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An Age-Structured Assessment Model for Georges Bank Winter Flounder

by

Jon K.T. Brodziak

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A Report of the 34th Northeast Regional Stock Assessment Workshop

An Age-Structured Assessment Model for Georges Bank Winter Flounder

by

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ABSTRACT

An age-structured assessment model for Georges Bank winter flounder (*Pseudopleuronectes americanus*) stock during 1964-2000 is developed to provide an alternative to VPA-based analyses of stock status. Age-structured population dynamics of winter flounder are modeled using standard forward-projection methods for statistical catch-at-age analyses.

Trends in the relative abundance of population biomass are measured by research survey indices for Georges Bank winter flounder. Three surveys were available: the NEFSC autumn groundfish survey (1963-2000), the NEFSC spring groundfish survey (1968-2000), and the Canadian spring groundfish survey (1987-2000). Two alternative models were examined in detail: (1) a model that used all three research survey time series (**WINC**, ***WIN***ter flounder model including ***C***anadian survey) and (2) a model that used the two NEFSC research survey time series (**WIN**, ***WIN***ter flounder model). Both the WINC and WIN models provided similar trends in population biomass and fishing mortality, indicating that results were robust to the inclusion of the Canadian research survey time series. Based on model diagnostics, the WIN model that used the two NEFSC research survey time series provided the best fit to the data.

Conditioned on the accuracy of the model and the assessment data, results of the best fit model indicate that: (i) Spawning biomass exceeded 20,000 mt in 1964 but declined to less than 3,000 mt in the early-1990s. Spawning biomass in year 2000 was roughly 9,900 mt; (ii) Fishing mortality (fully-recruited, age-4 estimate) increased steadily from less than 0.2 in the early-1960s to over 1.0 in the late-1980s and early-1990s, but has declined since then to roughly 0.32 in 2000; (iii) Stock-recruitment data show that the stock produced large year classes (>15 million recruits) in the 1960s and 1970s when spawning biomass was near or above 10,000 mt; (iv) Surplus production data show that the stock was most productive during the 1970s and early-1980s, with annual surplus production of roughly 3,000 mt. Since the mid-1980s annual surplus production has decreased to roughly 2,000 mt.

INTRODUCTION

An age-structured assessment model for Georges Bank winter flounder (*Pseudopleuronectes americanus*) stock during 1964-2000 is developed to provide an alternative to VPA-based analyses of stock status. Age-structured population dynamics of winter flounder are modeled using standard forward-projection methods for statistical catch-at-age analyses (Fournier and Archibald 1982, Methot 1990, Ianelli and Fournier 1998, Quinn and Deriso 1999). We describe the underlying population dynamics model, statistical estimation approach, Southern Demersal Working Group recommendations, model diagnostics, and model results below.

POPULATION DYNAMICS MODEL

The age-structured model is based on forward projection of population numbers at age. This modeling approach is based on the principle that population numbers through time are determined by recruitment and total mortality at age through time. That is, if one knew the time series of inputs and outputs to the population numbers and the initial population size at age, then one would have complete information on the population size, spawning biomass, and total mortality through time. In practice, one uses available sampling data and a statistical model of how the data were observed to estimate parameters to determine the time series of population sizes.

Population numbers at age through time are key variables in the age-structured model and the population numbers at age matrix $\mathbf{N}=(N_{y,a})_{YxA}$ contains this information. This matrix has dimensions Y by A, where Y is the number of years in the assessment time horizon and A is the number of age classes modeled. The oldest age (A) comprises a plus-group consisting of all fish age-A and older. The time horizon for winter flounder is 1964-2000 (Y=37). The choice of time horizon was determined by the availability of landings data which are first available in 1964 and a relative abundance index, the NEFSC autumn groundfish survey. The number of age classes in the model is 7, representing ages 1 through 7+.

Recruitment (numbers of age-1 fish) in year y (R_y) is modeled as a lognormal deviation from an average recruitment parameter (μ_R), where the V_y are independent and identically distributed (iid) normal random variables with zero mean and constant variance.

$$R_y = \mu_R e^{V_y} \tag{1}$$

For all years, y, from 1965-2000, $R_y = N_{y1}$ is estimated from the recruitment deviation and average recruitment parameter. The recruitment deviations are constrained to sum to zero over all years.

Initial population abundance at age in 1964 is based on recruitment deviations from average recruitment for 1959-1964 and natural mortality. For all ages a < A, the numbers at age in the first year (ystart=1) are estimated as a lognormal deviation from average recruitment as reduced by natural mortality (M)

$$N_{1,a} = \mu_R e^{V_{ystart-a+1}} e^{-(a-1)M} \tag{2}$$

For the plus group, the initial numbers at age is the sum of numbers at ages 7 and older based on average recruitment and recruitment deviations for ages 7 and older in 1964 along with the natural mortality rate

$$N_{1,A} = \frac{\mu_R e^{V_{ystart-A+1}} e^{-(A-1)M}}{1-e^{-M}} \tag{3}$$

Total mortality rates at age through time are also key variables in the population dynamics model. The total instantaneous mortality at age matrix $\mathbf{Z}=(Z_{y,a})_{YxA}$ and the instantaneous fishing mortality at age matrix $\mathbf{F}=(F_{y,a})_{YxA}$ both have dimensions Y by A. Instantaneous natural mortality at age is assumed to be constant with M equal to 0.2. Thus, for all years y, and age classes a, total mortality at age is the sum of fishing and natural mortality

$$Z_{y,a} = F_{y,a} + M \tag{4}$$

To determine total mortality, fishing mortalities will be estimated. While natural mortality might be estimable in some rare data-rich situations, M is often highly correlated with other parameters and is not estimable in practice (see for example, Schnute and Richards 1995).

Population numbers at age through time are computed from the initial population numbers at age, recruitment through time, and total mortality at age through time. For each age class, indexed by “a”, that is younger than the plus group (a < A), the number at age is sequentially determined using a standard survival model

$$N_{y,a} = N_{y-1,a-1} e^{-Z_{y-1,a-1}} \quad \textbf{(5)}$$

For the plus group, numbers at age are the sum of survivors of age A-1 and survivors from the plus group in the preceding year

$$N_{y,A} = N_{y-1,A-1} e^{-Z_{y-1,A-1}} + N_{y-1,A} e^{-Z_{y-1,A}} \quad \textbf{(6)}$$

Estimation of fishing mortality at age is facilitated by making the simplifying assumption that fishing mortality can be modeled as a separable process. This assumption implies that $F_{y,a}$ is determined from the average selectivity pattern of age-a fish (S_a) and fully-recruited fishing mortality in year y (F_y)

$$F_{y,a} = S_a F_y \quad \textbf{(7)}$$

While more complicated models of time-varying selectivity may be useful, this approximation is likely to be satisfactory if observation errors in the catch-at-age data are substantial.

Fully-recruited fishing mortality in each year is modeled as a lognormal deviation from average fishing mortality (μ_F), where the U_y are iid normal random variables with zero mean and constant variance

$$F_y = \mu_F e^{U_y} \quad \textbf{(8)}$$

The fishing mortality deviations (U_y) are constrained to sum to zero over all years.

Fishery selectivity at age is modeled as being time-invariant throughout the assessment time horizon. This approach was chosen for parsimony and because there was believed to be substantial errors in the observed fishery age composition, especially in recent years. In particular, winter flounder catch-at-age data to estimate fishery selectivity are limited to 1982-2000, a period when the fishery was prosecuted primarily by domestic trawl fishing vessels. Since 1993, fishery sampling intensity of Georges Bank winter flounder catches has been relatively low. As a result, temporal changes in fishery selectivity would likely be difficult to detect given relatively high measurement errors in the fishery age composition data.

The average fishery selectivity at age is estimated for ages 1 through 6. For ages 7 and older, fishery selectivity is assumed to be equal to the age-6 selectivity value. This approach was chosen to reflect the fact that age-7 fish were not likely to differ much from age-6 fish in their fishery selectivity. Two constraints are applied to the estimated selectivity at age coefficients. First, the selectivities are constrained to average 1 for estimated ages. This forces the scale of each coefficient to be near unity. Second, a constraint is applied to ensure that estimated selectivities change smoothly between adjacent ages. Details of the implementation of both constraints are described in the section on statistical estimation approach. Last, for each year, the selectivity at age values are rescaled so that the maximum selectivity at age value is unity. This rescaling ensures that estimated fully-recruited fishing mortality rates are directly comparable to biological reference points such as $F_{0.1}$.

Fishery removals from the population are accounted for through the fishery catch numbers at age matrix $\mathbf{C}=(C_{y,a})_{YxA}$ and the fishery catch biomass at age (yield) matrix $\mathbf{Y}=(Y_{y,a})_{YxA}$. Both **C** and **Y** have dimensions Y by A. Fishery catch at age in each year is computed in a standard manner from Baranov's catch equation using population numbers, fishing mortality, and total mortality at age

$$C_{y,a} = \frac{N_{y,a} F_{y,a} \left(1 - e^{-Z_{y,a}}\right)}{Z_{y,a}} \qquad \textbf{(9)}$$

Catch biomass at age in each year ($Y_{y,a}$) is approximated by the product of catch numbers at age and the long-term mean weights at age, where W_a is the mean weight at age computed as the average of mean Georges Bank weights at age from fishery sampling during 1982-2000

$$Y_{y,a} = C_{y,a} W_a \tag{10}$$

Use of the long-term mean weights at age is likely to be a useful approximation unless mean weights at age have varied substantially through time. Since fishery sampling has been relatively poor in recent years, the use of a long-term average was considered to be adequate given the likely errors in the observed annual mean weights at age computed from fishery samples.

Total fishery catch biomass in year y (Y_y) is the sum of yields by age class

$$Y_y = \sum_{a=1}^{A} Y_{y,a} \tag{11}$$

The calculated total fishery catch biomass time series is compared to observed values using a lognormal probability model. This model feature was included because it was expected that observed catches were not accurately reported in some years and that discards were not estimated for inclusion in the catch-at-age data.

Similarly, the proportion of fishery catch at age a in year y ($P_{y,a}$) is computed from estimated catch numbers

$$P_{y,a} = \frac{C_{y,a}}{\sum_a C_{y,a}} \tag{12}$$

The time series of fishery proportions at age are fitted to observed fishery values using a multinomial probability model (see for example, Fournier and Archibald 1982, Quinn and Deriso 1999). This model feature accounts for the possibility that the fishery catch-at-age data are measured with error.

Trends in the relative abundance of population biomass are measured by research survey indices for Georges Bank winter flounder. Three surveys were available: the NEFSC autumn groundfish survey (1963-2000), the NEFSC spring groundfish survey (1968-2000), and the Canadian spring groundfish survey (1987-2000). The survey biomass index in year y (I_y) for any of the surveys is modeled as a catchability coefficient (Q_{SURVEY}) times the population biomass that is vulnerable to the survey, where $S_{SURVEY,a}$ is survey selectivity at age a and p_{SURVEY} is the fraction of annual total mortality that occurs prior to the survey

$$I_y = Q_{SURVEY} \sum_a S_{SURVEY,a} W_a N_{y,a} e^{-p_{SURVEY} Z_{y,a}} \quad \textbf{(13)}$$

The survey biomass index time series are fitted to observed values using a lognormal probability model. This model feature accounts for the possibility that the survey relative abundance indices are measured with error.

Survey selectivity accounts for differential vulnerability of winter flounder age classes to the survey fishing gear and also for differential vulnerability due to differences in the behavior and distribution of juvenile and adult fish. For each of the three surveys, selectivity at age is modeled using Thompson's exponential-logistic model (Thompson 1994), where α, β, and γ are parameters and survey selectivity for winter flounder is assumed to be time invariant

$$S_{SURVEY,a} = \frac{1}{1-\gamma}\left(\frac{1-\gamma}{\gamma}\right)^{\gamma}\left(\frac{e^{\alpha\gamma(\beta-a)}}{1+e^{\alpha(\beta-a)}}\right) \quad \textbf{(14)}$$

This model has the useful property that the maximum selectivity value is unity. For values of $\gamma>0$ survey selectivity is dome-shaped, and survey selectivity is flat-topped (i.e., constant at older ages) when $\gamma=0$.

Survey age composition data provide information on the relative abundance of winter flounder age classes captured with the survey gear. Survey catch proportion at age a in year y ($P_{SURVEY,\, y,\, a}$) is computed from survey selectivity, the fraction of mortality occurring prior to the survey, and population numbers at age

$$P_{SURVEY,y,a} = \frac{S_{SURVEY,a} N_{y,a} e^{-p_{SURVEY} Z_{y,a}}}{\sum_a S_{SURVEY,a} N_{y,a} e^{-p_{SURVEY} Z_{y,a}}} \tag{15}$$

The time series of survey proportions at age are fitted to observed fishery values using a multinomial probability model. This model feature accounts for the possibility that the survey age composition data are measured with error.

STATISTICAL ESTIMATION APPROACH

The population dynamics model is fit to observed data using an iterative maximum likelihood estimation approach. The statistical model consists of ten likelihood components (L_j) and two penalty terms (P_k). The model objective function (Λ) is the weighted sum of the likelihood components and penalties where each summand is multiplied by an emphasis coefficient (λ_j) that reflects the relative importance of the data.

$$\Lambda = \sum_j \lambda_j L_j + \sum_k \lambda_k P_k \tag{16}$$

Each likelihood component is written as a negative log-likelihood so that the maximum likelihood estimates of model parameters are obtained by minimizing the objective function. The Automatic Differentiation Model Builder software is used to estimate a total of roughly 95 parameters depending upon the model configuration. The likelihood components and penalty terms are described below.

1. Recruitment

Recruitment strength is modeled by lognormal deviations from average recruitment for the period 1959-2000. A total of 42 recruitment deviation parameters (V_y) and one average recruitment parameter (μ_R) are estimated based on the objective function minimization. The recruitment likelihood component (L_1) is

$$L_1 = \frac{n_1}{2}\sum_y V_y^2 \qquad \textbf{(17)}$$

where

$$V_y = \ln(R_y) - \ln(\mu_R)$$

and the V_y are iid normal random variables with zero mean and constant variance and n_1 is the number of recruitment deviations.

2. Fishery age composition

Fishery age composition is modeled as a multinomial distribution for sampling catch numbers at age. The constant $N_{E,Fishery,y}$ denotes the effective sample size for the multinomial distribution for year y and is assumed to be 200 fish per year during 1982-1993, 100 fish per year during 1994-1997 and 2000, and 50 fish per year during 1998-1999. These different sample sizes were chosen to reflect the relative intensity of fishery sampling of Georges Bank winter flounder. The observed number of fish at age in the fishery samples is computed as the effective sample size times the observed proportion at age, denoted with a superscript "OBS" for all variables.
The negative log-likelihood of the multinomial sampling model for the fishery ages (L_2) is

$$L_2 = -\sum_y N_{E,Fishery,y} \sum_a \left(P_{y,a}^{OBS} \ln P_{y,a} - P_{y,a}^{OBS} \ln P_{y,a}^{OBS} \right) \qquad \textbf{(19)}$$

The second term in summation over ages indexed by "a" is a constant that scales L_2 to be zero if the observed and predicted proportions were identical. Six fishery selectivity coefficients (S_1 through S_6) are estimated based on the objective function minimization.

3. NEFSC Fall survey age composition

Fall survey age composition is also modeled as a multinomial distribution for sampling survey catch numbers at age. The constant $N_{E,Fall,y}$ denotes the effective sample size for the multinomial distribution for year y and is assumed to be constant across time for the years 1982-2000 when winter flounder autumn survey catch-at-age data are available. The observed number of fish at age in the survey samples is computed as the effective sample size times the observed proportion at age. The effective sample size was assumed to be 100 fish in each year. The negative log-likelihood of the multinomial sampling model for the autumn survey ages (L_3) is

$$L_3 = -\sum_y N_{E,Fall,y} \sum_a \left(P^{OBS}_{Fall,y,a} \ln P_{Fall,y,a} - P^{OBS}_{Fall,y,a} \ln P^{OBS}_{Fall,y,a} \right) \quad \textbf{(20)}$$

As with the fishery age composition, the second term in the summation over the age index "a" is a constant that scales L_3 to be zero if the observed and predicted proportions were identical. Three fall survey selectivity coefficients (α_{Fall}, β_{Fall}, γ_{Fall}) are estimated based on the objective function minimization using the survey selectivity model (Eqn. 14).

4.NEFSC Fall survey biomass index

The fall survey biomass index is modeled by lognormal deviations of predicted values from observed values during 1964-2000, where the log-transformed deviations $D_{Fall,\,y}$ are iid normal random variables with zero mean and constant variance

$$I^{OBS}_{Fall,y} = I_{Fall,y} e^{D_{Fall,y}} \quad \textbf{(21)}$$

The fall survey biomass likelihood component (L_4) is

$$L_4 = \frac{n_4}{2} \sum_y D^2_{Fall,y} \quad \textbf{(22)}$$

where n_4 is the number of observed fall survey index values. One fall survey catchability coefficient (Q_{Fall}) is estimated based on the objective function minimization.

5. NEFSC Spring survey age composition

Spring survey age composition is also modeled as a multinomial distribution for sampling survey catch numbers at age. The constant $N_{E,Spr,\,y}$ denotes the effective sample size for the multinomial distribution for year y and is assumed to be constant for the years 1982-2000 when winter flounder spring survey catch-at-age data are available. The observed number of fish at age in the survey samples is computed as the effective sample size times the observed proportion at age. The effective sample size was assumed to be 100 fish in each year. The negative log-likelihood of the multinomial sampling model for the spring survey ages (L_5) is

$$L_5 = -\sum_y N_{E,Spr,y} \sum_a \left(P^{OBS}_{Spr,y,a} \ln P_{Spr,y,a} - P^{OBS}_{Spr,y,a} \ln P^{OBS}_{Spr,y,a} \right) \quad \textbf{(23)}$$

Three spring survey selectivity coefficients (α_{Spr}, β_{Spr}, γ_{Spr}) are estimated based on the objective function minimization using the survey selectivity submodel (Eqn. 14).

6. NEFSC Spring survey biomass index

The spring survey biomass index is modeled by lognormal deviations of predicted values from observed values during 1968-2000, where the log-transformed deviations $D_{Spr,\,y}$ are iid normal random variables with zero mean and constant variance

$$I^{OBS}_{Spr,y} = I_{Spr,y} e^{D_{Spr,y}} \quad \textbf{(24)}$$

The spring survey biomass likelihood component (L_6) is

$$L_6 = \frac{n_6}{2} \sum_y D^2_{Spr,y} \quad \textbf{(25)}$$

where n_6 is the number of observed spring survey index values. One spring survey catchability coefficient (Q_{Spr}) is estimated based on the objective function minimization.

