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ILUSTRATIONS OF THE PRECAUTIONARY APPROACH USING 4TVW HADDOCK, 4VSW COD AND 3LNO AMERICA

by

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Introduction

There has been increasing interest recently in applying the precautionary approach to Canadian stocks. In order to get feeling for this method preliminary runs were made using two Canadian stocks (4TVW haddock and 4VsW cod) and one NAFO stock (3LNO plaice). The first purpose of these trials was to develop the appropriate software. The second, and more important, was to begin to manipulate and hence develop an understanding for the new and evolving ideas of the precautionary approach. Two symposia were held in 1997 in attempts to develop a framework to carry out precautionary analysis: the ICES Study Group on the Precautionary Approach to Fisheries Management (Copenhagen, Feb. 1997) and NAFO Scientific Council (June, 1997). We expand their work by including more of the non-equilibrium implications and develop a broader definition of risk analysis than is usually done.

Our analysis is based upon the integration of traditional yield per recruit analysis, which has been used to define such targets as $F_{0.1}$, and stock-recruitment models. The basic approach is a family of curves which are interrelated based on the work of Sissenwine and Shepherd (1987). These sets of curves are a convenient way to display the importance of the underlying biology of a stock as well as fishery management concepts.

As the work developed it became slightly more complicated. The final version, Appendix B, may be sued to assess the relative magnitudes of measurement error associated with the SPA and process error which is associated with the dynamics of stock and recruitment.

The text refers to examples from 4TVW haddock which was the first of these stocks used to develop the software. Results from the second stock (4VsW cod),are given in Appendix A. Finally, the analysis for 3LNO plaice which was carried out during the March 1998 NAFO meeting are given in Appendix B.

Methods

The Sissenwine and Shepherd (1987) plots are shown in Figure 1 for 4TVW haddock. The three subplots on the left are all functions of fishing mortality. The two subplots a) and b) are the traditional yield and (spawning stock) biomass per recruit relationships. In this case,

we used the Thompson-Bell method to estimate the yield and biomass per recruit. The center plot of the right-hand set (c) of three subplots is a Ricker stock-recruit function. The data to which it has been fit is included in this subplot. The stock-recruit curve and the points are mapped onto the subplot above (top-right) by dividing the biomass at each point by its recruitment; this is done so that the y-axis of the two uppermost plots will be the same which allows a link to be made between the left-hand figures and those on the right. Once this link is made the yield per recruit results can be transformed onto yields because at each level of F there is an accompanying recruitment. The equilibrium yields for each F (or SSB) are then plotted on the lowermost set of subplots, c) and f). The historical yields are plotted in f) for comparison with the equilibrium yields.

Results

The sensitivity of the various values to underlying data are explored in Figures 2-3. In Figure 2 the partial recruitment used in the base run is from the SPA (Frank et al. 1997) it is shifted so that one years age younger fish are caught and the oldest age are fully recruited. The yield per recruit curve is shifted downward while the biomass per recruit, a), is higher. The most dramatic effect is in subplot c) where the yield now crashes at an F of 1.2 as opposed to base run Fcrash which is greater than 2.5. The yield as a function of biomass, f), is only slightly affected. In Figure 3 the maturity ogive is shifted one year older, i.e., instead of 3 year olds being mature the age is now 4. The biomass per recruit is reduced a) but yield per recruit, b) is unaffected. FCrash is sensitive to the age of maturity. MSY and BMSY, the location of the peak of the yield curve in f) are both slightly reduced when the age of maturity is shifted one year older.

The linkage among the subplots is dependent upon the function which fits, or models, the relationship between stock and recruitment data. To make them more intuitive, we have reparameterized the Ricker relationship in terms of the maximum recruitment and the biomass which corresponds to that recruitment and call the new parameters RMax and Bmax. The usual a and b of the Ricker curves are then:

$$a = \exp(1) * RMax / Bmax$$
$$b = 1. / BMax$$

Figure 4 shows the sensitivity to a change in RMax from the base value of 35 to 22 million. Both yield curves, c) and f), are seen to be quite sensitive to Rmax. Because the stock-recruit relationship is quite noisy (Figure 1a) the fit of these data was investigated using conditioned bootstrapping. Briefly, the residuals from the base run are re-sampled and added to the fit data to make replicate data sets. The data are limited to 24 pairs and there are only 2 parameters in the model making a large number of replicates easily performed; 5000 were used for this analysis. The resultant Rmax and Bmax's are shown in Figure 5 as contours. The darkest region is the area which contains the most frequent 25% of pairs.

By re-sampling the distribution of the Ricker parameters, estimates of the uncertainty in various precautionary parameters may be found. For example, Figure 6 shows the cumulative distributions of MSY and BMSY that may be attributed to the lack of fit of the stock and recruit data to the Ricker curve. For example, while the best estimate of MSY is about 15 KT, there is about a 10% chance that MSY is less than 10 KT. The distribution of BMSY is shown in the lower plot of Figure 6 and has a similar distribution. Figure 7 shows the cumulatives for Fcrash and the carrying capacity. Fcrash has a discontinuity at

an F of 3 because this is the highest F used in the analysis and in approximately 35% of the trials Fcrash was greater that 3. Nonetheless, FCrash is seen to be relatively more sensitive than the other parameters shown in Figure 6 and 7.

Figure 8 focuses on applying the precautionary approach to our haddock stocks; it is comprised of subplots e) and f) from the base run. Ellipses have been added to the stock and recruit data to show the approximate uncertainty in their estimation from the VPA. The axes of each ellipse are the standard deviation in each dimension, assuming them to be independent. In reality the axes would be correlated and the ellipses tilted, but we have not included this into Figure 8. In some sense this plot may be thought of as a comparison between the measurement error (the size of the ellipses) and process error (the distance from the center of each ellipse to the stock-recruit curve). As expected, the most recent ellipse is the largest and they decrease as one goes back in time.

Figure 9 explores a potential precautionary plot with limit and precautionary values from 4TVW haddock. Blim is arbitrarily set from the stock and recruitment data as a lower limit of SSB in that there are no observations of recruitment at this level since the mid-70s. BMSY is used as Bpa, the precautionary level of biomass below which a more conservative fishing mortality (and yield) are imposed. Flim is set at F0.1 (= 0.26) and Fpa is set at half of F0.1. Although only an illustration, such a plot could be used for defining criteria for re-opening the fishery and setting catch levels while the stock is rebuilding.

Discussion

The analysis in preparation of a precautionary approach allows direct inclusion of the reproductive dynamics of the stock. We have assumed in these examples that the stock recruitment relationship is stationary - does not change over time. However, the data for 4TVW haddock would suggest that since the mid-80's the stock was not as productive as before. An extension of these analyses which incorporates changes in productivity should be undertaken.

Traditional risk analysis has only incorporated the errors which could be quantified from the VPA. When these are compared to the difficulty in determining a stock-recruit relationship which is needed in the precautionary analysis presented above, they are seen to be only one aspect of uncertainty and hence risk. More work should be directed at combining all quantifiable sources of uncertainty.

References

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Frank, K.T, R.K. Mohn and J.E. Simon. 1997. Assessment of 4TVW haddock in 1996. Can. Stock Ass. Secr. Res. Doc 97/107

MohnR. K., L.P. Fanning and W.J. MacEachern. 1998. .MS Assessment of 4VsW cod in 1997 incorporating additional sources of mortality.

Sissenwine,M.P. and Shepherd, J.G. 1987. An alternative perspective on recruitment overfishing and biological reference points. Can. J. Fish. Aquat. Sci. 44:913-918.

Figure 1. Precautionary plots for 4VW haddock - base run.

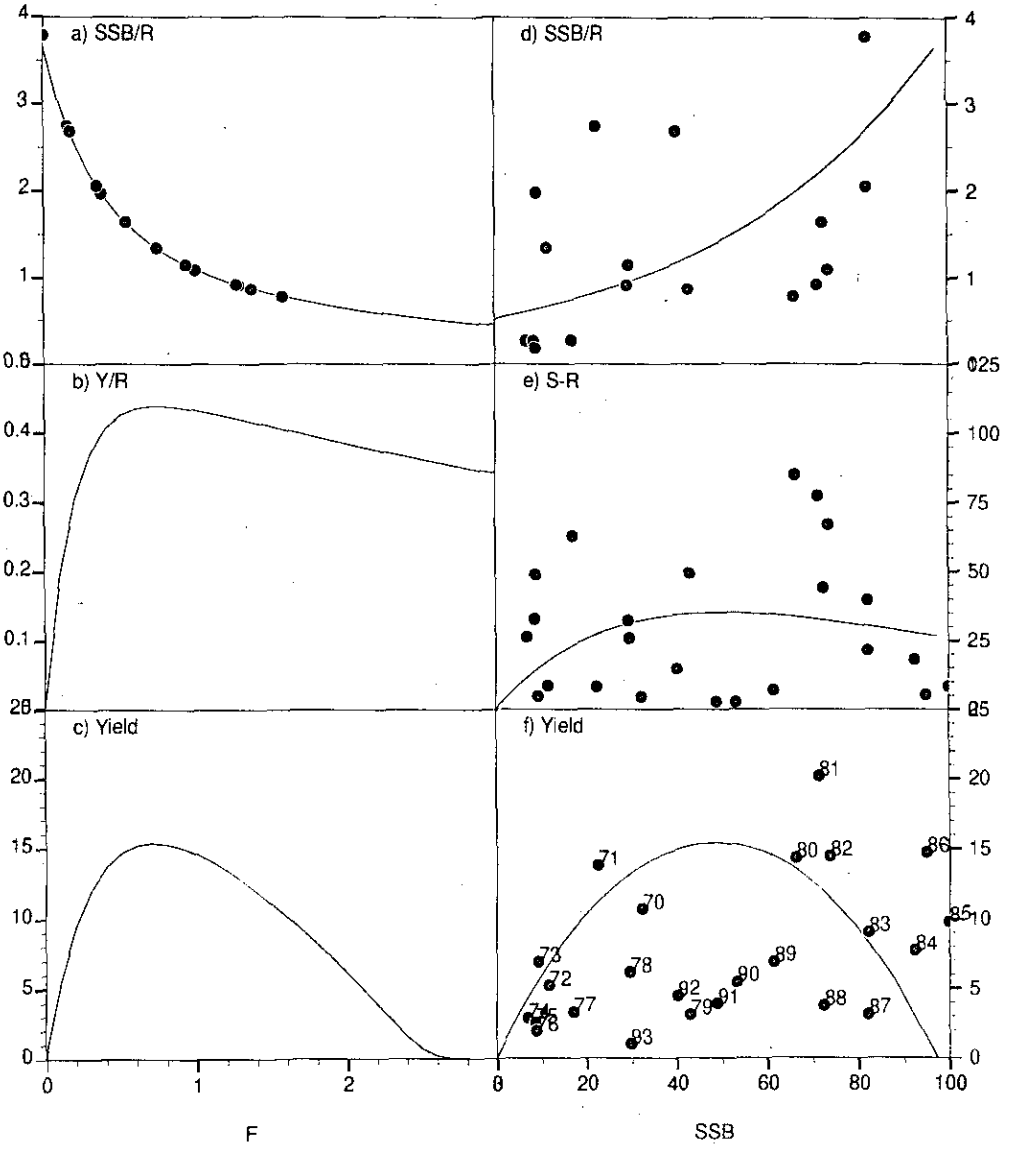


Figure 2. Sensitivity of precautionary plots to a change in partial recruitment.

