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AN ASSESSMENT ON PLAICE (*PLEURONECTES PLATESSA*) IN ICELANDIC WATERS: COMPARISON OF DIFFERENT ASSESSMENT MODELS AND ASSUMPTIONS

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ABSTRACT

The report presents a comparison of different assessment methods and the state of the plaice stock (*Pleuronectes platessa*) in Icelandic waters. Four alternative assessment methods are used: age-based ADAPT, length-based ADAPT, age-disaggregated dynamic and the surplus production model. Most of the data used in this study are from the Marine Research Institutes (MRI). Age-disaggregated observations are used as input data for the age-based ADAPT method and age-disaggregated dynamic production model. For the length-based ADAPT method, the length frequency data are used as the input source and converted into age using the slice method and then used as input data for the length-based ADAPT model and catch by year, biomass indices and CPUE for the surplus production model. The reference points model with R-S relationship (B-H) is used to estimate the stock state. The different models give similar trends in fishing mortality rates over the period studied (1987-2004) and similar F in the final year (0.16-0.25). The stock biomass declined from approximately 50,000 t in 1987 to around 22,000 t in 2004. Mean recruitment from 1987-2004 is around 30 million and declining. The long term predicted yield for the next 15 years is about 7,000-9,000 t and the short term predicted yield for the next three years is about 4,000-5,000 t. Results from the surplus production model show that the stock biomass declined from approximately 80,000-90,000 t in 1905 to around 14,000 t in 2000 and then increased to about 23,000 t in 2004. The estimates of reference points show that the current fishing mortality has declined to historically low levels. The recruitment between 1987 and 2004 was variable and included a few high values. Since 2000, recruitment has decreased and has been less than average. The SSB estimated in 2004 of 22,000 t is above the Bpa of 15,389 t. Short term predictions suggest that SSB will increase to around 26,000 t by 2007 at current levels of fishing mortality. The recommended fishing mortality from long term predictions is less than 0.26 for the period 2005-2015 to increase the stock and catch to around 40,000 t and 8,000 t.

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1 INTRODUCTION

Plaice, *Pleuronectes platessa* (Linnaeus, 1758) is a medium to large sized flatfish. Plaice is common all around Iceland from 0 to 200 m, on sandy or muddy bottoms. It can also tolerate fresh water for some time. In European waters it is found from the White Sea and the Barents Sea in the north down to the western part of the Mediterranean Sea in the south. Plaice undertakes large scale feeding and spawning migrations in the waters around Iceland (Jónsson 1992). The plaice's diet mainly consists of various benthic invertebrates, dominated by polychaetes and bivalves, but also sand eels to some extent (Pálsson 1983).

Plaice is a commercially important flatfish. Apart from plaice there are a number of other important flatfish stocks in Icelandic waters, including Greenland halibut, dab, long rough dab, lemon sole, witch and halibut. All these stocks are fully utilised by the Icelandic fleet and TACs have been established for them in recent years. Data on the plaice fishery in Iceland are available from the year 1913 for Iceland and from 1905 for other nations fishing in Icelandic waters (Figure 1). Because of its high value, it has sustained high catches in Icelandic waters. The catch was about 10,000 t/y and 5,000 t/y in the 1960s-70s, while from 1984-1997 the catches were 10,000 to 14,000 t/y, higher than ever before. Recent catches have been about 5,700 to 7,000 t/y (Table 1). Most of the catch is taken by Danish seine, but a considerable share is taken by bottom trawls. Most of the catch consists of 5-6 year old fish, 35-40 cm long. Fishing effort is considered too great and the abundance index for the fishable stock shows a marked decline in recent years (Table 4).

In 1986 the Marine Research Institute (MRI) initiated a sampling programme from landings and from that year onwards samples have been taken regularly from landings. Furthermore all vessels participating in the plaice fishery have been obliged since 1987 to fill out detailed logbooks for the MRI. Plaice catches have been registered, sexed and length measured in the Icelandic spring ground-fish survey (IGFS) since 1985. In 1995 the sampling scheme of the Nephrops survey off the south coast was reconstructed to include plaice.

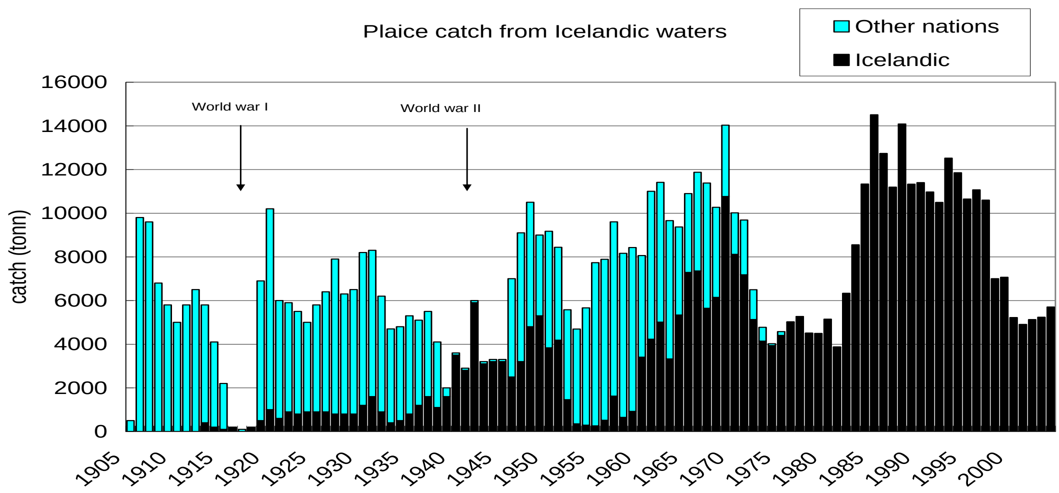

Figure 1: Plaice catch from Icelandic waters.

Since 1994 the MRI has given advice on the exploitation of plaice based on CPUE from Danish seine fleets, TAC for the fishing year 2004/2005 is 5,000 t based on CPUE, but the Marine Research Institute (MRI) recommended that fishing should be limited to 4,000 t in the period (Marine Research Institute 2004/2005).

Plaice is the most studied of Icelandic flatfishes. Studies on population dynamics have however been hampered by the different fishing gears used and lack of a continuity in the studies (Valtysson 1998**)**. Now this has been supplemented by increased sampling effort from ports of landing all around the country. Annual trawl surveys since 1985, covering most of the fishing grounds in Iceland, give valuable information on the trend in stock size of all the flatfish species.

In a discussion of model selection, Hilborn and Walters (1992) suggest adopting a pragmatic approach. Assuming the data are available, they imply that one should apply both surplus-production and age-structured methods, which, because they are fundamentally different, will provide a test of relative performance. The main objective of this study is to assess the plaice stock with various assessment methods to evaluate the effect of different assessment methods on the stock estimates, to obtain overall indication of stock trends and exploitation since 1987**,** Biological reference points (BRP) as well as short term and long term predictions. Four assessing methods are used: 1) ADAPT/VPA/Cohort analysis, a standard method of assessment using catches in number by age by year combined with tuning indices to obtain stock size in number at age. 2) Length-based ADAPT-VPA, using length frequency data as the input source. This method is performed in two steps. The first step is to disaggregate the age from the length distribution data using the least squares method, corresponding to a simplified version of the maximum likelihood method (slice). The second step is to use the VPA-ADAPT method to estimate stock size with the data obtained. 3) Age-disaggregated Dynamic Production Model (ADPM) using catches in number by age by year, CPUE and survey indices to fit the dynamics of the stock with internal age groups including various error assumptions. 4) Surplus production model using biomass indices from survey and CPUE to fit the dynamics of the stock.

2 MATERIAL AND METHODS

2.1 Available data and biological parameters

2.1.1 Available data

Most of the data used in this study are from the Marine Research Institutes (MRI) and unpublished.

The sets of data used include the following:

a. Total nominal annual catches in tons of plaice from Icelandic waters 1905-2004. Data from the annual report on the State of Marine Stocks in Icelandic Waters 2004/2005 (Table 1).

b. Catch in number by age by year (Table 2), mean length and weight at age from 1987-2004 (Tables 6 and 7), length along with length distributions from 1987-2005 (Table 8), the length-weight relationship data from 1994-2005 (MRI Databases) and maturity at age (Table 9) from 2002-2004.

c. CPUE indices: CPUE indices (Table 3) based on Icelandic Danish seine fleets log-books from 1991-2004. This is the mean catch when more than 10% of the total catch was plaice.

d. Icelandic ground fish survey (IGFS) indices from 1985 to 2005 (Tables 4 and 5). These are total abundance and recruitment indices of plaice based on data from the IGFS. They were estimated with the Cochran method by depth strata. The IGFS is designed for cod and therefore the sampling is not optimal for plaice.

2.1.2 Biological parameters

- Parameters for the von Bertalanffy (Bertalanffy 1938) growth equation. The growth parameters were estimated from the database on length at age (MRI Database) by finding the best fit to the observed length at age with the maximum likelihood method (Malcolm 2001).

$$L_a = L_\infty (1 - e^{-k(a-t_0)}) + \varepsilon$$

$$\hat{\sigma}^2 = \frac{\sum_{i=1}^{n} (L_{ai} - b\hat{L}_{ai})^2}{n}$$

$$LL = -\frac{n}{2}[Ln(2\pi) + 2\mathrm{Ln}(\hat{\sigma}) + 1]$$

$$MIN(-LL)$$

$$CV = \sqrt{\frac{LL}{n}}$$

where L_a is length at age a, L_∞ is the theoretical maximum length the species can reach, k is growth coefficient that measures the rate at which the L_∞ is reached, a is the age and t_0 is theoretical age at zero length, L_{ai} is the observation length, $\hat{L}_{ai}$ is estimated length and LL is the value of Maximum Likelihood, n is number of data points.

- Parameters for the length-weight relationship. The growth-weight relationship parameters were also estimated from the MRI database on length-weight, by finding the best fit to the observed weight with the maximum likelihood method.

$$W = \alpha L^{\beta} + \varepsilon$$

$$\hat{\sigma}^2 = \frac{\sum_{i=1}^{n} (W - b\hat{W})^2}{n}$$

$$LL = -\frac{n}{2}[Ln(2\pi) + 2\mathrm{Ln}(\hat{\sigma}) + 1]$$

$$MIN(-LL)$$

$$CV = \sqrt{\frac{LL}{n}}$$

where α and β are constants.

- Maturity rate at age estimation. The theoretical ogive of maturity at age is estimated from the equation below (Pearl and Reed 1922) with the data from MRI (Table 9).

$$\hat{\mathrm{P}}_{\mathrm{i}} = \frac{1}{1 + e^{a*(t - p_{50})}}$$

$$SSE = \sum_{i=1}^{n} (P_i - \hat{P}_i)^2$$

where $\hat{p}_i$ is the proportion of mature individuals at age group i, a and p_{50} are the parameters of the equation which will then be estimated by the least-squared method to give the best fit of expected-to-observed, and p_i is the proportion of mature individuals at age group i from the observed.

- Natural mortality rate (M): Preliminary studies on plaice in Faxaflói Bay (Sigurdsson 1962) in the late 1950s estimated a total annual mortality of 19%. This should be close to the natural mortality since catches were very low during this period. No further studies have been conducted on the natural mortality of plaice in Icelandic fishing grounds. The value used by the MRI for the witch flounder and the plaice is 0.15 and here we also use this value.

2.2 Stock assessment methods

2.2.1 Age-based ADAPT

ADAPT-VPA (Deriso1985, Gavaris 1988) is a well known method of assessment using catches in numbers at age (Table 2) combined with tuning indices to obtain stock size in numbers at age. In this method, it is assumed that fishing takes place at around the middle of the year and that natural mortality will only affect the stock before and after the fishing season. Natural mortality is assumed to be constant with regard to age and time and is denoted by M. This method uses fishing mortality rates in the last year as the starting point of the calculation instead of stock size of the last year. The fishing mortality rates of the last year are then determined by a "tuning" method, in this case based on ADAPT. The fishing mortality rate of the oldest group is taken as an average of fishing mortality rates for some penultimate younger age groups of the oldest during the same year.

The stock size in numbers in the last year is calculated through the inversion of the catch equation:

$$N_{ay} = \frac{C_{ay}}{(F_{ay} / Z_{ay}) * (1 - e^{-Z_{ay}})} \qquad (1)$$

Where N_{ay} is the size of the age group a in year y

$N_{a+1,y+1}$ is the size of the group a in the next year to the year y

Z_{ay} is the total mortality rate for the age group a in year y

F_{ay} is the fishing mortality rate for the age group a during year y

C_{ay} is the total catch in number of the age group a in year y

For a given age group *a* having the size N_{ay} at the beginning of year *y*, provided no fishing takes place in the first six months, the size of the year-class at the middle of the year will be (Pope 1982):

$$N_{ay} * e^{-M/2}$$

If the entire catch is taken at this point of time, the size of the year-class is reduced to:

$$N_{ay} * e^{-M/2} - C_{ay}$$

Then the year-class decreases due to natural mortality, so the survival of the year-class at the end of the year is:

$$N_{a+1,y+1} = (N_{ay} * e^{-M/2} - C_{ay}) * e^{-M/2} \qquad (2)$$

For back calculation of the stock size, this equation can be reversed:

$$N_{ay} = (N_{a+1,y+1} * e^{M/2} + C_{ay}) * e^{M/2} \qquad (3)$$

Since the stock size of the last year is already known from equation (1), the second to last year can be back calculated using equation (3).

Once the stock size N_{ay} of the last year and the second to last year is known, the fishing effort F_{ay} of the second to last year can be computed, using the basic equation:

$$N_{a+1,y+1} = N_{ay} * e^{-Z_{ay}}$$

The natural logarithm is taken on both sides to get the estimate of Z_{ay}:

$$Z_{ay} = \ln(N_{ay}) - \ln(N_{a+1,y+1})$$

The total mortality (Zay) is the sum of fishing mortality (F_{ay}) and natural mortality (M):

$$F_{ay} = Z_{ay} - M = \ln(N_{ay} / N_{a+1,y+1}) - M \qquad (4)$$

In principle, the fishing mortality rates of the oldest age groups can be estimated, but these are always prone to large errors. Therefore, the fishing mortality of the oldest age is set as the average of some younger age groups.

For the last year the estimation is reduced to estimating a single fishing mortality. It can be estimated on the basis of the patterns of the previous years. In some cases the selection patterns are not accurately determined and not in accordance with what is expected from the gear used. Therefore, the simplification is made that the selection pattern in the latest year is fixed equal to the average selection in some years prior to the last one. In this project, the average selection pattern is taken as the short term average selection pattern of the three years prior to the last one (1999-2001).

It is now possible to use exactly the same method to estimate the stock size of the third last year and then continue to back calculate stock sizes and mortality rates completing the stock size.

Survey and commercial fisheries information on biomass and CPUE are used as indices of abundance by year I, U, R indices (Tables 3a, 3b, 3c) which are assumed to be related to stock abundance as follows:

$$\hat{I}_y = q_1 * B_y \qquad \text{(y=1987-2004)}$$

$$\hat{U}_y = q_2 * B_y \qquad \text{(y=1991-2004)}$$

$$\hat{R}_y = q3 * N_{2,y} \qquad \text{(y=1987-2004)}$$

$$B_y = \sum_{a=2}^{20} (W_a * N_{ay})$$

where q_1, q_2 and q_3 are constants.

If VPA is employed with the correct input, it should provide a sound stock estimate. This estimate can in turn be used to compare indices from survey and CPUE data and therefore it is feasible to verify whether a given stock estimate is in accordance with a time series of survey and CPUE data.

One possible way to conduct such a comparison is through stating that for a given terminal fishing mortality coefficient in the last year and a given relationship with indices, the deviation (sum squared errors, SSE) in the forecast concerning indices is given by:

$$SSEI = \sum_{y=1}^{18} (\ln(I_y) - \ln(\hat{I}_y))^2 \qquad \text{(y=1987-2004)}$$

$$SSEU = \sum_{y=1}^{14} (\ln(U_y) - \ln(\hat{U}_y))^2 \qquad \text{(y=1991-2004)}$$

$$SSER = \sum_{y=1}^{18} (\ln(R_y) - \ln(\hat{R}_y))^2$$

$$SSE = w1 * SSEI + w2 * SSEU + w_3 * SSER \qquad (5)$$

where $w1$, $w2$ and $w3$ are weight for SSE.

Then $N_{ay}, B_y, F_{ay}, F_y, R_y$ are estimated from the Biomass and Recruitment of survey and CPUE, by finding the best fit to the observed the Biomass of survey and CPUE.

Where B_y is the predicted Biomass in year y

F_y is the predicted fishing mortality rate in year y

R_y is the predicted recruitment in year y

The age-disaggregated catches in numbers by age by year (Table 2) were used for the cohort analysis, the biomass and recruitment indices from survey (Tables 3, 4, 5) and CPUE from landing for the tuning process. The reference fishing mortality, F, is taken as the average fishing mortality of ages 6-12 as these age groups are dominant in the catch.

The selection pattern by age, S_a, is taken as average S_a of the years 1999-2001 (Table 13, Figure 6). Fishing effort of the oldest group is taken as the average of the fishing mortality of the three younger ages from age 17-19. The mean weight at age by year (Table 11) and maturity at age by year (Table 9) are used for estimating the stock biomass and spawning stock biomass.

The method of least-squares was used to estimate F and stock size of the last year by minimising the sum of squares of the differences between the observed and model predicted biomass and recruitment indices and CPUE.

2.2.2 Length-based ADAPT

In the length-based method used in this project, length distributions are disaggregated into age distributions, using available length frequency data on landings to obtain the total catch in number at age by year.

The length-based method uses the length frequency data as its input source. It contains two steps. The first step is to disaggregate the age from the length distribution data using the slice method. The second step is to use the method VPA-ADAPT as described in section 2.2.1 to analyse the data obtained.

The length frequency data, which will be used as input for the model, are from commercial landing samples in 1987-2004 (Table 8) and then frequency data were converted into total number (Table 10) according to catch from 1987-2004 (Table 1). The conversion to age distribution from length distribution data is performed with the slice method, from which the information on the mean length at age, standard deviation, and probability of density (or proportion) at age are also estimated.

The slice method (Stefansson G. 2005) can be shown by the following equation. The density function of the Gaussian distribution with mean length μ and variance σ^2 is given by:

$$f(x) = \frac{1}{\sqrt{2\pi}\sigma} e^{-(x-\mu)^2/(2\sigma^2)}$$

and the cumulative distribution is:

$$F(x) = \int_{-\infty}^{x} \phi(t)dt = \Phi(\frac{x-\mu}{\sigma})$$

Take a fixed age group of fish and assume that they are distributed along the length axis according to a Gaussian density, with some mean length (μ_a) and some standard deviation of length at age (σ_a).For this age group, the proportion of fish within length category l of width 1 is:

$$\Phi(\frac{(l+1/2)-\mu_a}{\sigma_a}) - \Phi(\frac{(l-1/2)-\mu_a}{\sigma_a})$$

Since this is the probability of a fish having a length between $l-\frac{1}{2}$ and $l+\frac{1}{2}$ now, suppose the true proportion of fish in age group a is π_a. In this case the proportion of fish in length group l, across all ages becomes:

$$\hat{P}_{la} = \sum_a \pi_a \{\Phi(\frac{(l+1/2)-\mu_a}{\sigma_a}) - \Phi(\frac{(l-1/2)-\mu_a}{\sigma_a})$$

$$SSE = \sum_{a=1}^{19} (\ln(P_{la}) - \ln(\hat{P}_{la}))^2 \qquad (a = \text{age 2-20})$$

The unknown parameters in this formula are the proportions in each age group, π_a, the mean length at age, μ_a, and the standard deviations, σ_a.

Given data (Table 8) on the proportions at length can be compared to the theoretical proportions. A formal statistical approach would be to estimate the unknown parameters by minimising the discrepancy between the observed and theoretical values.

2.2.3 Age-disaggregated dynamic production model

This model attempts to draw out the overall picture of how the stock has changed from year to year since 1987. The catch in number by age by year from Icelandic waters in 1987-2004 (Table 2), Biomass, recruitment indices (number at age 2) form survey and CPUE indices from Danish seine fleets log-books 1991-2004 (Tables 3-5) will be used to fit a dynamic stock production model with internal age groups. Various error assumptions, including process error, will be included.

Assuming that in 1986 there is no fishing of the stock and a virgin value of recruitment R_0 ($N_{1986,2} = R_0$), the stock size is calculated for this year is:

$$N_{a+1,1986} = N_{a,1986} * e^{-M}$$

where R_0 will be estimated.

After fishing commences in 1987, with initial series of F multipliers over years, the stock size by age by year is estimated as follows:

$$N_{a+1,y+1} = N_{ay} * e^{-Z_{ay}}$$

It is also assumed that there is a simple relationship between stock and recruitment (or production), expressed by the Beverton and Holt equation (Beverton and Holt 1957):

$$R = \alpha * B_y / (1 + B_y / K)$$

Where B_y is spawning stock biomass, α is a constant and K is the size of the spawning stock that produces half the maximum recruitment.

The parameters α, K, R_0, F will be adjusted to provide the best fit of the predicted-to-observed data. The fitting procedure used in this model is least-squares fitting (Malcolm 2001) (Shepherd 1999):

$$SSEC = \ln(\sum_{y=1987}^{2004}\sum_{a=2}^{20}(C_{ay} - \hat{C}_{ay})^2)$$
$$SSEB = \ln(\sum_{y=1987}^{2004}(B_y - \hat{B}_y)^2)$$
$$SSEU = \ln(\sum_{y=1991}^{2004}(U_y - \hat{U}_y)^2)$$
$$SSER = \ln(\sum_{y=1987}^{2004}(R_y - \hat{R}_y)^2)$$
$$SSE = w_c * SSEC + w_b * SSEB + w_u * SSEU + w_r * SSER$$

Where SSE is the total sum of squared errors, $\hat{C}_{ay}$, $\hat{B}_y$, $\hat{U}_y$, $\hat{R}_y$ are the model predicted catch in number by age by year, biomass indices, abundance indices and recruitment indices, w_c , w_b , w_u , w_r respectively is the weight for the corresponding SSE.

To predict the catch in number by age by year, the following equation is used:

$$\hat{C}_{ay} = \frac{F_{ay}}{Z_{ay}}(1 - e^{-Z_{ay}})N_{ay}$$

To predict biomass indices $\hat{B}_y$, it is assumed that there is a relationship between stock size and biomass indices from a survey:

$$\hat{B}_y = q_1 * B$$

where B is the exploitable biomass of the stock, $B = N_{ay} * W_{ay} * S_{ay}$
q_1 is a constant and S_{ay} is selection pattern by age by year.

To predict abundance indices $\hat{U}_y$, it is assumed that there is a relationship between stock size and CPUE indices:

$$\hat{U}_y = q_2 * B$$

q_2 is catchability and assumed to be constant every year.

To predict the recruitment index $\hat{R}_y$, the following equation is used:

$$\hat{R}_y = q_3 * N_{2,y}$$

where $N_{2,y}$ is the number of age 2 or the recruitment estimated from the stock- recruitment relationship.

2.2.4 A short term yield and biomass prediction for the next three years

With the given stock size estimation of the last year (2004), it is possible to compute catch projections. The outcome of the stock size estimation usually states the number of fish in the sea at the beginning of the last year for which data is available.

The stock size of the next three years is calculated using the following equation:

$$N_{ay} = N_{a-1,y-1} * e^{-Z_{a-1,y-1}}$$

$$B_y = \sum_{a=2}^{20} (N_{ay} * W_a * S_a)$$

where B_y is the exploitable biomass of the stock, W_a is weight at age and S_a is the selection pattern at age.

