APPENDIX B3. Female spiny dogfish Length Tuned Model (LTM)

<u>Introduction</u>

Incomplete age information on catch and survey indices, often limits the application of full age-structured assessment models tuned with age specific data (e.g. Virtual Population Analysis). Knowledge of a species growth and lifespan, along with total catch data, size composition of the removals, recruitment indices and indices on numbers and size composition of the large fish in a survey can provide insights on population status using a simple model framework.

Herein we used a simple forward projecting age-based model tuned with total catch, catch at length, age-1 recruitment (estimated from first length mode in the survey), and survey numbers and length frequency of the larger fish sizes. The Length Tuned Model (LTM) was developed in the AD model builder framework. The model estimates fishing mortality and recruitment in each year, fishing mortality to produce the initial population (Fstart), and Qs for each survey index.

<u>Methods</u>

Model configuration

The LTM model assumes growth follows the mean input length at age with predetermined input error in length at age. Therefore a growth model or estimates of the average mean lengths at age is essential for reliable results. The LTM model uses an input partial recruitment (pr) vector at length in each year for the calculation of population and catch age-length matrices. A starting population is computed for year one in the model. First the estimated populations numbers at age starting with age-1 recruitment get normally distributed at one cm length intervals using the mean length at age with the assumed standard deviation. Next the initial population numbers at age are calculated from the previous age at length abundance using the survival equation. An estimated fishing mortality (Fstart) is also used to produce the initial population. This F can be thought of as the average fishing mortality that occurred before the first year in the model. Now the process repeats itself with the total of the estimated abundance at age getting redistributed according to the mean length at age and standard deviation in the next age (age+1).

This two step process is used to incorporate the effects of length specific selectivities and fishing mortality.   The initial population length and age distribution is constructed by assuming that the population is at equilibrium with an initial value of F, say F_{start}. Length specific mortality is estimated as a two step process in which the population is first decremented for the length specific effects of mortality as follows:

$$N^*_{a,len,y_1} = N_{a-1,len,y_1} e^{-(PR_{len}F_{start}+M)}$$

In the second step, the total population of survivors is then redistributed over the lengths at age a by assuming that the proportions of numbers at length at age a follow a normal distribution with a mean length derived from the von Bertalanffy growth function.

$$N_{a,len,y_1} = \pi_{len,a} \sum_{len=0}^{L_\infty} N^*_{a,len,y_1}$$

where

$$\pi_{len,a} = \Phi\left(len+1 \mid \mu_a, \sigma_a^2\right) - \Phi\left(len \mid \mu_a, \sigma_a^2\right)$$

where

$$\mu_a = L_\infty\left(1 - e^{-K(a-t_0)}\right)$$

For spiny dogfish the variance of length at age a = σ_s^2 was obtained empirically from the Fig 5 in Nammack et al (standard deviation of 5 from ages 9+).

This model formulation does not explicitly track the dynamics of length groups across age because the consequences of differential survival at length at age a do not alter the mean length of fish at age a+1. However, it does more realistically account for the variations in age specific partial recruitment patterns by incorporating the expected distribution of lengths at age.

In the next step the population numbers at age and length for years after the calculation of the initial population use the previous age and year for the estimate of abundance. Here the calculations are done on a cohort basis. Like in the previous initial population survival equation the partial recruitment is taken from the input length vector.

$$N^*_{a,len,y} = N_{a-1,len,y-1}\, e^{-(PR_{len}F_{start}+M)}$$

second stage

$$N_{a,len,y} = \pi_{len,a} \sum_{len=0}^{L_\infty} N^*_{a,len,y}$$

Constant M is assumed along with an estimated length-weight relationship to convert estimated catch in numbers to landings in weight. The best available estimate of partial recruitment at

length is used as input to the model from knowledge of landings size distribution, fishing practice, regulations, and discarding. The standard Baranov's catch equation is used to remove the catch from the population in estimating fishing mortality.

$$C_{y,a,len} = \frac{N_{y,a,len} \, F_y \left(1 - e^{-\left(F_y PR_{len} + M\right)}\right)}{(F_y \, PR_{len}) + M}$$

Catch is converted to yield by assuming a time invariant average weight at length

$$Y_{y,a,len} = C_{y,a,len} W_{len}$$

The LTM model results in the calculation of population and catch age-length matrices for the starting population and then for each year thereafter. The model is programmed to estimate recruitment in year 1 and estimate variation in recruitment relative to recruitment in year 1 for each year thereafter. Estimated recruitment in year one can be thought of as the estimated average long term recruitment in the population since it produces the initial population. The residual sum of squares of the variation in recruitment $\sum(Vrec)^2$ is than used as a component of the total objective junction. The weight on the recruitment variation component of the objective junction (Vrec) can be used to penalize the model for estimating large changes in recruitment relative to estimated recruitment in year one.

The model requires an age-1 recruitment index for tuning or the user can assume relatively constant recruitment over time by putting a high weight on Vrec. Usually there is little overlap in ages at length for fish that are one and/or two years of age in a survey of abundance. The first mode in a survey can generally index age-1 recruitment using length slicing. In addition numbers and the length frequency of the larger fish in a survey where overlap in ages at a particular length occurs can be used for tuning population abundance. The model tunes to the catch and survey length frequency data using a multinomial distribution. The user specifies the minimum size (cm) for the model to fit. Different minimum sizes can be fit for the catch and survey data length frequency.

The number of parameters estimated is equal to the number of years in estimating F and recruitment plus one for the F to produce the initial population (Fstart) and for each survey Q. The total likelihood function to be minimized is made up of 10 likelihood components:

$$L_1 = \sum_{years}\left(l\,n(Y_{obs,y} + 1) - \ln\left(\sum_{a} \sum_{len} Y_{pred,len,a,y} + 1 \right) \right)^2$$

$$L_2 = -N_{eff} \sum_y \left(\sum_{len=80}^{L_\infty} \left(\left(C_{y,len} + 1 \right) \ln\left(1 + \sum_a C_{pred,y,a,len} \right) - \ln\left(C_{y,len} + 1 \right) \right) \right)$$

$$L_3 = \sum_{y=2}^{Nyears} \left(Vrec_y \right)^2 = \sum_{y=2}^{Nyears} \left(R_1 - R_y \right)^2$$

$$L_4 = \sum_y^{Nyears} \left(\ln\left(I_{FALL,1,y} + 1 \right) - \ln\left(1 + \sum_{len}^{L_\infty} N_{y,1,len} \right) q_{FALL} \right)^2$$

$$L_5 = \sum_{y=1992}^{Nyears} \left(\ln\left(I_{WINTER,1,y} + 1 \right) - \ln\left(1 + \sum_{len}^{L_\infty} N_{y,1,len} \right) q_{WINTER} \right)^2$$

$$L_6 = \sum_y^{Nyears} \left(\ln\left(I_{SPRING,1,y} + 1 \right) - \ln\left(1 + \sum_{len}^{L_\infty} N_{y,1,len} \right) q_{SPRING} \right)^2$$

$$L_7 = \sum_{y=1992}^{Nyears} \left(\ln\left(I_{WINTER,80+,y} + 1 \right) - \ln\left(\sum_a \sum_{len=80}^{L_\infty} \ln\left(N_{pred,y,a,len} + 1 \right) q_{WINTER,80+} \right) \right)^2$$

$$L_8 = -N_{eff} \sum_{y=1992}^{Nyears} \left(\sum_{len=80}^{L_\infty} \left(\left(I_{WINTER,y,len} + 1 \right) \ln\left(1 + \sum_a N_{pred,y,a,len} \right) - \ln\left(I_{WINTER,y,len} + 1 \right) \right) \right)$$

$$L_9 = \sum_{y}^{Nyears} \left(\ln\left(I_{SPRING,80+,y} + 1\right) - \ln\left(\sum_{a} \sum_{len=80}^{L_\infty} \ln\left(N_{pred,y,a,len} + 1\right) q_{SPRING,80+} \right) \right)^2$$

$$L_{10} = -N_{eff} \sum_{y} \left(\sum_{len=80}^{L_\infty} \left(\left(I_{SPRING,y,len} + 1\right) \ln\left(1 + \sum_{a} N_{pred,y,a,len} \right) - \ln\left(I_{SPRING,y,len} + 1\right) \right) \right)$$

In equation L_2 calculations of the sum of length is made from the user input catch length to the maximum length for fitting the catch. In equation L_7 through L_{10} the input survey length up to the maximum length is used in the calculation. For dogfish 80+ cm was used for both the catch and surveys.

$$Obj\ fcn = \sum_{i=1}^{10} \lambda_i L_i$$

Lambdas represent the weights to be set by the user for each likelihood component in the total objective function.

Female Dogfish LTM Model Results

The LTM model for dogfish (1981-2005) is limited to females only since there is a large difference in growth between the sexes (males $L_\infty = 82.5$ cm, female $L_\infty = 100.5$ cm) (Nammack et al). In addition most of the landings is comprised of females when the directed fishery targeted the larger fish. Eighty plus centimeter biomass indices for males and females possess very different trends with the male biomass remaining relatively constant over time. Female changes in biomass are presumably due to increases in mortality from the directed fishery. Therefore the working group assumed that female population trends are limiting for the population dynamics. Catch, surveys, and growth were limited to female fish in the LTM model.

Female growth and variation in mean lengths at age was taken from Nammack et al. (1985). Natural mortality was assumed to be 0.09 with a forty year lifespan. The catch length frequency, survey numbers and survey length frequency were fit to 80+ cm fish. Surveys were standardized by dividing each survey by its mean and multiplying by 1 million.

Preliminary runs of the LTM model assumed that landings are comprised of females in the (US, USSR, Canada, and other foreign landings). Half of the Recreation and B2 catch was assumed to be females and mortality occurred on 100 percent of the B2 releases. Preliminary runs used an approximation of the partial recruitment vector at length. Runs with different assumptions on the variation in recruitment (Vrec weight = 5, 1000, 0.1) showed little differences in F and biomass with the preliminary input data (Table 1, Fig 1-3). Adding the estimated partial recruitment at length in each year from the survey-landings analysis did not produce a large change in the results (run 7, Fig 4) (see selectivity estimation section).

Subsequent model runs used improved estimates of the female catch which included estimates of female commercial discards (runs 4-7, Fig 5-7)(See landings and estimated discard sections). Landings were prorated to female landings, the sex ratio from the fall inshore Massachusetts DMF survey (70% female) was applied to the recreational component with a 20% mortality rate on the B2 releases. Recreational catch were characterized with the discard length frequency. Adding the commercial discard catch and refined estimates of the female landings resulted in substantial changes to the preliminary catch trend with larger discard estimates early in the time series and a lower estimated B2 component later in the series. The catch length frequency also shifted to smaller fish after adding the discard information.

The working group reviewed a model run using the estimated partial recruitment pattern (survey-landings analysis) which included the discards in the catch length frequency. This partial recruitment estimation resulted in large changes in the partial recruitment during 1991 to 1997 when the directed fishery developed which landed larger fish. The estimated partial recruitment vector suggested that larger size fish were not fully selected during this period. This produced a high estimation of fishing mortality during that period. The working group chose a run using a constant selectivity given the problems of interpreting fishing mortality with the large shifts in the partial recruitment, in addition to the problems of estimating a partial recruitment pattern from catch comprised of both discard and landings. The final run used a constant partial recruitment with a L_{50} of 70 cm (alpha = 10.5, beta -.015) and Vrec weight of 1 (Figs 7). As a consequence of choosing a constant partial recruitment vector the LTM model has difficulty matching the observed catch length frequency for the larger fish in the catch when the directed fishery landed larger fish. In addition the observed and predicted total catch length frequencies do not match well in some years. However, the working group noted very similar trends in F and biomass among the different model configurations (Table 1 Fig1-7). It was also noted that decreases in recruitment after 1996 do not have a large influence on the model results because the long lifespan prevents these recruits from feeding back into the catch prior to the terminal year.

In all Dogfish model runs the LTM model estimates start F at the lower bound. The model predicts a virgin stock at the beginning of the model in 1981. All LTM model runs result in a decreasing trend to the total number of 80+ fish in both the winter and spring survey from beginning of the index to 2001. The model predicts more fish than was observed in the beginning of the spring survey (1981-1987) between the sizes of 80 and 90 cm. However the later part of the times series produced a better fit to the length frequency distributions.

After the working group meeting an error was discovered in the computation of commercial discards. LTM model runs 8 through 12 used the corrected length frequency and catch estimates (Table 3). The model runs with the corrected discards have lower catch at the beginning and a small increase in catch at the end of the time series. This resulted in an increase in F from 0.13 to 0.2 in the terminal year for the final run configuration (Tables 2 and 4). The corrected final run (run 8, Vrec=1, Fstart estimated at 0.001) results are given in Figures 8 to 13. Runs 9 through 12 are some additional sensitivity runs which compared the effects of a Vrec = 5, a fixed Fstart at 0.1 and 0.05 and a higher weight (increased from 10 to 50) on the spring 80+ index. Increasing the weight on Vrec decreased F in the terminal year from 0.2 to 0.14. However F and

Biomass trends were very similar between runs with a Vrec weight of 1 and 5. Fixing the Fstart at 0.1 and 0.05 may be more appropriate given the likely commercial discarding and the USSR landings in the 1970s. Fixing Fstart at 0.1 or 0.05 resulted in a slightly better fit to the Spring 80+ numbers. However the model had difficulty producing sufficient amounts of larger fish to match the observed length frequency data. Forcing the model to fit the Spring 80+ numbers did result in a higher estimated Fstart (0.08) but the fit to the catch suffered with lower catch being predicted during the period when discarding made up most of the catch (1981-1990) and higher predicted landing during the time of the directed fishery.

