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THE ASSESSMENT OF THE WITCH (*Glyptochephalus cynoglossus*) IN ICELANDIC WATERS. COMPARISON OF THE DIFFERENT ASSESSMENT MODELS AND ASSUMPTIONS

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ABSTRACT

The report presents a comparison of different assessment methods on the witch stock (*Glyptocephalus cynoglossus*) in Icelandic waters. Three alternative assessment methods are used: age-based ADAPT, length-based ADAPT and Age-disaggregated Dynamic Production Model.

Most of the data used in this study are unpublished and were made available to the author in form of unpublished preliminary reports or as tables extracted by the staff of the Marine Research Institutes (MRI) from the MRI-database.

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 input source and converted into age using the least squares corresponding to a simplified version of maximum likelihood method (Macdonald and Pitcher, 1979) and then used as input data for an ADAPT analysis.

The different models give similar trend in fishing mortality rates over the period used (1987-1999) and about the same $\overline{F}$ in the final year (0.18-0.22). The stock biomass declined from approximately 18000 tons in 1987 to around 10000 tons in early 2000. The predicted yield for the year 2000 is about 1200-1400 tons.

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1 INTRODUCTION

As reported by Steinarsson et al. (1989), the witch flounder (*Glyptocephalus cynoglossus*) is characterized as a fairly slow-growing and long-lived species. Witch has been recorded all around Iceland at depths of 25-500 m. Most of the commercial catches occur from the relatively warm waters off the south and south-west coasts at depths of 100-160 m on quite distinctly marked muddy bottom areas (Figure 1). Witch has not been exploited off the north and east coast because of the relatively low density in those colder areas.
Before 1986 witch was only caught as by-catch in the demersal and Norway lobster fisheries. In late 1986 an intensive targeted Danish-seine fishery began off the south coast. The increased interest for witch was a consequence of more limited fishing for other demersal

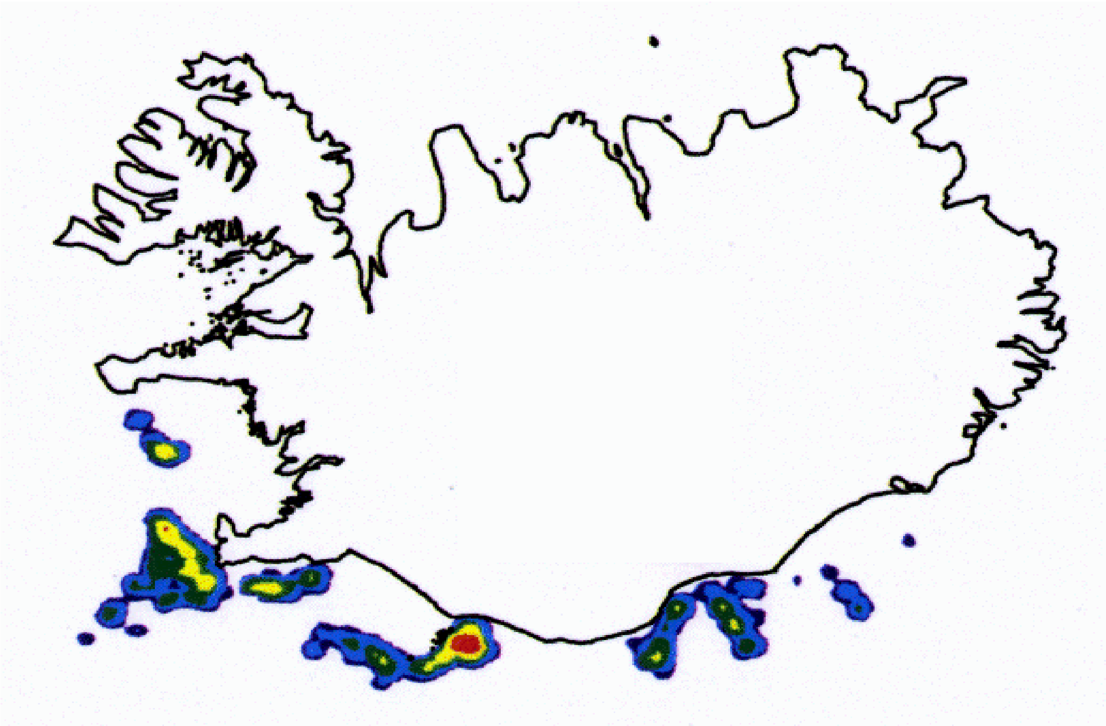

Figure 1: Main fishing grounds of the witch in Icelandic waters

species, increased marketing and development of new processing lines. Annual landings increased from 5-1400 tons in 1973-1986 to over 3000 tons in 1986 and to a maximum of about 4600 tons in 1987. After 1987 landings declined sharply to about 1300 tons in 1990 and have been fluctuating since then between 1000-1900 tons. Total landings in 1999 were about 1400 tons (Figure 2).

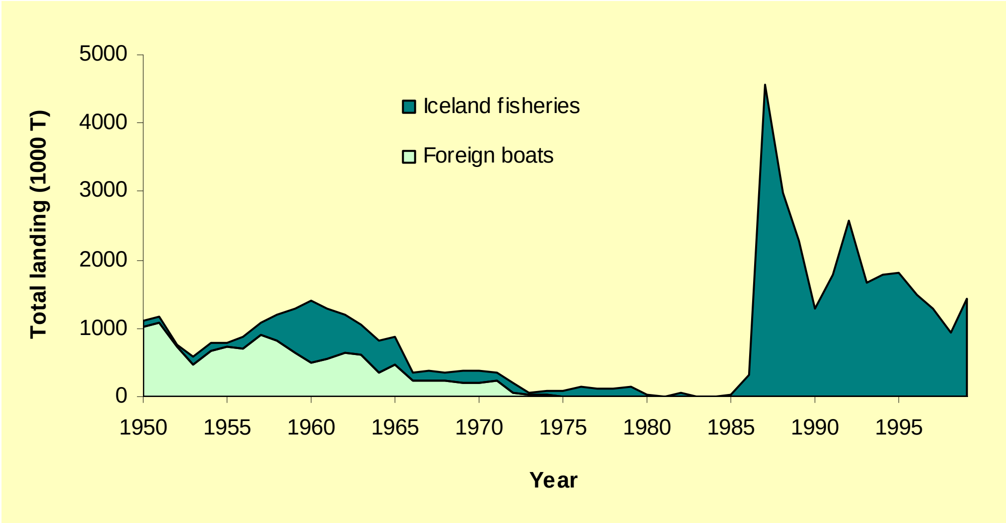

Figure 2. Catches in tons of witch from Icelandic waters from 1950-1999 (MRI 2000a).

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

Since 1994 the MRI has given advice on the exploitation of witch based on CPUE from Danish seine fleets, effort, indices from the IGFS, indices from Nephrops survey, and on preliminary VPA/Cohort analysis (Steinarsson per. comm.). The total allowable catch (TAC) for witch in recent years has been set at 1100 tons (Information Centre of Icelandic Ministry of Fisheries 2000).

The main objective of this study is to assess the witch stock with various assessment methods to evaluate the effect of different assessment methods on the stock estimates as well as to obtain overall indication of stock trend and exploitation since 1987.

Three assessing methods are used: 1) ADAPT/VPA/Cohort analysis, a standard method of assessment using catches in number at age combining with tuning indices to obtain stock size in number at age, 2) Length-based ADAPT-VPA using length frequency data as input source. It is performed in two steps. The first step is to disaggregate the age from the length distribution data using the least square method, corresponding to a simplified version of maximum likelihood method (Macdonald and Pitcher 1979). The second step is to use VPA-ADAPT method to estimate stock size with the data obtained, 3) Age-disaggregated Dynamic Production Model using catches, CPUE and different survey indices to fit the dynamics of the stock with internal age groups including various error assumptions.

A preliminary unpublished assessment result on the witch stock using Extended Survivor Analysis (XSA) (Hjörleifsson pers. comm.) (MRI 2000b) is also presented.

2 MATERIAL AND METHODS

2.1 Available data

Most of the data used in this study are unpublished and were made available to the author in the form of unpublished preliminary reports or as tables extracted by the staff of the Marine Research Institutes (MRI) from the MRI Database.

The sets of data used are as following:

a. Total nominal annual catches in tons of witch from Icelandic waters 1950-1999. Data from the annual report on the State of Marine Stocks in Icelandic Waters 1999/2000. (Appendix, Table 1).

b. Catch in number by age by year (Appendix, Table 2a), mean weight at age (Appendix, Table 4a) and maturity at age (Appendix, Table 5a) in catches from 1987-2000 calculated from samples of otolith and length along with length distributions and the length-weight relationship. Unpublished data used for a preliminary VPA analysis of the witch stock in the MRI (Hjörleifsson pers. comm.).

c. CPUE indices: CPUE indices (Appendix, Table 3a) based on Icelandic Danish seine fleets log-books 1987-1999. This is the mean catch when more than 70% of the total catch was witch (Pálsson pers. comm.).

d. IGFS indices 1987-1999 (Appendix, Table 3a): These are total abundance indices of witch based on data from the Icelandic Ground Fish Survey that were estimated with the Cochran method by depth strata. The IGFS is designed for cod and therefore the sampling is not optimal for witch (Björnsson pers. com.).

e. Nephrops survey indices (Appendix, Tables 3b and 3c): Total and age-disaggregated abundance indices based on data from the Icelandic Nephrops survey conducted annually off the south coast of Iceland. The survey was redesigned in 1995 to allow for more intensive sampling of witch (Pálsson pers. comm.).

f. Other data:

- The mean length at age (Appendix, Table 4d), maturity at age (Appendix, Table 5a), and maturity rate at length (Appendix, Table 5c) from Nephrops survey. Data extracted from the MRI Databases (Steinarsson pers. comm.)
- Length distributions from commercial landing samples 1987-1999 (Appendix, Table 6a). Data extracted from the MRI-databases (Steinarsson pers. comm.).
- Length-weight relationships: $\mathbf{W=0.00139*L^{3.4373}}$**.** The parameters of the length-weight relationship were determined from sampling the catches of commercial seiners in 1989 (Steinarsson et al. 1989)

2.2 Methods

2.2.1 Age-based ADAPT

An Excel spreadsheet analysis was set up for the year-classes from 1987-2000 using catches in number at age in 1987-1999 (Appendix, Table 2a) and CPUE indices from Nephrops survey 1995-1999 (Appendix, Table 3c).

ADAPT-VPA is a well known method of assessment using catches in numbers at age combined with tuning indices to obtain stock size in numbers at age (Stefánsson 1992). 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 a 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:

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

Where $\mathbf{N_{a\,y}}$	is the size of the age group a in year y
$\mathbf{N_{a+1,\,y+1}}$	is the size of the group a in the next year to the year y
$\mathbf{Z_{a\,y}}$	is the total mortality rate for the age group a in year y
$\mathbf{F_{a\,y}}$	is the fishing mortality rate for the age group a during year y
$\mathbf{C_{a\,y}}$	is the total catch in number of the age group a in year y

For a given age group ***a*** having the size $\mathbf{N_{ay}}$ at the beginning of the year ***y***, provided no fishing taking place in the period of first six months, the size of the year-class at the middle of the year will be

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

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

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

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

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

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

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

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

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

$$\mathbf{N_{a+1,\,y+1} = N_{ay} * e^{-Zay}}$$

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

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

The total mortality ($\mathbf{Z_{ay}}$) is the sum of fishing mortality ($\mathbf{F_{ay}}$) and natural mortality (**M**), so we have:

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

In principle, the fishing mortality rates on the oldest age groups can be estimated, but these are always prone to large errors. Therefore, the fishing mortality on 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 pattern are badly 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 3 years prior to the last one (1994-1996).

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 chart.