The natural mortality for the last year is known. The fishing mortality rate of the next three years is assumed to be equal to the fishing mortality of the last year. That means that the fishing pattern is assumed to remain the same from 2004 to 2005:

$$F_{ay} = F_{a-1,y-1}$$

The catch in number by age of the next three years will now be calculated using the catch equation:

$$C_{ay} = \frac{F_{ay}}{Z_{ay}} * (1 - e^{-Z_{ay}}) * N_{ay}$$

The recruitment of the next three years is estimated by the B-H recruitment model with the biomass of the previous year.

Total yield of the next three years will be estimated by the equation:

$$Y_y = \sum_{a=2}^{20} (C_{ay} * W_{ay})$$

where W_{ay} is the mean weight at age from the length-weight relationship model (2.12).
The input data are from the results of age-disaggregated dynamic production model.

2.2.5 Surplus production model

Here is a model from Polacheck *et al.* (1993). Now that surplus –production models have moved away from their equilibrium-based origins they provide a useful tool in the assessment of stocks for which there is only limited information available. They also can provide insights as to the relative performance of the stock through time. The available data, biomass indices from survey (Table 4) and CPUE (Table 3) from Danish seine fleets log-books, are used for fitting the surplus –production model. The generalised stock production model is:

$$B_{t+1} = B_t + \frac{r}{p} B_t (1 - (\frac{B_t}{K})^p) - Y_t$$

where Y_t is the total catch in year t, and p is a constant, here assuming $p = 1, 0.00001$,if p=1, this is equivalent to the Schaefer model, and if p=0, this is equivalent to the Fox model.

The fitting method is as follows:

$$SSEB = \sum_{y=1987}^{2004} (\ln(B_y) - \ln(\hat{B}_y))^2$$

$$SSEU = \sum_{y=1991}^{2004} (\ln(U_y) - \ln(\hat{U}_y))^2$$

$$SSE = w_b * SSEB + w_u * SSEU$$

where SSE is total sum of squared errors, B_y, U_y is biomass index from survey and CPUE indices from the logbooks of Danish seine fleets since 1991-2004, $\hat{B}_y, \hat{U}_y$ is the predicted biomass index and abundance indices from the surplus production model.

The parameters K , r were estimated from the catch by year, biomass index from the survey and CPUE, by finding the best fit to the observed data, and then the biomass at year, surplus production, MSY and instantaneous fishing mortality rate at MSY can be estimated.

2.2.6 Biological reference points

In order to define these long term objectives the values of the fishing level have to be considered, which allow loose catches in weight, while also ensuring the conservation of the stocks. The extreme values of the biomass or the fishing level, which might seriously affect the self renovation of the stocks, also have to be considered. These fishing level values, of catch and biomass are designated as biological reference points (BRP) (Emygdio 2003).

For this section's analyses, some models are used to validate the average size-F estimates we obtained earlier, and to assess several biological reference points important to fishery management. The most relevant contemporaneous fishery management benchmarks include: $F_{0.1}$, F_{max}, F_{msy}, F_{med}, F_{high}, F_{crash}, $B_{0.1}$, B_{loss}, B_{pa} and F_{pa}.

- $F_{0.1}$ is the value of F where Y/R is equal to 10 percent of (Y/R) maximum.
- F_{max} is the point of the curve, Y/R against F, where Y/R is maximum.
- F_{msy} is the value of F which produces the maximum yield in the long term.
- F_{med} is the F value corresponding to the median B/R ratio in the long term B/R relation against F.
- F_{high} is the F value corresponding to the lower B/R ratio (fractile is 10%) in the long term B/R relation against F.
- F_{crash} is the fishing level F which will produce a long term spawning biomass per recruit (S/R) equal to the inverse of the instantaneous rate of variation of R with the biomass.
- $B_{0.1}$ is the spawning biomass value corresponding to the $F_{0.1.}$
- B_{loss} is the smallest spawning biomass observed in the series of annual values of the spawning biomass (Lowest Observed Spawning Stock).
- B_{pa} is between 1.39 B_{loss} and 1.64 B_{loss}.
- F_{pa} is between 0.47 F_{crash} and 0.61 F_{crash}

- The model used are as follows:

$$\text{Yr}=\frac{Y}{R}=\int_0^\infty F_a * W_a e^{-(M+a*F_a)} da$$

$$\text{Sr}=\frac{S}{R}=\int_0^\infty W_a * P_a * e^{-(M+a*F_a)} da$$

$$R=\frac{\alpha * S}{1+S/K} * e^{N(0,\sigma^2)}$$

$$Se = K*(\alpha * Sr - 1)$$

$$\text{Re} = \alpha * Se/(1+Se/K)$$

$$Ye = \text{Re} * Yr$$

F_a is the fishing mortality at age, M is the natural mortality, R is the number of recruits, W_a is the average weight at age, P_a is the maturity rate at age, Yr is yield per recruitment, Sr is biomass per recruitment, and Se, Re and Ye is equilibrium biomass, recruitment and yield.

The input data are the calculated results from biological parameters and above models.

2.2.7 A long term prediction

2.2.7.1 A long term prediction based on the analysis of Y/R and S/R with uncertainty

To obtain the best possible utilisation of the plaice stock, a long term prediction for the catch and biomass is necessary (Stefansson G. 1992). Especially when calculation of yield per recruit, spawning stock per recruit and the relationship between recruitment and spawning stock have been completed, it is possible to calculate the total yield potential of the stock with regard to different effort (fishing mortality). But the effects of variable environmental conditions will bring about differences in recruitment in the future (TemaNord FISHERIES 1997), so here the uncertainty factors are taken into account.

The used model is as follows:

$$R = \frac{\alpha * S}{1 + S/K} * e^{N(0,\sigma^2)}$$
$$Y = (Y/R) * R$$
$$S = K * (\alpha * (S/R) - 1)$$

where $e^{N(0,\sigma^2)}$ is the variability of lognormal with a μ of 0 and variance σ^2.

The input data are the parameters value for growth and recruitment-stock relationship.

2.2.7.2 A long term prediction based on the analysis of surplus production with uncertainty

A similar simulation of uncertainty (CV=0.25) is carried out with surplus production model here. Assuming the catch in the future is respectively 7150 t (corresponding to the mean fishing mortality from 1987-2004), 5700 t (2004). The model used is as follows:

$$B_{t+1} = B_t + \frac{r}{p} B_t (1 - (\frac{B_t}{K})^p) * e^{N(0,\sigma^2)} - Y_t$$

The input data are from the results of surplus production model.

3 RESULTS

Most fisheries models in this report are quite complex, involving many parameters and non-linear relationships between the variables. There are usually no analytical solutions or linearising transformations available for the more difficult models. Numerical methods (Dennis and Schnabel 1983) were used when fitting these multi-parameter, non-linear models to data and R (R Development Core Team 2005) was also used for all of the calculations and the plots here.

3.1 Biological parameters

Maximum likelihood method was used to estimate parameters of the von Bertalanffy growth equation (Figure 2). The trawl survey data were used because the trawl survey uses small mesh sizes compared to the Danish seine fleet, and should adequately sample younger age classes. The maximum likelihood method also was used to estimate parameters of the length-weight relationship (Figure 3). Here, the landing data from 1994-2005 (MRI Databases) was used.

The mean weight at age as calculated using the mean length at age from the von Bertalanffy equation and the length weight relationship above. The results are shown in Table 11.

The parameters of the maturity ogive, a and p_{50}, are determined by the least squares method fitting estimated-to-observed maturity they are -0.878 and 4.341 respectively (Figure 4).

3.2 Estimation of mean catch in number by age by year from length distribution data

The length distributions are highly mixed, the modes in the distribution are far fewer than the number of ages and the overlap between ages is large. Because of that, some difficulties came up in the fitting process resulting in unreasonable values of the mean lengths or standard deviations, although the total squared errors were relatively low.

Therefore, in some cases the mean length at some ages had to be fixed equal to a more reasonable value from the von Berlalanffy equation. Here we fixed all mean lengths and standard deviations. Some initial values are given as proportions per age class and through iteration values that gave better fit were found (Table 12, Figure 5).

3.3 Age-based ADAPT model

The estimates of F**,** recruitment, and stock size are presented in Table 14 and Figure 7. The model estimates the stock size in 1987 at about 50,000 t. Then it declines continuously until in 2000, it is at the lowest level at about 15,000 t. However, it increases after that to about 25,000 t in 2005. This trend shows a good fit to the IGFS data. The average annual recruitment is about 29 million juveniles per year. With a few exceptions, this has however declined during this period, reaching the lowest point in 2005. The uncertainty about recruitment estimates is however highest for the most recent years with the VPA method. The recruitment estimates give a reasonably good fit to the recruitment indices from the survey. The estimated fishing mortality is about 0.33 in 1987. It increases after that continuously until in 1997, it is at the highest level at about 0.781, and then starts to decline to about 0.21 in 2004. The mean value of F is about 0.5 from 1987 to 2004. The parameters of the R-S relationship are K= 18,797 t, α = 0.00238 (R=0.00238*SSB/(1+SSB/18797)). But it did not give a very good fit to the CPUE .

3.4 Length-based ADAPT model

The age-disaggregated catches in number by year (Table 12) converted from length distributions from landings were used for the cohort analysis, the biomass and recruitment indices from survey and CPUE from landing for the tuning process (Tables 3, 4, 5). The same procedures were used for the projection. The $\overline{F}_{6-12}$ in the last year is estimated as 0.161, and parameters of the R-S relationship are K= 19,863 t, α = 0.00225 (R=0.00225*SSB/(1+SSB/19863)). The estimates of F, recruitment, parameters of the R-S relationship and stock size are presented in Table 14 and Figure 8.

3.5 Age-disaggregated dynamic production model

The natural mortality was set at M=0.15 as in the previous methods. The Beverton and Holt stock-recruitment relationship (Beverton 1957) was used to project the recruitment of the stock for each year. The selection pattern was taken from the selection pattern used in the age-based ADAPT model. The mean weight at age and maturity at age as in the previous methods (2.12) were used to calculate the exploitable and spawning biomass and predicted yield. Catch in number by age by year of plaice in Icelandic waters 1987-2004 (Table 2), various total abundance indices such as IGFS biomass indices 1987-2004, Danish seine fleet CPUE and recruitment indices (age 2) from IGFS survey (Tables 3, 4, 5) were used to fit the model. The log scale of errors as used to fit recruitment, CPUE indices and IGFS survey biomass indices in order to attain the best fit of the estimated-to-observed. It should be noted that when log-scale is used, the coefficient of variation (CV) of the data can be estimated as:

$$CV = \sqrt{\frac{SSE}{n}}$$

where n is number of data points. The results show in Table 15.

The production model fits very well with the series of observed catch in number by age by year, IGFS biomass indices. However, the model does not give a good fit with either of the recruitment indices because of the short time series and high variance in the indices, or Danish seine CPUE indices because of short time series (1991-2004) (Figures 9, 10).

The parameters of the Beverton-Holt stock recruitment relationship were estimated as K = 20416 t, α = 0.0027 (R=0.0027*SSB/(1+SSB/20416)). The value of $\overline{F}_{6-12}$ in the last year is estimated as 0.253. The estimates of F, recruitment, parameters of the R-S relationship and stock size are presented in Table 14.

3.6 A short term yield and biomass prediction

Population numbers for the catch forecast were taken from the age-based model, the length-based ADAPT and the production models output and recruitment from the mean value during the period 2002-2004. Fishing mortalities were also the mean F at age in 2004. Although F has shown a general decreasing trend over the last six years (1999-2004), this trend does not appear to have been continued into 2004 for the age-disaggregated dynamic production model and the last year value of F would be used for the prediction. The predicted landings and SSB in 2005-2007 are given in Table 16. The short term predictions show the same declining trend in catch and biomass as age-based ADAPT and the length-based ADAPT models because of under estimates for the recruitment in the last two years, while the slightly increasing trend in catch and biomass is from the production models, and the estimated catch and biomass will increase to around 5,600 t and 26, 000t by 2007.

3.7 Surplus production model

The parameters K, r, MSY and F_{MSY} were estimated from the catch by year, biomass index from survey and CPUE, by finding the best fit to the observed data. The model fits very well with the series of observed IGFS biomass. However, the model does not give a good fit with the Danish seine CPUE indices, the predicted results are given in Table 18 and Figures 11-13. The present biomass is estimated at between 21,675 and 19,244 t depending on the p value used (Table 18), other parameters like K, r, MSY, F_{msy} and B_{msy} respectively are 95,018-78,883 t, 0.256-0.477, 8,933-9,410 t, 0.256-0.239 and 34,955-39,442 t. The analysis of the surplus production model demonstrates that the exploitable stock has been declining from around 90,000 t of unfished biomass in 1905 to the current level of around 20,000 t (Figure 13), because the catch was always more than the surplus production during the periods 1946-1971 and 1983-1999 after 2000 the catch has been maintained about 5,000 t, and the stock has increased slightly to around 21,000 t, this is consistent with the survey data.

3.8 Biological reference points

All the estimated biological reference point values are given in Table 17 and Figures 14-20. F_{pa}, B_{pa} were considered according to FAO's recommendation (Emygdio 2003). The rate of fishing mortality that produces "maximum sustainable yield" from Y/R , F_{max} was about 0.39. But fishing at Fmax reduced spawning stock biomass and the spawning potential ratio (the proportion of the virgin spawning biomass available) to about 29,502 t and 25% respectively. At F 0.1 SSB and SSB/B0 was 66,530 t and 55% (mean SSB/B0) respectively. Remarkably, the current estimated rate of fishing mortality of $\overline{F}$ =0.5 for the mean F from 1987-2004 has reduced the SSB, SSB/B0 and recruitment to 21,276 t, less than 18% of SSB/B0 and almost half the maximum recruitment (28 millions) (Figures 15-18). In Figures 19-20, the most recent fishing mortality (1997-2004) is well below the Fpa, this could partly explain the increasing SSB in recent years, but the SSB is below the Bpa from 1997 to 2002, and the current SSB is still at a low level near the Bpa.

The results are shown in Table 17. B0 is virgin stock, and the estimate values for B0 from the surplus production and the R-S relationship of the B-H model are around 90,000 t (p=0.00001) and 180,185 t respectively.

3.9 Long term prediction

3.9.1 Long term prediction based on the analysis of YPR and SPR with uncertainty

The stock and recruitment data for the time series are shown in Figure 9. Here the affects of variable environmental conditions will be taken into account as a variance around the mean (CV=0.25). The typical results from one simulation (section 2.2.7.1) then correspond to the effects of certain environmental conditions on the stock and the catch. One simulation thus provides examples of possible developments of stock and catch for a few years into the future. Other simulations correspond to other possibilities for assumptions or environmental conditions. About 100 simulations of a catch and biomass should give a survey of what kind of development is likely and what is unlikely to happen. Here the annual catch used was 7,150 t (corresponding to 0.5 of fishing mortality), 5,700 t (2004) and 4,000 t respectively (MRI recommendation) and then simulated 100 times. The predicted results are given in Table 19 and Figures 21-26. Here the figures display various lines. The narrow lines correspond to a few simulation curves. If all the curves are plotted, the overall picture becomes somewhat unclear. It is, however, possible to plot a line in such a way that for each year one half of the curves is above it and the other half below. This line is represented by the broad. The figures also show 5% and 95% fractiles, i.e. those curves that are of such a nature that there is a 5% or 95% probability of being above or below them. The broad curve closest to the bottom of the figures thus shows that the probability of stock collapse is less than 5% since the probability for the spawning stock at each particular time to stay above the lowest curve, which in fact rises with time, is 95%.

The estimates show that the predicted biomass will maintain a stable low level of around 22,000 t until 2020 with 95% chances of staying between 21,389 t and 27,213 t and 5% between 21,389 t and 18,861 t. The predicted catch also maintains a stable level of 7,200 t with 95% chances of staying between 7,150 t and 9,155 t and 5% between 7,150 t and 6,207 t, if fishing mortality is 0.5 for each year (mean value from 1987-2004) (Figure 22). For a fishing mortality of 0.38, the predicted biomass will increase from 21,389 t to 31,313 t with a 95% probability of changing between 21,389 t and 36,284 t and 5% probability of changing from 21,389 t to 25,786 t. The predicted catch will increase from 5,675 t to 8,537 t with 95% probability of changing from 5,675 t to 9,824 t and 5% probability of changing from 5,675 t to 7,019 t (Figure 24). Predicted biomass will increase from 21,389 t to 45,450 t with a 95% likelihood of changing from 21,389 t to 54,633 t and a 5% likelihood of changing from 21,389 t to 39,643 t. However, the predicted catch at fishing mortality of 0.26 will increase from 4,059 t to 9,026 t with a 95% likelihood of changing from 4,059 t to 10,895 t and a 5% likelihood of changing from 4,059 t to 7,845 t (Figure 26).

3.9.2 Long term prediction based on the analysis of surplus production with uncertainty

Given annual catch of 5,700 t (2004) and 7,150 t (the mean fishing mortality from 1987 to 2004 is 0.5) and then simulated 100 times. The predicted results are given in Table 20 and Figures 27-32. The predictions from the surplus production model also show that the predicted biomass will increase to 61,443 t in 2018 from 23,959 t in 2005 with 95% chances of staying between 27,962 t and 68,833 t and 5% between 21,568 t and 53,179 t (Figure 28), the predicted equilibrium yield will decrease from 8,435 t to 6,846 t with 95% probability of changing from 8,741 t to 7,869 t and 5% probability of changing from 8,173 t to 5,661 t (Figure 29), if catch for each year is 5,700 t. At the same time, if catch for each year is 7,150 t then the predicted biomass will increase from 23,135 t to 48,234 t with 95% chances of staying between 27,626 t and 57,406 t and 5% between 20,207 t and 33,984 t (Figure 31). The predicted equilibrium yield will decrease from 8,376 t to 8,505 t with 95% probability of changing from 8,721 t to 8,919 t and 5% probability of changing from 7,994 t to 7,387 t (Figure 32).

3.10 Comparison of results from models

3.10.1 Fishing mortality

The overall pattern in fishing mortality rates (F_{6-12}) as estimated by the three different models show a similar trend (Figure 33). Fishing mortality is relatively low at the beginning of the target fishery in 1987 and then increases until 1999. After 1999, fishing mortality decreases again to a minimum in 2004. The length-based ADAPT model gives somewhat lower Fs at the beginning of the period (1987-1998) and the production model suggests higher Fs in the period. The estimates from the age-based ADAPT model indicates an increase in value of Fs in the first three years and then the Fs decrease again until 1999. All three models give similar estimates for F in the last years, or from 0.16 to 0.25 (for 6-12 years old).

3.10.2 Stock size

The age-based model, the production model, the length-based ADAPT model and surplus production model give almost the same trend for stock biomass in the period 1987-2004 (Figure 34). In recent years, the biomass seems to be slowly increasing. The stock is estimated to be around 50,000 t in 1987 and in the range of 22,000-31,000 t in 2004. The production model gives the lowest value, the age-based ADAPT and surplus production models give similar values. The length-based ADAPT model gives lower estimate of the stock biomass (around 41,364 t) in the beginning but higher (31,497 t) in the last year. This reflects the relatively low F values estimated from this model.

3.10.3 Recruitment

The estimates of recruitment (age 2) from the three methods are shown in Figure 35. The trend in the recruitment pattern is similar except for the last two years. While the results from length-based ADAPT and age-based ADAPT models show a similar trend of a sharp decrease in the last two years. The lower values from the age-based ADAPT and length-based ADAPT models in the last two years compared to the production model results reflect the good fit in recruitment indices from the survey in the final year. The production model gives a smooth recruitment pattern with a declining trend over the period.

3.10.4 Yield and biomass prediction

3.10.4.1 Short term yield and biomass prediction

The results of yield and biomass predictions for the years 2005-2007 from the three models given, after refitting the three models with different assumptions of fishing mortality rates of F=0.211, 0.161 and 0.253 are presented in Table 16.

The results from the age-based model and length-based model are very similar for the yield (5,400-4,800 t) and have a gradual decrease because of the lower estimate for recruitment in the last two years, and the biomass prediction from the length-based model is very high (38,000-35,000 t), but the results of the production model are stable (yield: 5,400-5,600 t, biomass: 26,000 t) and have a slight increase because of its optimistic stock assessment in the last year.

3.10.4.2 Long term yield and biomass prediction

Two models for the long term prediction give a similar trend while the prediction values are not the same. For the model based on the analysis of Y/R and S/R, given fishing mortality respectively being 0.5 (mean F from 1987-2004), 0.38 (catch=5,700 t for 2005) and 0.26 (catch = 4,000 t for 2005 from MRI recommendation). The predictions of yield and biomass respectively are around 7,200 t and 22,000 t, 6,000-85,000 t and 21,000-31,000 t, 4,000-9,000 t and 21,000-45,000 t (Table 19, Figures 21-26). The model based on the analysis of surplus production gives bigger values for the equilibrium yield and biomass 8,500 t and 23,000-48,000 t for the catch 7,150 t, 8,500-7,000 t and 24,000-60,000 t for the catch 5,700 t (Table 20, Figures 27-32), because in the condition of same biomass, the surplus production model will give bigger equilibrium yields.

4 DISCUSSION AND FUTURE WORK

All models, as well as the survey index and CPUE from fishing fleets, indicate that the plaice stock biomass is at a low level close to Bpa, though current biomass is increasing slowly. Taking these estimates into account, if catch is carried out according to Table 19, the long term yield and biomass are probably at a level of around 9,000 t/y and 40,000 t. It has to be considered however that the assessment for this stock can overestimate SSB and under-estimate fishing mortality because discard estimates are not included in the assessment.

The age-based ADAPT method gave lower recruitment like the length-based method in the last two years. The most likely explanation is that recruitment indices are declining rapidly in recent years from the survey (Table 5, 21-25 cm). The uncertainty in recruitment estimates is however high for at least two reasons: firstly because uncertainty about the recruitment for the last years is inherited in the VPA method and secondly is because the recruitment indices from the survey can be inaccurate since they are based on length frequency data.

The length-based method gave the most optimistic estimate of stock size and recruitment in the last two years is also low like in the age-based ADAPT model. This is probably because it was based on rather uncertain catch in number at age. The large number of age groups and slow growth of plaice gives serious problems when disaggregating the length distributions. Future work should emphasise parameter reduction techniques such as fixing all mean lengths at age across years or incorporating the length distributions directly as data into the age-disaggregated production model.

The production model gave a very good fit for the catch in number by age by year and biomass indices from survey. It could account for the recent recruitment events, which are reflected in the results of the other models, such as the surplus production model. In the future, one can expand the fitting process of the age-disaggregated production model by using weights on index series and trying to do the bootstrap to test different error scales (log-transform or normal) and confidence intervals.

The predicted yield for the years 2005-2007 is consistent between the three models (4,800-5,600 t), but the length-based ADAPT model gives higher estimates of stock size.

The surplus production model demonstrates that stock size of plaice changed and why stock size had been decreasing rapidly from 1905-2004, but the data for model fit are only from 1987-2004. This may produce errors to the estimation of K and α for the model.

The estimates for biological reference points are based on the von Bertalanffy equation, length-weight relationship, maturity proportion, natural mortality, selection pattern and R-S relationship, the errors for each part estimated above may lead to errors in biological reference points. At same time, the MSY is similar to the surplus production model, according to the analysis of biological reference points, in the long run, these reference points are important for plaice fisheries management.