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Table 1. Female dogfish LTM runs of residual sum of squares, input weights, estimated Qs, estimated Fstart, and age 1 recruitment in year 1.

run number	1	2	3	4	5	6	7
Catch makeup	landing+B2s	landing+B2s	landing+B2s	landing+B2s	land + discards	land + discards	land + discards
PR used	approximation	approximation	approximation	estimated	estimated	estimated	constant
total objective function	196.1	129.1	237.1	190.0	187.7	149.5	154.0
total catch	0.1	0.1	0.4	0.0	0.1	0.1	0.1
catch len freq 80+	18.7	18.2	19.1	15.1	6.2	6.5	9.7
Vrec	4.8	49.1	0.0	4.6	4.4	22.0	21.9
Fall age 1	31.1	19.7	45.8	31.4	31.8	22.0	22.9
Spring age 1	29.0	11.5	47.4	29.1	30.0	16.7	16.6
Winter age 1	7.1	6.9	10.4	7.0	7.2	6.3	6.3
Winter 80+ len freq	7.5	7.1	9.7	7.6	7.7	7.6	7.7
Winter 80+ numbers	3.3	3.4	3.2	3.3	3.5	3.6	3.5
Spring 80+ len freq	23.3	23.5	24.9	22.0	21.8	21.9	22.6
Spring 80+ numbers	5.9	5.7	5.9	5.9	7.9	7.8	7.6
wt total catch	10	10	10	10	10	10	10
effective sample size wt catch len freq 80+	200	200	200	200	200	200	200
wt Vrec	5	0.1	1000	5	5	1	1
wt Fall age 1	1	1	1	1	1	1	1
wt Spring age 1	2	2	2	2	2	2	2
wt Winter age 1	2	2	2	2	2	2	2
effective sample size wt Winter 80+ len freq	200	200	200	200	200	200	200
wt Winter 80+ numbers	2	2	2	2	2	2	2
effective sample size Spring 80+ len freq	200	200	200	200	200	200	200
wt Spring 80+ numbers	2	2	2	2	2	2	2
Q Fall age 1	0.79	0.83	0.78	0.79	0.76	0.78	0.78
Q Spring age 1	0.81	0.84	0.80	0.81	0.78	0.80	0.80
Q Winter age 1	0.84	0.91	0.82	0.84	0.82	0.85	0.85
Q Winter 80+ numbers	0.82	0.82	0.82	0.82	0.82	0.82	0.83
Q Spring 80+ numbers	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Fstart	0.001	0.001	0.001	0.001	0.001	0.001	0.001
recruitment year 1	11.7	11.4	13.9	11.5	20.1	19.0	18.7

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Table 2. Female dogfish LTM run 7 F-mult, age 1 recruitment and 80+ population biomass.

| year	F Fmult	age 1 recruitment millions	population 80+ biomass metric tons
1981	0.11	18.7	249,088
1982	0.11	27.9	226,115
1983	0.12	35.1	203,969
1984	0.12	7.0	184,298
1985	0.11	44.1	166,699
1986	0.11	26.1	152,300
1987	0.11	42.7	140,084
1988	0.12	25.1	129,440
1989	0.12	30.7	119,434
1990	0.23	18.1	111,442
1991	0.18	24.3	95,923
1992	0.30	17.8	88,054
1993	0.34	25.2	74,275
1994	0.34	26.3	62,012
1995	0.42	9.1	53,516
1996	0.44	8.4	44,778
1997	0.26	3.8	38,075
1998	0.40	4.0	38,169
1999	0.35	3.4	33,711
2000	0.28	6.1	30,763
2001	0.21	3.2	29,944
2002	0.21	3.9	31,039
2003	0.13	5.8	32,473
2004	0.20	13.6	35,969
2005	0.13	6.5	36,244

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Table 3. Female dogfish LTM runs using the corrected Discard data. The residual sum of squares, input weights, estimated Qs, estimated Fstart, and age 1 recruitment in year 1 are shown.

run number	8	9	10	11	12
Description	final run	vrec = 5	fixed Fstart = 0.1	fixed Fstart = 0.05	increase spr survey wt
Catch makeup	land + discards	land + discards	land + discards	land + discards	land + discards
PR used	constant	constant	constant	constant	constant
total objective function	153.9	193.1	190.6	170.4	429.2
total catch	0.1	0.0	0.2	0.1	3.0
catch len freq 80+	13.4	13.0	26.7	19.2	24.2
Vrec	21.3	4.8	23.3	22.1	24.4
Fall age 1	22.5	31.5	24.3	23.5	21.9
Spring age 1	16.2	29.2	16.9	16.6	17.5
Winter age 1	6.2	7.1	6.4	6.3	6.5
Winter 80+ len freq	7.6	8.2	8.4	7.9	8.9
Winter 80+ numbers	3.5	3.3	3.4	3.4	3.2
Spring 80+ len freq	22.5	22.7	40.3	30.8	36.7
Spring 80+ numbers	7.1	7.1	6.0	6.4	4.6
wt total catch	10	10	10	10	10
effective sample size wt catch len freq 80+	200	200	200	200	200
wt Vrec	1	5	1	1	1
wt Fall age 1	1	1	1	1	1
wt Spring age 1	2	2	2	2	2
wt Winter age 1	2	2	2	2	2
effective sample size wt Winter 80+ len freq	200	200	200	200	200
wt Winter 80+ numbers	2	2	2	2	2
effective sample size Spring 80+ len freq	200	200	200	200	200
wt Spring 80+ numbers	2	2	2	2	50
Q Fall age 1	0.79	0.77	0.78	0.78	0.78
Q Spring age 1	0.81	0.79	0.80	0.80	0.80
Q Winter age 1	0.86	0.83	0.85	0.85	0.85
Q Winter 80+ numbers	0.83	0.83	0.83	0.83	0.83
Q Spring 80+ numbers	0.81	0.80	0.81	0.81	0.81
Fstart	0.001	0.001	0.100	0.050	0.078
recruitment year 1	15.3	16.3	21.5	20.0	21.1

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Table 4. Female dogfish LTM run 8 (Final run with corrected catch including commercial discards) F-mult, age 1 recruitment and 80+ population biomass.

