steadily declined with no sign of improvement. Pattern B, exemplified by Southern Grand Banks cod, shows the same type of decline as A, but this is followed by an increase in SSB with recruitment still declining. In pattern C (e.g. Eastern Baltic cod) the SSB first increases with stable recruitment, followed by a sharp decline in recruitment to a much lower level and somewhat later a reduction also in SSB. The last pattern, D, is seen in the Northeast Arctic cod and initially follows a type A pattern, but then recruitment is temporarily improved followed first by an increase in SSB, then by reduced recruitment and finally by reduced SSB to form a loop.

DISCUSSION

It is important when discussing the plots in Figures 3 and 4 to bear in mind that they represent moving averages. Thus, we are considering large-scale and long-term changes in the stocks. The aim is not to discuss the results for the individual stocks, but the overall implications of the results.

The data clearly show that recruitment for cod has been generally lower at low levels of SSB. A crude illustration of this is given in Figure 5 where all the values for SSB and recruitment have been scaled relative to the mean for each stock, set to 100 in the plots. Figure 5a shows the normal SSB and recruitment plot and Figure 5b the plot of moving average (in this case 50 points) with SSB ranked according to size. The indicated relationship is of the Beverton and Holt type, but with a fairly clear dependency of recruitment of SSB even at the highest levels of SSB. It is possible, however, that the limited time span of the historical series prevents a Ricker-type relationship from being indicated.

The time trajectory of SSB and recruitment reveals some patterns which can be explained by the combination of periodical recruitment and high exploitation rates. Assuming a constant rate of exploitation, periods of poor recruitment will almost inevitably reduce the spawning stock, with a time lag depending on the difference between age at recruitment and age at first maturity. If high exploitation already has reduced SSB to a historical low level, this development would dominate the left-hand side of the plots, creating type A patterns. However, in type A recruitment continues to decrease and it is not possible to tell whether this is a continued decline in recruitment caused by e.g. environmental conditions or an effect of the low SSB levels the poor recruitment has generated.

An indication that the former assumption may be valid, at least in some cases, is the type B pattern, where recruitment continues to decline even if SSB increases. The increase in SSB seen in these examples presumably is the effect of reduced exploitation.

The type C pattern is similar to the A pattern, but with a different history in the earliest years and with relatively stable recruitment as the SSB is declining. The pattern strongly indicates

that there has been a large reduction in the long-term level of recruitment which appears to be unrelated to the SSB.

The type D pattern shows the development which can be expected when a period of poor recruitment is followed by a clear improvement in recruitment. This is what happens when a stock is recovering and the loops in the diagrams might in some cases appropriately be named "stock-recovery loops". However, when the loop resembles a full circle a new stock decline is indicated.

Although there are a number of cod stocks where the trend is downwards with no sign of recovery, the experience from some cod stocks makes it seem realistic to assume that recovery sooner or later will take place provided that appropriate management measures are enforced. The time perspective for such a recovery is, however, unknown. The historical time series of data available for fish stocks are generally too short to give much information about long-term changes in the recruitment and even when the causes for reduced recruitment can be linked to environmental or other factors, changes in these factors are difficult to predict.

In management advice, a crucial point is to what extent low SSBs affects the recruitment and to define at which level of SSB it is necessary to take special management actions. Most cod stocks are too heavily exploited and there is nothing to be gained in a long-term perspective by fishing stocks down to levels where past experience indicate that recruitment will suffer or where SSB is reduced below historical low levels. Although apparent SSB and recruitment relationships for individual stocks to some extent may be questioned, it is difficult to ignore the combined experience from 20 cod stocks showing a clear tendency for lower recruitment at low SSB levels.

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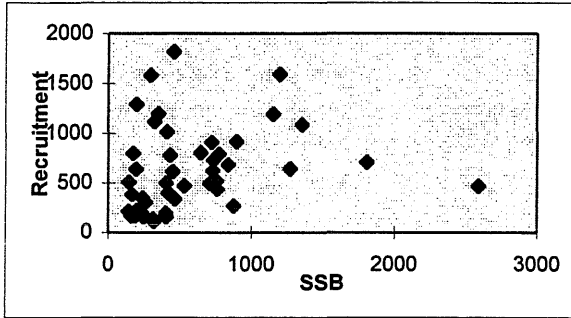
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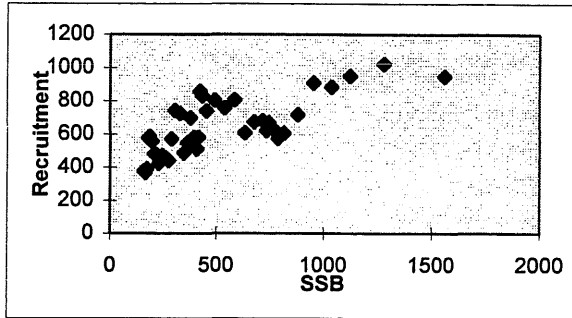
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Figure 1. SSB v. recruitment for Northeast Arctic Cod. SSB ranked according to size. Development of plot with increasing number of points in the moving average.

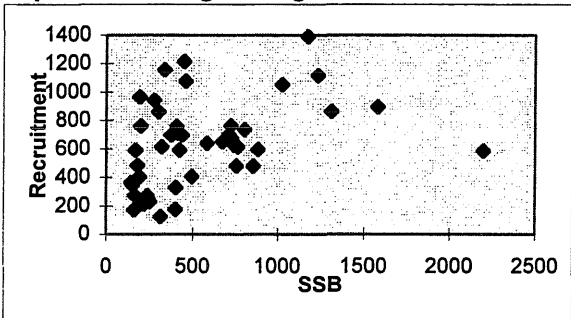
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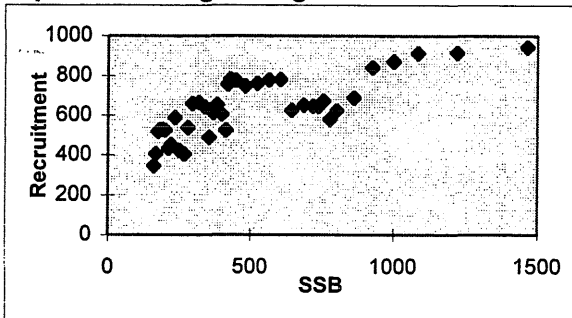
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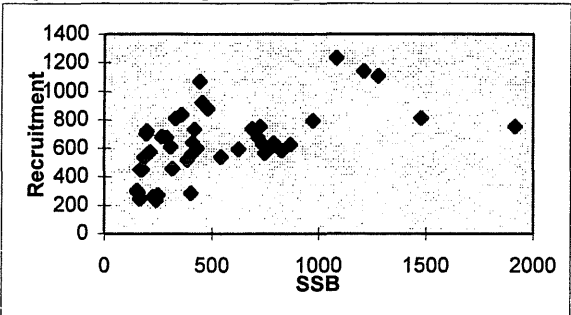
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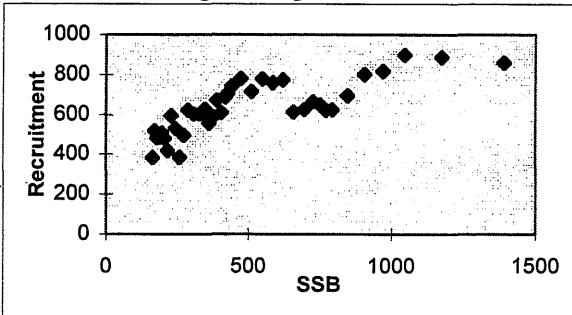
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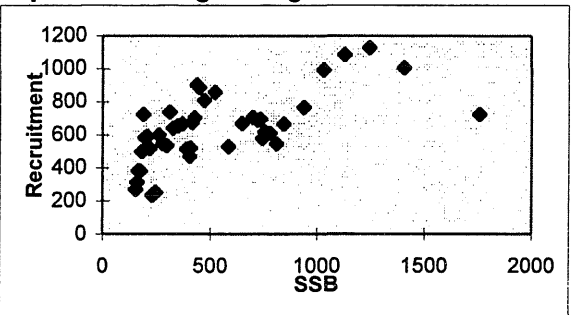
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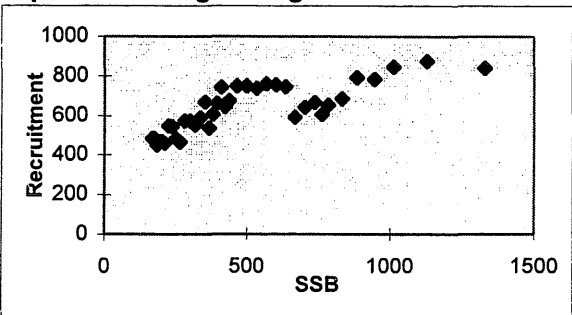
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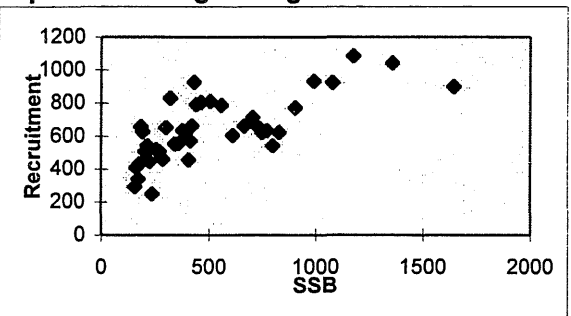
4-points moving average



9-points moving average



5-points moving average



10-points moving average

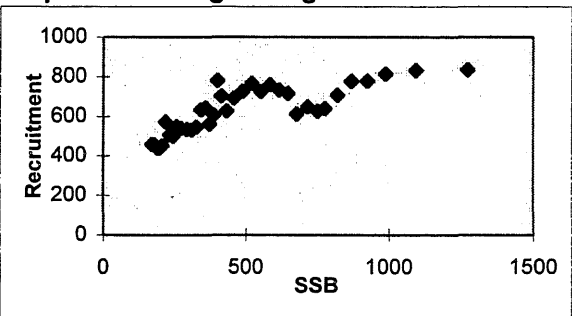


Figure 2a. SSB vs Recruitment plots with Beverton and Holt (whole) and Ricker (broken) curves indicated.

