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# Cod Stock-Recruitment Relationship in NAFO Divisions 3NO

by

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## ABSTRACT

The cod stock-recruitment relationships in NAFO Div. 3NO were studied by the basic Ricker model and modified Ricker model. Although the models do not adjust to the empirical data, inclusion of the American plaice spawning biomass improves the fit. Adding the mackerel adult biomass also improves the model. Including these two variables in the Ricker model explains almost all variation of the cod stock-recruitment relationship in the area.

The confidence level of the parameters in the proposed equation were determined by the bootstrap technique, and its accuracy tested.

Was realized a simulation study was performed. The response surfaces show the relations between the four variables studied.

## INTRODUCTION

Stock recruitment theory values attempts to predict the numbers of recruits generated by a certain population level, and has two clasic orientations developed by Ricker (1954) and Beverton and Holt (1957). Recently other simple functions have been proposed but adding parameters (Shepherd, 1982). More complex functions with additional parameters which can represent environment influences have also beeb used. (Hightower and Grossman, 1985; Lovejoy, 1986; Swarzman et al. 1987). The recent proposals to study recruitment processes are more complicated functions, and more terms and more parameters are caculated.

There are few reasons for optimism in identifying accurate models of stock-recruitment relationships, and for two kinds of reasons. On the one hand it is very difficult to identify a model from the empirical data, and on the other, even if this can be achieved, the system rarely remains in a similar situation for a long time.

In a previous paper (Paz and Larrañeta, 1989) we obtained a significant and positive correlation between cod year-class size in NAFO Div. 3NO and American plaice spawning biomass in Div. 3LNO, ($r= 0.857$, $p< 0.001$ $n= 20$). That was interpreted by supposing a strong predation of 0-group cod on 0-group American plaice. A frther result was a negative correlation between cod recruitment and mackerel adult biomass ($r= -0.438$, $p= 0.041$, $n= 22$), which suggests a competitive relation between adult mackerel and prerecruit cod.

To take these assumptions into account, the cod stock-recruitment relationship in Nafo Div 3NO by a modified Ricker model was studied.

MATERIAL AND METHODS

Data on cod recruitment (N3) and spawning biomass (B6+) in Div. 3NO (Table 1) have been taken from Bishop et.al (1990), American plaice spawning biomass (B11+) in Div. 3LNO from Brodie (1989), and mackerel biomass (B1+) referred to Labrador North Carolina area from figure 19.1 in Anon. (1986).

The recruitment calculated for recent years by VPA normaly gives underestimates and the data ($N_3$) corresponding to the years 1986-1989 has been rejected. The last most recent estimate accepted was $N_3$ in 1985, which corresponds to the 1982 year- class.

**Table 1** shows recruitment values corresponding to the 1956-1983 year-classes. Taking as recruit the numbers at 3 years age ($N_3$), each recruitment value corresponds to the year-class 3 years previously. The same table gives the other three variables considered: cod spawning biomass, American plaice spawning biomass and mackerel adult biomass.

**The Ricker model.** Ricker (1954) proposed a model applied frequently. It can be writte as:

$$\mathbf{R} = \mathbf{AS}\, \mathbf{e}^{-\mathbf{bS}}$$

when: **R** is recruitment ; S is spawning population size;
been **A** and **b** are the density-independent and density-dependent parameters respectively. That is to say, **A** is a survival rate of recruit numbers by biomass unit, and **b** is a density-dependent coefficient that describes how recruit numbers decline with increasing biomass.

The outstanding general property of this model more is that it can be dome-shapep, so that recruitment decreases at high levels of biomass .

**Biological asumptions of the Ricker model.** In the Ricker model, the underlying hypothesis is that egg and juvenile mortality rates are more dependent on the intiial stock than the present population density, and recruitment increases with biomass until certain levels.

**Parameter estimation.** For calculating the parameter values we start from the Ricker equation: $\mathbf{R= ASe^{-bS}}$, or $\mathbf{R/S= Ae^{-bS}}$. Taking logarihtms $\mathbf{ln(R/S)= ln\ (Ae^{-bS})}$, or: $\mathbf{ln(R/S) = ln(A)+(-bS) \dashrightarrow lnA-bS}$. In this way the expressions are transformed into linear expessions, and **b** can be calculated easily, since the regression slope represents **ln(R/S)** on S. Then **ln A** is the origin ordinate value (when S= 0).