year	F Fmult	age 1 recruitment millions	population 80+ biomass metric tons
1981	0.09	15.3	203,804
1982	0.10	24.6	187,940
1983	0.10	31.5	172,256
1984	0.09	6.2	158,557
1985	0.09	40.9	146,513
1986	0.09	23.9	135,898
1987	0.09	40.7	127,651
1988	0.09	23.5	120,440
1989	0.11	29.8	113,378
1990	0.21	16.9	106,456
1991	0.18	23.4	92,054
1992	0.27	16.3	83,910
1993	0.33	23.3	72,035
1994	0.30	24.3	60,246
1995	0.44	8.1	53,251
1996	0.46	7.4	43,581
1997	0.26	3.3	36,394
1998	0.42	3.5	36,449
1999	0.37	3.0	31,702
2000	0.30	5.4	28,460
2001	0.25	2.8	27,076
2002	0.25	3.5	27,292
2003	0.17	5.1	27,766
2004	0.23	12.0	29,894
2005	0.20	5.7	29,442
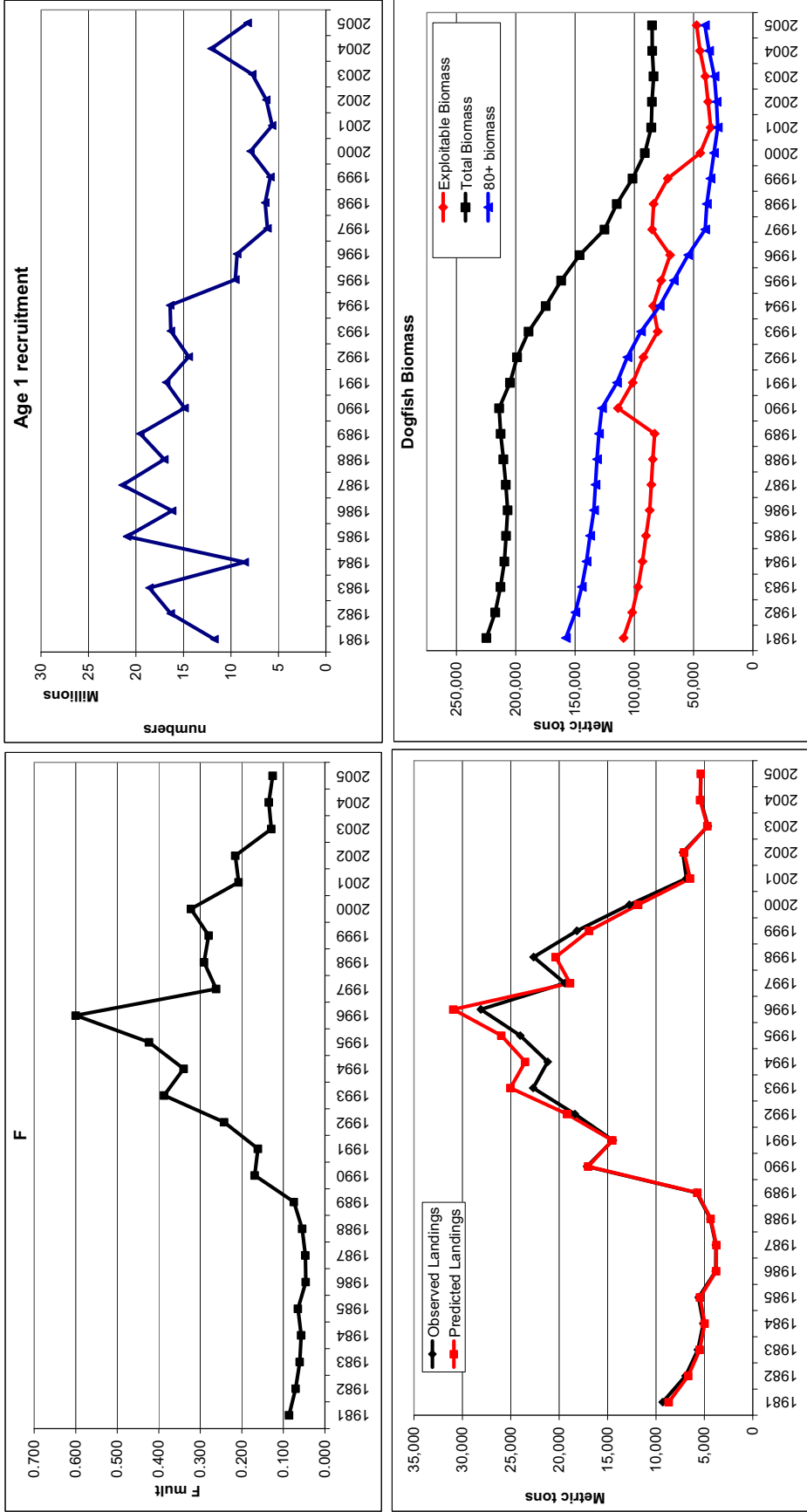
APPENDIX B3. Fig 1. Female dogfish LTM run 1 with preliminary landings and no commercial discard estimates with a Vrec weight of 5.
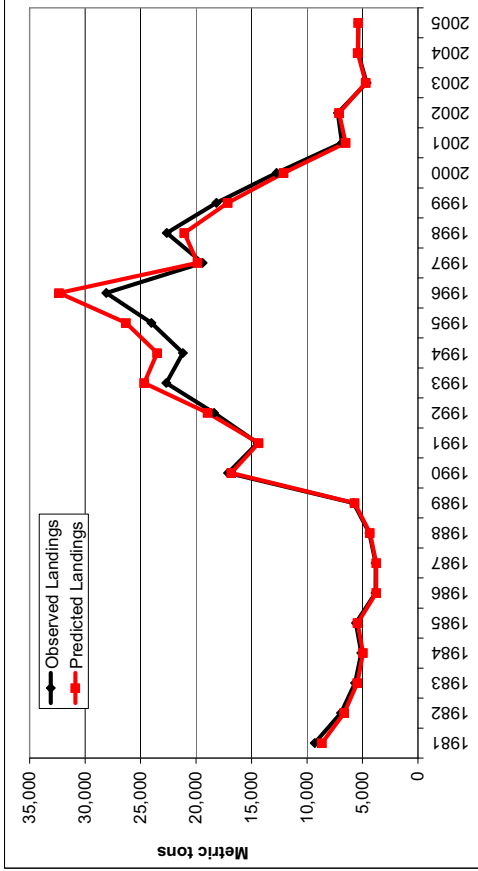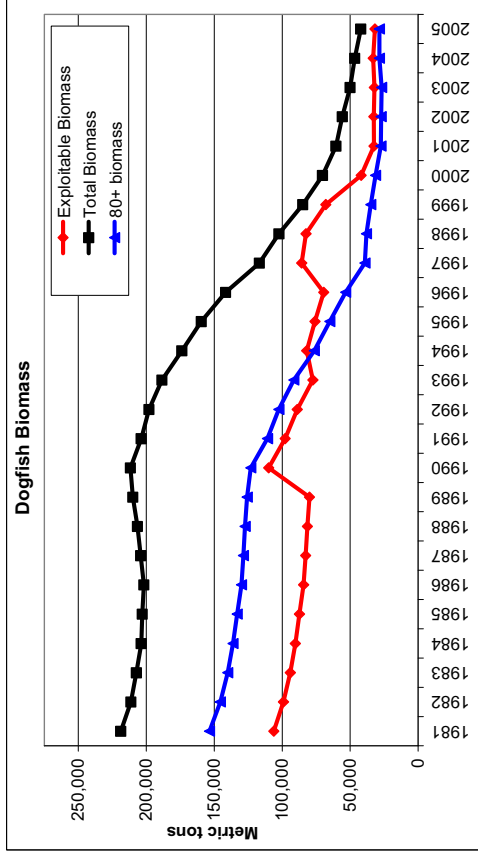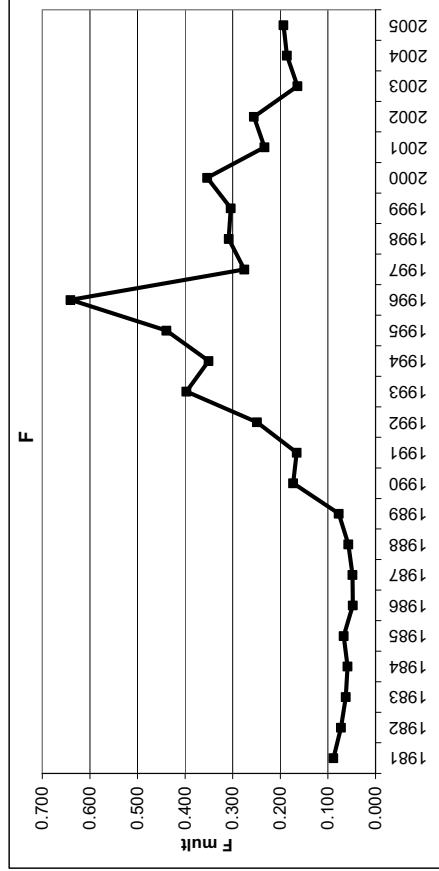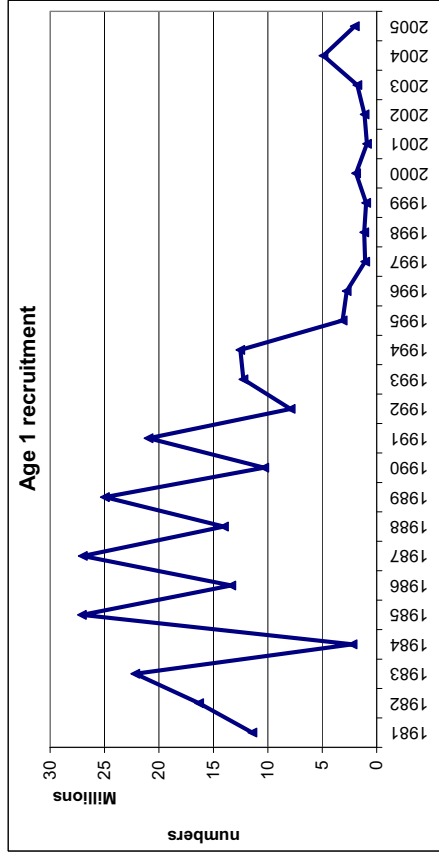
APPENDIX B3. Fig 2. Female dogfish LTM run 2 with preliminary landings and no commercial discard estimates with Vrec weight of 0.1.
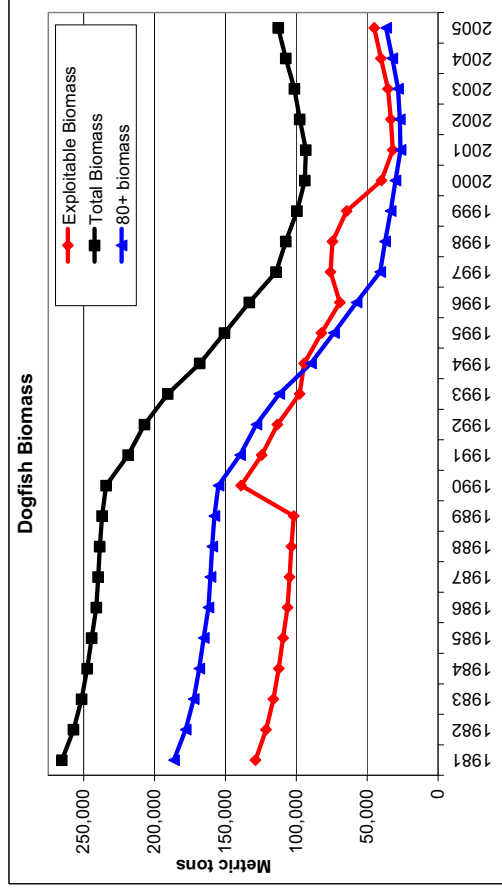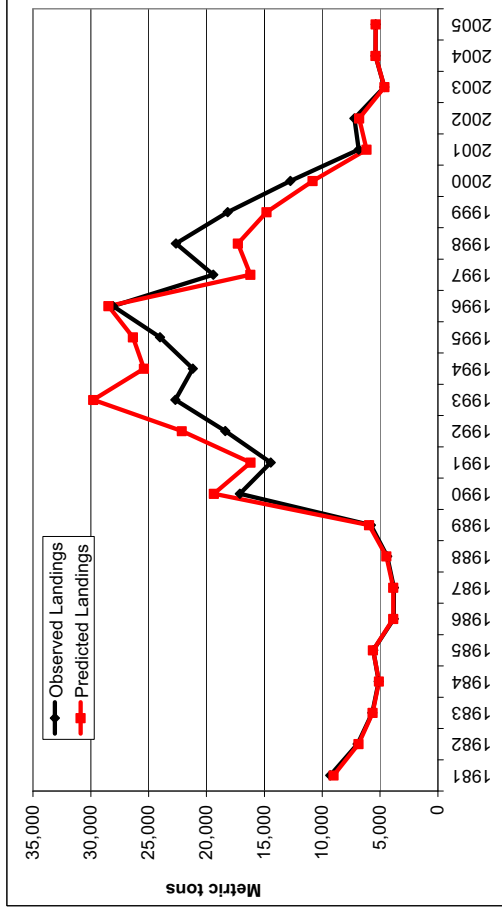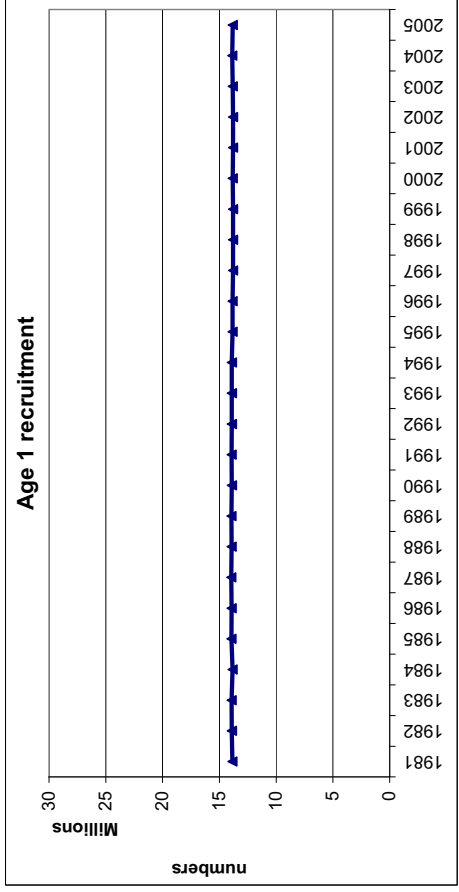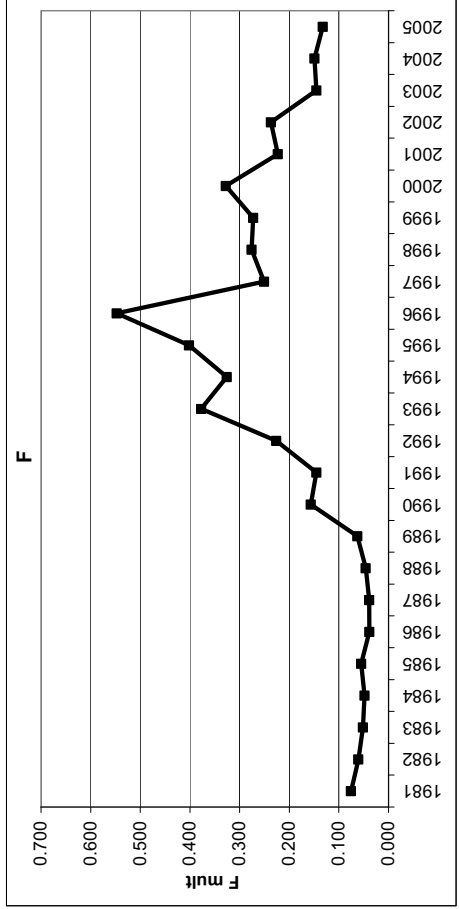
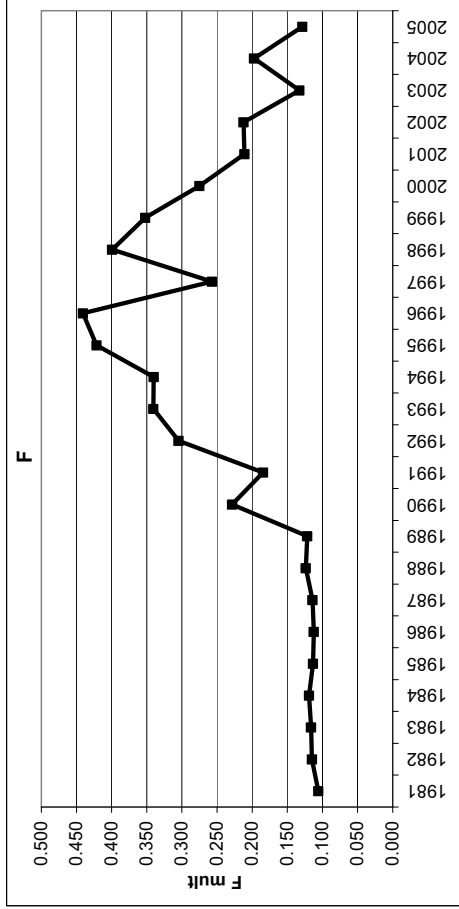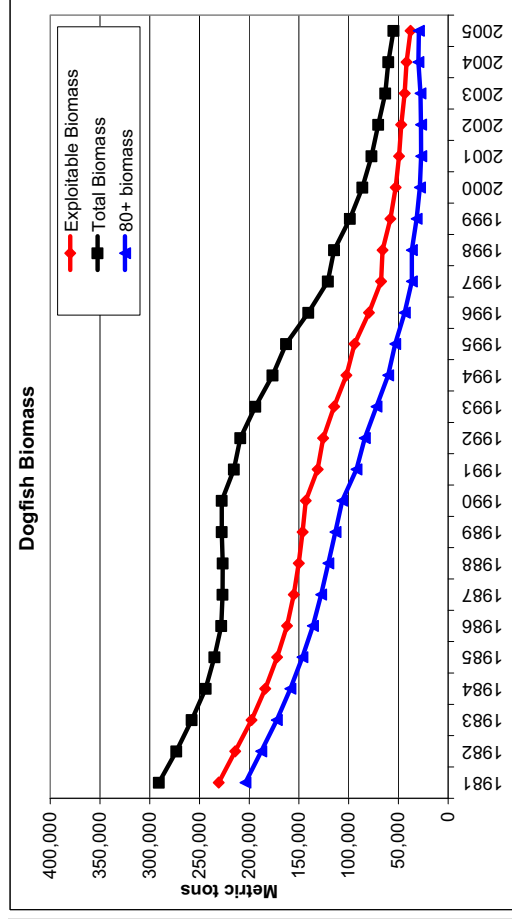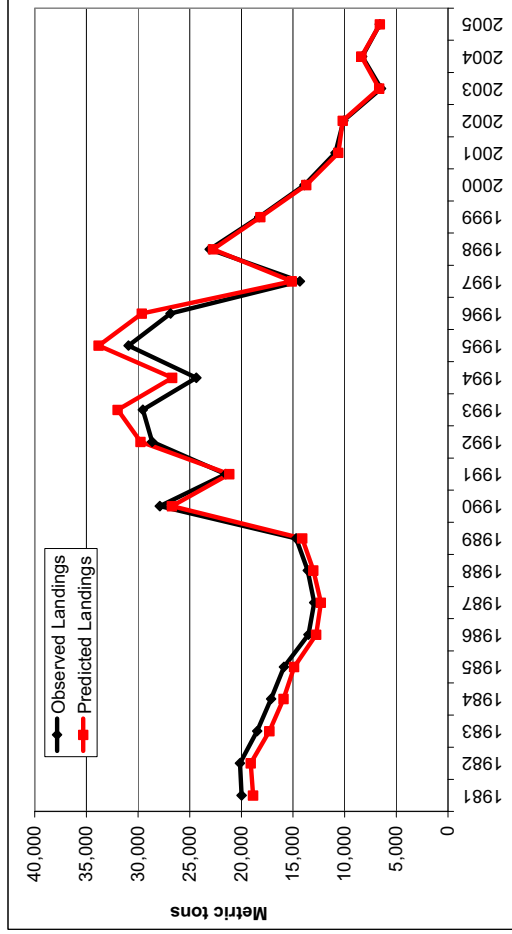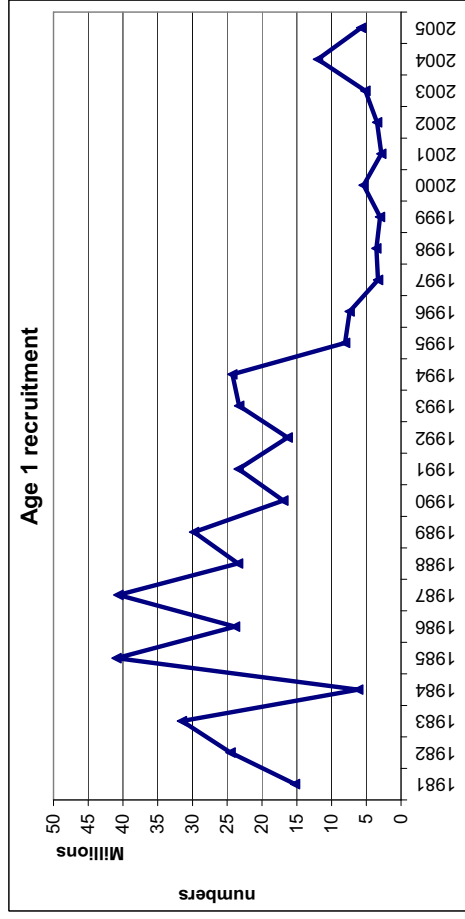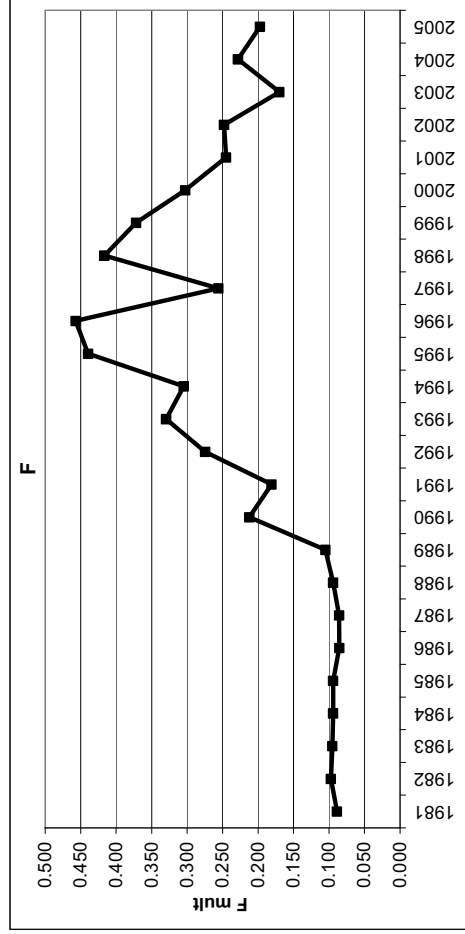APPENDIX B3. Fig 3. Female dogfish LTM run 3 with preliminary landings and no commercial discard estimates with Vrec weight 1000.
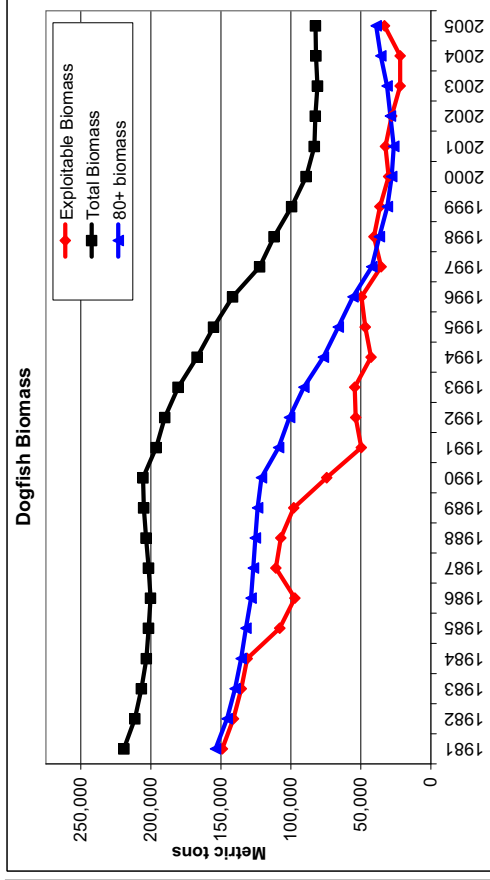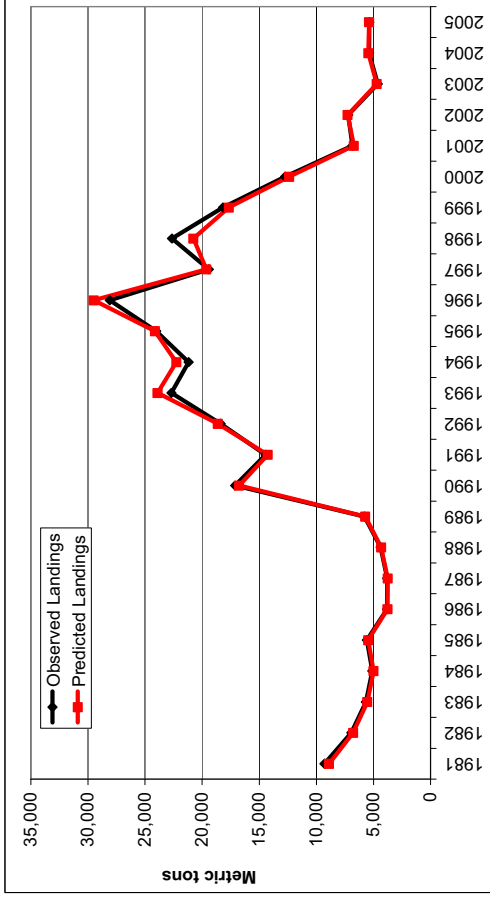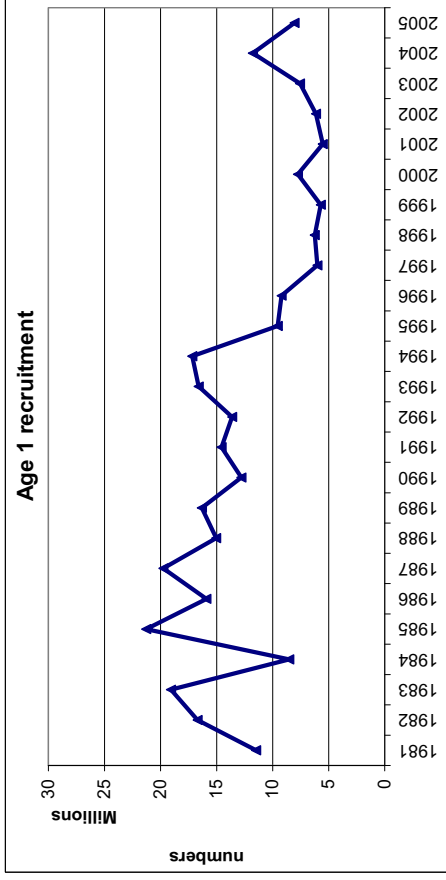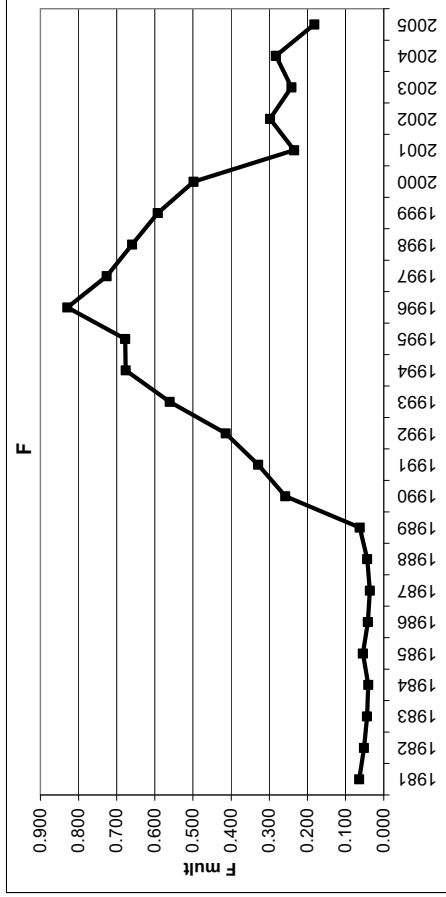
APPENDIX B3. Fig 4. Female dogfish LTM run 4 with preliminary landings, no commercial discard estimates, estimated pr, Vrec weight 5.