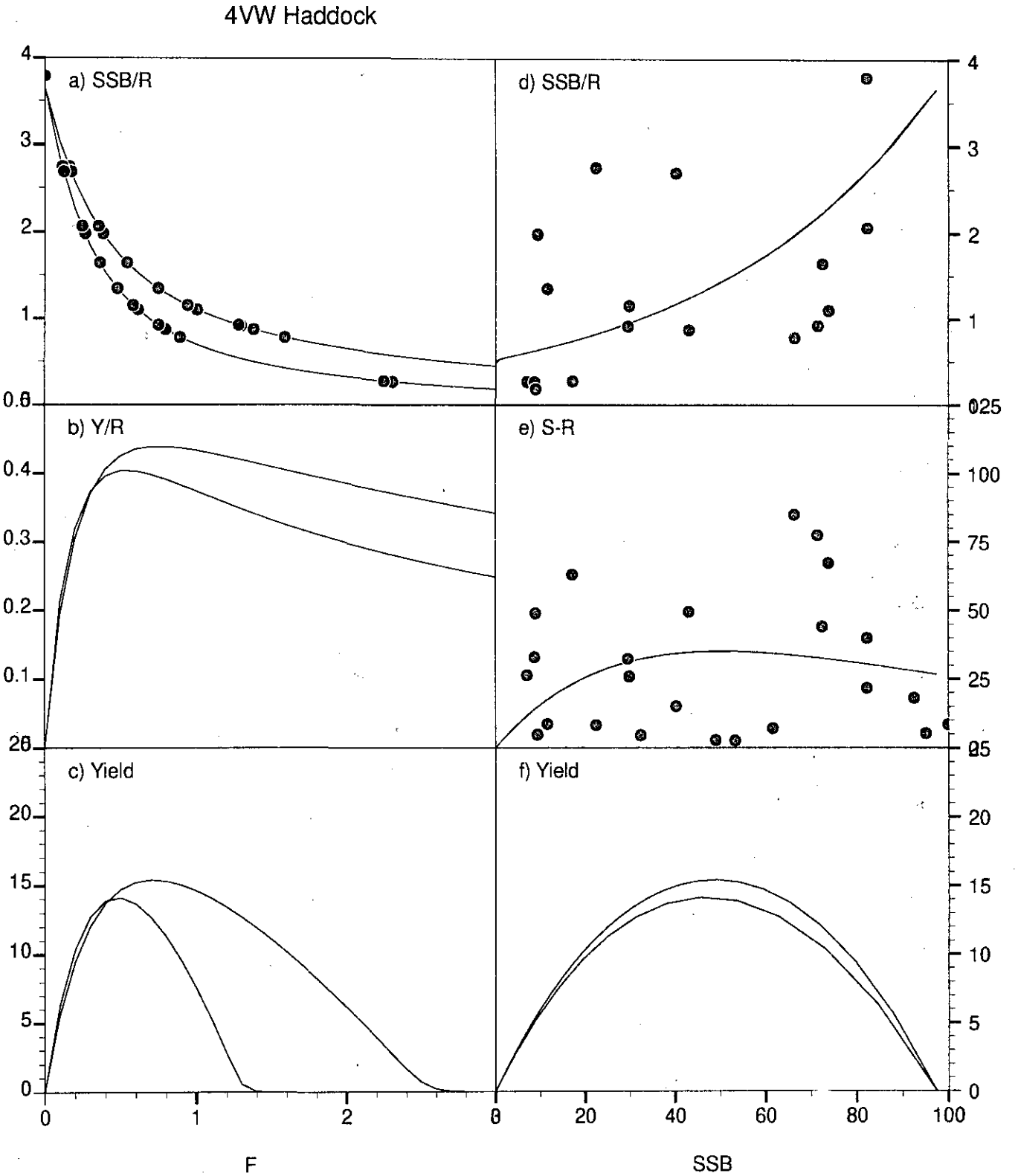


Figure 3. Sensitivity of precautionary plots to a change in maturity ogive.

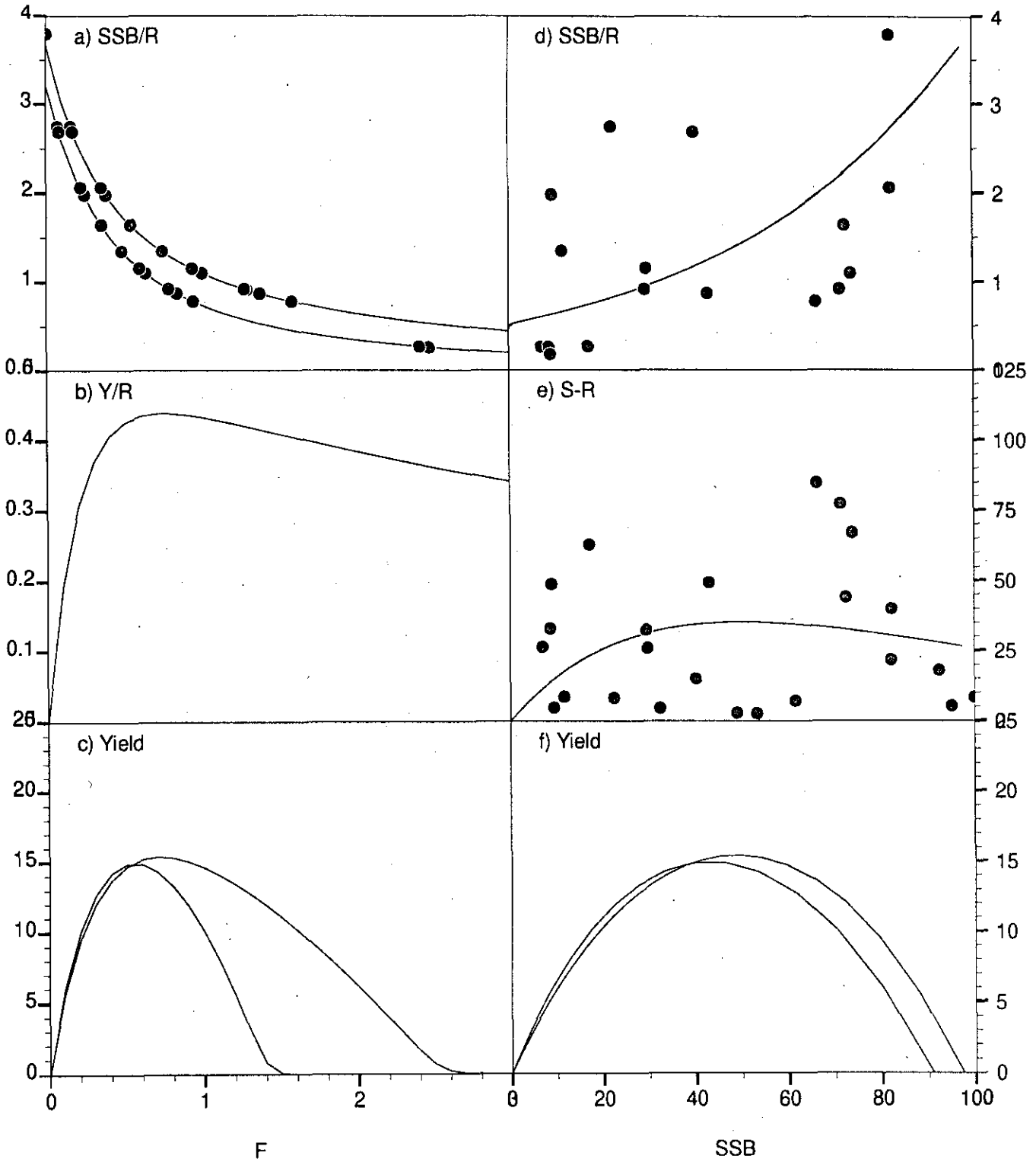


Figure 4. Sensitivity of precautionary plots to a change in Ricker RMax.