7. Canadian Spring survey age composition

Canadian spring survey age composition is also modeled as a multinomial distribution for sampling survey catch numbers at age. The constant $N_{E,CANSpr,\,y}$ denotes the effective sample size for the multinomial distribution for year y and is assumed to be constant for the years 1987-2000 when winter flounder Canadian spring survey catch-at-age data are available. The observed number of fish at age in the survey samples is computed as the effective sample size times the observed proportion at age. The effective sample size was assumed to be 200 fish in each year. The negative log-likelihood of the multinomial sampling model for the Canadian spring survey ages (L_7) is

$$L_7 = -\sum_y N_{E,CANSpr,y} \sum_a \left(P^{OBS}_{CANSpr,y,a} \ln P_{CANSpr,y,a} - P^{OBS}_{CANSpr,y,a} \ln P^{OBS}_{CANSpr,y,a} \right) \quad \textbf{(26)}$$

Three Canadian spring survey selectivity coefficients (α_{CANSpr}, β_{CANSpr}, γ_{CANSpr}) are estimated based on the objective function minimization using the survey selectivity model (Eqn. 14).

8. Canadian Spring survey biomass index

The Canadian spring survey biomass index is modeled by lognormal deviations of predicted values from observed values during 1987-2000, where the log-transformed deviations $D_{CANSpr,y}$ are iid normal random variables with zero mean and constant variance

$$I^{OBS}_{CANSpr,y} = I_{CANSpr,y} e^{D_{CANSpr,y}} \quad \textbf{(27)}$$

The Canadian spring survey biomass likelihood component (L_8) is

$$L_8 = \frac{n_8}{2} \sum_y D^2_{CANSpr,y} \quad \textbf{(28)}$$

where n_8 is the number of observed Canadian spring survey index values. One Canadian spring survey catchability coefficient (Q_{CANSpr}) is estimated based on the objective function minimization.

9. Catch biomass

Catch biomass is modeled by lognormal deviations of predicted values from observed values during 1934-1999, where T_y are iid normal random variables with zero mean and constant variance

$$Y^{OBS}_y = Y_y e^{T_y} \quad \textbf{(29)}$$

The catch biomass likelihood component (L_9) is

$$L_9 = \frac{n_9}{2} \sum_y T^2_y \quad \textbf{(30)}$$

where n_9 is the number of observed catch biomass values.

10. Fishing mortality

Annual values of fully-recruited fishing mortality are modeled as lognormal deviations from average fishing mortality during the period 1934-2000. A total of 37 fishing mortality deviation parameters (U_y) and one average fishing mortality parameter (μ_F) are estimated based on the objective function minimization. The fishing mortality likelihood component (L_{10}) is

$$L_{10} = \frac{n_{10}}{2} \sum_{y} U_y^2 \qquad \textbf{(31)}$$

where

$$U_y = \ln(F_y) - \ln(\mu_F)$$

and n_{10} is the number of observed catch values.

11. Fishery selectivity

Two constraints on fishery selectivity are included in a penalty function. The fishery selectivity penalty function (P_1) is

$$P_1 = \left(\tfrac{1}{7} \sum_{a=1}^{7} S_a - 1 \right)^2 + \sum_{a=1}^{5} \left(S_a - 2S_{a+1} + S_{a+2} \right)^2 \qquad \textbf{(33)}$$

The first term constrains the fishery selectivity coefficients to scale to an average of 1. The second term constrains the fishery selectivity coefficient of age a+1 to be near to the linear prediction of this value interpolated from age a and age a+2 selectivities over the range of estimated selectivity coefficients.

12. Fishing mortality penalty

One constraint on fishing mortality is imposed to ensure that during the early phases of the iterative estimation process the observed catch could not be generated by an extremely small F on an extremely large population size. The fishing mortality penalty function (P_2) is

$$P_2 = 10\sum_y \left(F_y - 0.1\right)^2 \Leftrightarrow phase < 3$$
$$P_2 = \tfrac{1}{1000}\sum_y \left(F_y - 0.1\right)^2 \Leftrightarrow phase \geq 3 \qquad \textbf{(34)}$$

The constraint is weighted with a value of 10 for the initial estimation phases and is weighted with a value of 0.001 for all later estimation phases. The value of 0.1 was used because this value is sufficient to ensure that the estimated mean F will be on the order of the value of natural mortality for Georges Bank winter flounder.

Initial values are input for all parameters before the estimation phases are conducted. A total of nine estimation phases were used for the iterative minimization of the objective function. Any parameters first estimated in a given phase, say N, are estimated in all subsequent phases, N+1, N+2, etc. The first phase estimates average recruitment. The second phase estimates average fishing mortality and fishing mortality deviations. The third phase estimates recruitment deviations. The fourth phase estimates fishery and NEFSC spring survey selectivity coefficients. The fifth phase estimates the spring survey catchability coefficient. The sixth phase estimates the NEFSC fall survey selectivity coefficients. The seventh phase estimates the fall survey catchability coefficient. The eighth phase estimates the Canadian spring survey selectivity coefficients. The ninth phase estimates the Canadian spring survey catchability coefficient.

The twelve emphasis values (λs) used for the baseline model were:

1. Recruitment λ_1=10
2. Fishery age composition λ_2=1
3. NEFSC Fall survey age composition λ_3=1
4. NEFSC Fall survey biomass index λ_4=10
5. NEFSC Spring survey age composition λ_5=1
6. NEFSC Spring survey biomass index λ_6=10
7. Canadian Spring survey age composition λ_7=1
8. Canadian Spring survey biomass index λ_8=10

9. Catch biomass λ_9=100
10. Fishing mortality λ_{10}=1
11. Fishery selectivity penalty λ_{11}=10
12. Fishing mortality penalty λ_{12}=1

SOUTHERN DEMERSAL WORKING GROUP RECOMMENDATIONS

After making some adjustments to the initial model configuration to better reflect the timing of the surveys and the emphasis factors for the fishery and survey age composition likelihood components, the Southern Demersal Working Group recommended that two final models be examined: (1) a model that used all three research survey time series (**WINC**, *WIN*ter flounder model including *C*anadian survey) and (2) a model that used the two NEFSC research survey time series (**WIN**, *WIN*ter flounder model). Both the WINC and WIN models provided similar trends in population biomass and fishing mortality, indicating that results were robust to the inclusion of the Canadian research survey time series.

MODEL DIAGNOSTICS

Model diagnostics showed that the WIN model provided a better fit to the observed catch biomass series (RMSE=0.137) than the WINC model (RMSE=0.149). The WIN model also provided a better fit to the NEFSC fall biomass series (RMSE=0.356) than the WINC model (RMSE=0.373). The fits to the NEFSC spring biomass series were nearly identical for the two models (WIN, RMSE=0.472 vs WINC, RMSE=0.473). In addition, the trend in the observed Canadian spring biomass series was lower than the WINC model predictions during 1998-2000, suggesting that the Canadian survey was not tracking relative abundance in recent years. Overall, the WIN model that used the two NEFSC research survey time series provided the best fit to the catch biomass and NEFSC survey biomass series while the WINC model provided a poor fit to the Canadian survey biomass series in recent years (see Figure 4 below). The condition numbers of the hessian matrices of the two models were also different with the WINC model having a much higher condition number ($\kappa=6.83 \cdot 10^{12}$) than the WIN model ($\kappa=2.83 \cdot 10^{7}$). This indicated that the numercial solution of the WINC model was not well-determined relative to the WIN model. Based on model diagnostics, the WIN model that used the two NEFSC research survey time series was considered to be the best model among the statistical catch-at-age models examined for winter flounder. Computer code to fit the WIN model, the input data file, and the standard deviation parameter file are listed in the Appendix.

Plots of diagnostics for the two models include the discrepancies between observed data and predicted values for the catch biomass series (Figure 1), the fall survey biomass series (Figure 2), the spring survey biomass series (Figure 3), and the Canadian spring survey biomass series (Figure 4, shown for the WINC model only). For the best fit WIN model, diagnostic plots include the fishery age composition series (Figure 5), the fall survey age composition series (Figure 6), and the spring survey age composition series (Figure 7). For the WINC model, a diagnostic plot of the Canadian spring survey age composition series is also shown (Figure 8).

MODEL RESULTS

Model estimates of spawning biomass, fishing mortality, recruitment, and population biomass for the WIN model during the period 1963-2000 are listed in Table 1. Fishery and survey selectivity estimates at age are shown in Figure 9. Recruitment estimates are shown in Figure 10 (see also Table 1). Population biomass estimates are shown in Figure 11 (see also Table 1). Spawning biomass estimates (at start of the spawning season) are shown in Figure 12 (see also Table 1). Fishing mortality estimates are shown in Figure 13 (see also Table 1). Stock-recruitment data are shown in Figure 14. Surplus production implied by the age-structured estimates of exploitable biomass and observed catches are shown in Figure 15.

Other model outputs included depletion ratios for year 2000, relative to 1964, for spawning biomass (46%) and population biomass (53%). Similarly, depletion ratios for year 2000, relative to 1982, were computed for spawning biomass (88%) and population biomass (81%). Long-term average recruitment was estimated to be 5.550 million age-1 fish during 1959-1999.

Sensitivity to the assumed value of M was investigated by systematically varying this parameter using the likelihood profile feature of the AD Model Builder software. This analysis showed that the model was not stable for moderate departures from M=0.2. In particular, running the baseline model under alternative assumptions about M showed that the model did not converge in its final configuration for M=0.195, 0.196, 0.2005, 0.201, 0.2015, 0.2025, 0.203, while it did converge for M=0.197 (-lnL=3445.2), M=0.198 (-lnL=3444.8), M=0.199 (-lnL=3444.2), and M=0.202 (-lnL=3443.0). The objective function value for the assumed value of M=0.2 was -lnL=3443.8. This suggested that the objective function surface was a complicated function of natural mortality and that the model was sensitive to the assumed value.

Based on the Southern Demersal Working Group's recommendations, a sensitivity analysis was conducted on the value of the effective sample size time series for the fishery age composition likelihood. This was done to see how the model results might change if different effective sample sizes were used. The SDWG suggested multiplying the effective sample size time series by ½ and 2. The use of multipliers of less than 0.8 did not lead to model convergence, presumably because there was insufficient information assigned to the fishery age composition in these cases. Nonetheless, estimated spawning biomass, a key model output, was insensitive to using effective sample sizes that were 80% and 200% of the baseline values, which ranged from 50 to 200 fish (Figure 16). Overall, this suggested that the model solution would not be well-determined if effective sample sizes for the fishery age composition were below 40 fish per year, but, for values above this, the results appeared to be robust.

CONCLUSIONS

Conditioned on the accuracy of the model and the assessment data, results of the best fit model indicate that:

- The Georges Bank winter flounder stock appears to have a dome-shaped fishery selectivity pattern with age-4 fish being fully-recruited (Figure 9).
- The NEFSC fall bottom trawl survey appears to have a dome-shaped selectivity pattern and provides an index of the relative number of age-5 fish (Figure 9).
- The NEFSC spring bottom trawl survey appears to have an asymptotic selectivity pattern and provides an index of the relative number of age-3 and older fish (Figure 9).
- Recruitment appears to have been relatively strong during the early-1970 to early-1980s with the 1974 year class being the largest observed during 1964-2000 (Figure 10).
- Population biomass was over 20,000 mt in the early-1960s, declined to less than 5,000 mt in the early-1990s, and has subsequently increased to roughly 10,000 mt in year 2000 (Figure 11).
- Spawning biomass exceeded 20,000 mt in 1964 but declined to less than 3,000 mt in the early-1990s (Figure 12). Spawning biomass in year 2000 was roughly 9,900 mt.
- Fishing mortality (fully-recruited, age-4 estimate) increased steadily from less than 0.2 in the early-1960s to over 1.0 in the late-1980s and early-1990s (Figure 13), but has declined since then to roughly 0.32 in 2000.
- Stock-recruitment data show that the stock produced large year classes (>15 million recruits) in the 1960s and 1970s when spawning biomass was near or above 10,000 mt (Figure 14).

- Surplus production data show that the stock was most productive during the 1970s and early-1980s (Figure 15), with annual surplus production of roughly 3,000 mt. Since the mid-1980s annual surplus production has decreased to roughly 2,000 mt.

- The results of the age-structured model appear to be sensitive to the assumed value of natural mortality of 0.2.

- The results of the age-structured model do not appear to be sensitive to the effective sample size for the fishery age composition data provided that effective sample sizes of 50-200 fish are collected each year.

ACKNOWLEDGMENTS

I thank the members of the Southern Demersal Working Group for their helpful comments and suggestions. I also thank the members of the 34th Northeast Regional Stock Assessment Review Committee for their helpful comments and thoughtful review.

LITERATURE CITED

Fournier, D. A., and C. P. Archibald. 1982. A general theory for analyzing catch at age data. Can. J. Fish. Aquat. Sci. 39:1195-1207.

Ianelli, J. N., and D. A. Fournier. 1998. Alternative age-structured analyses of NRC simulated stock assessment data. NOAA Tech. Memo. NMFS-F/SPO-30. pp. 81-96.

Methot, R. D. 1990. Synthesis model: an adaptive framework for analysis of diverse stock assessment data. Int. North Pac. Fish. Comm. Bull. 50:259-277.

Quinn, T. P., II, and R. B. Deriso.1999. Quantitative fish dynamics. Oxford University Press, New York, 542 pp.

Schnute, J. T., and L. J. Richards. 1995. The influence of error on population estimates from catch-age models. Can. J. Fish. Aquat. Sci. 52:2063-2077.

Thompson, G. G. 1994. Confounding of gear selectivity and the natural mortality rate in cases where the former is a nonmonotone function of age. Can. J. Fish. Aquat. Sci. 51:2654-2664.

Table 1. Baseline model results for Georges Bank winter flounder.

Year	Population biomass (mt)	Spawning biomass (mt)	Exploitable biomass (mt)	Recruitment (thousands of age-1 fish)	Fishing mortality	Surplus production (mt)
1964	22826.2	21676.4	13539.9	1445.9	0.13	954.8
1965	20011.2	18943.5	12977.7	2063.2	0.15	-425.2
1966	20039.7	16295.8	10865.5	15293.4	0.24	195.9
1967	18517.5	15626.9	8864.3	3081.4	0.36	3125.2
1968	16539.7	14772.4	9640.6	4455.3	0.25	2345.6
1969	15379.3	13455.5	9987.1	4786.8	0.28	1207.7
1970	14996.9	12154.5	8676.8	9241.8	0.35	1457.4
1971	14362.9	11503.7	7418.2	5966.8	0.69	3524.7
1972	14333.2	9849.8	6759.9	15867.4	0.87	3678.6
1973	12751.0	9160.7	5926.5	6306.8	0.79	3680.8
1974	11413.1	9048.7	6631.3	5778.1	0.51	2714.0
1975	13598.3	8868.6	7127.4	18178.6	0.54	2718.8
1976	13691.9	10358.8	6909.2	4439.5	0.32	3999.3
1977	15039.8	12052.0	9015.5	9322.5	0.45	3840.5
1978	15246.5	11878.0	9262.0	8822.0	0.46	2450.1
1979	15037.9	11648.6	8462.0	9240.5	0.46	2829.3
1980	15209.2	11630.1	8227.3	9565.8	0.60	3726.5
1981	15335.1	11149.7	7978.8	12555.0	0.61	3829.3
1982	14804.4	11211.2	7796.1	8414.2	0.42	4104.6
1983	14269.8	11935.9	8920.7	3601.1	0.54	3264.7
1984	12790.0	10157.0	8277.4	6906.5	0.98	674.1
1985	9456.7	6919.0	5020.5	6487.6	0.87	1268.4
1986	8687.7	6097.6	4125.9	7678.8	0.62	2248.2
1987	8454.3	6368.6	4587.0	3707.5	0.95	2156.4
1988	7839.5	5186.5	4074.5	8755.6	1.21	1789.8
1989	6515.1	4390.5	3005.3	4044.8	1.09	2009.5
1990	5615.1	4078.0	3123.8	3193.4	1.41	1072.6
1991	4503.3	2795.5	2243.4	5287.0	1.41	1258.1
1992	3886.7	2467.1	1673.4	3139.4	1.20	2023.7
1993	4155.9	2500.1	1848.1	5422.7	1.17	1679.5
1994	4602.5	2695.8	1844.5	5759.9	0.70	1673.7
1995	6035.0	3685.5	2546.2	7742.6	0.39	2048.7
1996	7545.3	5263.1	3834.9	5617.8	0.56	2091.1
1997	7745.3	5991.2	4590.0	4029.4	0.47	1756.1
1998	8877.9	6276.4	4916.1	9554.6	0.31	1874.8
1999	10801.3	7752.0	5455.9	8671.2	0.21	2516.3
2000	12041.8	9874.0	6930.2	3901.7	0.32	

Figure 1. Georges Bank winter flounder catch biomass (mt) fit for the WIN (A) and WINC (B) models, 1964-2000

