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CHANGES IN THE PRECISION OF SHORT-TERM FORECASTS UNDER DIFFERENT LEVELS OF EXPLOITATION

by

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SUMMARY

In heavily exploited fish populations, imprecision in catch forecasts is often blamed on the sensitivity of the forecast to recruiting fish. Recruitment is difficult to estimate precisely and cannot usually be predicted from stock size. Using sensitivity analysis, this paper investigates whether reducing exploitation levels improves the precision of catch and stock forecasts. Although sensitivity to recruitment is reduced, the forecast becomes more sensitive to other quantities such as current stock size and fishing mortality. As these are more difficult to estimate in lightly exploited stocks, the precision of the forecast may deteriorate as the level of exploitation decreases.

INTRODUCTION

The forecasting of catches is a common necessity in the management of a stock. Typically, catches are forecast for one or two years ahead and these frequently form the basis of the Total Allowable Catch (TAC) or quota set by regulatory bodies. Where TACs are the principal management tool, the accuracy of the catch forecast is crucial to the success of the management policy. Ultimately the precision of any forecast will depend on the quality of the data on which it is based. However, there is inevitably, with most assessments, a degree of subjectivity or "judgement" in the choice of input values which will have an effect on any forecast. For example, an assessment working group may have conflicting data on the size of a recruiting year class. The group will have to decide on the basis of its experience the appropriate value to use and then proceed with the forecast. In these circumstances it is important to understand how much the forecast depends on the particular value for recruitment which was chosen. Generally, there are a number of input values which are subject to uncertainty and this multiplies the problem of evaluating which input values are important. It would be useful to have a simple means of determining the sensitivity of the forecast to the input values so that greater care can be given to the estimation of the important ones while those which contribute little can be left alone. This paper reports the application of a simple linear sensitivity analysis to the North Sea haddock to illustrate the utility of the approach.

The North Sea haddock stock is heavily exploited and the consensus view is that fishing mortality should be reduced (Anon, 1990). This judgment is, of course, made on biological grounds. There is a potential problem with reducing fishing mortality in that forecasts may become less accurate. Reducing fishing mortality will generally reduce the dependence of the forecast on recruitment, improving its precision but it becomes more difficult to estimate current stock size which counteracts this. When fishing mortality is low most analytical methods such as Virtual Population Analysis (VPA) converge more slowly. This introduces more uncertainty into the input values for the forecast. A lower fishing mortality therefore makes the forecast more dependent on the survivors of the existing stock which in turn is estimated with greater uncertainty. In these circumstances it may be more difficult to manage the stock at the target level of exploitation. This paper investigates this problem using sensitivity analysis on steady state populations to show that in reducing fishing mortality, the benefits of a lower dependence on recruitment may be more than offset by greater uncertainty in the estimates of other input values.

METHODS

The standard ICES procedure for performing short term forecasts for North Sea haddock is to estimate vectors of population size and fishing mortality from VPA for the most recent year. These are then rolled forward with recruitment estimates to give estimates of future catches. When the fishing mortality vector is held constant in the forecast period, the so called *status quo* forecast is obtained. The *status quo* forecast is a convenient reference value and is the forecast used throughout this paper. A more detailed outline of the procedure is given in Cook *et al.* (1991). In this paper, steady state "per recruit" populations have been generated using the current exploitation pattern for North Sea haddock scaled to various levels of relative effort. Catch forecast therefore represent an "average" forecast under the particular level of effort in steady state conditions.

a) Linear Sensitivity Analysis

Each time a forecast is performed on a stock it is of interest to know which are the important input values. The important ones will vary from year to year because the magnitude of the input values will change as recruitment, for example, fluctuates. This question can be investigated using simple linear sensitivity analysis.

An output value or "state variable" from a model is the result of the input variables or "parameters". The problem is to quantify the effect of each parameter on the state variable. For a given set of parameters, θ, this can be investigated by considering the effect of small changes in the parameters on the state variable. If a small change in one of the parameters has a large effect then the state variable is said to be highly sensitive to that parameter. Clearly the magnitude of the effect will be related to the slope of the function in the region of the point θ. A sensitivity coefficient can therefore be defined as:

$$\theta_i \frac{\delta(g(\theta))}{\delta\theta_i} \quad \text{(Laurec and Mesnil, 1987)}$$

where g(θ) is the function for the state variable. It is straightforward to calculate these coefficients and this method has been used to investigate the sensitivity of haddock forecasts in different years.

b) Fourier Amplitude Sensitivity Test (FAST)