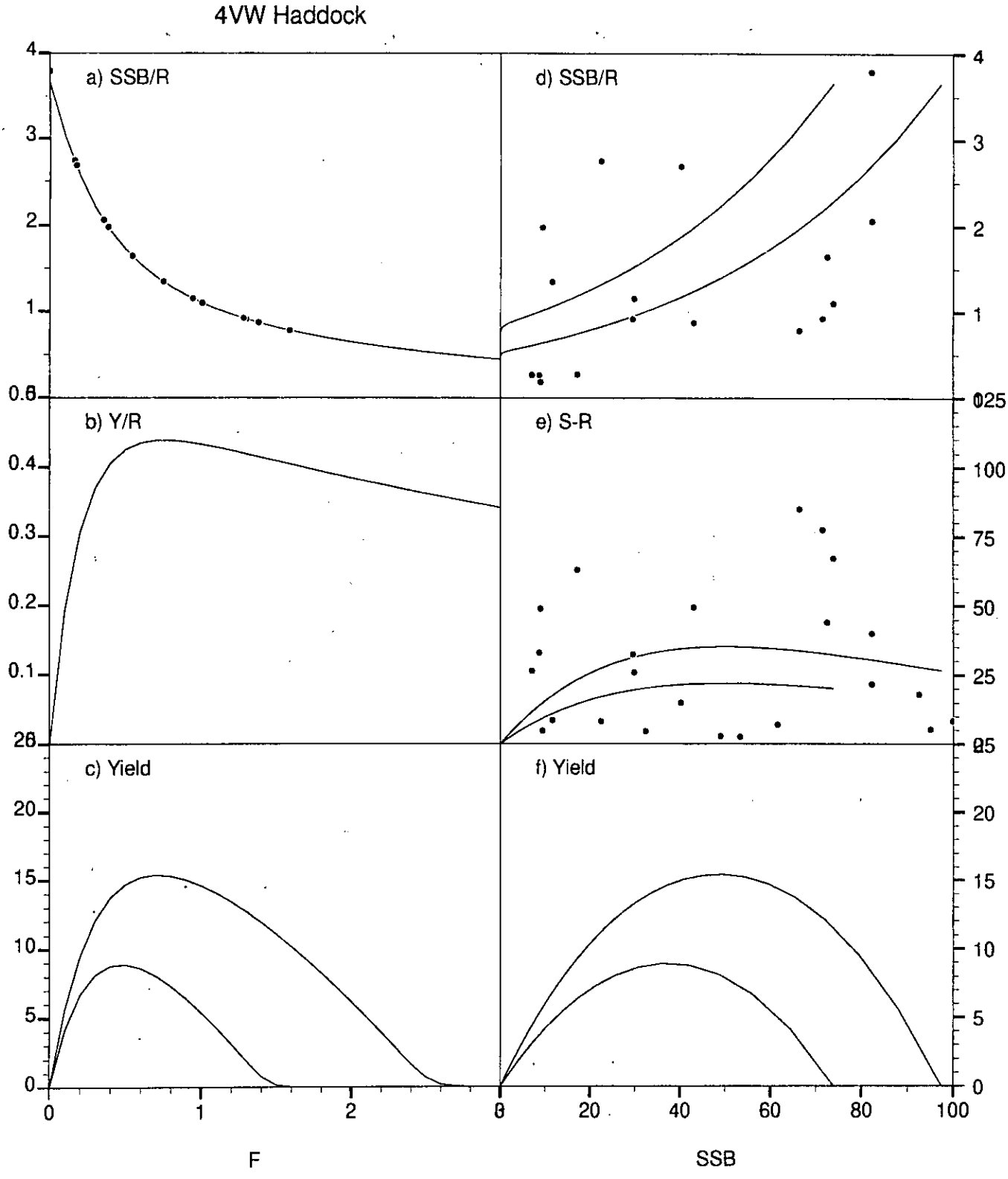
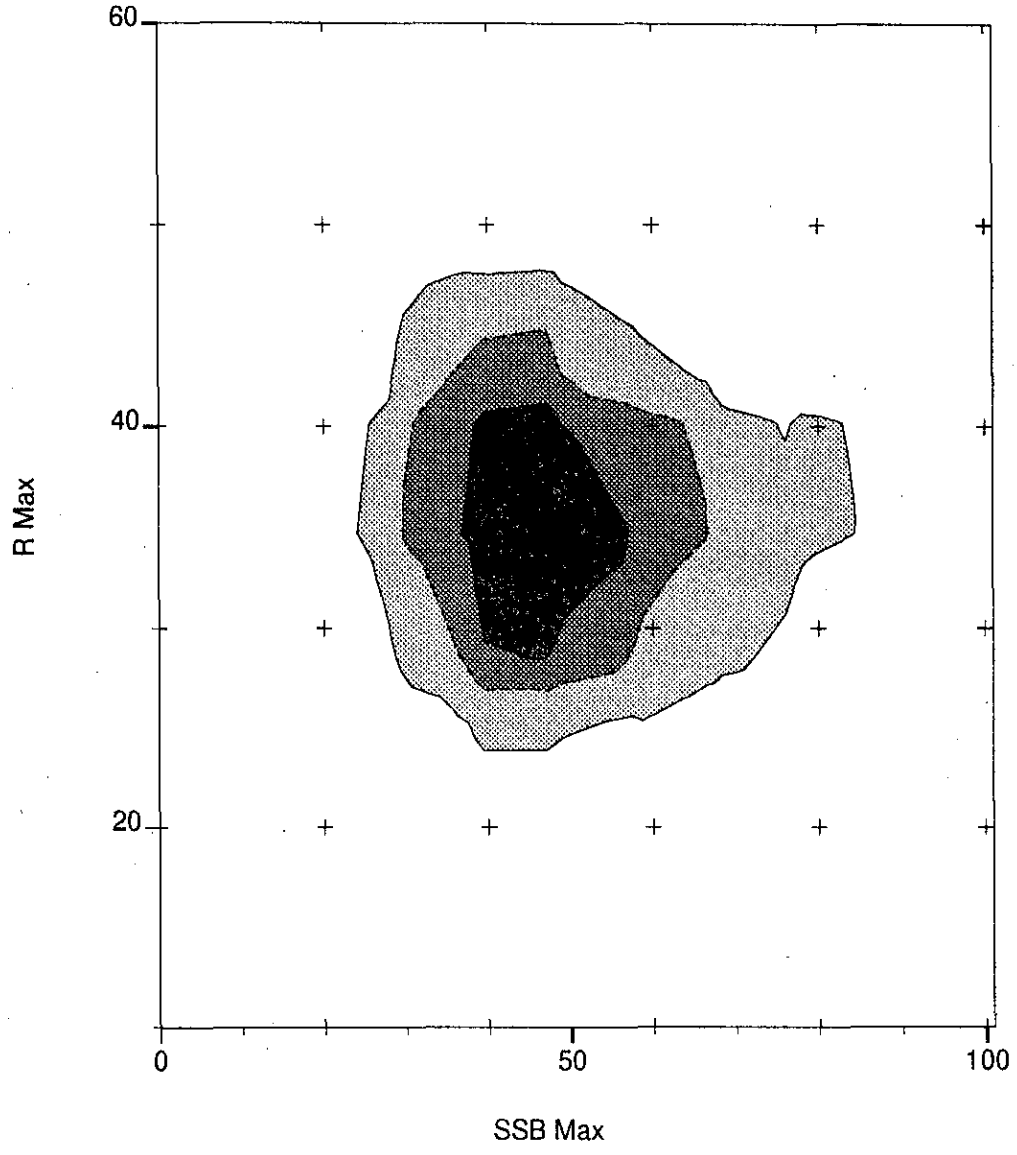
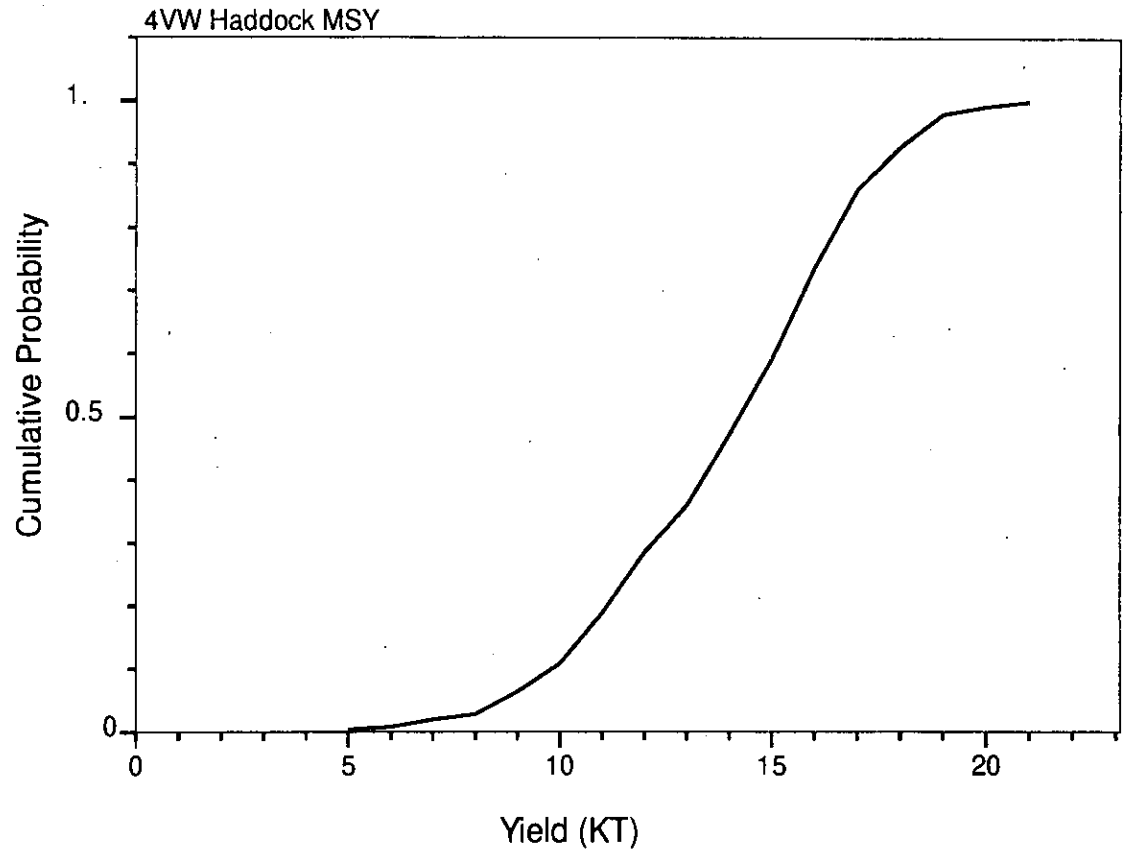


Figure 5. Contoured of bootstrap Ricker coefficients for 4VW Haddock



The darkest region encloses 25% of the replicat estimates, the next is 50% and the lightest is 75%.

Figure 6. Cumulative distributions of MSY and BMSY from precautionary analysis due to uncertainty in stock-recruit fit to Ricker model.



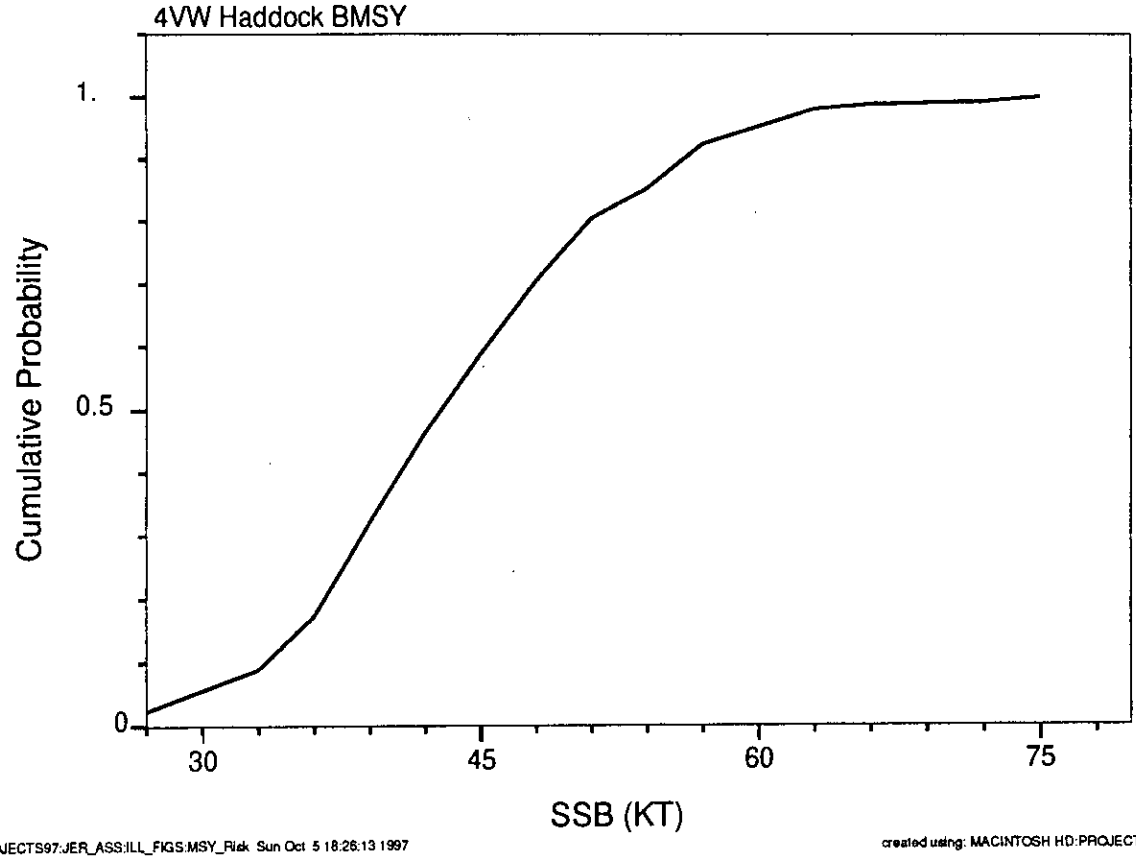
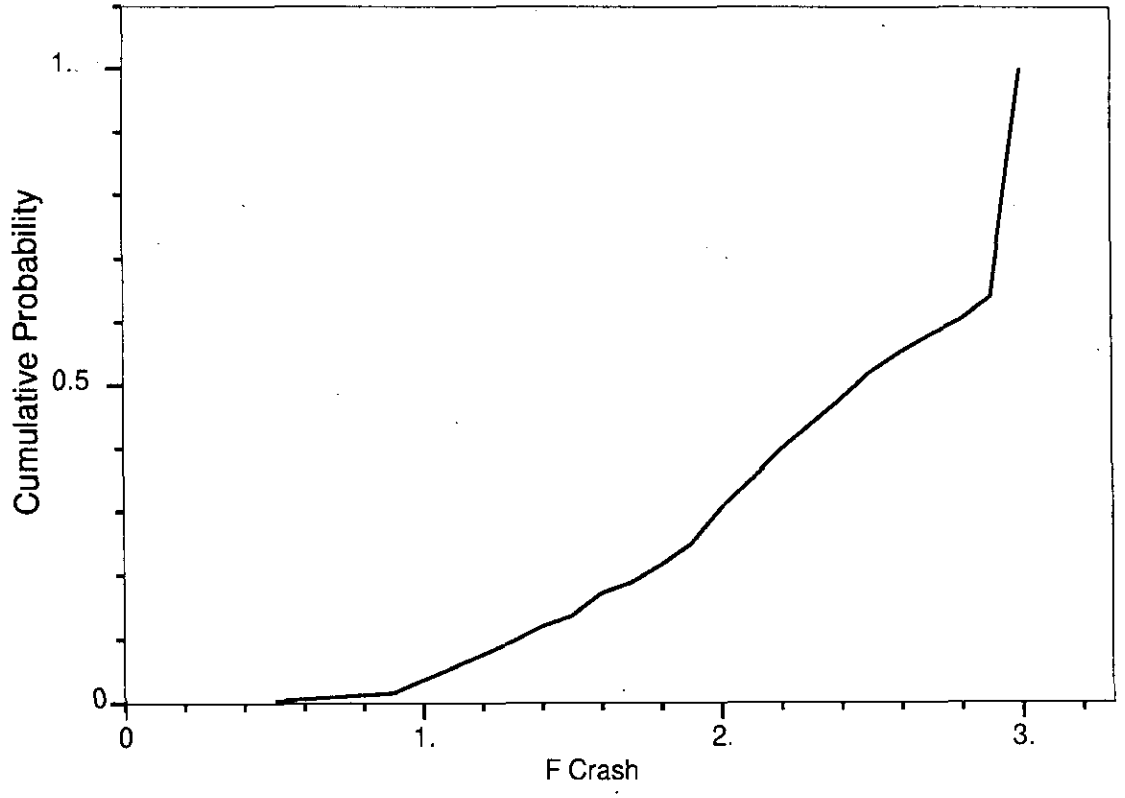


Figure 7. Cumulative distributions of FCrash and BMSY from precautionary analysis due to uncertainty in stock-recruit fit to Ricker model.