One hundred simulations of two models for long term prediction with uncertainty (CV=25%) gave approximately the same results of yield, but gave different values of biomass prediction with an optimistic estimate for the surplus production model. The two models predict that the current very low biomass will increase to 30,000 t in five years for the prediction based on the analysis of Y/R and S/R and 36,000 t for the prediction based on the surplus production model. If catches are kept at a constant level of 4,000 t/y and 5,700 t/y for the surplus production model, or the fishing mortality constant at 0.26 and 0.38 for the surplus production model, then the stock size will increase to 41,000 t and 55,000 t respectively by 2015.. At the same time, the sustainable yield will increase to about 8,000 – 9,000 t and 7,000 – 8,500 t. The current very low biomass will be maintained by 2020 for the model based on analysis of Y/R and S/R if the fishing mortality is kept at a constant level of mean fishing mortality in 1987 – 2004, or F = 0.5.

The plaice is mostly fished in the North Sea and close by waters. The stocks are in various shapes, some such as in the Irish Sea are increasing and in good health (mostly based on catch at age models www.ices.dk). The North Sea stock itself is however at a current low level, or below Bpa.

China, like Iceland, is endowed with substantial fish stocks in both its inshore and offshore waters. The stock sizes have not yet been sufficiently studied. The plaice which is fished in Icelandic waters differs in many respects from the fishes of China, but some of the methods and skills used to develop this project may be applicable to Chinese conditions. At the same time, these methods and skills must benefit the marine fisheries education of China in the future.

5 CONCLUSION

- Fishing mortality has declined to historical lows since 1987. The fishing mortality estimated in 2004 of 0.25 is however well below the Fpa of 0.6 (Figure 20). It is interesting to note that our Fpa is the same value as for North Sea plaice (www.ices.dk).

- Recruitment between 1987 and 2004 was variable and included few high values. Since 2000, recruitment has been less than average (30 millions) (Table 14).

- The SSB estimated in 2004 of around 22,000 t is above the B_{pa} of around 15,000 t. SSB was relatively low in the 1990s, while SSB has a slightly increasing trend if the fishing mortality maintains the current levels for the future (Figure 20).

- The estimates from the two long term predictions show that the probability of the SSB falling below B_{pa} remains very small, even if fishing mortality is 0.5 (Figures 21-32).

- The predictions from the reference points model show that current F (0.25) is close to the value (0.2) giving maximum yield (Figures 16-18).

- For the increasing SSB to around 40,000 t as quickly as possible, fishing mortality from 2005-2014 should be maintained below 0.26 (Figure 26).

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APPENDIX: TABLES AND FIGURES

Table 1 : Nominal catch in tons from Icelandic waters (MRI Databases)

Year	Iceland fisheries	Foreign boats	Total(T)	Year	Iceland fisheries	Foreign boats	Total(T)
1905		388	388	**1955**	259	7474	7733
1906		9836	9836	**1956**	515	7373	7888
1907		9075	9075	**1957**	1622	7981	9603
1908		6747	6747	**1958**	648	7515	8163
1909		5523	5523	**1959**	921	7507	8428
1910		4933	4933	**1960**	3405	4654	8059
1911		5552	5552	**1961**	4226	6775	11001
1912		6733	6733	**1962**	5010	6401	11411
1913	387	5178	5565	**1963**	3325	6333	9658
1914	175	4030	4205	**1964**	5336	4032	9368
1915	109	2397	2506	**1965**	7286	3704	10990
1916	178	125	303	**1966**	7354	4521	11875
1917	5	36	41	**1967**	5644	5736	11380
1918	202	0	202	**1968**	6144	4126	10270
1919	473	6330	6803	**1969**	10764	3267	14031
1920	912	9456	10368	**1970**	8117	1901	10018
1921	527	5487	6014	**1971**	7179	2509	9688
1922	864	5008	5872	**1972**	5129	1367	6496
1923		5601	5601	**1973**	4137	641	4778
1924		5244	5244	**1974**	3936	85	4021
1925		5920	5920	**1975**	4399	176	4575
1926	670	5856	6526	**1976**	4993	32	5025
1927	688	7193	7881	**1977**	5267	3	5270
1928	601	5792	6393	**1978**	4499	5	4504
1929	687	5876	6563	**1979**	4491	1	4492
1930	1139	7139	8278	**1980**	5145	0	5145
1931	1650	6847	8497	**1981**	3840	35	3875
1932	932	5466	6398	**1982**	6303	28	6331
1933	413	4229	4642	**1983**	8552	0	8552
1934	597	4073	4670	**1984**	11334	1	11335
1935	796	4541	5337	**1985**	14508	2	14510
1936	1172	3977	5149	**1986**	12738	0	12738
1937	1565	4002	5567	**1987**	11192	0	11192
1938	1077	3073	4150	**1988**	14078	9	14087
1939	1575	423	1998	**1989**	11330	0	11330
1940	3619	28	3647	**1990**	11400	0	11400
1941	2742	57	2799	**1991**	10792	0	10792
1942	5949	74	6023	**1992**	10494	0	10494
1943	3399	59	3458	**1993**	12522	0	12522
1944	3167	60	3227	**1994**	11854	0	11854
1945	3193	97	3290	**1995**	10649	0	10649
1946	2638	1728	4366	**1996**	11063	0	11063
1947	3363	3874	7237	**1997**	10540	0	10540

1948	4730	4580	9310	**1998**	7106	0	7106
1949	5334	5238	10572	**1999**	7064	0	7064
1950	3834	5338	9172	**2000**	5218	0	5218
1951	4183	4256	8439	**2001**	4905	0	4905
1952	1457	3121	4578	**2002**	5126	0	5126
1953	350	4343	4693	**2003**	5236	0	5236
1954	289	5374	5663	**2004**	5704	0	5704

Table 2: Catch in number(million) by age by year.

Age/Year	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
1																		
2	0,040	0,000	0,000	0,000	0,000	0,045	0,105	0,000	0,093	0,034	0,130	0,101	0,030	0,015	0,013	0,010	0,000	0,002
3	0,780	0,000	0,054	0,204	0,076	0,210	1,469	1,278	1,062	0,436	0,276	1,015	0,108	0,213	0,484	0,088	0,085	0,070
4	2,352	2,479	0,431	1,386	1,614	1,686	4,494	5,781	2,651	2,093	1,396	1,175	1,178	0,340	1,362	1,141	0,739	0,613
5	2,476	6,707	3,745	5,093	7,705	3,838	5,838	6,680	7,869	2,720	3,172	3,133	2,116	1,161	1,133	1,797	1,968	1,724
6	3,456	4,250	4,422	4,202	3,543	4,628	4,140	3,536	4,840	6,790	1,916	2,828	2,816	1,454	1,756	1,204	2,094	2,758
7	2,481	2,635	3,179	4,422	3,556	4,028	3,854	3,503	1,836	3,564	4,122	1,537	2,147	1,668	1,306	1,352	1,206	1,785
8	2,965	4,901	1,317	1,328	2,883	2,429	1,859	1,322	1,306	1,545	2,139	1,748	1,146	1,267	0,981	0,960	0,895	1,012
9	1,490	2,024	1,947	0,894	1,056	1,676	1,093	0,871	0,397	0,736	0,889	0,886	1,300	0,747	0,637	0,671	0,562	0,457
10	1,592	0,390	1,477	1,734	0,601	0,460	0,645	0,358	0,151	0,277	0,438	0,183	0,402	0,567	0,272	0,414	0,341	0,332
11	0,332	0,596	0,550	0,283	0,242	0,171	0,184	0,299	0,138	0,219	0,191	0,106	0,126	0,296	0,129	0,203	0,229	0,090
12	0,309	0,100	1,112	0,168	0,114	0,100	0,089	0,025	0,066	0,149	0,188	0,043	0,067	0,093	0,110	0,130	0,104	0,065
13	0,000	0,000	0,000	0,000	0,000	0,059	0,053	0,182	0,070	0,114	0,183	0,040	0,043	0,019	0,012	0,034	0,048	0,008
14	0,000	0,000	0,000	0,000	0,000	0,039	0,046	0,282	0,016	0,035	0,129	0,010	0,013	0,018	0,003	0,000	0,014	0,000
15	0,000	0,000	0,000	0,000	0,000	0,025	0,050	0,010	0,032	0,012	0,068	0,010	0,008	0,012	0,000	0,006	0,003	0,000
16	0,000	0,000	0,000	0,000	0,000	0,039	0,021	0,062	0,012	0,013	0,079	0,000	0,005	0,005	0,000	0,000	0,007	0,000
17	0,000	0,000	0,000	0,000	0,000	0,036	0,017	0,059	0,034	0,003	0,045	0,000	0,000	0,003	0,000	0,000	0,000	0,000
18	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,109	0,010	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
19	0,000	0,000	0,000	0,000	0,000	0,003	0,003	0,000	0,140	0,008	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
20	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,004	0,000	0,000	0,010	0,000	0,000	0,000	0,000	0,000	0,000
Total						19,472	23,960	24,357	20,727	18,748	15,361	12,825	11,505	7,878	8,198	8,010	8,295	8,916

Table 3: CPUE indices based on Icelandic Danish seine fleets log-books 1991-2004.

Year	Set	Catch	Cpue(KG)
1991	12474	4514995	362
1992	12177	3802167	312,2
1993	20757	6537155	314,9
1994	27303	7871534	288,3
1995	25912	7259550	280,2
1996	22117	6208011	280,7
1997	22004	5556533	252,5
1998	15669	3951730	252,2
1999	12572	3104897	247
2000	12765	2909545	227,9
2001	10995	2678408	243,6
2002	11085	2954308	266,5

2003	13893	3002846	216,1
2004	14927	3631509	243,3

Table 4: Total biomass indices of plaice in tons based on data from the IGFS.

Year	Total(T)	cv	40 cm +	cv	35 cm +	cv	30 cm +	cv	25 cm +	cv
1985	44844,8	0,208	20556,4	0,265	35309,4	0,235	43371,6	0,213	44796,8	0,208
1986	25269,5	0,167	12286,6	0,172	20946,1	0,181	23812,9	0,173	24078,8	0,172
1987	18673,2	0,194	9752,5	0,224	15978,2	0,213	18164,8	0,199	18609,4	0,194
1988	21475,3	0,208	10044,5	0,241	17252,7	0,23	20521,7	0,218	21394,7	0,209
1989	11430	0,152	5457	0,191	8850,6	0,156	10826,6	0,147	11378,4	0,152
1990	11565,5	0,138	4742,3	0,179	8608,2	0,141	11196,3	0,14	11541,3	0,139
1991	13986,1	0,187	5960,5	0,237	10578,2	0,193	13254,6	0,185	13947,8	0,188
1992	12791,6	0,277	4072,3	0,221	8693,1	0,231	11858,3	0,267	12734,3	0,279
1993	11067,1	0,136	4644,2	0,196	8333,2	0,156	10468,8	0,14	10996,5	0,136
1994	8758,3	0,152	3084,1	0,175	5858,8	0,161	7800,2	0,152	8582,5	0,152
1995	5872,7	0,214	1836,6	0,226	3701,9	0,181	5176,2	0,174	5830,3	0,212
1996	6389	0,226	2242,4	0,198	3977,1	0,162	5698,6	0,185	6350,3	0,226
1997	4439,4	0,166	2017,2	0,231	3528,4	0,195	4220,2	0,175	4413,7	0,168
1998	4509,1	0,163	1899,1	0,17	3408,8	0,159	4189,3	0,168	4479,6	0,164
1999	5984,6	0,176	2894,6	0,154	4522,9	0,169	5631,7	0,18	5930,1	0,177
2000	3789,2	0,172	2188,1	0,217	3381,4	0,184	3736,9	0,174	3785,2	0,172
2001	3688,6	0,235	1985,4	0,204	3154,5	0,241	3595,3	0,239	3682,9	0,235
2002	5223,8	0,176	2483,7	0,215	4301,3	0,174	5028	0,178	5208,4	0,176
2003	6287,9	0,239	2684,8	0,225	4810,6	0,214	6026,3	0,236	6270,4	0,239
2004	9964	0,266	4923,9	0,264	7758,5	0,224	9675,0	0,258	9960,5	0,266
2005	7606,7	0,172	4506,6	0,222	6854,8	0,183	7537,7	0,174	7600,6	0,173

Table 5: Recruitment indices of plaice in number(million) based on the IGFS.

Year	46-50cm	41-45 cm	36-40 cm	31-35 cm	26-30 cm	**21-25 cm**	<= 20 cm
1985	2,7705	11,9879	22,433	20,9567	7,9294	**0,7567**	0,0625
1986	1,9305	6,5721	13,6117	8,5527	1,4303	**0,1458**	0,0516
1987	1,8166	4,5533	9,3699	6,6042	1,9769	**0,6863**	0,1549
1988	2,1465	4,7545	11,178	8,3837	4,4756	**0,8021**	0,0705
1989	1,1212	2,7134	5,2143	5,0991	2,7889	**0,4004**	0,1173
1990	0,9172	2,433	5,5961	6,6742	2,0555	**0,2139**	0,0688
1991	1,0672	3,0022	7,0324	6,6933	3,5841	**0,4221**	0,0637
1992	0,745	2,1095	6,5623	8,1265	4,3134	**0,7102**	0,2025
1993	0,8051	2,2765	5,2693	5,732	2,5368	**0,8556**	0,0638
1994	0,5079	1,6461	4,0373	4,8626	3,428	**1,7838**	0,0851
1995	0,2696	0,9196	2,7723	3,514	3,0722	**0,4882**	0,0746
1996	0,3804	1,2191	2,7262	3,8499	3,2537	**0,4956**	0,0374
1997	0,4025	1,0406	2,296	1,8746	0,9103	**0,2244**	0,1012
1998	0,274	1,1554	2,4051	1,9993	1,37	**0,2794**	0,0053
1999	0,4991	1,6338	2,5934	2,809	1,5303	**0,5576**	0,0136
2000	0,487	1,1096	1,8755	1,0686	0,253	**0,0346**	0,0163
2001	0,3582	1,089	1,8991	1,1907	0,5197	**0,053**	0,0197
2002	0,3975	1,4909	2,7003	2,1083	0,849	**0,2057**	0,0022
2003	0,4918	1,5556	3,1157	3,2754	1,2823	**0,1733**	0,0307
2004	0,8171	2,7794	4,5658	4,517	1,8642	**0,0951**	0,0118

2005	0,8448	2,5962	3,6839	2,0296	0,3899	**0,0646**	0

Table 6: Mean length at age(cm)calculated from trawl survey (1987,1990,1991)

Age	Mean length
2	19.5
3	24.11
4	29.4
5	32.17
6	35.84
7	39.19
8	40.72
9	42.5
10	45.37
11	46.62
12	48.47
13	46.57
14	50
15	51.8
16	55.5

Table 7: Mean weight at age in landings(g), sexes combined, from ageing data (MRI Database).

Age/Year	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
2	264	264	264	264	264	301	317	317	277	289	279	248	257	231	196	207		186
3	356	356	356	356	356	360	354	322	342	355	378	333	384	284	296	334	307	292
4	332	373	400	287	305	390	390	389	401	428	458	371	436	357	418	396	391	385
5	449	427	454	418	388	456	466	439	448	510	525	473	461	477	499	509	481	508
6	540	552	535	533	479	491	555	495	504	558	616	540	564	578	597	592	585	603
7	658	553	553	547	564	569	588	518	680	618	685	635	629	688	664	654	681	683
8	730	902	683	644	614	579	640	641	772	736	779	722	701	765	734	784	754	785
9	769	667	761	805	665	670	706	742	925	871	938	748	822	772	789	866	827	833
10	910	689	926	949	832	891	735	792	840	958	1078	884	954	867	873	943	921	996
11	1085	677	706	808	1006	930	825	911	1031	1030	1119	965	1114	951	994	1041	1093	1072
12	1190	547	982	1105	1448	1110	1179	589	904	1113	1168	1139	1172	1086	1107	1236	1240	1189
13	1068	1068	1068	1068	1068	954	1034	836	1084	926	1268	996	1300	1210	1320	1232	1541	1187
14	1206	1206	1206	1206	1206	1077	1255	835	1198	1043	1370	1317	1368	1391	1026	1026	1734	1026
15	1295	1295	1295	1295	1295	1091	1281	1408	1353	1483	1360	1297	941	1443	1295	1385	2445	1295
16	1219	1219	1219	1219	1219	1320	1222	635	1310	1371	1456	1219	1983	1383	1219	1484	1825	1655
17	1380	1380	1380	1380	1380	1334	1442	900	1606	1477	1523	1380	1380	1127	1380	1380	1380	1380
18	1069	1069	1069	1069	1069	1069	1069	1266	872	1069	1069	1069	1069	1069	1069	1069	1069	1069
19	1334	1334	1334	1334	1334	1334	1334	1332	1186	1477	1332	1820	1454	1454	1454	1454	1454	1454
20	1148	1148	1148	1148	1148	1148	1148	1148	1148	1148	1148	1148	1148	1148	1148	1148	1148	1148

Table 8: Length frequency samples from commercial landings 1987-2004 (MRI Databases).

length	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
18												1							
19										1		1							1
20													1				1		
21										1		1	1						1
22															1	1			3
23										4		1	5			2	1	2	4
24										5	5	1	29	4	7	5	2	7	12
25							1		2	13	4	8	59	6	8	16	9	11	18
26							1	1	1	37	14	20	135	20	29	33	27	20	26
27			1		1	8	3	10	12	90	39	63	222	55	49	82	42	40	65
28	1				8	25	17	26	22	173	68	127	296	85	104	100	73	64	114
29	3		3		14	53	24	54	34	323	87	212	382	126	163	153	132	149	198
30	8	3	4	3	43	104	58	100	70	513	137	198	433	152	227	197	204	274	318
31	7		11	20	63	185	94	213	107	667	220	290	446	183	247	259	370	413	485
32	7	5	12	44	101	279	101	304	167	907	244	322	522	232	290	350	530	632	602
33	10	3	13	65	149	338	154	388	259	1126	345	417	471	226	299	468	665	827	926
34	10	6	26	98	121	349	180	366	239	1078	434	565	475	340	371	570	936	1136	1232
35	10	11	27	90	127	324	171	339	229	1024	494	736	523	378	483	624	1115	1381	1504
36	9	8	18	95	106	274	130	239	177	790	526	861	527	461	541	684	1245	1680	1939
37	7	12	15	101	84	234	135	231	134	634	485	923	627	457	662	690	1244	1673	2201
38	7	5	15	71	47	169	107	215	89	491	449	853	609	510	833	617	1142	1735	2241
39	7	9	24	70	54	129	96	188	60	347	424	745	602	523	912	571	1132	1597	2275
40	5	9	10	56	38	80	74	168	57	248	358	656	586	512	1005	528	997	1406	2038
41	5	4	4	47	32	57	53	112	44	234	335	551	509	448	954	490	867	1118	1800
42	4	4	6	36	41	40	65	102	39	202	277	492	419	440	884	440	749	967	1556
43	2	5	2	29	31	31	32	86	29	149	215	399	381	363	763	366	664	841	1266
44		1	3	20	19	22	46	70	17	167	162	324	303	298	684	333	564	686	1076
45	2	5		13	15	15	28	76	18	116	147	258	248	271	582	279	474	541	791
46			1	11	13	15	26	52	22	91	105	194	186	202	551	248	434	456	675
47	2	2		10	12	17	15	43	12	80	75	173	168	163	450	225	347	400	618
48		1		7	5	3	16	25	7	50	65	152	102	135	357	181	283	297	431
49		2		7	8	8	17	26	8	40	36	105	80	88	271	145	228	226	359
50		1	1	3	3		11	21	6	32	23	89	50	69	177	99	182	181	238
51		1		1	1	2	8	15	3	13	22	53	37	37	161	76	143	141	193
52			1	4	1	1	5	10	5	16	11	41	27	38	82	61	121	109	187
53					3	2	6	5	2	8	12	17	28	23	57	33	84	72	111
54		1		2	1		5	3	1	6	3	15	12	15	44	19	54	71	94
55				1			2	2	2	4	1	15	5	10	29	16	36	46	53
56		1			1	1		1	2	5	3	10	2	4	15	11	23	29	45
57		1		1	1	1		2		3	2	11	5	6	10	12	14	13	30
58				1		1				2	1	7	2	3	6	2	10	21	19
59								1	1	3	1	1	1	1	8		6	10	13
60							1	1	1		1	2	1		5		3	11	9
61								1		1	2		1	1		2	3	14	6
62												1	1		1			4	8

63	2	1	2			5	3
64			1	1	2	7	2
65			1			7	2
66			2			5	2
67						2	1
68	1		1			1	3
69						2	
70							
71	1					1	
72					1		
73							
74					1		

Table 9: Maturity rates from IGFS in 2002-2004.

Year	Age	Percent by mature														
2002	2-16	0	0.19	0.46	0.56	0.78	0.93	0.96	0.98	0.97	1	1	1	1	1	1
2003	3-16		0.15	0.54	0.70	0.84	0.94	0.93	0.97	0.97	1	1	1	1	1	1
2004	2-13	0	0.27	0.39	0.61	0.83	0.88	0.97	0.97	0.97	0.97	0.86	1			

Table 10: Calculated total number (million) at length from length distribution and catch.