In the investigation of the effect of changing the level of exploitation on a stock, we are interested not only in how the sensitivity of the forecast changes but also how the precision of the forecast is affected. The linear analysis gives a very simple measure of the effect of the magnitude of a parameter on the forecast. However, it is also important to know how the imprecision in the estimate of the parameter translates into errors in the forecast. This could be estimated in a similar fashion to the linear sensitivity analysis by taking a linear approximation to the function at the point θ and using conventional formulae for the summation of variances. This approach requires that the imprecision in the parameters is small which is often not the case in making forecasts. Another approach to overcome this problem would be to use Monte Carlo simulation, but this is potentially very time consuming when large numbers of parameters are involved. A middle way is to use the FAST (Cukier *et al.*, 1978) which effectively performs a simulation experiment with the minimum number of realisations by carefully choosing sets of parameters from their "probability distributions". This is done in such a way that the variability in the state variable (the forecast) can be identified with each parameter. A popular guide to FAST is given in Hilden (1988).

In order to perform the analysis, the parameter values need to be specified and also their range of "uncertainty". Thus a parameter with an uncertainty of 1.25 would yield values between plus or minus 25% of the nominal value. In this study uncertainties were chosen to reflect about twice the coefficient of variation of the parameter.

Since the purpose of the study is to investigate the effect of reducing fishing mortality on the precision of the forecast, there is a need to relate the level of fishing mortality to the uncertainty in the parameters. This has been done by considering the way in which the parameters are typically estimated. This problem is most readily appreciated by considering the way in which errors in the input values to VPA are propagated. Errors in population size, N, are related by the well known formula:

$$\frac{DN_t}{N_t} = \frac{DN_{t+1} \quad e^{-F}t}{N_{t+1}} \qquad (1)$$

where DN is the error in N and F is the fishing mortality. A similar formula can be developed for the error in F:

$$\frac{DF_t}{F_t} = \frac{DN_{t+1}(e^{-F}t-1)}{F_t N_{t+1}} \qquad (2)$$

When there are errors in the catches then it is possible to show that equation (1) becomes:

$$\frac{DN_t}{N_t} = \frac{DC_t}{C_t}\left(\frac{F_t e^{M/2}(1-e^{-Z}t)}{Z_t}\right) + \frac{DN_{t+1}e^{-F}t}{N_{t+1}} \qquad (3)$$

The LHSs in these equations could be considered as the uncertainty in the estimates of N and F. These formulae have therefore been used to generate the uncertainty for each parameter under different levels of F. It is noteworthy that in equation (3), the right hand term is very small for high values of F. Hence for a heavily exploited stock the errors in the estimates depend mostly on errors in the catch. (The term in brackets is large for large F). When F is small the expression in brackets is small and the estimates are dominated by the cumulative error represented in the right hand term. This term propagates the error in the estimate of input F to VPA.

RESULTS

Linear Sensitivity Analysis

Results from this analysis are given in Figures 1a-d and 2a-d for the forecast yield (Yt+n) and spawning stock biomass (St+n) where n is the number of years ahead of the last data year (t). Results are shown for *status quo* effort (ie 1) and for a 60% reduction in effort (ie 0.4). The figures reveal the fairly obvious result that as F is reduced, the sensitivity to recruitment is reduced. However, the sensitivity to other quantities is increased. Thus although the forecast will be less sensitive to errors in the estimate of recruitment, it will be more sensitive to estimates of present population size and fishing mortality. If the precision of these estimates deteriorates as F decreases then the forecast will suffer.

FAST Analysis

Table 1 shows the uncertainty estimated for F and N generated using equations (2) and (3) for various levels of effort. The error in the catch used in the equations is also given and was estimated by performing a factor analysis on the catch at age data for haddock to estimate the measurement error on each age group in the catch. The uncertainty for future recruiting year classes (R3 and onwards) reflects the overall coefficient of variation of recruitment in this stock.

Figure 3 shows the coefficient of variation of forecast yield for one, two, three and four years ahead calculated from FAST. These CVs do not represent an estimate of the true variability of the forecast but a relative estimate. They suggest that reducing effort will in general degrade the quality of the forecast. For the four year forecast, there is some improvement in the CV for intermediate levels of effort. This is because there is a substantial reduction in the effect of recruiting year classes (which have high uncertainty) that more than offsets the higher uncertainty accruing to the other parameters in the forecast.

Figure 4 shows the equivalent results for the forecast spawning stock biomass. Similar changes are evident.

CONCLUSION

This paper examines the possible consequences of reducing the overall level of effort on the precision of short term forecasts. Although the sensitivity of forecasts to recruitment is reduced, this appears to be more than offset by a sensitivity to other input parameters which may not be adequately estimated under lower levels of exploitation.