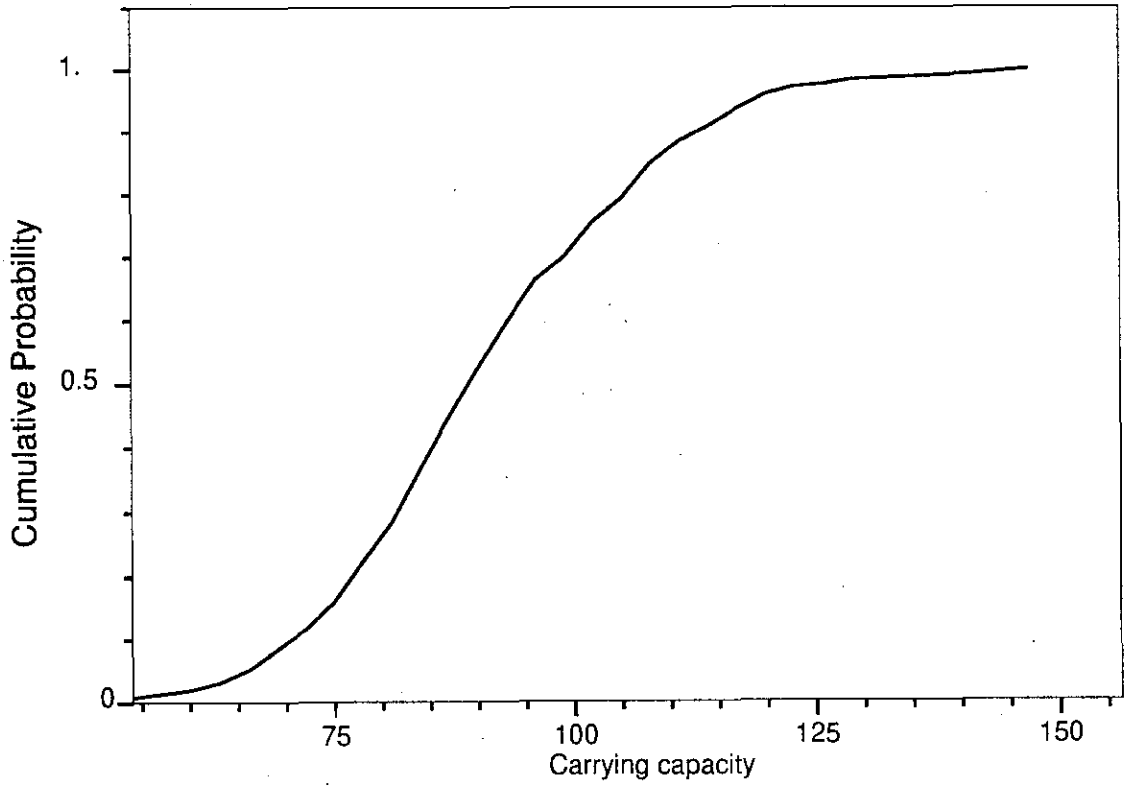


Figure 8. Stock recruit with SPA uncertainty expressed as ellipses.

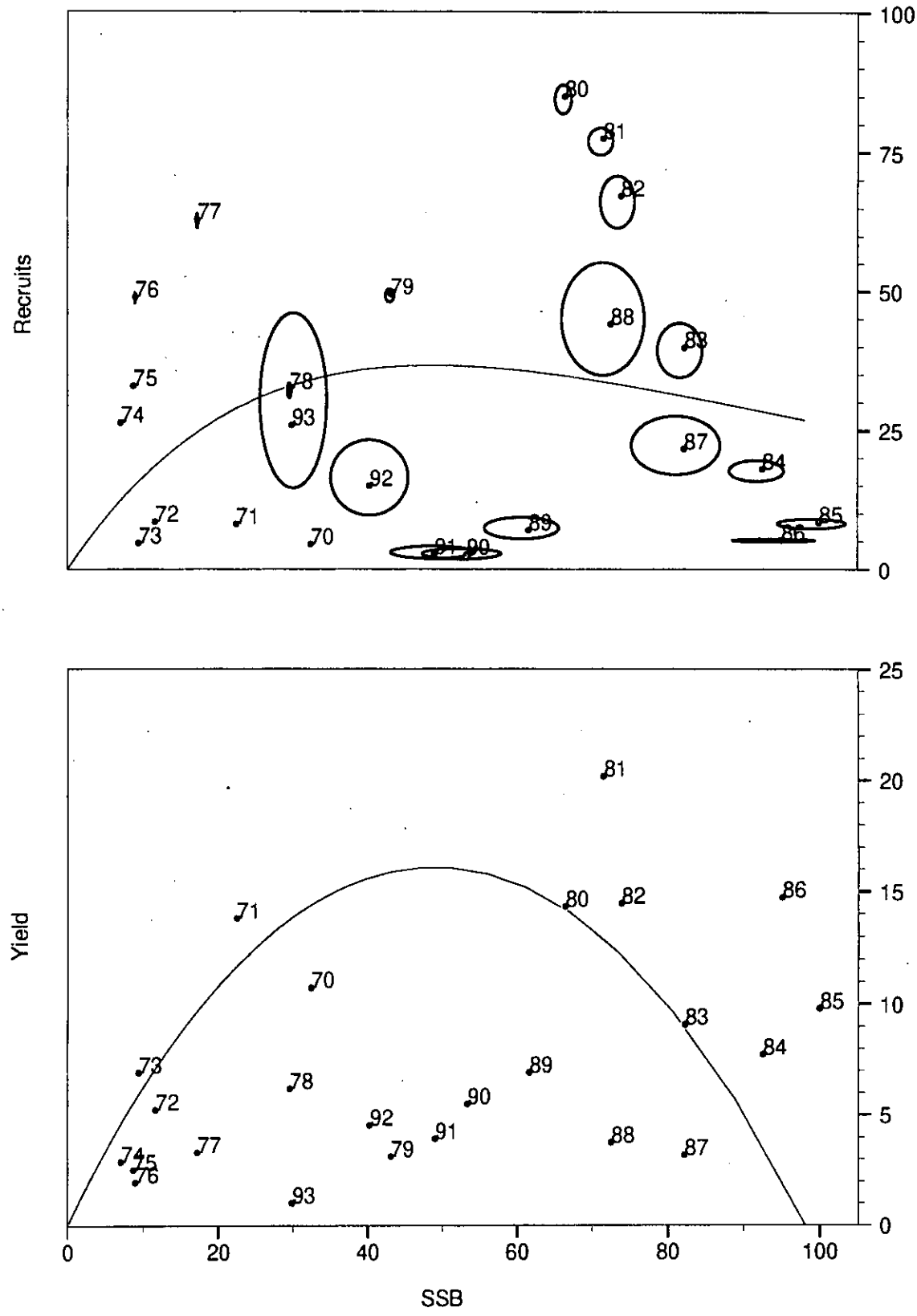


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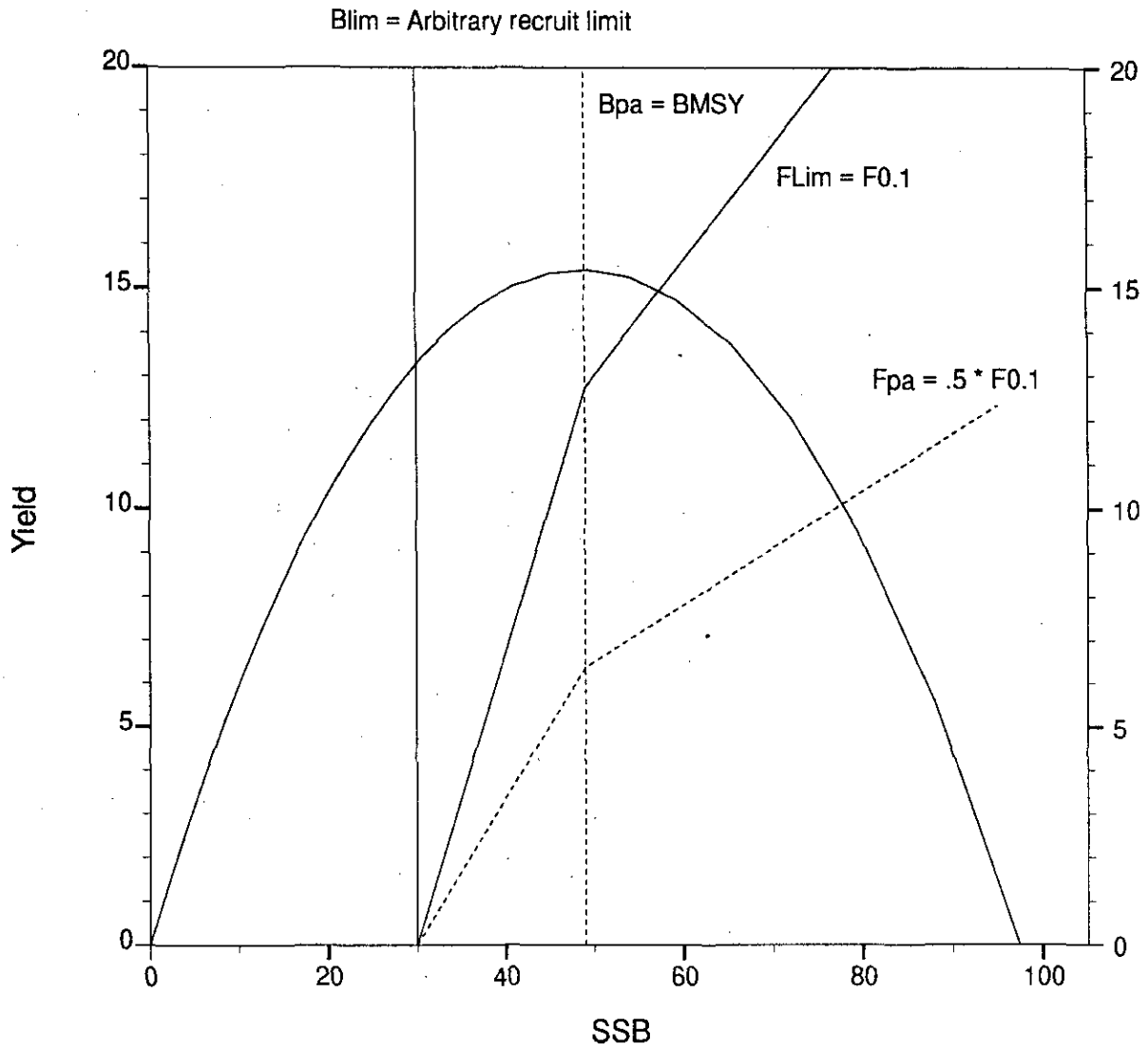
Figure 9 . Precautionary yield plot for 4VW haddock.



Appendix A. 4VsW Cod

Several analogous figures to those referred to in the text are presented for 4VsW cod. Figure A1 is the analog of Figure 1 and shows the equilibrium yield and underlying data for 4VsW cod. It should be mentioned that this example uses a natural mortality of 0.2, and further, that seals are not included.

Figure A2 is the analog of Figure 8 and shows the estimation error in the SPA which is less than for 4TVW haddock. The stock-recruit relationship (upper panel) is fit to a Ricker curve. This panel show the relative magnitude of the measurement error (ellipses) versus process error (the residuals between each point on the stock recruit curve and the curve itself. The years are denoted for each data point and the yield shows an asymptote at about 50 KT.