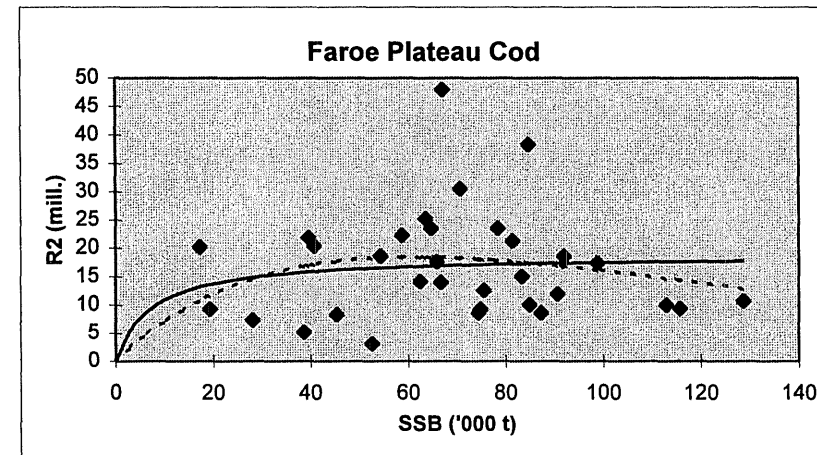
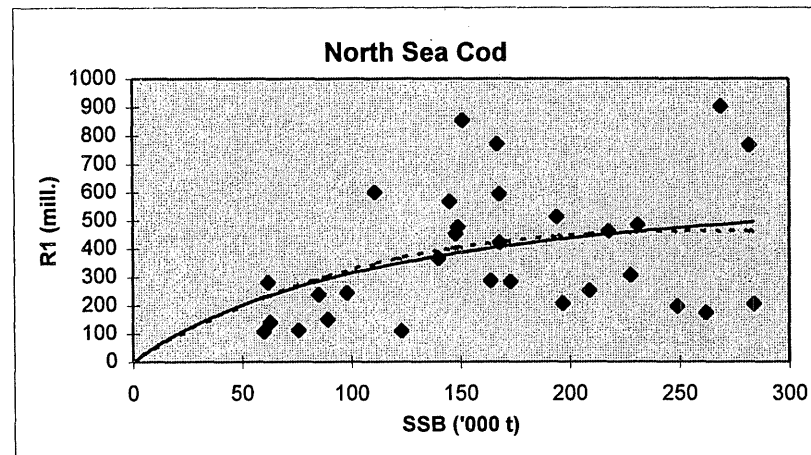
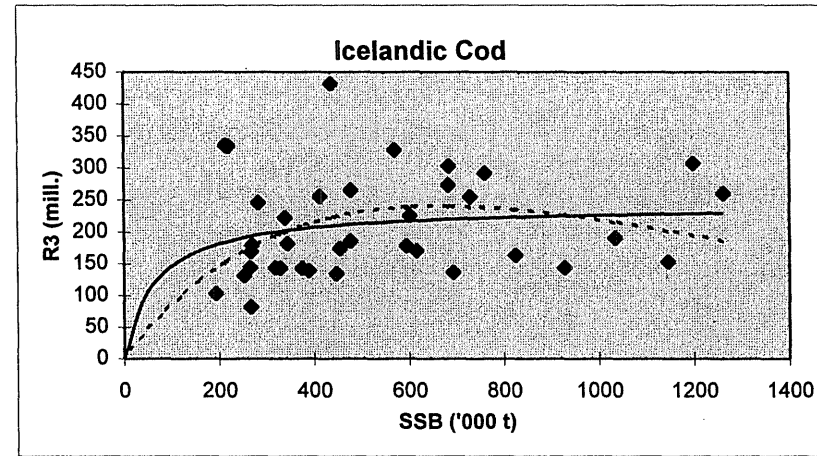
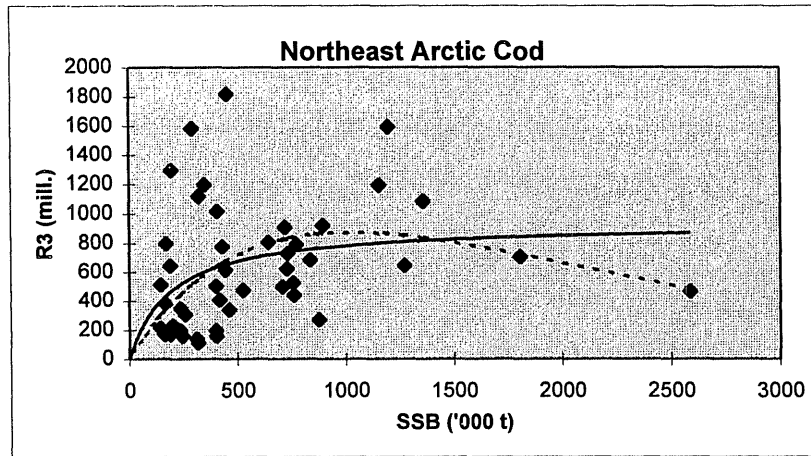


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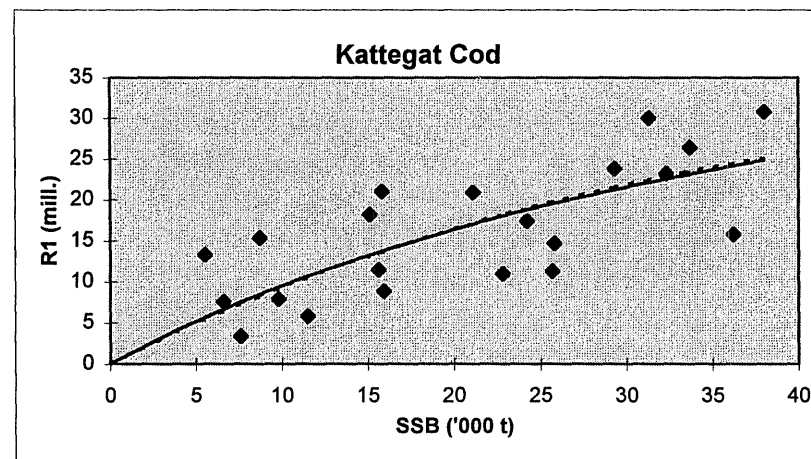
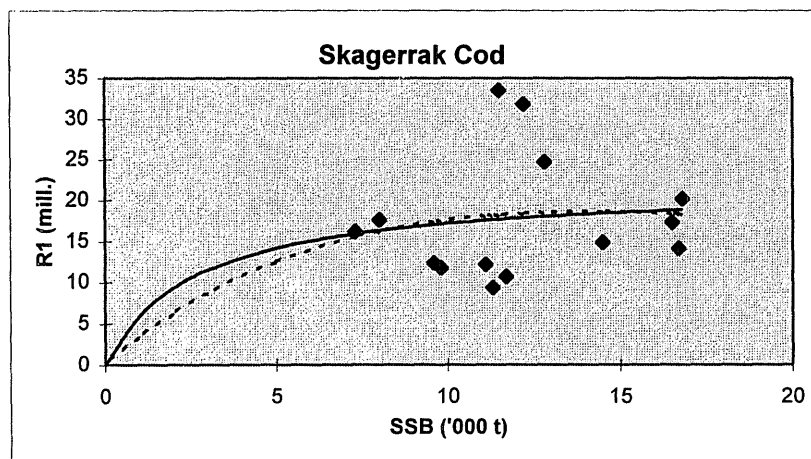
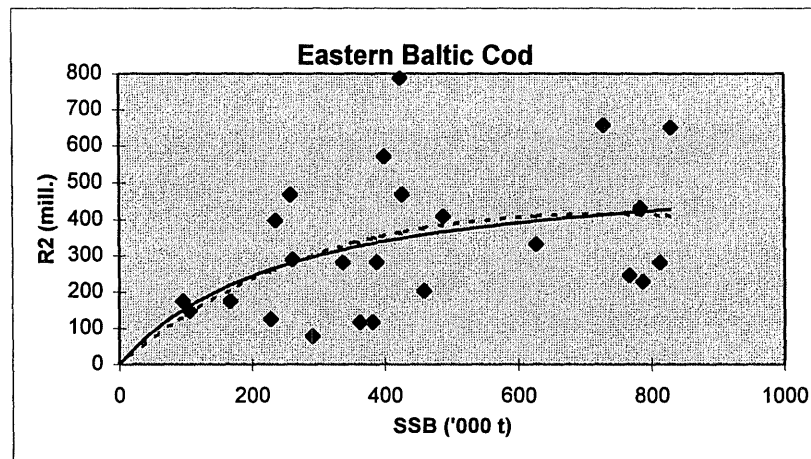
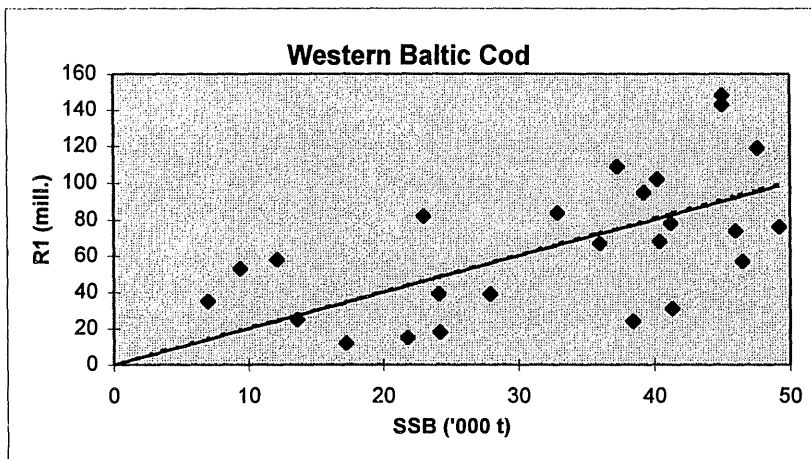


Figure 2c. SSB vs Recruitment plots with Beverton and Holt (whole) and Ricker (broken) curves indicated.