Survey information on catch per towing hour is used as indices of abundance in number by age group by year ($\mathbf{U_{ay}}$) which is assumed to be related to stock abundance as follows:

$$\mathbf{U_{ay} = q_a * N_{ay}} \qquad \textbf{(5)}$$

Where $\mathbf{q_a}$ is constant in time but assumed to be variable by age group. For a given stock size estimation and coefficients ($\mathbf{q_a}$), predicted value $\mathbf{\hat{U}_{ay}}$ can be computed.

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

One possible way to conduct such a comparison is through stating that for 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:

$$\mathbf{SSE} = \sum_{ay} \mathbf{w_{ay} * (lnU_{ay} - ln\hat{U}_{ay})^2}$$

$$\textit{i.e.} \qquad \mathbf{SSE} = \sum_{ay} \mathbf{w_{ay} * [lnU_{ay} - ln(q_a * N_{ay})]^2} \qquad \mathbf{(6)}$$

Then unknown coefficients in the model are therefore the catchability ($\mathbf{q_a}$) and the fishing mortality rate of the last year. So only fishing mortality $\overline{F}$ for the last year need to be estimated (in this project it is estimated as the average of fishing mortality rates of three years 1994-1996).

For a given $\overline{F}$, the coefficient $\mathbf{q_a}$ is estimated as the average of $\ln(\mathbf{q_a}) = \ln(\mathbf{U_a}/\mathbf{N_a})$. Thus it becomes simple to compute SSE for each value of $\overline{F}$. Different values may be tested for $\overline{F}$ until a low value for SSE has been established. Thus an estimation of the fishing mortality for the last year has been obtained.

The equation (6) contains scaling coefficient (weight), $\mathbf{w_{ay}}$, which should indicate the relative precision for the age groups in the survey data. These numbers can be estimated by examining how low the sums of square can be for each age.

2.2.2 Length-based ADAPT method

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

The length-based method uses the length frequency data as input source. It will contain two steps. The first step is to disaggregate the age from the length distribution data using the least square corresponding to a simplified version of maximum likelihood (Macdonald and Pitcher 1979, Hasselblad 1966). The second step is to use the method VPA-ADAPT as described in chapter 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 1987-1999 (Appendix, Table 6a) and from the Nephrops survey indices 1995-1999 (Appendix, Table 3a). The conversion to age distribution from length distribution data is performed with a simplified version of the length frequency analysis method of Macdonald and Pitcher (1979), from which the information of the mean length at age, standard deviation, and probability of density (or proportion) at age are also estimated. These are then used to calculate the mean weight at age and maturity proportion at age.

- *Estimation of annual catch in numbers at length from length frequency samples:*

$$\mathbf{C_y} = \frac{\mathbf{Y_y}}{\overline{\overline{\mathbf{W}}}_\mathbf{y}}$$

Where $\mathbf{Y}_y$ is the total landing in year y,

$\overline{\mathbf{W}}_y$ is the mean weight of individual in year y, which is calculated as follows:

$$\overline{\mathbf{W}}_y = \frac{\sum_i w_i * f_i}{\sum_i f_i}$$

Where w_i is the mean weight of individuals at length class i, converted from length using the length weight relationship ($\mathbf{W=0.00139*L^{3.4373}}$) and f_i is the frequency of length class i.

- *Length-age conversion:*

If a distribution mixture consists of k ages, and the distribution of the age a can be described by the probability density function $f_a(x)$, the overall probability density function $g(x)$ appropriate to samples from the mixed population can be written as:

$$g(x) = \sum_{1}^{k} p_a * f_a(x) \quad (1)$$

Where p_i denotes the relative abundance of age a as a proportion of the total population and must therefore satisfy the following conditions:

$$\sum_{1}^{k} p_a = 1 \qquad \text{and} \qquad 1 \geq p_a \geq 0 \qquad (2)$$

The $f_1(x), \ldots, f_k(x)$ have a common functional form but have different means and, possibly, different variances. It can be written $f_a(x) = f(x|\mu_a, \sigma_a)$ where μ_a, σ_a denote the mean length and standard deviation of age a. If the age distributions are assumed to be normal, then:

$$f(x|\mu_a, \sigma_a) = \frac{1}{\sqrt{2\pi\delta^2}} * e^{\frac{1}{2}[-(x-\mu)/\delta]^2} \qquad (3)$$

The means and standard deviations should satisfy the constraints:

$$\sigma_a > 0 \qquad (a = 1, \ldots, k) \qquad (4)$$

$$\mu_1 < \mu_2 < \ldots \mu_k \text{ and } \sigma_1 < \sigma_2 < \ldots < \sigma_k \qquad (5)$$

In fisheries age-size analyses, this is a natural constraint and the case of equal means and standard deviations should not arise.

A necessary condition for the estimation problem to be meaningful is that the mixture be identifiable. That is, given k, the functional form of $f(x|\mu, \sigma)$, and the constraints (2), (4), (5), then identifiability implies that no two distinct sets of parameter values can give rise to the same mixed probability density function $g(x)$. In principle, we can determine all parameters of the mixture exactly if we know $g(x)$ exactly and if the normality assumption is valid. In practice, of course, we do not know $g(x)$. Instead, we only have a length-frequency distribution from which we estimate ***g(x)*** . Furthermore, the true form of the distribution of length, weight, or other parameter of size within each age group is never known exactly, and a normal distribution is usually chosen only because it is reasonable and convenient.

- *Mean weight at age estimation:*

When the mean length at age has been estimated by separating length frequency of each year-class from the total length-frequency distribution using the Macdonald and Pitcher model, the mean weight at age will be estimated using the length weight relationship.

- *Maturity rate at age estimation:*

The theoretical ogive of maturity at length is estimated from the equation (Pearl and Reed 1920) as quoted by Skúladottir and Pétursson (1999):

$$p_i = (1 + e^{-(a+bi)})^{-1}$$

where p_i is the propotion of mature individuals in length group i, a and b 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.

With the mean length at age estimated by the Macdonald and Pitcher method, this equation is used to estimate the maturity rate at age.

2.2.3 Age-disaggregated dynamic production model

The model attempts to draw the overall picture of how the stock has changed from year to year since 1987. The nominal catches from Icelandic waters in 1987-1999 (Appendix, Table 1) and various CPUE indices from different surveys (Nephrops survey 1995-1999, Danish seine CPUE 1987-1999, Icelandic Ground Fish Survey 1987-1999) (Appendix, Tables 3a, b & d) will be used to fit a dynamic stock production model with internal age groups. The model will be extended to include age-disaggregated recruitment indices obtained from the mentioned Nephrops survey. Various error assumptions, including process error, will be included.

The change of the stock biomass is often expressed by the dynamic stock production model:

$$\mathbf{B_{y+1} = B_y - Y_y + R_y}$$

where B denotes the total biomass. This equation states that the stock size in the next year is equal to stock size of this year minus catch and plus production over the year.

In this project the approach is different since an age-disaggregated dynamic production model is used.

Assuming that in 1986 there is no fishing of the stock and a virgin value of recruitment $\mathbf{R_o}$ $(\mathbf{N_{3,1986}=R_o})$**,** the stock size is calculated for this year is:

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

where $\mathbf{R_o}$ will be estimated.

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

$$N_{a+1,\,y+1} = N_{a,\,y} * e^{-Zay}$$

The number of individuals in the age group, which is treated as a plus group, is calculated as:

$$N_{a\,y} = N_{a-1,\,y-1} * e^{-Za-1,y-1} + N_{a,\,y-1} * e^{-Za,y-1}$$

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

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

Where **B** is spawning stock biomass and **K** is the maximum biomass or starting biomass $\mathbf{B_o}$.

The parameters $\boldsymbol{\alpha}$, **K**, $\mathbf{R_o}$, $\overline{\mathbf{F}}$ will be adjusted to provide the best fit of the predicted-to-observed time series of catch data and abundance indices. The fitting procedure used in this model is least-squares fitting:

$$SSE = \sum_y (U_y - \hat{U}_y)^2 + \sum_y (R_y - \hat{R}_y)^2 + \sum_y (Y_y - \hat{Y}_y)^2$$

Where **SSE** is total sum of squared errors, $\hat{U}_y$, $\hat{R}_y$, $\hat{Y}_y$ are annual model predicted abundance indices, recruitment indices and yield over years from the model.

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

$$\hat{U}_y = q * B_y$$

where $\mathbf{B_y}$ is the exploitable biomass of the stock, $B_y = \sum_a N_{ay} * w_{ay} * S_{ay}$

q is catchability and assumed to be constant every year, $q=(1/k)*\sum_{y=1}^{k} (U_y/B_y)$

To predict the yield, the following equation is used:

$$\hat{Y}_y = \sum_{ay} \hat{Y}_{ay} = \sum_{ay} \frac{F_{ay}}{Z_{ay}} * (1 - e^{-Zay}) * N_{ay} * w_{ay}$$

To predict the recruitment index, the following equation is used:

$$\hat{R}_y = r * N_{3,y}$$

where $N_{3,y}$ is the number of age 3 or the recruitment estimated from stock-recruitment relationship and coefficient $r = (1/k) * \sum_{y=1}^{k} (U_3/N_{3,y})$

2.2.4 Yield prediction for the next year.

With the given stock size estimation of the last year (1999), it is possible to compute catch projections. The outcome of 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 year 2000 is calculated using the following equation:

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

The natural mortality for the last year is known. The fishing mortality rate of the year to come is assumed to be equal to the fishing mortality of the last year. That means that the fishing pattern is assumed remain the same from 1999 to 2000:

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

The catch in number by age of the year to come 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 year is assumed to be equal to the average of the recruitment of the previous years.

Total yield of the year to come will be estimated by the equation:

$$Y_y = \sum_a Y_{ay} = \sum_a C_{ay} * w_{ay}$$

Where w_{ay} is the mean weight at age in the year of prediction.

In the case of age-based VPA and production model, the mean weight at age in year 2000 is available. In the case of length-based ADAPT, it will be estimated as the average of mean weight at age in the previous years.

The projection will be run with two different assumptions of natural mortality, M=0.05 and M=0.25 on the prediction of the catch for the year 2000.

3 RESULTS

3.1 Estimation of mean length at age and catch in number by age by year from length distribution data

The input data, catches in number by length estimated from length frequency samples of commercial landings and standardized length distributions from Nephrops survey, are presented in the Appendix, Table 3b and Figure 1a, Table 6b and Figure 2a respectively.

The length of the fish in landings ranges from 22-50 cm and in survey data from 15-50 cm. That reflects the difference in the selectivity of the gear used (smaller mesh size in the Nephrops survey). In the survey dataset, the recruitment (22-25 cm) can be seen very clearly in almost all years, especially in 1997 and 1999 (Appendix, Figure 1a).

These data were used as input for age-disaggregation model (Macdonald and Pitcher) with a given value for the component (k) in the mixed length distribution and a set of initial values that define the distribution of each component (mean length, standard deviation and probability of density). According to the age data, the age distributions in landings span the age groups from 3-14, and in the survey data from 2-14. Accordingly, the number of age groups was set to 12 (or k=12) in the landings and 13 (k=13) in the survey. The initial input including mean length at age (μ_a), standard deviation (σ_a) and probability of density at age (p_a) was initialized in accordance with the constraints of the model. By changing the initial value and minimizing total squared errors from estimated-to-observed over all length groups, the mean length, standard deviation and proportion at age was estimated. This was done separately for each year.

The length distributions are highly mixed, the number of modes in the distribution is far less than number of ages (k=12 and 13) and the overlap between ages is large. Because of that, some difficulties came up in the fitting process resulting to unreasonable values to 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. In such cases, the mean values for the corresponding ages for other years were used as initial values.

The observed and fitted length distributions are presented in the Appendix, Figures 1a and 2a. The fit is clearly very good but this is of course due to the large number of parameters.