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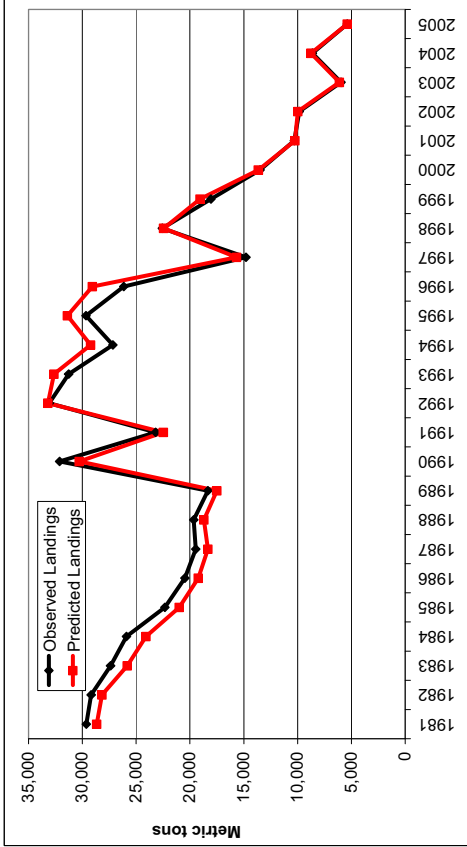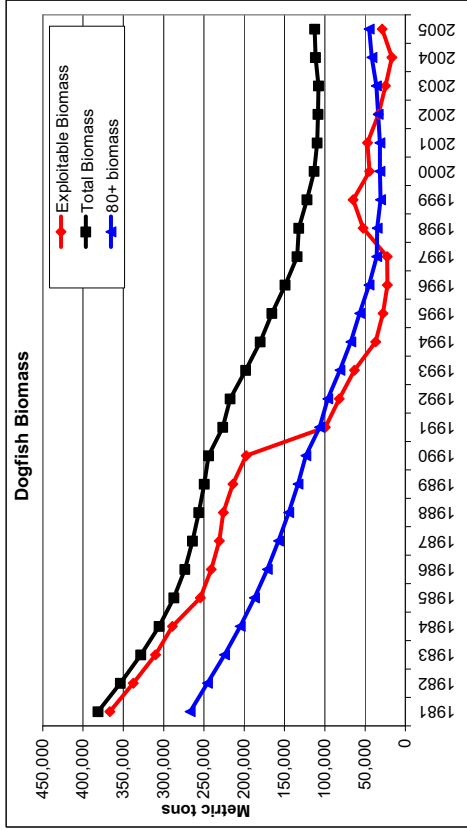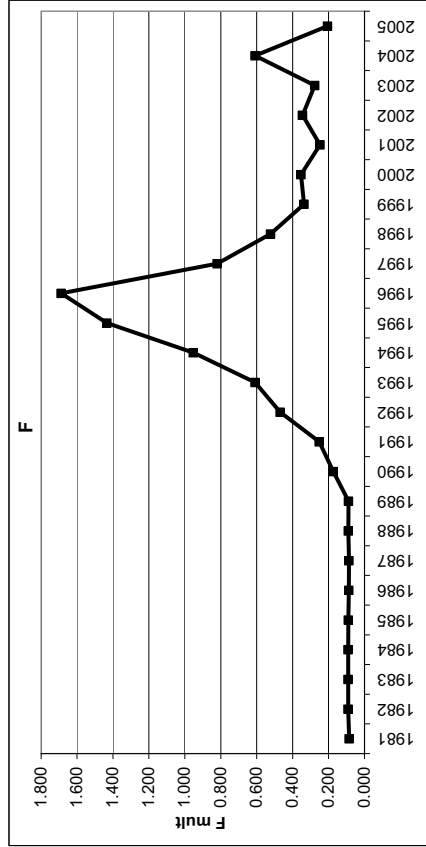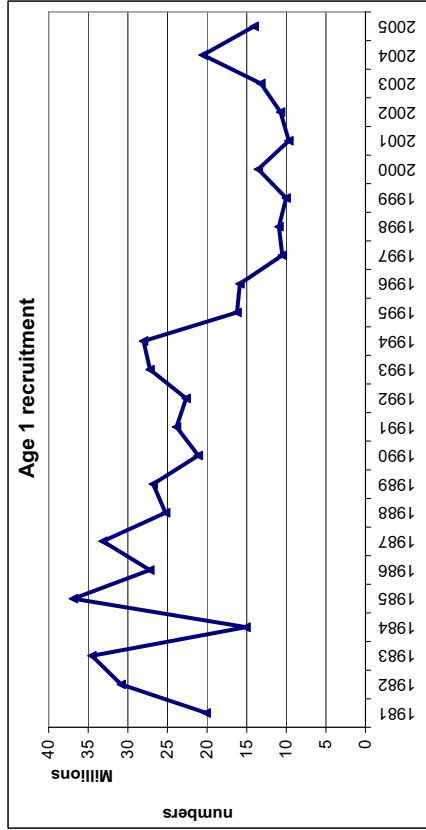
APPENDIX B3. Fig. 5. Female dogfish LTM run 5 with updated female landings and commercial discards, estimated pr, Vrec weight 5.
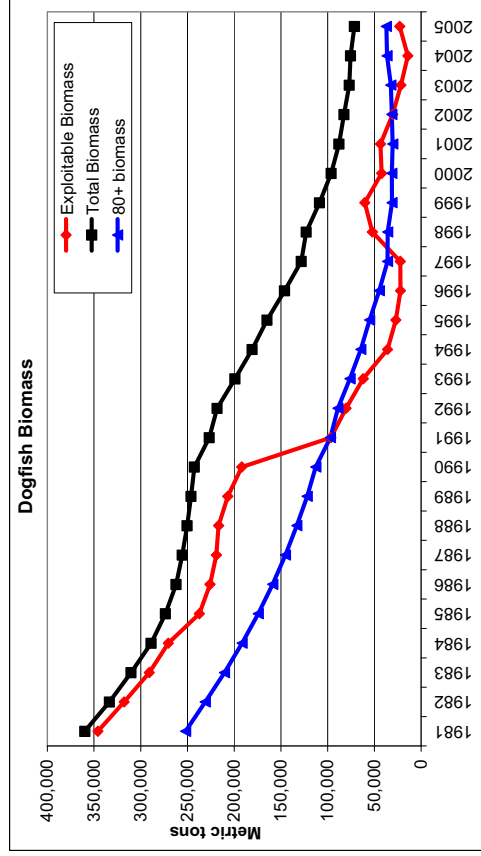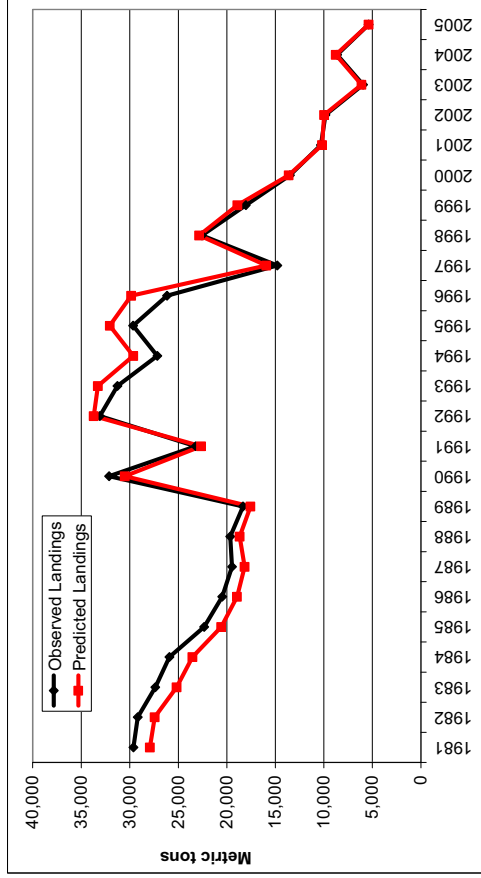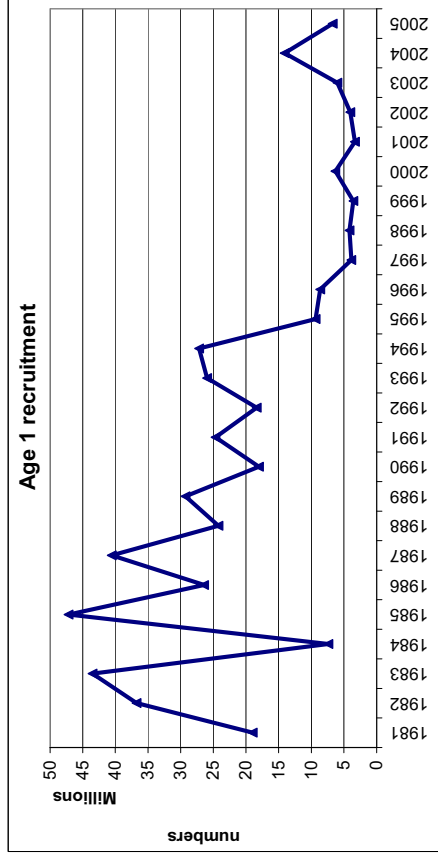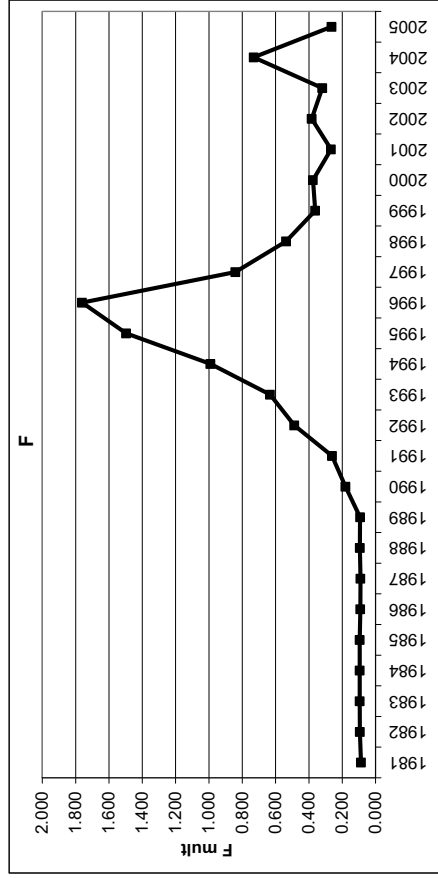
APPENDIX B3. Fig. 6. Female dogfish LTM run 6 with updated female landings and commercial discards, estimated pr and a Vrec weight 1.
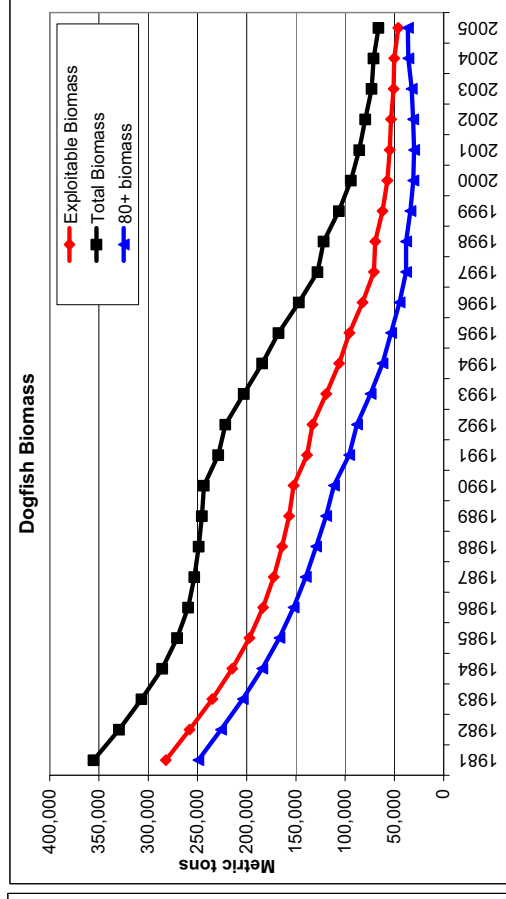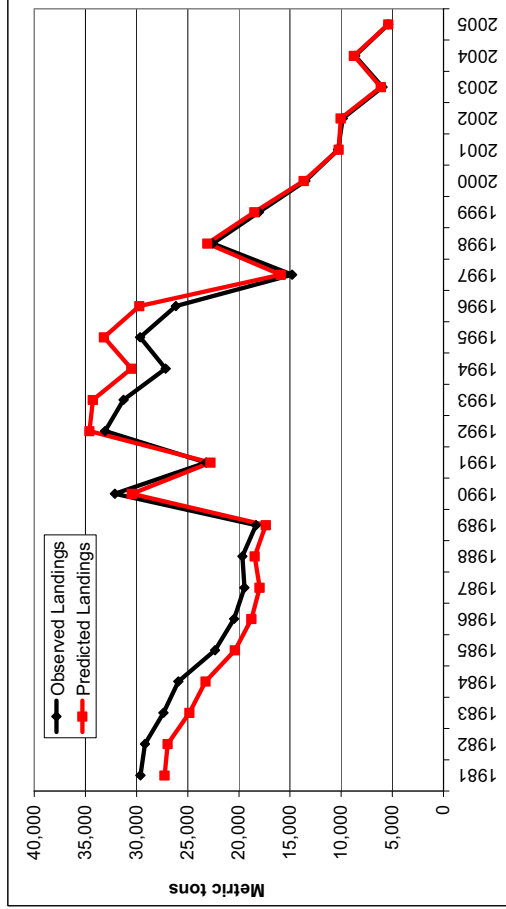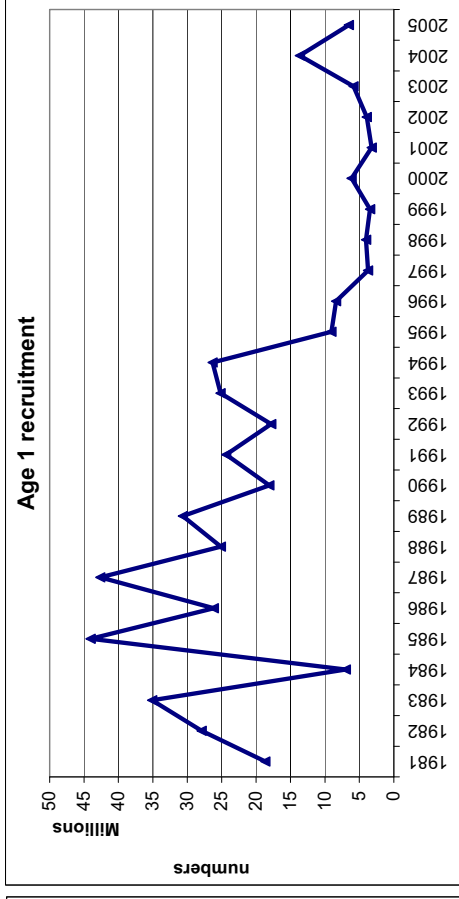
APPENDIX B3. Fig. 7. Female dogfish LTM run 7 with updated female landings and commercial discard estimates, constant pr, and Vrec weight of 1.