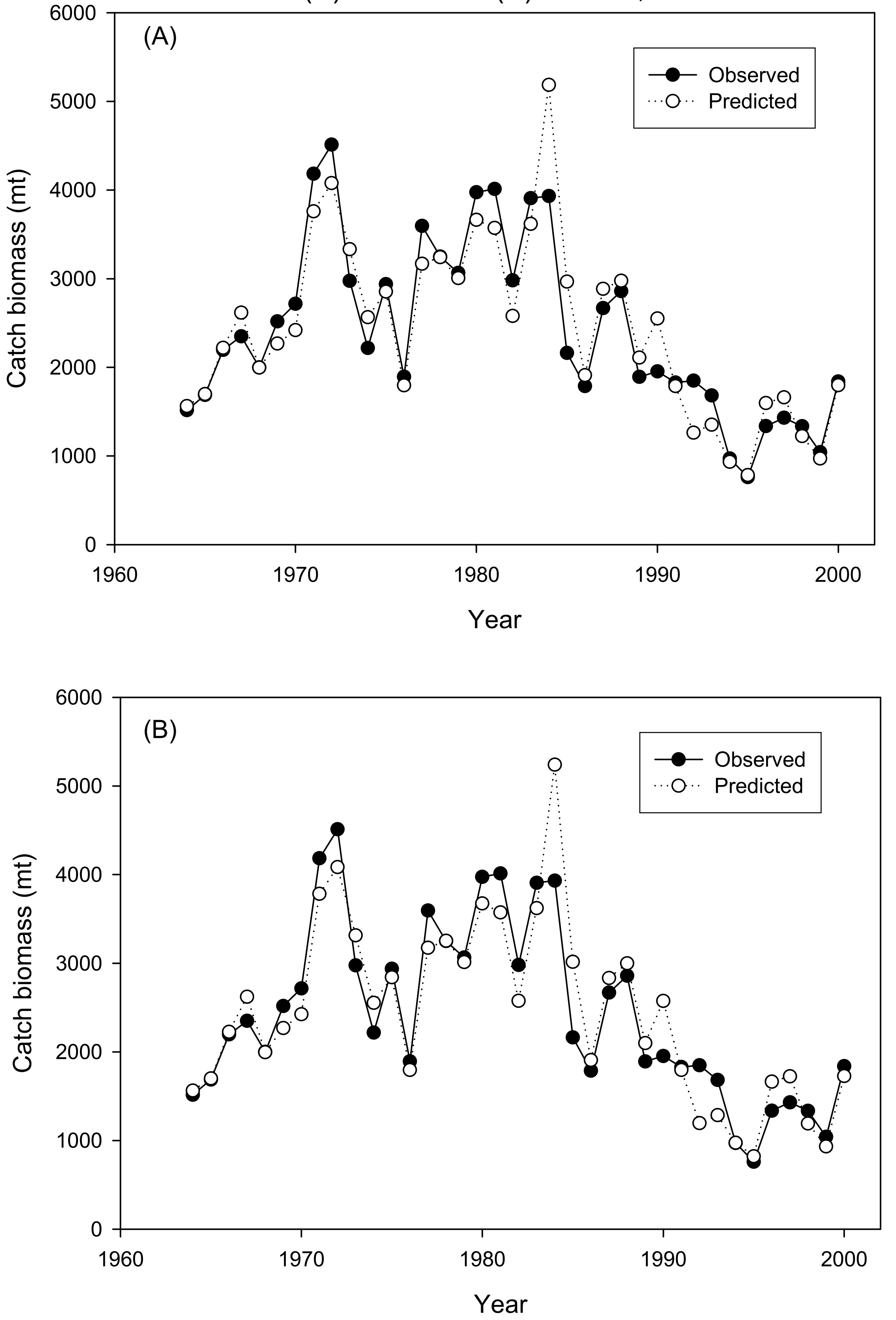


Figure 2. Winter flounder fall survey biomass index fit for the WIN (A) and WINC (B) models, 1964-2000

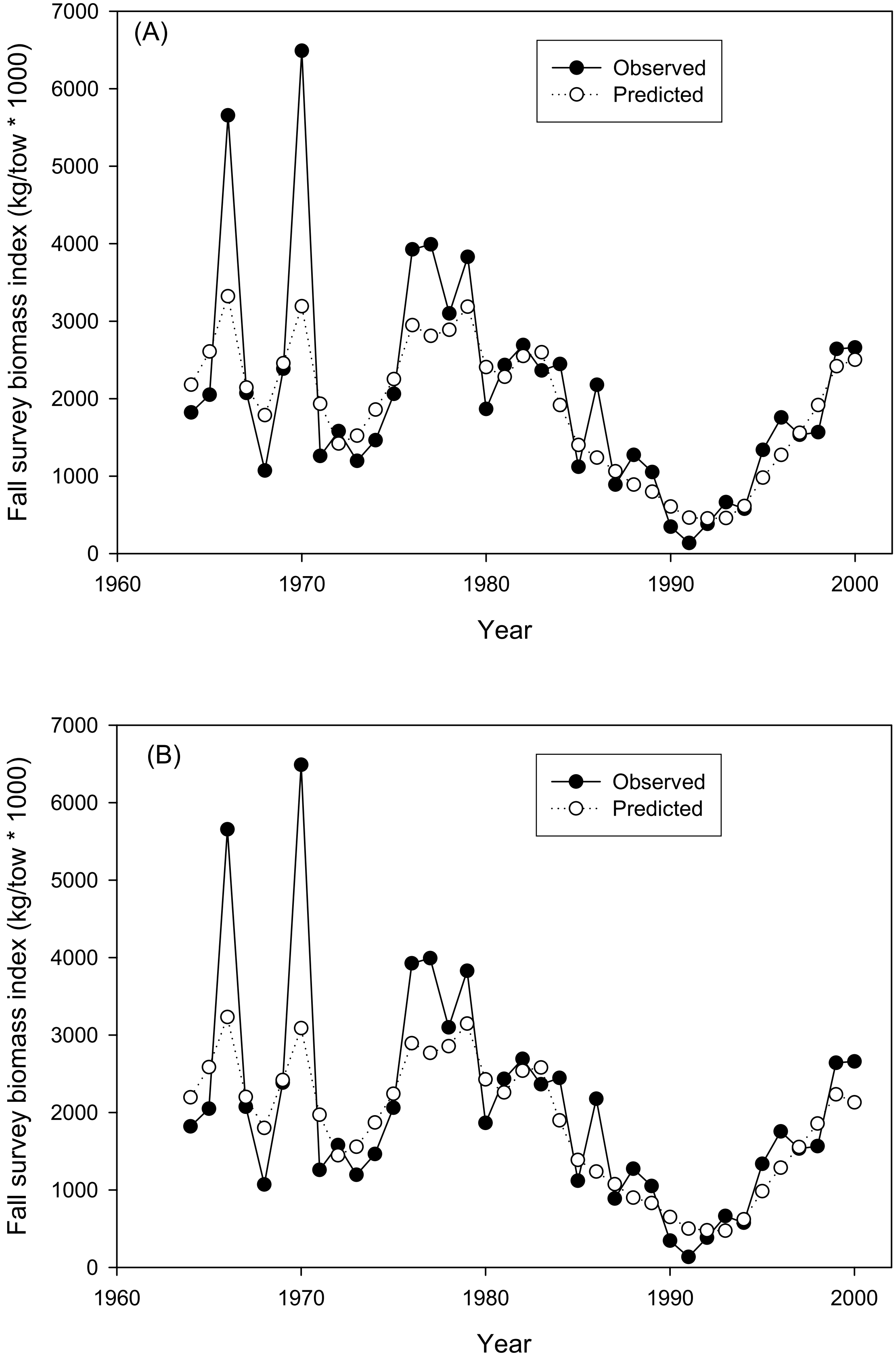
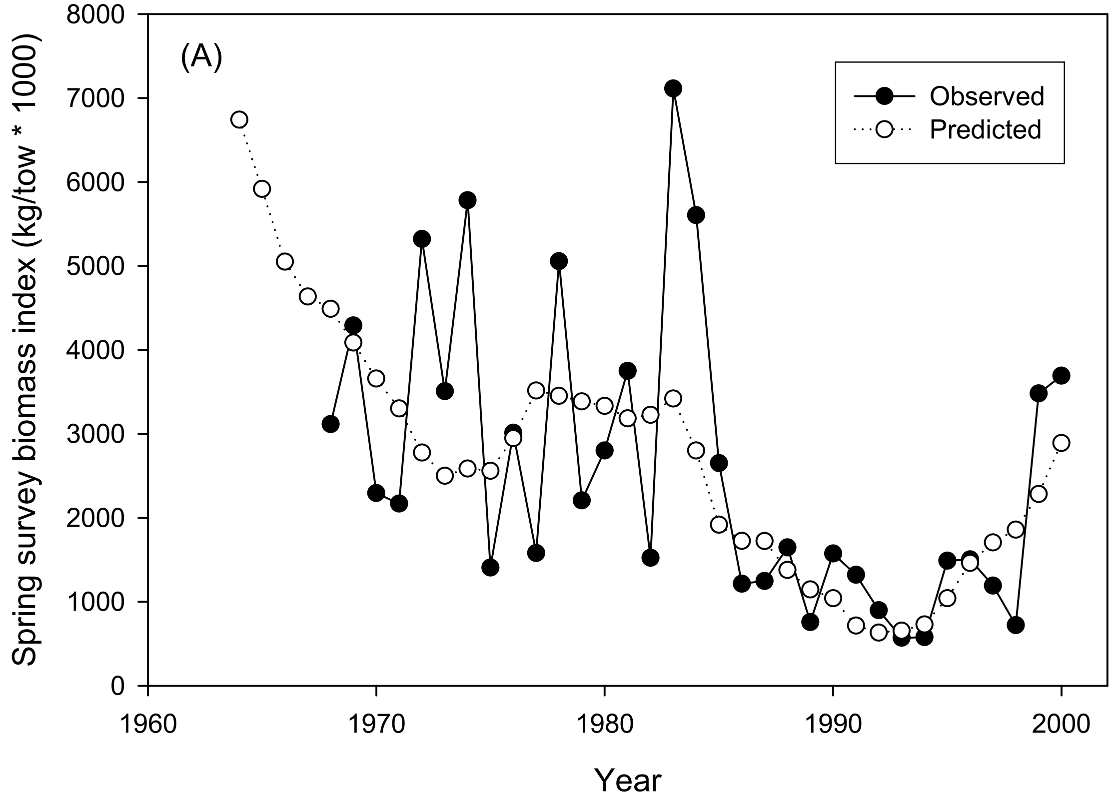


Figure 3. Winter flounder spring survey biomass index fit for the WIN (A) and WINC (B) models, 1968-2000



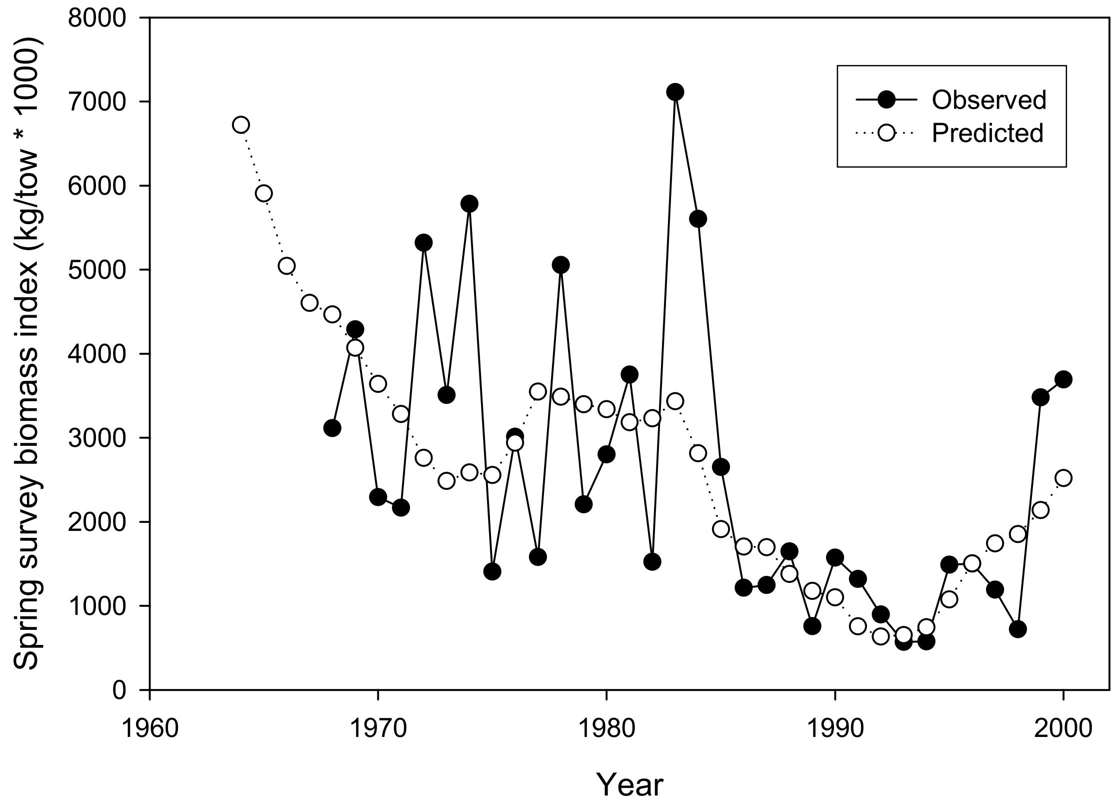


Figure 4. Winter flounder Canadian spring survey biomass index fit for the WINC model, 1987-2000

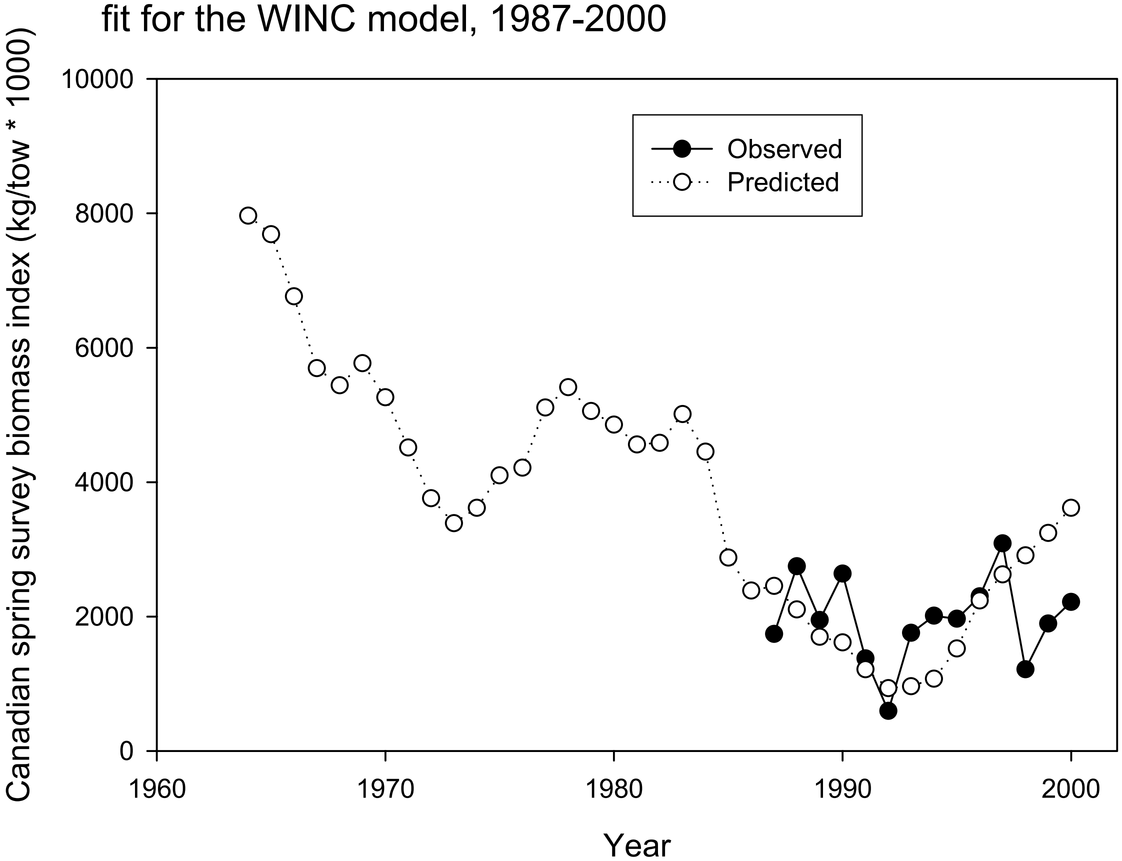


Figure 5. Winter flounder fishery age composition residuals for the WIN model, 1982-2000

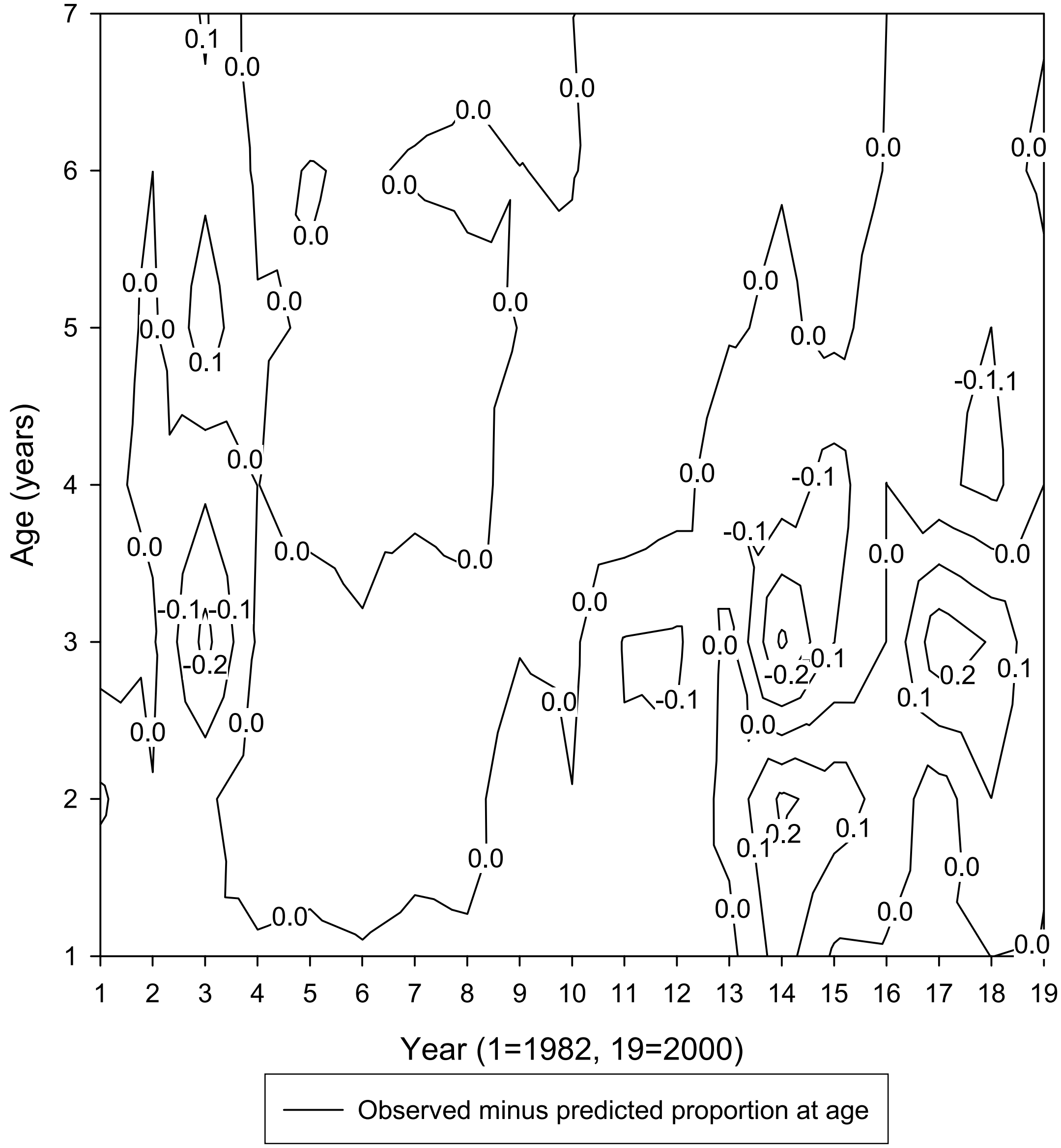


Figure 6. Winter flounder fall survey age composition residuals for the WIN model, 1982-2000