The estimates of age-disaggregated catch and abundance indices are shown in the Appendix, Tables 2b and 3d respectively. The comparisons between the model estimates and the age-data estimates for catch and survey indices are presented in the Appendix, Figures 1b & c and 2b & c respectively. There is a good fit (R^2>0.5) of estimated-to-observed in year 1997 for survey data and in 1998, 1990, 1991, 1994, 1997 (R^2>0.5) for landing data. More than 50% of the estimates in both cases do not have good fit (R^2<0.5). The fitting results are also presented by age over the year for the estimates from landing and survey data in the Appendix, Figures 1d and 2d. The best fit was obtained in the age groups 8, 10, 11 (R^2>0.5) in landings and 3, 8 and 9 (R^2>0.7) in survey data. For the other ages the fit was not good (R^2<0.5). This indicates that the proportion at age was not well estimated.

The estimated catch in number at age and the age-disaggregated abundance indices are presented in the Appendix, Tables 2b and 3c. The estimated mean lengths at age and corresponding standard errors from landings and survey data are presented in the Appendix, Table 4d and Figure 3a. The estimated mean lengths at age 3-7 in the landings were higher than those in surveys. That is because the length distribution obtained from commercial landings was influenced by the gear selectivity, which often results in the overestimation of the mean length at age of younger fish. The mean length at age 5-8 estimated from the length distributions in both the landings and the surveys is around 10% lower than the estimates from the age data in the surveys (Appendix, Figure 3a).

The estimated von Bertalaffy growth parameters from the mean length at age derived from survey data are L_∞=93.998 cm, K=3.592 and t_0=-0.041. In Icelandic waters, according the report by Steinarsson et al. (1989), the maximum length of witch observed is 72 cm. The life span of witch can be up to 30 years (Burnett 1987).

3.2 Maturity and mean weight at age

The mean weight at age in landings and in surveys as calculated using the mean length at age from Section 3.1 and the length weight relationship given in Section 2.1 is given in the Appendix, Tables 4b and c respectively. The means and standard errors of the mean weight by year are shown in the Appendix, Figure 3a.

The maturity at age in landings and surveys is estimated from the converted mean length at age by year using the length maturity ogive. The length maturity ogive is estimated from the observation of maturity at length from the Nephrops survey (Table 5c). The parameters of the maturity ogive, a and b, were determined by least square method fitting estimated-to-observed as –9.02 and 0.30 respectively. The length maturity ogive is presented in the Appendix, Figure 4. The length at which 50% of the population is mature was estimated to be approximately 30 cm.

The proportion mature at age calculated by the above-described method is compared in the Appendix, Figure 5 to the maturity ogive calculated from otolith data. In fact, the selectivity of the fishing gear does not take maturity into account, but only the length. Using the age-disaggregation model's mean length at age for the calculation of maturity may produce errors if the mean length at age was not well estimated. In this case, the maturity ogive from otolith data results in 10% higher maturity for ages 4-6. Apart from that, the curves are similar, indicating that 50% of the population is mature between ages 5 and age 6.

3.3 Age-based ADAPT model

The age-disaggregated catches in numbers by year (Appendix, Table 2a) were used for the cohort analysis and the age-disaggregated abundance indices from Nephrops survey (Appendix, Table 3c) for the tuning process. The reference fishing mortality, $\overline{\mathbf{F}}$, is taken as the average fishing mortality of ages from 6-11 as these age groups are dominant in the catch. The selection pattern by age, $\mathbf{S_a}$, is taken as average $\mathbf{S_a}$ of the years 1994-1996. Fishing effort of the oldest group is taken as the average of the fishing mortality of three younger ages from 11-13. The natural mortality used in the base case analysis was set at M=0.15. The mean weight at age by year (Appendix, Table 4a) and maturity at age by year (Appendix, Table 5a) that were estimated from otolith samples is used for estimating the stock biomass and spawning stock biomass.

The method of least-square was used to estimate $\overline{\mathbf{F}}$ and stock size of the last year by minimizing the sum of squares of the differences between the observed and model predicted age-disaggregated abundance indices. The comparison of abundance indices and stock estimates by age is shown in the Appendix, Figure 6. The correlation coefficient for the age groups 3, 4 and 6 was below 0.5 (R^2<0.5), but for other age groups the fit was quite good (R^2>0.6). The $\overline{\mathbf{F}}_{6-11}$ in the last year is estimated as 0.22. The estimates of $\overline{\mathbf{F}}$ and stock size are presented in the Appendix, Table 7.

3.4 Length-based ADAPT model

The age-disaggregated catches in number by year (Appendix, Table 2b) converted from length distributions from landings were used for the cohort analysis and the age-disaggregated abundance indices converted from length distributions from the Nephrops survey (Appendix, Table 3d) for the tuning process. The same procedures were used for the projection. The resulting fits of abundance indices and stock estimates are presented in the Appendix, Figure 7. The correlation coefficient is less than 0.4 (R^2<0.4) for almost all age groups, except for age groups 10, 12 and 13 (R^2>0.6). The value of $\overline{\mathbf{F}}_{6-11}$ in the last year is estimated as 0.19. The estimates of $\overline{\mathbf{F}}$ and stock size are presented in the Appendix, Table 7.

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 is used to project the recruitment of the stock for each year. The selection pattern was taken from the selection pattern used in age-based ADAPT model. The mean weight at age by year and maturity at age by year estimated from otolith samples was used to calculate the biomass and predicted yield. Total nominal landings of witch in Icelandic waters 1987-1999 (Appendix, Table 1), various total abundance indices such as: IGFS indices 1987-1999, Danish seine fleet CPUE (Appendix, Table 3a) and Nephrops survey indices 1995-1999 (Appendix, Table 3b), and recruitment indices (age 3) from age-disaggregated indices of Nephrops survey were used to fit the model. The log scale of errors was used to fit recruitment, CPUE indices and Nephrops survey total indices in order to obtain the best fit of 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:

$$\mathbf{CV}= \sqrt{\frac{\mathbf{SSE}}{\mathbf{T}}}$$

where **T** is number of data points (Table 1).

Table 1: CV estimates.

Series	SSE (Sum of squared errors)	CV
Yield	0.00001	
Danish Seine CPUE	0.194	0.1
Nephrops survey abundance indices	0.224	0.2
IGFS abundance indices	6.071	
Nephrops survey recruitment indices	5.608	1.1

The production model fits very well with the series of observed yield, Danish seine CPUE indices and IGFS indices (Appendix, Figure 8). However, the model doesn't give a good fit with either the recruitment indices because of the short time series and high variance in the indices, or the Nephrops survey abundance indices because of short time series.

The parameters of the Beverten-Holt stock recruitment relationship were estimated as K=4220292 kg, a=0.87 and the initial value of recruitment for the virgin stock Ro=12351152 individual. The value of $\overline{F}_{6-11}$ in the last year is estimated as 0.20. The estimates of $\overline{F}$ and stock size are presented in the Appendix, Table 7.

3.6 Comparison of results from models

3.6.1 Fishing mortality

The overall pattern in fishing mortality rates ($\overline{F}_{6-11}$) as estimated by the three different models and from the preliminary MRI-XSA analysis show a similar trend (Appendix, Figure 9). That is a relatively high F at the beginning of the target fishery in 1987 and then a sharp decrease until 1990. After 1990, the Fs increase again to a maximum in 1995 and have been decreasing in the last few years. The length-based ADAPT model gives somewhat higher F's at the beginning of the period (1987-1990) and the production model suggests lower Fs in the first two years. The estimates from the age-based ADAPT model do not indicate an increase in value of Fs in the last year as the two others models and the preliminary MRI-XSA. All three models give similar estimates for $\overline{F}$ in the last years, $\overline{F}_{6-11}$=0.18-0.22 which is markedly lower than the MRI-XSA estimate of 0.42.

3.6.2 Recruitment

The estimates of recruitment (age 3) from the three methods are shown in the Appendix, Figure 10, where the recruitment estimated from preliminary ADAPT is also inserted for the purpose of comparison.

The trend in the recruitment pattern resulting from the age-based ADAPT model is similar to the results from the preliminary MRI-XSA model, except for the last year where a long-term average was used in the MRI-XSA. The higher values from the age-based ADAPT model in recent years compared to the MRI-XSA results reflect the lower estimates of Fs in the final year. The production model gives a smooth recruitment pattern with a declining trend over the period. The length-based ADAPT model gives quite distinctive results indicating far higher recruitment in recent years starting with similar estimates in the beginning of the period.

3.6.3 Stock size

The age-based model, the production model and the MRI-XSA model give similar estimates for stock biomass in the period 1987-1999 (Appendix, Figure 11). In recent years, the biomass seems to be relatively stable at about a half to one third of the level at the beginning of the period. The stock is estimated to be around 18000 tons in 1987 and in the range of 8800-11000 tons in the beginning of the year 2000. The MRI-XSA model gives the lowest value, the age-based ADAPT and production models give similar values. The length-based ADAPT model gives lower estimate of the stock biomass (around 14500 tons) in the beginning but higher (18000 tons) in the last year. This reflects the relatively high F values estimated from this model in the beginning of the period and good recruitment in recent years. The spawning stock biomass estimated from the three models are in good agreement with the estimates of around 13000 tons in 1987 and 5500-8000 tons in the beginning of the year 2000, although the length-based ADAPT model gives lower estimates of in the period of 1987-1990 of around 8000-10000 tons and higher in the last year (1999) of about 10000 tons.

3.6.4 Yield prediction

The results of yield prediction for the year 2000 from three models given after refitting completely the three models with different assumptions of natural mortality M=0.05 and M=0.25 is presented in Table 2. The prediction of next-year's catch gives the sensitivity of the assessments against different assumptions of natural mortality.

Table 2: Yield prediction for the year 2000.

Model	Base case: M=0.15		M=0.25		M=0.05	
	$\overline{F}_{6-11}$ terminal	Total yield (T)	$\overline{F}_{6-11}$ terminal	Total yield (T)	$\overline{F}_{6-11}$ terminal	Total yield (T)
Age-based ADAPT	0.22	1282	0.19	1199	0.25	1339
Length-based ADAPT	0.19	1667	0.17	1569	0.22	1769
Production Model	0.20	1334	0.25	1326	0.21	1414

The results from the age-based model and production model are very similar (1200-1400 tons) but the result of the length-based model is higher (around 1700 tons) because of its optimistic stock assessment in the last year.

Independently of the methods used, the different assumptions of natural mortality do not have much effect on the prediction.

4 DISCUSSION AND FUTURE WORK

The same datasets have been used in the age-based ADAPT and the XSA preliminary assessment, but the resulting Fs in the last year are quite different (0.22 and 0.42 respectively). The most likely explanation is that the preliminary assessment was run with XSA (the Lowestoft package) that assumed a non-linear relationship between abundance indices and stock size ($\mathbf{U=\alpha*N^{\beta}}$) for ages 3-5 and weighted indices for each age group by the inverse variance.

The length-based method gave the most optimistic estimate of stock size and recruitment in recent years because it was based on rather uncertain catch in number at age. The large number of age groups and slow growth of witch gives serious problems when disaggregating the length distributions. Future work should emphasize parameter reduction techniques such as either fixing all mean length at age across years or incorporating the length distributions directly as data into the age-disaggregated production model.

As the production model assumes a generalized level of recruitment as a function of stock biomass, it could not account for the distinct recent recruitment events, which are reflected in the results of the other models, such as in 1997 as observed in the Nephrops survey (Appendix, Figure 1a). That is why the estimates of the recruitment from the production model give a smooth trend over time. This may produce errors to the estimation of next year's biomass. However, the age-based model and the preliminary XSA result in a similar pattern and biomass estimate as from the production model. In future, one can expand the fitting process of the age-disaggregated production model by using weights on index series and testing different error scales (log-transform or normal) and try to estimate the selection pattern as well.

The predicted yield for the year 2000 is consistent between the age-based ADAPT and the production models (1200-1400 tons), but length-based ADAPT model gives higher estimate of stock size in the last year (1999) thus predicts greater yield (1700 tons). In each model, yield prediction seems to be robust to assumptions of natural mortality.