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TABLE 1

Uncertainties in the parameters for different levels of relative effort. *Status quo* corresponds to a relative effort of 1. The estimated error in the catch (DCt/Ct) from factor analysis is also shown

Relative effort	1.00	0.80	0.60	0.50	0.40
R1	1.66	1.76	1.91	2.02	2.18
N1	1.64	1.74	1.89	2.00	2.15
N2	1.50	1.59	1.74	1.85	2.00
N3	1.28	1.37	1.51	1.61	1.74
N4	1.34	1.44	1.59	1.68	1.80
N5	1.58	1.67	1.79	1.86	1.93
N6	2.00	2.00	2.00	2.00	2.00
F0	1.66	1.76	1.91	2.02	2.17
F1	1.61	1.71	1.86	1.98	2.13
F2	1.34	1.44	1.59	1.70	1.85
F3	1.17	1.24	1.37	1.47	1.60
F4	1.20	1.29	1.43	1.52	1.64
F5	1.37	1.47	1.60	1.68	1.77
F6	2.00	2.00	2.00	2.00	2.00
R2	1.66	1.76	1.91	2.02	2.18
R3	2.50	2.50	2.50	2.50	2.50
R4	2.50	2.50	2.50	2.50	2.50
R5	2.50	2.50	2.50	2.50	2.50

Age	"error" in catch
0	1.40
1	0.82
2	0.55
3	0.22
4	0.20
5	0.29
6	0.29

R1 = recruitment at age 0 in year t
R2 = recruitment at age 0 in year t+1
R3 = etc

N1 = number at age 1 in year t
N2 = number at age 2 in year t
N3 = etc

F0 = fishing mortality at age 0
F1 = fishing mortality at age 1
F2 = etc

FIGURE LEGENDS

Figure 1 Sensitivity coefficients from linear analysis for two levels of fishing mortality (F). For definitions of parameter labels R1 etc see Table 1: a) catch forecast in year t+1; b) catch forecast in year t+2; c) catch forecast in year t+3; d) catch forecast in year t+4.

Figure 2 Sensitivity coefficients from linear analysis for two levels of fishing mortality (F). For definitions of parameter labels R1 etc see Table 1: a) SSB forecast in year t+1; b) SSB forecast in year t+2; c) SSB forecast in year t+3; d) SSB forecast in year t+4.

Figure 3 Coefficient of variation from FAST for forecast landings under different levels of relative fishing mortality. The curves are for one, two, three and four years ahead of the last data year t.

Figure 4 Coefficient of variation from FAST for forecast spawning stock biomass under different levels of relative fishing mortality. The curves are for one, two, three and four years ahead of the last data year t.