Length(cm)	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
18	0	0	0	0	0	0	0	0	0	0	0.002	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0.002	0	0.002	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0.001	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0.002	0	0.002	0.001	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0.001	0.001	0	0	0.001
23	0	0	0	0	0	0	0	0	0.009	0	0.002	0.006	0	0	0.002	0	0.001	0.001
24	0	0	0	0	0	0	0	0	0.011	0.016	0.002	0.037	0.006	0.004	0.004	0.001	0.003	0.004
25	0	0	0	0	0	0.011	0	0.025	0.029	0.012	0.013	0.075	0.009	0.004	0.013	0.004	0.004	0.006
26	0	0	0	0	0	0.011	0.006	0.012	0.081	0.044	0.033	0.171	0.03	0.016	0.027	0.013	0.008	0.008
27	0	0.135	0	0.019	0.064	0.033	0.064	0.149	0.198	0.122	0.104	0.281	0.082	0.027	0.067	0.021	0.016	0.02
28	0	0	0	0.149	0.2	0.185	0.166	0.273	0.38	0.212	0.21	0.375	0.127	0.058	0.082	0.036	0.025	0.036
29	0	0.406	0	0.261	0.423	0.261	0.345	0.422	0.709	0.272	0.35	0.484	0.189	0.09	0.125	0.065	0.059	0.062
30	0.49	0.542	0.062	0.801	0.83	0.63	0.639	0.87	1.126	0.428	0.327	0.549	0.227	0.126	0.161	0.1	0.109	0.1
31	0	1.489	0.415	1.173	1.477	1.021	1.361	1.329	1.464	0.687	0.479	0.565	0.274	0.137	0.212	0.181	0.164	0.152
32	0.816	1.625	0.912	1.881	2.227	1.097	1.943	2.074	1.991	0.762	0.532	0.661	0.347	0.16	0.286	0.259	0.251	0.189
33	0.49	1.76	1.347	2.775	2.698	1.672	2.48	3.217	2.472	1.077	0.689	0.597	0.338	0.165	0.383	0.325	0.328	0.29
34	0.98	3.52	2.031	2.254	2.786	1.954	2.339	2.969	2.366	1.355	0.934	0.602	0.509	0.205	0.466	0.458	0.451	0.386
35	1.796	3.656	1.865	2.365	2.587	1.857	2.166	2.845	2.248	1.542	1.216	0.663	0.566	0.267	0.511	0.546	0.548	0.471
36	1.306	2.437	1.969	1.974	2.187	1.411	1.527	2.199	1.734	1.642	1.423	0.668	0.69	0.299	0.56	0.609	0.666	0.608
37	1.959	2.031	2.093	1.564	1.868	1.466	1.476	1.665	1.392	1.514	1.525	0.794	0.684	0.366	0.565	0.609	0.663	0.69
38	0.816	2.031	1.471	0.875	1.349	1.162	1.374	1.106	1.078	1.402	1.41	0.772	0.763	0.461	0.505	0.559	0.688	0.702
39	1.469	3.25	1.451	1.006	1.03	1.042	1.201	0.745	0.762	1.324	1.231	0.763	0.783	0.505	0.467	0.554	0.633	0.713
40	1.469	1.354	1.161	0.708	0.639	0.803	1.074	0.708	0.544	1.118	1.084	0.742	0.766	0.556	0.432	0.488	0.558	0.639
41	0.653	0.542	0.974	0.596	0.455	0.575	0.716	0.547	0.514	1.046	0.911	0.645	0.67	0.528	0.401	0.424	0.443	0.564
42	0.653	0.812	0.746	0.764	0.319	0.706	0.652	0.484	0.443	0.865	0.813	0.531	0.658	0.489	0.36	0.367	0.384	0.488
43	0.816	0.271	0.601	0.577	0.247	0.347	0.55	0.36	0.327	0.671	0.659	0.483	0.543	0.422	0.3	0.325	0.334	0.397

44	0.163	0.406	0.415	0.354	0.176	0.499	0.447	0.211	0.367	0.506	0.535	0.384	0.446	0.379	0.273	0.276	0.272	0.337
45	0.816	0	0.269	0.279	0.12	0.304	0.486	0.224	0.255	0.459	0.426	0.314	0.406	0.322	0.228	0.232	0.215	0.248
46	0	0.135	0.228	0.242	0.12	0.282	0.332	0.273	0.2	0.328	0.321	0.236	0.302	0.305	0.203	0.212	0.181	0.212
47	0.327	0	0.207	0.223	0.136	0.163	0.275	0.149	0.176	0.234	0.286	0.213	0.244	0.249	0.184	0.17	0.159	0.194
48	0.163	0	0.145	0.093	0.024	0.174	0.16	0.087	0.11	0.203	0.251	0.129	0.202	0.198	0.148	0.139	0.118	0.135
49	0.327	0	0.145	0.149	0.064	0.185	0.166	0.099	0.088	0.112	0.174	0.101	0.132	0.15	0.119	0.112	0.09	0.113
50	0.163	0.135	0.062	0.056	0	0.119	0.134	0.075	0.07	0.072	0.147	0.063	0.103	0.098	0.081	0.089	0.072	0.075
51	0.163	0	0.021	0.019	0.016	0.087	0.096	0.037	0.029	0.069	0.088	0.047	0.055	0.089	0.062	0.07	0.056	0.06
52	0	0.135	0.083	0.019	0.008	0.054	0.064	0.062	0.035	0.034	0.068	0.034	0.057	0.045	0.05	0.059	0.043	0.059
53	0	0	0	0.056	0.016	0.065	0.032	0.025	0.018	0.037	0.028	0.035	0.034	0.032	0.027	0.041	0.029	0.035
54	0.163	0	0.041	0.019	0	0.054	0.019	0.012	0.013	0.009	0.025	0.015	0.022	0.024	0.016	0.026	0.028	0.029
55	0	0	0.021	0	0	0.022	0.013	0.025	0.009	0.003	0.025	0.006	0.015	0.016	0.013	0.018	0.018	0.017
56	0.163	0	0	0.019	0.008	0	0.006	0.025	0.011	0.009	0.017	0.003	0.006	0.008	0.009	0.011	0.012	0.014
57	0.163	0	0.021	0.019	0.008	0	0.013	0	0.007	0.006	0.018	0.006	0.009	0.006	0.01	0.007	0.005	0.009
58	0	0	0.021	0	0.008	0	0	0	0.004	0.003	0.012	0.003	0.004	0.003	0.002	0.005	0.008	0.006
59	0	0	0	0	0	0	0.006	0.012	0.007	0.003	0.002	0.001	0.001	0.004	0	0.003	0.004	0.004
60	0	0	0	0	0	0.011	0.006	0.012	0	0.003	0.003	0.001	0	0.003	0	0.001	0.004	0.003
61	0	0	0	0	0	0	0.006	0	0.002	0.006	0	0.001	0.001	0	0.002	0.001	0.006	0.002
62	0	0	0	0	0	0	0	0	0	0	0.002	0.001	0	0.001	0	0	0.002	0.003
63	0	0	0	0	0	0	0	0	0	0	0	0.003	0.001	0.001	0	0	0.002	0.001
64	0	0	0	0	0	0	0	0	0	0	0	0	0	0.001	0.001	0.001	0.003	0.001
65	0	0	0	0	0	0	0	0	0	0	0	0	0	0.001	0	0	0.003	0.001
66	0	0	0	0	0	0	0	0	0	0	0	0	0	0.001	0	0	0.002	0.001
67	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.001	0
68	0	0	0	0	0	0	0	0	0	0	0	0.001	0	0.001	0	0	0	0.001
69	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.001	0
70	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
71	0	0	0	0	0	0	0	0	0	0	0	0.001	0	0	0	0	0	0
72	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
73	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
74	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 11: Mean weight at age as calculated from the von Bertalanffy and length-weight relationship.

age	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
wt.	76	156	259	377	504	633	760	882	996	1102	1199	1287	1366	1436	1498	1553	1601	1643	1680

Table 12: Age-disaggregated catch in number (millions) estimated from length distribution.

Year	a2	a3	a4	a5	a6	a7	a8	a9	a10	a11	a12	a13	a14	a15	a16	a17	a18	a19	a20
1987	0.03	0.70	2.10	2.22	3.08	2.22	2.64	1.34	1.42	0.29	0.28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1988	0.00	0.00	2.75	7.44	4.69	2.91	5.44	2.24	0.43	0.67	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1989	0.00	0.06	0.45	3.85	4.56	3.27	1.35	2.01	1.52	0.56	1.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1990	0.00	0.21	1.49	5.50	4.54	4.78	1.43	0.96	1.88	0.30	0.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1991	0.00	0.09	1.66	7.96	3.67	3.67	2.99	1.08	0.62	0.24	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1992	0.00	0.07	1.37	6.58	3.03	3.03	2.47	0.90	0.51	0.20	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1993	0.00	0.08	1.68	8.07	3.71	3.71	3.01	1.10	0.63	0.25	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1994	0.00	1.22	5.54	6.40	3.39	3.37	1.26	0.84	0.35	0.28	0.02	0.16	0.28	0.00	0.07	0.05	0.09	0.00	0.00
1995	0.08	1.08	2.72	8.08	4.97	1.89	1.34	0.40	0.15	0.15	0.06	0.06	0.02	0.04	0.02	0.04	0.00	0.15	0.00
1996	0.04	0.42	2.04	2.64	6.59	3.46	1.49	0.71	0.27	0.22	0.15	0.11	0.04	0.02	0.02	0.00	0.00	0.00	0.00
1997	0.13	0.30	1.49	3.38	2.05	4.40	2.28	0.95	0.48	0.20	0.20	0.20	0.13	0.07	0.08	0.05	0.00	0.00	0.00
1998	0.26	0.53	1.23	1.20	1.63	1.42	1.33	0.84	0.64	0.71	0.43	0.44	0.27	0.24	0.22	0.18	0.14	0.09	0.28
1999	0.20	0.34	0.62	0.71	1.45	1.35	1.30	0.86	0.69	0.70	0.46	0.42	0.23	0.22	0.18	0.15	0.12	0.07	0.23
2000	0.01	0.18	0.29	1.00	1.26	1.44	1.10	0.65	0.49	0.26	0.08	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00
2001	0.01	0.43	1.22	1.02	1.58	1.17	0.88	0.57	0.24	0.12	0.10	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2002	0.01	0.08	1.05	1.66	1.11	1.26	0.89	0.62	0.39	0.19	0.12	0.03	0.00	0.01	0.00	0.00	0.00	0.00	0.00
2003	0.00	0.08	0.68	1.82	1.93	1.11	0.83	0.52	0.31	0.21	0.10	0.05	0.02	0.00	0.01	0.00	0.00	0.00	0.00
2004	0.00	0.06	0.56	1.56	2.50	1.62	0.92	0.41	0.30	0.08	0.06	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 13: Selection pattern by age from VPA.

age	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Sa	0.0025	0.0362	0.1822	0.5429	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Table 14: Main results from four models: age-based ADAPT, length-based ADAPT, agedisaggregated production model (ADPM) and surplus production model(SPM).

	Fishing mortality($\overline{F}_{6-12}$)			Recruitment (Millions) Age 2			Spawning stock biomass(T)			
Year	Age-based ADAPT	Length-based ADAPT	ADPM	Age-based ADAPT	Length-based ADAPT	ADPM	Age-based ADAPT	Length-based ADAPT	ADPM	SPM K=95018t R=0.256
1987	0.329	0.271	0.285	35.8	41.1	36.2	50765	41364	46875	46000
1988	0.381	0.361	0.540	40.1	41.0	44.8	49467	43323	45098	43336
1989	0.724	0.344	0.388	33.5	41.5	30.6	45295	39973	36240	37943
1990	0.497	0.355	0.439	32.1	39.2	30.1	42324	38671	34503	35514
1991	0.463	0.347	0.556	47.6	43.9	41.8	39852	37289	31987	33046
1992	0.486	0.303	0.551	58.4	54.1	55.1	36623	35912	27106	31174
1993	0.531	0.409	0.788	25.3	25.1	19.5	33162	35952	24159	29558
1994	0.497	0.316	0.797	29.6	25.1	24.5	31109	34294	19884	25857
1995	0.344	0.248	0.653	25.2	18.6	23.0	29578	33819	18381	22603
1996	0.548	0.319	0.709	22.0	19.7	16.0	22991	32652	17277	20249
1997	0.781	0.408	0.592	21.4	20.1	16.6	20612	29166	15163	17185
1998	0.468	0.427	0.555	21.8	23.9	13.8	17506	23798	13569	14155
1999	0.592	0.672	0.612	30.7	33.6	28.4	17082	18913	12525	13937
2000	0.752	0.482	0.389	42.9	48.7	36.1	15928	15258	11072	13710
2001	0.470	0.304	0.387	28.0	32.5	26.4	16603	16901	11750	15274
2002	0.515	0.318	0.265	23.7	28.1	23.8	19359	20729	13735	17504
2003	0.424	0.227	0.220	11.5	13.9	22.0	23321	26116	17568	19945
2004	0.211	0.161	0.253	4.1	2.7	24.3	27058	31497	21800	22666
Average	0.501	0.348	0.499	29.7	30.7	28.5	29924	30868	23261	25536

Table 15: CV estimates from age-disaggregated dynamic production model.

Time Series	**SSE** (Sum of squared errors)	**CV**
Catch in number by age by year	3.531	0.4429
IGFS biomass indices from survey	17.610	0.9891
CPUE from Danish seine fleet	10.756	0.8765
Recruitment indices (age 2) from IGFS survey	1.125	0.2500

Table 16: Results of a short term yield and biomass prediction from 2005 to 2007.

Year		Yield(t)	SSB(t)
Age-based ADAPT (F=0.211)	2005	5590	31358
	2006	5337	30019
	2007	4776	26865
Length-based ADAPT (F=0.161)	2005	5308	38155
	2006	5282	38047
	2007	4895	35271
Production Model (F=0.253)	2005	5443	25894
	2006	5557	26444
	2007	5621	26740

Table 17: Reference points from the BRP model.

	Fish Mort Ages 6-12	Equilibrium Yield (T)	Equilibrium SSB (T)	SSB/B0 (%)	Equilibrium Recruitment (millions)
Average Current	0.5	7197	21276	11. 8-23.6	28
Fmax	0.39	8185	29502	16.4-32.8	32.6
F_{msy}	0.2	9819	60697	33.7-67.4	41
F0.1	0.18	9689	66530	36.9-73.8	42.3
Fmed	0.6	5806	15258	8.5-17	23.6
F_{high}	1.1	1235	2207	1.2-2.4	5.4
F_{crash}	1.3	0	0	0	0
F=0	0	0	B0:90000-180185	100	50

Table 18: Predicted results from the surplus production model.

year	P=0.00001,k=95018t r=0.256,msy=8933t Fmsy=0.256,Bmsy=34955t			P=1,k=78883t r=0.477,msy=9410t Fmsy= 0.239,Bmsy= 39442t		year	P=0.00001,k=95018t r=0.256,msy=8933t Fmsy=0.256,Bmsy=34955t			P=1,k=78883t r=0.477,msy=9410t Fmsy= 0.239,Bmsy= 39442t	
	Biomass (t)	Surplus production (t)	Catch (t)	Biomass (t)	Surplus production (t)		Biomass (t)	Surplus production (t)	Catch (t)	Biomass (t)	Surplus production (t)
1905	95021	0	388	78883	0	1955	65273	6264	7733	62019	6327
1906	94633	99	9836	78495	184	1956	63803	6494	7888	60613	6699
1907	84895	2444	9075	68844	4181	1957	62409	6704	9603	59424	6995
1908	78265	3880	6747	63949	5777	1958	59511	7116	8163	56816	7584
1909	75398	4457	5523	62979	6059	1959	58464	7256	8428	56237	7704
1910	74332	4664	4933	63515	5905	1960	57292	7407	8059	55513	7848
1911	74063	4716	5552	64487	5616	1961	56641	7489	11001	55302	7889
1912	73227	4875	6733	64551	5596	1962	53128	7893	11411	52189	8427
1913	71370	5220	5565	63414	5934	1963	49611	8239	9658	49205	8834
1914	71025	5283	4205	63783	5826	1964	48192	8361	9368	48381	8927
1915	72103	5086	2506	65404	5333	1965	47185	8441	10990	47940	8973
1916	74682	4597	303	68231	4397	1966	44636	8618	11875	45923	9156
1917	78976	3733	41	72325	2869	1967	41379	8791	11380	43204	9325
1918	82668	2942	202	75153	1696	1968	38790	8881	10270	41149	9393
1919	85408	2328	6803	76647	1037	1969	37401	8912	14031	40271	9406
1920	80933	3319	10368	70881	3431	1970	32281	8906	10018	35646	9323
1921	73884	4750	6014	63944	5779	1971	31170	8879	9688	34951	9288
1922	72620	4989	5872	63708	5848	1972	30360	8852	6496	34551	9266
1923	71737	5153	5601	63685	5855	1973	32716	8914	4778	37321	9383
1924	71289	5235	5244	63939	5780	1974	36852	8920	4021	41926	9373
1925	71280	5237	5920	64475	5620	1975	41751	8774	4575	47278	9039
1926	70597	5360	6526	64174	5710	1976	45951	8531	5025	51742	8495
1927	69431	5567	7881	63358	5950	1977	49457	8253	5270	55212	7906
1928	67117	5963	6393	61427	6486	1978	52440	7966	4504	57847	7361
1929	66687	6034	6563	61521	6461	1979	55902	7578	4492	60704	6675
1930	66158	6121	8278	61419	6488	1980	58988	7187	5145	62888	6085
1931	64001	6464	8497	59629	6945	1981	61030	6905	3875	63828	5813
1932	61968	6769	6398	58077	7309	1982	64060	6454	6331	65766	5218
1933	62339	6715	4642	58989	7099	1983	64183	6435	8552	64653	5565
1934	64412	6400	4670	61446	6481	1984	62067	6755	11335	61666	6422
1935	66142	6124	5337	63257	5979	1985	57487	7383	14510	56754	7597
1936	66928	5994	5149	63899	5792	1986	50359	8171	12738	49841	8756
1937	67774	5853	5567	64542	5599	1987	45792	8542	11192	45859	9161
1938	68059	5804	4150	64574	5589	1988	43142	8705	14087	43828	9294
1939	69713	5517	1998	66014	5139	1989	37761	8905	11330	39035	9409
1940	73233	4874	3647	69155	4070	1990	35336	8932	11400	37114	9377
1941	74460	4640	2799	69577	3917	1991	32868	8917	10792	35091	9296
1942	76301	4278	6023	70695	3502	1992	30993	8873	10494	33595	9203
1943	74556	4621	3458	68174	4417	1993	29372	8812	12522	32305	9102
1944	75719	4394	3227	69132	4078	1994	25662	8585	11854	28885	8736
1945	76886	4161	3290	69983	3768	1995	22393	8271	10649	25767	8279
1946	77757	3984	4366	70461	3590	1996	20015	7967	11063	23397	7853
1947	77375	4062	7237	69685	3877	1997	16919	7461	10540	20186	7167
1948	74200	4690	9310	66325	5038	1998	13840	6814	7106	16814	6313
1949	69580	5541	10572	62054	6317	1999	13548	6744	7064	16021	6092
1950	64549	6378	9172	57799	7372	2000	13227	6665	5218	15049	5811
1951	61755	6801	8439	55999	7752	2001	14674	7005	4905	15642	5984
1952	60116	7033	4578	55312	7887	2002	16774	7434	5126	16721	6287
1953	62572	6680	4693	58620	7185	2003	19082	7828	5236	17882	6598
1954	64559	6377	5663	61112	6569	2004	21675	8186	5704	19244	6943

Table 19 : Predicted yield and biomass for long term based on the analysis of Y/R and S/R with uncertainty (CV=0.25).

Year	F=0.5 Catch=7150t(2005)						F=0.38 Catch=5700t(2005)					
	my	95%y	5%y	mb	95%b	5%b	my	95%y	5%y	mb	95%b	5%b
2005	7150	7150	7150	21389	21389	21389	5675	5675	5675	21389	21389	21389
2006	7150	7156	7147	21389	21521	21300	6122	6128	6119	22876	23041	22786
2007	7151	7203	7119	21388	21962	21112	6472	6514	6444	24031	24584	23616
2008	7153	7435	7004	21379	23028	20655	6722	6930	6569	24930	26244	23719
2009	7141	8020	6745	21418	24316	20269	6899	7481	6406	25825	28065	23329
2010	7158	8509	6597	21575	25246	19641	7136	7934	6187	26702	29101	23185
2011	7183	8889	6394	21518	26383	19434	7390	8169	6290	27310	29970	23576
2012	7196	9018	6309	21634	26857	18910	7519	8401	6492	27785	30983	24205
2013	7347	8967	6142	21895	26851	18423	7620	8609	6451	28080	31824	24084
2014	7307	8900	6031	21817	26588	18207	7685	8827	6683	28599	32246	24975
2015	7314	8797	6140	21852	26360	18481	7874	8848	6901	29030	32878	25654
2016	7253	8980	6169	21817	26422	18767	7977	9084	7127	29299	33746	25991
2017	7263	8880	6172	21912	26522	18450	8018	9471	7119	29832	35105	26189
2018	7259	9083	6153	21930	26928	18453	8176	9497	7119	30219	35107	26005
2019	7360	9036	6052	22182	27304	18605	8283	9760	7019	30676	35827	25975
2020	7400	9155	6207	22128	27213	18861	8537	9824	7019	31313	36284	25786

Table 20: Predicted yield and biomass for long term based on the analysis of Y/R and S/R with uncertainty (CV=0.25).

year	F=0.26 Catch=4000t(2005)					
	my	95%y	5%y	mb	95%b	5%b
2005	4059	4059	4059	21389	21389	21389
2006	4736	4739	4734	24532	24647	24446
2007	5326	5347	5309	27246	27693	26903
2008	5805	5917	5715	29504	30772	28532
2009	6181	6553	5892	31514	34111	29401
2010	6555	7282	5948	33390	37458	30058
2011	6909	8025	6040	35053	40312	31232
2012	7305	8412	6401	37153	42597	32719
2013	7661	8796	6743	38682	44550	34241
2014	7909	9374	6902	39862	46499	34778
2015	8147	9750	6961	41245	48698	35386
2016	8386	9916	7110	42190	49852	36057
2017	8626	10155	7266	43340	50999	36727
2018	8850	10464	7441	44288	52632	37655
2019	8883	10646	7651	44509	53412	38913
2020	9026	10895	7845	45450	54633	39643

Table 21: Predicted equilibrium yield and biomass for long term based on the analysis of surplus production with uncertainty (CV=0.25).

Year	**Catch=7150t (all years)**						**Catch=5700t (all years)**					
	my	95%y	5%y	mb	95%b	5%b	my	95%y	5%y	mb	95%b	5%b
2005	8376	8721	7994	23135	27626	20207	8435	8741	8173	23959	27962	21568
2006	8352	8795	7967	24919	28993	20019	8689	8909	8252	27113	32405	22231
2007	8523	8923	8028	26623	33290	20450	8851	8932	8467	30494	36573	24287
2008	8656	8930	8082	28459	36582	20854	8894	8932	8662	33272	42299	26897
2009	8768	8932	8059	30378	40751	20680	8889	8932	8360	36255	47061	29876
2010	8843	8933	8069	31357	41901	20755	8831	8930	8087	40288	51127	32389
2011	8857	8933	8255	34240	45827	22891	8690	8920	7823	43421	53654	34668
2012	8861	8932	8148	35915	47778	24552	8440	8891	7642	47196	55308	38105
2013	8839	8930	8060	38331	49437	25520	8205	8841	7168	49994	59087	39989
2014	8823	8932	7880	39832	52570	28987	7969	8641	6942	52406	60702	44240
2015	8780	8932	7711	40812	52572	29172	7615	8556	6743	55592	61690	45408
2016	8719	8926	7406	44130	54951	29847	7311	8270	6367	58042	64143	48915
2017	8597	8920	7505	45808	56441	32322	7031	7972	6072	60129	66365	51856
2018	8505	8919	7387	48234	57406	33984	6846	7869	5661	61443	68833	53179