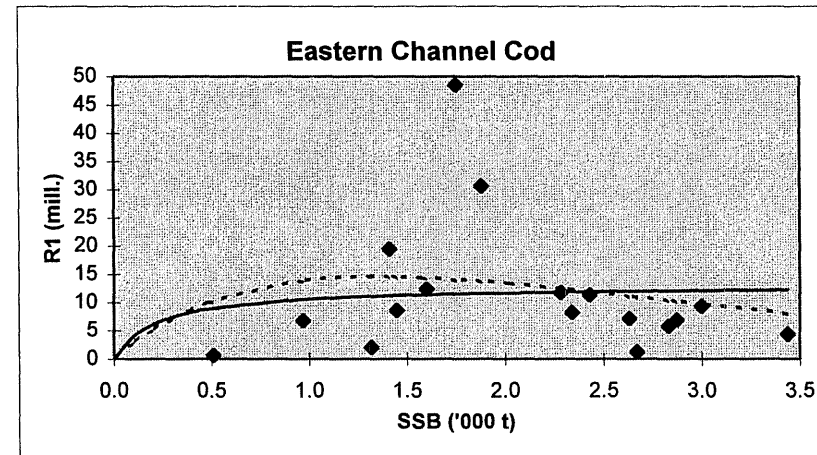
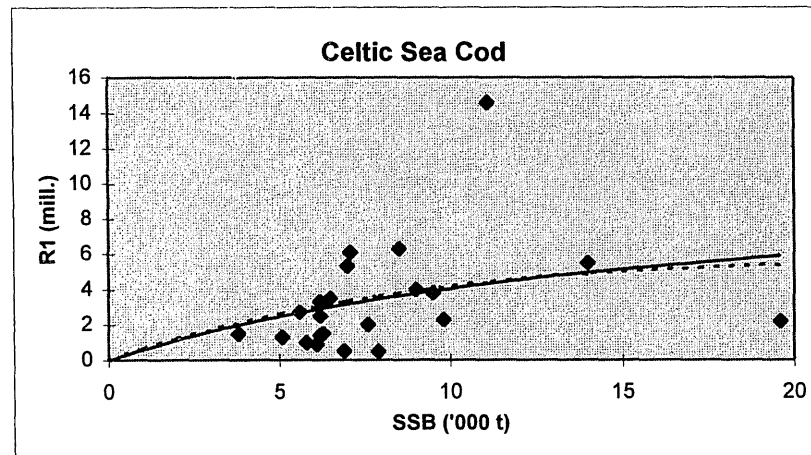
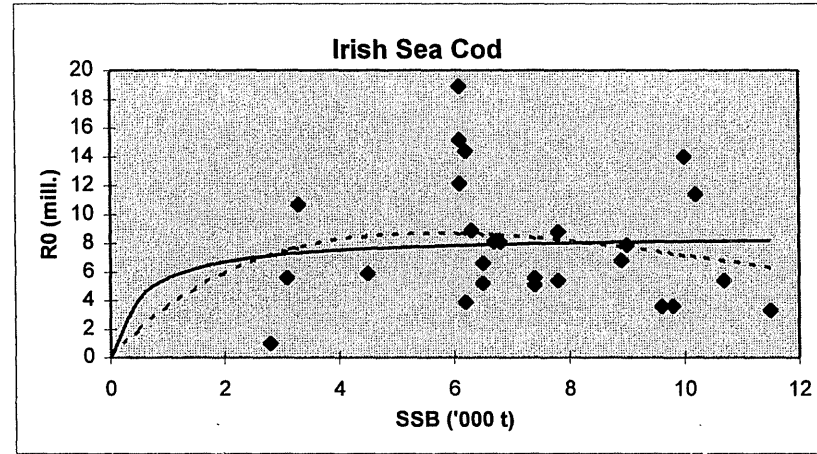
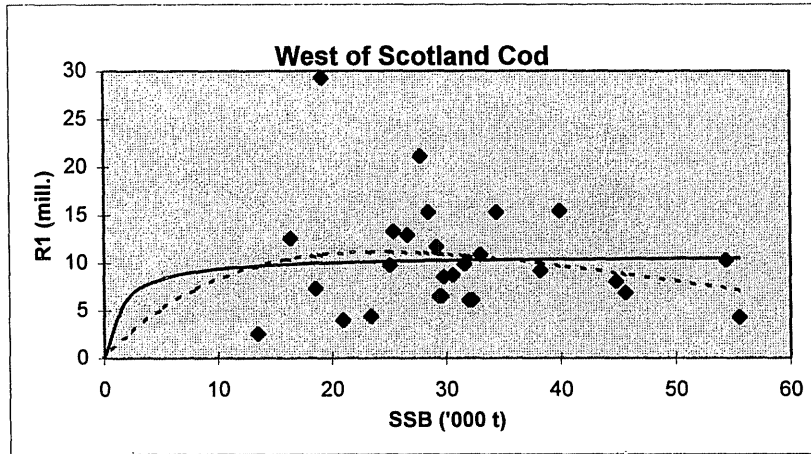


Figure 2d. SSB vs Recruitment plots with Beverton and Holt (whole) and Ricker (broken) curves indicated.

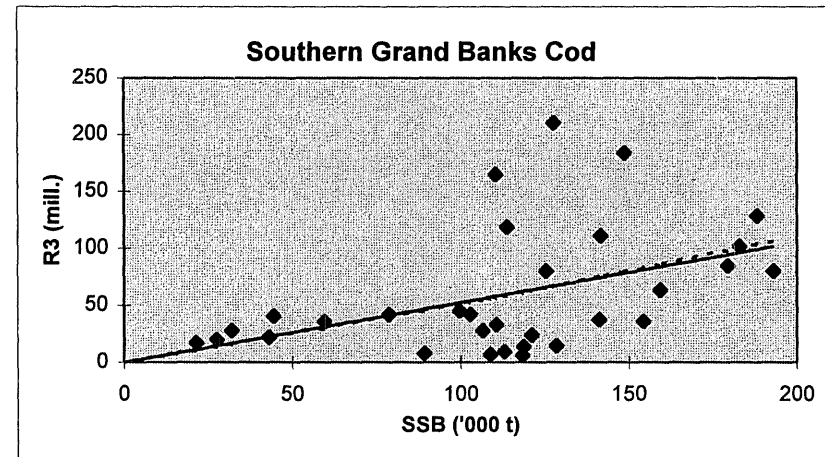
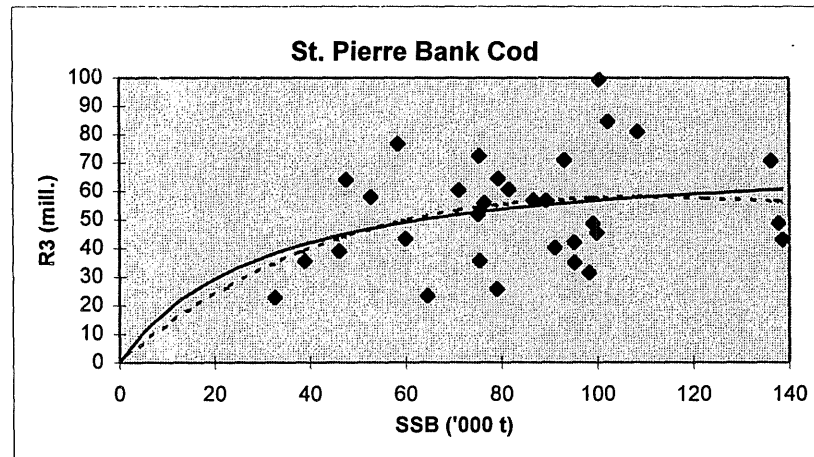
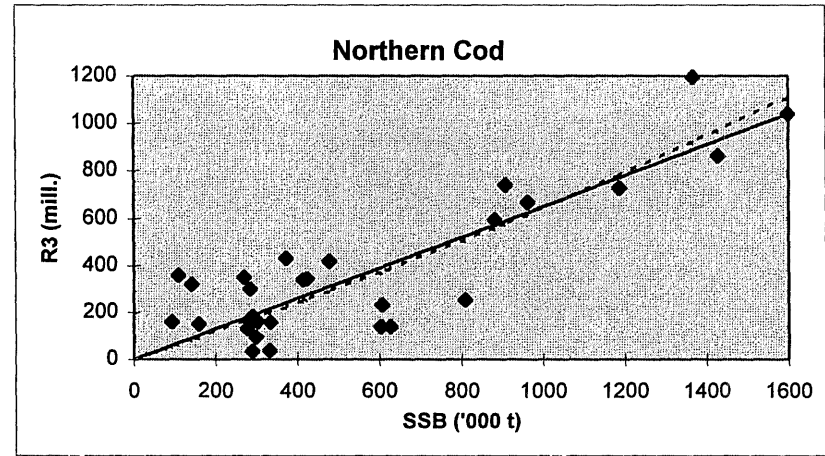
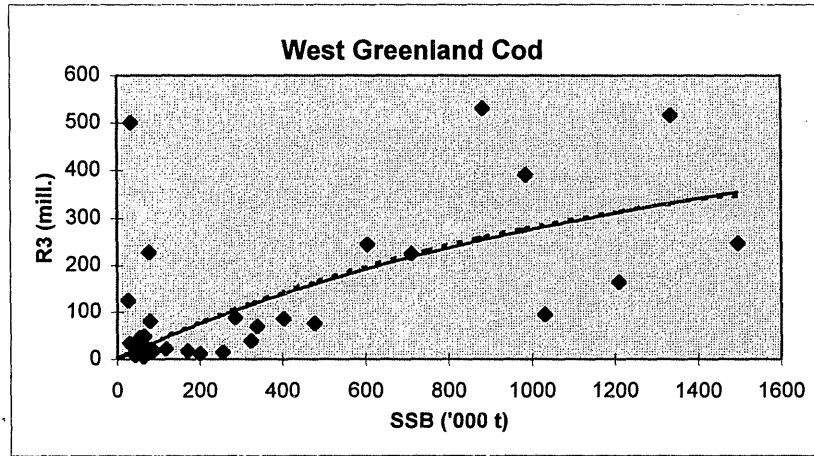


Figure 2e. SSB vs Recruitment plots with Beverton and Holt (whole) and Ricker (broken) curves indicated.