Fig. 1a
HADDOCK CATCH PREDICTION

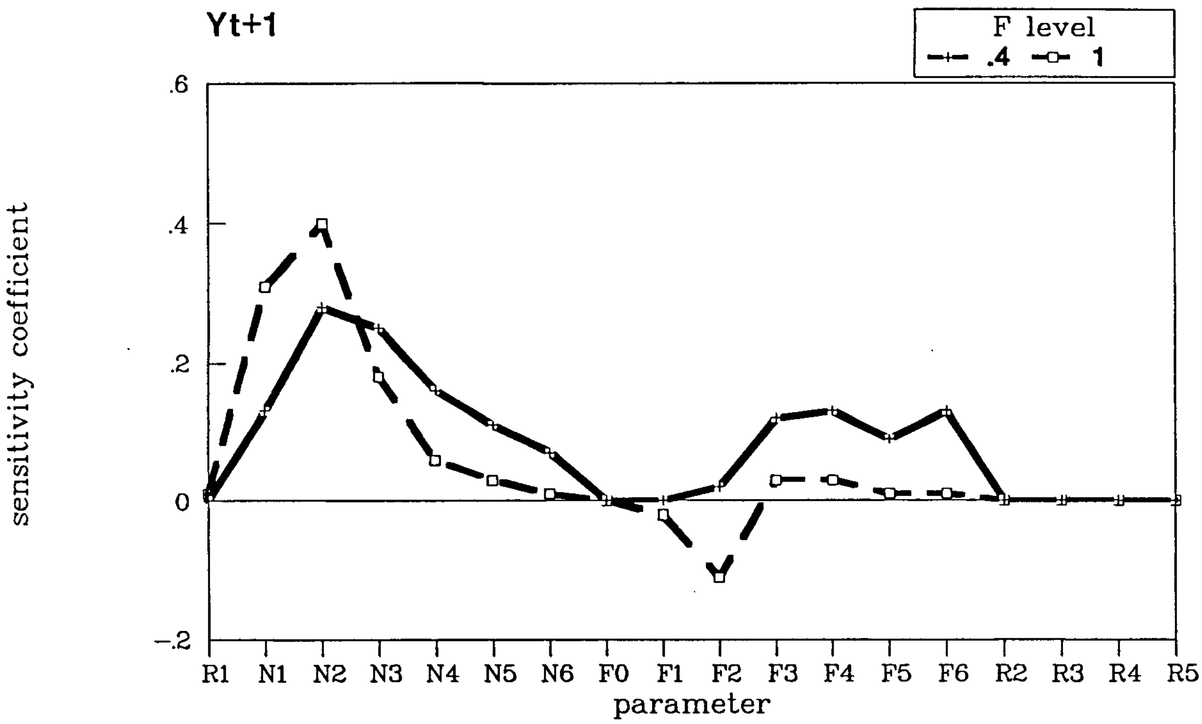

Fig. 1b
HADDOCK CATCH PREDICTION

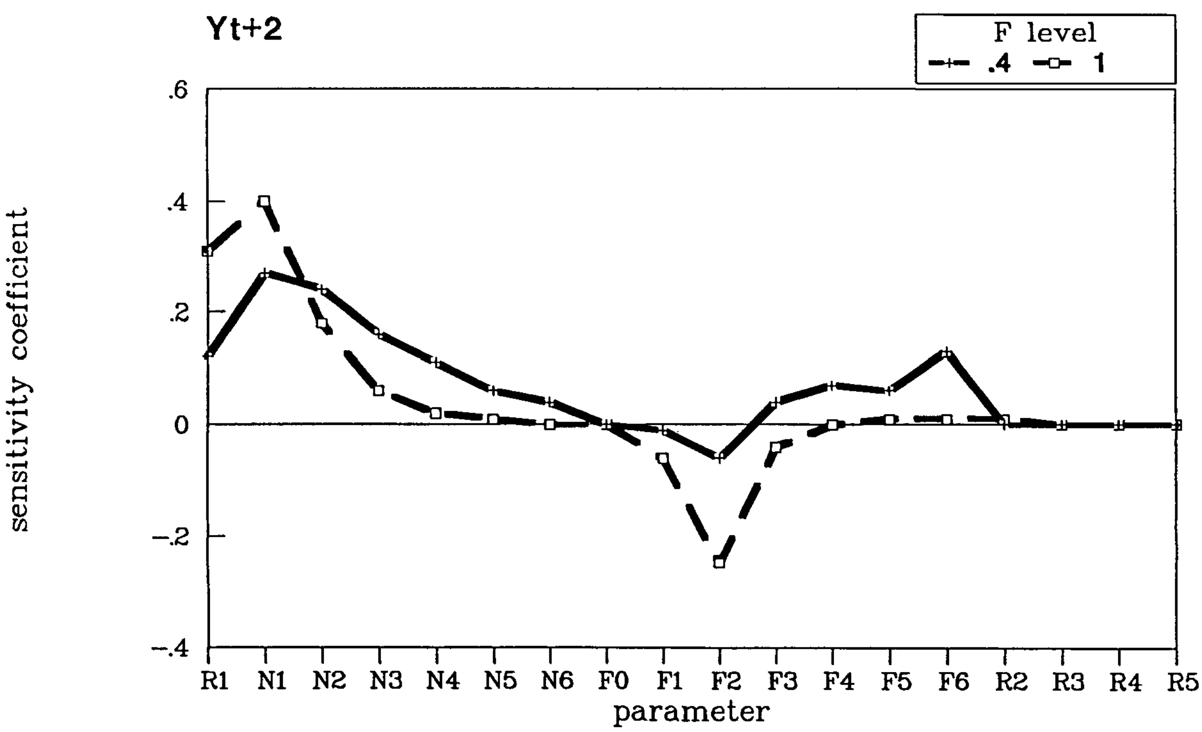