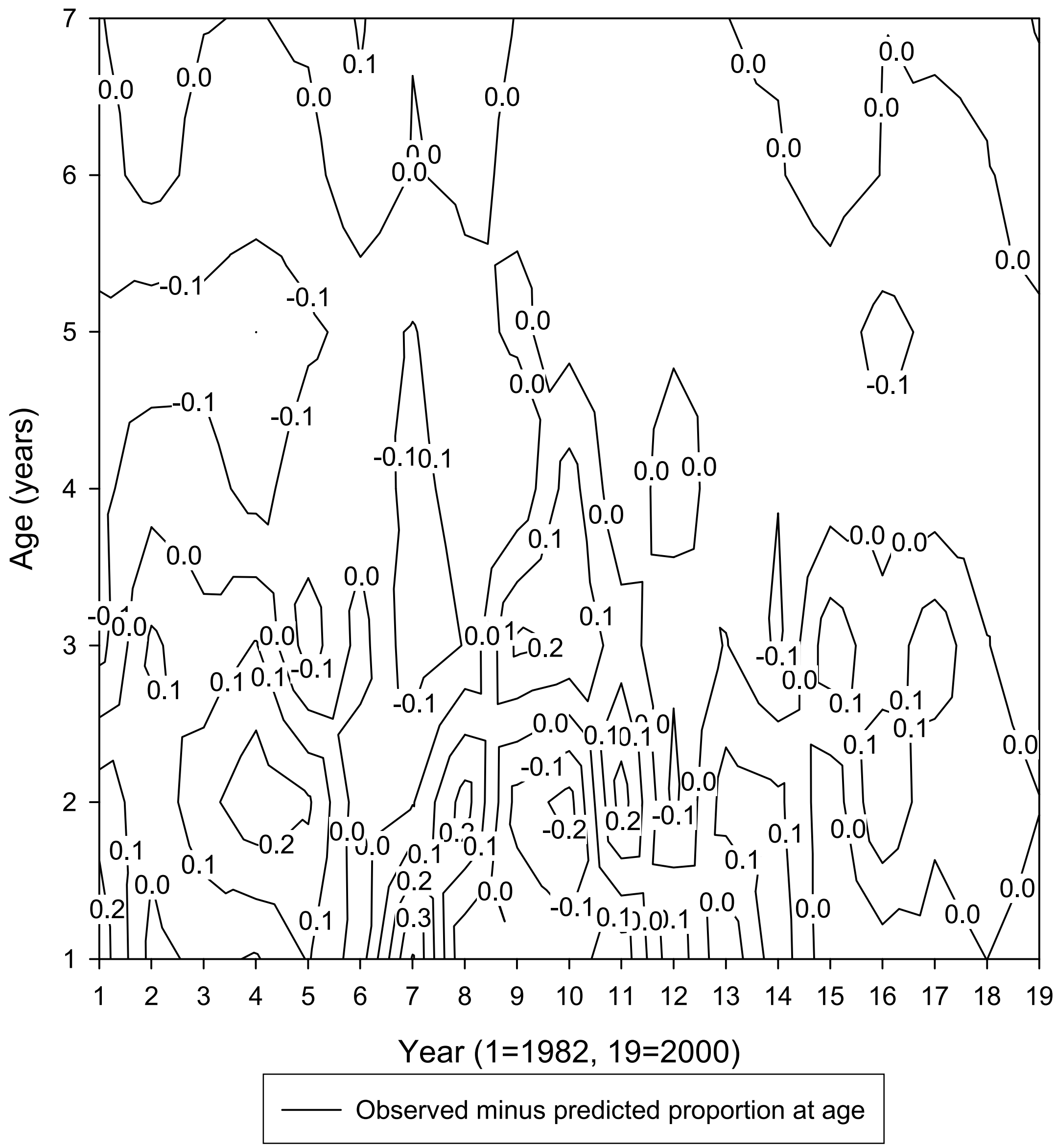


Figure 7. Winter flounder spring survey age composition residuals for the WIN model, 1982-2000

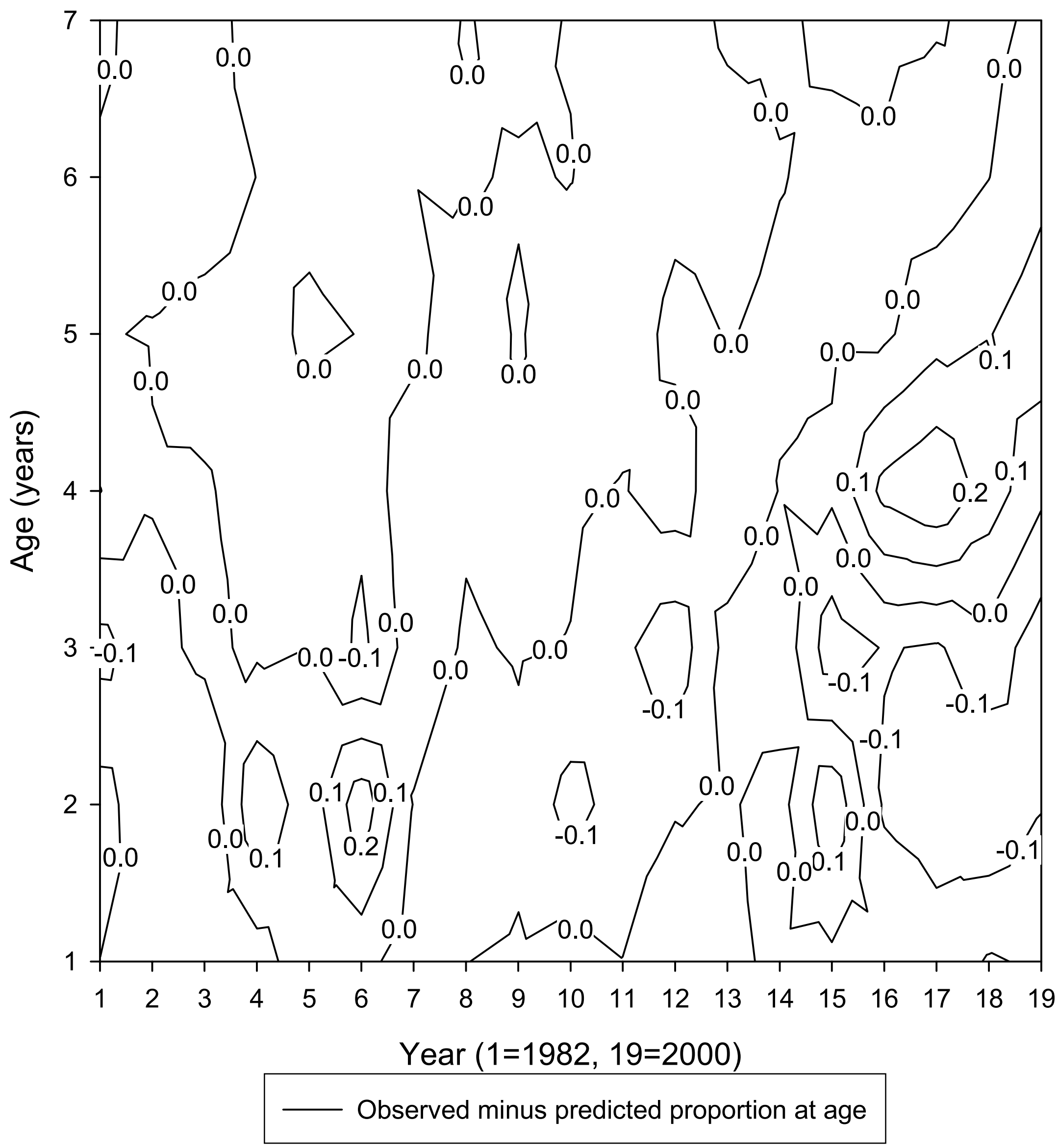


Figure 8. Winter flounder Canadian spring survey age composition residuals for the WINC model, 1987-2000

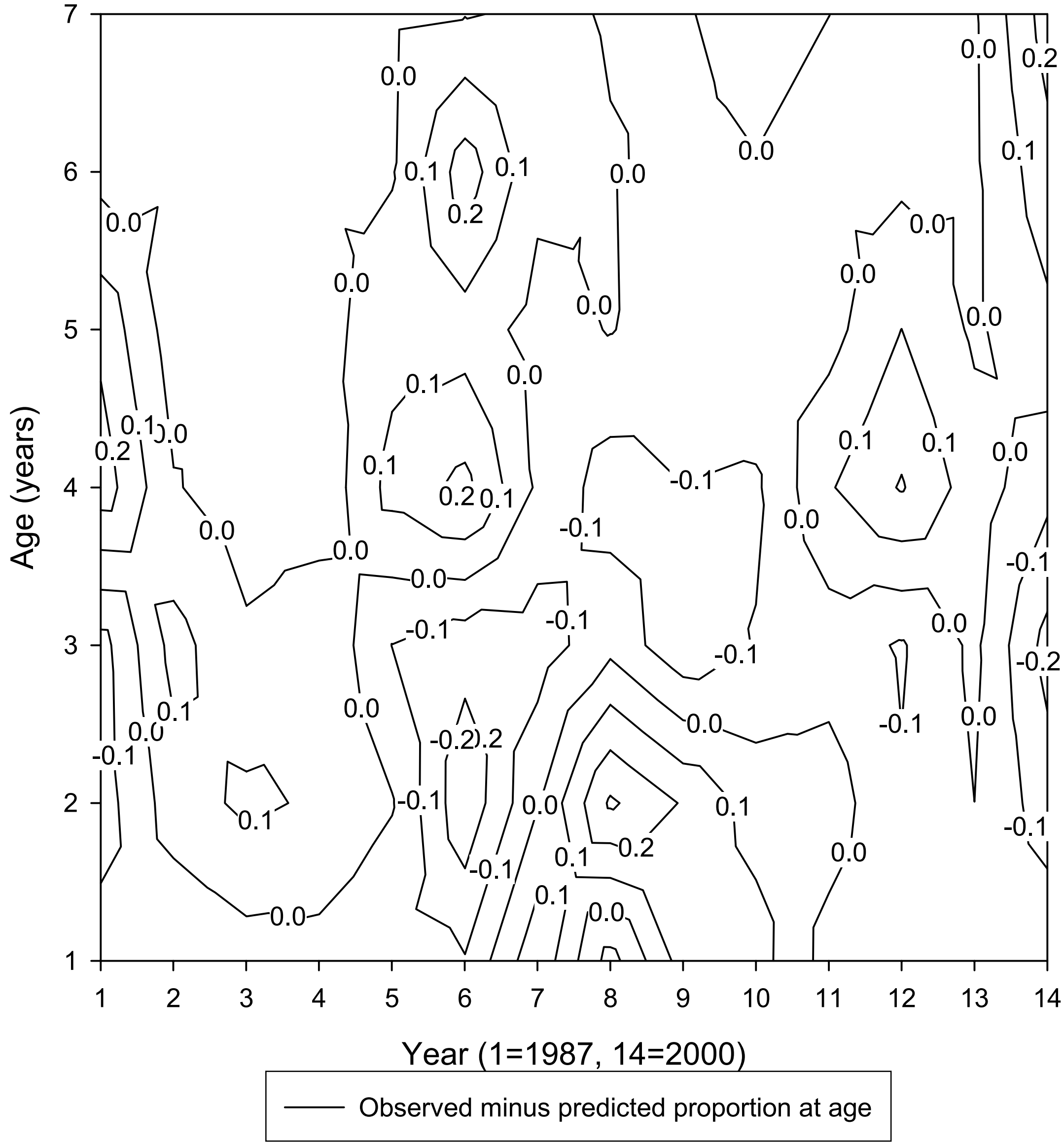
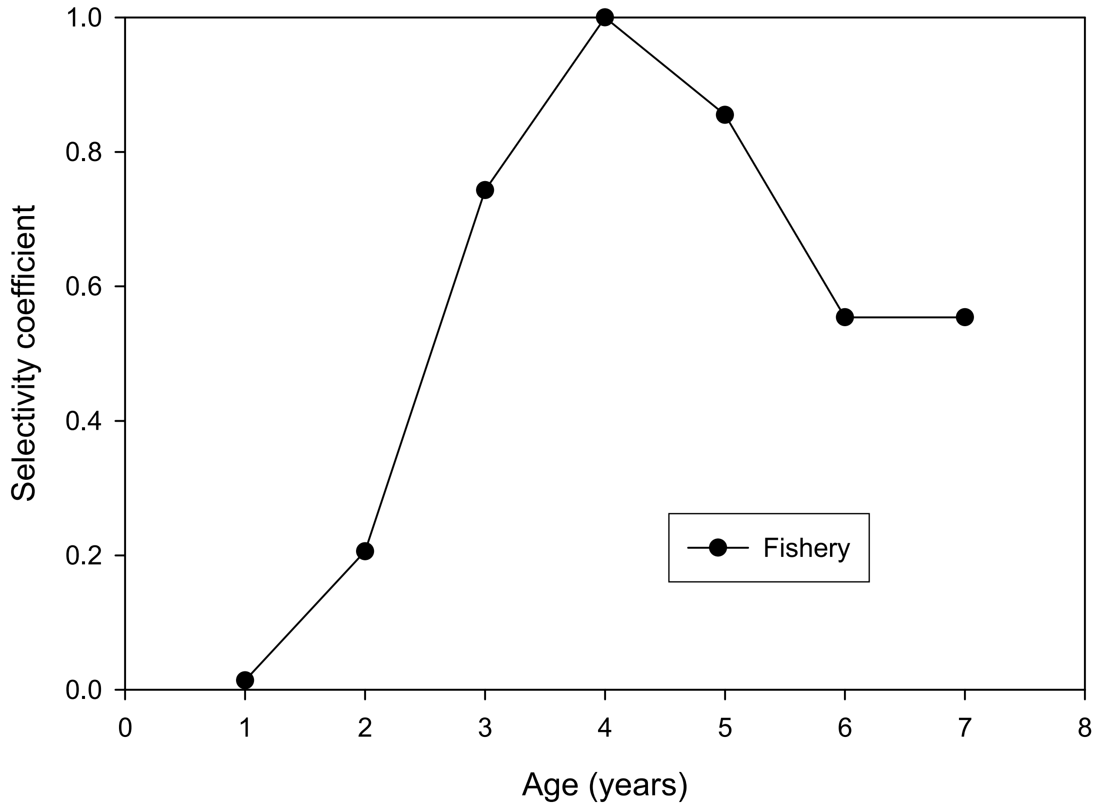