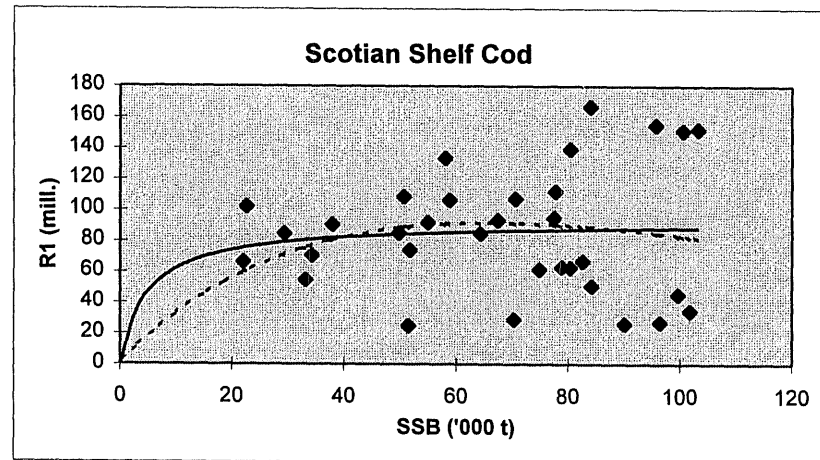
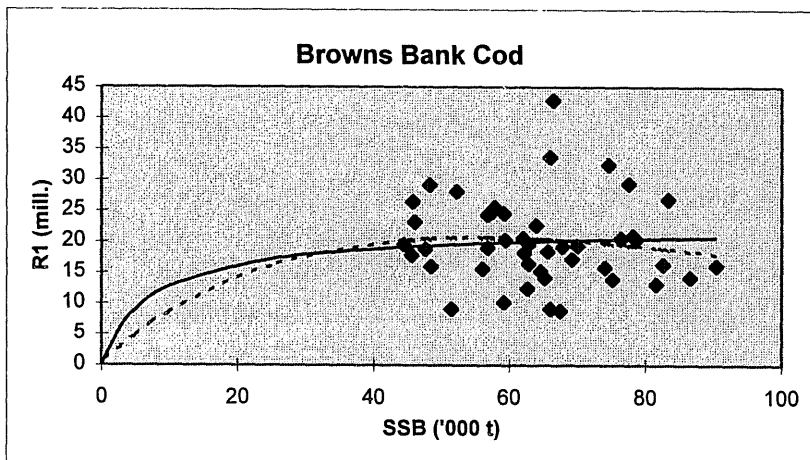
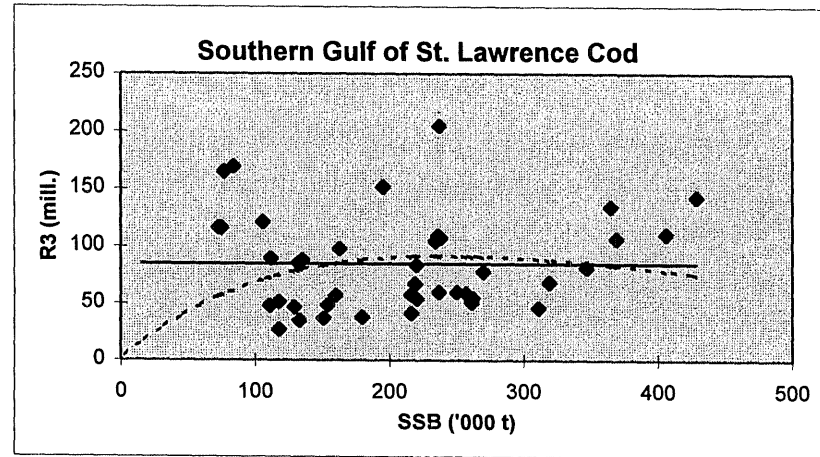
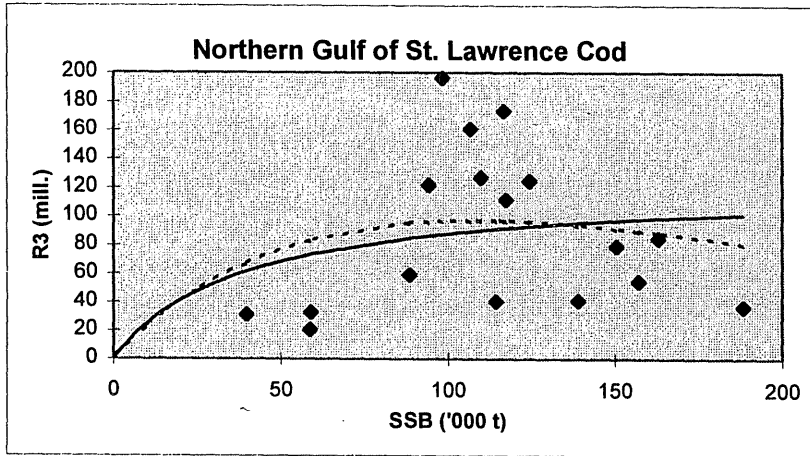


Figure 3a. SSB vs Recruitment. SSB ranked according to size and moving average of 10 points applied. Beverton and Holt (whole) and Ricker (broken) curves indicated.

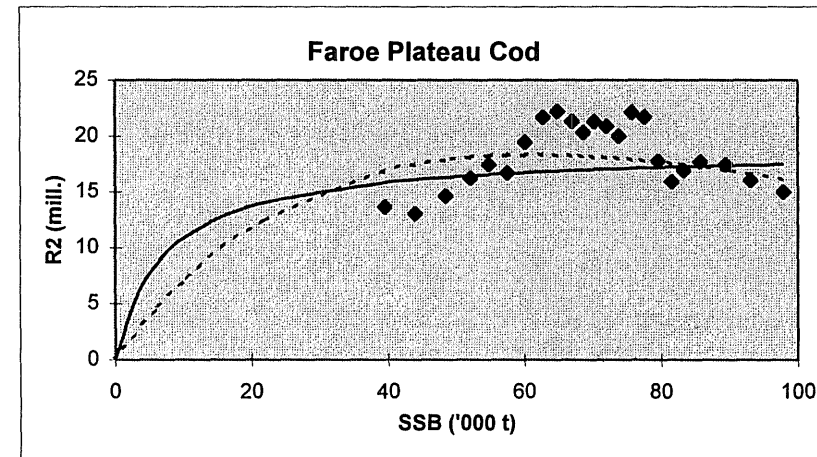
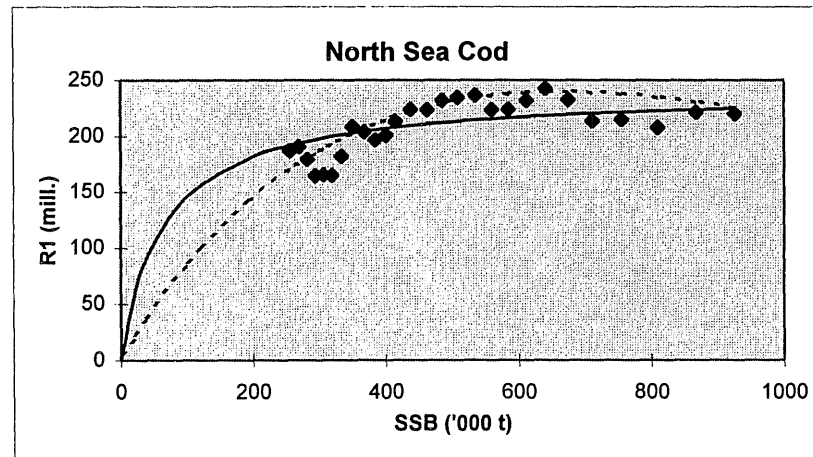
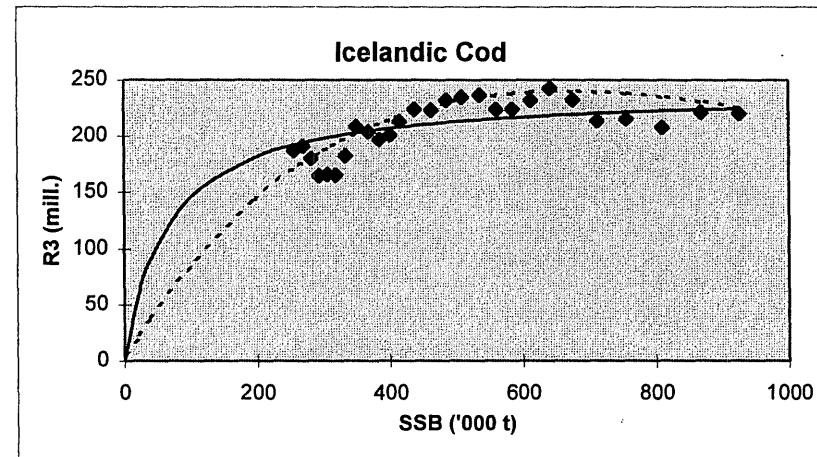
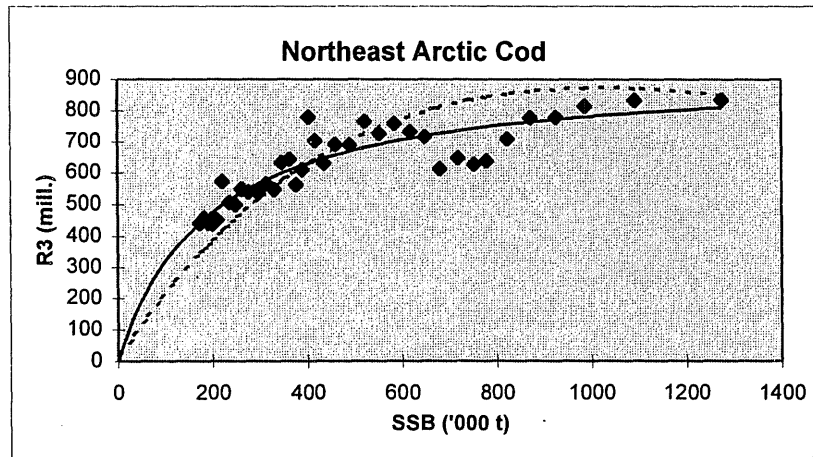