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APPENDIX: TABLES AND FIGURES

Table 1: Nominal catches in tons from Icelandic waters
(State of Marine Stock in Icelandic water 1999/2000)

Year	Iceland fisheries	Foreign boats	Total (T)	Year	Iceland fisheries	Foreign boats	Total (T)
1950	88	1018	1106	**1975**	69	10	79
1951	81	1083	1164	**1976**	143	4	147
1952	30	720	750	**1977**	115		115
1953	138	456	594	**1978**	120		120
1954	112	666	778	**1979**	140		140
1955	34	741	775	**1980**	19		19
1956	167	715	882	**1981**	3		3
1957	200	892	1092	**1982**	54		54
1958	372	814	1186	**1983**	10		10
1959	646	653	1299	**1984**	11		11
1960	931	486	1417	**1985**	32		32
1961	725	570	1295	**1986**	335		335
1962	559	644	1203	**1987**	4566		4566
1963	431	614	1045	**1988**	2974		2974
1964	469	355	824	**1989**	2267		2267
1965	412	473	885	**1990**	1278		1278
1966	122	237	359	**1991**	1775		1775
1967	162	224	386	**1992**	2564		2564
1968	132	226	358	**1993**	1658		1658
1969	166	213	379	**1994**	1771		1771
1970	169	212	381	**1995**	1816		1816
1971	125	221	346	**1996**	1486		1486
1972	138	65	203	**1997**	1272		1272
1973	22	37	59	**1998**	947		947
1974	52	26	78	**1999**	1419		1419

Table 2a:Age-disaggregated catch in number (1000) calculated from age data, 1987-1999
(*MRI Databases)*

Age/Year	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
3	0	0	0	0	49	0	0	71	250	6	54	80	12
4	28	177	0	0	51	11	0	616	182	153	10	1156	123
5	371	760	246	30	479	67	49	459	967	503	208	121	902
6	865	2050	1731	430	1131	45	46	466	499	877	373	302	405
7	894	862	2884	1071	1572	90	186	669	613	493	615	438	398
8	128	134	970	758	125	109	282	335	811	518	286	411	519

	5	4			4	9							
9	1642	1674	689	433	600	2003	851	686	562	396	291	193	397
10	2286	1383	804	428	93	1126	1353	870	470	311	263	144	117
11	3043	662	360	248	244	890	883	495	777	283	273	115	114
12	1116	503	137	161	40	535	519	316	293	152	186	33	32
13	899	89	48	176	31	437	144	142	159	67	119	25	14
14	624	131	26	70	1	480	253	237	167	32	36	3	13

Table 2b: Age-disaggregated catch in number (1000) estimated from length distribution

Age/Year	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
3	48	62	19	11	68	12	35	9	89	7	43	26	21
4	148	228	168	40	199	63	145	64	184	40	62	88	81
5	245	429	479	224	390	154	539	185	458	73	82	189	210
6	467	924	690	430	952	614	743	483	771	456	233	349	440
7	1471	1564	1352	779	897	1337	671	609	1307	552	430	386	664
8	1884	1716	2374	801	922	1825	862	778	940	803	380	513	709
9	4094	1967	1336	649	1091	1295	607	1182	952	783	510	626	613
10	3297	1503	696	505	828	793	318	1209	693	492	360	215	589
11	1049	831	335	224	301	443	597	568	462	322	325	209	330
12	316	248	287	121	46	175	85	102	87	166	100	102	105
13	104	99	86	18	31	34	56	86	48	98	136	71	29
14	24	38	70	14	21	20	33	29	30	18	54	34	7

Table 3a: Abundance indices from Icelandic Ground Fish Survey (IGFS) and Danish seine CPUE (*MRI Databases*).

Year	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
IGFS Survey indices	2.14	1.83	2.82	3.01	1.91	2.48	2.14	1.58	1.69	1.33	1.48	1.16	1.34
Danish seine CPUE indices	956.2	851.1	614	637.5	647	473.6	441.3	407.3	347.1	333.6	360	328.3	453.6

Table 3b: Abundance indices (average number of witch per nautical mile) from Nephrops surveys (*MRI Databases*).

Length (cm)	1995	1996	1997	1998	1999	Length (cm)	1995	1996	1997	1998	1999
9					0.02	**35**	1.44	1.10	0.91	1.15	2.20
10					0.00	**36**	1.44	1.11	0.98	0.97	1.66

11					0.02	**37**	1.34	0.91	1.10	1.11	1.50
12		0.01	0.00	0.00	0.01	**38**	1.21	1.02	0.80	0.99	1.58
13		0.01	0.00	0.00	0.01	**39**	1.13	0.89	0.76	0.68	1.10
14		0.05	0.00	0.00	0.11	**40**	1.00	0.82	0.43	0.77	0.97
15		0.13	0.00	0.01	0.06	**41**	0.91	0.84	0.41	0.63	0.68
16		0.21	0.02	0.10	0.11	**42**	0.77	0.84	0.42	0.53	0.60
17	0.00	0.28	0.05	0.29	0.06	**43**	0.53	0.57	0.35	0.41	0.46
18	0.01	0.25	0.13	0.16	0.22	**44**	0.52	0.55	0.26	0.34	0.31
19	0.02	0.21	0.32	0.27	0.20	**45**	0.33	0.41	0.21	0.29	0.38
20	0.13	0.19	0.79	0.30	0.57	**46**	0.22	0.26	0.16	0.19	0.12
21	0.24	0.16	1.27	0.27	0.80	**47**	0.15	0.23	0.10	0.10	0.11
22	0.34	0.22	1.60	0.22	0.99	**48**	0.13	0.10	0.09	0.09	0.07
23	0.51	0.16	2.01	0.38	1.52	**49**	0.08	0.10	0.03	0.07	0.06
24	0.75	0.25	1.85	0.65	1.81	**50**	0.05	0.07	0.04	0.05	0.04
25	0.98	0.42	1.58	1.04	2.31	**51**	0.04	0.04	0.04	0.02	0.02
26	1.03	0.49	1.52	1.62	2.52	**52**	0.02	0.02	0.03	0.02	0.05
27	1.23	0.87	0.97	2.40	1.96	**53**	0.00	0.01	0.00	0.02	0.00
28	1.14	1.23	0.87	3.19	1.98	**54**	0.00	0.01	0.01	0.01	0.00
29	1.18	1.03	0.73	3.02	1.93	**55**	0.02	0.00	0.00	0.00	0.01
30	1.48	1.40	1.22	3.06	2.84	**56**		0.00	0.00	0.00	0.00
31	1.38	1.19	0.98	2.33	2.17	**57**		0.00	0.00	0.00	0.00
32	1.51	1.34	1.16	1.71	2.30	**58**		0.01	0.00	0.00	0.00
33	1.48	1.34	1.02	1.56	2.41						
34	1.45	1.13	0.99	1.21	2.61	***Total index***	***26.20***	***22.07***	***26.19***	***32.12***	***41.11***

Table 3c: Age-disaggregated abundance indices from Nephrops survey (*MRI Databases*)

Age/ Year	**1995**	**1996**	**1997**	**1998**	**1999**
2	0	163	186	112	66
3	318	62	1117	349	764
4	372	488	151	1509	1059
5	450	271	313	101	1266
6	134	334	157	230	174
7	193	173	331	313	223
8	188	148	82	177	214
9	199	143	90	111	193
10	206	192	49	157	89
11	266	163	56	91	47
12	173	85	56	45	37
13	69	11	24	18	9
14	13	8	7	0	4

Table 3d: Age-disaggregated abundance indices converted from length frequency data in Nephrops survey

Age/Year	**1995**	**1996**	**1997**	**1998**	**1999**
2	0.41	1.09	2.32	0.35	1.66
3	0.87	0.77	5.04	1.00	3.12
4	2.97	0.43	3.81	1.95	6.95
5	2.88	4.34	1.12	8.18	4.18
6	3.08	4.06	2.67	7.85	6.25
7	3.95	2.04	3.81	4.27	6.07
8	3.55	2.26	1.88	2.70	4.81
9	3.61	2.20	1.49	2.71	3.77
10	2.52	2.00	2.15	1.30	2.04
11	1.68	2.14	1.38	1.11	1.45
12	0.40	0.67	0.28	0.42	0.42
13	0.26	0.28	0.19	0.27	0.37
14	0.02	0.15	0.07	0.13	0.33

Table 4a: Mean weight at age in landings (kg) from ageing data (*MRI Database*)

ge/Year	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
3	).116	0.116	0.116	0.116	0.116	0.116	0.116	0.109	0.120	0.207	0.124	0.145	0.163	0.144
4	).124	0.124	0.124	0.124	0.163	0.163	0.163	0.181	0.186	0.248	0.207	0.205	0.219	0.21
5	).147	0.182	0.147	0.142	0.206	0.255	0.172	0.205	0.224	0.286	0.345	0.295	0.276	0.305
6	).203	0.214	0.204	0.219	0.264	0.278	0.253	0.230	0.273	0.304	0.356	0.319	0.339	0.338
7	).205	0.301	0.252	0.277	0.282	0.278	0.220	0.282	0.298	0.375	0.401	0.374	0.385	0.387
8	).291	0.324	0.331	0.302	0.354	0.331	0.225	0.304	0.328	0.411	0.453	0.417	0.435	0.435
9	).321	0.328	0.348	0.352	0.404	0.328	0.293	0.346	0.380	0.451	0.537	0.491	0.489	0.506
10	).376	0.387	0.360	0.382	0.342	0.333	0.350	0.397	0.351	0.523	0.569	0.541	0.568	0.559
11	).372	0.393	0.536	0.476	0.492	0.426	0.363	0.467	0.350	0.520	0.595	0.532	0.636	0.588
12	).439	0.462	0.469	0.460	0.528	0.528	0.404	0.482	0.389	0.568	0.656	0.603	0.716	0.658
13	).426	0.475	0.536	0.560	0.500	0.454	0.534	0.511	0.350	0.662	0.591	0.652	0.793	0.679
14	).426	0.475	0.536	0.560	0.500	0.454	0.534	0.511	0.389	0.662	0.656	0.652	0.793	0.679

Table 4b: Mean weight at age in landings (kg) estimated from length distributions

Age/Year	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
3	0.069	0.083	0.082	0.115	0.106	0.098	0.095	0.072	0.097	0.104	0.107	0.095	0.128	0.102
4	0.092	0.109	0.106	0.141	0.134	0.161	0.156	0.097	0.123	0.140	0.136	0.123	0.158	0.133
5	0.123	0.139	0.147	0.177	0.177	0.184	0.197	0.129	0.160	0.173	0.205	0.158	0.197	0.179
6	0.157	0.175	0.183	0.212	0.216	0.219	0.245	0.158	0.193	0.217	0.263	0.197	0.241	0.226
7	0.210	0.219	0.211	0.256	0.273	0.272	0.313	0.199	0.254	0.282	0.327	0.245	0.296	0.285
8	0.275	0.266	0.263	0.302	0.276	0.336	0.384	0.250	0.322	0.310	0.388	0.298	0.357	0.332
9	0.327	0.325	0.331	0.367	0.363	0.411	0.388	0.322	0.379	0.401	0.470	0.371	0.428	0.414
10	0.416	0.400	0.408	0.440	0.434	0.514	0.391	0.414	0.386	0.499	0.549	0.452	0.495	0.500
11	0.559	0.509	0.429	0.564	0.573	0.647	0.565	0.530	0.390	0.635	0.675	0.501	0.548	0.604
12	0.653	0.641	0.549	0.722	0.760	0.845	0.570	0.664	0.562	0.697	0.817	0.607	0.552	0.707
13	0.658	0.688	0.553	0.798	0.766	0.953	0.574	0.779	0.566	0.702	0.823	0.612	0.557	0.713
14	0.663	0.693	0.778	0.863	0.835	0.960	0.579	0.785	0.940	0.707	0.829	0.698	0.561	0.745