Several authors consider that finding a significant relation between **ln(R/S)** and S demostrates a stock- recruitment relationship, but it is not true. It can be a mistaken result due the presence of the variable S in the two terms of the expression. The stock-recruitment relationship validation must be done by statistic comparison between empirical recruitment values and the predicted values from the model.

**Inclusion of environmental variables in the Ricker model.** According the results obtained with the correlations (Paz and Larrañeta, 1989) it is reasonable to think that

American plaice spawning products can have an effect on the cod stock-recruitment relationship. So, its inclusion in the model should improve its correspondence with the empirical data of cod recruitment NAFO Divisions 3NO.

To begin, we used the following the transformation : $A = e^{a}$, that is to say $a=\ln A$, and obtained the expression: $R= e^{a}Se^{-bS}$, equal to: $Se^{a-bS}$.

In this way, including as exponents the density-dependent and density-independent parameters, it is easy to add to the model the factor effects, fi: $R= Se^{a'-bS\ cfi}\ \varepsilon$.
In the linear form we obtain the expression: $\ln(R/S)= a'-bS+cf_i\ \varepsilon$, where $\varepsilon$ is the residual or total error.

Stocker et al. (1985), applied the Ricker model to mackerel data from Georgia Strait and included several environmental variables. In the same way, one can add interactions between species such the competition, and predation (Walters et al., 1985).

The correlation between American plaice spawning biomass and cod recruitment has a positive sign, and this will be the sign in the equation proposed. Writing plaice spawning biomass as $S_{plat}$, the resulting equation is: $R= Se^{a-bS+cS_{plat}}$,
or in linear form: $\ln(R/S)= a-bS+cS_{plat}$

Where **a**, **b** and **c** are the parameters to be calculated; **a** and **b** express mean environmental conditions, density-independents and density-dependents respectively, whereas **c** expresses the magnitude of the American plaice biomass effect on cod recruitment. The same criterion was used to include the mackerel adult biomass.

The comparison between the calulated or predicted values from the model and the empirical values was done to obtain a $\varepsilon$ value, which represents the residual unexplained due to factors not considered, and also measured errors.

## RESULTS AND DISCUSSION

The calculations made the grafics which appear in figure 1. It are shown:

**a**) The relationship between empirical values of cod spawning biomass and subsequent recruitment .

**b**: The fit to basic Ricker model from the data.

**c**: The fit to the same model when it the American plaice spawning biomass is included .

**d**: The fit when the mackerel adult biomass (B1+) is also added .

In the figure 1 we see that model Ricker basic does not fit to the data. According to the model there is no cod stock-recruitment relationship, but when American plaice spawning biomass is included, denoted by the correlations (Paz and Larrañeta, 1989) as a variable related with cod recruitment, the fit improves. Finally, when the mackerel adult biomass is also added as depresing element (predator), the fit improves a little more, as can be seen in figures 1 and 2.

The resultant equation was: **$\ln(R/S)= 0.25596 + 0.00089\ S$,**

and the parameter values were $A= e^{0.25596}= 1.29170$;

$b= 0.00089$.

The correlation coefficient value result low: $R^2= 0.364$. (Table 2)

By introducing American plaice spawning biomass we obtained the equation:

$$\ln(R/S)=-0.1980 +0.00110\ S+0.00078\ S_{plat}$$

Parameter values were: A=0.82037 and b=0.0011.

The fit improves appreciably: $R^2= 0.647$. The result is shown in figure 2b. and Table 3

Adding mackerel adult biomass, with minus sign, the fit improves again as shown by the $R^2$ value ($R^2$=0.688) and by the residual values decreasing, from 2.142 to 1.89. (Figure 2c and Table 4)

The equation is: **$\ln(R/S)= 0.44 -0.00115\ S + 0.00079\ S_{plat}-0.00023\ S_{xar}$** *(1)*

In this case the parameter values A and b were 1.5527 and - 0.00115 respectively, and $\varepsilon$= 1.89.

**Determination of the confidence levels of the parameters values calculated.** The equation with the best fit *(1)* has a high significance level ($p< 0.001$), but the confidence levels of the values obtained for each coefficient are unknown .