Fig. 1c
HADDOCK CATCH PREDICTION

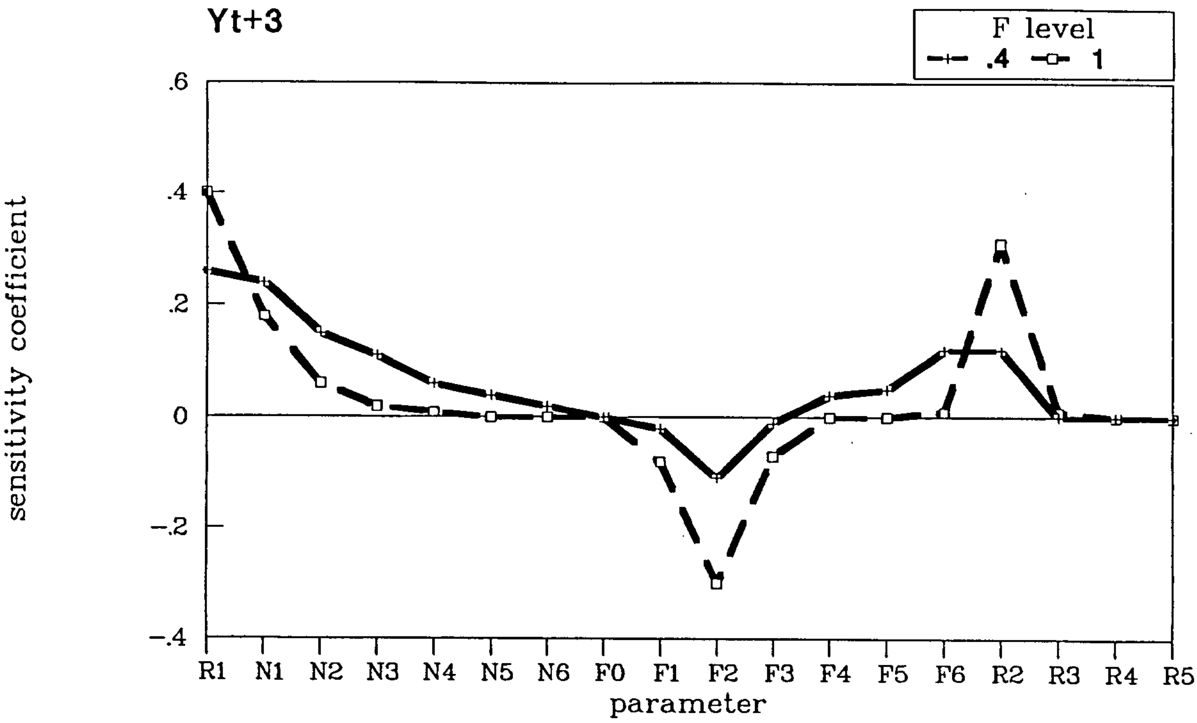

Fig. 1d
HADDOCK CATCH PREDICTION

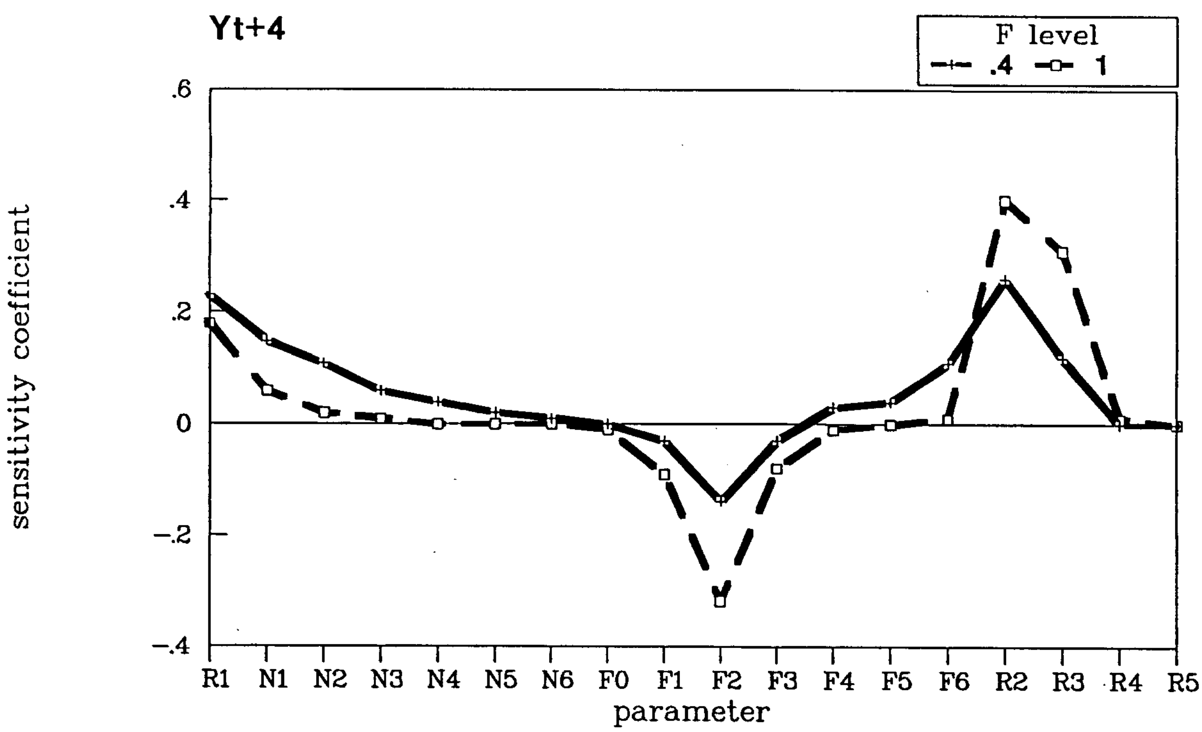