Table 4c: Mean weight at age (kg) Nephrops survey estimated from length distributions

Age/Year	1995	1996	1997	1998	1999
2	0.048	0.023	0.046	0.023	0.046
3	0.071	0.050	0.067	0.041	0.067
4	0.092	0.089	0.097	0.083	0.095
5	0.137	0.134	0.125	0.126	0.135
6	0.171	0.206	0.175	0.167	0.172
7	0.225	0.230	0.239	0.233	0.233
8	0.290	0.314	0.297	0.292	0.282
9	0.369	0.366	0.340	0.384	0.374
10	0.466	0.454	0.407	0.444	0.443
11	0.572	0.550	0.507	0.532	0.519
12	0.663	0.675	0.577	0.628	0.617
13	0.750	0.790	0.680	0.730	0.716

Table 4d: Mean length at age (cm) calculated from age data and length distributions in Nephrops survey

Age/Year	Age data	Length data
2	19.4	19.2
3	24.6	22.1
4	29.1	25.2
5	32.4	28.0
6	34.8	30.6
7	36.3	33.1
8	38.1	35.5
9	39.4	37.8
10	41.4	39.9
11	41.7	42.2
12	43.0	44.2
13	44.8	46.2

14	0.912	0.870	0.807	0.781	0.832

14	46.2	48.1

Table 5a: Maturity rates estimated from age data in Nephrops survey (1) and Landing (2)

Age	Maturity rate (1)	Maturity rate (2)
2	0.01	
3	0.06	0.15
4	0.30	0.42
5	0.51	0.51
6	0.70	0.75
7	0.72	0.83
8	0.83	0.92
9	0.88	0.95
10	0.93	0.97
11	0.94	0.99
12	0.98	1
13	1	1
14	1	1

Table 5b: Maturity rates estimated using length frequency data from Nephrops survey (1) and Landings (2)

Age	Maturity rate (1)	Maturity rate (2)
2	0.02	0
3	0.06	0.18
4	0.16	0.34
5	0.35	0.52
6	0.58	0.68
7	0.77	0.82
8	0.89	0.90
9	0.95	0.95
10	0.98	0.97
11	0.99	0.99
12	1	1
13	1	1
14	1	1

Table 5c: Average maturity rate at length estimated using Nephrops surveys data

Length (cm)	Proportion mature	Length (cm)	Proportion mature	Length (cm)	Proportion mature	Length (cm)	Proportion mature
11	0.00	**20**	0.01	**29**	0.50	**49**	0.97
12	0.00	**21**	0.01	**30**	0.56	**50**	0.97
13	0.00	**22**	0.02	**31**	0.59	**51**	0.95
14	0.00	**23**	0.03	**32**	0.70	**52**	1.00
15	0.00	**24**	0.10	**33**	0.75	**53**	1.00
16	0.00	**25**	0.15	**45**	0.95	**54**	1.00
17	0.00	**26**	0.22	**46**	0.95	**55**	1.00
18	0.00	**27**	0.33	**47**	0.93	**56**	1.00
19	0.00	**28**	0.38	**48**	0.93		

Table 6a: Length frequency samples from commercial landings 1987-1999 (*MRI Databases*)

Length (cm)	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
0	0	0	0	0	0	0	0	0	0	0	0	0	1
1	0	0	0	0	0	0	0	1	0	0	0	0	0
13	0	1	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	1	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	1	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	2	0	0	0	0	0
19	1	0	0	0	0	0	0	0	0	0	0	0	1
20	0	0	1	0	0	0	0	1	0	0	2	0	1
21	1	0	0	0	1	0	0	1	0	0	0	0	0
22	1	0	0	0	0	0	0	3	0	0	0	0	2
23	5	1	0	0	1	0	0	1	0	1	2	0	2
24	7	9	3	0	0	0	1	2	2	2	0	0	5

25	14	14	6	0	1	0	4	8	7	1	4	11	2
26	15	38	19	0	4	1	3	16	15	4	10	10	13
27	20	56	16	2	3	0	0	14	22	5	11	31	23
28	28	83	27	3	13	1	7	55	31	11	16	32	31
29	37	101	61	5	6	3	13	68	45	25	10	57	49
30	48	159	75	17	15	12	22	87	81	24	3	82	98
31	74	197	131	28	25	21	45	90	81	66	11	117	150
32	104	264	170	51	43	44	58	102	89	82	20	142	232
33	123	321	188	45	47	58	63	106	110	123	26	112	316
34	158	319	215	89	55	80	69	115	134	160	48	156	410
35	236	332	203	77	66	106	59	120	143	194	61	162	478
36	284	329	152	74	39	102	86	144	134	211	83	179	616
37	289	316	133	53	36	126	94	154	135	184	101	161	555
38	253	251	95	58	43	98	88	126	100	167	93	190	556
39	209	232	80	45	37	84	82	151	85	160	94	127	431
40	169	144	55	37	28	64	63	115	63	154	97	98	404
41	113	121	38	23	16	45	42	84	40	123	112	91	329
42	75	102	27	15	9	47	31	66	36	91	88	83	280
43	69	71	24	15	10	28	35	52	15	104	77	50	203
44	45	43	11	11	6	30	23	25	12	63	69	41	151
45	23	32	8	5	2	23	11	24	10	51	53	32	108
46	16	19	7	3	3	14	12	11	4	34	65	19	54
47	12	9	5	6	0	10	4	8	0	32	28	12	48
48	5	6	5	1	1	4	4	9	4	15	23	4	31
49	5	5	0	1	0	7	0	4	1	12	24	4	13
50	2	3	2	2	0	3	1	4	3	11	12	2	10
51	1	0	1	0	0	1	0	1	1	2	13	0	6
52	1	0	0	1	0	1	0	0	0	6	5	0	5
53	0	0	0	0	0	0	0	0	0	1	3	0	1
54	1	0	0	0	0	1	0	1	0	0	0	1	3
55	0	0	0	0	0	0	0	0	0	1	0	0	0
56	0	0	0	1	0	0	0	0	0	1	0	0	0
Total	**2444**	**3578**	**1758**	**668**	**510**	**1014**	**920**	**1773**	**1403**	**2121**	**1264**	**2006**	**5618**

Table 6b: Raised catch in numbers (1000) by length (*MRI Databases*)

Length (cm)	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
13	0	3	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	3	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	3	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	6	0	0	0	0	0
19	5	0	0	0	0	0	0	0	0	0	0	0	1
20	0	0	4	0	0	0	0	3	0	0	4	0	1
21	5	0	0	0	11	0	0	3	0	0	0	0	0
22	5	0	0	0	0	0	0	9	0	0	0	0	1
23	27	3	0	0	11	0	0	3	0	2	4	0	1
24	38	24	13	0	0	0	5	6	9	4	0	0	3
25	75	38	27	0	11	0	20	24	30	2	9	16	1
26	81	102	85	0	45	7	15	48	64	7	21	14	9
27	108	151	72	11	34	0	0	42	95	9	24	44	16
28	151	224	121	17	146	7	36	166	133	20	34	45	21
29	199	272	274	29	68	20	66	205	193	45	21	81	33
30	258	429	337	97	169	80	112	262	348	43	6	116	66
31	398	531	588	160	282	140	230	271	348	119	24	166	102
32	560	712	763	292	484	294	296	307	382	148	43	201	157
33	662	866	844	257	529	387	322	319	473	222	56	159	214
34	850	860	965	509	620	534	353	346	576	288	103	221	278
35	1270	895	911	441	744	707	302	362	614	349	131	230	324
36	1528	887	682	423	439	681	440	434	576	380	178	254	417
37	1555	852	597	303	406	841	480	464	580	331	217	228	376
38	1361	677	427	332	484	654	450	380	430	301	200	269	376
39	1125	626	359	257	417	561	419	455	365	288	202	180	292
40	909	388	247	212	315	427	322	346	271	277	208	139	273
41	608	326	171	132	180	300	215	253	172	222	241	129	223
42	404	275	121	86	101	314	158	199	155	164	189	118	190
43	371	191	108	86	113	187	179	157	64	187	165	71	137
44	242	116	49	63	68	200	118	75	52	113	148	58	102
45	124	86	36	29	23	153	56	72	43	92	114	45	73
46	86	51	31	17	34	93	61	33	17	61	140	27	37
47	65	24	22	34	0	67	20	24	0	58	60	17	32
48	27	16	22	6	11	27	20	27	17	27	49	6	21
49	27	13	0	6	0	47	0	12	4	22	52	6	9
50	11	8	9	11	0	20	5	12	13	20	26	3	7
51	5	0	4	0	0	7	0	3	4	4	28	0	4
52	5	0	0	6	0	7	0	0	0	11	11	0	3
53	0	0	0	0	0	0	0	0	0	2	6	0	1
54	5	0	0	0	0	7	0	3	0	0	0	1	2
55	0	0	0	0	0	0	0	0	0	2	0	0	0
56	0	0	0	6	0	0	0	0	0	2	0	0	0
Total	**13151**	**9649**	**7893**	**3822**	**5745**	**6767**	**4703**	**5342**	**6027**	**3820**	**2716**	**2842**	**3803**

Table 7: Main results from three models: Age-based ADAPT, Length-based ADAPT, Age-disaggregated production model (ADPM) and the XSA preliminary results

	Fishing mortality rate ($\overline{F}_{6-11}$)				**Recruitment (1000)**				**Total Biomass (T)**				**Spawning Stock Biomass (T)**			
ear	**Age-based ADAPT**	**Length-based ADAPT**	**ADPM**	**XSA**	**Age-based ADAPT**	**Length-based ADAPT**	**ADPM**	**XSA**	**Age-based ADAPT**	**Length-based ADAPT**	**ADPM**	**XSA**	**Age-based ADAPT**	**Length-based ADAPT**	**ADPM**	**XSA**
1987	0.55	0.67	0.34	0.59	15865	16396	32101	15741	19059	14454	17863	17289	13866	10195	14307	17289
1988	0.39	0.65	0.28	0.48	8170	14141	26368	8006	17155	12267	15553	15553	12519	7625	11882	15553
1989	0.24	0.55	0.24	0.32	5680	10919	20946	5646	14409	10613	13612	12811	11150	6349	10189	12811
1990	0.13	0.32	0.15	0.16	6061	11213	22406	6006	13100	11723	12758	11718	10486	6747	9327	11718
1991	0.17	0.36	0.20	0.19	5761	12105	23790	5313	13809	12035	14255	12417	11261	7306	10353	12417
1992	0.31	0.46	0.35	0.33	5213	12475	25547	5179	11793	12881	13532	10616	9606	8032	9733	10616
1993	0.35	0.37	0.30	0.36	10823	11489	22588	9143	8702	12210	10128	7862	6378	7306	7221	7862
1994	0.37	0.44	0.31	0.38	9621	14495	28271	6615	8906	9130	10415	7885	6166	5689	7477	7885
1995	0.54	0.43	0.37	0.55	6769	16480	30189	6601	8102	10898	10007	7126	5274	6070	6963	7126
1996	0.43	0.37	0.25	0.46	7117	16488	28302	4020	9526	12327	11758	7727	5857	6658	7986	7727
1997	0.49	0.26	0.19	0.52	19608	18960	30468	11875	10814	15170	11620	8062	6382	8342	8404	8062
1998	0.28	0.15	0.15	0.33	5366	19684	29682	8242	10776	13721	10589	8069	6646	7517	7718	8069
1999	0.22	0.19	0.20	0.42	1258	15605	21877	7000	10705	18288	11316	8848	7391	10393	8296	8848