There are several procedures for calculating the statistical variability by resampling from real data. Here we applied the *boosstrap method.* The bootstrap was proposed by Efron (1979a, 1981). It consists of generating new random sanples with repetition the original serie, and realizating after the calculation with each its. The values distribution of each coefficient was trated as a distribution make with real values (Stine, 1985). This method involves no assumption of normality in the data. This technique was used in the cacth age analysis (Deriso et al., 1985).

Were calculated the residuals of each datum in the adjusted curve; random it with repetition this residuals; was make new serie of recruitment values adding the randomly residuals to recruitments predicted, calculated by the adjust; was adjusted the curve from new data serie resulting a new equation. By a iterative process was obtained a coefficients values serie. It will has a normal distribution, can estimated their variability or confidence level.

We did 100 repetitions. The coefficient value distributions are show in figure 3.

Table 5 gives the coefficient values calculated from equation *(1)*; the mean value of 100 replicate, and the interval 2S values.

The parameters values calculated for the adjusted equation proposed lie within the 99% confidence interval with regard to the normal distribution.

As a final synthesis, we show the data and the three fitting attempts in chronological order (Fig. 4). The figure shows the progession of the fit in relation to the data.

**Simulation models with the modified Ricker equation.** Afetr testing the fit to the Ricker model with American plaice (B11+) and mackerel (B1+) included, we did a simulation to test the performance of the four variables studied. The simulation was made in a range close to the empirical range.

The coefficients obtained in the best fit (equation *1*), corresponding to the Ricker model including American plaice (B11+) and mackerel (B1+) were used.

Values of cod spawning biomass, and also a. plaice spawning biomass in increasing order were taken. The mackerel adult biomass was considered in three levels: high, mean and low, as a state variable, as well as in a range defined by the empirical values.

The response surfaces appears in **figure 5**. The three grafics shown the progressive pointing of the surface when increqasing American plaice biomass value, even with cod biomass equal values. The cod recruitment increases with increasing American plaice biomass in the three cases. Also, observe the inhibitory effect of adult mackerel on cod recruitment. So, for identical levels of American plaice and cod biomass, the highest recruitments were obtained with the lower level of mackerel, and the smaller values with the maximum mackerel level.

The response surface results accord with the hypothesis that American plaice spawning products are food for 0-group cod and increase its survival, and that mackerel, during northward spring migrations, feed on cod larvae and fingerlings and have a negative influence on cod recruitment.

Summarizing, in the period studied by the modified Ricker model, with combined effects of the three variables: cod spawning biomass, American plaice spawning biomass and mackerel adult biomass, we can explain the cod stock-recruitment relationship variations in NAFO div. 3NO.

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| Year Class | Cod Recruitment (N3) | Cod Recruits (000) | Cod Biomass (B6+,tons) | A. plaice (B11+,tons) | Mackerel (B1+,tons) |
|---|---|---|---|---|---|
| 1956 | 1959 | 53698 | -- | -- | -- |
| 1957 | 1960 | 53179 | -- | -- | -- |
| 1958 | 1961 | 82134 | -- | -- | -- |
| 1959 | 1962 | 107755 | 89220 | -- | -- |
| 1960 | 1963 | 78284 | 72956 | -- | -- |
| 1961 | 1964 | 112516 | 90018 | -- | -- |
| 1962 | 1965 | 162762 | 80480 | -- | -- |
| 1963 | 1966 | 210243 | 88029 | -- | 275 |
| 1964 | 1967 | 183387 | 112830 | -- | 311 |
| 1965 | 1968 | 101714 | 120660 | 138197 | 323 |
| 1966 | 1969 | 128599 | 104875 | 158756 | 371 |
| 1967 | 1970 | 80905 | 93820 | 157325 | 623 |
| 1968 | 1971 | 86121 | 83341 | 138837 | 1198 |
| 1969 | 1972 | 63163 | 81217 | 120238 | 1533 |
| 1970 | 1973 | 37594 | 82481 | 94378 | 1856 |
| 1971 | 1974 | 41586 | 90799 | 81403 | 1868 |
| 1972 | 1975 | 26552 | 81758 | 62129 | 1653 |
| 1973 | 1976 | 33510 | 61446 | 52619 | 1389 |
| 1974 | 1977 | 52753 | 60994 | 50889 | 1126 |
| 1975 | 1978 | 61688 | 27912 | 45906 | 970 |
| 1976 | 1979 | 21747 | 23903 | 39864 | 719 |
| 1977 | 1980 | 23345 | 36541 | 45515 | 491 |
| 1978 | 1981 | 33823 | 42314 | 48818 | 467 |
| 1979 | 1982 | 24673 | 52004 | 60846 | 503 |
| 1980 | 1983 | 35426 | 103667 | 67125 | 467 |
| 1981 | 1984 | 47223 | 157436 | 53278 | 479 |
| 1982 | 1985 | 32581 | 172654 | 46852 | 599 |