APPENDIX B3. Fig. 8. Female dogfish Final LTM run 8 with corrected catch including commercial discards, constant pr, and Vrec weight of 1.
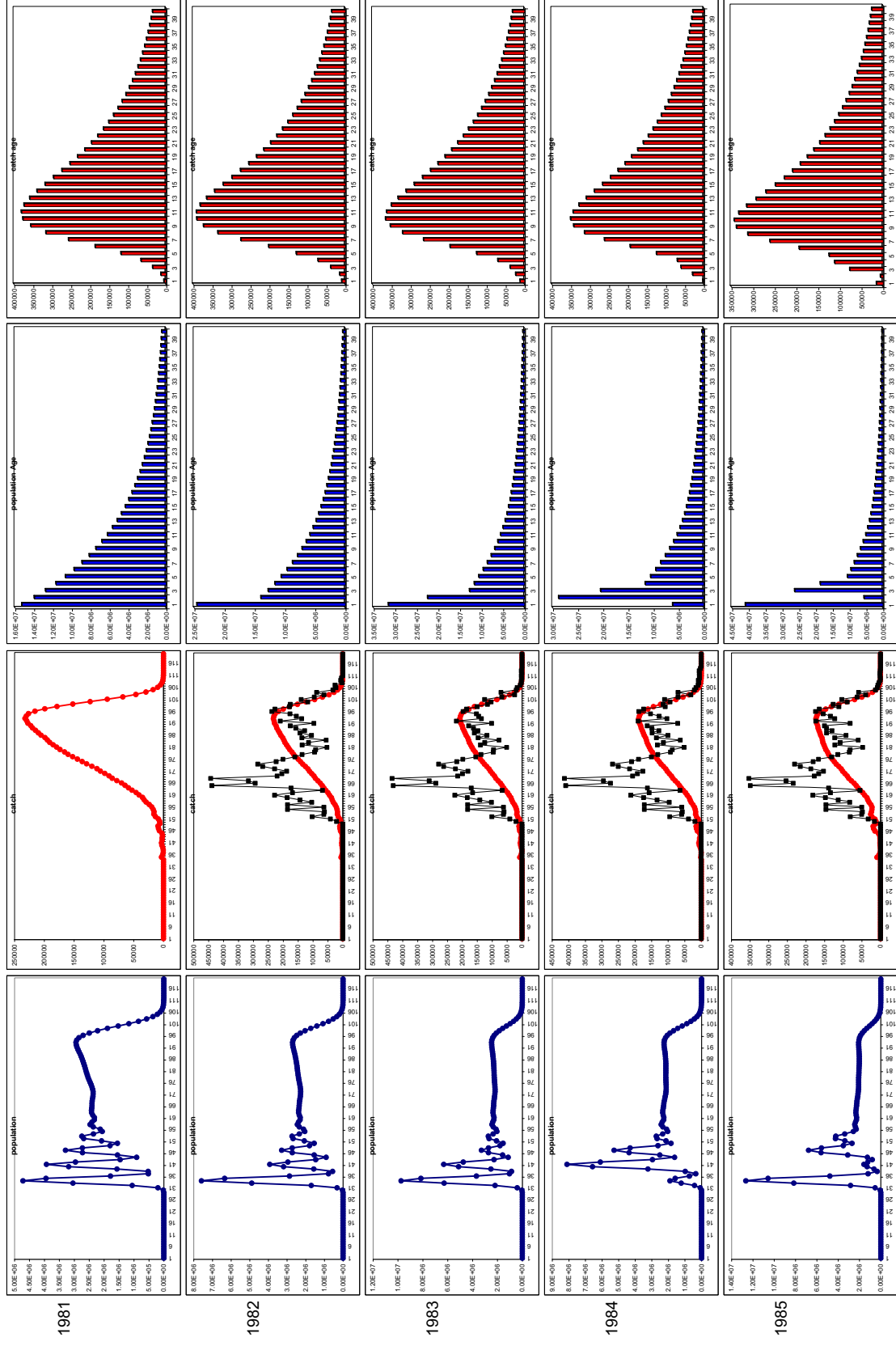
APPENDIX B3. Fig. 8. Female dogfish LTM run 8 population length frequency, observed (squares) and predicted (dots) catch length frequency, population age frequency and catch frequency from 1981-2005

Fig. 8. cont.

Fig. 8. cont.

Fig. 8. cont.

Fig. 8. cont.