Fig. 2a
HADDOCK SSB PREDICTION

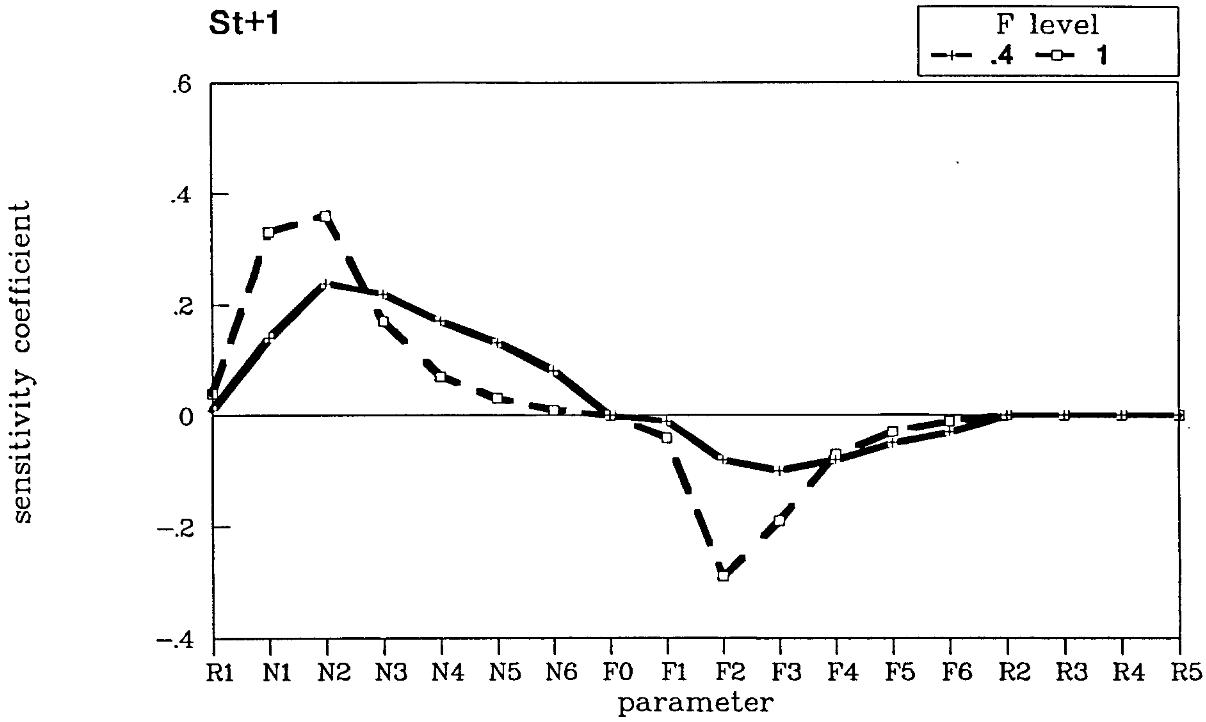

Fig. 2b
HADDOCK SSB PREDICTION

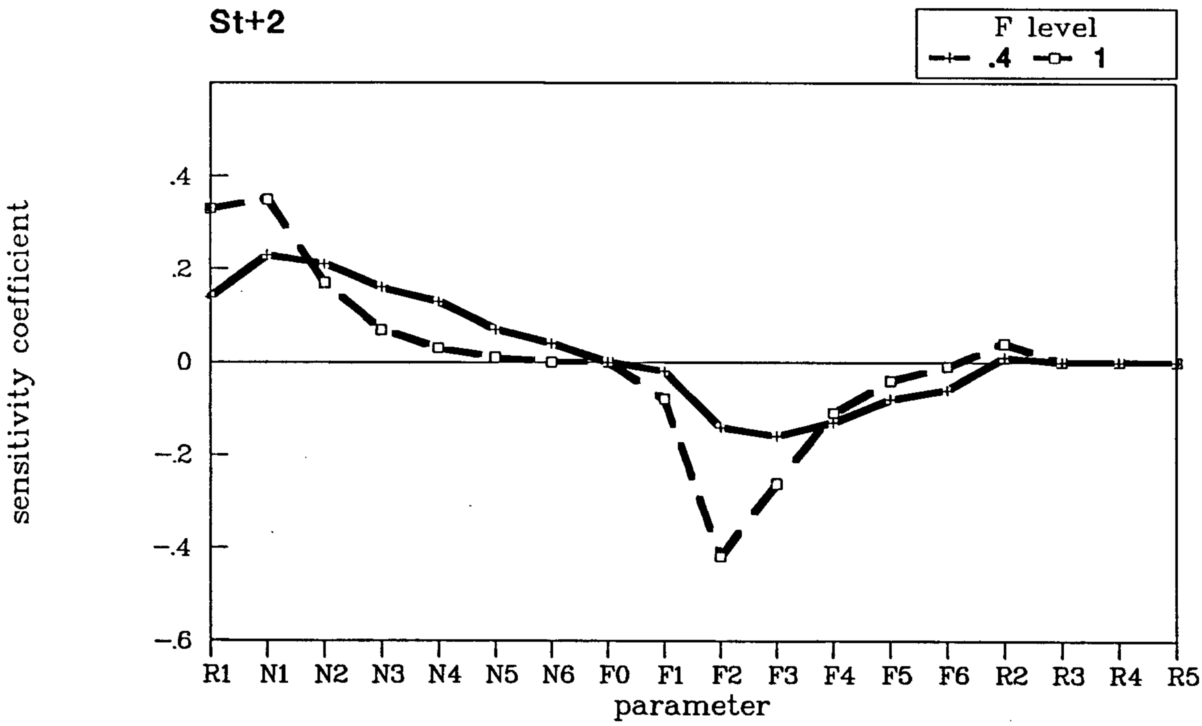