**Table 1**.- Cod Div. 3NO spawning stock•Table 1.- Cod Div. 3NO spawning stock (B6+) and recruitment (N3) From (Bishop et al. (1990); American plaice spawning biomass (B11+) from Baird and Bishop (1989) las Divisiones. 3NO; Mackerel adult biomass from figure 19.1 anon. (1986).

| Source | F.D. | Sum Squares | F Test |
|---|---|---|---|
| Regression | 1 | 2.206 | 9.154 |
| Residual | 16 | 3.860 | p< 0.05 |
| Total | 17 | | --- |

**Table 2**.- ANOVA corresponds to fit Ricker model from the empirical data.

| Source | F.D. | Sum Squares | F Test |
|---|---|---|---|
| Regresion | 2 | 3.924 | 13.739 |
| Residual | 15 | 2.142 | p<0.05 |
| Total | 17 | 6.066 | -- |

**Table 3**.- ANOVA corresponds to fit to Ricker model modificated with the inclusion of the American plaice spawning biomass.

| Source | F.D. | Sum Squares | F Test |
|---|---|---|---|
| Regression | 3 | 4.176 | 10.311 |
| Residual | 14 | 1.89 | p< 0.05 |
| Total | 17 | 6.066 | -- |

**Table 4**.-ANOVA corresponds to adjust to Ricker model modificated also, with the inclusion of the mackerel adult biomass.

| | Cod (B6+) | A. plaice (B11+) | Mackerel (B1+) |
|---|---|---|---|
| Coefficient value obtained | $-1.102\ 10^{-3}$ | $8.545\ 10^{-4}$ | $-2.293\ 10^{-4}$ |
| Mean bootstrap distribution | $-1.154\ 10^{-3}$ | $7.933\ 10^{-4}$ | $-2.205\ 10^{-4}$ |
| Interval 99% (min.) values | $-1.191\ 10^{-3}$ | $8.119\ 10^{-4}$ | $-2.639\ 10^{-4}$ |
| (max.) | $-1.03\ 10^{-3}$ | $8.971\ 10^{-4}$ | $-1.77\ 10^{-4}$ |