2001

2002

2003

2004
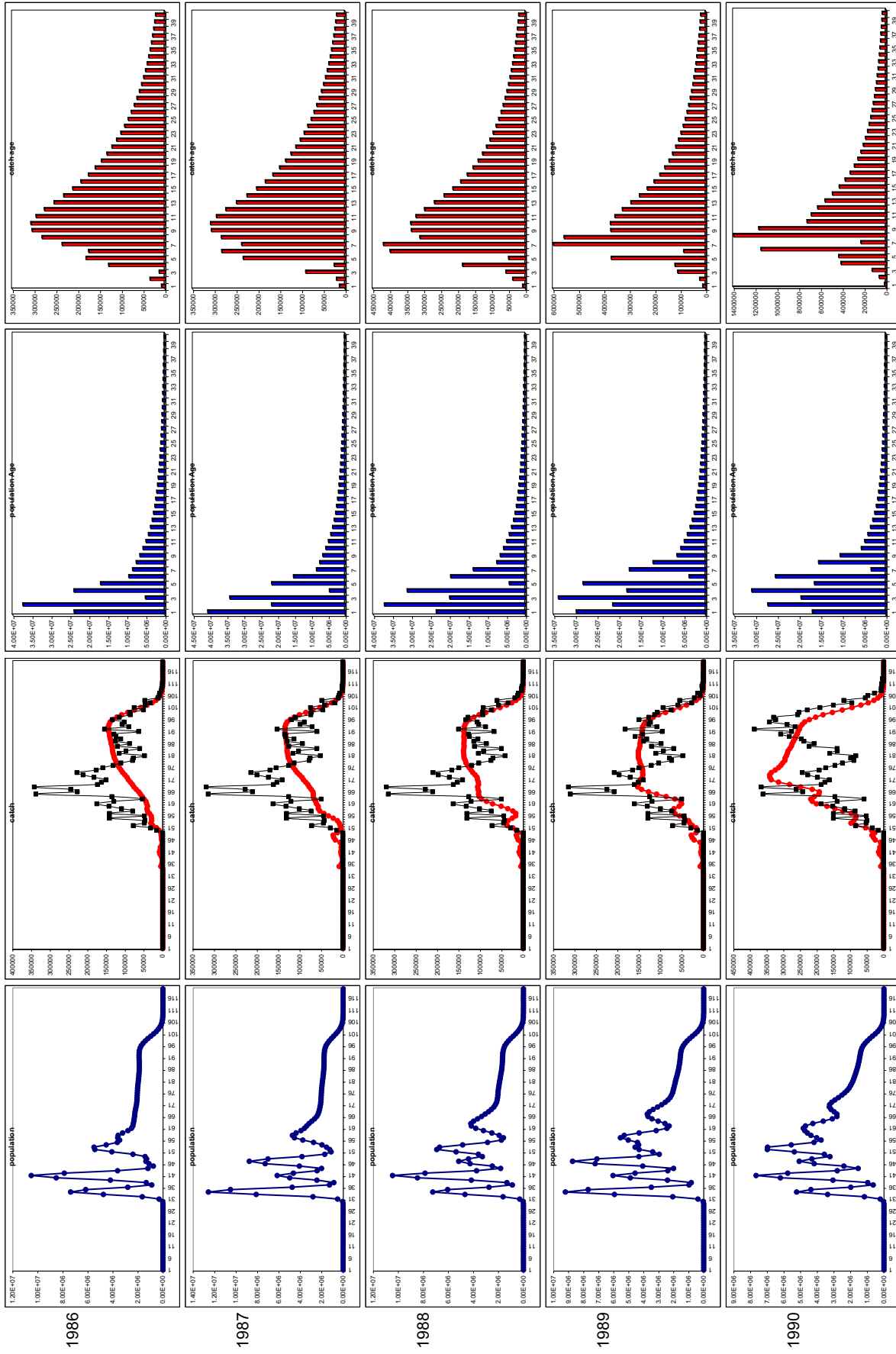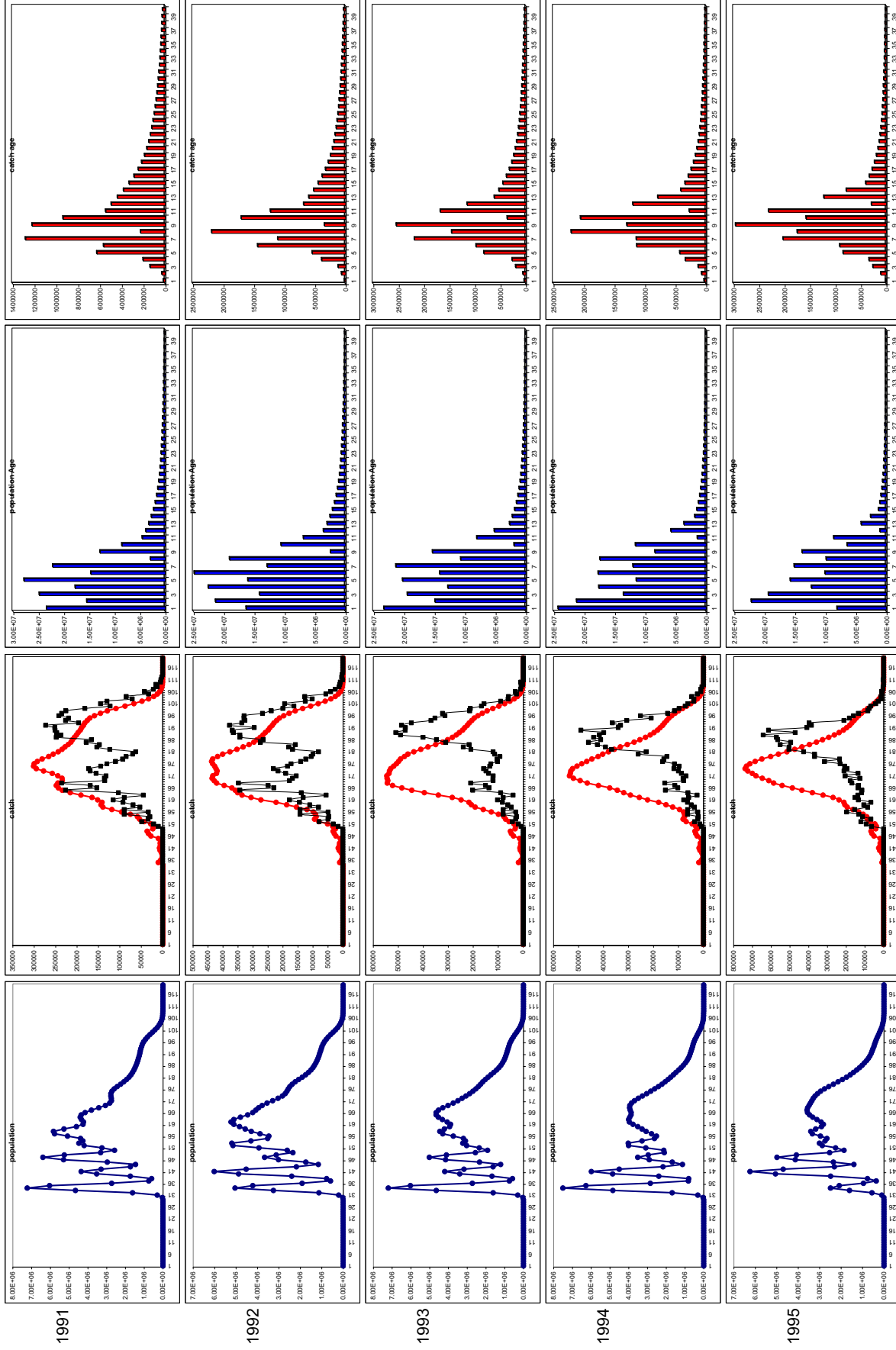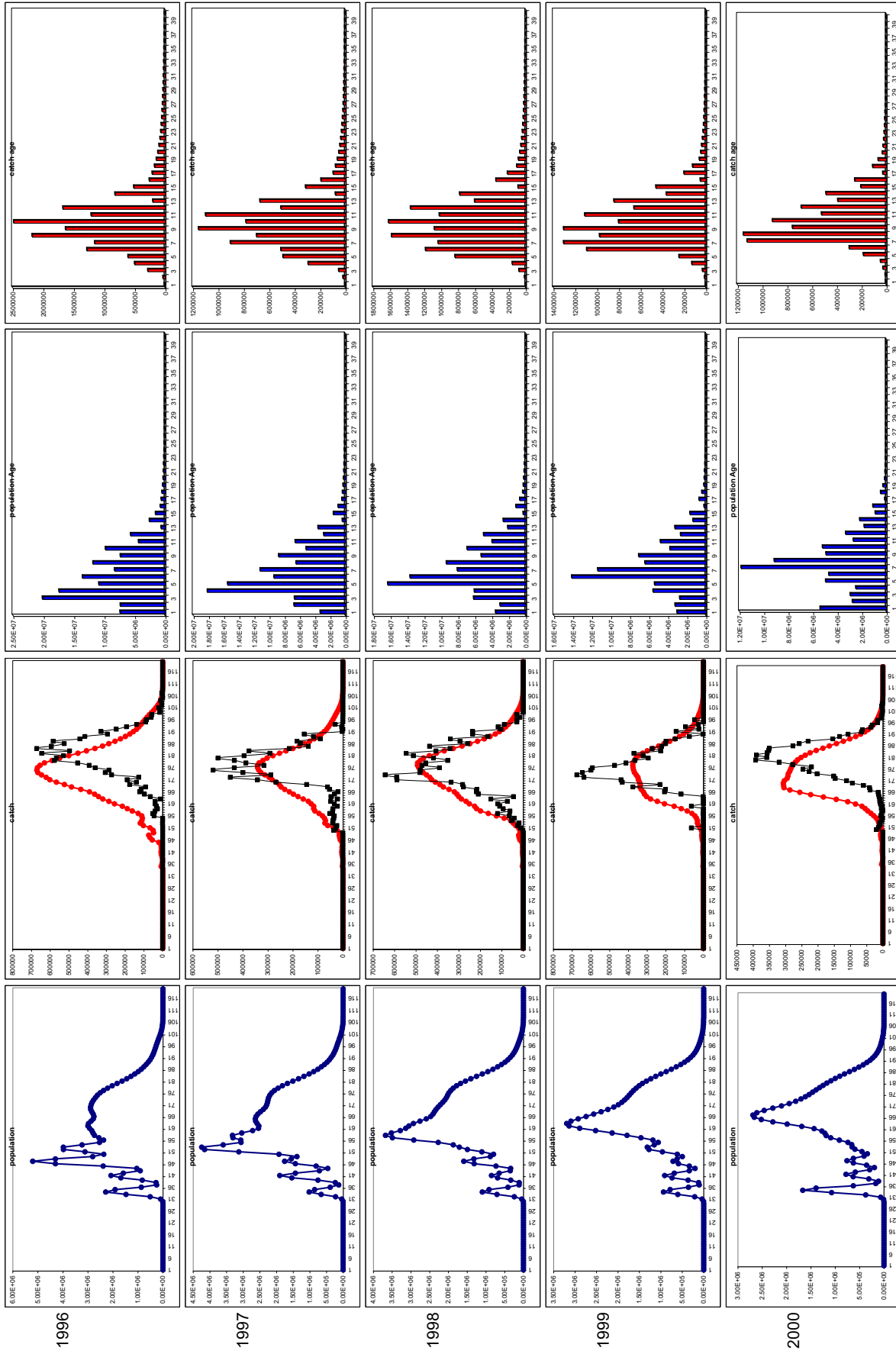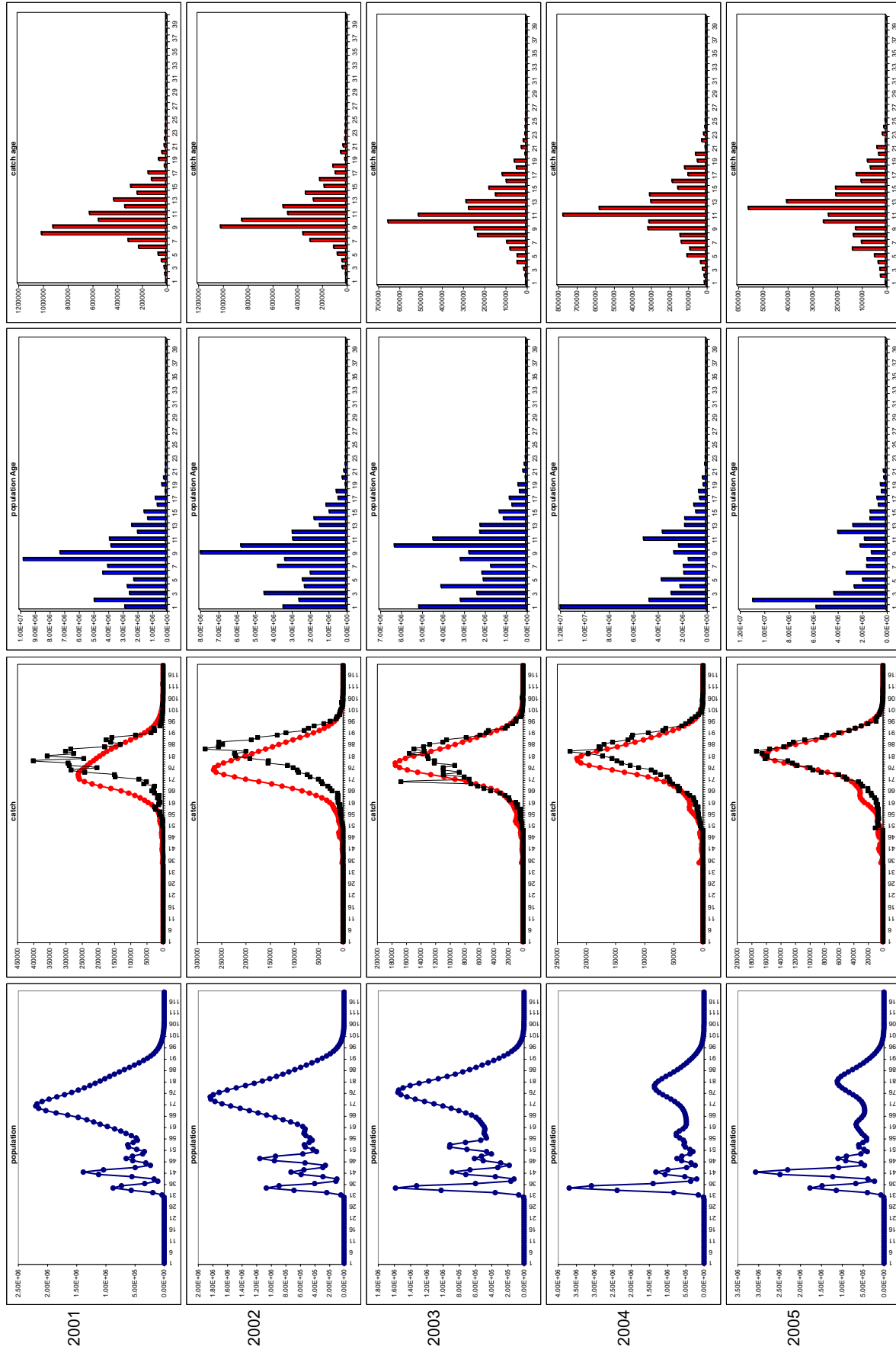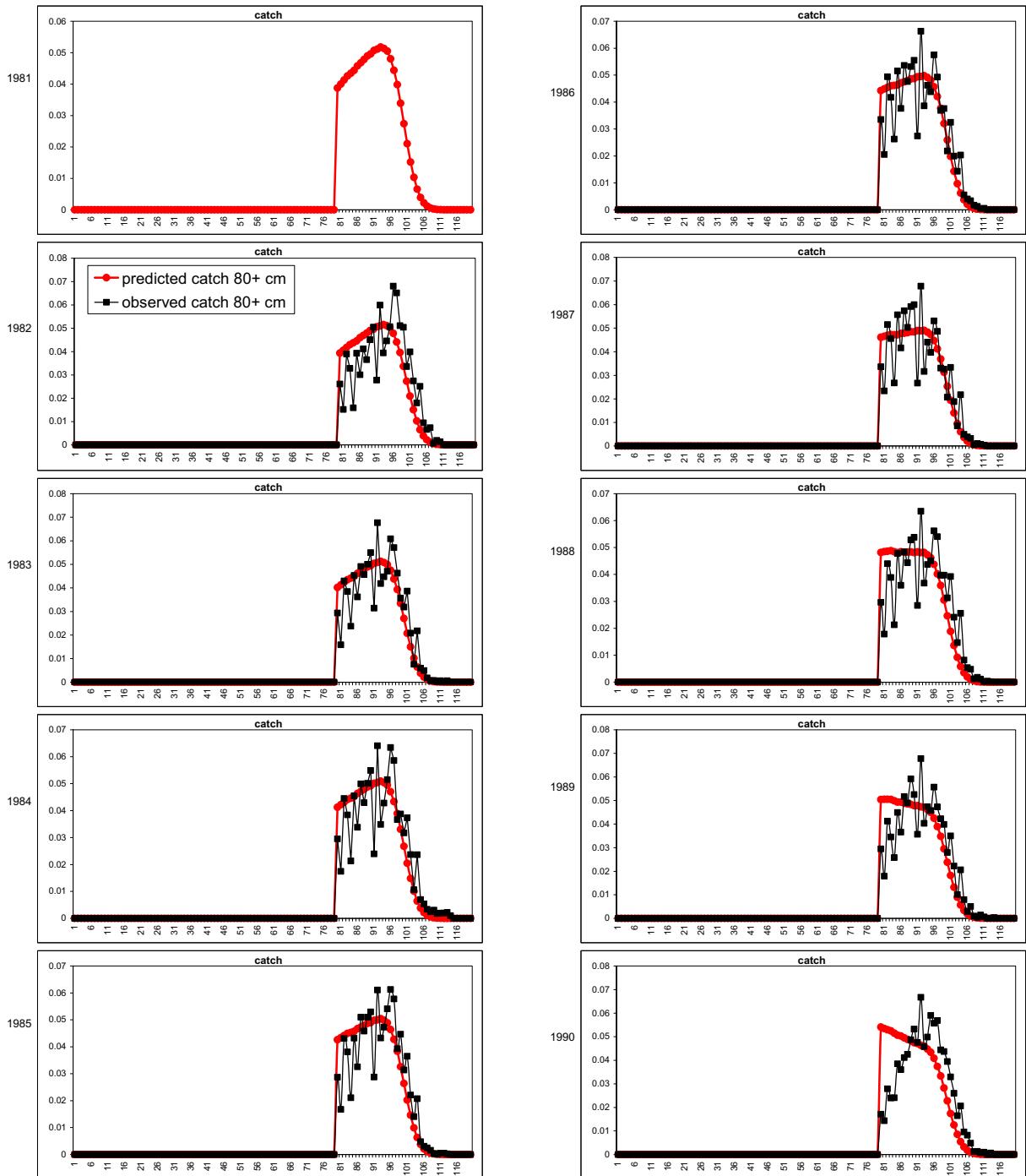
2005

APPENDIX B3. Fig. 9. Female dogfish LTM run 8 observed (squares) and predicted (dots) fitted catch length frequency for 80+ cm fish from 1981-2005.
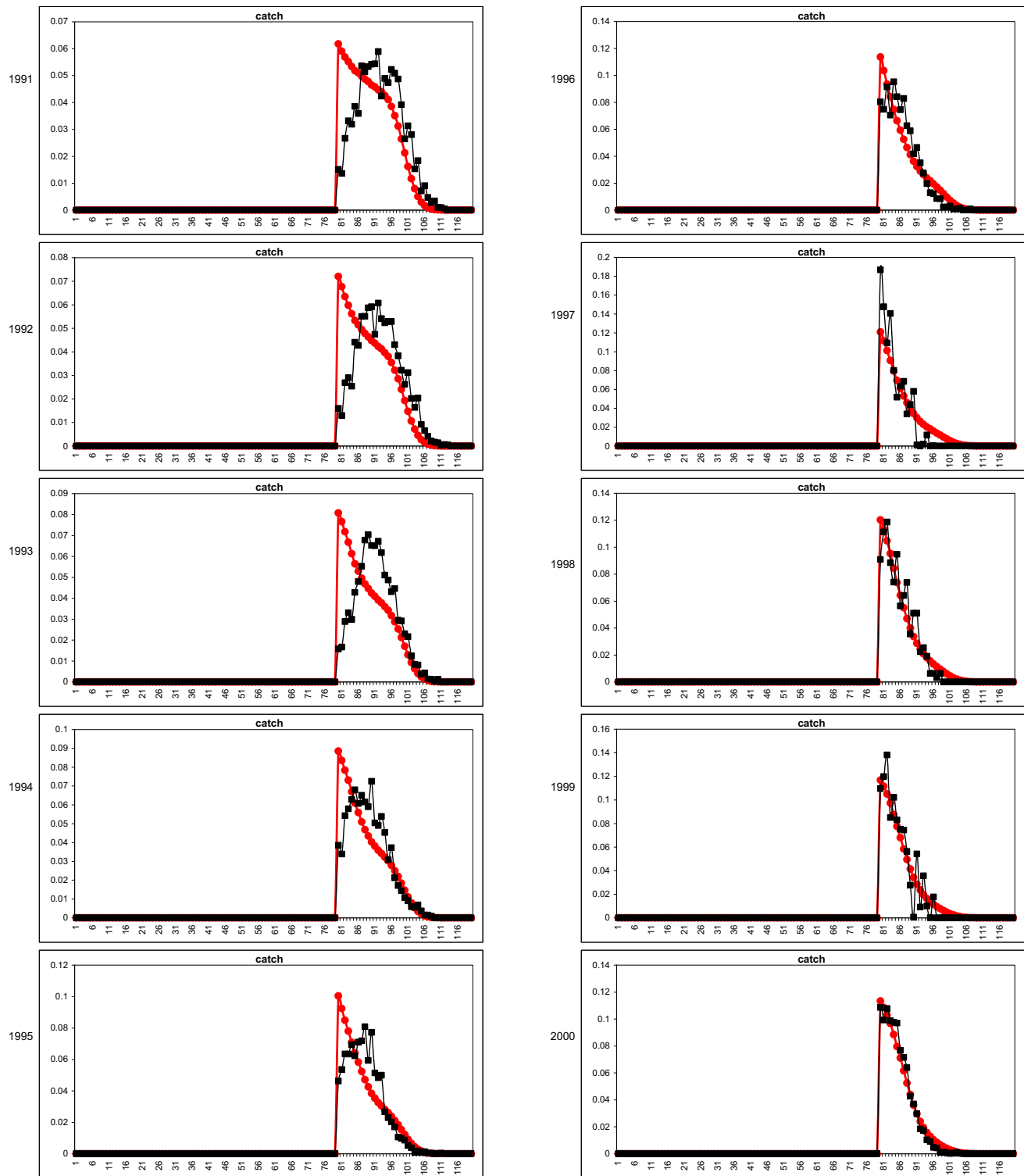
Fig. 9. cont

Fig. 9. cont.