Fig. 2c
HADDOCK SSB PREDICTION

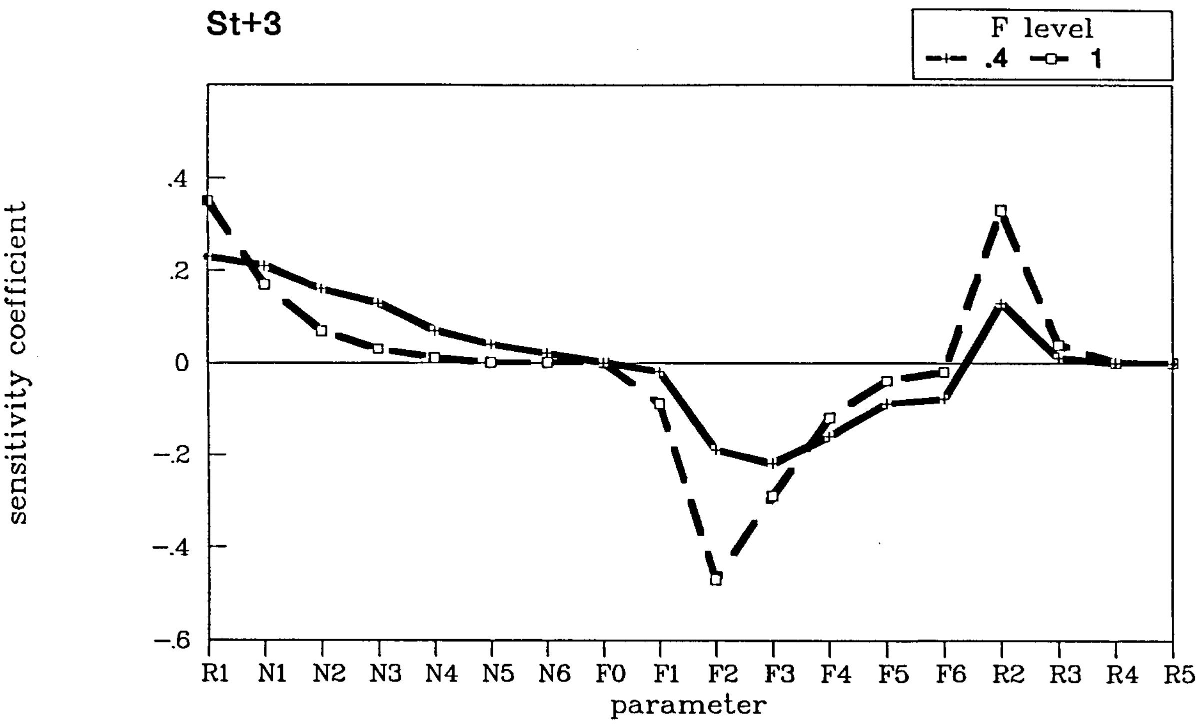

Fig. 2d
HADDOCK SSB PREDICTION

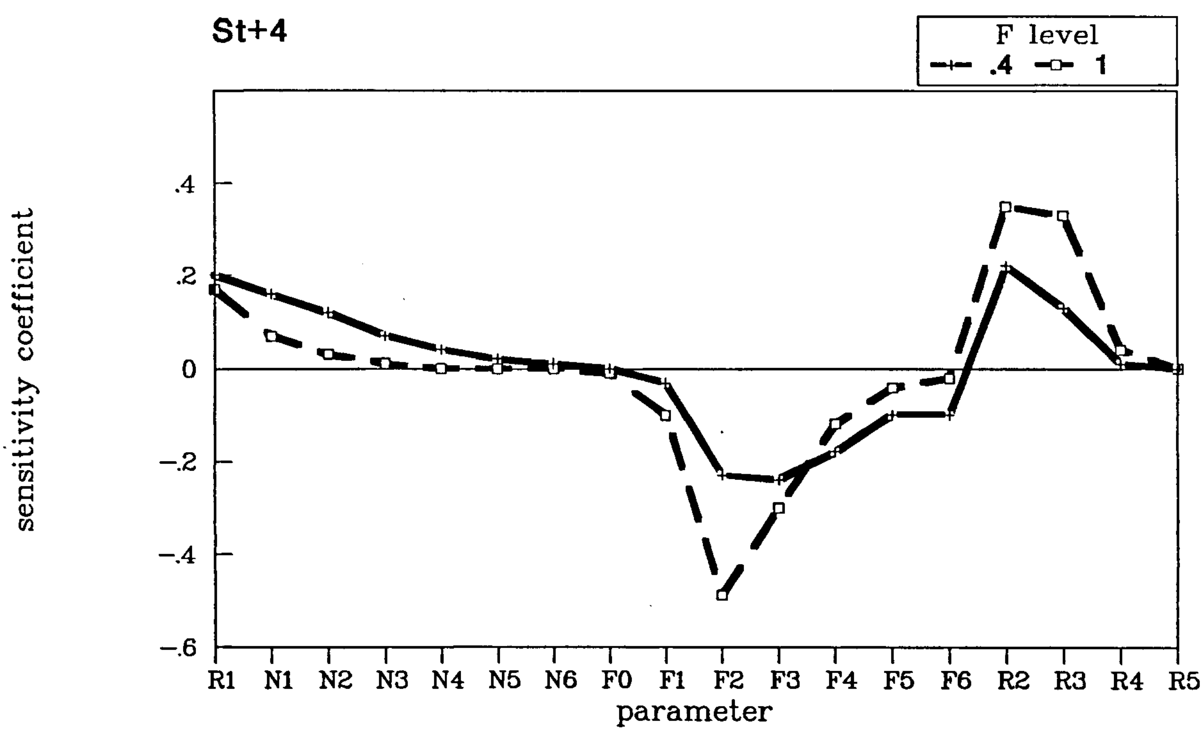