Figure A3 shows the biomass precautionary limits and yield curves. Superimposed on the equilibrium yields is the distribution of spawning stock biomass in 1998 and a projection for 1999 under a 10 KT harvest. These distributions are derived from 1000 bootstrap replicates after bias correction.

Figure A4 (upper panel) shows the distribution of 3000 bootstrap Ricker parameters (after redefinition and analogous to Figure 5. The lower panel of Figure A4 is the resultant distribution of MSY and BMSY. Blim in Figure A3 is half of BMSY so one can approximate the distribution of Blim. This has been done in Figure A5 which contains the distribution of the current stock as well as the estimated distribution of Blim.

Figure A1. 4VsW cod equilibrium yield plots

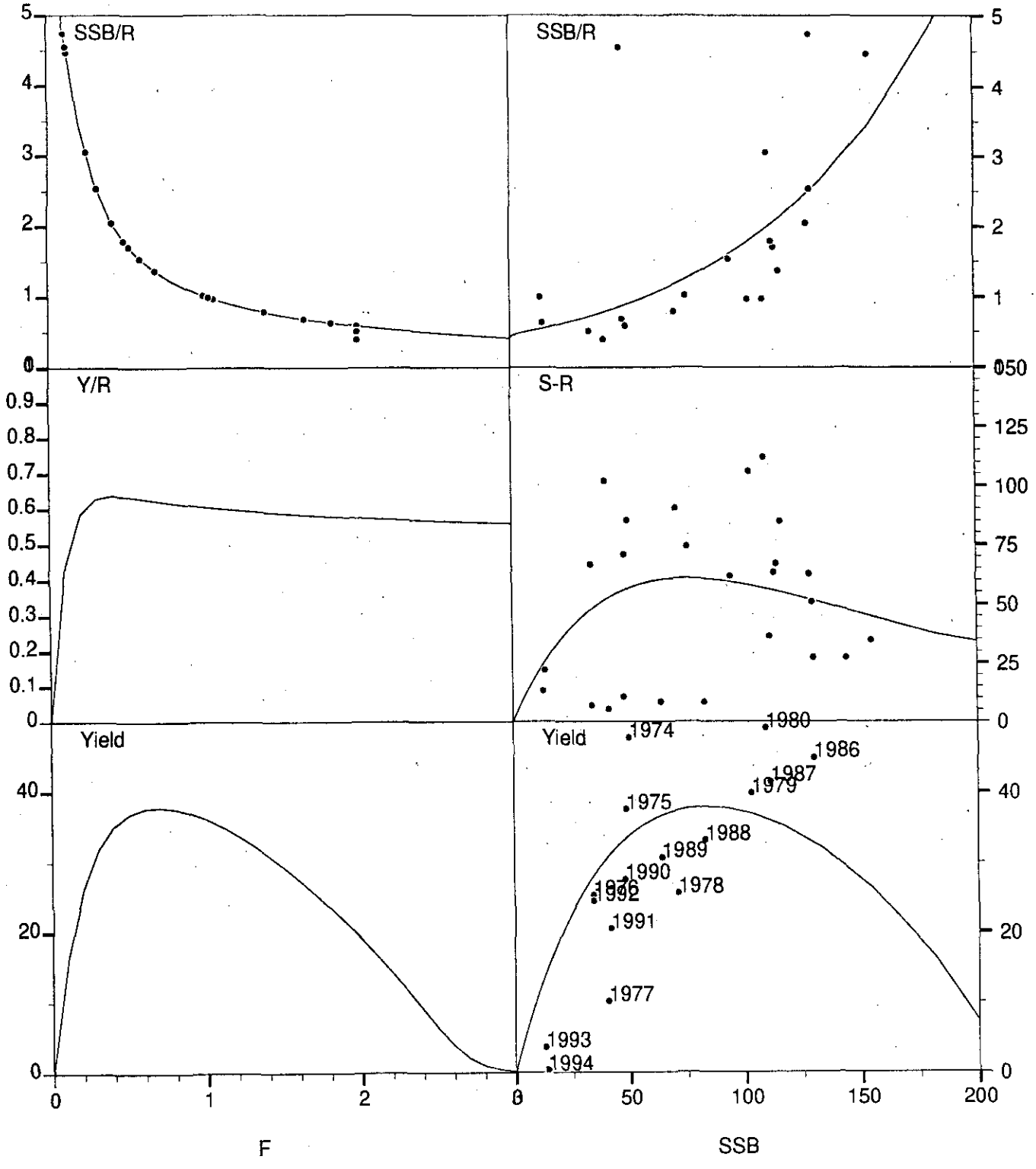
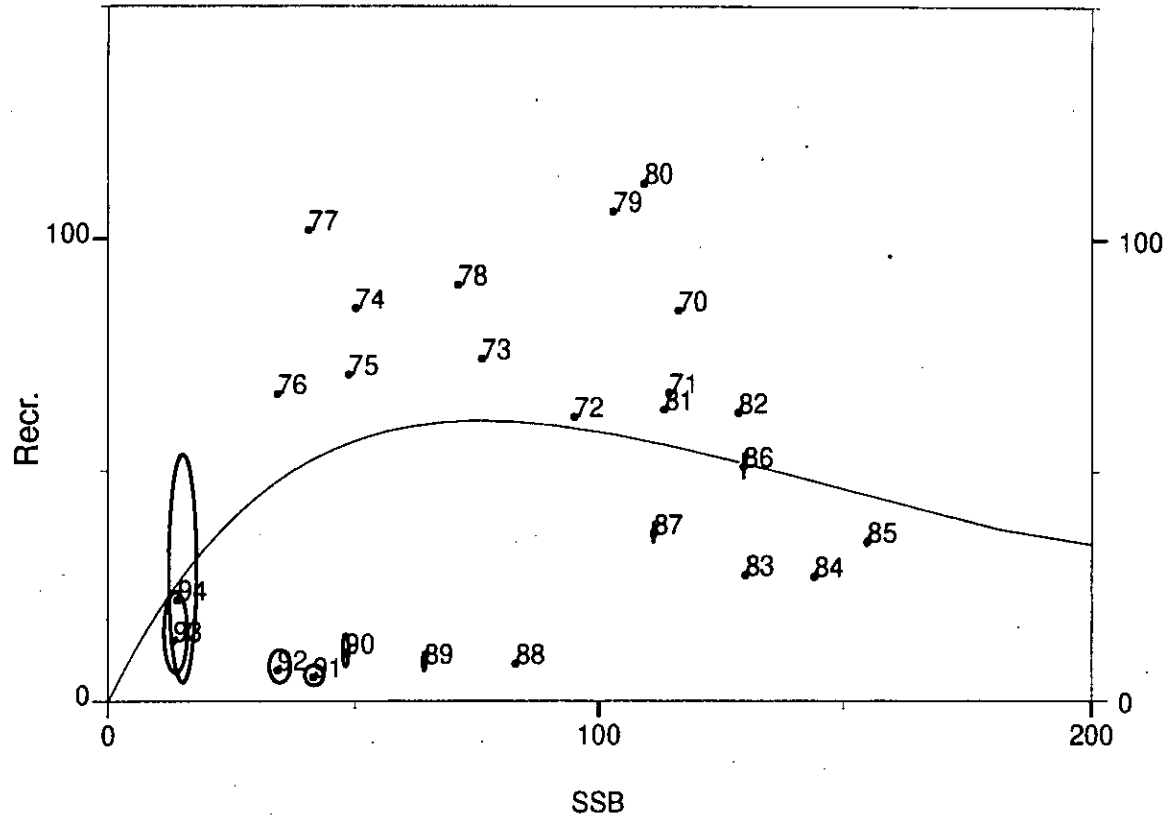
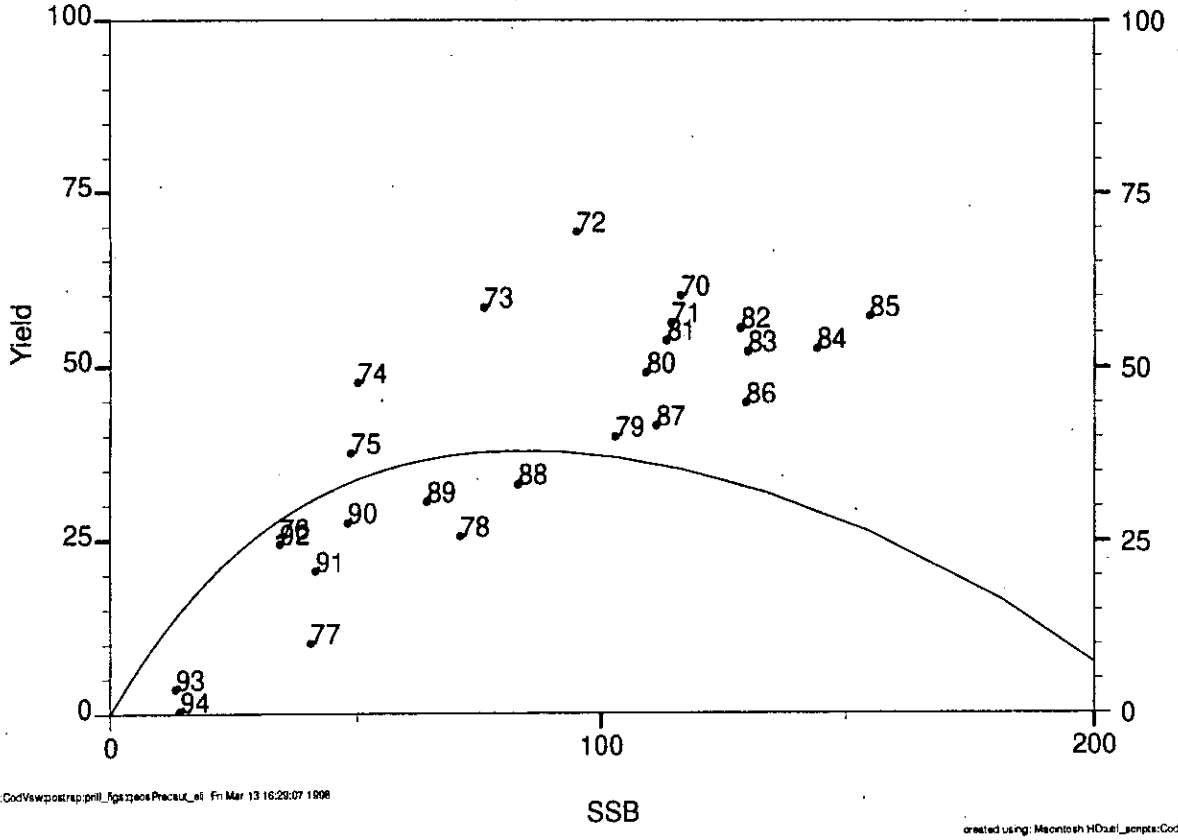


Figure A2. Stock-recruit and yield models fit to 4VsW cod.
Ellipses are single SD of NLLS estimates





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stock 4VsW cod model BaseM2

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Figure A3. Precautionary analysis of 4VsW cod. The one year projection assumes a TAC of 10000 t. BLim is half of BMSY. Ypa is half of F0.1.