Where my:is median equilibrium yield

95%y:is 95% fractile for the equilibrium yield

5%y:is 5% fractile for the equilibrium yield

mb: is median biomass

95%b: is 95% fractile for the biomass

5%b: is 5% fractile for the biomass

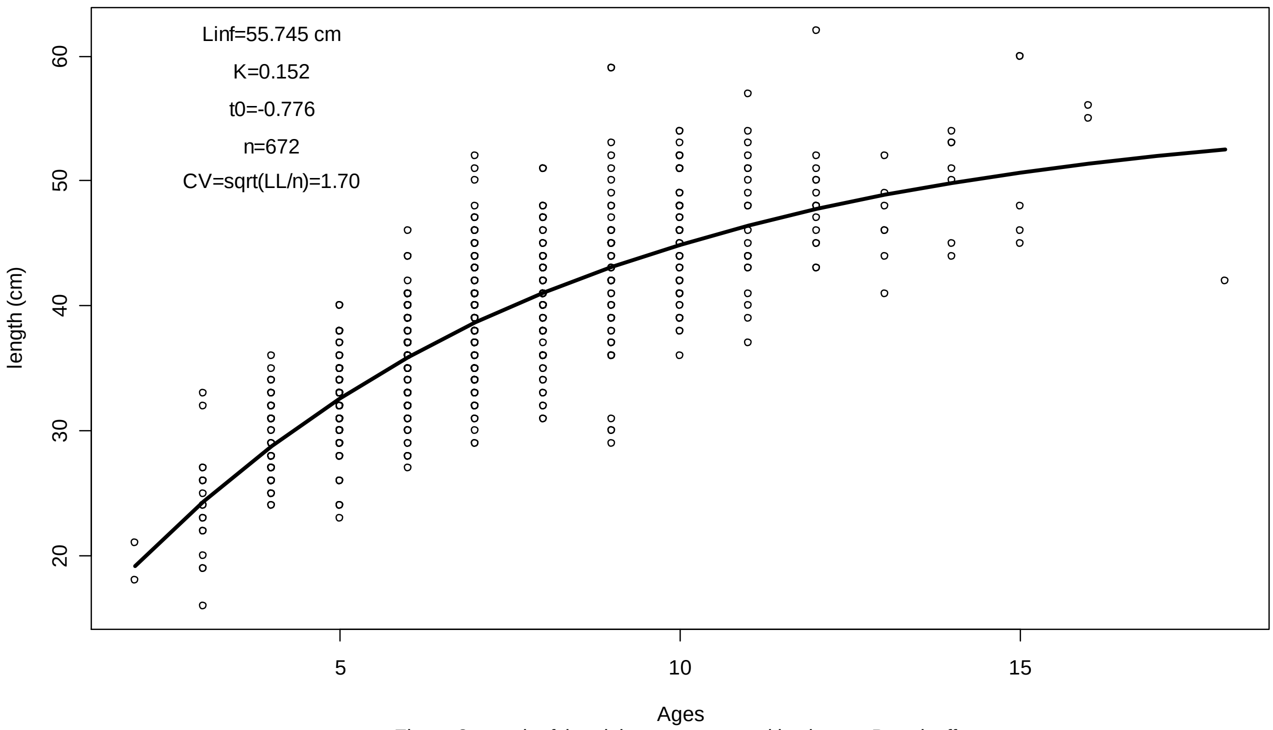


Figure 2.growth of the plaice as expressed by the von Bertalanffy

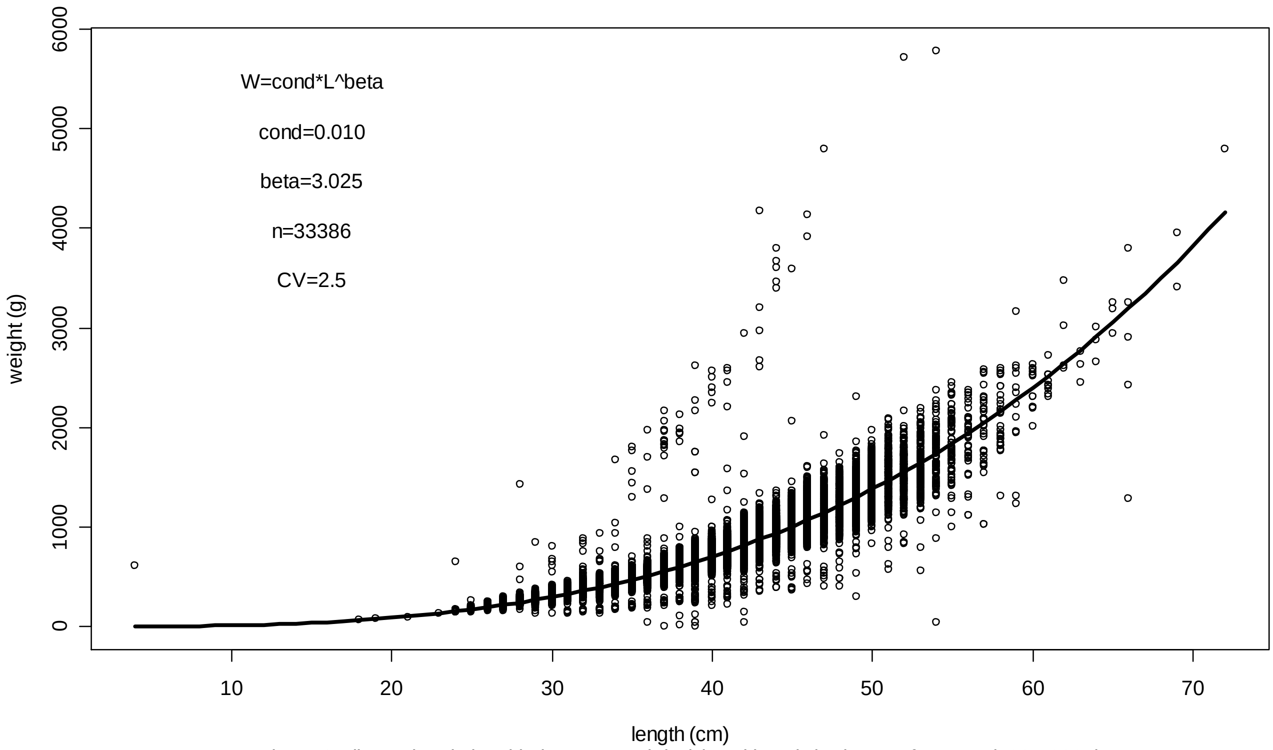


Figure 3.Allometric relationship between weight (g) and length (cm). Data from MRI(1994-2005)

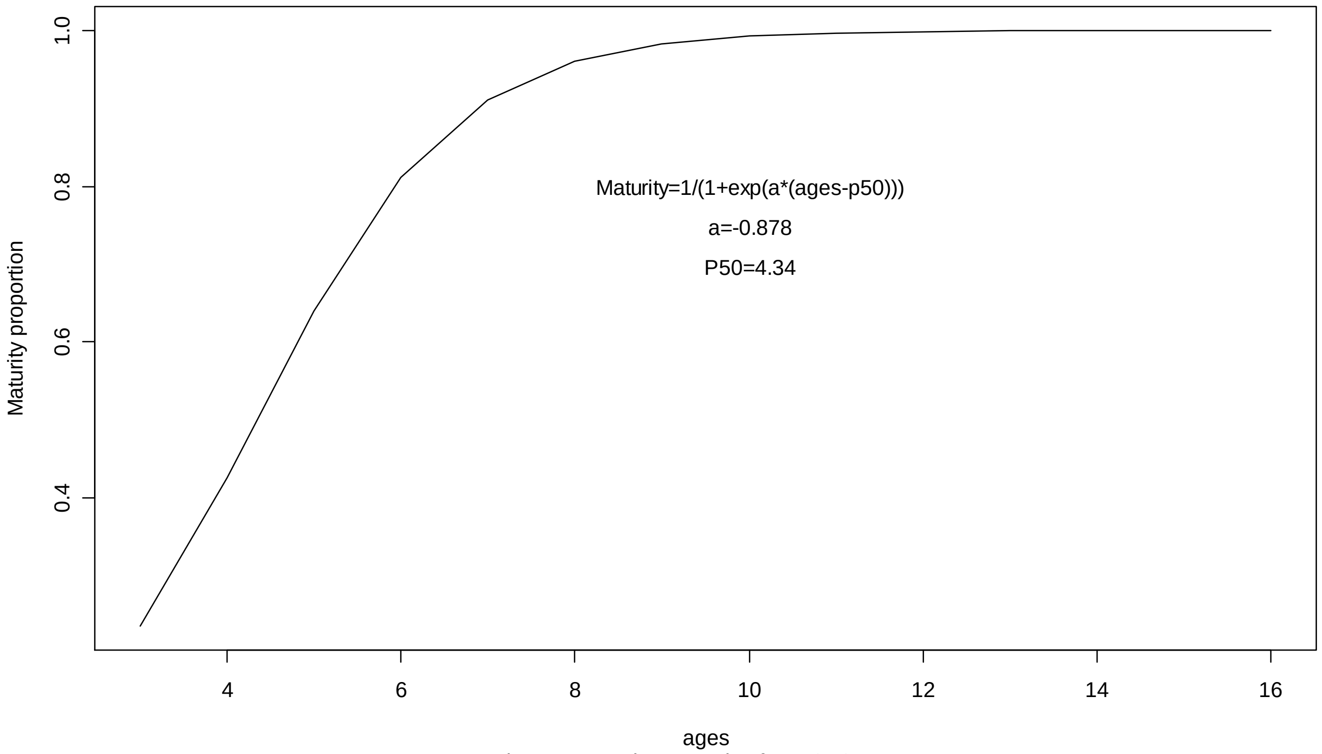
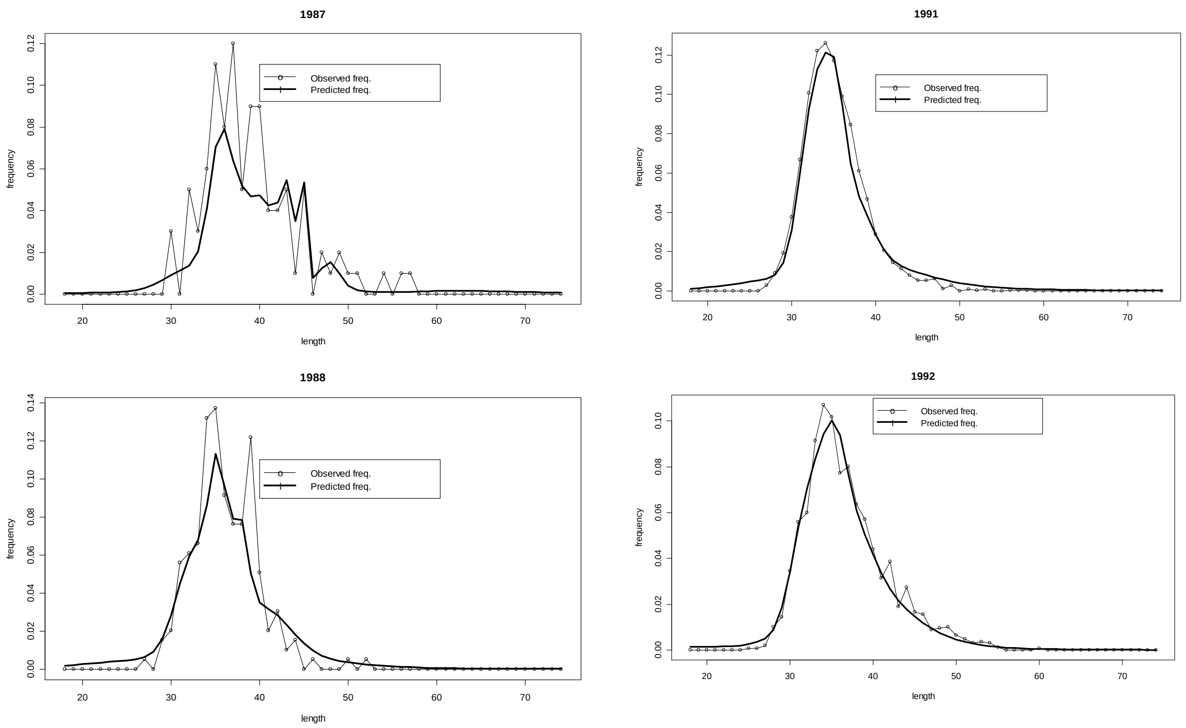
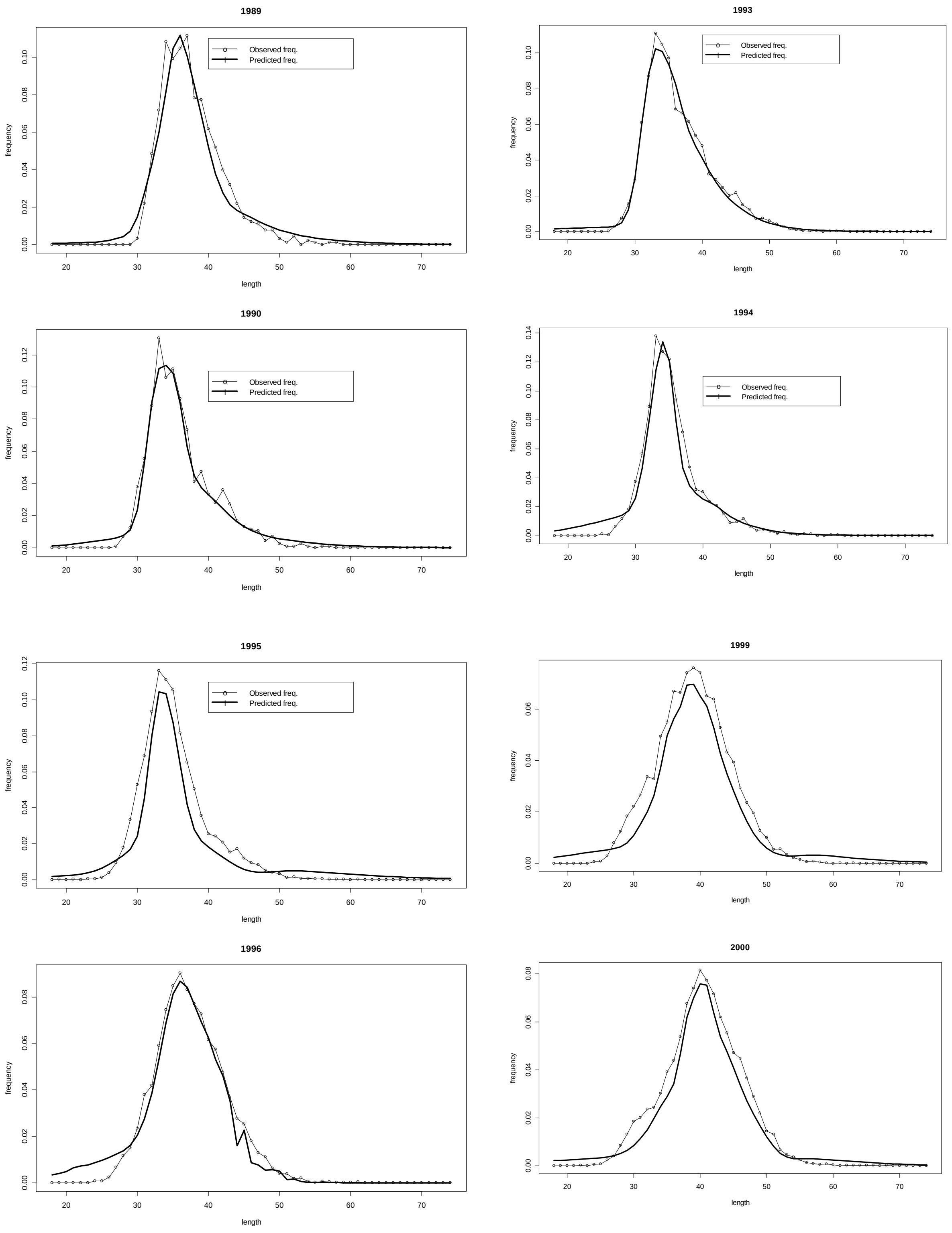


Figure 4. Maturity proportion from IGFS survey




1989
Observed freq.
Predicted freq.
frequency
length
1993
Observed freq.
Predicted freq.
frequency
length
1990
Observed freq.
Predicted freq.
frequency
length
1994
Observed freq.
Predicted freq.
frequency
length
1995
Observed freq.
Predicted freq.
frequency
length
1999
frequency
length
1996
frequency
length
2000
frequency
length

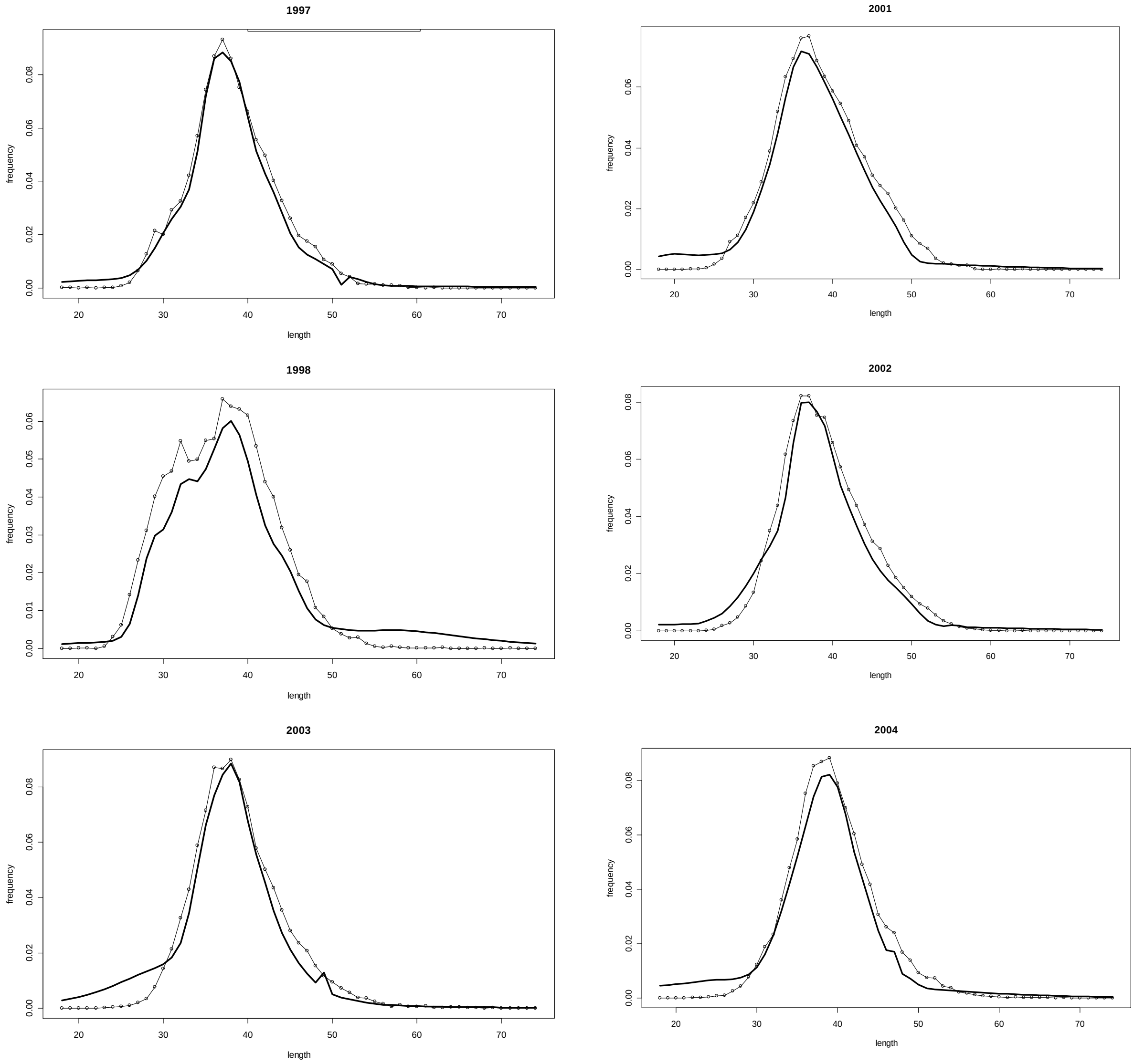


Figure 5.length distributions in landing from 1987-2004 and the fitted curves from the slice method.

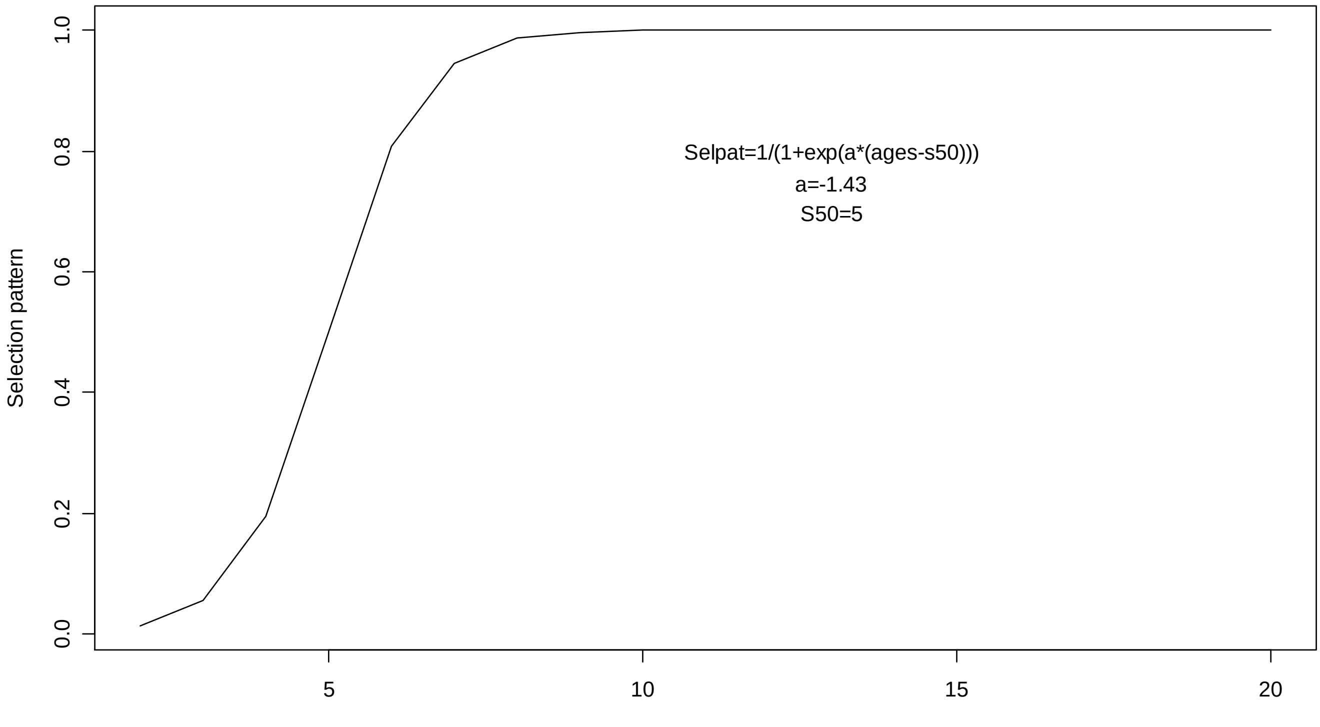


Figure 6. selection pattern from VPA model

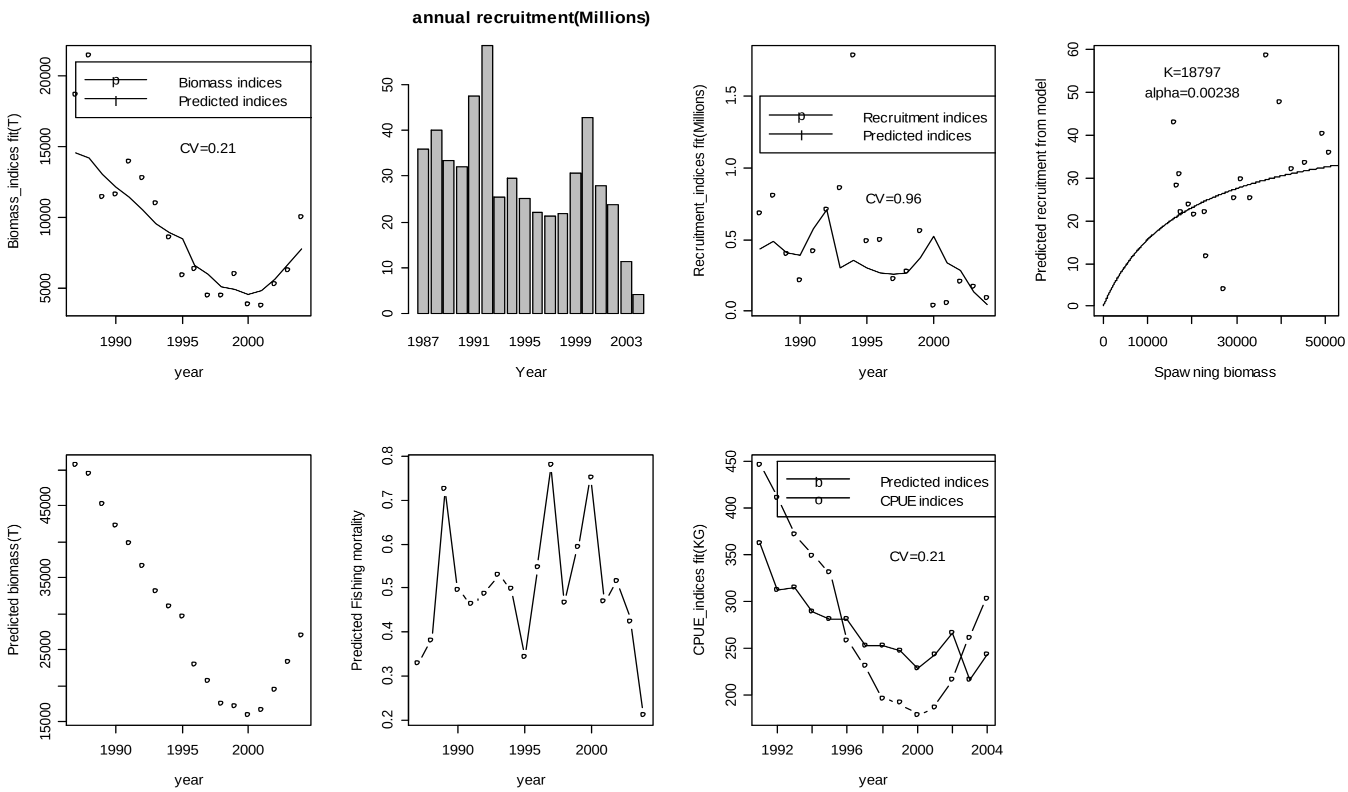


Figure 7. Biomass,recruitment and CPUE fit from Age-based ADAPT model.