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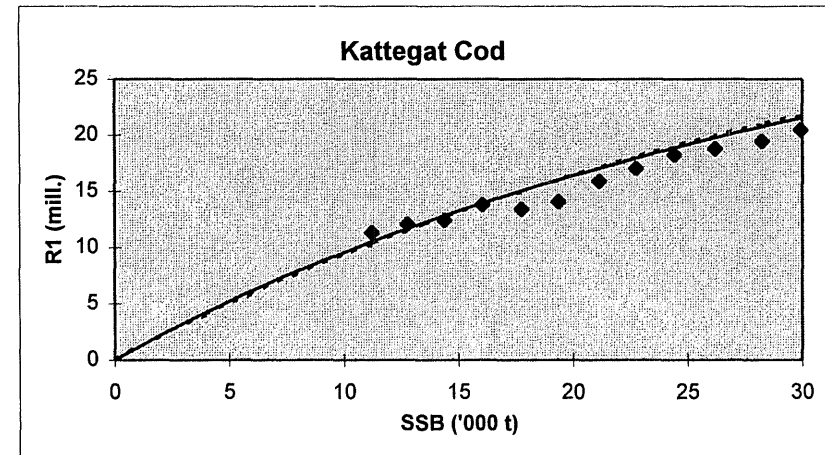
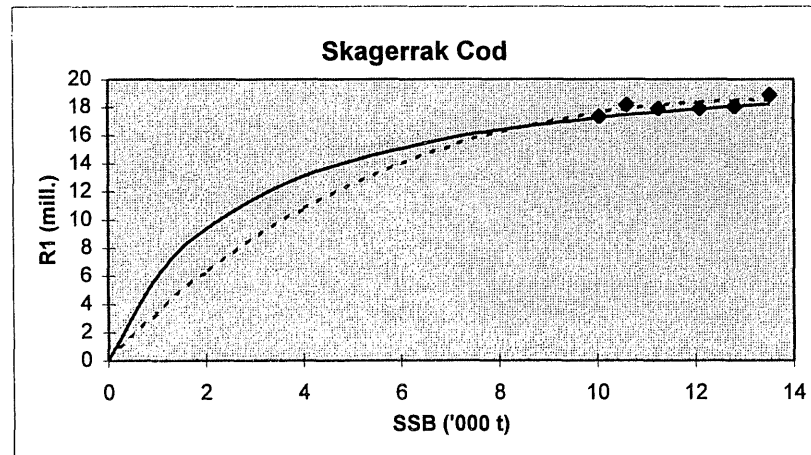
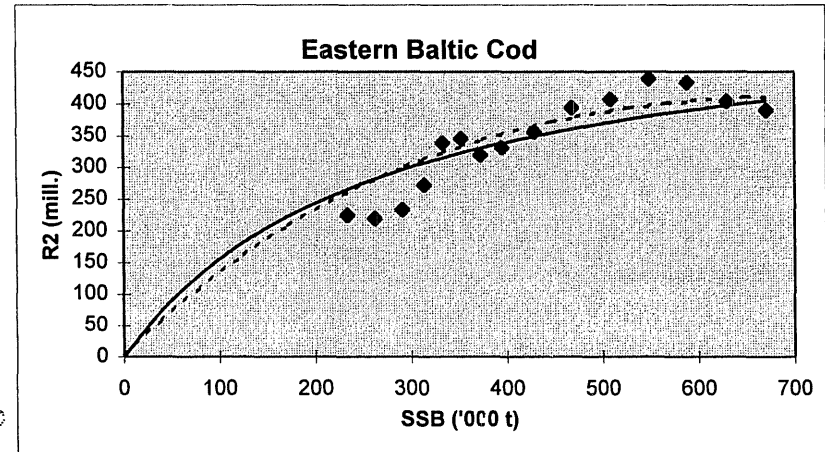
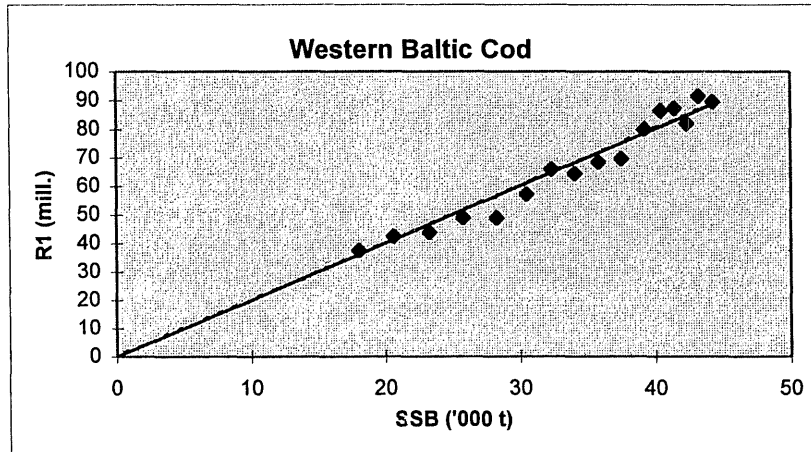


Figure 3c. SSB vs Recruitment. SSB ranked according to size and moving average of 10 points applied. Beverton and Holt (whole) and Ricker (broken) curves indicated.

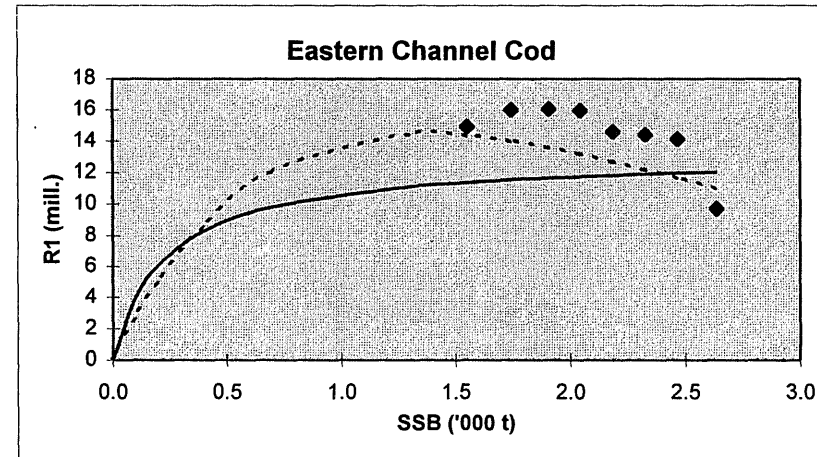
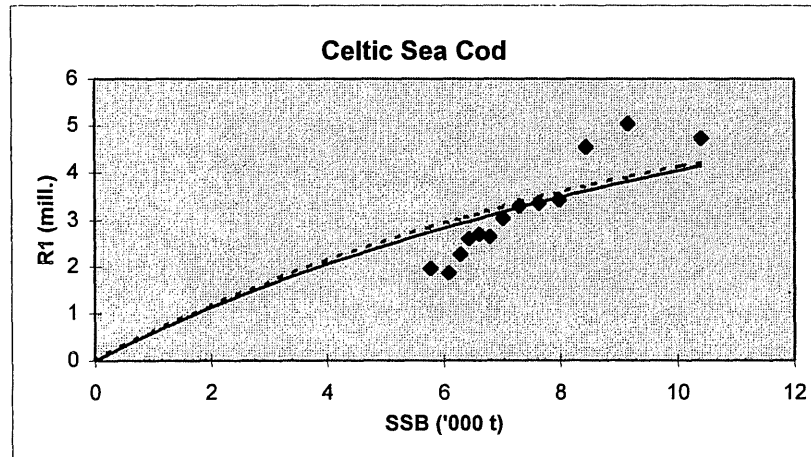
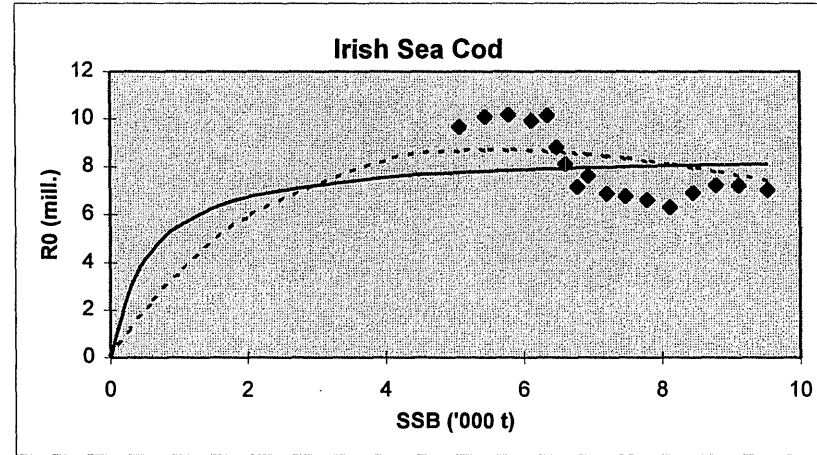
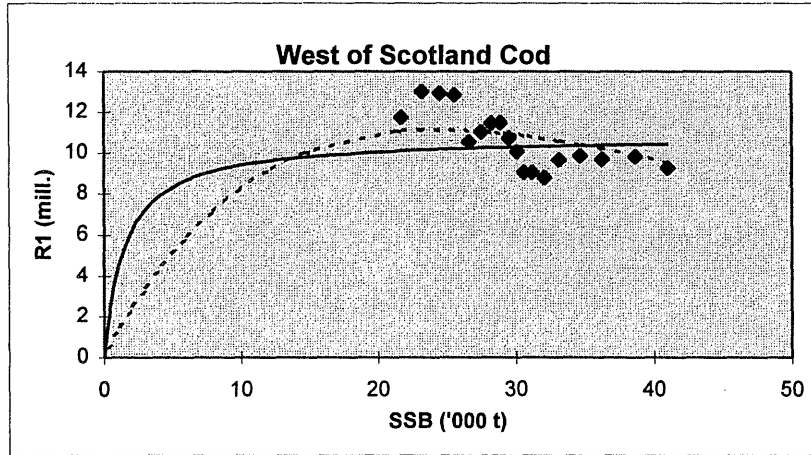


Figure 3d. SSB vs Recruitment. SSB ranked according to size and moving average of 10 points applied. Beverton and Holt (whole) and Ricker (broken) curves indicated.