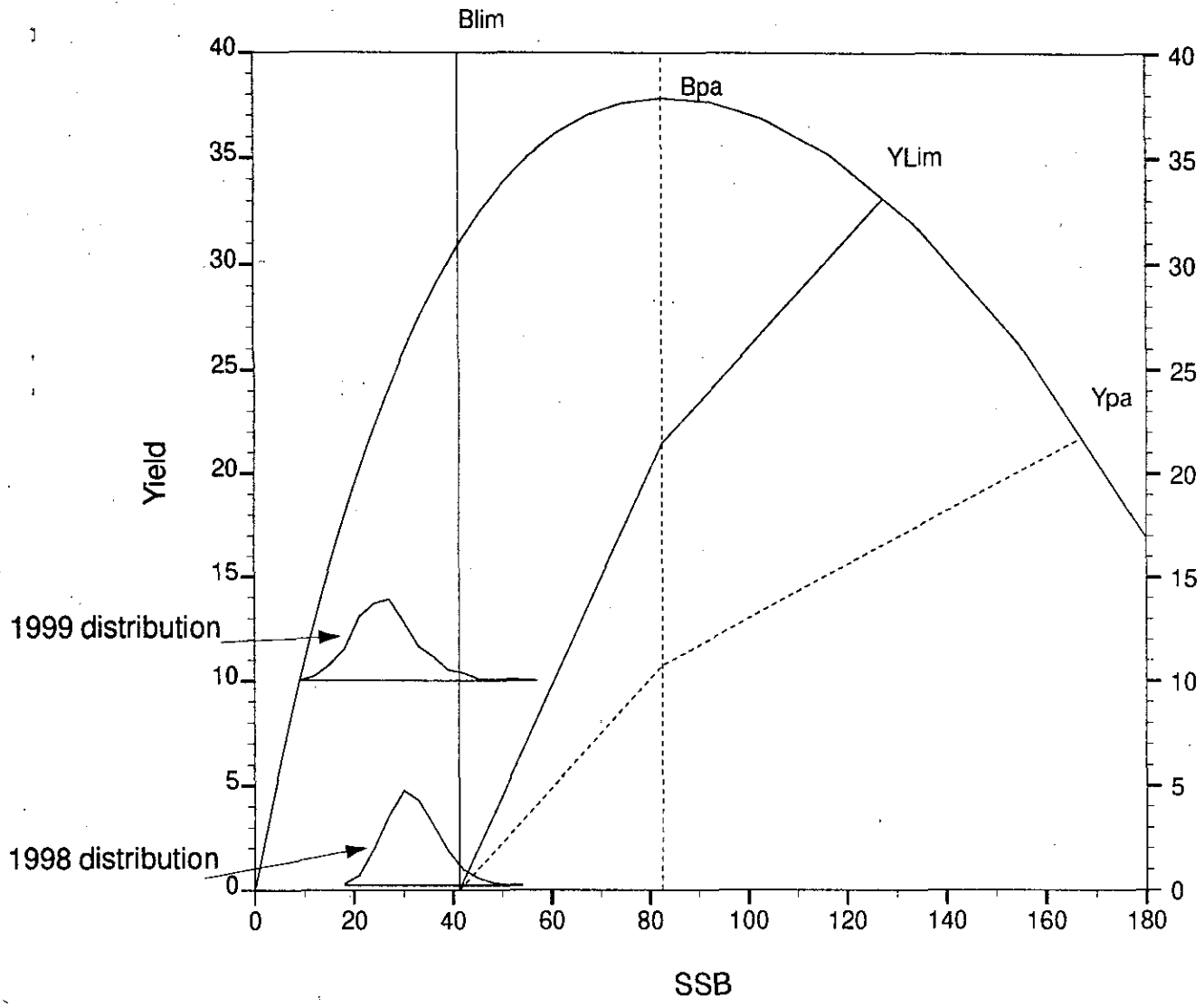
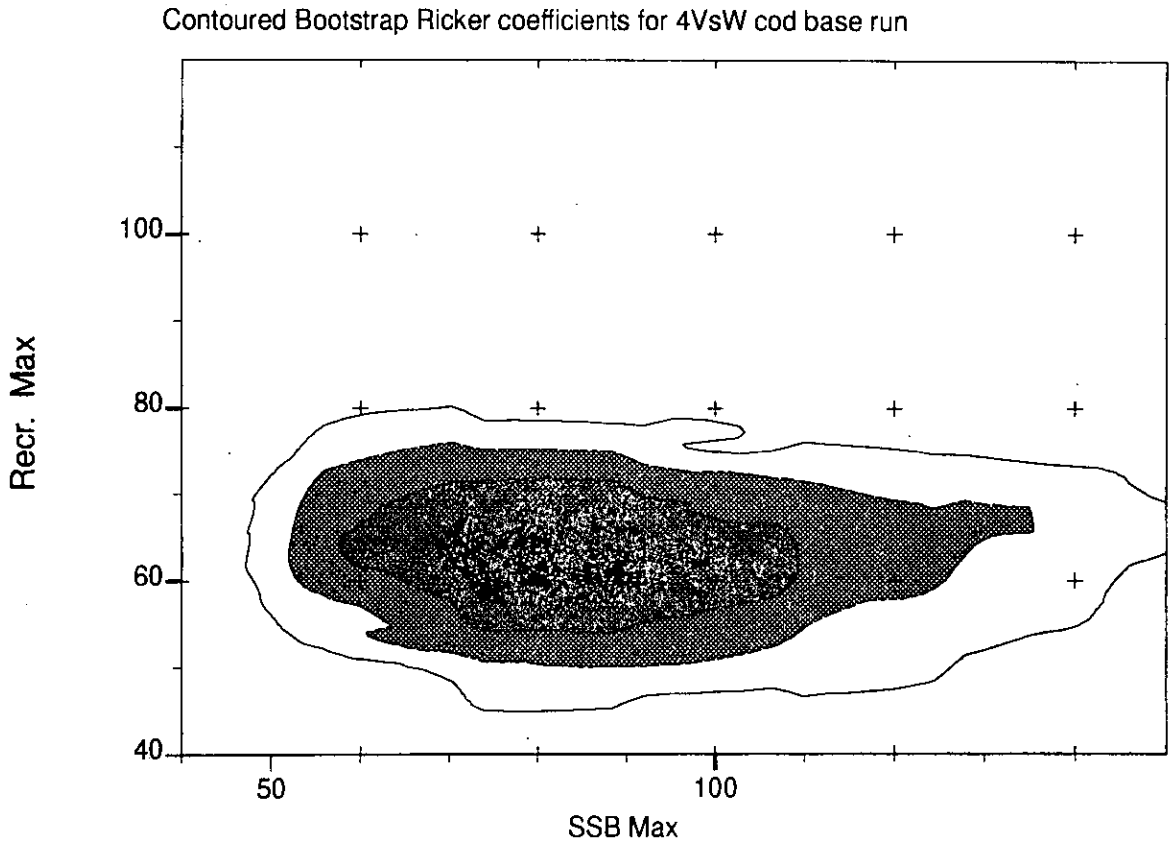


Figure A4. Contoured distributions of 3000 bootstrap estimates of a reparamterized Ricker recruitment function. Contours are of 75 50 25 and 10 th %iles.



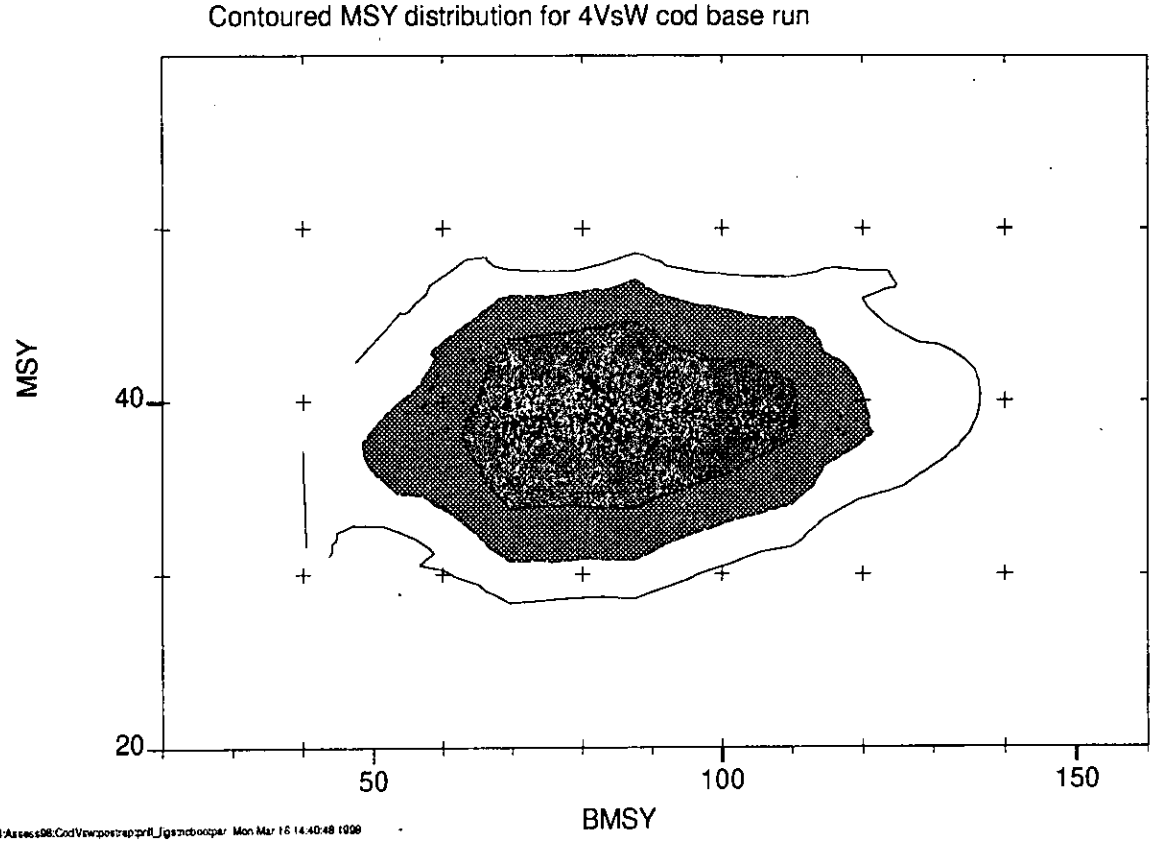


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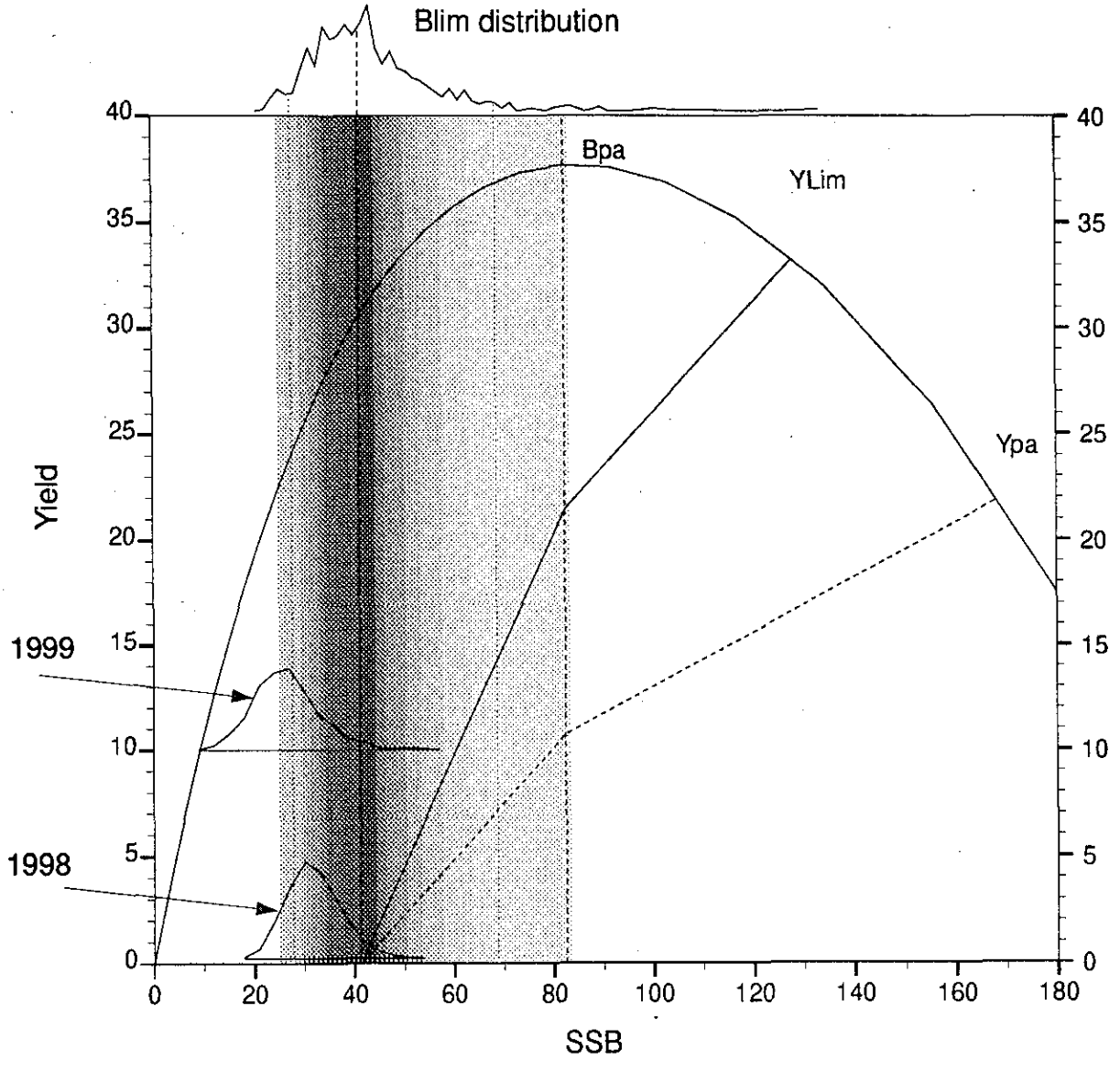
Figure A5. Precautionary analysis of 4VsW cod. The one year projection assumes a TAC of 10,000 t. Blim is esimated from 1000 bootstrap replicates of Ricker recruitment parameters.