LN scale

Not Logged
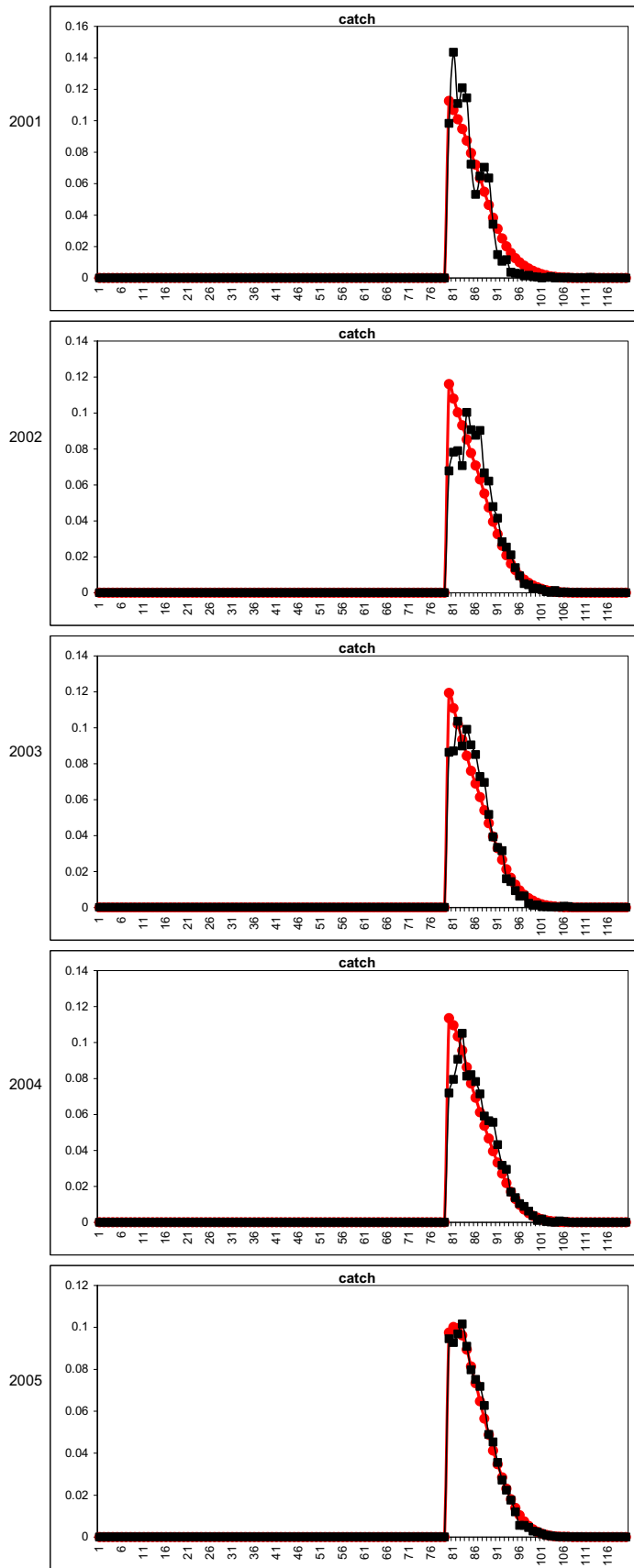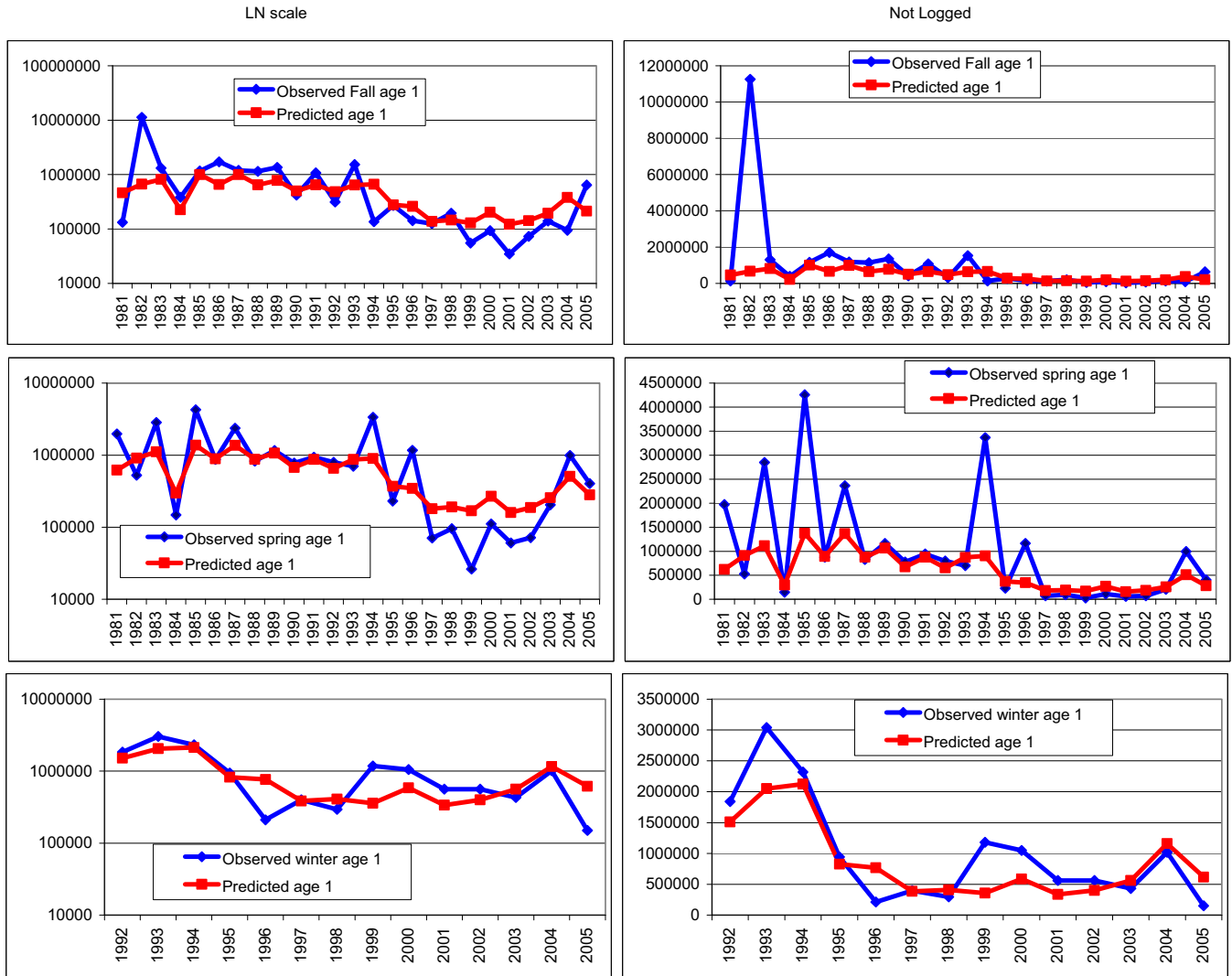
APPENDIX B3. Figure 10. Female dogfish run 8 ln and nominal observed and predicted age 1 recruitment indices for the Fall, Spring, and winter NEFSC surveys.
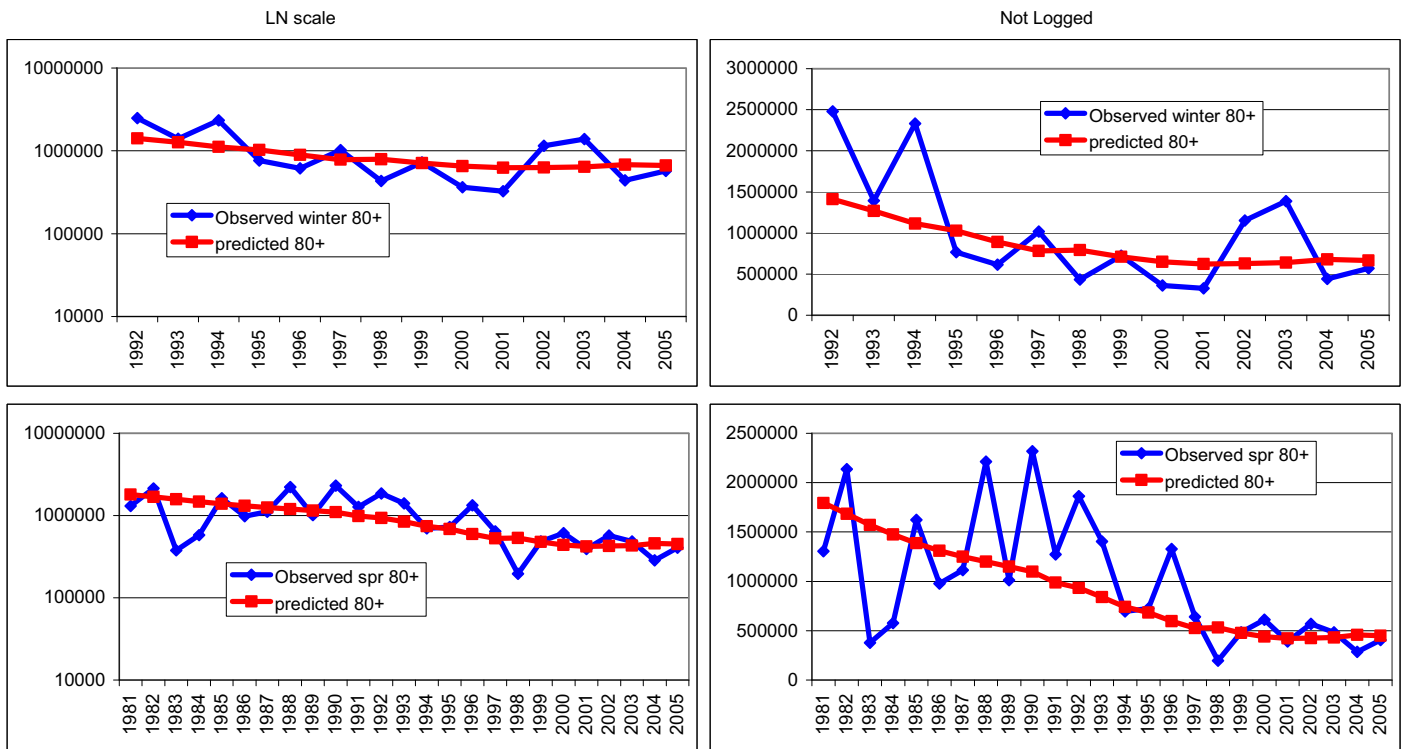
APPENDIX B3. Figure 11. Female dogfish run 8 ln and nominal observed and predicted 80+ cm number indices for the NEFSC winter and spring surveys.
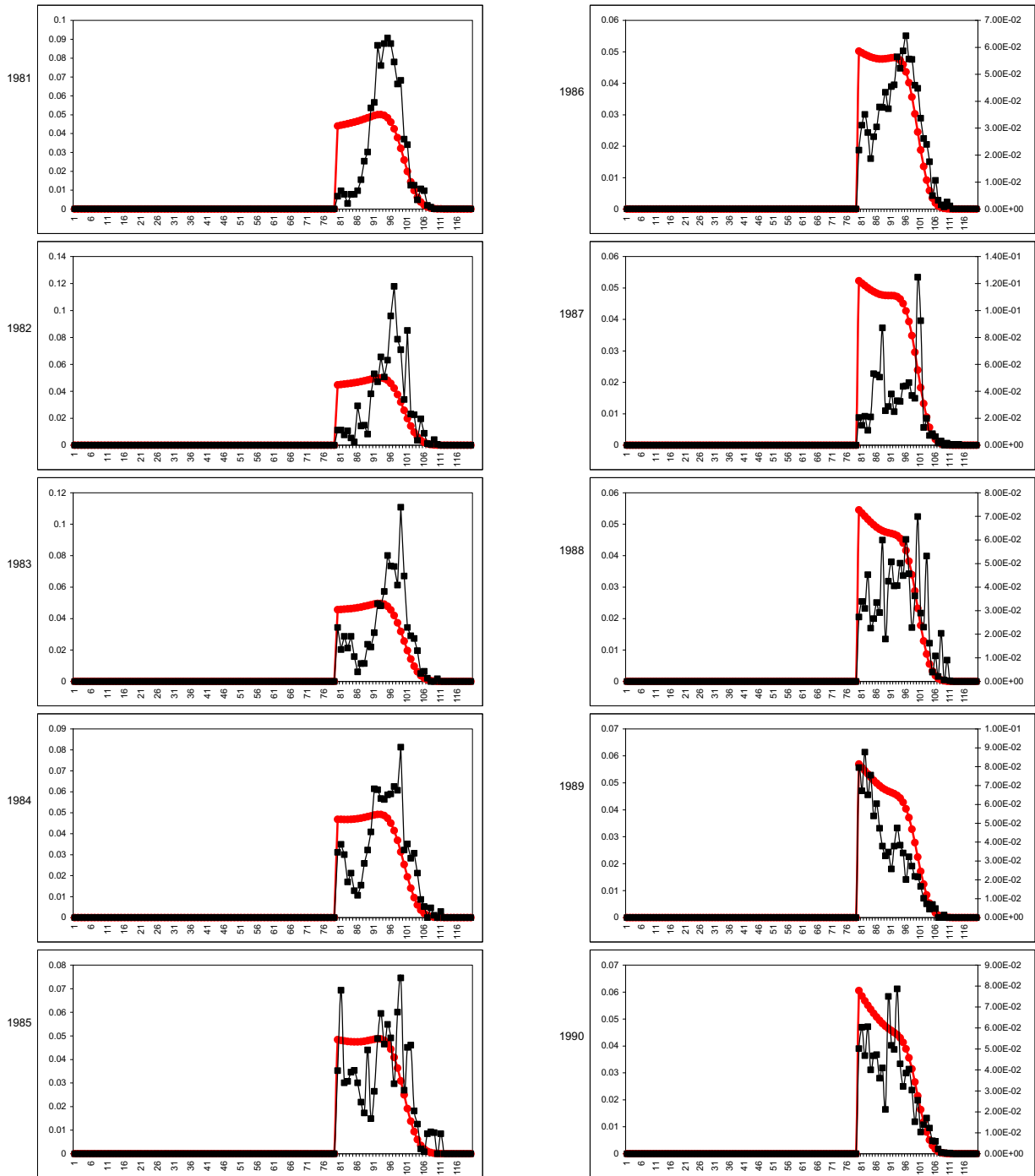
APPENDIX B3. Fig. 12. Female dogfish LTM run 8 observed (squares) and predicted (dots) fitted length frequency for 80+ cm fish for the NEFSC Spring survey from 1981-2005.
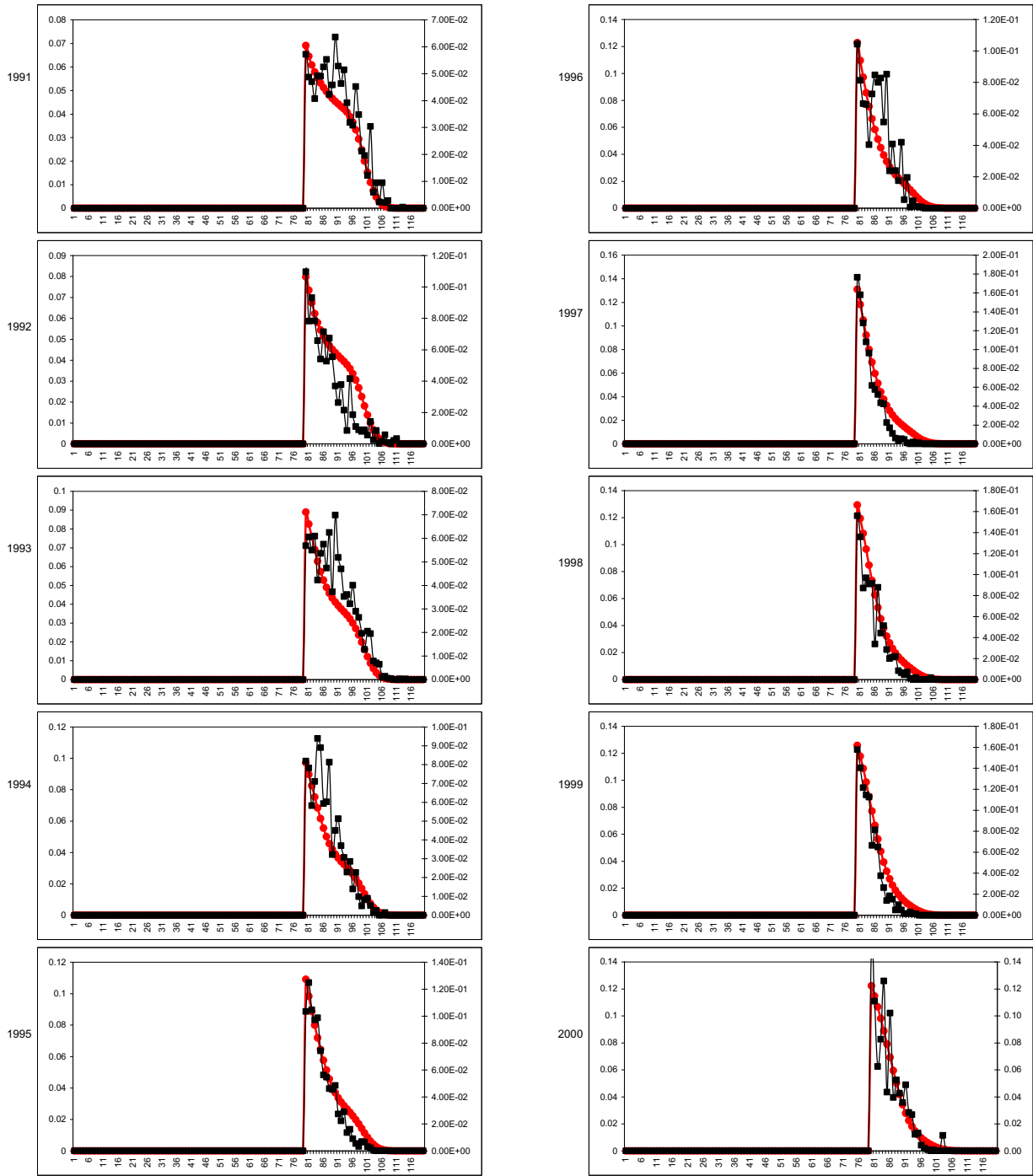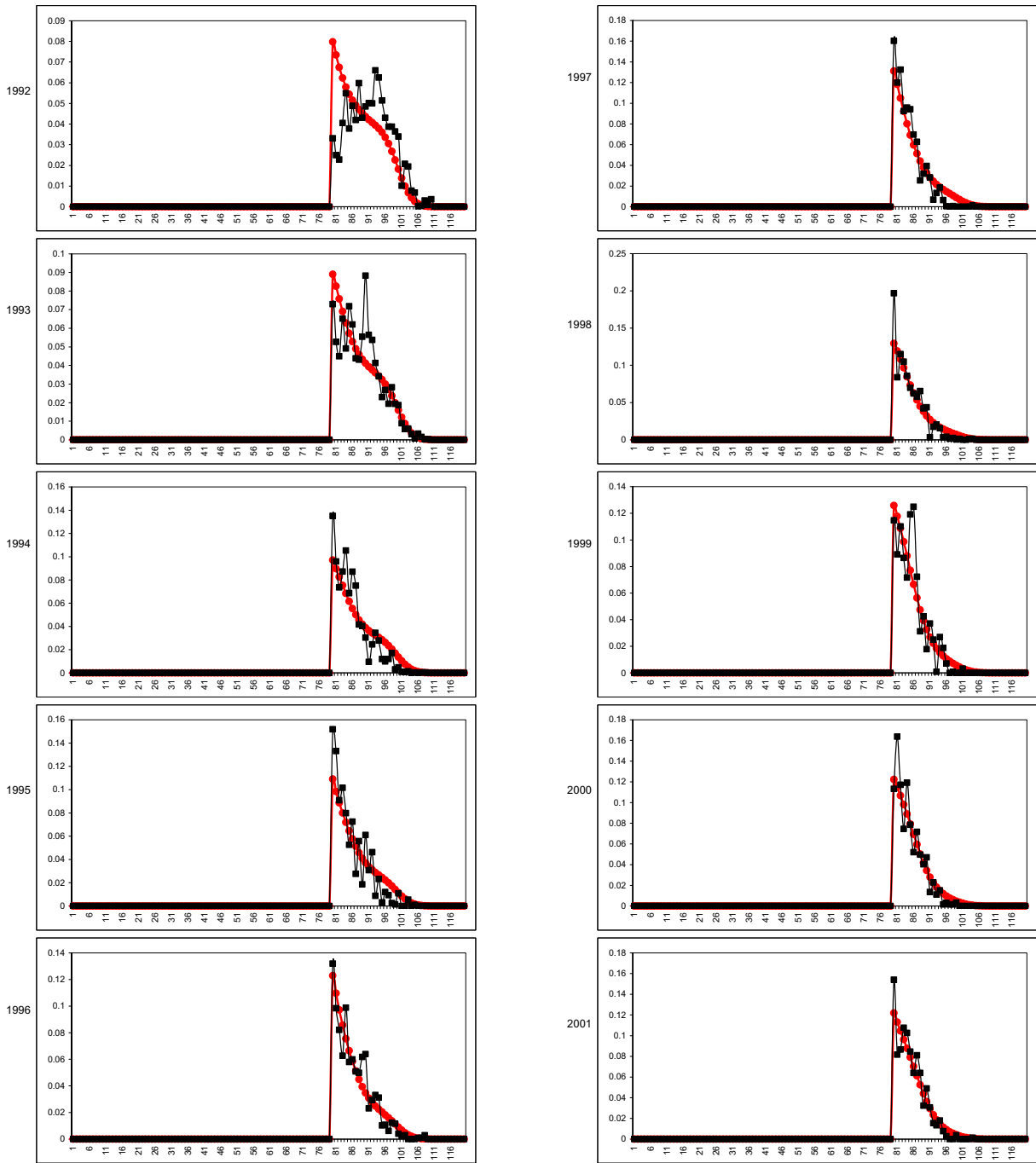
Fig. 12. cont.
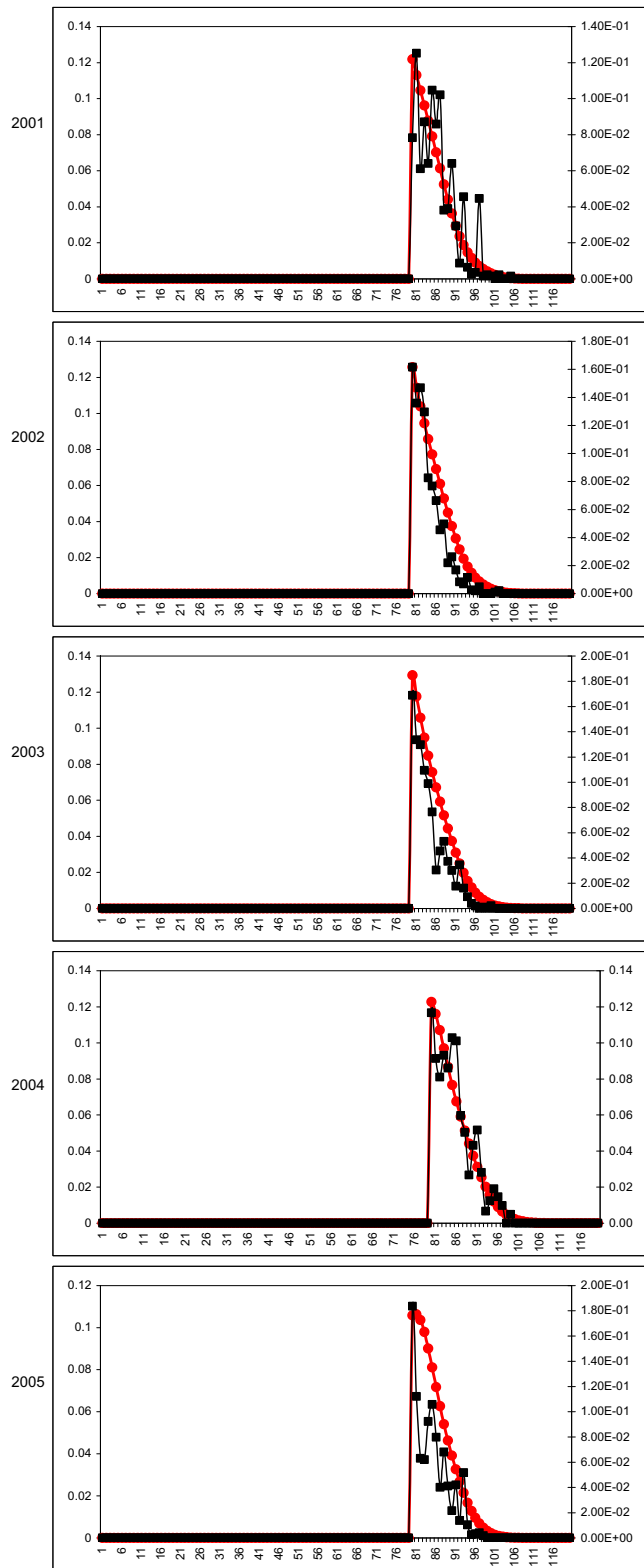
Fig. 12. cont.