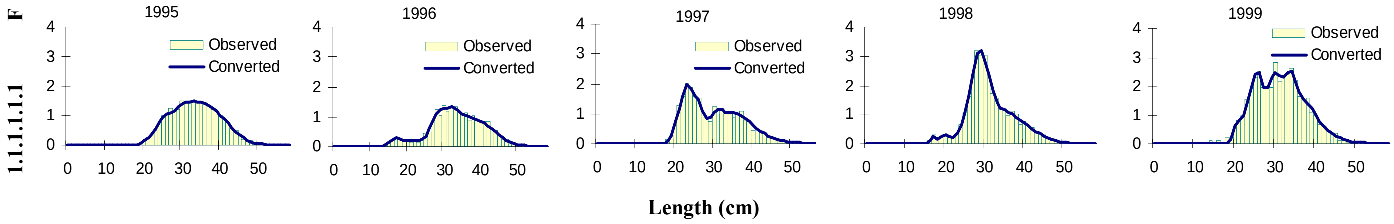

Figure 1a: Length distributions from Nephrops surveys and the fitted curves from the age-diaggregation model by year

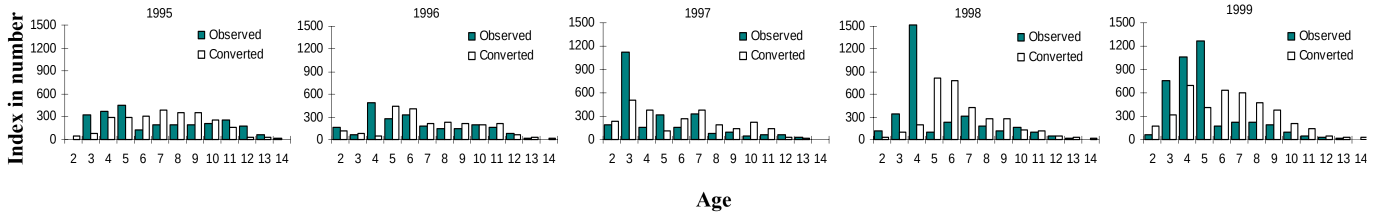

Figure 1b: Observed age-diaggregated abundance indices from the Nephrops surveys compared to the results from age-disaggregation model by year

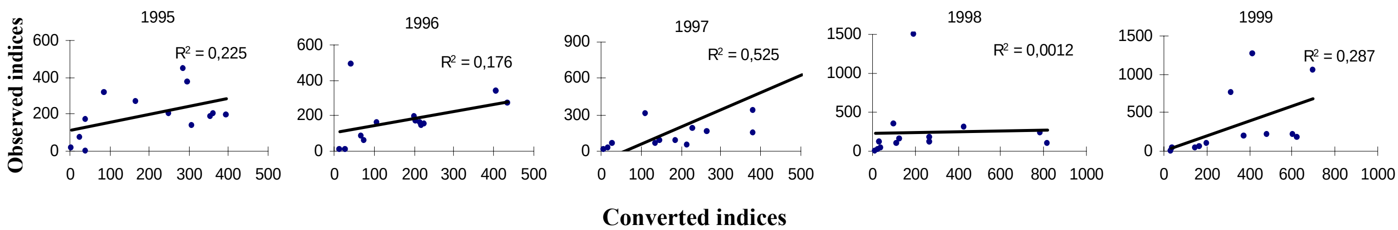

Figure 1c: Observed age-diaggregated abundance indices from the Nephrops surveys compared to the results from age-disaggregation model

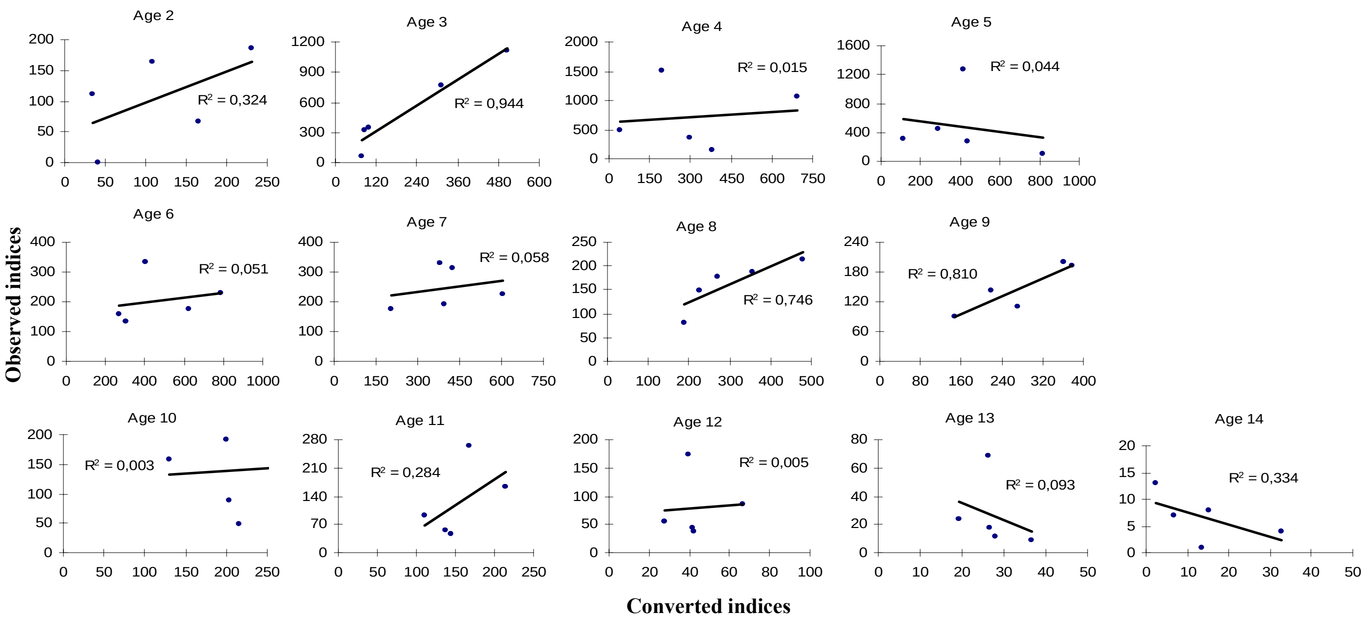

Figure 1d: Age-disaggregated indices from Nephrops surveys estimated from age data (observed) and from length distributions (converted from age-disaggregation model) by age groups

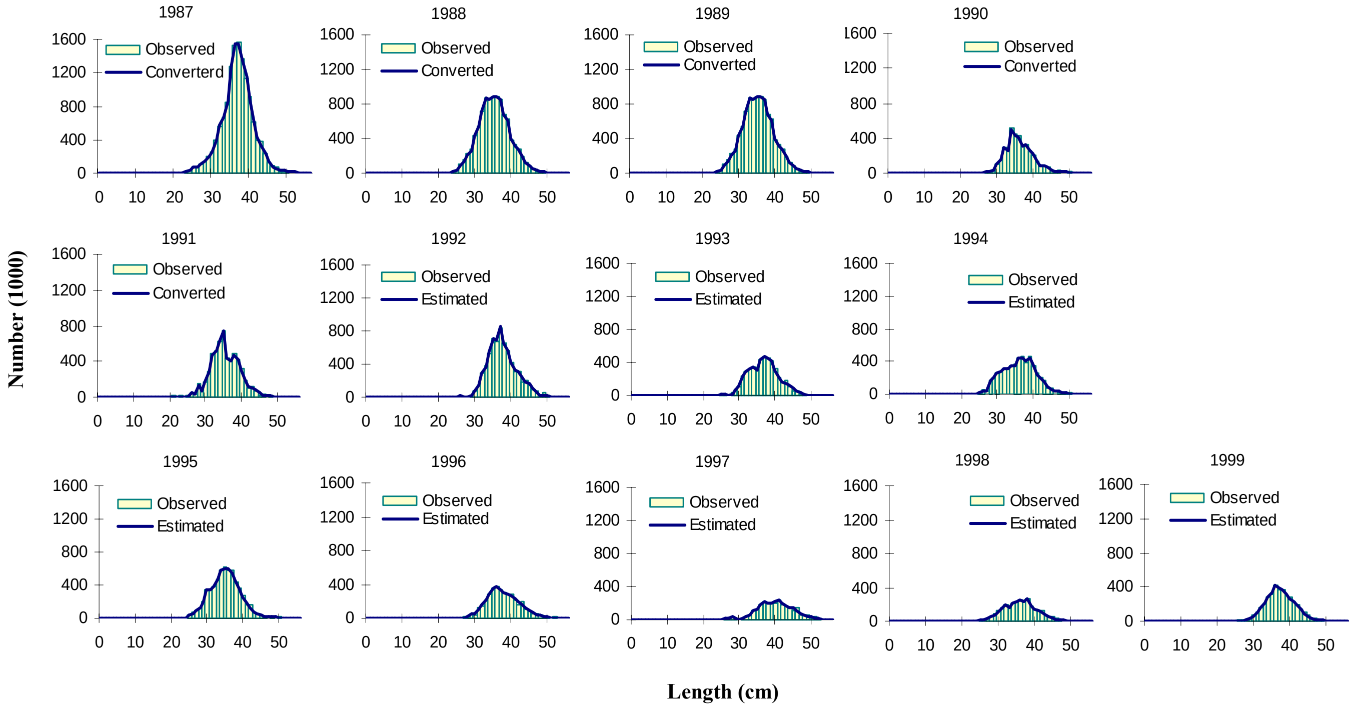

Figure 2a: Length distributions in landing and the fitted curves from the age-aggregation model

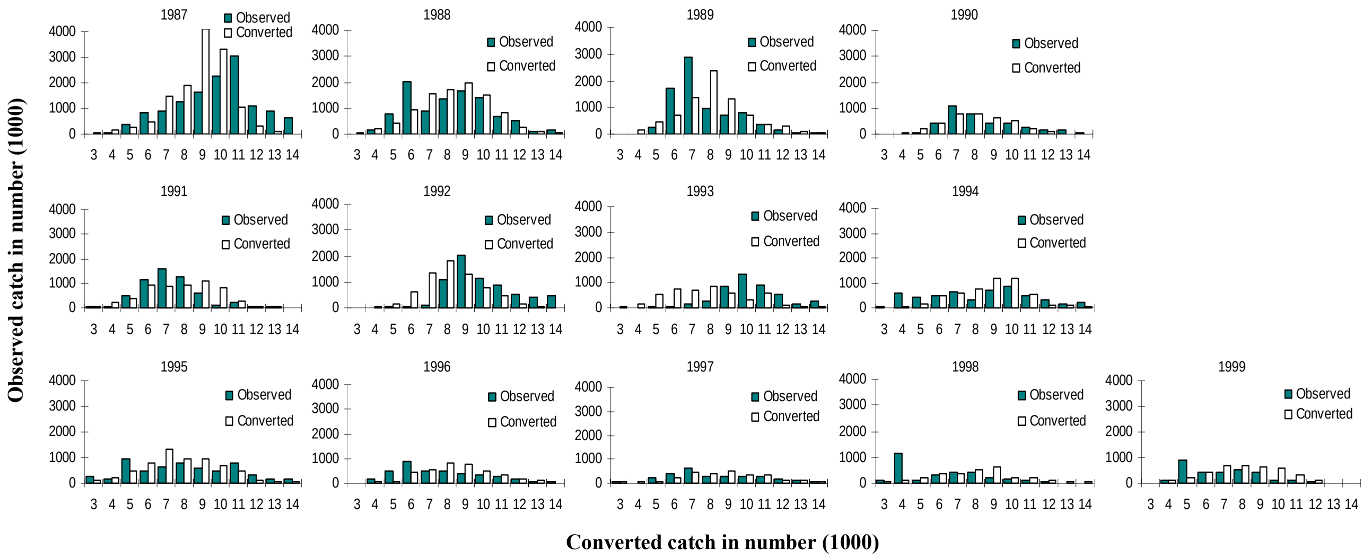

Figure 2b: Observed age-diaggregated catch in number (1000) compared to the results from age-disaggregation model by year