Figure 9. Selectivity curves for the WIN model

George Bank winter flounder fishery selectivity



George Bank winter flounder survey selectivity

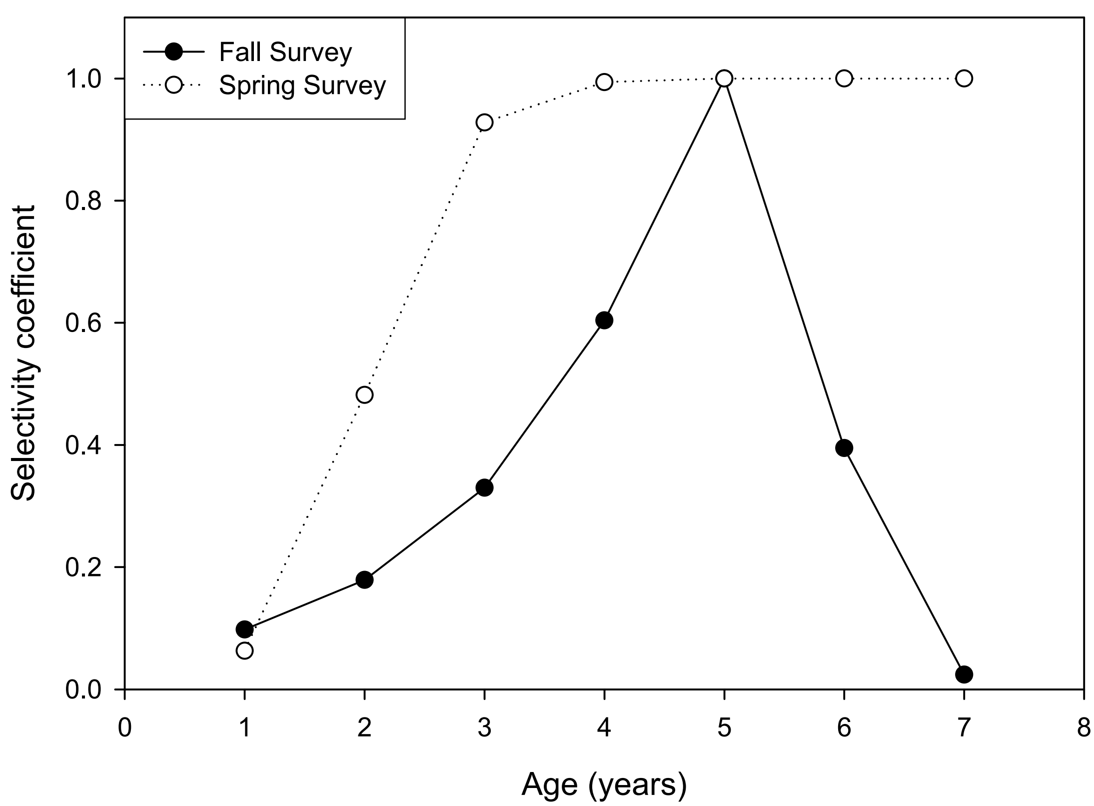


Figure 10. Recruitment estimates for the WIN model

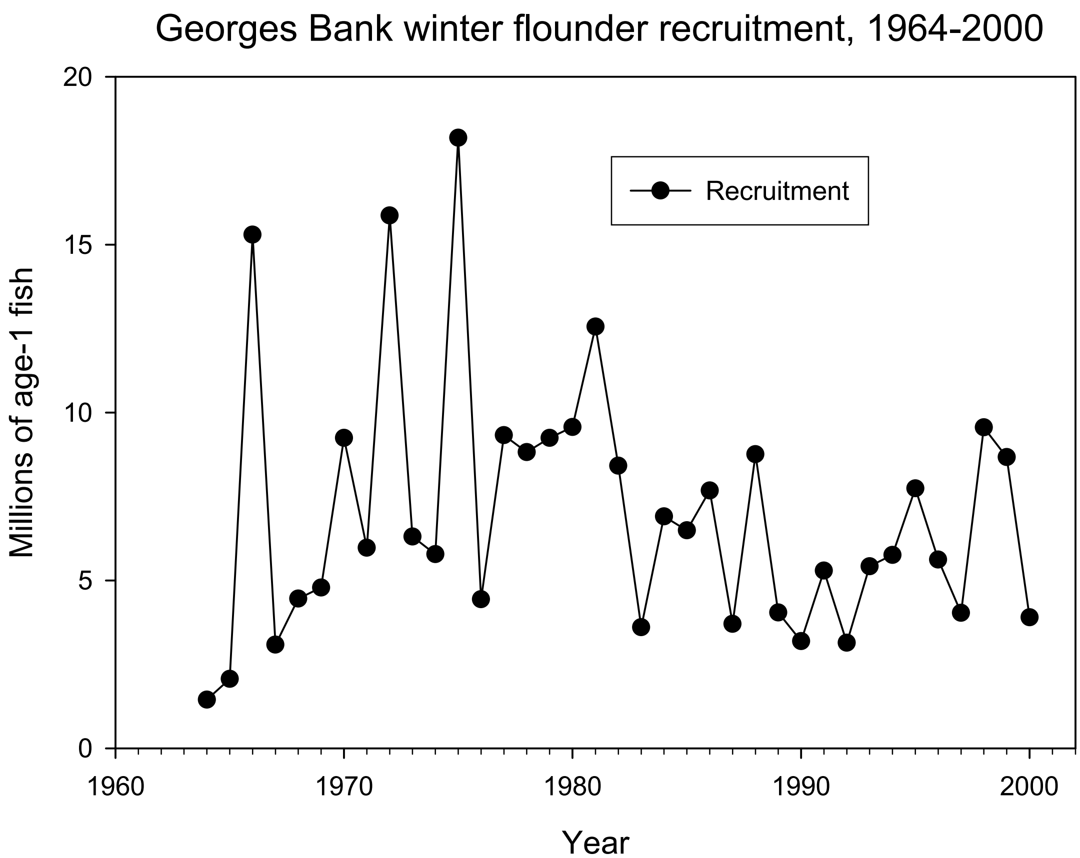


Figure 11. Population biomass estimates for the WIN model

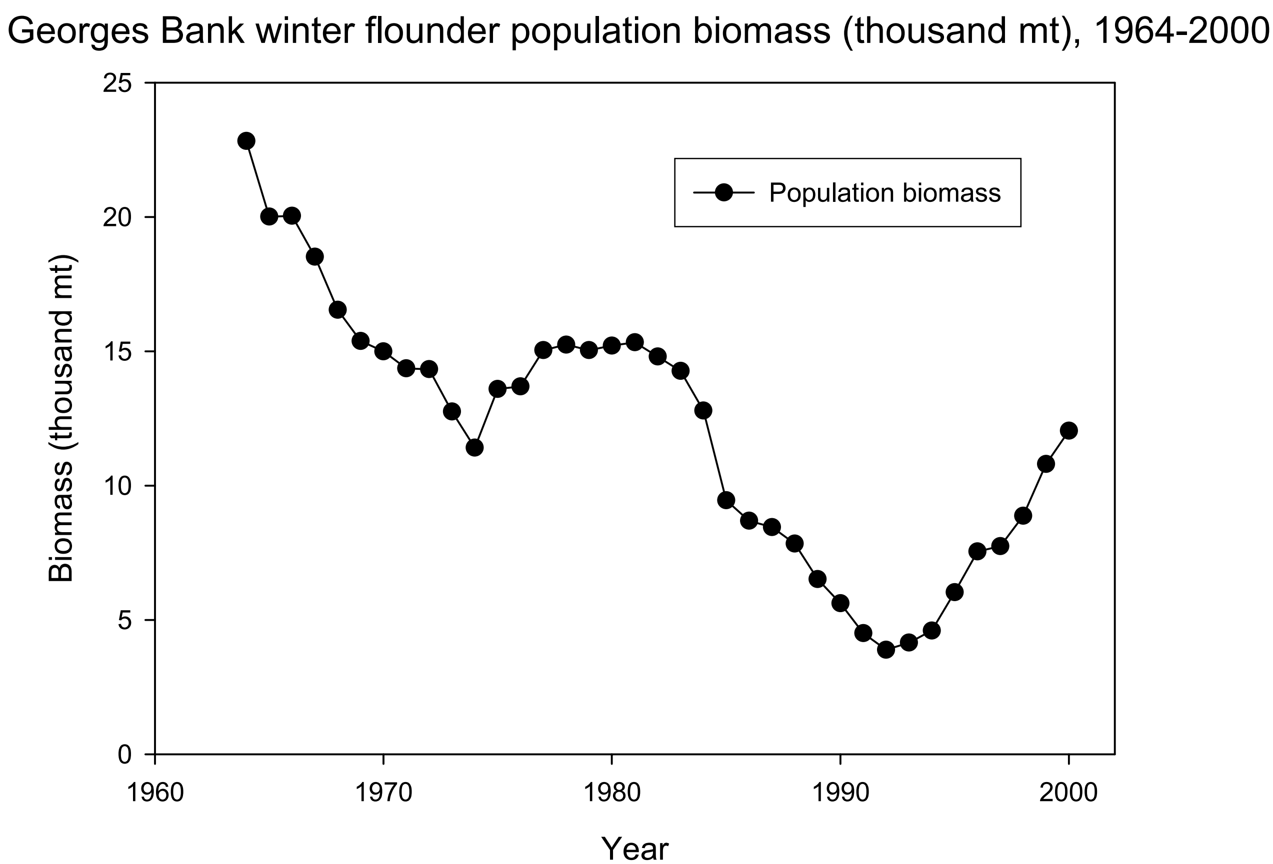


Figure 12. Spawning biomass estimates for the WIN model

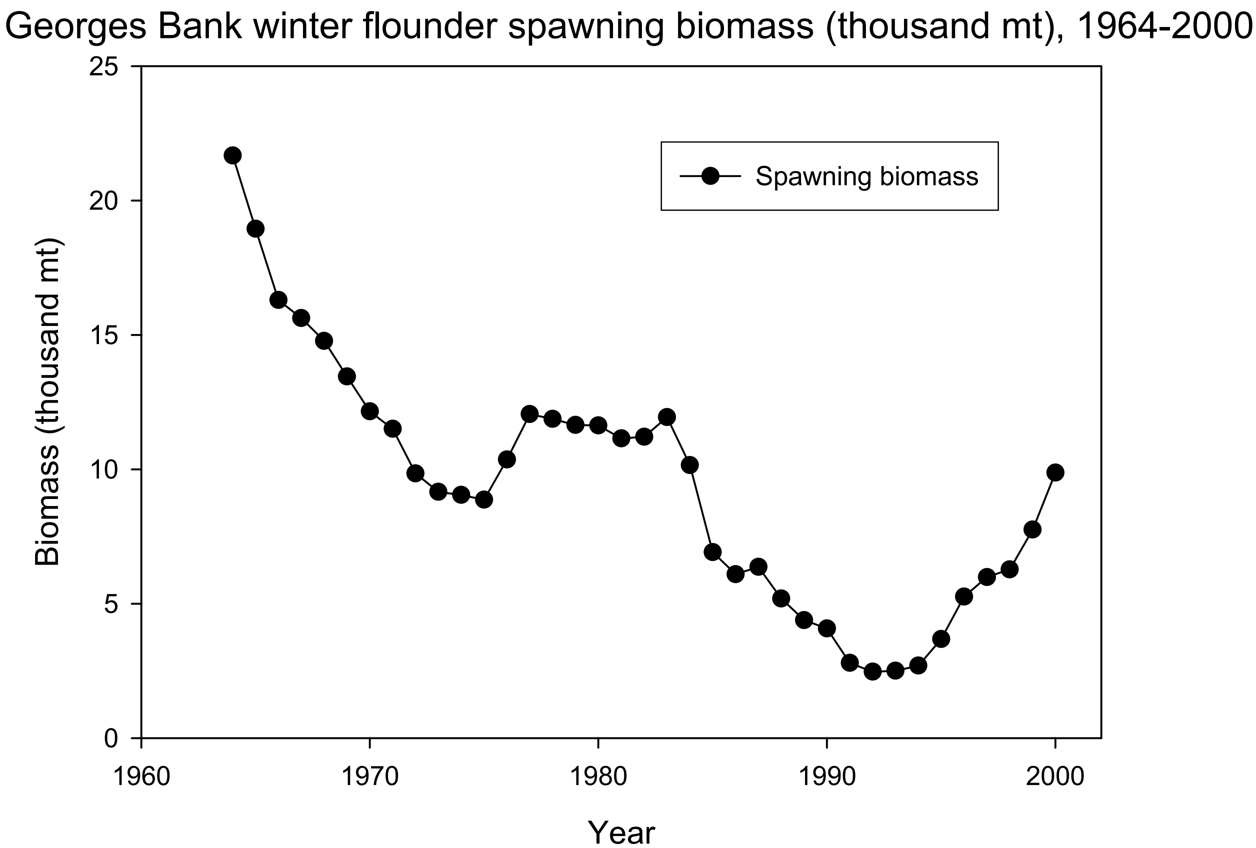


Figure 13. Fishing mortality estimates for the WIN model

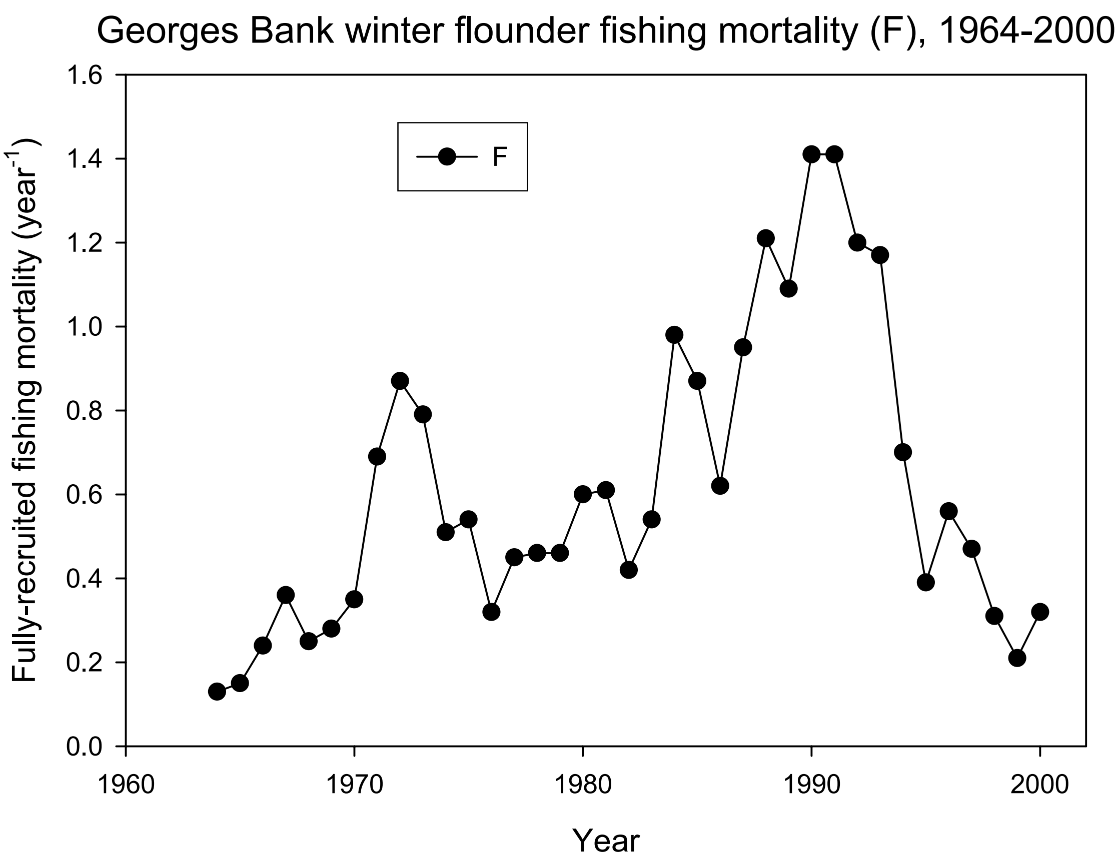


Figure 14. Stock-recruitment estimates for the WIN model

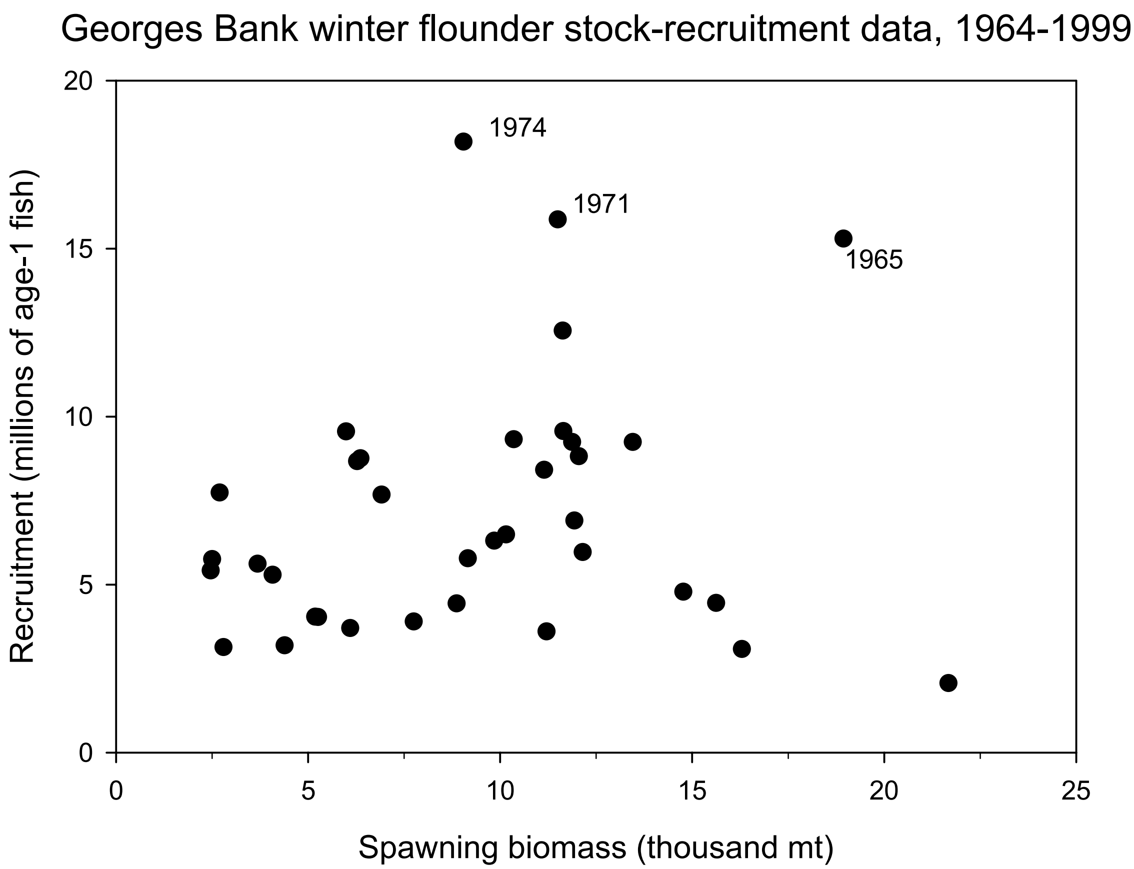


Figure 15. Surplus production estimates for the WIN model

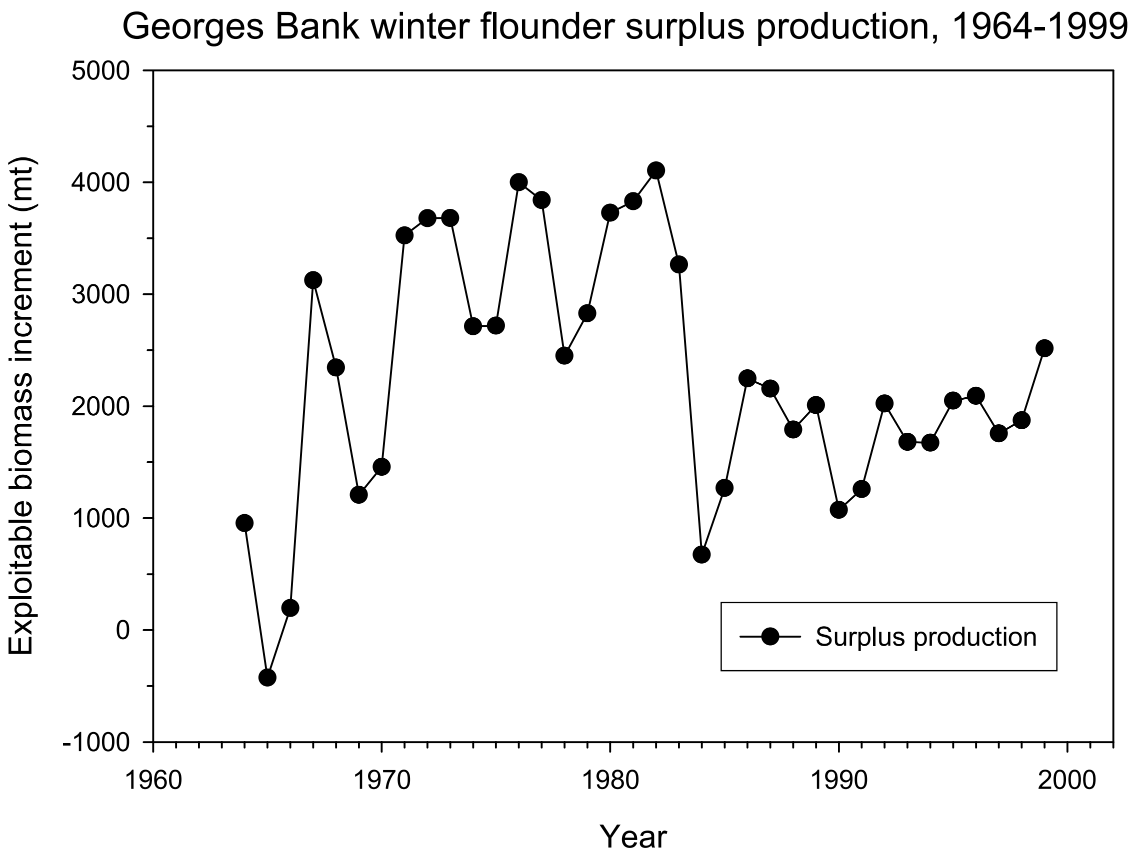
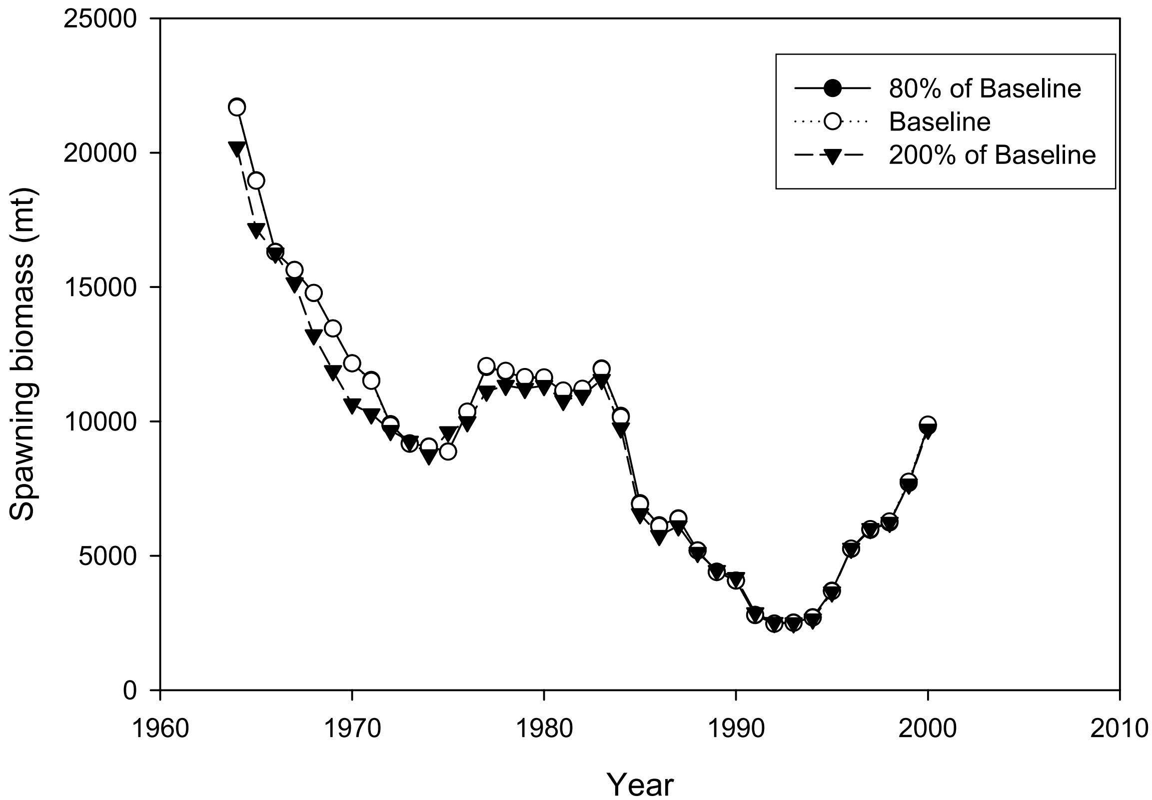