**Table 5**.- Coefficient values of the equation result and mean and interval +/-2s parameters bootstrap caculated.

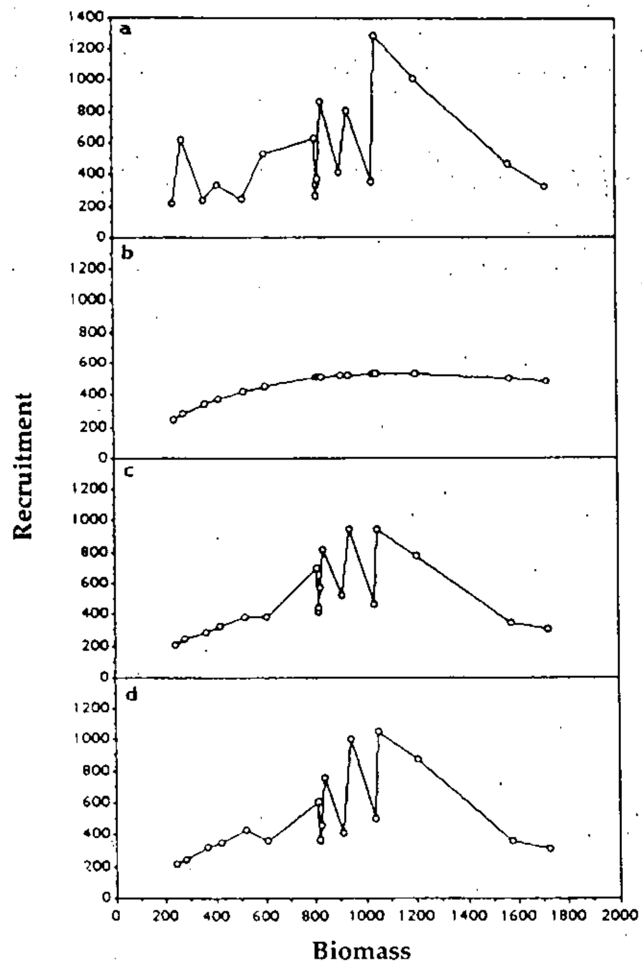


**Figure 1**.- Cod stock-recruitment relationship, NAFO divs. 3NO: 1956-84. **a)** empirical data; **b)** values obtained with Ricker model; **c)** modified Ricker model including American plaice spawning biomass; **d)** Values resulting to adjust the modified Ricker model with inclusion the American plaice spawning biomass and the mackerel adult biomass.

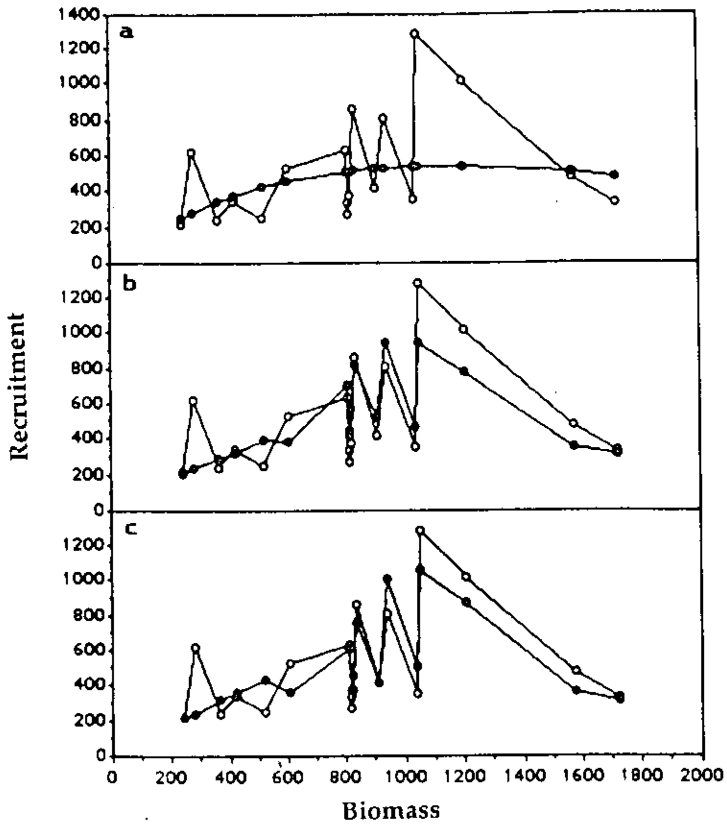


**Figure** 2.- Cod stock-recruitment in NAFO divisions 3NO: 1956-84. Empirical data compared with **a)** the result values obtained with the Ricker model; **b)** the fitted curve by the Ricker model with introduction American plaice spawning biomass **c)** results values from Ricker model with introduction American plaice spawning biomass and the mackerel adult biomass.

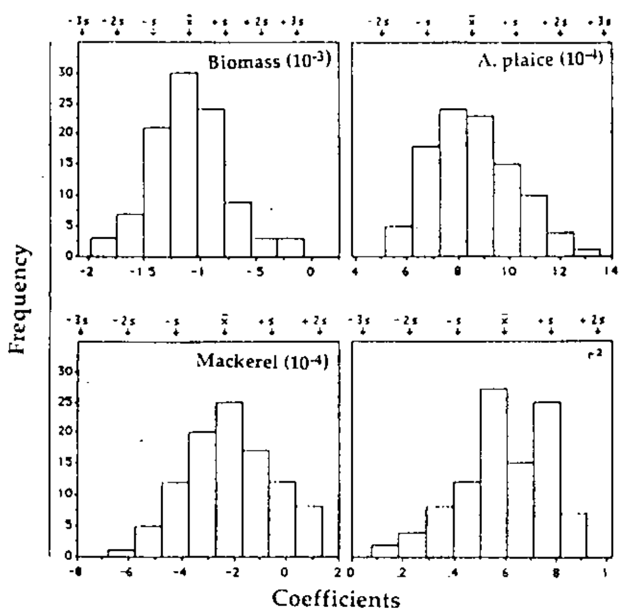


**Figure** 3.- Coefficient values frequency distribution, auto generated by bootstrap, corresponding the equation results to applied the Ricker model modified with American plaice spawning biomass and mackerel adult biomass.