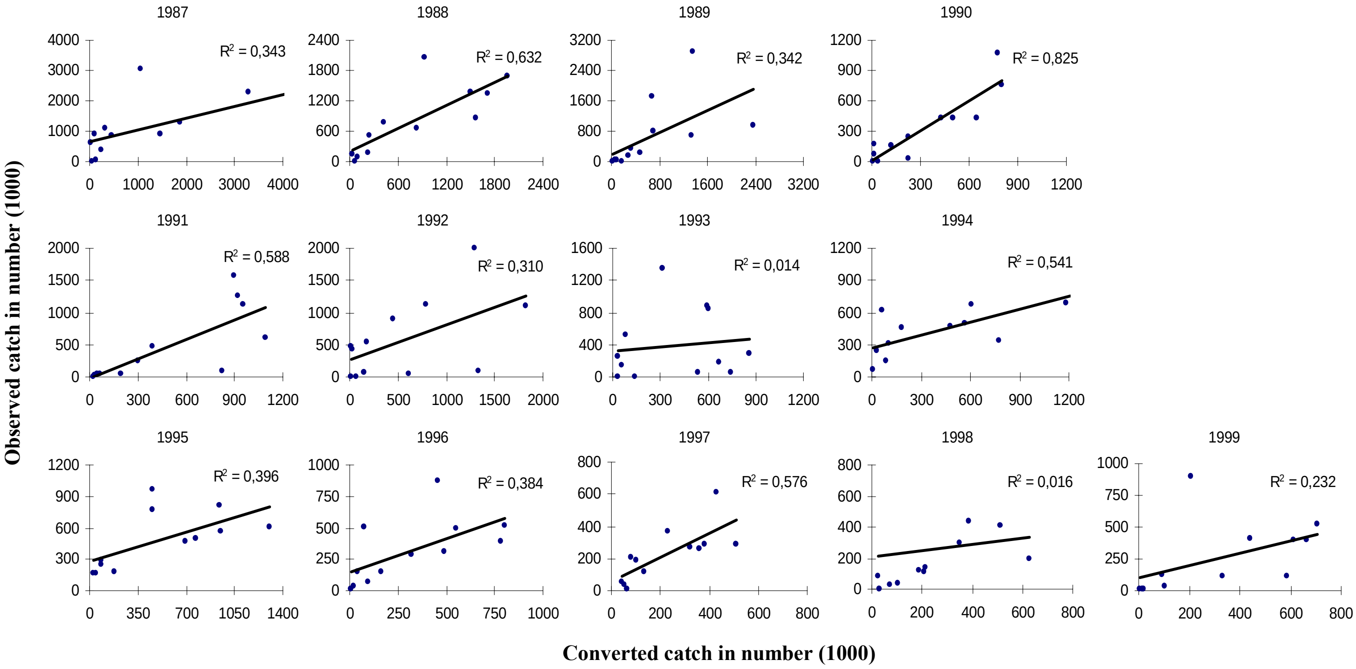

Figure 2c: Observed age-diaggregated catch in number (1000) compared to the results from age-disaggregation model by year

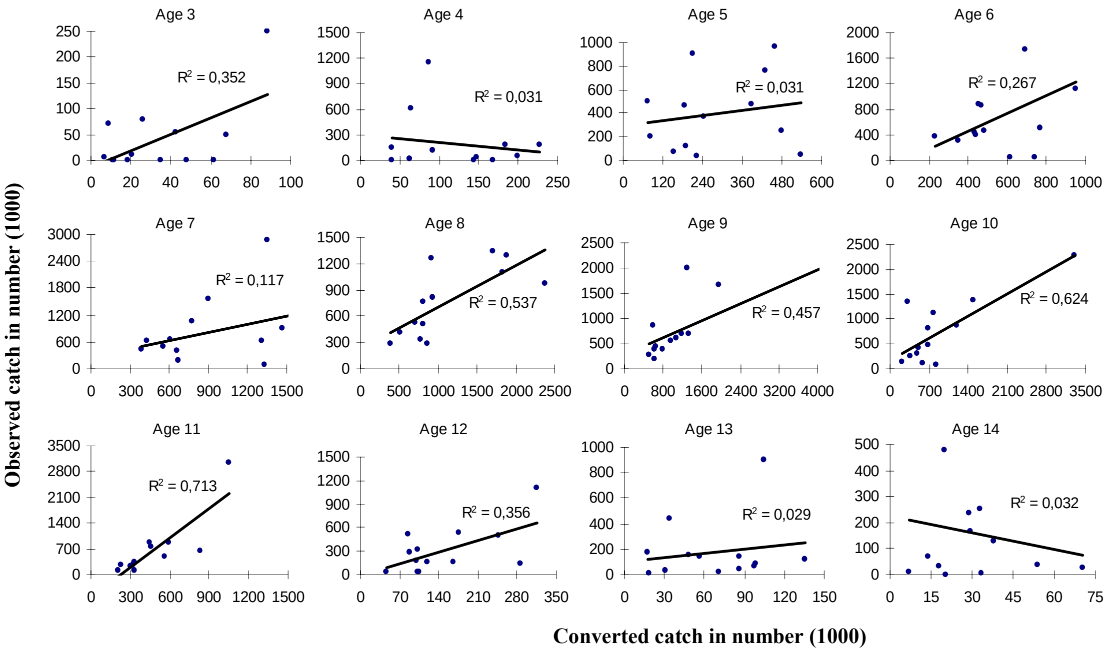

Figure 2d: Observed age-diaggregated catch in number (1000) compared to the results from age-disaggregation model by age group

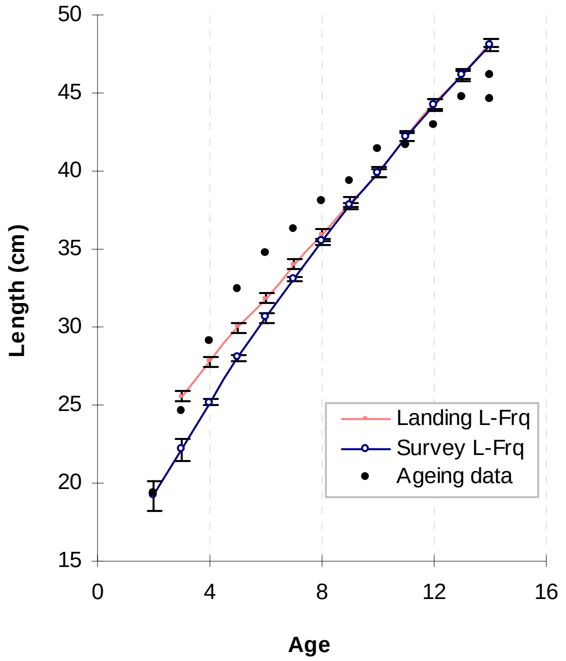

Figure 3a: Mean length (cm) at age and standard errors estiamted from length distributions data from landings and the Nephrops surveys, and the calculated from age data.

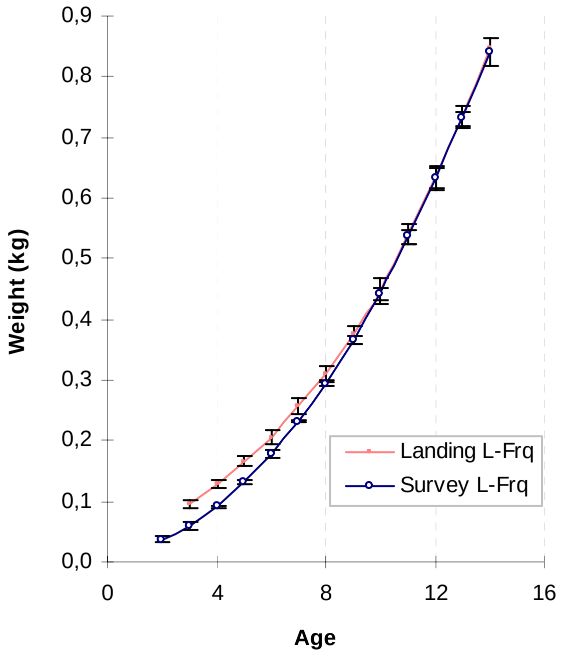

Figure 3b: Mean weight (kg) at age and standard errors derived from length distributions data

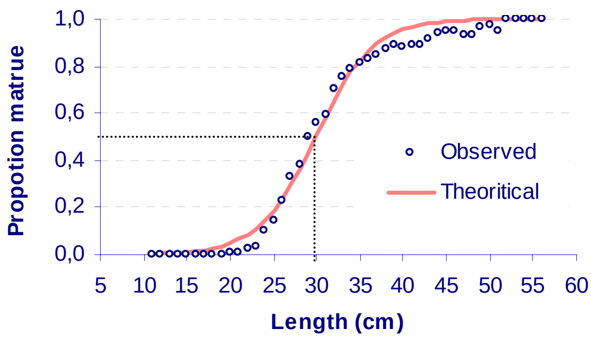

Figure 4: Length maturity ogive (a=0.902 b=0.30) estimated from observations of maturity by length in the Nephrops survey, 1995-1999

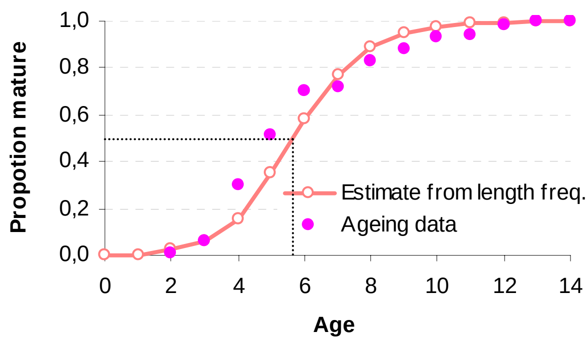

Figure 5: Average maturity rate derived from length distributions data and the ageing data in the Nephrops survey, 1995-1999

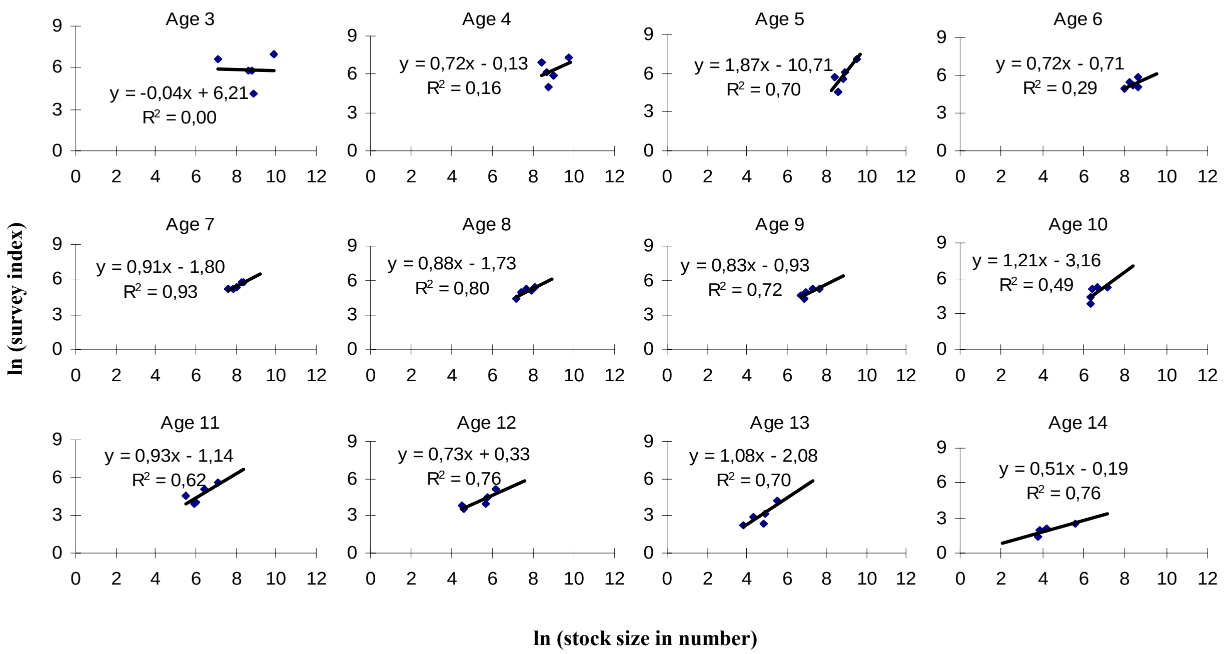

Figure 6: Abundance indices from Nephrops survey versus stock in number from Age-based ADAPT model