Figure 16. Sensitivity of WIN Baseline model to effective sample size of the fishery age composition likelihood component



Appendix. AD Model Builder computer code to fit the WIN model, the input data file, and the standard deviation parameter file.

Computer Code

```
  //WINTER FLOUNDER AGE-STRUCTURED MODEL
  //JON BRODZIAK NEFSC OCTOBER 2001
  //COMMENT LINES BEGIN WITH "//"
DATA_SECTION
  //READ DATA FROM INPUT FILE "WIN.DAT"
  init_int styr
  init_int endyr
  init_int nages
  init_int nselages_fish
  init_vector catch_bio(styr,endyr)
  init_int nobs_fish
  init_ivector yrs_fish(1,nobs_fish)
  init_vector nsamples_fish(1,nobs_fish)
  init_matrix obs_p_fish(1,nobs_fish,1,nages)
  init_int nobs_FALL
  init_ivector yrs_FALL(1,nobs_FALL)
  init_number zfrac_FALL
  init_vector obs_FALL(1,nobs_FALL)
  init_int nsamples_FALL
  init_matrix obs_p_FALL(1,nobs_FALL,1,nages)
  init_int nobs_SPR
  init_ivector yrs_SPR(1,nobs_SPR)
  init_number zfrac_SPR
  init_vector obs_SPR(1,nobs_SPR)
  init_int nsamples_SPR
  init_matrix obs_p_SPR(1,nobs_SPR,1,nages)
  init_vector wt(1,nages)
  init_number zfrac_spawn
  init_vector maturity(1,nages)
  init_number lambda_recruitment
  init_number lambda_fishery_age
  init_number lambda_FALL_age
  init_number lambda_biomass_index_FALL
  init_number lambda_SPR_age
  init_number lambda_biomass_index_SPR
  init_number lambda_catch_biomass
  init_number lambda_fishery_sel
  init_number lambda_f_penalty

  int styr_rec

 LOCAL_CALCS
 //COMPUTE YEAR OF FIRST RECRUITMENT DEVIATION TO BE ESTIMATED
  styr_rec=styr-nages+2;
 END_CALCS


INITIALIZATION_SECTION
  //PROVIDE INITIAL PARAMETER VALUES
  //NATURAL MORTALITY (NOT ESTIMATED)
  M 0.20

  //MEAN RECRUITMENT) IN THOUSANDS OF FISH
  mean_log_rec 8.45

  //LOG(MEAN ANNUAL FISHING MORTALITY)
  log_avg_fmort -2.5
```

```
 //FALL SURVEY INDEX PARAMETERS
 qFALL 1.
 exp_FALL 1.
 log_gamma_FALL -2.
 log_beta_FALL 0.
 log_a50_FALL 1.5

 //SPRING SURVEY INDEX PARAMETERS
 qSPR 1.
 exp_SPR 1.
 log_gamma_SPR -25.
 log_beta_SPR 0.
 log_a50_SPR 1.5

PARAMETER_SECTION
 //DECLARE MODEL PARAMETERS AND VARIABLES
 init_bounded_number M(.02,.25,-1)
 init_number mean_log_rec(1)
 init_bounded_dev_vector rec_dev(styr_rec,endyr,-15,15,3)

 init_bounded_number qFALL(.001,1000.,7)
 init_bounded_number exp_FALL(.25,4.,-1)
 init_bounded_number log_gamma_FALL(-50.,0.999,6)
 init_bounded_number log_beta_FALL(-50.,10.,6)
 init_bounded_number log_a50_FALL(0.,3.,6)

 init_bounded_number qSPR(.001,1000.,5)
 init_bounded_number exp_SPR(.25,4.,-1)
//FIX log_gamma_SPR at -25 to assume flat-topped curve
 init_bounded_number log_gamma_SPR(-50.,0.999,-1)
 init_bounded_number log_beta_SPR(-50.,10.,4)
 init_bounded_number log_a50_SPR(0.,3.,4)

 init_number log_avg_fmort(2)
 init_bounded_dev_vector fmort_dev(styr,endyr,-15,15,2)

 init_vector log_selcoffs_fish(1,nselages_fish,4)

 vector log_sel_fish(1,nages)
 vector sel(1,nages)
 vector sel_FALL(1,nages)
 vector sel_SPR(1,nages)
 number avgsel_fish

 vector rec_years(styr_rec,endyr)
 vector years(styr,endyr)
 vector ages(1,nages)

 vector totn_FALL(styr,endyr)
 vector totn_SPR(styr,endyr)
 vector popnbiom(styr,endyr)
 sdreport_vector spawnbiom(styr,endyr)
 sdreport_vector recruitment(styr,endyr)
 vector explbiom(styr,endyr)
 vector surplus_production(styr,endyr-1)
 vector pred_FALL(styr,endyr)
 vector pred_SPR(styr,endyr)
 matrix pred_p_fish(styr,endyr,1,nages)
 matrix pred_p_FALL(styr,endyr,1,nages)
 matrix pred_p_SPR(styr,endyr,1,nages)
 vector pred_catch(styr,endyr)

 vector natage_FALL(1,nages)
 vector natage_SPR(1,nages)
 vector natage_spawn(1,nages)
 matrix natage(styr,endyr,1,nages)
```

```
  matrix catage(styr,endyr,1,nages)
  matrix Z(styr,endyr,1,nages)
  matrix F(styr,endyr,1,nages)
  matrix S(styr,endyr,1,nages)

  number beta_FALL
  number gamma_FALL
  number a50_FALL
  number beta_SPR
  number gamma_SPR
  number a50_SPR

  number survival

  vector offset(1,4)
  number rec_like
  number catch_like
  vector age_like(1,4)
  vector sel_like(1,4)
  number fpen
  number FALL_like
  number SPR_like

  number rmse_catch_bio
  number rmse_FALL
  number rmse_SPR

  objective_function_value f

  sdreport_number endbiom
  sdreport_number depletion_popnbiom
  sdreport_number endspawn
  sdreport_number depspawn
  sdreport_number deppopnbiom82
  sdreport_number depspawn82
  sdreport_vector endN(1,nages)
  likeprof_number endF


RUNTIME_SECTION
  convergence_criteria 1e-6;

PRELIMINARY_CALCS_SECTION

  //SET TIME HORIZON:years
  for (int i=styr; i<=endyr; i++)
    {
    years(i)=i;
    }

  //SET RECRUITMENT TIME HORIZON:rec_years
  for (i=styr_rec; i<=endyr; i++)
    {
    rec_years(i)=i;
    }

  //SET AGE CLASSES:ages
  for (i=1; i<=nages; i++)
    {
    ages(i)=i;
    }

  //RESCALE FALL SURVEY INDEX
  obs_FALL*=1000;

  //RESCALE SPRING SURVEY INDEX
```

```
obs_SPR*=1000;

//CHECK INPUT DATA
cout << "START YEAR: "<<styr<< endl;
cout << "END YEAR: "<<endyr<< endl;
cout << "AGE CLASSES: "<<nages<<endl;
cout << "FISHERY SELECTED AGES: "<<nselages_fish<<endl;
cout << "CATCH BIOMASS" << endl;
cout << catch_bio << endl;
cout << "FISHERY YEARS"<<endl;
cout << yrs_fish<< endl;
cout << "FALL SURVEY YEARS"<<endl;
cout << yrs_FALL<< endl;
cout << "FRACTION OF Z BEFORE FALL SURVEY"<<endl;
cout << zfrac_FALL<< endl;
cout << "FALL SURVEY INDEX"<<endl;
cout << obs_FALL<< endl;
cout << "SPRING SURVEY YEARS"<<endl;
cout << yrs_SPR<< endl;
cout << "FRACTION OF Z BEFORE SPRING SURVEY"<<endl;
cout << zfrac_SPR<< endl;
cout << "SPRING SURVEY INDEX"<<endl;
cout << obs_SPR<< endl;
cout << "FISHERY AGE COMPOSITION"<<endl;
cout << obs_p_fish<< endl;
cout << "FALL SURVEY AGE COMPOSITION"<<endl;
cout << obs_p_FALL<< endl;
cout << "SPRING SURVEY AGE COMPOSITION"<<endl;
cout << obs_p_SPR<< endl;
cout << "WEIGHT AT AGE"<<endl;
cout << wt<< endl;
cout << "FRACTION OF Z BEFORE SPAWNING"<<endl;
cout << zfrac_spawn<< endl;
cout << "MATURITY AT AGE"<<endl;
cout << maturity<< endl;
cout << "LAMBDA RECRUITMENT: " << lambda_recruitment <<endl;
cout << "LAMBDA FISHERY AGE: " <<lambda_fishery_age <<endl;
cout << "LAMBDA FALL SURVEY AGE: " <<lambda_FALL_age <<endl;
cout << "LAMBDA FALL SURVEY INDEX: " <<lambda_biomass_index_FALL <<endl;
cout << "LAMBDA SPRING SURVEY AGE: " <<lambda_SPR_age <<endl;
cout << "LAMBDA SPRING SURVEY INDEX: " <<lambda_biomass_index_SPR <<endl;
cout << "LAMBDA CATCH BIOMASS: " <<lambda_catch_biomass <<endl;
cout << "LAMBDA FISHERY SELECTIVITY: " <<lambda_fishery_sel <<endl;
cout << "LAMBDA F PENALTY: " <<lambda_f_penalty <<endl;

//COMPUTE OFFSET FOR FISHERY AGE MULTINOMIAL
  for (i=1; i <= nobs_fish; i++)
    {
    //CHECK FOR FISHERY AGE DATA IN YEAR i, -99 = MISSING DATA
    if (obs_p_fish(i,1) >= 0.0)
      obs_p_fish(i)=obs_p_fish(i)/sum(obs_p_fish(i));
    for (int j=1; j<=nages; j++)
      {
        if (obs_p_fish(i,j)>0.0)
          {
          offset(1)-=nsamples_fish(i)*obs_p_fish(i,j)*log(obs_p_fish(i,j));
          }
      }
    }
//cout << "FISHERY PROPORTION AT AGE DATA" << endl;
//cout << obs_p_fish << endl;

//COMPUTE OFFSET FOR AUTUMN SURVEY AGE MULTINOMIAL
  for (i=1; i <= nobs_FALL; i++)
    {
    //CHECK FOR AGE DATA IN YEAR i, -99 = MISSING DATA
```

```
      if (obs_p_FALL(i,1) >= 0.0)
        obs_p_FALL(i)=obs_p_FALL(i)/sum(obs_p_FALL(i));
      for (int j=1; j<=nages; j++)
        {
         if (obs_p_FALL(i,j)>0.0)
           {
           offset(2)-=nsamples_FALL*obs_p_FALL(i,j)*log(obs_p_FALL(i,j));
           }
        }
      }
  //cout << "FALL SURVEY PROPORTION AT AGE DATA" << endl;
  //cout << obs_p_FALL << endl;

  //COMPUTE OFFSET FOR SPRING SURVEY AGE MULTINOMIAL
     for (i=1; i <= nobs_SPR; i++)
      {
      //CHECK FOR AGE DATA IN YEAR i, -99 = MISSING DATA
      if (obs_p_SPR(i,1) >= 0.0)
        obs_p_SPR(i)=obs_p_SPR(i)/sum(obs_p_SPR(i));
      for (int j=1; j<=nages; j++)
        {
         if (obs_p_SPR(i,j)>0.0)
           {
           offset(3)-=nsamples_SPR*obs_p_SPR(i,j)*log(obs_p_SPR(i,j));
           }
        }
      }
  //cout << "SPRING SURVEY PROPORTION AT AGE DATA" << endl;
  //cout << obs_p_SPR << endl;

TOP_OF_MAIN_SECTION
  //ALLOCATE SPACE IN READ-WRITE MEMORY
  arrmblsize=2000000;
  gradient_structure::set_GRADSTACK_BUFFER_SIZE(2000000);
  gradient_structure::set_CMPDIF_BUFFER_SIZE(60000000);

PROCEDURE_SECTION
  //DO THE FUNCTION CALLS IN SEQUENCE
  get_selectivity();
  get_mortality();
  survival=mfexp(-1.0* M);
  get_numbers_at_age();
  get_catch_at_age();
  evaluate_the_objective_function();

FUNCTION get_selectivity
  //FISHERY SELECTIVITY ESTIMATION FOR AGES 1 TO NSELAGES_FISH
  //SET AVERAGE TO 1 AND THEN RESCALE SO MAX VALUE=1
  for (int j=1;j<=nselages_fish;j++)
    {
    log_sel_fish(j)=log_selcoffs_fish(j);
    }
  for (j=nselages_fish+1;j<=nages;j++)
    {
    log_sel_fish(j)=log_sel_fish(j-1);
    }
  avgsel_fish=log(mean(mfexp(log_selcoffs_fish)));
  log_sel_fish-=log(mean(exp(log_sel_fish)));
  sel=mfexp(log_sel_fish);
  sel/=max(sel);
  //cout<<"FISHERY SELECTIVITY"<<endl;
  //cout<<sel<<endl;
  //cout<<"MAXIMUM VALUE: "<<max(sel)<<endl;

  //AUTUMN SURVEY SELECTIVITY ESTIMATION VIA THOMPSON MODEL
  beta_FALL=mfexp(log_beta_FALL);
```

```
  gamma_FALL=mfexp(log_gamma_FALL);
  a50_FALL=mfexp(log_a50_FALL);
  for (j=1; j<=nages; j++)
    {
    sel_FALL(j)=(1./(1.-gamma_FALL))*pow((1.-gamma_FALL)/gamma_FALL,
              gamma_FALL)*(exp(beta_FALL*gamma_FALL*(a50_FALL-
              double(j)))/(1+exp(beta_FALL*(a50_FALL-double(j)))));
    }
  sel_FALL/=max(sel_FALL);
  //cout<<"FALL SURVEY SELECTIVITY"<<endl;
  //cout<<sel_FALL<<endl;
  //cout<<"MAXIMUM VALUE: "<<max(sel_FALL)<<endl;

  //SPRING SURVEY SELECTIVITY ESTIMATION VIA THOMPSON MODEL
  beta_SPR=mfexp(log_beta_SPR);
  gamma_SPR=mfexp(log_gamma_SPR);
  a50_SPR=mfexp(log_a50_SPR);
  for (j=1; j<=nages; j++)
    {
    sel_SPR(j)=(1./(1.-gamma_SPR))*pow((1.-gamma_SPR)/gamma_SPR,
              gamma_SPR)*(exp(beta_SPR*gamma_SPR*(a50_SPR-
              double(j)))/(1+exp(beta_SPR*(a50_SPR-double(j)))));
    }
  sel_SPR/=max(sel_SPR);
  //cout<<"SPRING SURVEY SELECTIVITY"<<endl;
  //cout<<sel_SPR<<endl;
  //cout<<"MAXIMUM VALUE: "<<max(sel_SPR)<<endl;

  //cout << "END OF GET SELECTIVITY" << endl;


FUNCTION get_mortality
  //COMPUTE TOTAL MORTALITY BY YEAR AND AGE
  //COMPUTE FISHING MORTALITY MATRIX
  for (int i=styr;i<=endyr;i++)
    {
    for (int j=1;j<=nages;j++)
      {
      F(i,j)=sel(j)*mfexp(log_avg_fmort + fmort_dev(i));
      }
    }

  //COMPUTE TOTAL MORTALITY MATRIX
    Z=F+M;

  //COMPUTE SURVIVAL MATRIX
    S=mfexp(-1.0*Z);

  //cout << "END OF GET MORTALITY" << endl;

FUNCTION get_numbers_at_age
  //COMPUTE NUMBERS AT AGE MATRIX
  int itmp;

  //COMPUTE NUMBERS AT AGE IN INITIAL YEAR
  for (int j=1;j<nages;j++)
    {
     itmp=styr+1-j;
     natage(styr,j)=mfexp(mean_log_rec-M*double(j-1)+rec_dev(itmp));
    }
    natage(styr,nages)=mfexp(mean_log_rec-M*(nages-1))/
                  (1. - survival);

  //COMPUTE RECRUITMENT IN SUBSEQUENT YEARS
  for (int i=styr+1;i<=endyr;i++)
    {
```

```
      natage(i,1)=mfexp(mean_log_rec+rec_dev(i));
    }