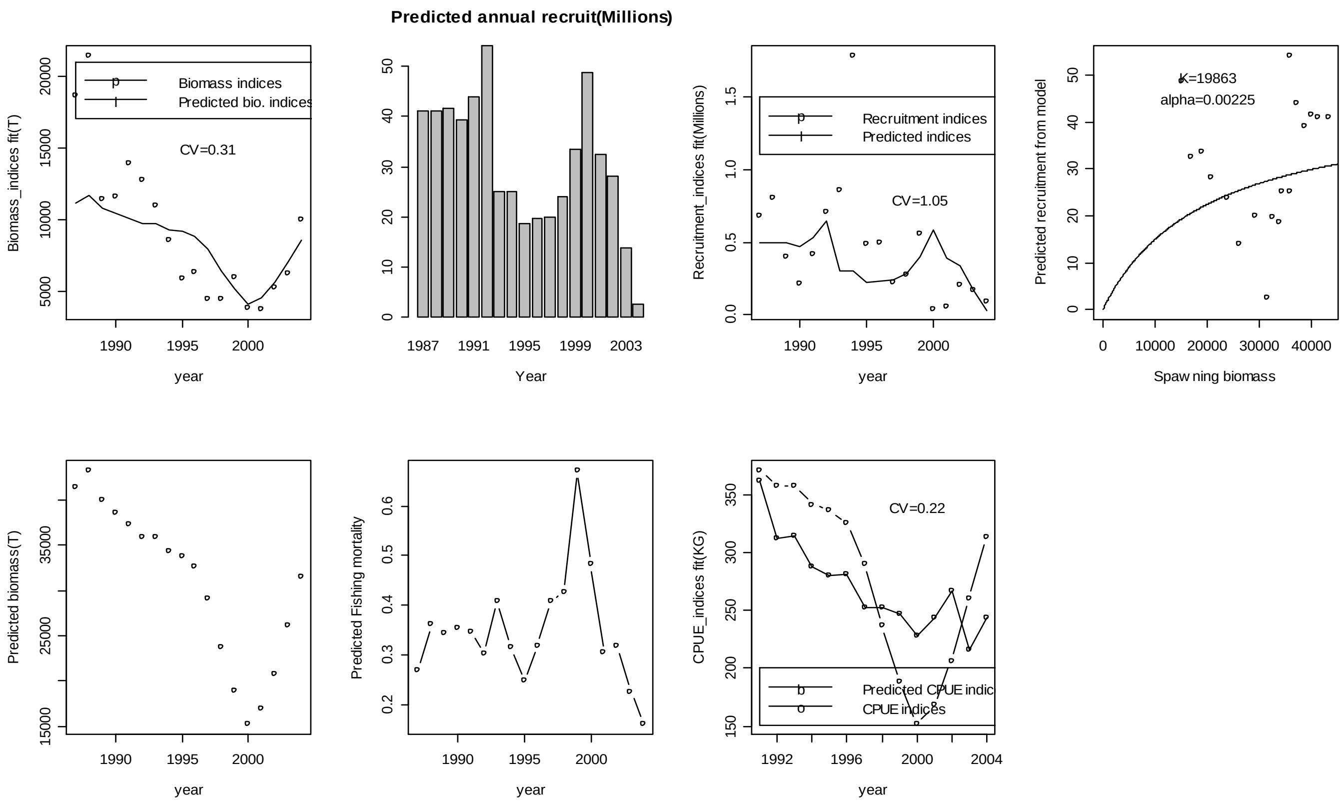


Figure 8. Biomass,recruitment and CPUE fit from Length-based ADAPT model.

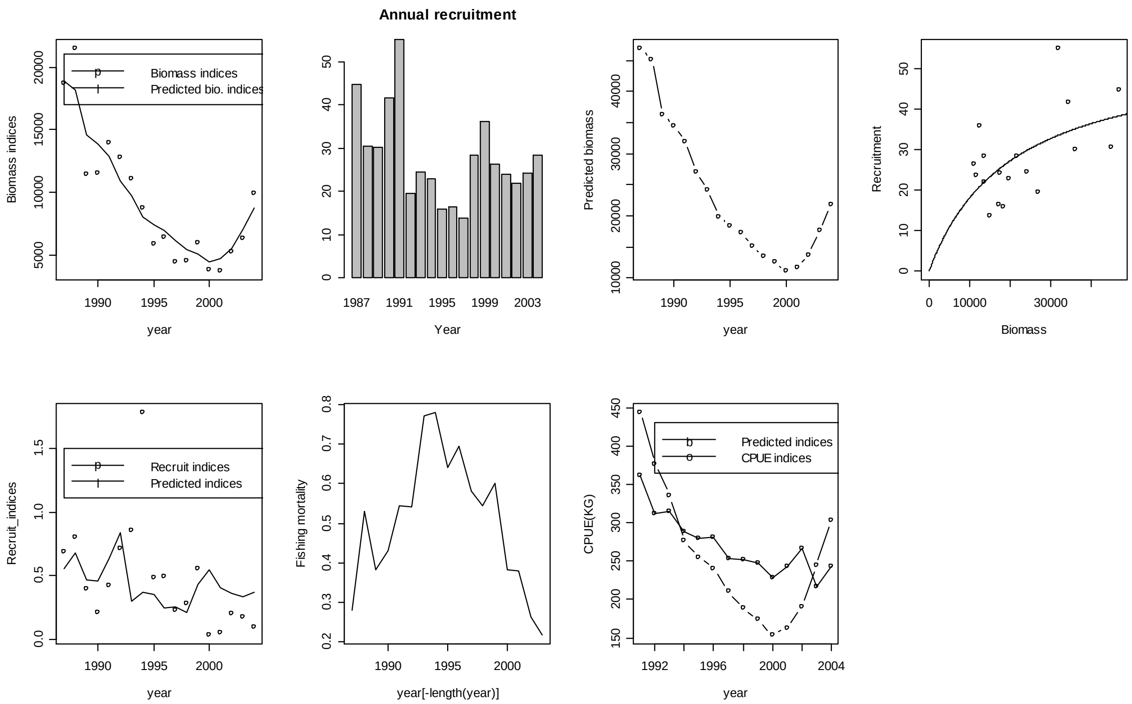


Figure 9. Biomass,recruitment and CPUE fit from Age-disaggregated dynamic production model.

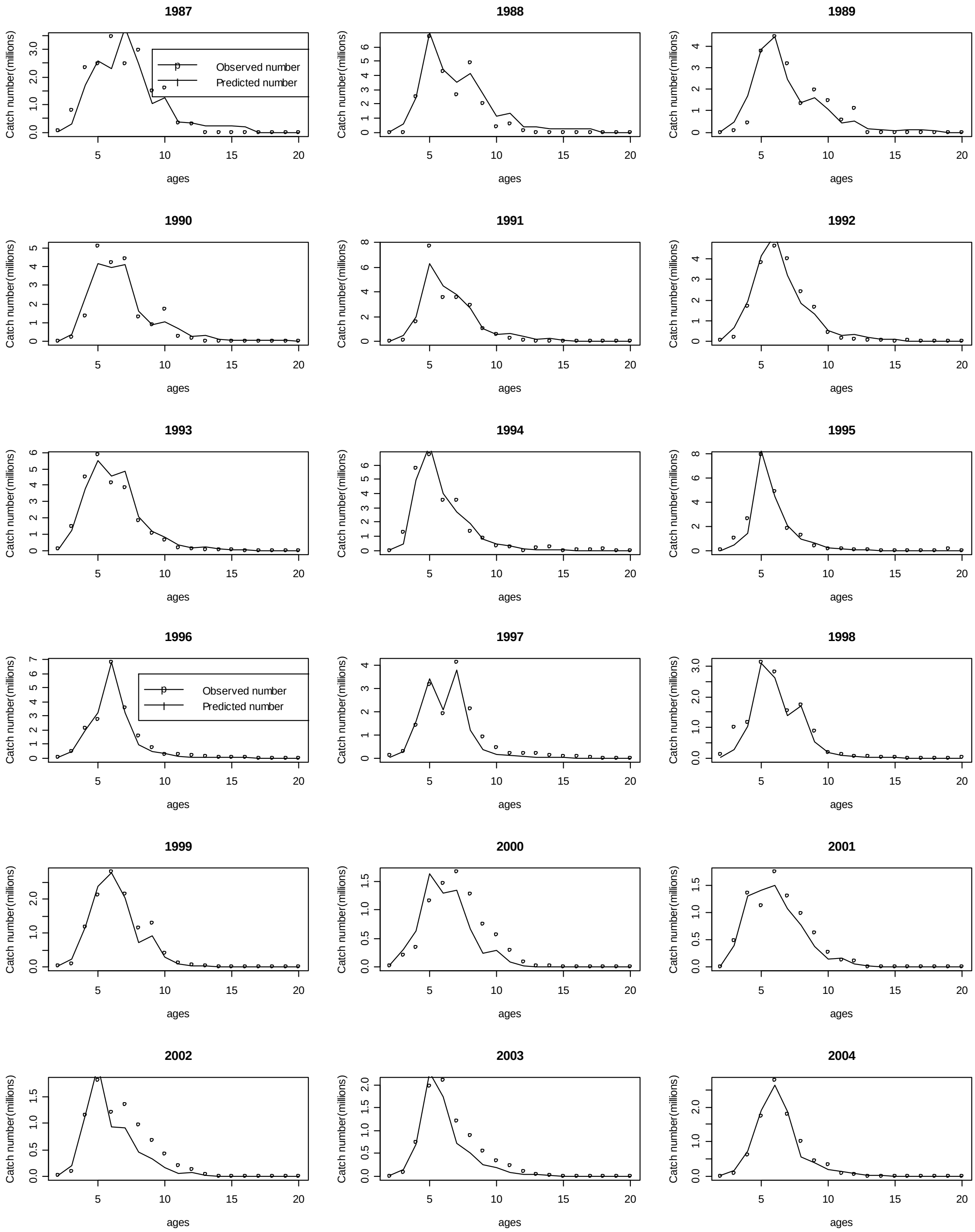


Figure 10. Catch in number by age by year fit from Age-disaggregated dynamic production model.

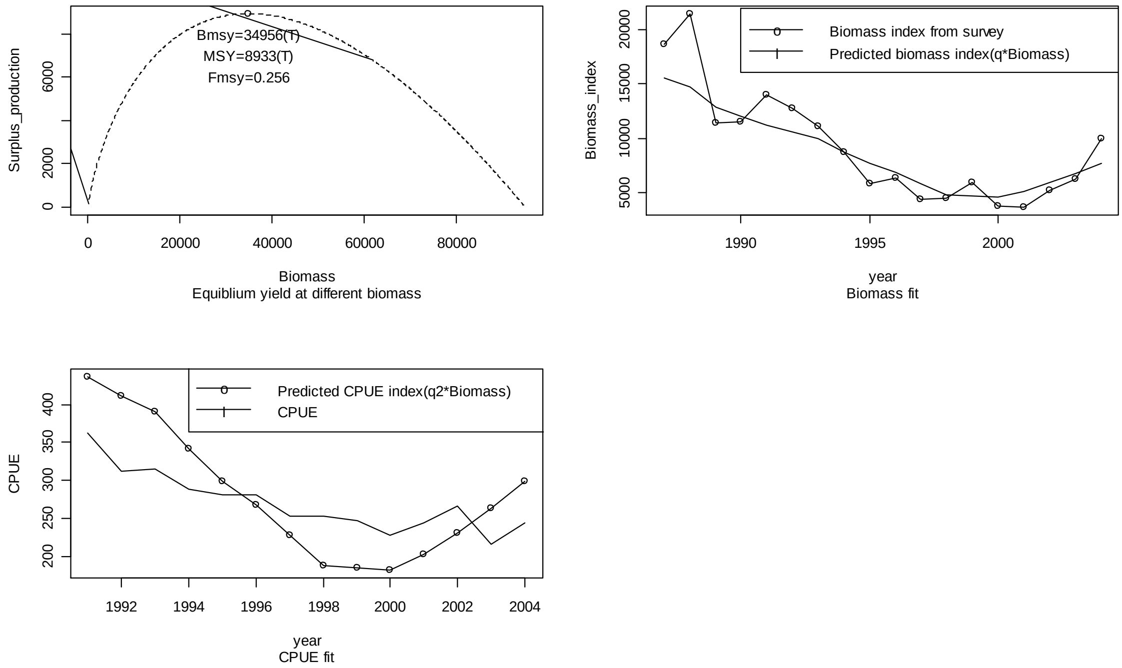


Figure 11.Surplus production,biomass indices and CPUE fit from surplus production model (p=0.00001).

Figure 12.Predicted Biomass(T) from Surplus and Age-Structured Model,Catch and Equiblium yield (p=0.00001)

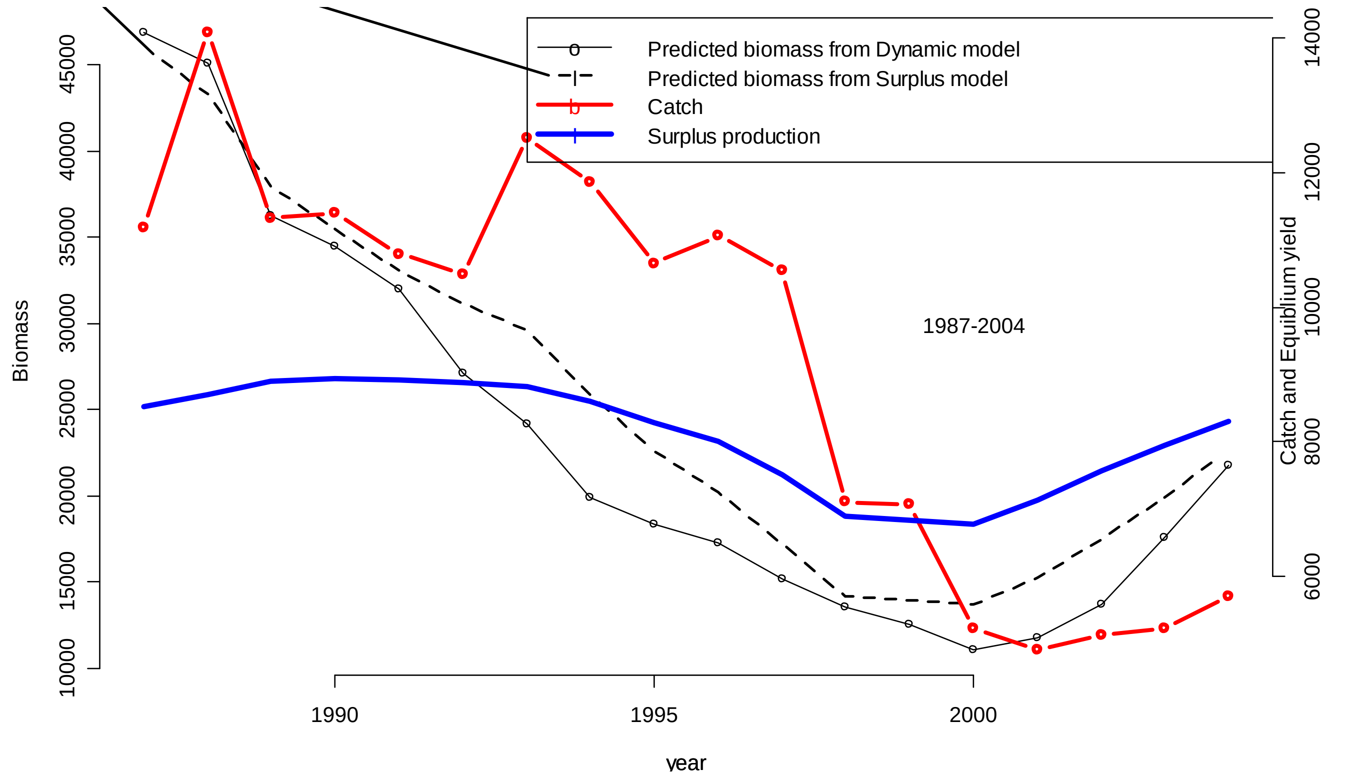


Figure 13.Predicted Biomass(T) from Surplus Model,Catch and Equiblium yield from 1905-2004 (p=0.00001)

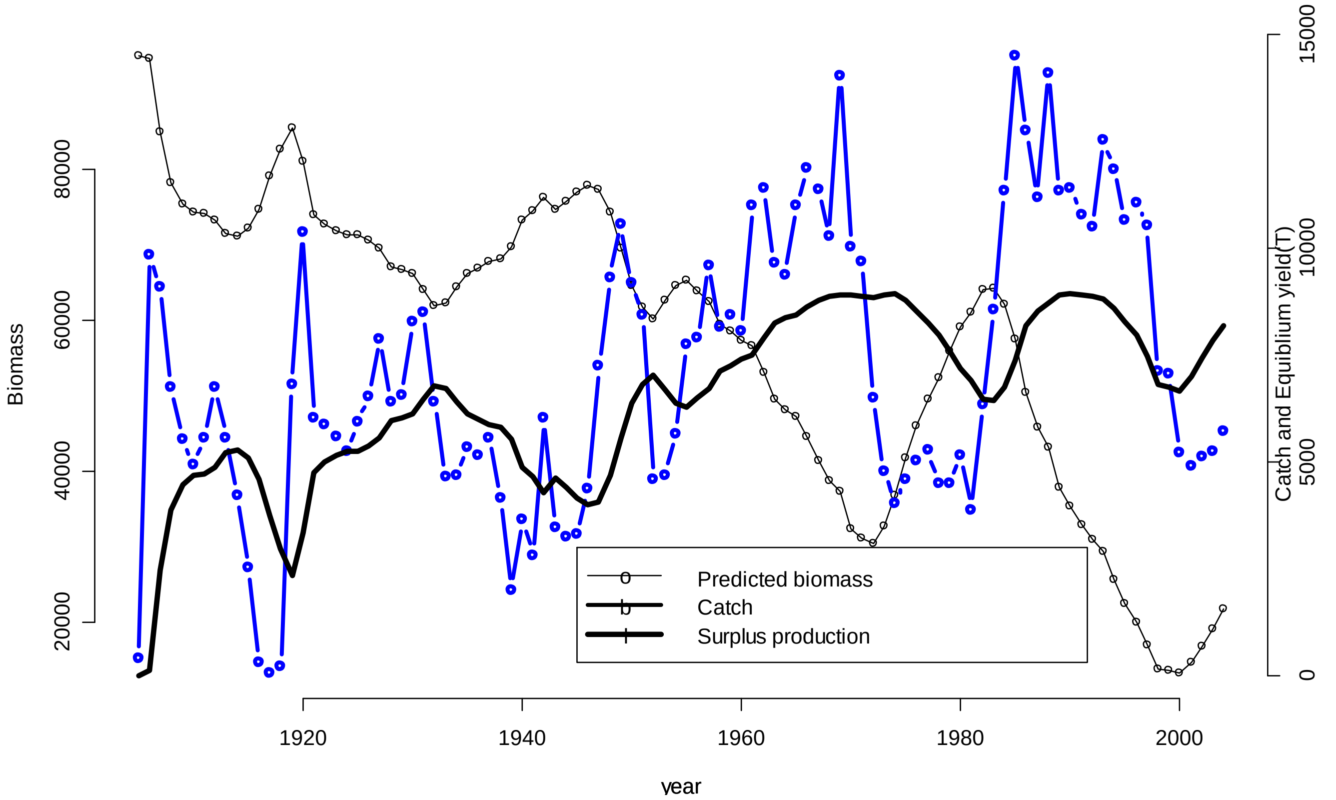
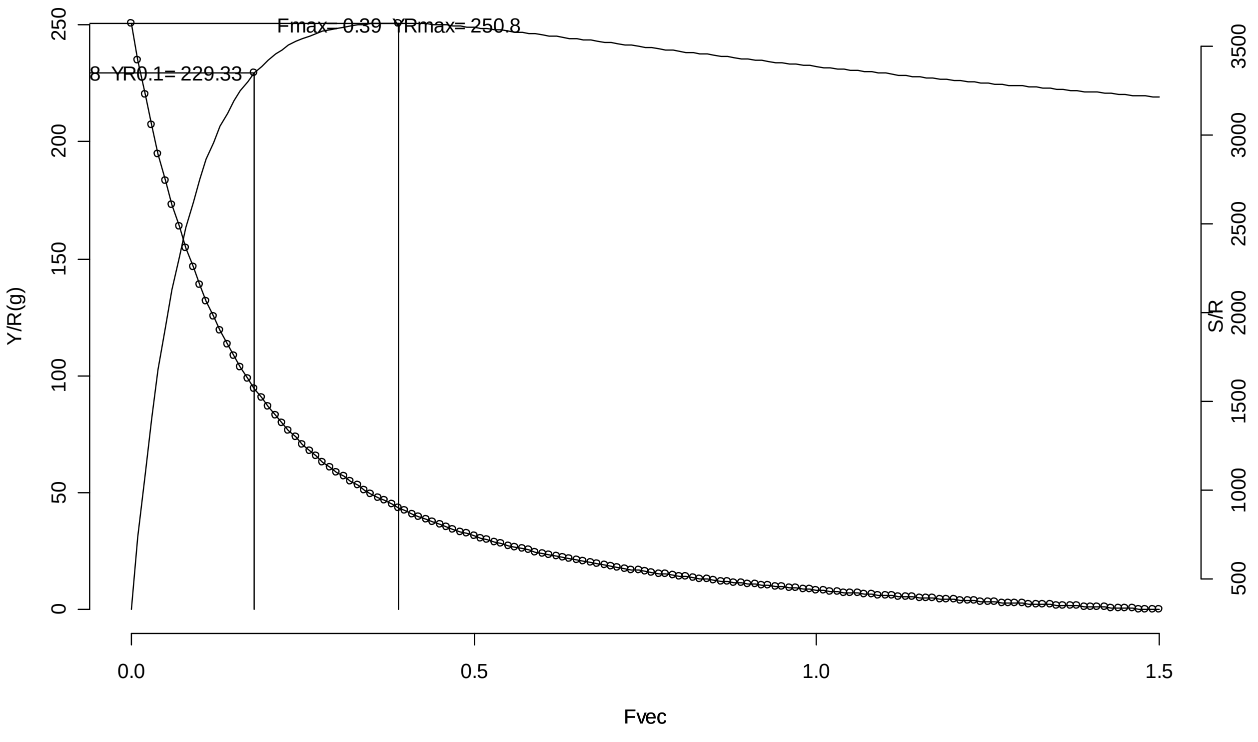