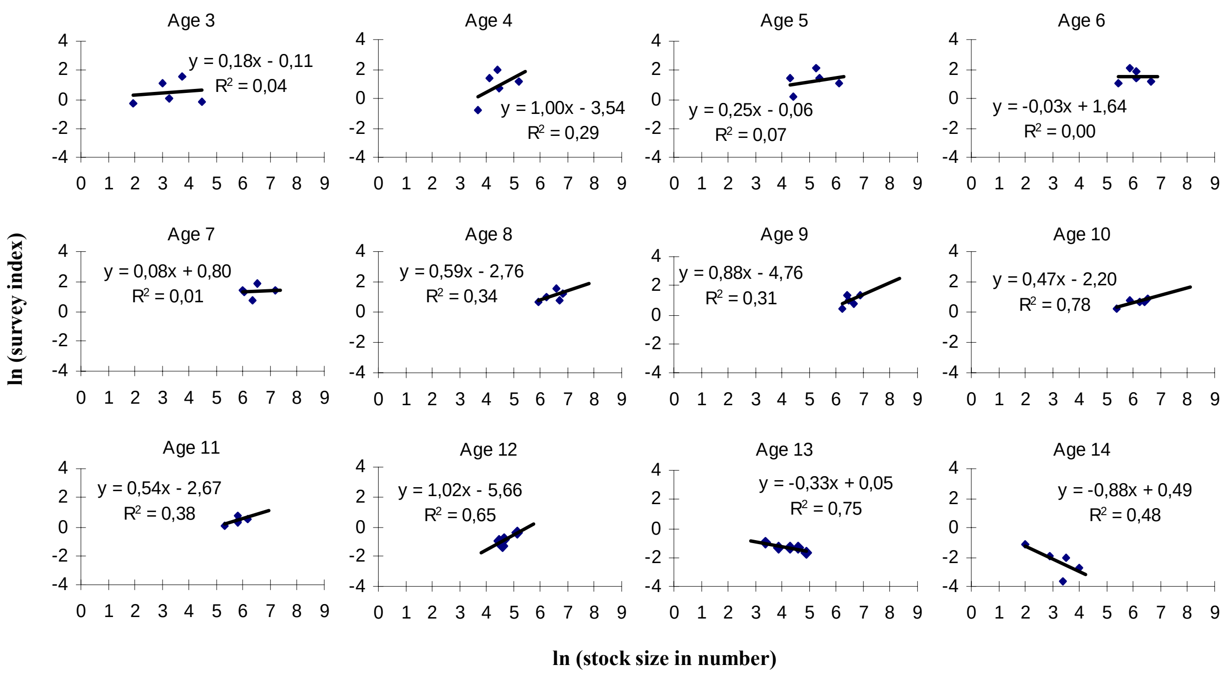

Figure 7: Abundance indices from Nephrops survey versus stock in number from Length-based ADAPT model

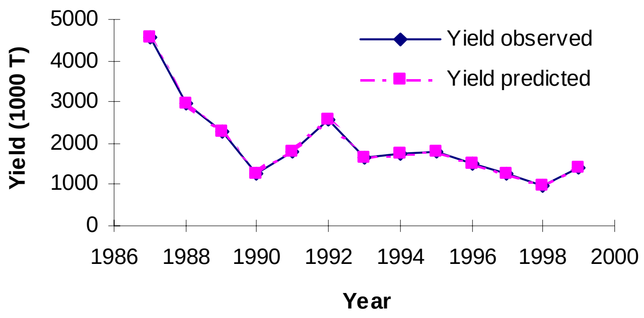

Figure 8a: Observed and predicted yields.

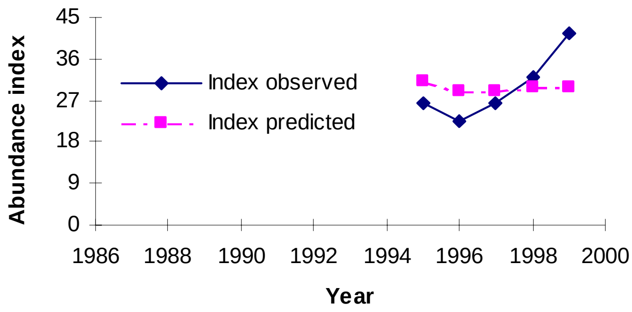

Figure 8d: Total abundance indices of Nephrops survey 1995-1999 and the model estimates

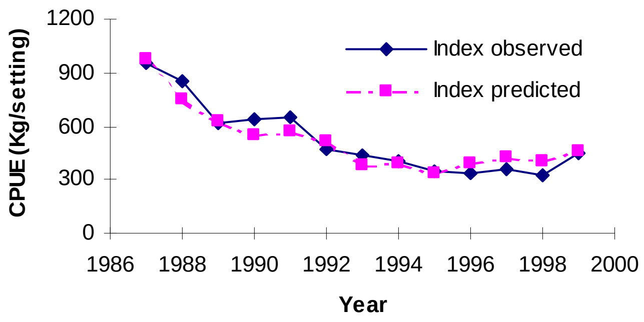

Figure 8b: Danish seine fleet CPUE indices (kg/setting) and the model estimates

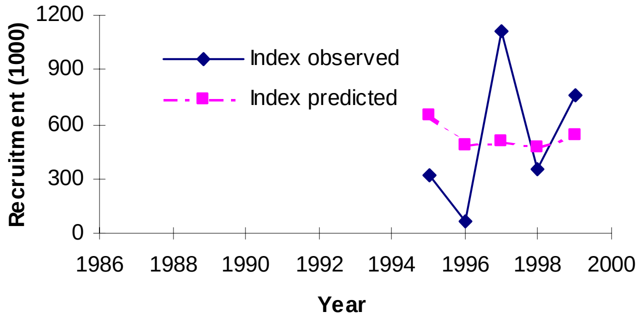

Figure 8e: Recruitment indices of Nephrops survey and the model estimates

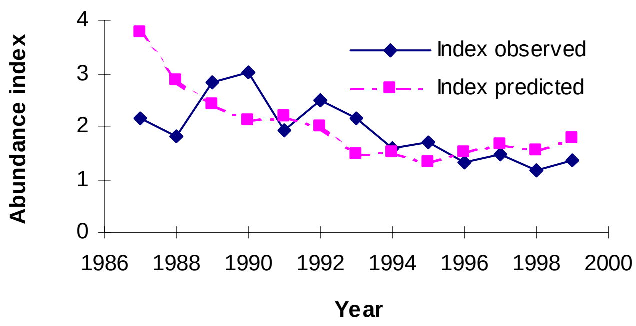

Figure 8c: Abundance indices of IGFS and the model estimates

Figure 8(a,b,c,d,e): Comparison of various indices to the estimates of the age-disaggregated dynamic production model

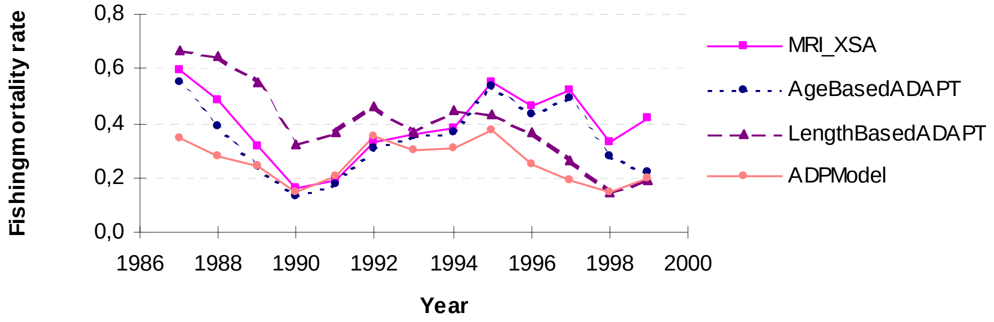

Figure 9: Fishing mortality rates estimated by different models

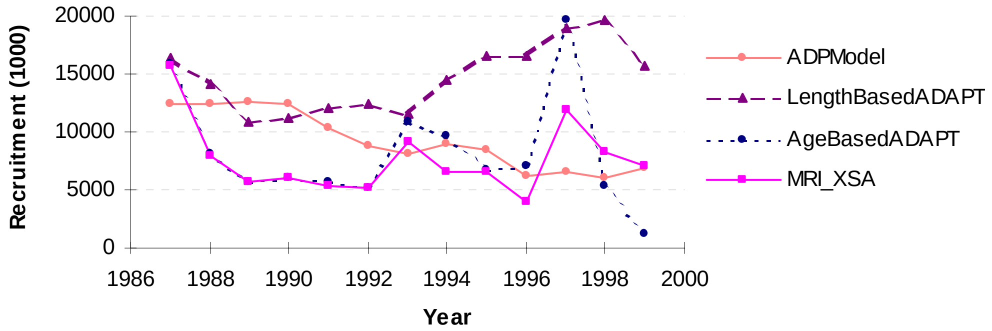

Figure 10: Recruitment estimated from different models

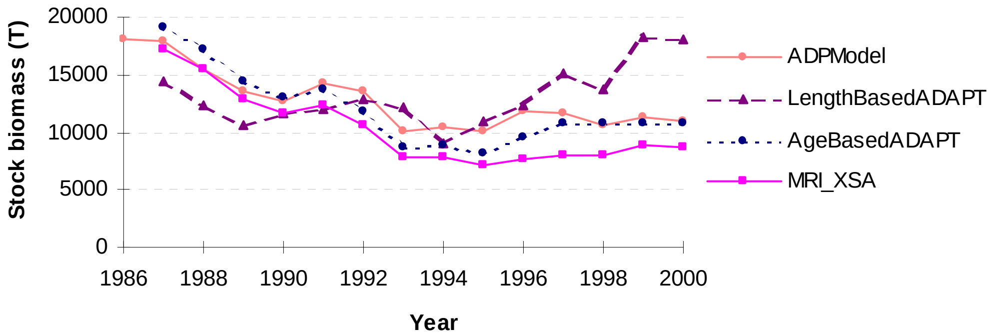

Figure 11: Total stock biomass estimated from different models

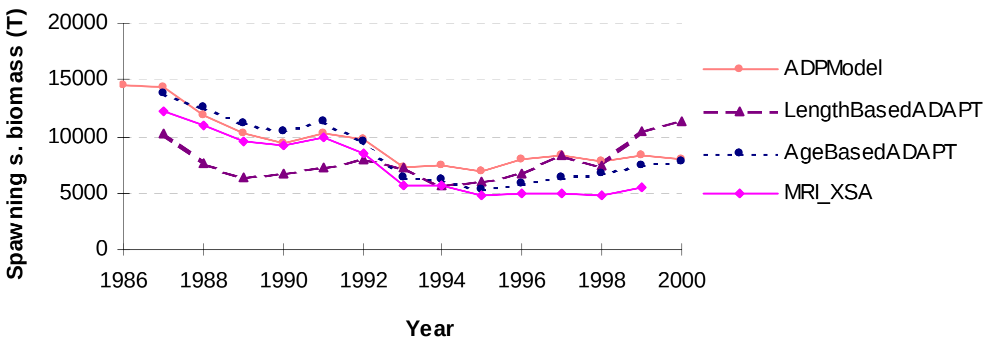

Figure 12: Total spawning stock biomass estimated from different models