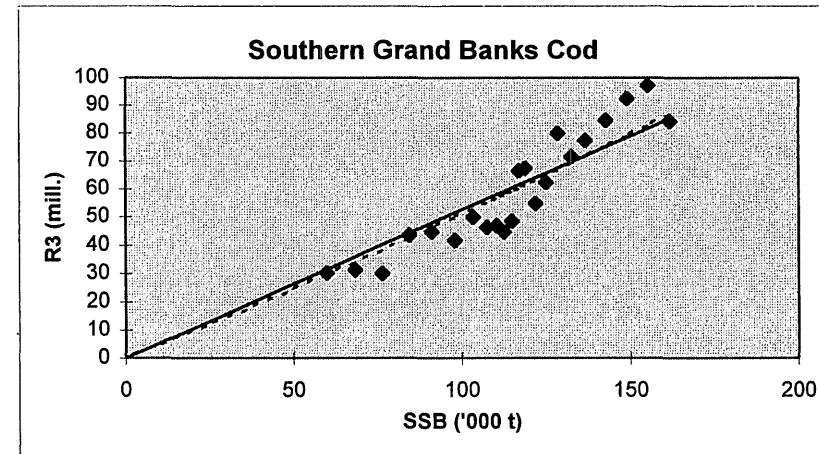
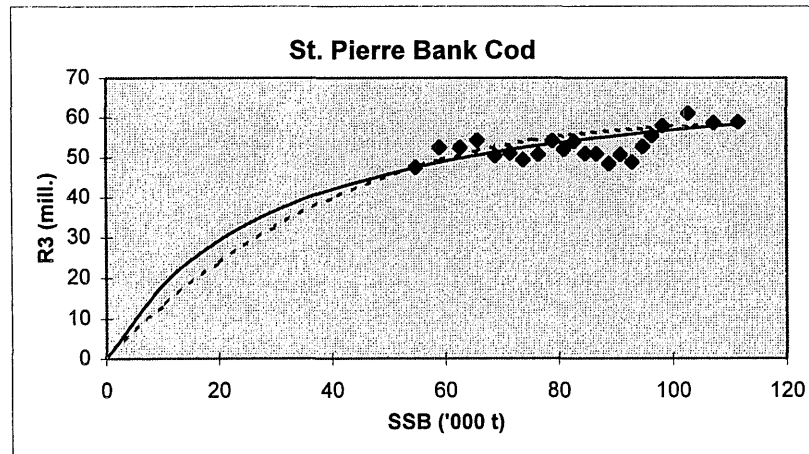
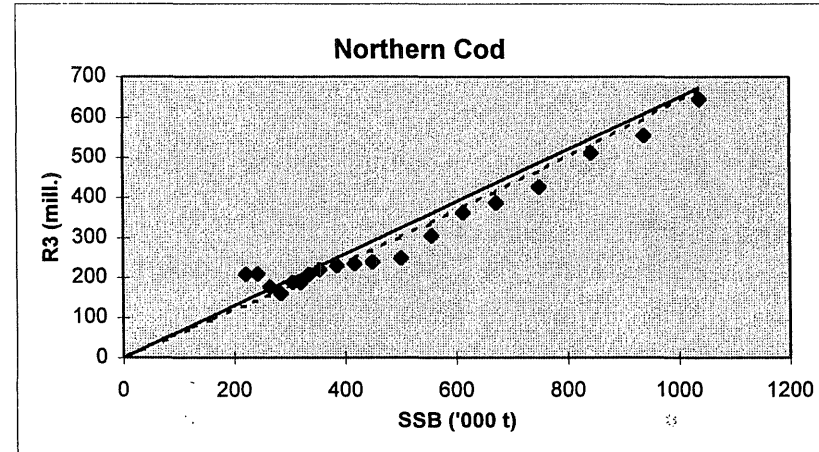
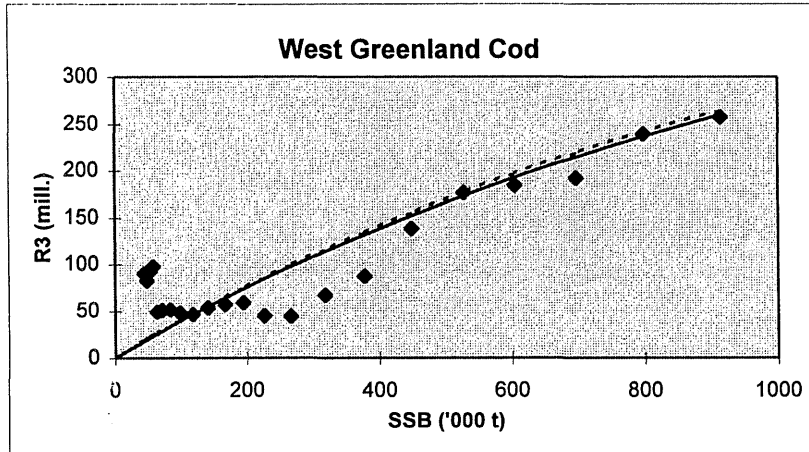


Figure 3e. SSB vs Recruitment. SSB ranked according to size and moving average of 10 points applied. Beverton and Holt (whole) and Ricker (broken) curves indicated.

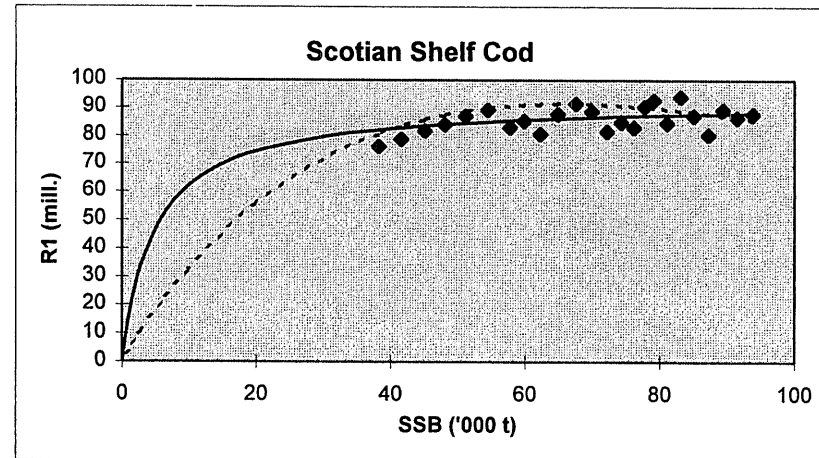
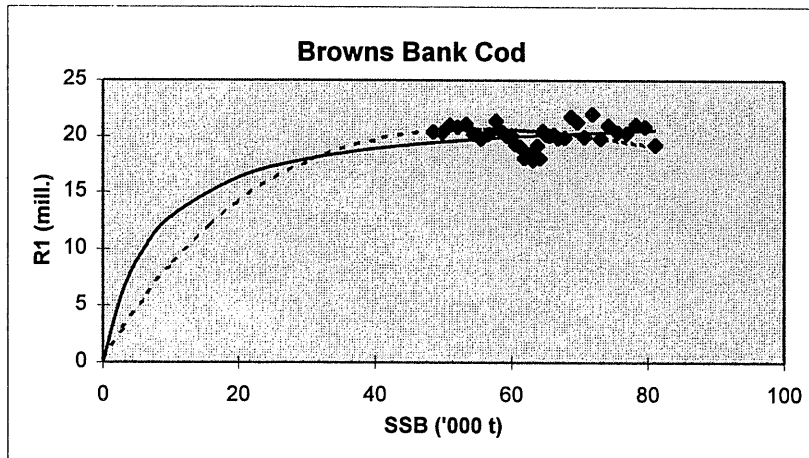
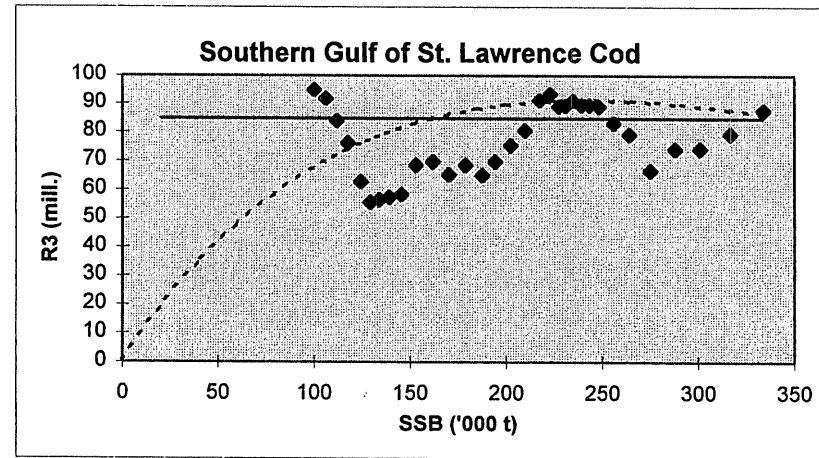
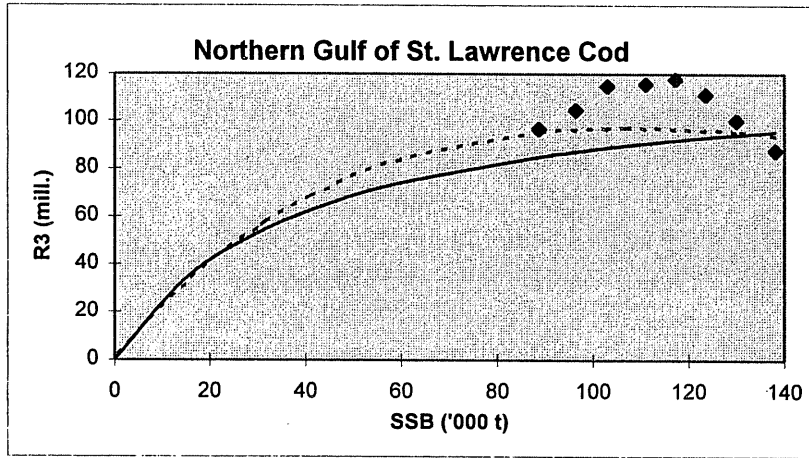


Figure 4a. Time trajectory of SSB vs Recruitment. 10 years moving average.
The starting point is marked by an open square.