  //COMPUTE NUMBERS AT AGES 2 TO PLUS-GROUP VIA FORWARD PROJECTION
  for (i=styr;i< endyr;i++)
    {
      for (j=2;j<=nages;j++)
        {
        natage(i+1)(j)=natage(i)(j-1)*S(i)(j-1);
        }
      natage(i+1,nages)+=natage(i,nages)*S(i,nages);
    }

  //COMPUTE VARIABLES DERIVED FROM NUMBERS AT AGE MATRIX
  for (i=styr;i<=endyr;i++)
    {

    //COMPUTE PREDICTED FALL SURVEY INDEX AND AGE COMPOSITION
     natage_FALL=elem_prod(natage(i),mfexp(-zfrac_FALL*Z(i)));
     totn_FALL(i)=(natage_FALL*sel_FALL);
     pred_FALL(i)=qFALL*pow((natage_FALL*elem_prod(sel_FALL,wt)),exp_FALL);
     pred_p_FALL(i)=elem_prod(sel_FALL,natage_FALL)/totn_FALL(i);

    //COMPUTE PREDICTED SPRING SURVEY INDEX AND AGE COMPOSITION
     natage_SPR=elem_prod(natage(i),mfexp(-zfrac_SPR*Z(i)));
     totn_SPR(i)=(natage_SPR*sel_SPR);
     pred_SPR(i)=qSPR*pow((natage_SPR*elem_prod(sel_SPR,wt)),exp_SPR);
     pred_p_SPR(i)=elem_prod(sel_SPR,natage_SPR)/totn_SPR(i);

     //COMPUTE POPULATION AND SPAWNING AND EXPLOITABLE BIOMASS
     popnbiom(i)=natage(i)*wt;
     natage_spawn=elem_prod(natage(i),mfexp(-zfrac_spawn*Z(i)));
     spawnbiom(i)=natage_spawn*elem_prod(maturity,wt);
     explbiom(i)=natage(i)*elem_prod(sel,wt);

     //COMPUTE RECRUITMENT
     recruitment(i)=mfexp(mean_log_rec+rec_dev(i));

    }

    //COMPUTE ANNUAL SURPLUS PRODUCTION
    for (i=styr;i<endyr;i++)
      {
      surplus_production(i)=explbiom(i+1)-explbiom(i)+catch_bio(i);
      }

    //COMPUTE DEPLETION RATIOS FOR POPULATION AND SPAWNING BIOMASS
    depletion_popnbiom=popnbiom(endyr)/popnbiom(styr);
    depspawn=spawnbiom(endyr)/spawnbiom(styr);
    deppopnbiom82=popnbiom(endyr)/popnbiom(1982);
    depspawn82=spawnbiom(endyr)/spawnbiom(1982);

    //COMPUTE POPULATION AND SPAWNING BIOMASS IN ENDING YEAR
    endbiom=popnbiom(endyr);
    endspawn=spawnbiom(endyr);

    //COMPUTE F AND NUMBERS AT AGE IN ENDING YEAR
    endF=mfexp(log_avg_fmort+fmort_dev(endyr));
    endN=natage(endyr);

  //cout << "END OF GET NUMBERS AT AGE" << endl;

FUNCTION get_catch_at_age
  //COMPUTE CATCH NUMBERS BY YEAR AND AGE
  for (int i=styr; i<=endyr; i++)
  {
```

```
  pred_catch(i)=0.;

  //APPLY THE CATCH EQUATION
  for (int j = 1 ; j<= nages; j++)
    {
    catage(i,j) = natage(i,j)*F(i,j)*(1.-S(i,j))/Z(i,j);

    //COMPUTE PREDICTED CATCH BIOMASS
    pred_catch(i)+=catage(i,j)*wt(j);
    }

    //COMPUTE PREDICTED FISHERY AGE COMPOSITION
    pred_p_fish(i)=catage(i)/sum(catage(i));
  }
 //cout << "END OF GET CATCH AT AGE" << endl;


FUNCTION evaluate_the_objective_function
 //COMPUTE THE MODEL LIKELIHOOD (f)
 f=.0;

 //DO THIS WHEN RECRUITMENT DEVIATIONS ARE ESTIMATED (PHASE>2)
 if (active(rec_dev))
   {
   age_like=0.;
   int ii;

   //COMPUTE RECRUITMENT LIKELIHOOD COMPONENT
   rec_like=norm2(rec_dev);
   f+=lambda_recruitment*rec_like;

   //COMPUTE AGE COMPOSITION LIKELIHOODS
   //FISHERY COMPONENT
   for (int i=1; i <= nobs_fish; i++)
     {
     ii=yrs_fish(i);
     for (int j=1; j<=nages; j++)
       {
       if (obs_p_fish(i,1) >= 0.0)
         age_like(1)-=nsamples_fish(i)*obs_p_fish(i,j)*log(pred_p_fish(ii,j)+1.e-13);
      //cout << "FISHERY AGE: "<<age_like(1) << " " << i << " "<<j<< endl;
       }
     }
     age_like(1)-=offset(1);
     age_like(1)*=lambda_fishery_age;

   //AUTUMN SURVEY COMPONENT
   for (i=1; i <= nobs_FALL; i++)
     {
     ii=yrs_FALL(i);
     for (int j=1; j<=nages; j++)
       {
       if (obs_p_FALL(i,1) >= 0.0)
         age_like(2)-=nsamples_FALL*obs_p_FALL(i,j)*log(pred_p_FALL(ii,j)+1.e-13);
      //cout << "FALL SURVEY AGE: " << age_like(2) << " " << i << " "<<j<< endl;
       }
     }
     age_like(2)-=offset(2);
     age_like(2)*=lambda_FALL_age;

   //SPRING SURVEY COMPONENT
   for (i=1; i <= nobs_SPR; i++)
     {
     ii=yrs_SPR(i);
     for (int j=1; j<=nages; j++)
       {
```

```
    if (obs_p_SPR(i,1) >= 0.0)
      age_like(3)-=nsamples_SPR*obs_p_SPR(i,j)*log(pred_p_SPR(ii,j)+1.e-13);
   //cout << "SPRING SURVEY AGE: " << age_like(3) << " " << i << " "<<j<< endl;
    }
   }
   age_like(3)-=offset(3);
   age_like(3)*=lambda_SPR_age;

   f+=sum(age_like);
  }

//COMPUTE AUTUMN SURVEY INDEX LIKELIHOOD (LOGNORMAL)
FALL_like=norm2(log(obs_FALL+0.001)-log(pred_FALL(yrs_FALL)+0.001));
FALL_like*=0.5*double(size_count(obs_FALL));
f+=lambda_biomass_index_FALL*FALL_like;

//COMPUTE ROOT MEAN SQUARED ERROR FOR FALL SURVEY INDEX FIT
rmse_FALL=norm(log(obs_FALL+0.001)-log(pred_FALL(yrs_FALL)+0.001));
rmse_FALL*=1.0/sqrt(double(size_count(obs_FALL)));

//COMPUTE SPRING SURVEY INDEX LIKELIHOOD (LOGNORMAL)
SPR_like=norm2(log(obs_SPR+0.001)-log(pred_SPR(yrs_SPR)+0.001));
SPR_like*=0.5*double(size_count(obs_SPR));
f+=lambda_biomass_index_SPR*SPR_like;

//COMPUTE ROOT MEAN SQUARED ERROR FOR SPRING SURVEY INDEX FIT
rmse_SPR=norm(log(obs_SPR+0.001)-log(pred_SPR(yrs_SPR)+0.001));
rmse_SPR*=1.0/sqrt(double(size_count(obs_SPR)));

//COMPUTE CATCH BIOMASS LIKELIHOOD
catch_like=norm2(log(catch_bio+0.000001)-log(pred_catch+0.000001));
catch_like*=0.5*double(size_count(catch_bio));
f+=lambda_catch_biomass*catch_like;

//COMPUTE ROOT MEAN SQUARED ERROR FOR CATCH BIOMASS FIT
rmse_catch_bio=norm(log(catch_bio+0.000001)-log(pred_catch+0.000001));
rmse_catch_bio*=1.0/sqrt(double(size_count(catch_bio)));

//COMPUTE SELECTIVITY LIKELIHOODS
//FISHERY COMPONENT
sel_like(1)=norm2(first_difference(first_difference(log_sel_fish)));
f+=lambda_fishery_sel*square(avgsel_fish);

//SURVEY COMPONENTS (PLACEHOLDERS FOR FUTURE USE)
sel_like(2)=0.;
sel_like(3)=0.;
sel_like(4)=0.;

f+=lambda_fishery_sel*sel_like(1);

//COMPUTE F PENALTY LIKELIHOOD CONSTRAINT
//HIGH PENALTY IF ESTIMATION PHASE < 3
//LOW PENALTY IF ESTIMATION PHASE >= 3
if (current_phase()<3)
  {
  fpen=10.*norm2(mfexp(fmort_dev+log_avg_fmort)-.1);
  }
else
  {
  fpen=0.001*norm2(mfexp(fmort_dev+log_avg_fmort)-.1);
  }
if (active(fmort_dev))
  {
  fpen+=norm2(fmort_dev);
  }
f+=lambda_f_penalty*fpen;
```

```
REPORT_SECTION
  //OUTPUT RESULTS TO FILE "WIN.REP"

  report << "Winter Flounder Age-structured Model WIN" << endl;

  report << "Estimated Numbers (000s) of Fish at Age (year,age)" << endl;
  report << natage << endl;
  report << "Estimated Fishing Mortality (year,age)" << endl;
  report << F << endl;

  report << "Observed FALL SURVEY Biomass Index (year)" << endl;
  report << yrs_FALL << endl;
  report << obs_FALL << endl;
  report << "Predicted FALL SURVEY Biomass Index (year)" << endl;
  report << pred_FALL << endl;
  report << "Residuals for FALL SURVEY Biomass Index (year)" << endl;
  report << obs_FALL - pred_FALL(yrs_FALL) << endl;

  report << "Observed SPRING SURVEY Biomass Index (year)" << endl;
  report << yrs_SPR << endl;
  report << obs_SPR << endl;
  report << "Predicted SPRING SURVEY Biomass Index (year)" << endl;
  report << pred_SPR << endl;
  report << "Residuals for SPRING SURVEY Biomass Index (year)" << endl;
  report << obs_SPR - pred_SPR(yrs_SPR) << endl;

  report << "Fishery age composition effective sample size (year)" << endl;
  report << yrs_fish << endl;
  report << nsamples_fish << endl;

  report << "Observed Fishery Proportion at Age (year,age)" << endl;
  report << obs_p_fish << endl;
  report << "Predicted Fishery Proportion at Age (year,age)" << endl;
  report << pred_p_fish << endl;

  report << "Observed FALL SURVEY Proportion at Age (year,age)" << endl;
  report << obs_p_FALL<< endl;
  report << "Predicted FALL SURVEY Proportion at Age (year,age)" << endl;
  report << pred_p_FALL<< endl;

  report << "Observed SPRING SURVEY Proportion at Age (year,age)" << endl;
  report << obs_p_SPR<< endl;
  report << "Predicted SPRING SURVEY Proportion at Age (year,age)" << endl;
  report << pred_p_SPR<< endl;

  report << "Population Biomass (mt) by Year"<< endl;
  report << years << endl;
  report << popnbiom << endl;
  report << "Population Biomass in 2000" << endl;
  report << endbiom << endl;
  report << "Depletion ratio in 2000 for population biomass" << endl;
  report << depletion_popnbiom << endl;
  report << "Depletion ratio in 2000 relative to 1982 population biomass" << endl;
  report << deppopnbiom82 << endl;

  report << "Spawning Biomass (mt) by Year" << endl;
  report << years << endl;
  report << spawnbiom << endl;
  report << "Spawning Biomass in 2000" << endl;
  report << endspawn << endl;
  report << "Depletion ratio in 2000 for spawning biomass" << endl;
  report << depspawn << endl;
  report << "Depletion ratio in 2000 relative to 1982 spawning biomass" << endl;
  report << depspawn82 << endl;
```

```
report << "Exploitable Biomass (mt) by Year"<< endl;
report << years << endl;
report << explbiom << endl;

report << "Population numbers at age (thousands) in 2000" << endl;
report << ages << endl;
report << endN << endl;

report << "Mean Recruitment (thousands of age-1 recruits)" << endl;
report << mfexp(mean_log_rec) << endl;

report << "Recruitment (thousands of age-1 recruits) by Year" << endl;
report << rec_years << endl;
report << mfexp(mean_log_rec+rec_dev) << endl;

report << "Observed Catch Biomass (mt) by Year" << endl;
report << years << endl;
report << catch_bio << endl;
report << "Predicted Catch Biomass (mt) by Year" << endl;
report << pred_catch << endl;
report << "Residuals for Catch Biomass (year)" << endl;
report << catch_bio - pred_catch << endl;

report << "Annual Surplus Production (mt)" << endl;
report << years << endl;
report << surplus_production << endl;

report << "Estimated Average Annual Fishing Mortality by Year" << endl;
report << years << endl;
report << mfexp(log_avg_fmort+fmort_dev) << endl;
report << "Fishing Mortality in 2000" << endl;
report << endF << endl;

report << "Fishery Selectivity by Age" << endl;
report << ages << endl;
report << sel << endl;

report << "FALL SURVEY Selectivity by Age" << endl;
report << ages << endl;
report << sel_FALL << endl;

report << "SPRING SURVEY Selectivity by Age" << endl;
report << ages << endl;
report << sel_SPR << endl;

report << "OBJECTIVE FUNCTION VALUE: " << f << endl;

report << "LIKELIHOOD EMPHASIS FACTORS" << endl;
report<< "RECRUITMENT::FISHERY AGE::FALL SURVEY AGE::SPRING SURVEY AGE::F PENALTY"<<endl;
report << lambda_recruitment<<"  "<< lambda_fishery_age<< " "<<lambda_FALL_age<<" "<<lambda_SPR_age<<"
"<<lambda_f_penalty<<endl;
report<< "FISHERY SELECTIVITY::CATCH BIOMASS::FALL SURVEY INDEX::SPRING SURVEY INDEX"<<endl;
report << lambda_fishery_sel<<" "<<lambda_catch_biomass<<" "<<lambda_biomass_index_FALL<<"
"<<lambda_biomass_index_SPR<<endl;

report << "LIKELIHOOD COMPONENTS" << endl;
report<< "RECRUITMENT::FISHERY AGE::FALL SURVEY AGE::SPRING SURVEY AGE::F PENALTY"<<endl;
report << rec_like<<"  "<< age_like<< " "<<fpen<<endl;
report<< "FISHERY SELECTIVITY::CATCH BIOMASS::FALL SURVEY INDEX::SPRING SURVEY INDEX"<<endl;
report << sel_like(1)+square(avgsel_fish)<<" "<<catch_like<<" "<<FALL_like<<" "<<SPR_like<<endl;

report << "ROOT MEAN SQUARE ERRORS" << endl;
report << "CATCH BIOMASS: " << rmse_catch_bio << endl;
report << "FALL SURVEY INDEX: " << rmse_FALL << endl;
report << "SPRING SURVEY INDEX: " << rmse_SPR << endl;
```