Figure 14.Yield and biomass per recruit(g) for Plaice



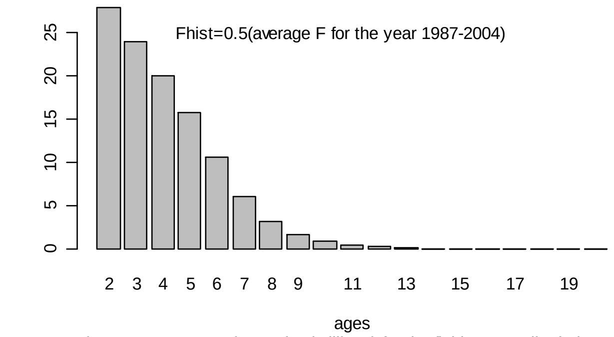


Figure 15.Age group in number(millions) for the fishing mortality being 0.5

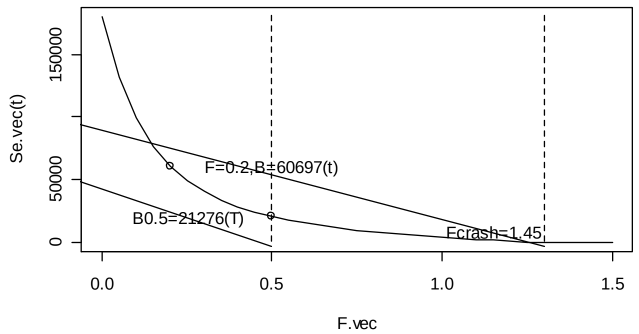


Figure 16.Equilibrium spawning stock for each value of the fishing mortality

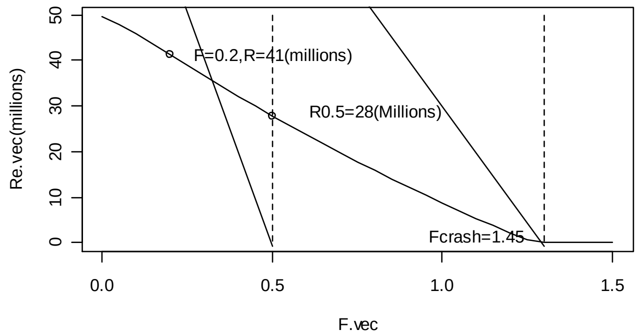


Figure 17.Equilibrium recruit for each value of the fishing mortality

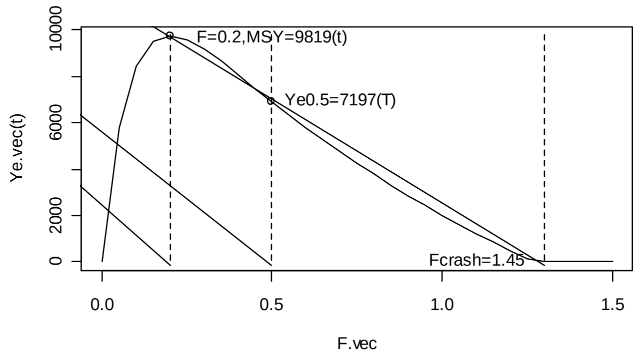


Figure 18.Equilibrium yield for each value of the fishing mortality

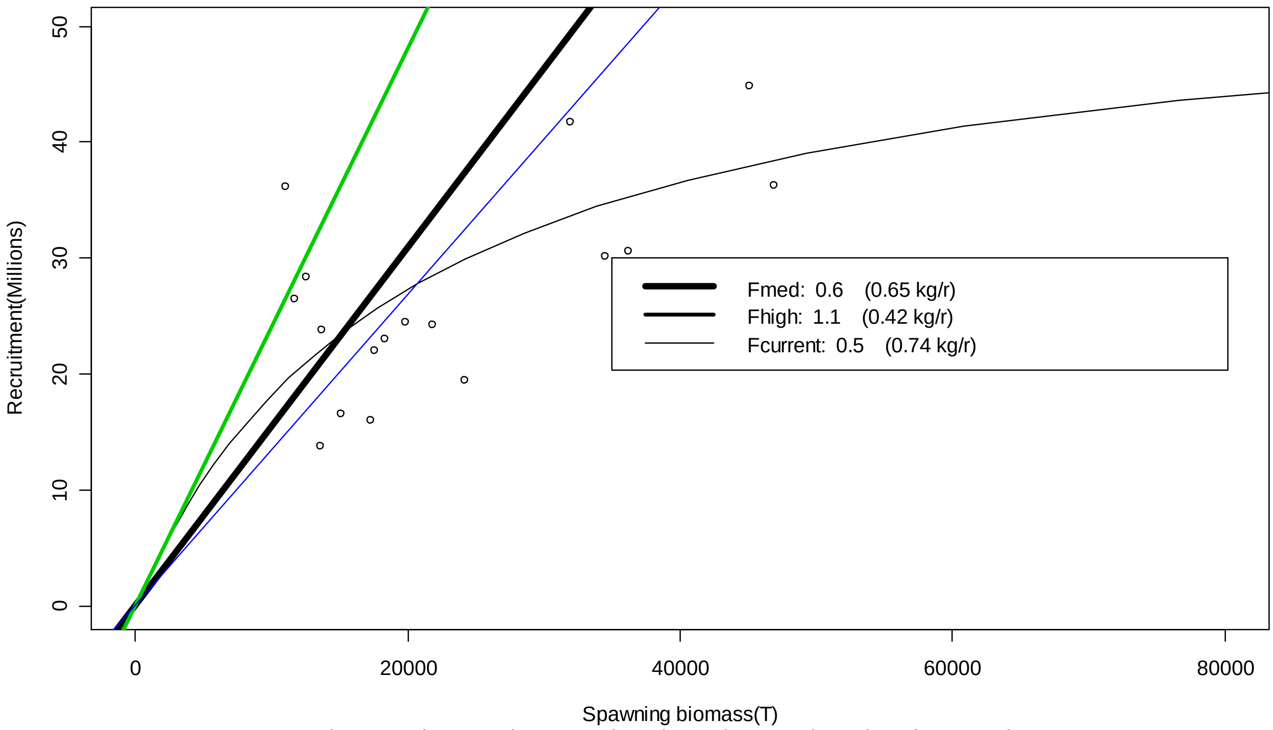


Figure 19.Short-term (1987-2004) stock-recruit scatterplot and F reference points

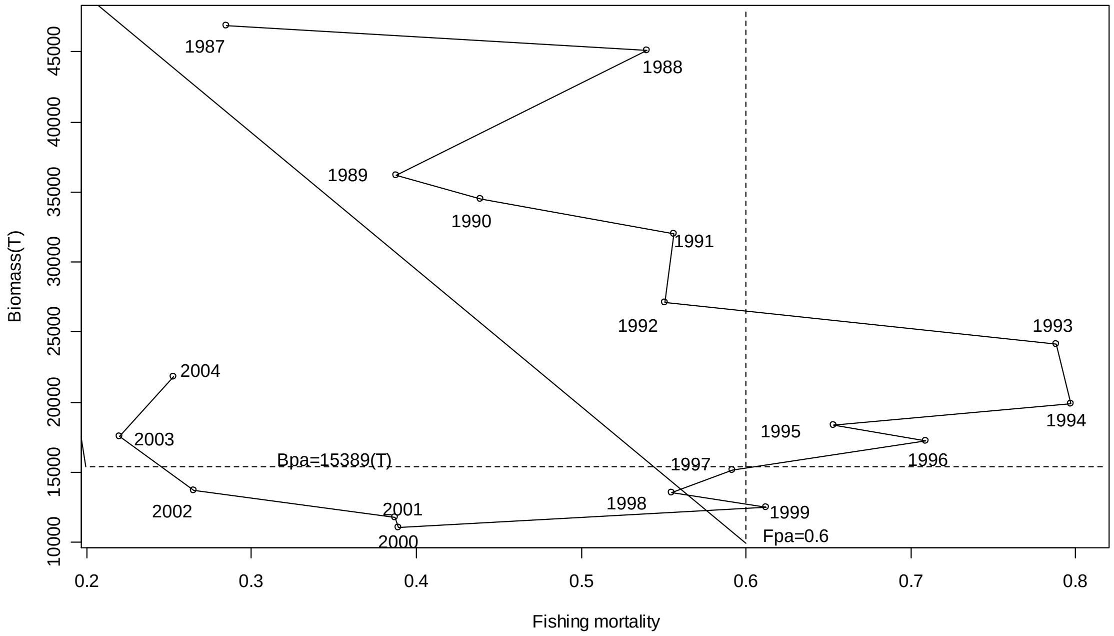


Figure 20. Plot showing SSB against Fbar(6-12) for the period 1987-2004

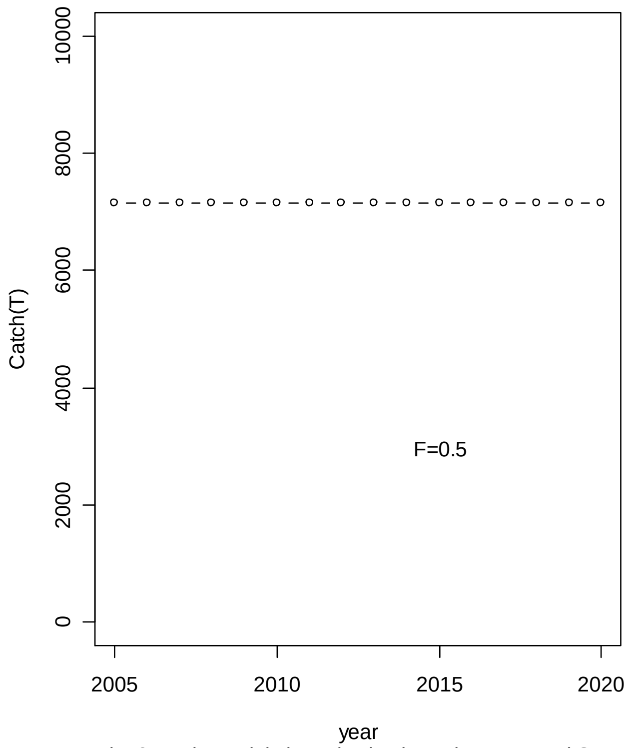


Fig. 21.A deterministic projection based on YPR and SPR

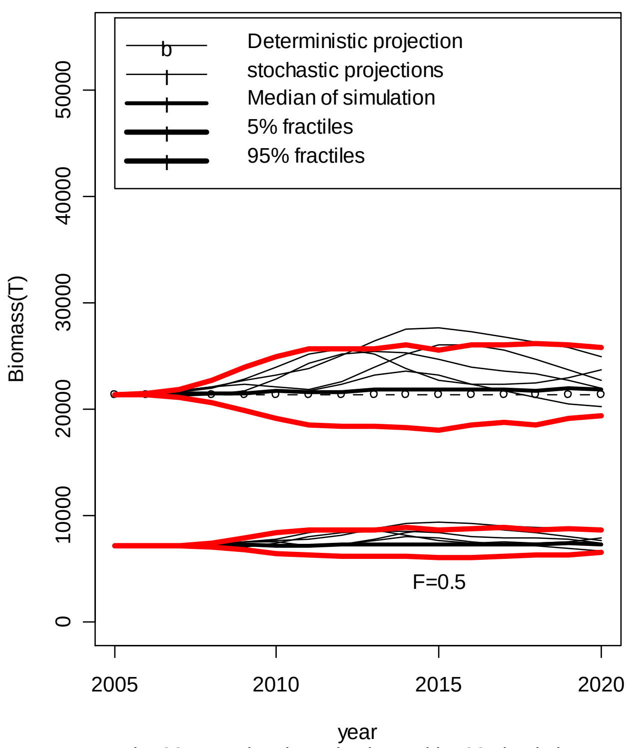


Fig. 22.A stochastic projections with 100 simulations

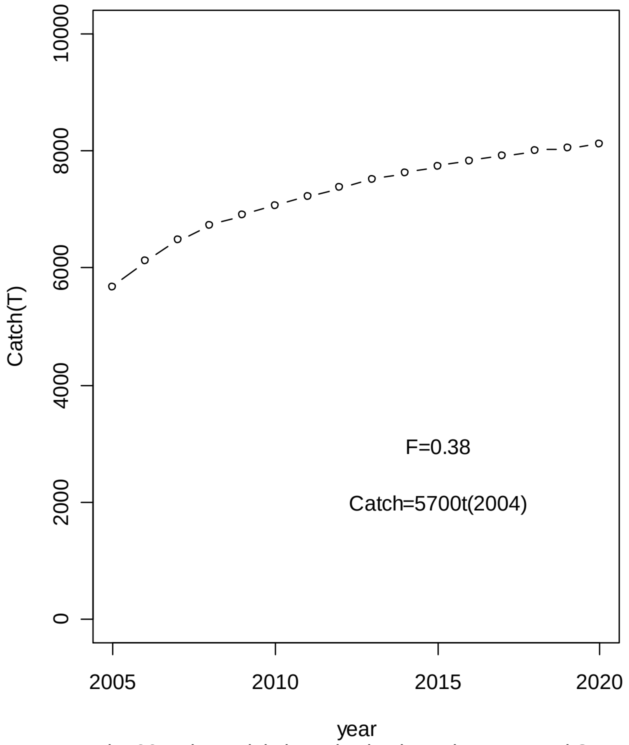


Fig. 23.A deterministic projection based on YPR and SPR

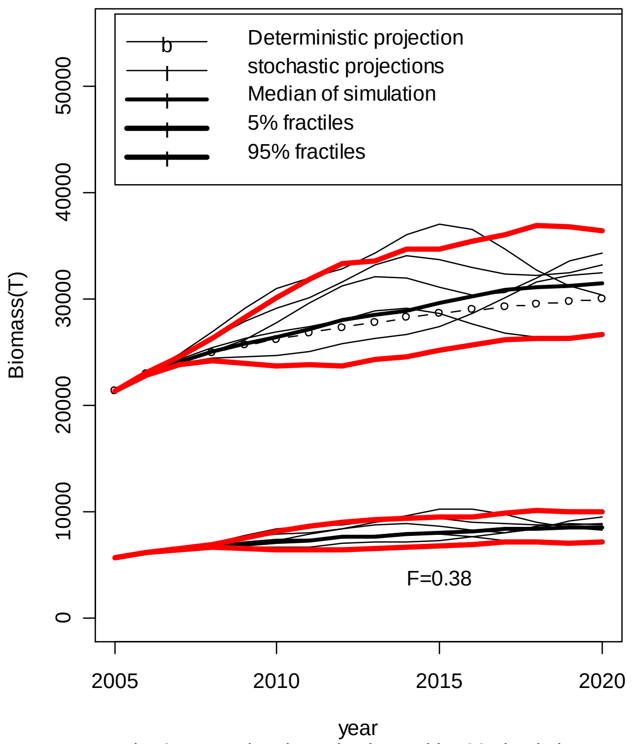


Fig. 24.A stochastic projections with 100 simulations

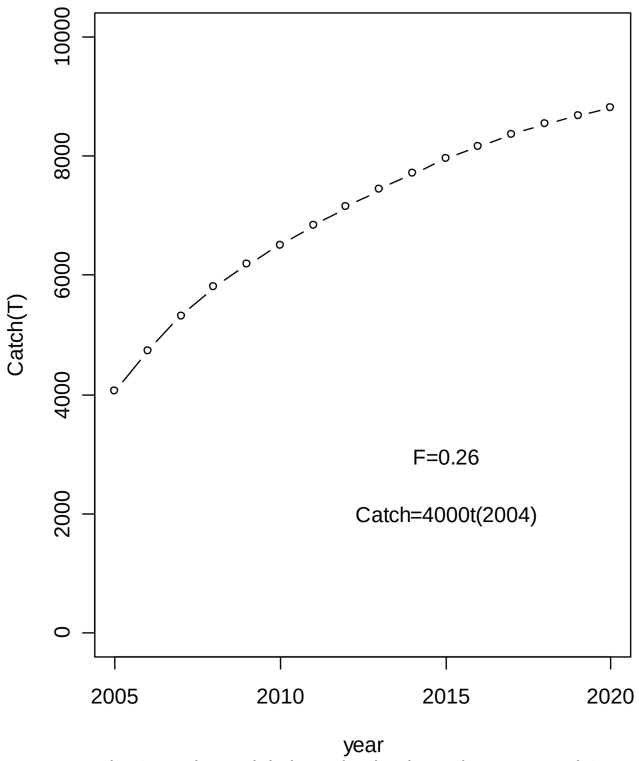


Fig. 25.A deterministic projection based on YPR and SPR

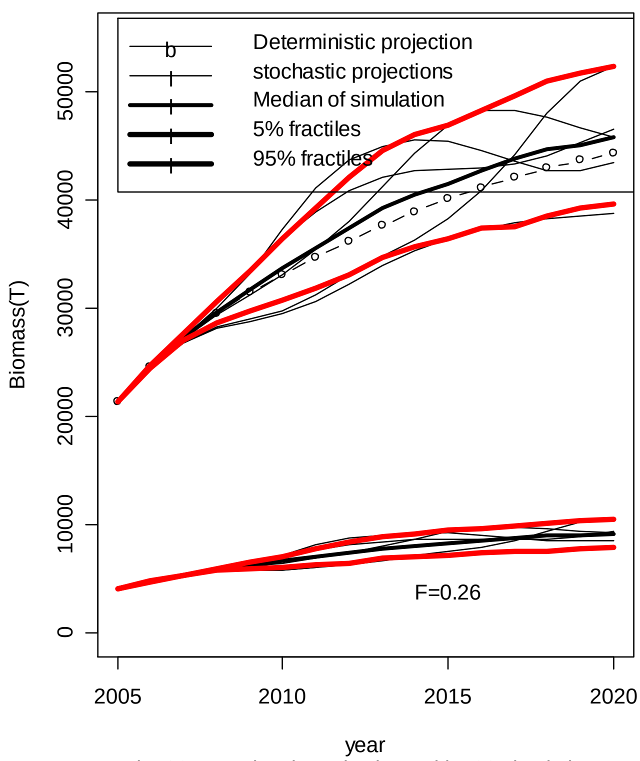


Fig. 26.A stochastic projections with 100 simulations

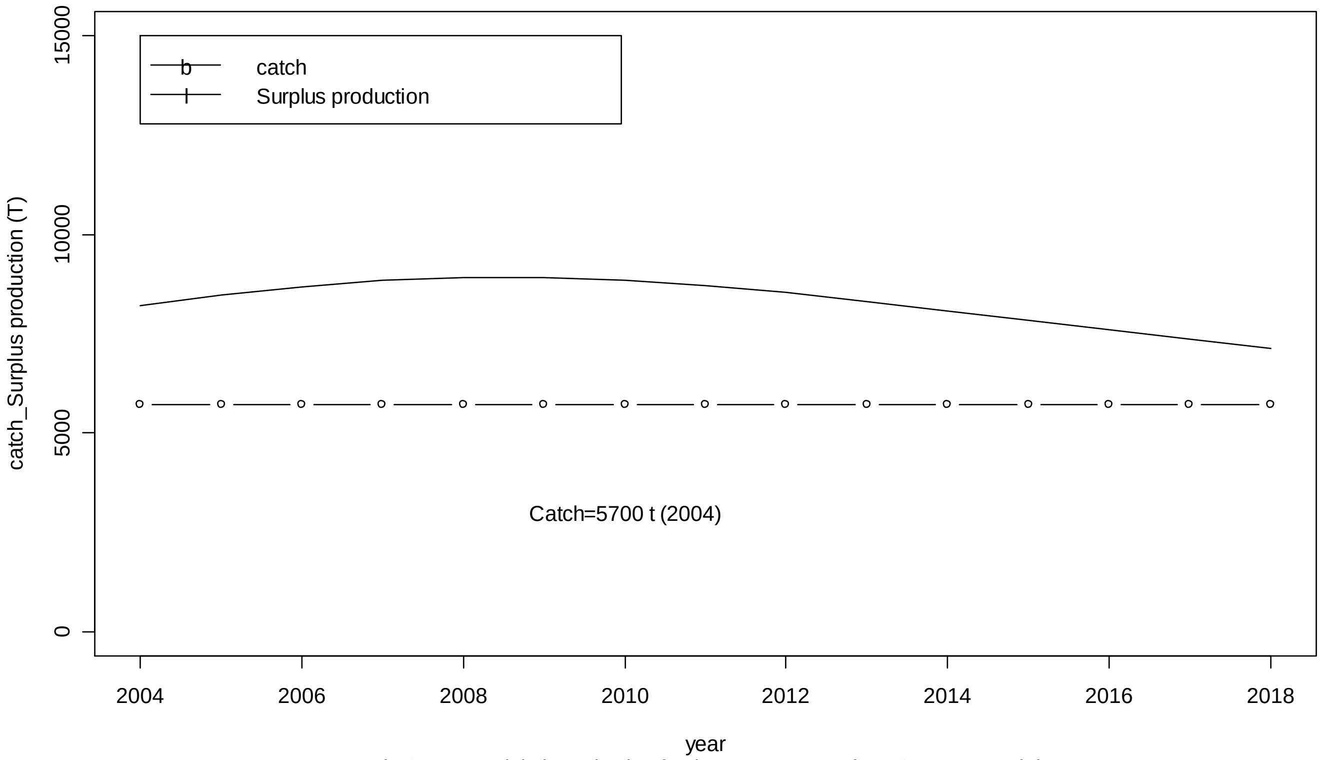


Fig.27.Deterministic projection for the next 15 years from Sur_pro. model

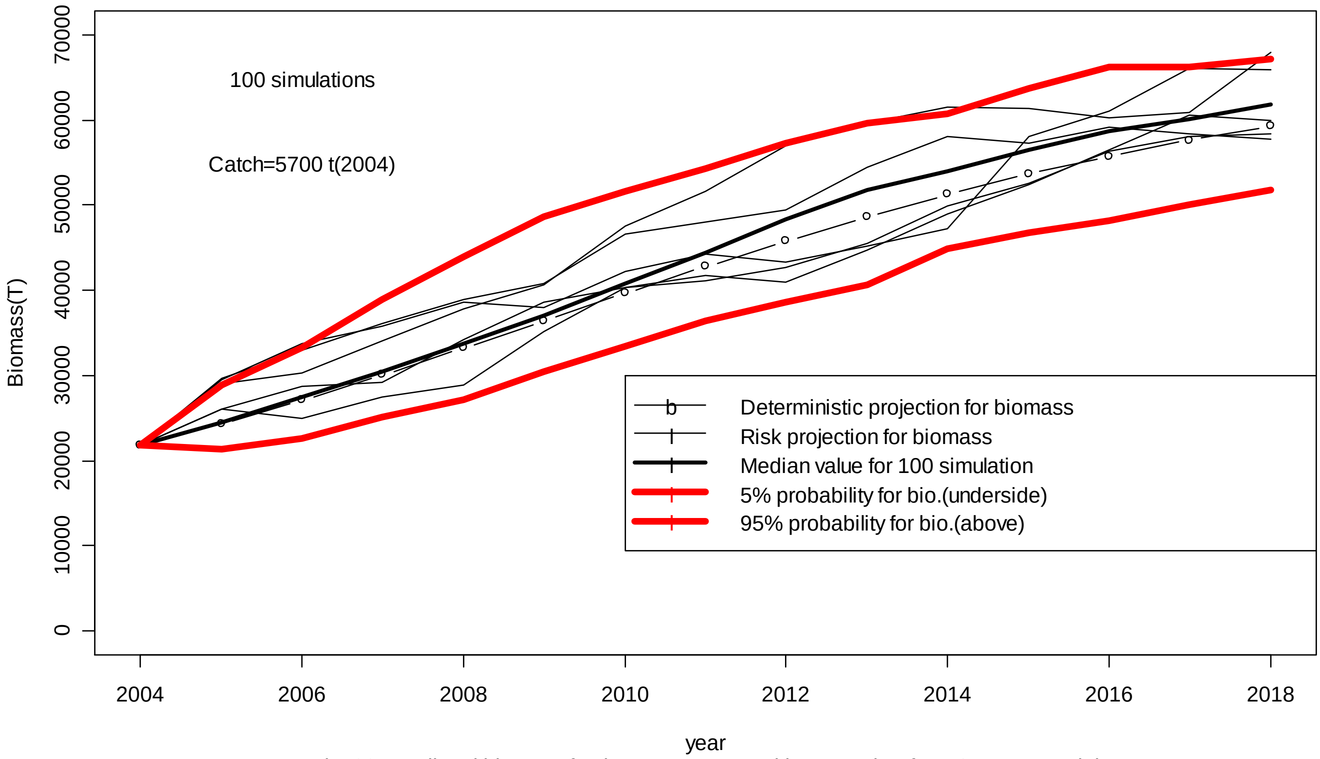


Fig. 28. Predicted biomass for the next 15 years with Uncertainty from Sur pro. model