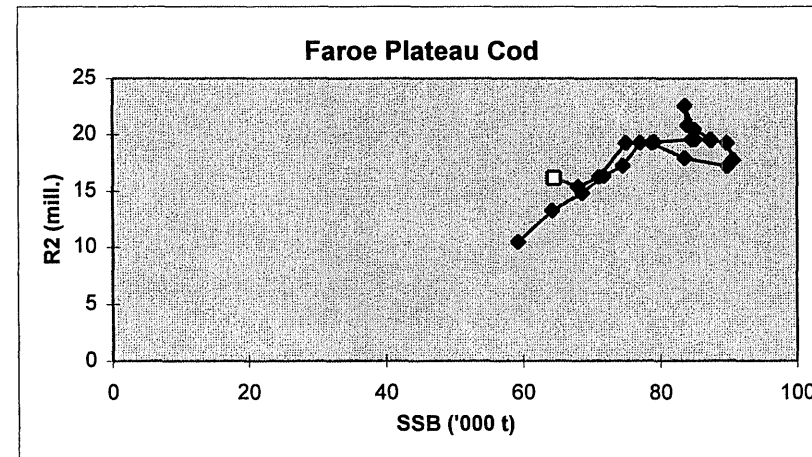
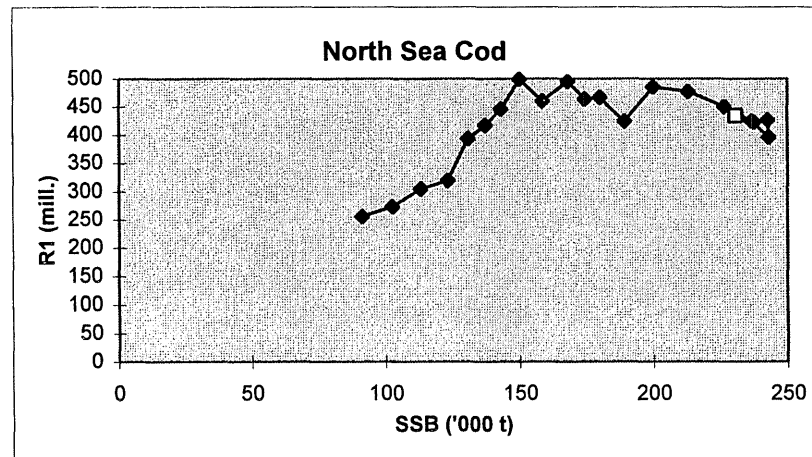
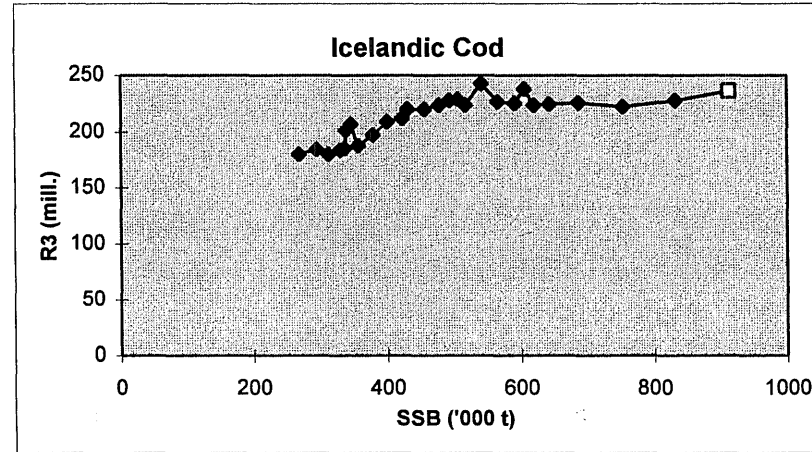
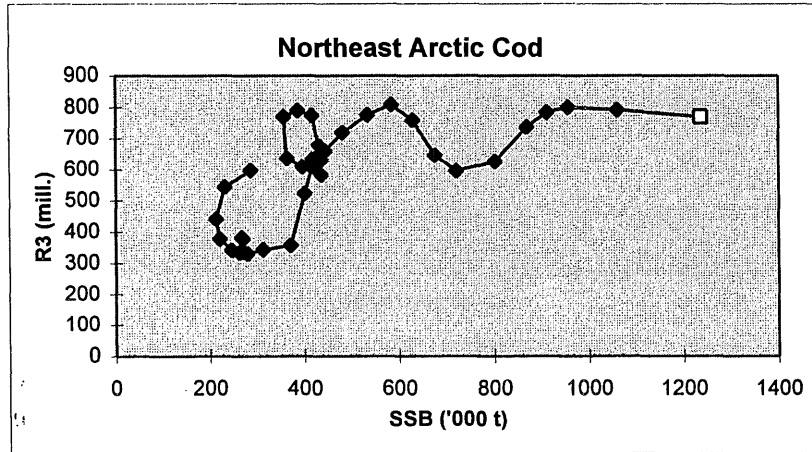


Figure 4b. Time trajectory of SSB vs Recruitment. 10 years moving average.
The starting point is marked by an open square.

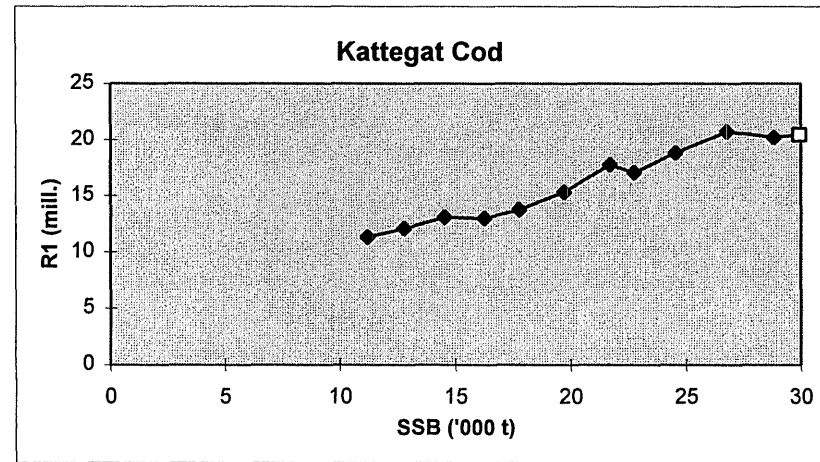
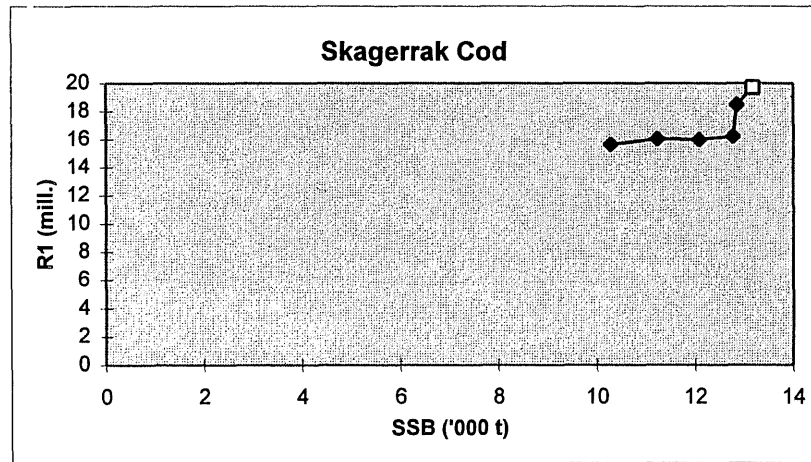
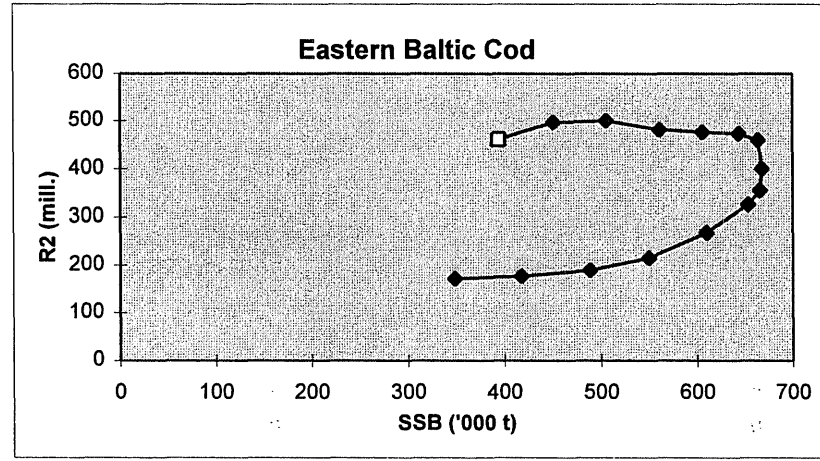
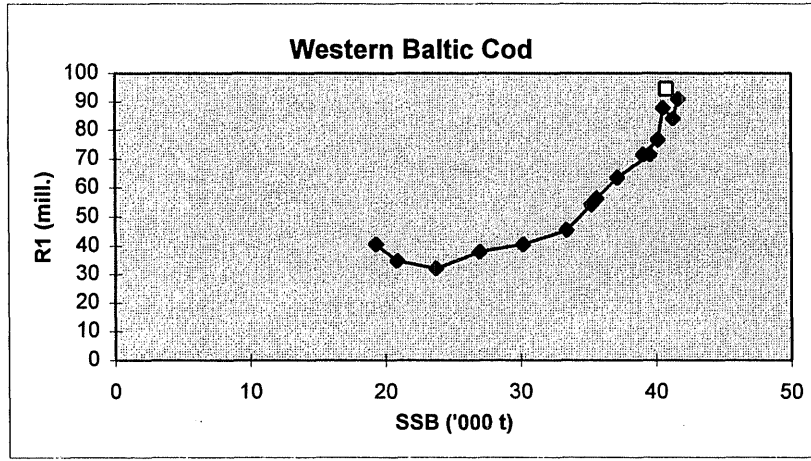


Figure 4c. Time trajectory of SSB vs Recruitment. 10 years moving average.
 The starting point is marked by an open square.