Appendix B. 3LNO Plaice

A standard SPA is performed using ACON software (Black, 1993). The residuals from the tuning (in this case ages 6-11) are re-sampled for each age (conditioned bootstrapping) to produce 1000 pseudo-surveys. Then, the original catch data and each pseudo-survey are used to estimate new SPA numbers. After bias correction, the resultant 1000 numbers at age estimates are used to approximate the probable distribution of 3LNO plaice in 1993, i.e. the measurement error. This step is the basis of standard risk analysis. For SPAs using catch data for the period 1960-92, the coefficient of variation (CV) for spawning stock biomass in 1993 is about 20%

Equilibrium yield as a function of fishing mortality and spawning stock biomass is estimated following the approach of Sissenwine & Shepherd (1987). See Figures B1 and B2. This method of yield estimation requires a stock-recruit relationship. For this study a Ricker relationship is assumed. The residuals between the stock-recruit function and the SPA data upon which is based, reflects process error. Analogous to the measurement error estimation, these residuals were re-sampled and new stock recruit parameters estimated. For each pair of bootstrapped Ricker parameters, the MSY and BMSY were estimated in the Sissenwine-Shepherd framework. The bootstrap BMSY estimates were then compiled to approximate underlying distribution. See Figure B3 If Blim is assumed to be half of BMSY its uncertainty is approximated using BMSY distribution scaled by one half. Although the distribution is fairly skewed, it CV is about 30%.

Figure B4 summarizes these results. The measurement error is depicted as the small distribution in the lower left side of the figure rot the 1993 SSB. Blim is the broad set of lines in the neighborhood of 120 kt. For this analysis spawning stock is approximated by 9+ biomass. This figure shows the relative magnitude of process and measurement errors. It also shows a provisional estimation of Bbuff as the 95%tile of the Blim distribution.

Figure B1. 3LNO plaice equilibrium yield plots

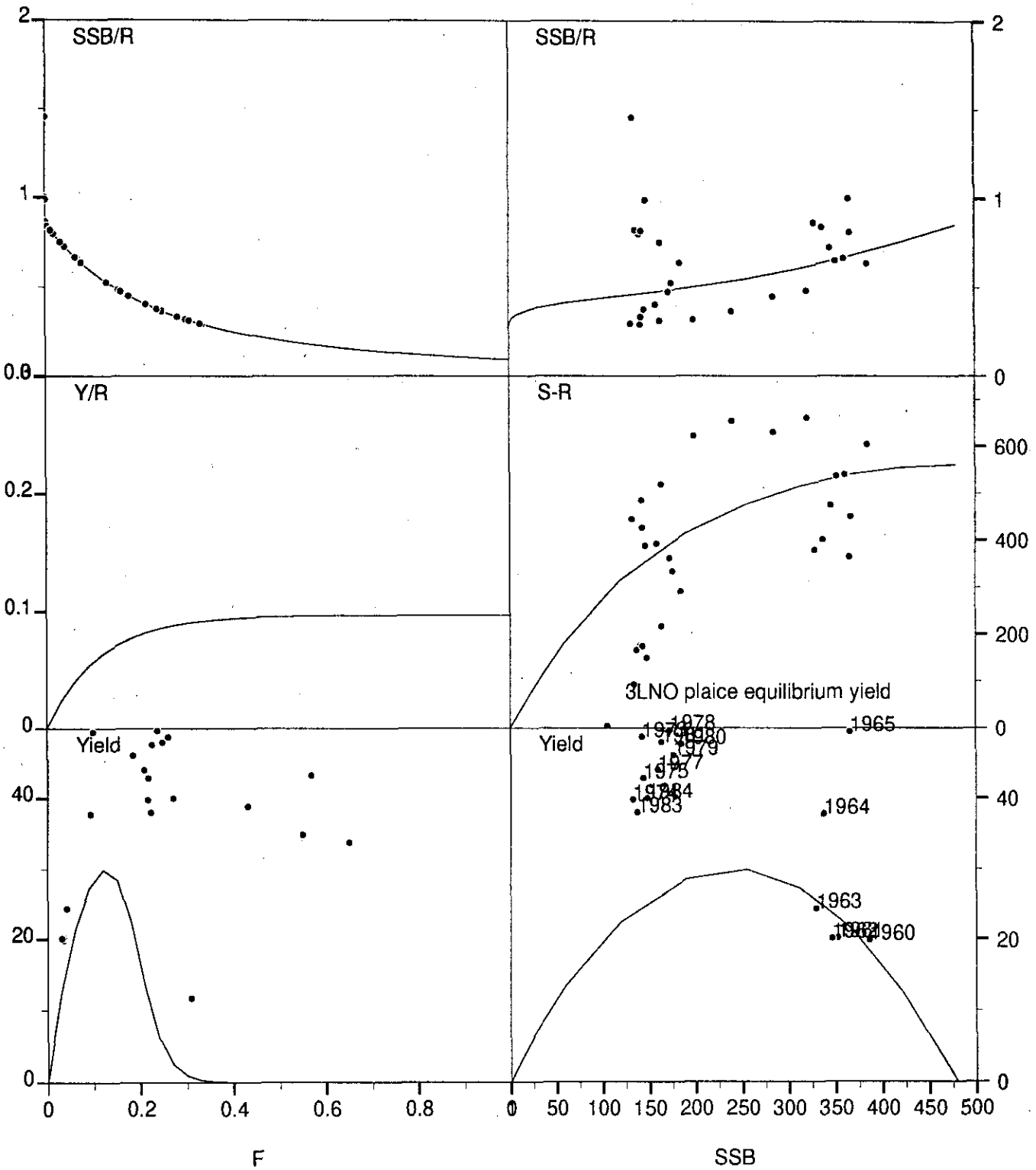
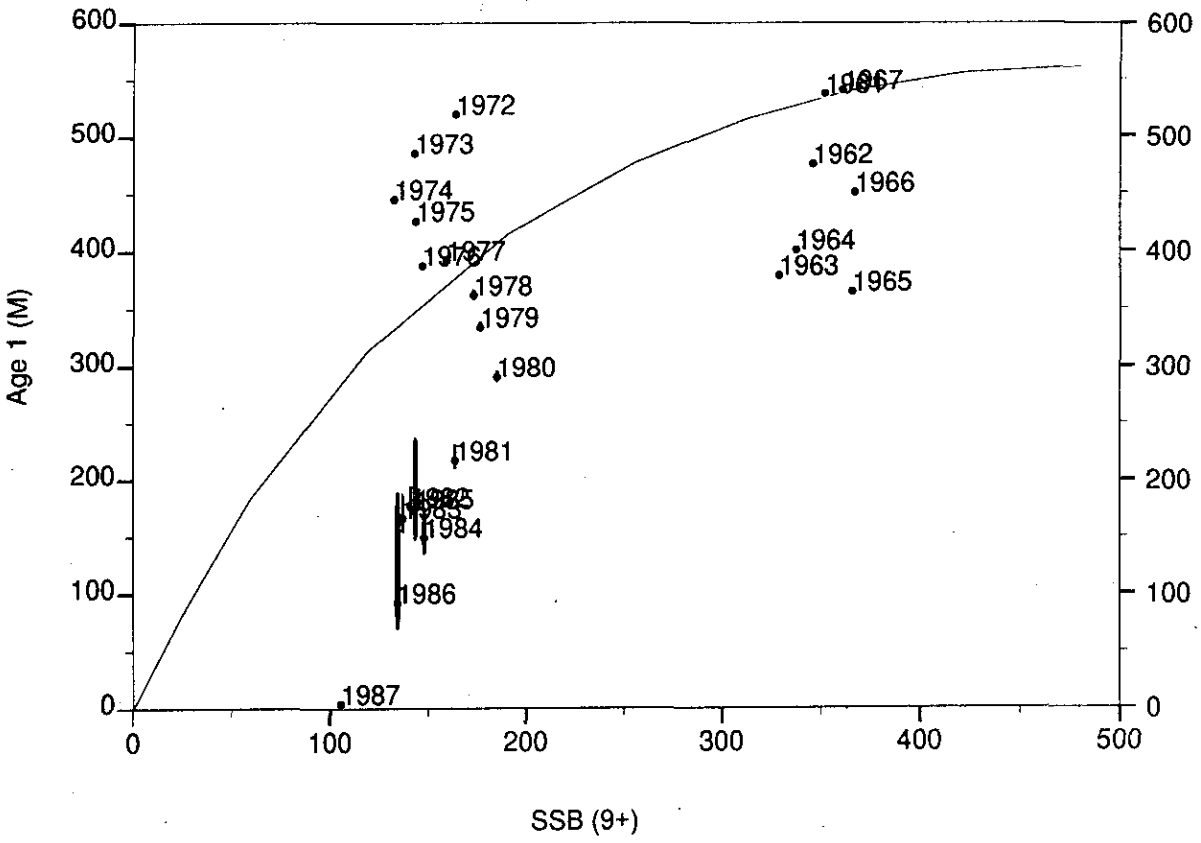


Figure B2. Stock recruitment relationship and historical and eequilibrium yield for 3LNO plaice