APPENDIX B3. Fig. 13. Female dogfish LTM run 8 observed (squares) and predicted (dots) fitted length frequency for 80+ cm fish for the NEFSC Winter survey from 1992-2005.
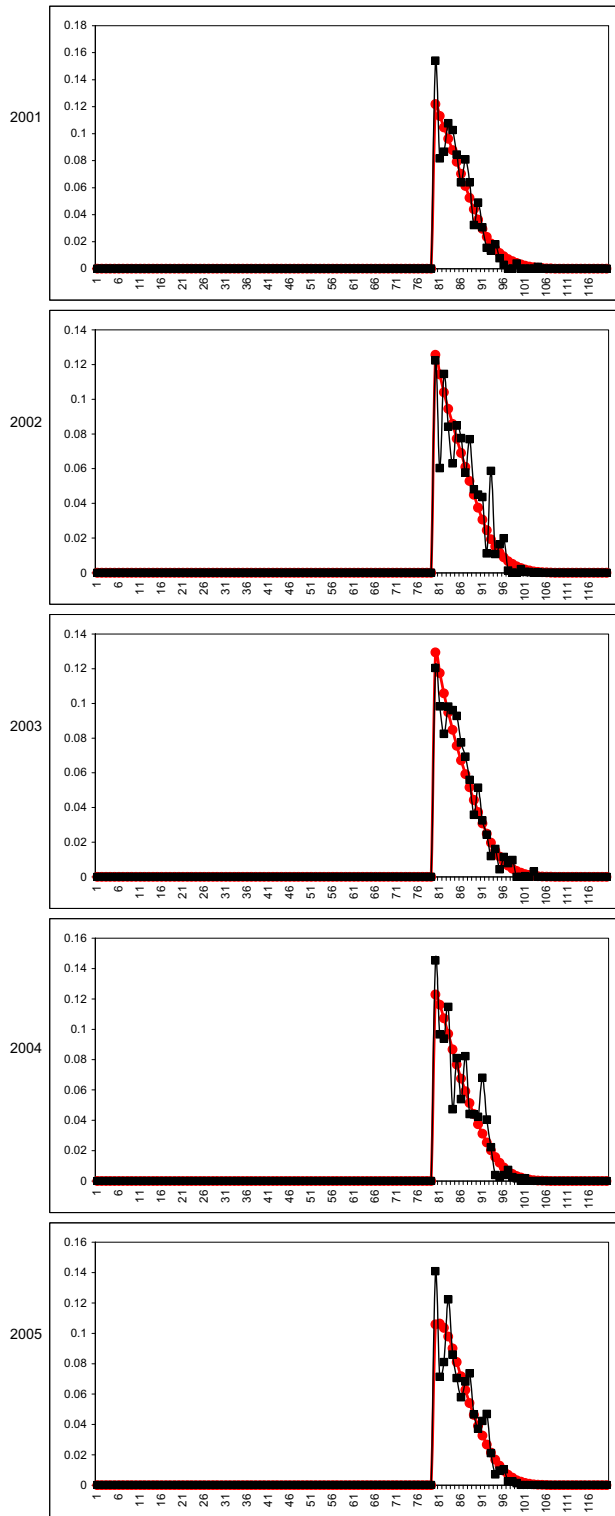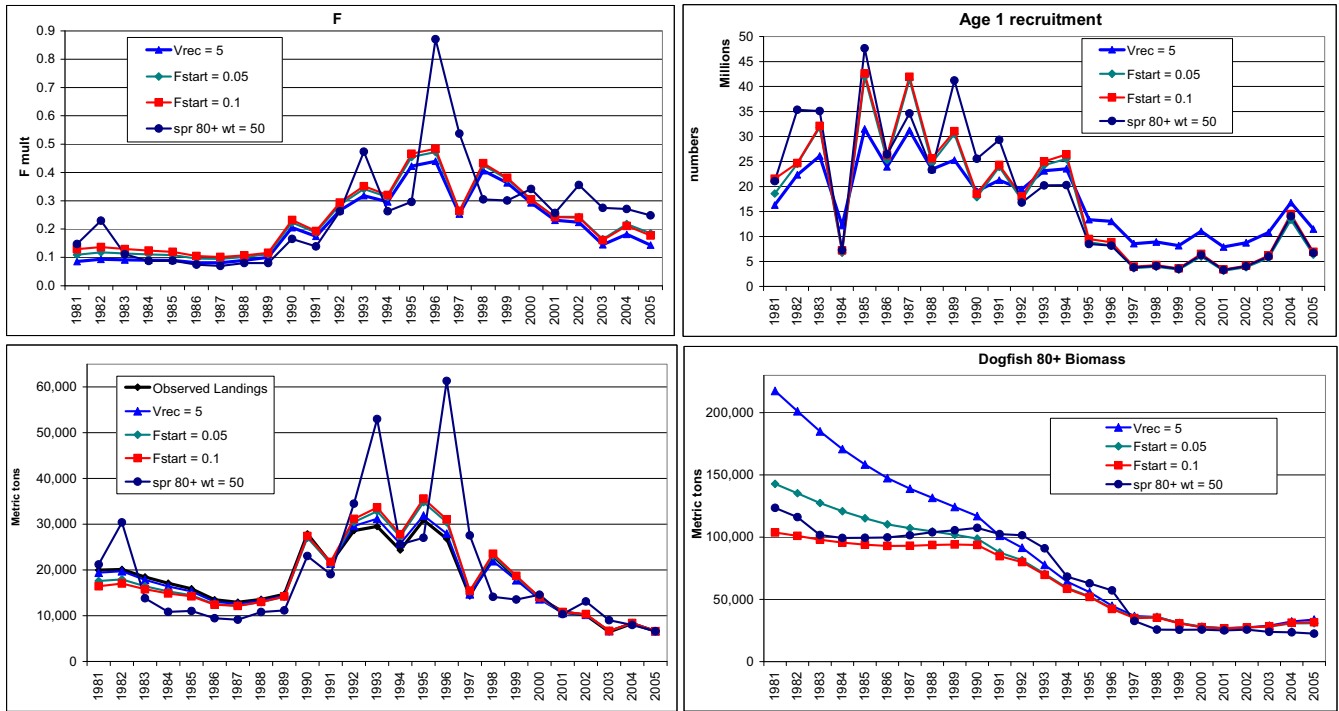
Fig. 13. cont.

APPENDIX B3. Fig. 14. Female dogfish LTM runs 9-12 with corrected catch including commercial discards and constant pr. Runs 9-12 compare the effects of Vrec = 5, a fixed Fstart at 0.05 and 0.1, and a higher weight (50) on the spring 80+ index.