//END OF MODEL

Input Data File

```
# Styr endyr
1964 2000
# Number of age classes
7
# Number of age classes for selectivity estimation
6
# Catch biomass:1964 to 2000, n=37
1517    1687    2197    2349    1999    2518    2716    4183    4512    2976    2218    2937    1893
        3594    3250    3064    3975    4012    2980    3908    3931    2163    1787    2669    2859
        1891    1953    1828    1849    1683    972     760     1336    1430    1335    1042    1839
# Number years of fishery age data 1982-2000
19
# Years of age fishery data
1982    1983    1984    1985    1986    1987    1988    1989    1990    1991    1992    1993    1994
        1995    1996    1997    1998    1999    2000
# Number of age samples in fishery (nsamples_fish)
200 200 200 200 200 200 200 200 200 200 200 100 100 100 100 100 50 50 100
# Fishery age composition data 1 2 3 4 5 6 7+
0.00000 0.08486 0.41064 0.25206 0.12279 0.06206 0.06759
0.00157 0.12224 0.45068 0.22582 0.08562 0.03200 0.08208
0.00000 0.05432 0.10992 0.26437 0.27156 0.12245 0.17738
0.00647 0.26544 0.22862 0.26775 0.16188 0.03678 0.03306
0.00000 0.24850 0.49630 0.08792 0.08545 0.04886 0.03297
0.00000 0.30680 0.39872 0.21318 0.03159 0.02101 0.02870
0.00000 0.17289 0.57407 0.17440 0.04079 0.01854 0.01931
0.00000 0.40298 0.35663 0.14864 0.04296 0.03114 0.01766
0.00000 0.09098 0.62677 0.20613 0.05692 0.01404 0.00515
0.00000 0.19447 0.41678 0.31196 0.04457 0.01240 0.01982
0.00000 0.27448 0.26059 0.25070 0.16133 0.03178 0.02113
0.01507 0.12209 0.46449 0.18316 0.12986 0.06627 0.01906
0.00000 0.34688 0.37904 0.16016 0.04382 0.03691 0.03320
0.17432 0.44893 0.17637 0.12455 0.04998 0.01249 0.01335
0.00000 0.39007 0.30046 0.12727 0.08299 0.05508 0.04412
0.00000 0.20124 0.46752 0.24724 0.05527 0.01459 0.01413
0.00359 0.04938 0.62445 0.27636 0.03345 0.00860 0.00418
0.01678 0.31642 0.42977 0.14492 0.07181 0.01608 0.00423
0.00000 0.16969 0.44941 0.16627 0.10002 0.07469 0.03991
# Number of years of FALL SURVEY data 1964-2000
37
# Years of FALL SURVEY data
1964    1965    1966    1967    1968    1969    1970    1971    1972    1973    1974    1975    1976
        1977    1978    1979    1980    1981    1982    1983    1984    1985    1986    1987    1988
        1989    1990    1991    1992    1993    1994    1995    1996    1997    1998    1999    2000
# Fraction of Z Prior to FALL SURVEY (fraction of year)
0.75
# Untransformed FALL SURVEY biomass index
1.822   2.05    5.655   2.074   1.072   2.385   6.49    1.259   1.58    1.195   1.464   2.061   3.925
        3.992   3.1     3.829   1.865   2.434   2.692   2.363   2.445   1.119   2.178   0.889   1.273
        1.051   0.346   0.136   0.384   0.663   0.578   1.337   1.756   1.534   1.565   2.641   2.66
# Number of age samples in FALL SURVEY (nsamples_FALL)
100
# FALL SURVEY age composition data
-99     -99     -99     -99     -99     -99     -99
-99     -99     -99     -99     -99     -99     -99
-99     -99     -99     -99     -99     -99     -99
-99     -99     -99     -99     -99     -99     -99
-99     -99     -99     -99     -99     -99     -99
-99     -99     -99     -99     -99     -99     -99
-99     -99     -99     -99     -99     -99     -99
-99     -99     -99     -99     -99     -99     -99
```

```
-99	-99	-99	-99	-99	-99	-99
-99	-99	-99	-99	-99	-99	-99
-99	-99	-99	-99	-99	-99	-99
-99	-99	-99	-99	-99	-99	-99
-99	-99	-99	-99	-99	-99	-99
-99	-99	-99	-99	-99	-99	-99
-99	-99	-99	-99	-99	-99	-99
-99	-99	-99	-99	-99	-99	-99
-99	-99	-99	-99	-99	-99	-99
-99	-99	-99	-99	-99	-99	-99
0.39119	0.42743	0.08732	0.06710	0.02423	0.00273	0.00000
0.02611	0.22086	0.42943	0.18562	0.02169	0.07220	0.04409
0.17857	0.26801	0.24763	0.21944	0.06231	0.01591	0.00813
0.17298	0.53288	0.22308	0.04219	0.01444	0.01444	0.00000
0.32442	0.46462	0.10849	0.06005	0.01420	0.00714	0.02107
0.06907	0.26720	0.28637	0.15901	0.00000	0.10360	0.11476
0.72489	0.15738	0.09565	0.00979	0.00000	0.00615	0.00615
0.06271	0.69030	0.04701	0.09227	0.04721	0.03744	0.02305
0.16881	0.12058	0.60812	0.00000	0.10249	0.00000	0.00000
0.28464	0.00000	0.38702	0.32834	0.00000	0.00000	0.00000
0.03443	0.68125	0.23156	0.01389	0.03887	0.00000	0.00000
0.50592	0.11283	0.21099	0.14772	0.02255	0.00000	0.00000
0.18945	0.49293	0.18186	0.09771	0.03805	0.00000	0.00000
0.41367	0.38391	0.15375	0.02052	0.02044	0.00000	0.00770
0.07968	0.21967	0.40560	0.15832	0.03574	0.06070	0.04029
0.04531	0.39693	0.33262	0.17132	0.03563	0.01640	0.00180
0.15952	0.14311	0.36919	0.20744	0.09460	0.01062	0.01552
0.14880	0.30322	0.13468	0.12637	0.23342	0.03395	0.01956
0.02297	0.21601	0.21592	0.13434	0.20023	0.09406	0.11647
# Number of years of SPRING SURVEY data 1968-2000
33
# SPRING SURVEY years
1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
	1993	1994	1995	1996	1997	1998	1999	2000
# Fraction of Z Prior to SPRING SURVEY (fraction of year)
0.25
# SPRING SURVEY biomass index
3.114	4.29	2.294	2.168	5.321	3.507	5.782	1.407	3.012	1.58	5.055	2.206	2.801
	3.749	1.523	7.111	5.604	2.65	1.214	1.247	1.648	0.757	1.573	1.319	0.898
	0.57	0.578	1.489	1.504	1.192	0.722	3.479	3.693
# Number of age samples in SPRING SURVEY (nsamples_SPR)
100
# SPRING SURVEY age composition data
-99	-99	-99	-99	-99	-99	-99
-99	-99	-99	-99	-99	-99	-99
-99	-99	-99	-99	-99	-99	-99
-99	-99	-99	-99	-99	-99	-99
-99	-99	-99	-99	-99	-99	-99
-99	-99	-99	-99	-99	-99	-99
-99	-99	-99	-99	-99	-99	-99
-99	-99	-99	-99	-99	-99	-99
-99	-99	-99	-99	-99	-99	-99
-99	-99	-99	-99	-99	-99	-99
-99	-99	-99	-99	-99	-99	-99
-99	-99	-99	-99	-99	-99	-99
-99	-99	-99	-99	-99	-99	-99
-99	-99	-99	-99	-99	-99	-99
0.03256445	0.348646378	0.170123409	0.26361698	0.07734057	0.066227305
0.041480907
0.00312664	0.122095306	0.372834492	0.188206379	0.07976407	0.08290808
0.151065033
0.006363204	0.025637641	0.3457253	0.277974336	0.082880076	0.098669272
0.162750172
0.0	0.482292237	0.161910718	0.163787038	0.103484221	0.057488338	0.031037448
0.125667782	0.33042089	0.368865146	0.057866094	0.07983424	0.037345849	0
```

```
0.057474135 0.5882269 0.208669283 0.104851944 0.032215483 0 0.008562255
0.024786325 0.183042735 0.490735043 0.232444444 0.039692308 0.01408547
0.015213675
0.037182448 0.408929946 0.205773672 0.17382602 0.119938414 0.013856813
0.040492687
0.045308598 0.217909383 0.557367107 0.118444524 0.034819836 0.026150553 0
0.112447459 0.143410046 0.343043822 0.241458238 0.114528278 0.015023513
0.030088643
0.050995903 0.423788671 0.211046758 0.09824834 0.10312191 0.077270801
0.035527617
0.167436376 0.267957158 0.326422325 0.151321608 0 0.045494743 0.04136779
0.097391035 0.445382055 0.316095069 0.079043121 0.027792831 0.034295889 0
0.056916482 0.299203858 0.481512669 0.112340198 0.038850188 0.011176606 0
0.016079533 0.526950508 0.186384266 0.211281608 0.029781716 0.011368057
0.018154312
0.014977317 0.119507799 0.332732583 0.415698216 0.070784911 0.014977317
0.031321857
0.0 0.030569404 0.212673839 0.559564419 0.162686959 0 0.034505379
0.057981987 0.141130401 0.160579559 0.338911369 0.231327503 0.051638167
0.018431014
0.004073781 0.138915922 0.230689148 0.140364377 0.256919769 0.148874052
0.080162951
# Weight at age 1 2 3 4 5 6 7+
0.207 0.371 0.511 0.736 0.997 1.281 1.648
# Fraction of Z Prior to Spawning Season (fraction of year)
0.083
# Maturity at age 1 2 3 4 5 6 7+
0.05 0.62 0.98 1.00 1.00 1.00 1.00
# Likelihood emphasis: recruitment
10.0
# Likelihood emphasis: fishery age composition
1.0
# Likelihood emphasis: FALL SURVEY age composition
1.0
# Likelihood emphasis: FALL SURVEY biomass index
10.0
# Likelihood emphasis: SPRING SURVEY age composition
1.0
# Likelihood emphasis: SPRING SURVEY biomass index
10.0
# Likelihood emphasis: catch biomass
10.0
# Likelihood emphasis: fishery selectivity
10.0
# Likelihood emphasis: F penalty
1.0
```

Standard Deviation Parameter File

index	name	value	std dev
1	mean_log_rec	8.6215e+00	1.7002e-02
2	rec_dev	-8.2050e-01	1.6275e-01
3	rec_dev	-1.2486e+00	1.3983e-01
4	rec_dev	-1.0944e+00	1.5023e-01
5	rec_dev	7.4126e-01	6.7549e-02
6	rec_dev	-8.4282e-01	1.6241e-01
7	rec_dev	-1.3451e+00	1.4344e-01
8	rec_dev	-9.8949e-01	1.5730e-01
9	rec_dev	1.0137e+00	6.1918e-02
10	rec_dev	-5.8837e-01	1.7445e-01
11	rec_dev	-2.1967e-01	1.7382e-01
12	rec_dev	-1.4790e-01	1.9466e-01
13	rec_dev	5.0998e-01	1.8554e-01
14	rec_dev	7.2459e-02	2.1847e-01

15	rec_dev	1.0505e+00	1.0822e-01
16	rec_dev	1.2788e-01	2.0868e-01
17	rec_dev	4.0319e-02	2.0795e-01
18	rec_dev	1.1865e+00	9.6898e-02
19	rec_dev	-2.2321e-01	1.9630e-01
20	rec_dev	5.1868e-01	1.2550e-01
21	rec_dev	4.6350e-01	1.0412e-01
22	rec_dev	5.0984e-01	7.4753e-02
23	rec_dev	5.4443e-01	5.7669e-02
24	rec_dev	8.1636e-01	4.9546e-02
25	rec_dev	4.1616e-01	5.8773e-02
26	rec_dev	-4.3253e-01	7.1735e-02
27	rec_dev	2.1871e-01	4.9439e-02
28	rec_dev	1.5614e-01	5.2478e-02
29	rec_dev	3.2470e-01	5.1051e-02
30	rec_dev	-4.0341e-01	6.2112e-02
31	rec_dev	4.5593e-01	4.3474e-02
32	rec_dev	-3.1633e-01	5.6364e-02
33	rec_dev	-5.5266e-01	6.0753e-02
34	rec_dev	-4.8512e-02	4.7871e-02
35	rec_dev	-5.6973e-01	6.3774e-02
36	rec_dev	-2.3163e-02	4.8388e-02
37	rec_dev	3.7160e-02	5.0147e-02
38	rec_dev	3.3298e-01	4.5074e-02
39	rec_dev	1.2184e-02	5.5837e-02
40	rec_dev	-3.2015e-01	8.0130e-02
41	rec_dev	5.4326e-01	7.4621e-02
42	rec_dev	4.4625e-01	1.1027e-01
43	rec_dev	-3.5234e-01	1.8716e-01
44	qFALL	7.8547e-01	3.8040e-02
45	log_gamma_FALL	-1.8483e-01	1.0644e-02
46	log_beta_FALL	1.2829e+00	4.4374e-02
47	log_a50_FALL	1.7234e+00	7.0717e-03
48	qSPR	3.3045e-01	1.2884e-02
49	log_beta_SPR	9.6575e-01	5.9038e-02
50	log_a50_SPR	7.0653e-01	2.6172e-02
51	log_avg_fmort	-6.4774e-01	4.0836e-02
52	fmort_dev	-1.3730e+00	6.4691e-02
53	fmort_dev	-1.2356e+00	5.9459e-02
54	fmort_dev	-7.6300e-01	6.2047e-02
55	fmort_dev	-3.7726e-01	6.8532e-02
56	fmort_dev	-7.5135e-01	5.7105e-02
57	fmort_dev	-6.3439e-01	5.2751e-02
58	fmort_dev	-4.1164e-01	5.6960e-02
59	fmort_dev	2.7401e-01	6.3205e-02
60	fmort_dev	5.1091e-01	5.6296e-02
61	fmort_dev	4.1293e-01	6.1328e-02
62	fmort_dev	-3.0238e-02	5.9496e-02
63	fmort_dev	3.7326e-02	5.7395e-02
64	fmort_dev	-4.9396e-01	5.9352e-02
65	fmort_dev	-1.4176e-01	5.0880e-02
66	fmort_dev	-1.2949e-01	5.4191e-02
67	fmort_dev	-1.2996e-01	5.4272e-02
68	fmort_dev	1.3864e-01	4.9948e-02
69	fmort_dev	1.4762e-01	4.7535e-02
70	fmort_dev	-2.1702e-01	4.8527e-02
71	fmort_dev	3.4252e-02	4.8676e-02
72	fmort_dev	6.2844e-01	4.6381e-02
73	fmort_dev	5.1043e-01	5.3372e-02
74	fmort_dev	1.7459e-01	5.2940e-02
75	fmort_dev	5.9198e-01	5.0505e-02
76	fmort_dev	8.3680e-01	4.6599e-02
77	fmort_dev	7.3242e-01	5.1137e-02
78	fmort_dev	9.8974e-01	4.7055e-02
79	fmort_dev	9.9438e-01	4.6675e-02
80	fmort_dev	8.2763e-01	4.6682e-02

81	fmort_dev	8.0826e-01	4.7569e-02
82	fmort_dev	2.9701e-01	5.4910e-02
83	fmort_dev	-2.9966e-01	5.6301e-02
84	fmort_dev	6.5725e-02	5.5130e-02
85	fmort_dev	-9.7817e-02	5.6121e-02
86	fmort_dev	-5.2763e-01	5.2924e-02
87	fmort_dev	-9.0487e-01	5.3794e-02
88	fmort_dev	-4.9443e-01	5.9806e-02
89	log_selcoffs_fish	-3.7076e+00	2.5569e-01
90	log_selcoffs_fish	-1.0016e+00	2.2794e-01
91	log_selcoffs_fish	2.7917e-01	2.2589e-01
92	log_selcoffs_fish	5.7593e-01	2.2597e-01
93	log_selcoffs_fish	4.1973e-01	2.2705e-01
94	log_selcoffs_fish	-1.4280e-02	2.3325e-01
95	spawnbiom	2.1676e+04	4.8604e+02
96	spawnbiom	1.8943e+04	4.9879e+02
97	spawnbiom	1.6296e+04	4.8540e+02
98	spawnbiom	1.5627e+04	5.0103e+02
99	spawnbiom	1.4772e+04	5.3400e+02
100	spawnbiom	1.3455e+04	5.2512e+02
101	spawnbiom	1.2154e+04	5.2700e+02
102	spawnbiom	1.1504e+04	4.2093e+02
103	spawnbiom	9.8498e+03	3.6567e+02
104	spawnbiom	9.1607e+03	2.9671e+02
105	spawnbiom	9.0487e+03	3.1476e+02
106	spawnbiom	8.8685e+03	3.4346e+02
107	spawnbiom	1.0359e+04	3.3947e+02
108	spawnbiom	1.2052e+04	3.8969e+02
109	spawnbiom	1.1878e+04	3.8176e+02
110	spawnbiom	1.1649e+04	3.8238e+02
111	spawnbiom	1.1630e+04	3.7208e+02
112	spawnbiom	1.1150e+04	3.6392e+02
113	spawnbiom	1.1211e+04	3.3988e+02
114	spawnbiom	1.1936e+04	3.3971e+02
115	spawnbiom	1.0157e+04	3.0797e+02
116	spawnbiom	6.9190e+03	2.3348e+02
117	spawnbiom	6.0976e+03	2.1309e+02
118	spawnbiom	6.3685e+03	1.9874e+02
119	spawnbiom	5.1865e+03	1.6603e+02
120	spawnbiom	4.3905e+03	1.2716e+02
121	spawnbiom	4.0780e+03	1.1806e+02
122	spawnbiom	2.7955e+03	8.4724e+01
123	spawnbiom	2.4671e+03	6.8815e+01
124	spawnbiom	2.5001e+03	6.9560e+01
125	spawnbiom	2.6958e+03	7.2263e+01
126	spawnbiom	3.6855e+03	9.6371e+01
127	spawnbiom	5.2631e+03	1.3767e+02
128	spawnbiom	5.9912e+03	1.7974e+02
129	spawnbiom	6.2764e+03	2.1396e+02
130	spawnbiom	7.7520e+03	2.6217e+02
131	spawnbiom	9.8740e+03	3.7012e+02
132	recruitment	1.4459e+03	2.1202e+02
133	recruitment	2.0632e+03	3.3071e+02
134	recruitment	1.5293e+04	9.0035e+02
135	recruitment	3.0814e+03	5.4537e+02
136	recruitment	4.4552e+03	7.8581e+02
137	recruitment	4.7868e+03	9.4116e+02
138	recruitment	9.2418e+03	1.6688e+03
139	recruitment	5.9668e+03	1.3215e+03
140	recruitment	1.5867e+04	1.6339e+03
141	recruitment	6.3068e+03	1.3394e+03
142	recruitment	5.7781e+03	1.2133e+03
143	recruitment	1.8179e+04	1.6815e+03
144	recruitment	4.4395e+03	8.8476e+02
145	recruitment	9.3225e+03	1.1728e+03
146	recruitment	8.8220e+03	9.1351e+02

147	recruitment	9.2405e+03	6.8942e+02
148	recruitment	9.5657e+03	5.4987e+02
149	recruitment	1.2555e+04	6.0146e+02
150	recruitment	8.4142e+03	4.9152e+02
151	recruitment	3.6011e+03	2.5964e+02
152	recruitment	6.9065e+03	3.3611e+02
153	recruitment	6.4876e+03	3.3295e+02
154	recruitment	7.6788e+03	3.7497e+02
155	recruitment	3.7074e+03	2.2646e+02
156	recruitment	8.7556e+03	3.5621e+02
157	recruitment	4.0448e+03	2.2319e+02
158	recruitment	3.1934e+03	1.9114e+02
159	recruitment	5.2870e+03	2.4584e+02
160	recruitment	3.1394e+03	2.0001e+02
161	recruitment	5.4227e+03	2.5661e+02
162	recruitment	5.7599e+03	2.8643e+02
163	recruitment	7.7426e+03	3.4616e+02
164	recruitment	5.6178e+03	3.1303e+02
165	recruitment	4.0294e+03	3.2557e+02
166	recruitment	9.5546e+03	7.2283e+02
167	recruitment	8.6711e+03	9.7608e+02
168	recruitment	3.9017e+03	7.4857e+02
169	endbiom	1.2042e+04	4.7784e+02
170	depletion_popnbiom	5.2754e-01	1.7868e-02
171	endspawn	9.8740e+03	3.7012e+02
172	depspawn	4.5552e-01	1.4254e-02
173	deppopnbiom82	8.1339e-01	3.0019e-02
174	depspawn82	8.8073e-01	2.9353e-02
175	endN	3.9017e+03	7.4857e+02
176	endN	7.0786e+03	7.9681e+02
177	endN	6.1046e+03	4.6207e+02
178	endN	1.7612e+03	1.4514e+02
179	endN	1.4610e+03	9.3273e+01
180	endN	1.0872e+03	6.9742e+01
181	endN	8.1489e+02	5.9018e+01
182	endF	3.1912e-01	2.3925e-02

Research Communications Unit
Northeast Fisheries Science Center
National Marine Fisheries Service, NOAA
166 Water St.
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STANDARD MAIL A

Publications and Reports of the Northeast Fisheries Science Center

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Fishermen's Report -- This information report is a quick-turnaround report on the distribution and relative abundance of commercial fisheries resources as derived from each of the NEFSC's periodic research vessel surveys of the Northeast's continental shelf. There is no scientific review, nor any technical or copy editing, of this report.

The Shark Tagger -- This newsletter is an annual summary of tagging and recapture data on large pelagic sharks as derived from the NMFS's Cooperative Shark Tagging Program; it also presents information on the biology (movement, growth, reproduction, etc.) of these sharks as subsequently derived from the tagging and recapture data. There is internal scientific review, but no technical or copy editing, of this newsletter.

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