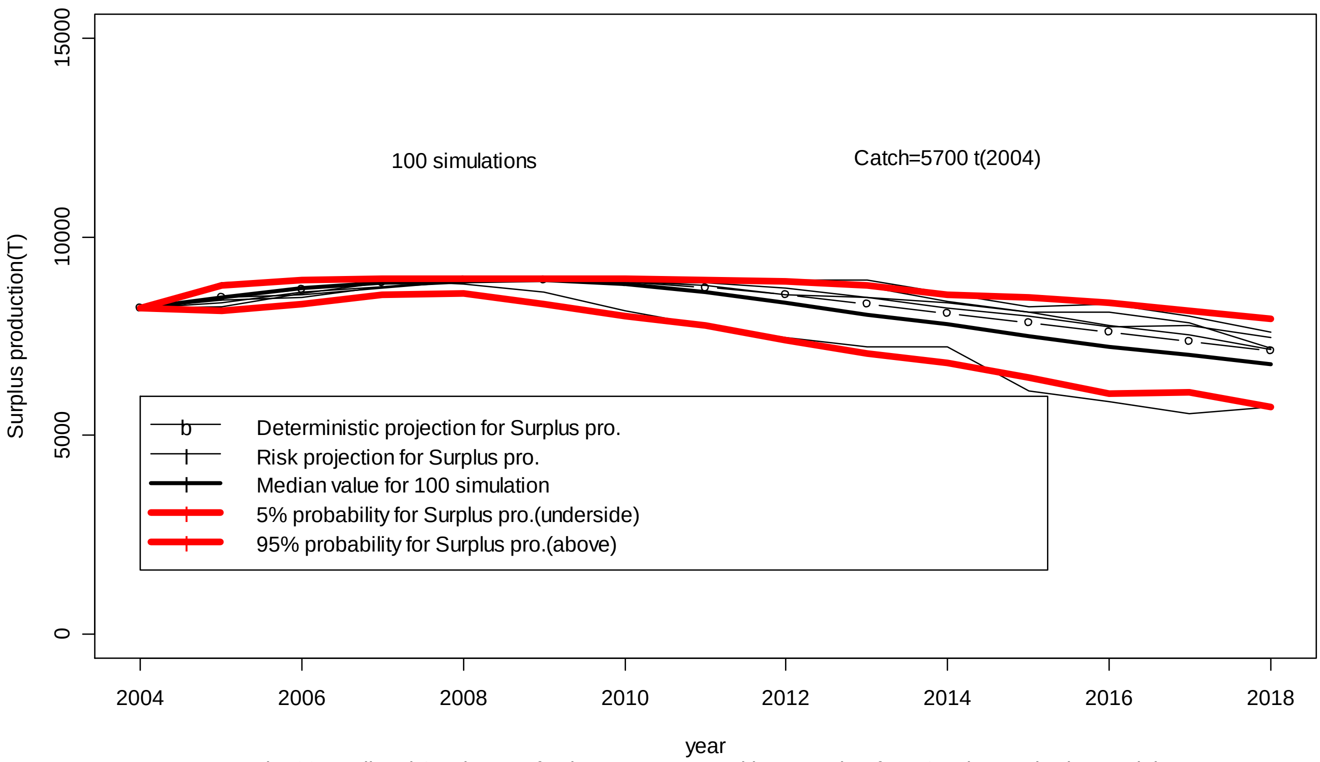


Fig. 29.Predicted Surplus pro. for the next 15 years with Uncertainty from Surplus production model

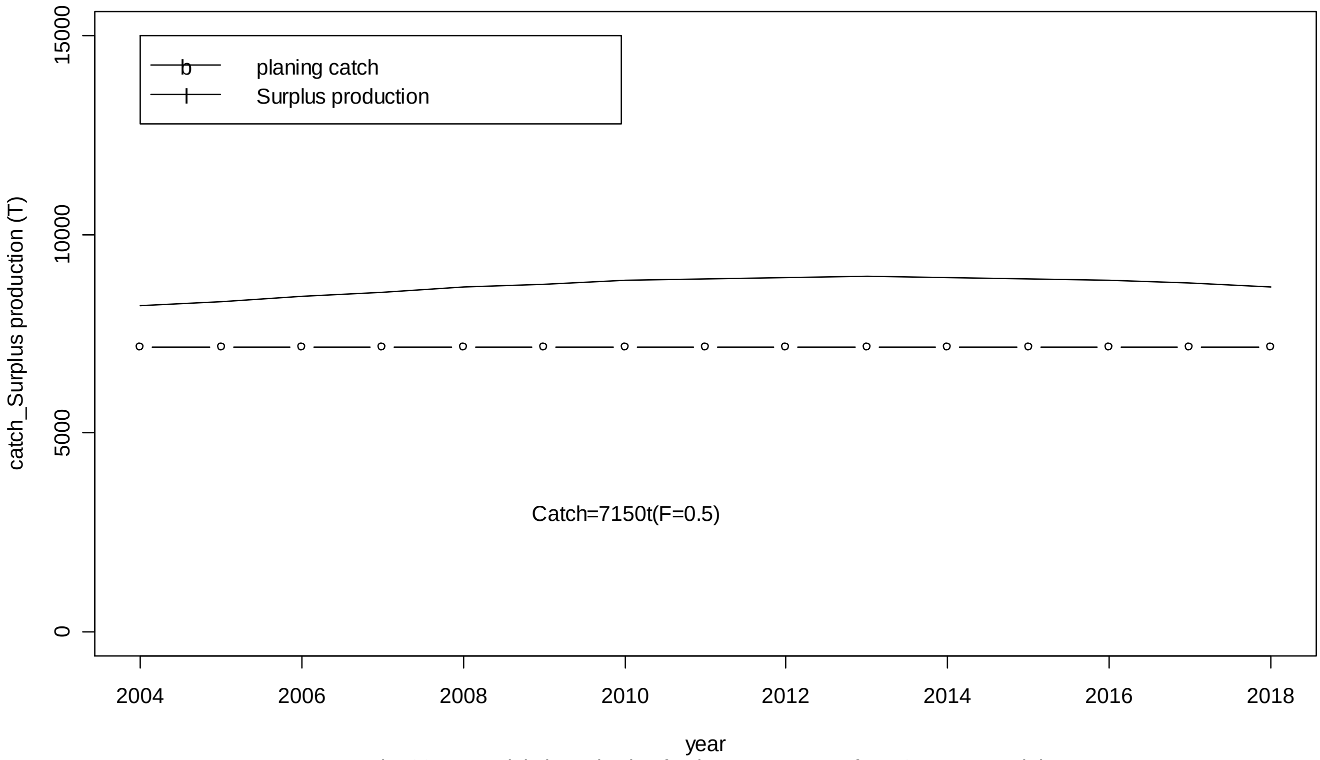


Fig. 30.Deterministic projection for the next 15 years from Sur pro. model

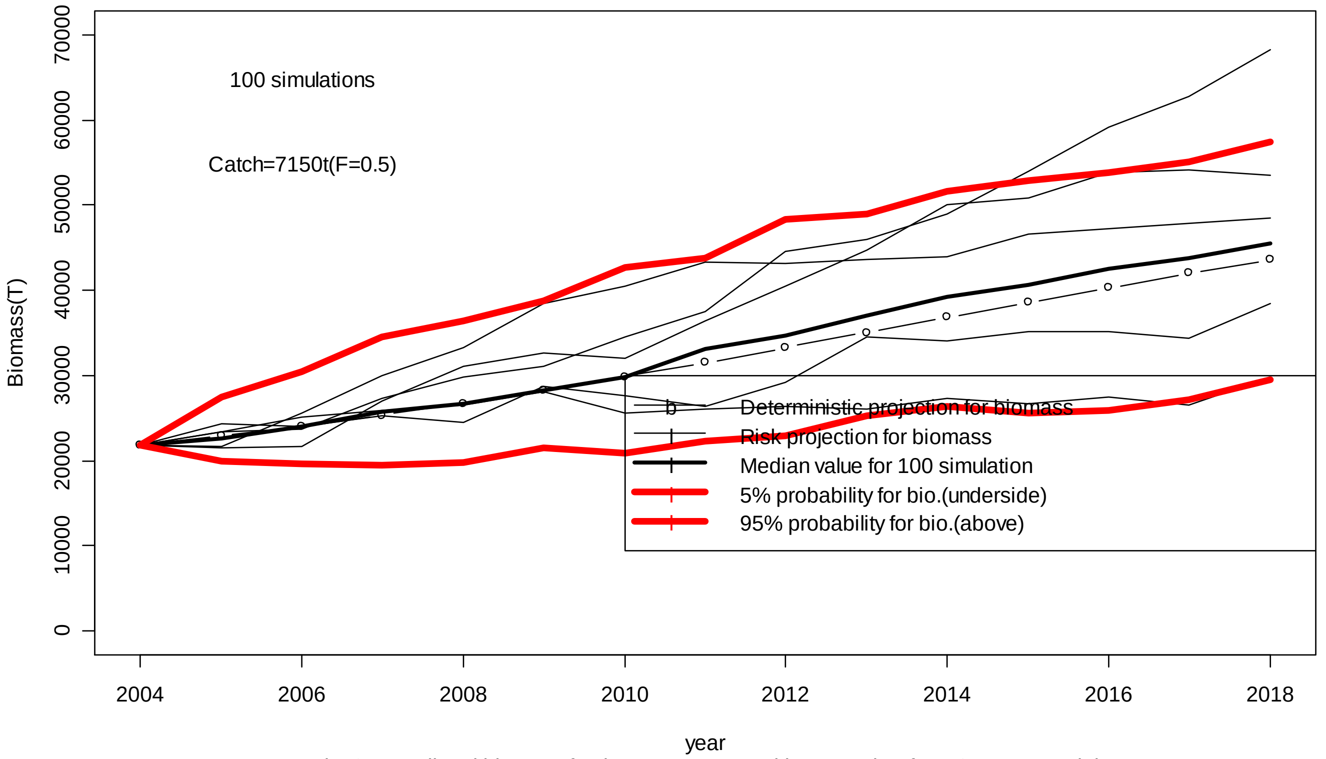


Fig. 31. Predicted biomass for the next 15 years with Uncertainty from Sur pro. model

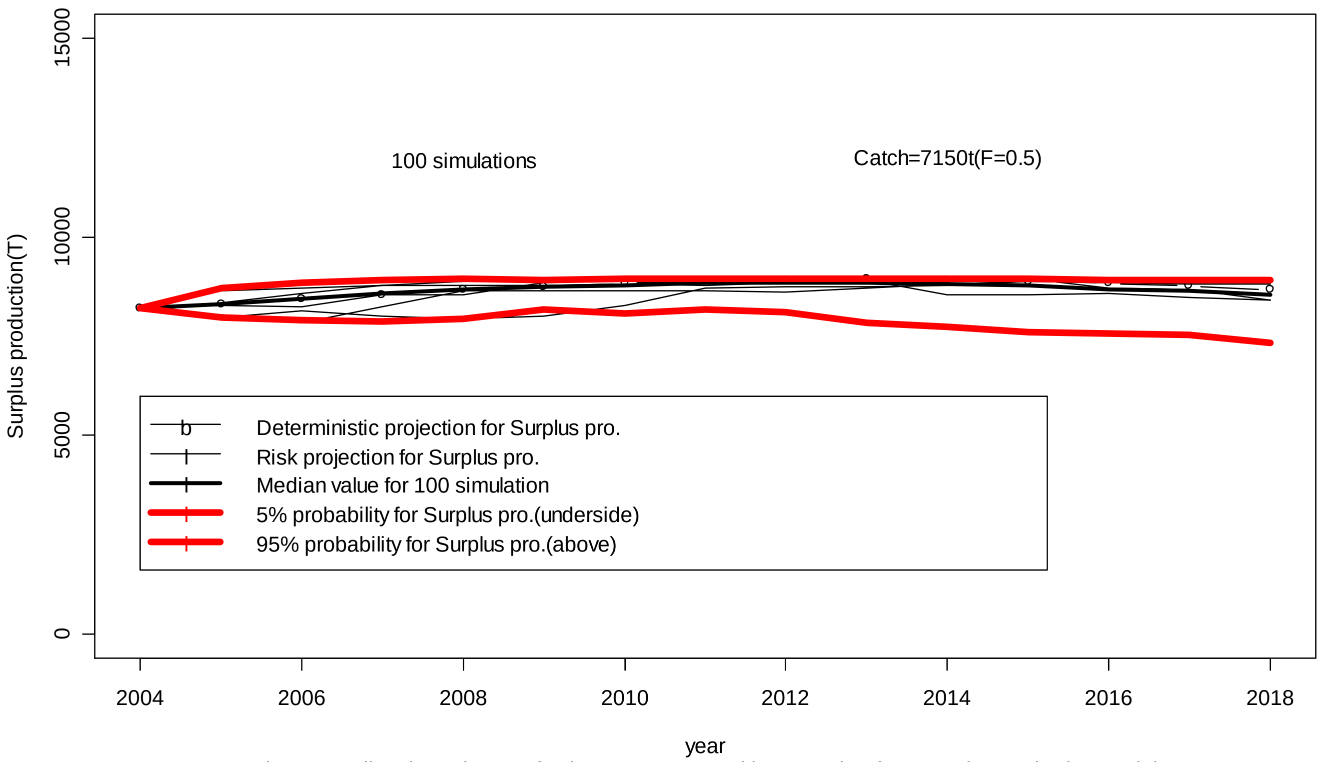


Fig. 32.Predicted Surplus pro. for the next 15 years with Uncertainty from Surplus production model

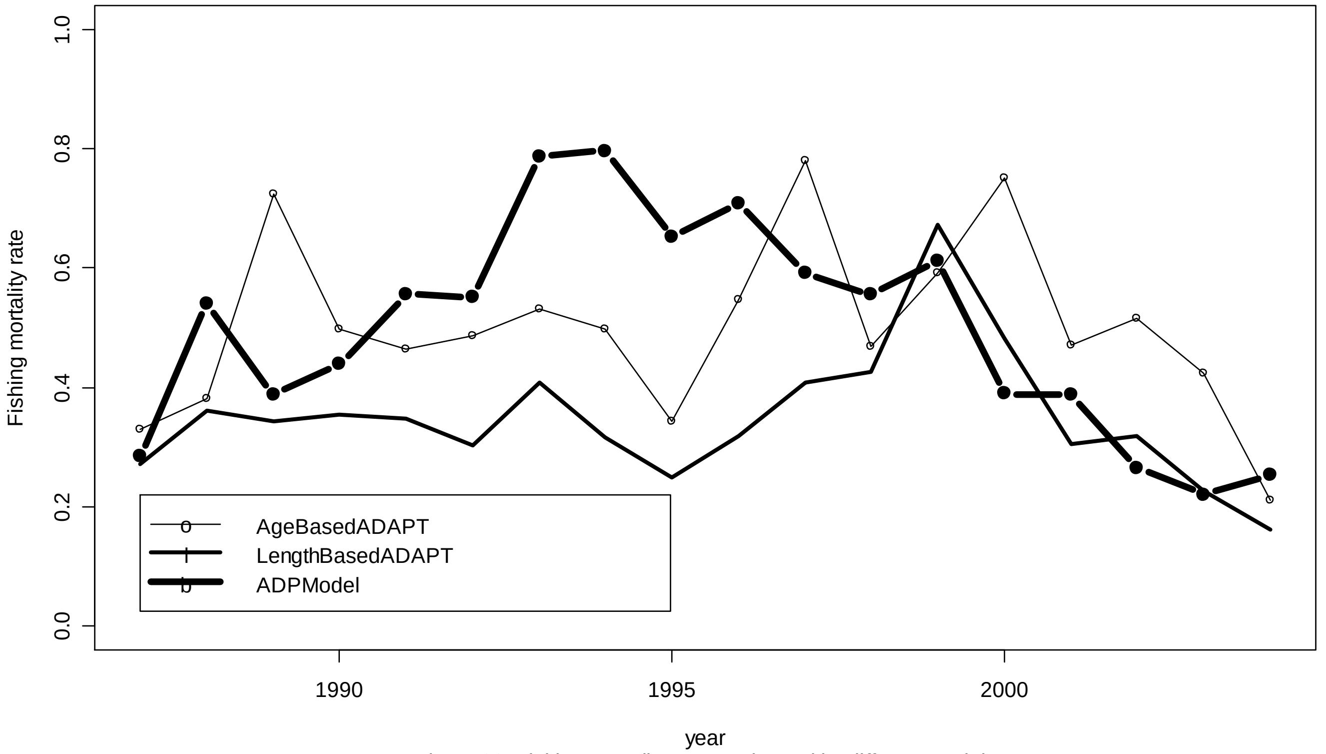


Figure 33. Fishing mortality rates estimated by different models

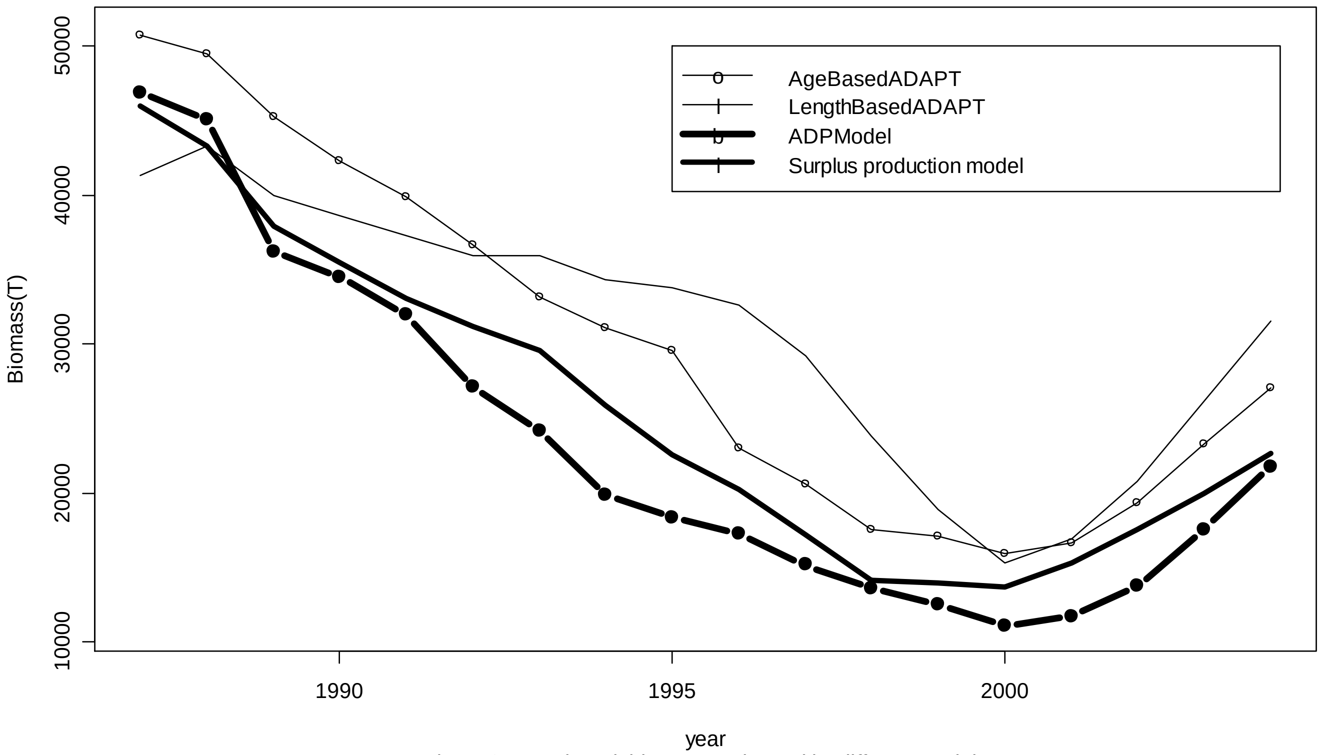


Figure 34. Total stock biomass estimated by different models

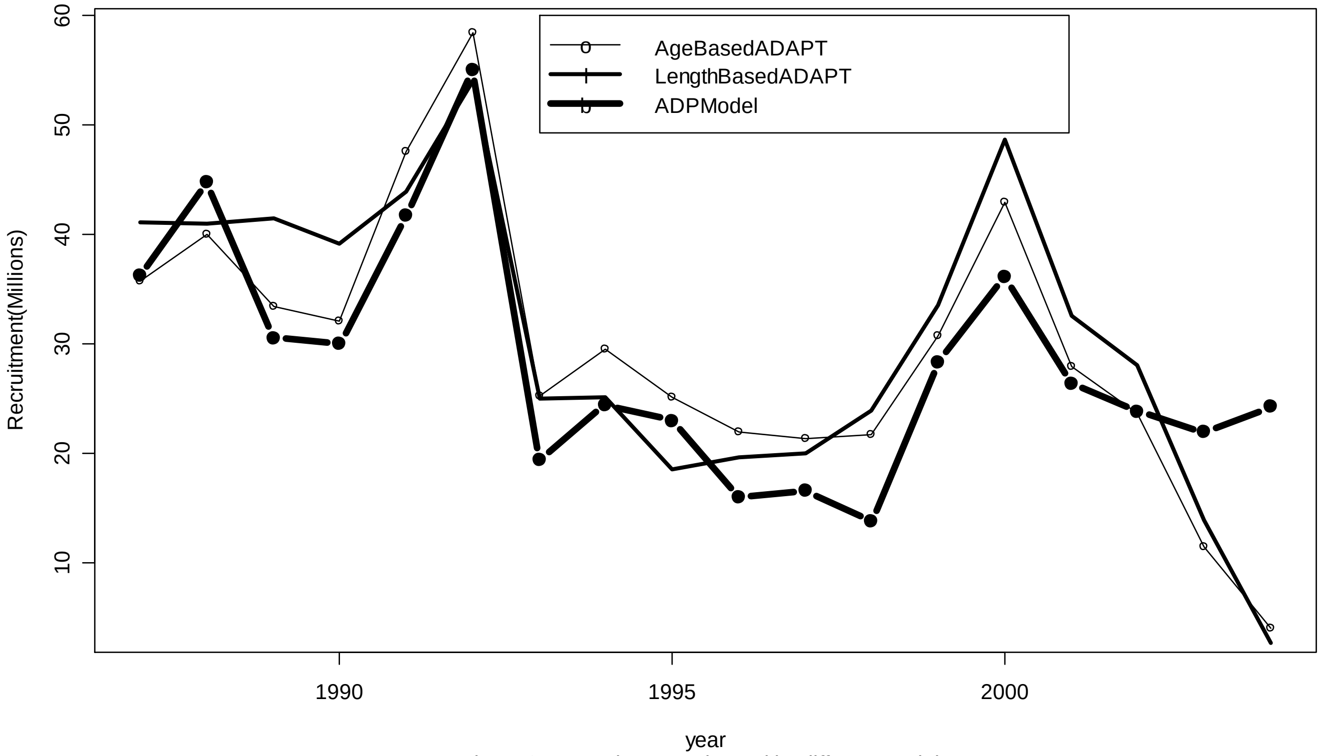


Figure 35. Recruitment estimated by different models