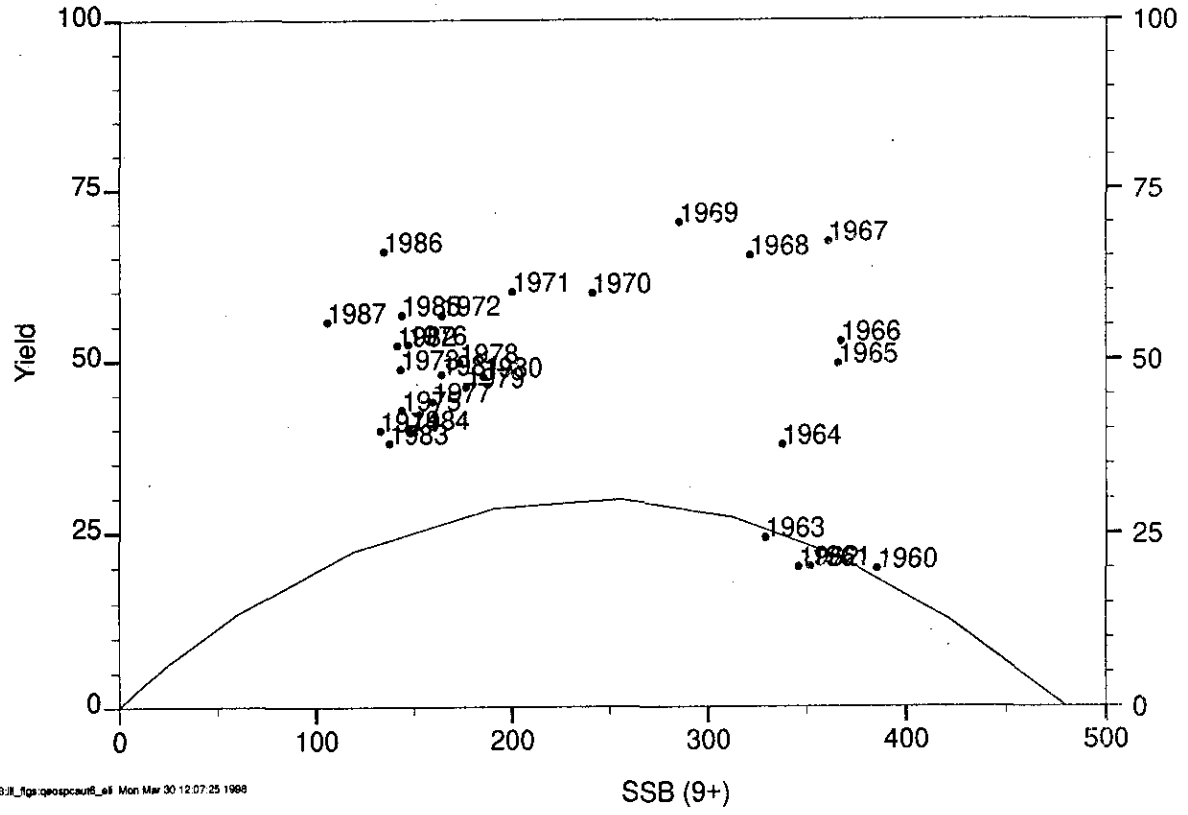


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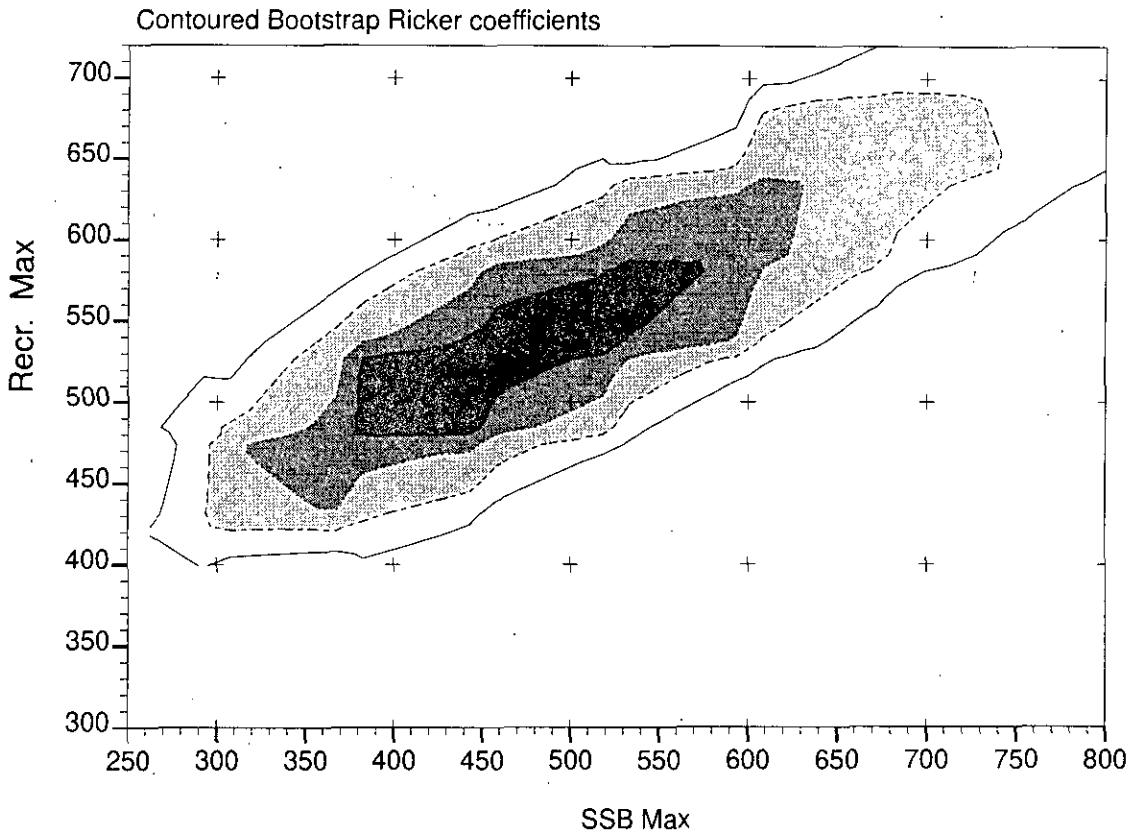
Figure B3. Uncertainty in 3LNO plaice stock recruit parameters and resulting MSY and BMSY estimates.



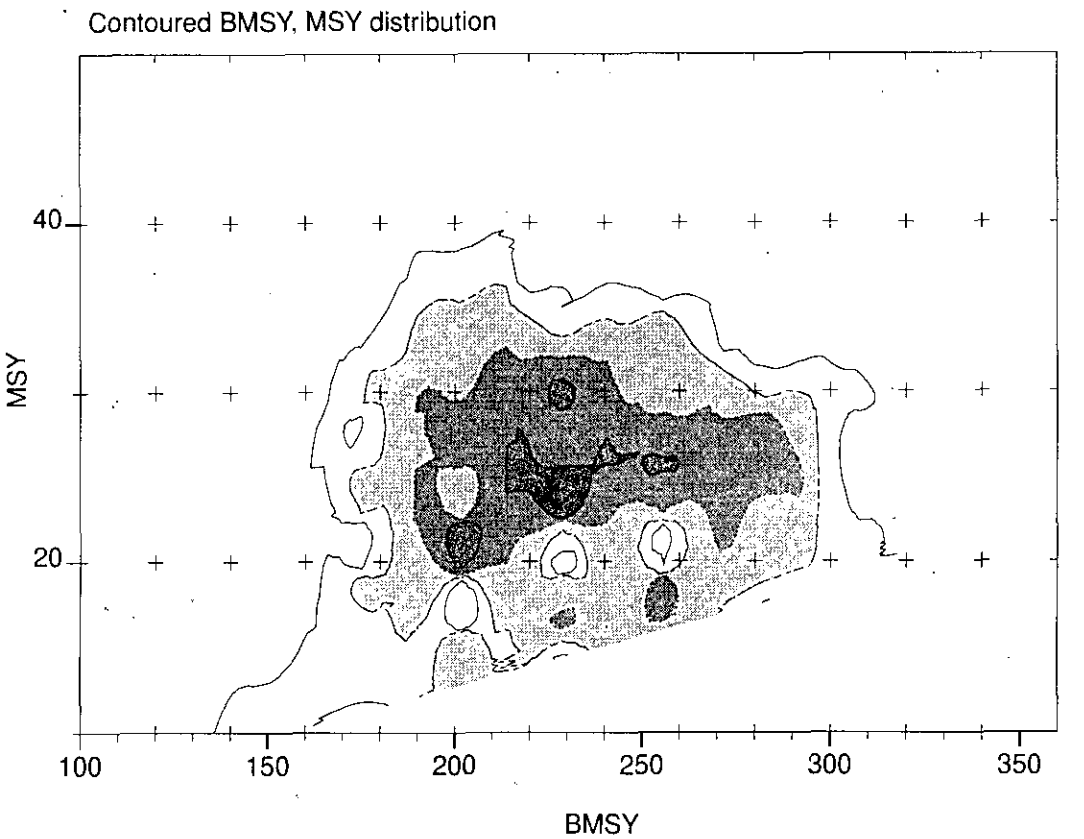
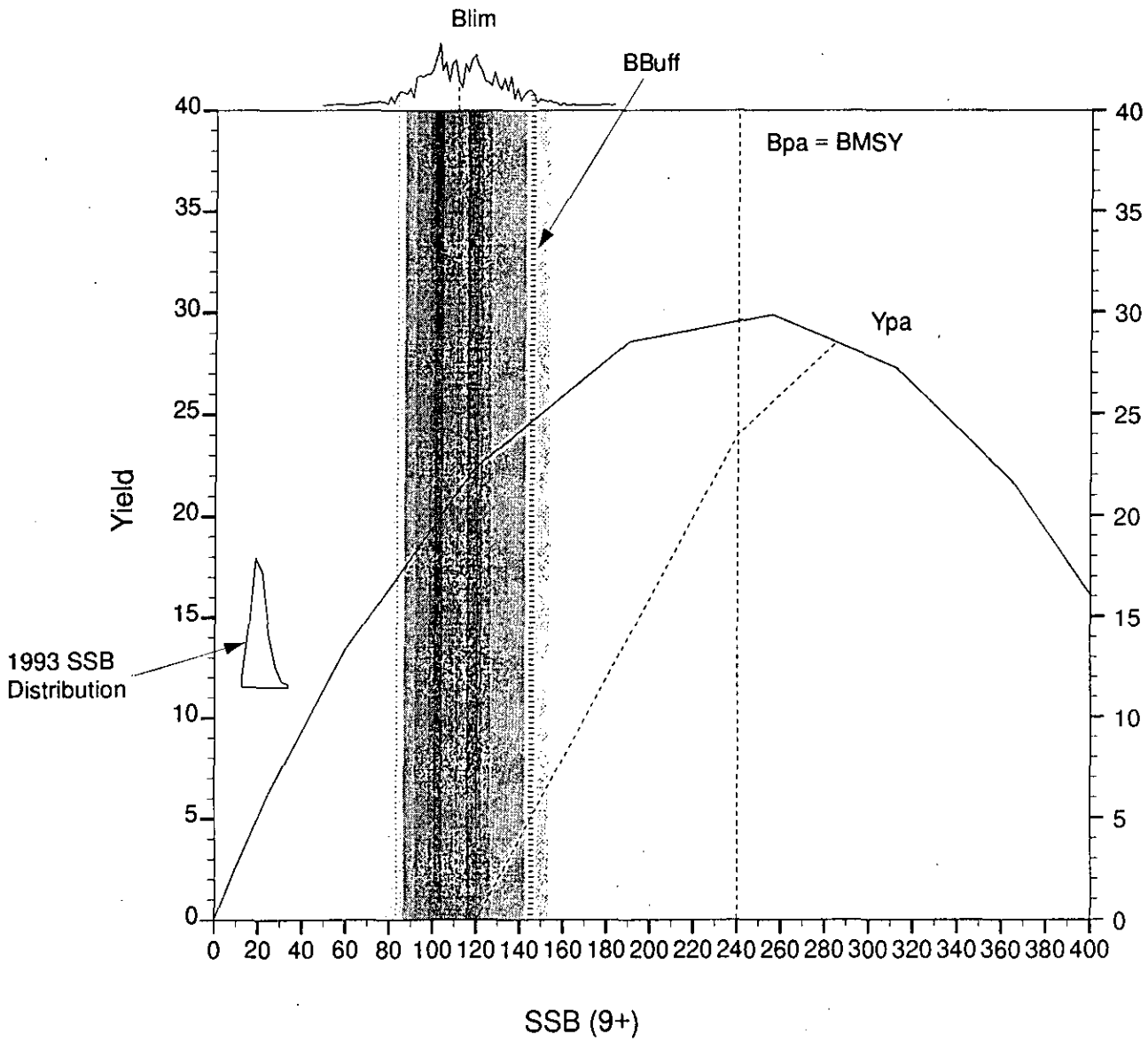


Figure B4 . Measurement and process error estimates for 3LNO plaice.



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