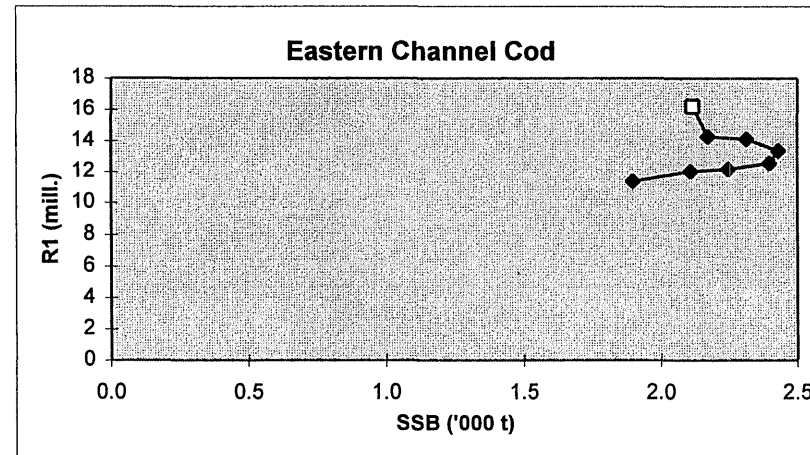
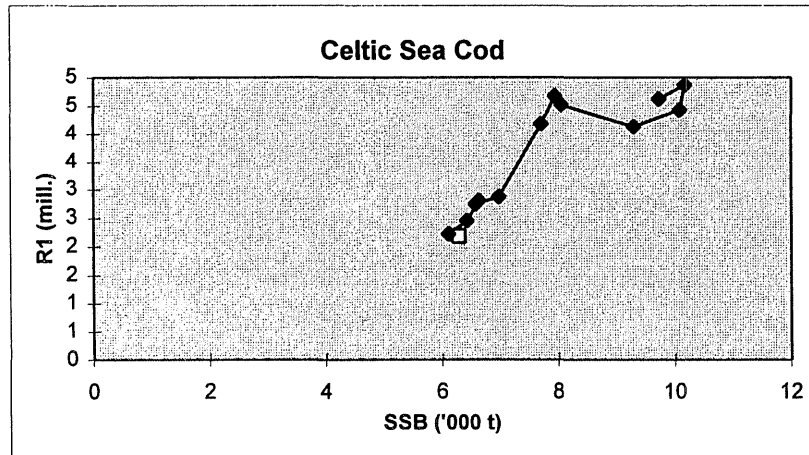
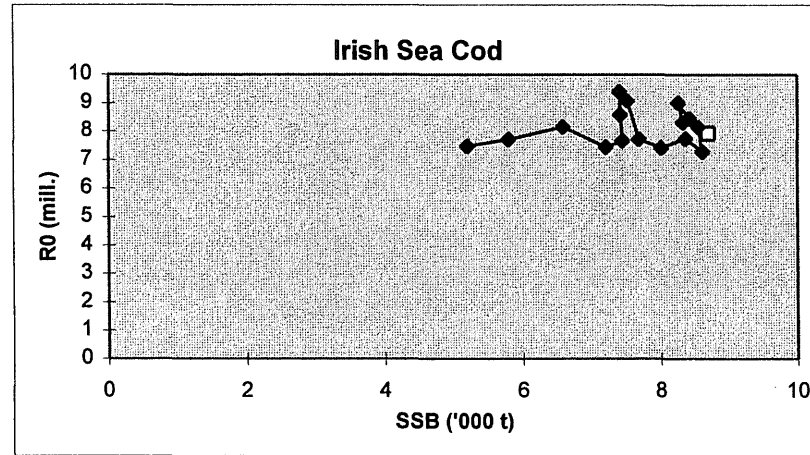
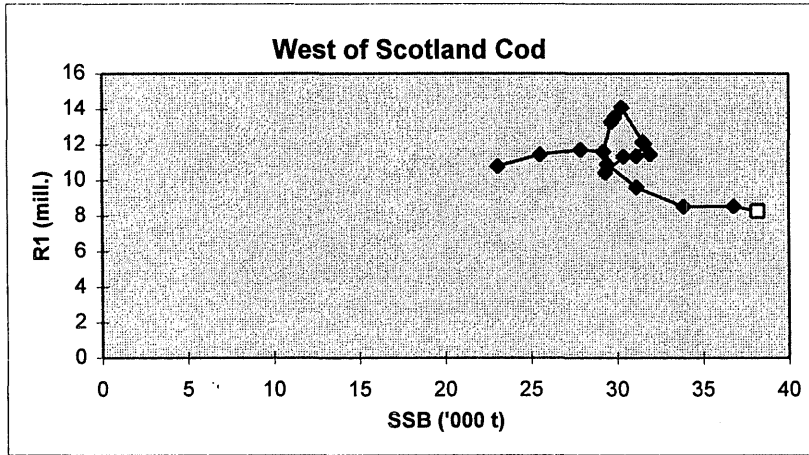


Figure 4d. Time trajectory of SSB vs Recruitment. 10 years moving average.
The starting point is marked by an open square.

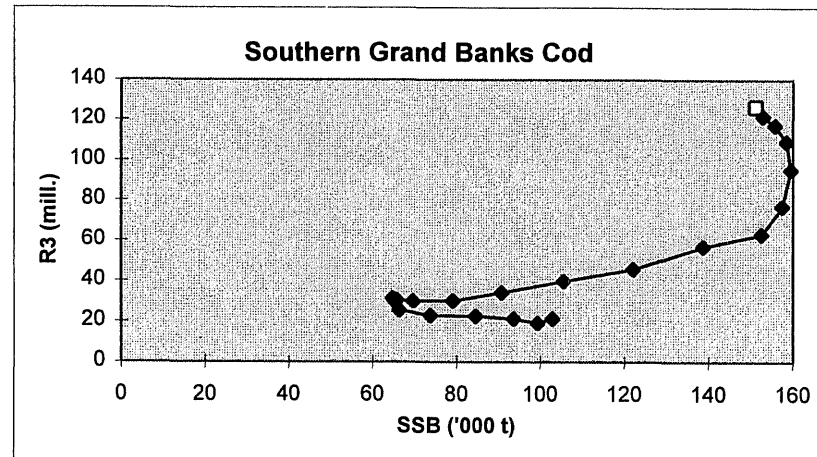
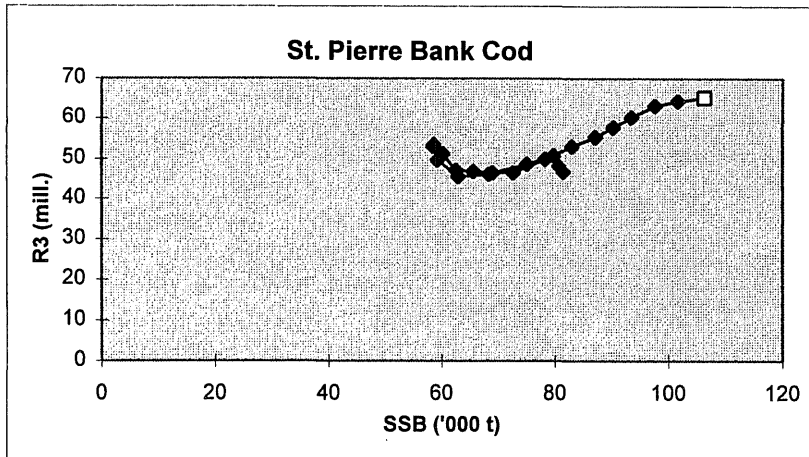
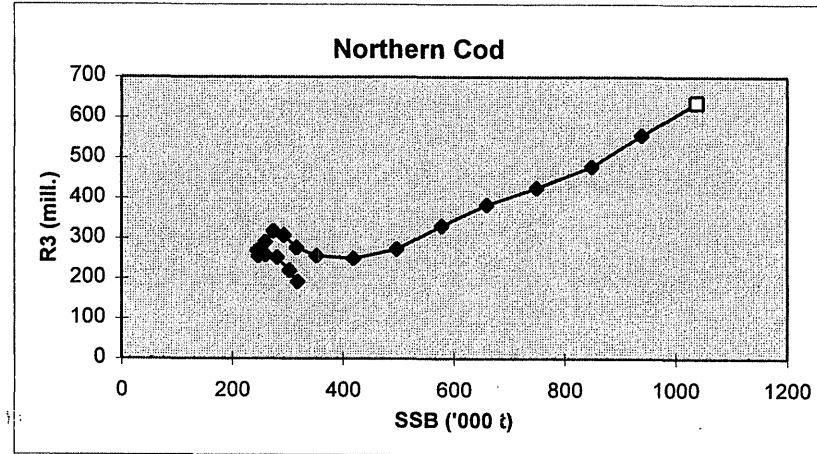
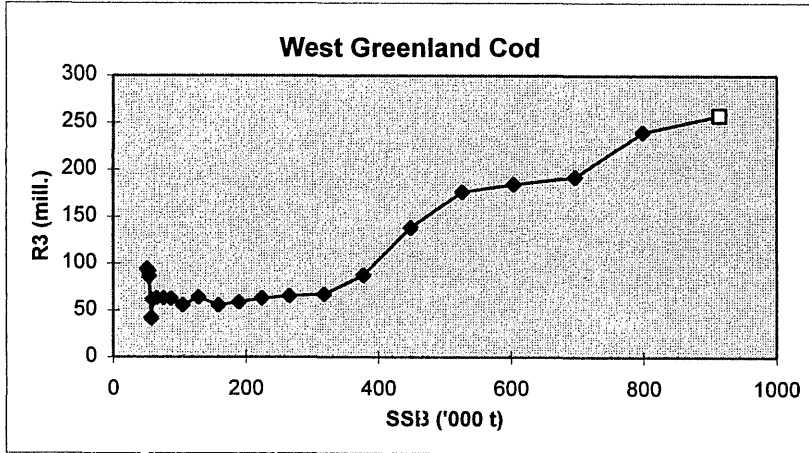


Figure 5a. SSB vs Recruitment. Summary of cod stocks.
SSB and recruitment scaled to mean (100) for each stock.

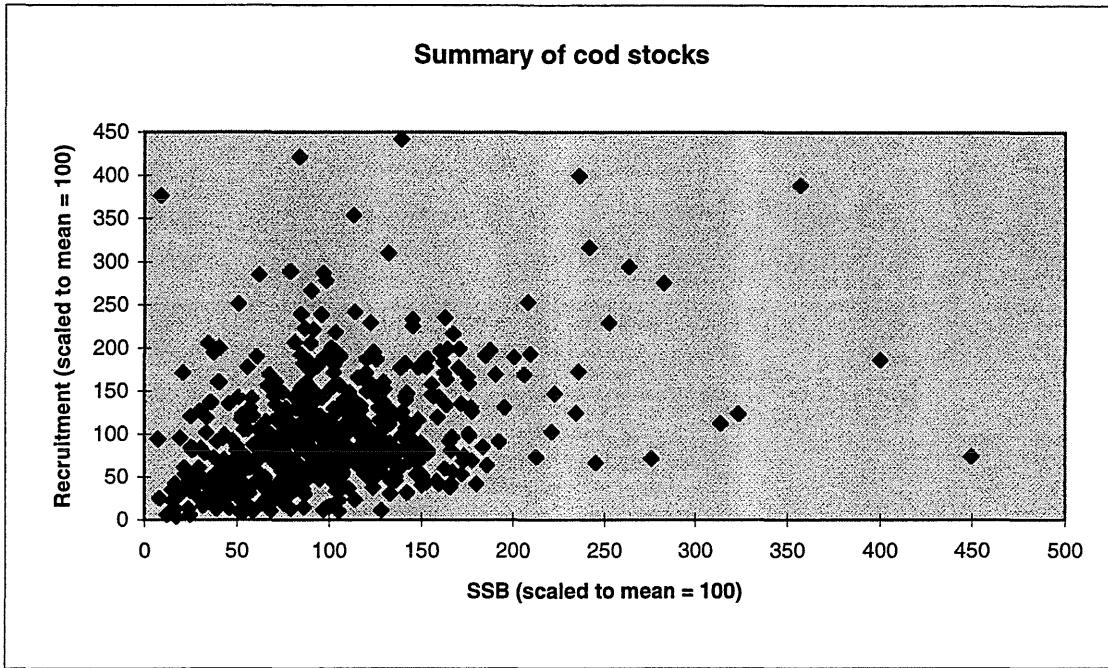


Figure 5b. SSB vs Recruitment. Summary of cod stocks.
SSB and recruitment scaled to mean (100) for each stock.
SSB ranked according to size and moving average of 50 points applied.