Fig.3
North sea Haddock
Forecast landings

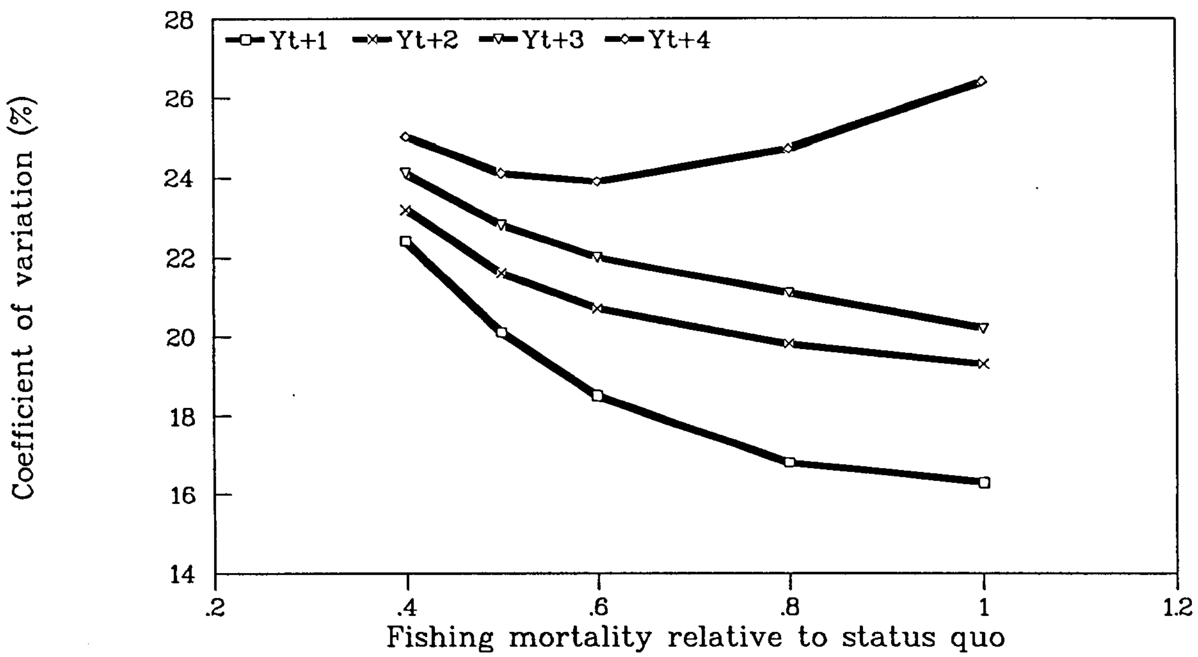

Fig. 4
North Sea Haddock
Spawning stock biomass