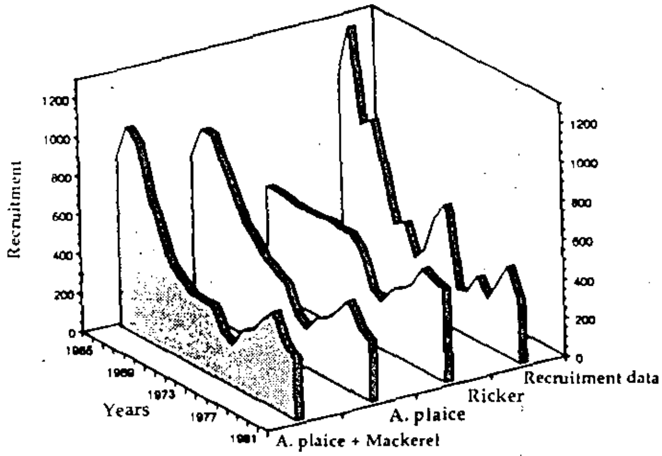


**Figure 4.-** Chronological evolution of the recruitment empirical values, and de los three adjusts attempts: Ricker, Ricker with the American plaice (B11+) and Ricker with the American plaice (B11+) and mackerel biomass(B1+).

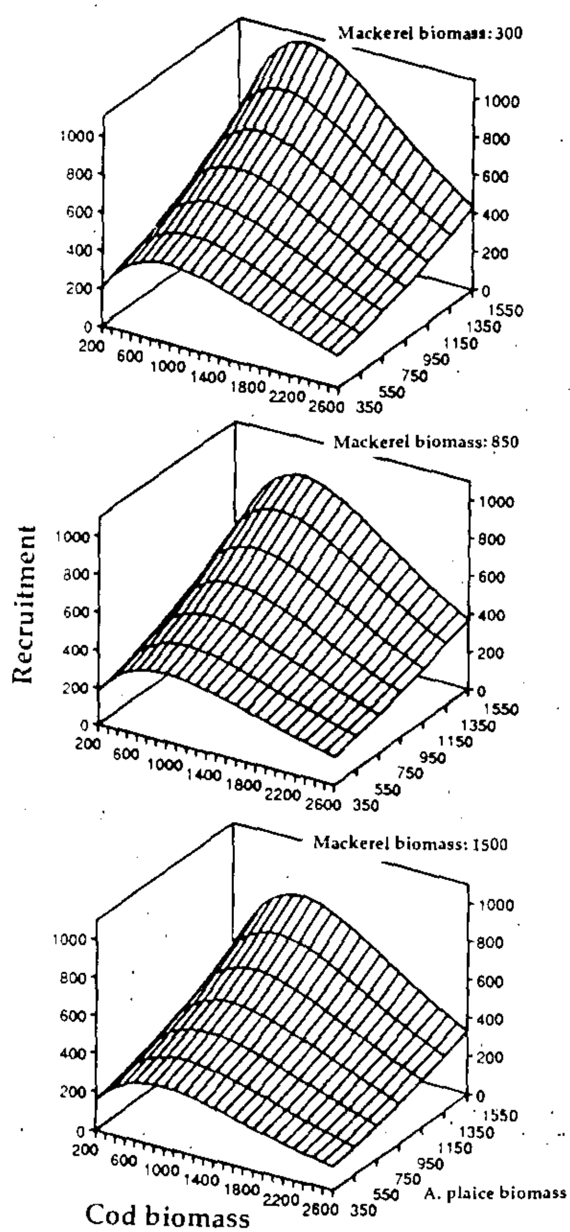


**Figure 5.-** Simulation by modified Ricker model including the American plaice (B11+), and considering three mackerel biomass (B1+) levels; **a)** mackerel biomass low level; **b)** mean level Mackerel biomass and **c)** high level mackerel biomass.