Is Overfishing of Atlantic Menhaden Taking Place?

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Summary

The sensitivities examined in the recent update of the 2010 benchmark assessment of Atlantic menhaden are extended to include a case which combines estimable doming of the selectivities at age for both the reduction and bait fisheries, with a statistically defensible effective sample size for the catch-at-age term in the likelihood maximised in the fitting procedure for the Beaufort Assessment Model. The results are found to be preferred to the current Base case under the AIC model selection criterion, and indicate appreciably higher biomasses over recent years. F15% and F30% reference points are re-evaluated for both the Base case and this preferred sensitivity, with averaging of biological parameters over the past 10 years rather than the full period from 1955 to provide estimates more reflective of current conditions. The results indicate that in terms of the Base case, the fishing mortality F was below the F15% threshold for the first decade of the century, and furthermore that when selectivity doming is taken into account it was also below the F30% target level during this period.

1. Introduction

The Atlantic Menhaden stock is currently assessed using the Beaufort Assessment Model (BAM) which treats the two fisheries (reduction and bait) separately, each with its own selectivity function. Earlier in 2012 the benchmark assessment reported in Anon. (2010) was re-analysed using the routine update procedure to take account of new resource monitoring information which had become available in the interim to provide a (updated) Base case. In addition, several sensitivities (selected on the basis of their possible greater impact on results) were examined.

As recommended by the 2010 peer review panel, these sensitivities included consideration (though only separately in this instance, and not in combination) of:

a) reducing the sample sizes used for age data in the likelihood maximized when fitting the model to data to median effective sample sizes determined by equating the residual variances expected under the multinomial distribution assumed to that evident from fits to actual data; and

b) allowing a dome in selectivity to be estimated for each of the two fisheries instead of assuming both to be asymptotically flat at larger ages as is assumed for the Base case.

Sensitivity b) was found to increase estimates of spawning biomass substantially. However, the statistical significance of this result could not be assessed because of the overweighting of the age data through the use of actual rather than effective sample sizes in computing the likelihood. Here a) and b) are considered jointly so that the contribution of the age data to the likelihood are appropriately weighted, and consequently statistically based model selection criteria such as the Akaike Information Criterion (or AIC) may be used to select amongst alternative models so as to be able to draw the most reliable inferences about the status of the resource and fishery.

2. Methods

The BAM (Anon. 2010) was used for these analyses, implemented using the code and input files for the 2012 update assessment which were kindly provided by Amy Schueller. Three cases (model runs) are considered:

a) Case 1: The Base case as in the 2012 update of the 2010 benchmark assessment.
b) Case 2: The Base case but with the median effective sample size used for the contribution of the age data to the likelihood.
c) Case 3: Case 2 with the addition of allowance for dome shaped selectivity for both the reduction and the bait fisheries over the 1994-2011 period. This requires the estimation of 8 additional parameters compared to cases 1 and 2.

Fishing mortality reference points were then calculated from the results of these assessments using a spawning biomass per recruit approach as set out in equations A.1 to A.6 in the Appendix.

3. Results

Table 1 summarises the results from the three model runs in terms of the various contributions to the negative log likelihood – ln*L*. The important comparison is that between Case 3 and Case 2 which are equivalently formulated and so allow application of the AIC model selection criterion, where $AIC = -2\ln L_{TOTAL} + 2p$ with p being the number of estimable parameters. The first term is a measure of how well the model fits the data, while the second term is a penalty for the addition of further estimable parameters (Burnham and Anderson, 1998). Both these statistics are shown at the bottom of Table 1. Essentially in moving from Case 2 to Case 3, the –ln*L* value drops from 424 to 389 with the addition of 8 estimable parameters. Accordingly, the inclusion of these additional 8 parameters to quantify domed fishing selectivity vectors for the post-1994 period for the reduction and bait fisheries are clearly justified, with AIC decreasing by 54 points from 1227 for Case 2 to 1173 for Case 3.

This means that there is a clear and sound statistical justification for the introduction of domed selectivity for both fisheries, and for preferring this over the updated Base case when drawing inferences about the status of the resource and associated fishery. This can be seen from Fig. 1 which shows spawning biomass and recruitment time series for the Base case and Case 3 with the domed selectivities. Bands reflecting 95% confidence intervals can be computed for these trajectories from the Hessians for the model fits; those for spawning biomass for Case 3 with its domed selectivities are well above the corresponding Base case values from 1991 onwards. This reconfirms that once doming is taken into account, there is statistically strong evidence that the biomass over recent years has been well above the currently accepted estimates which have been provided by the (now updated) Base case.

Plots of the selectivity vectors for each fishery are shown in Fig. 2a for the Base case (flat selectivity at older ages throughout the assessment period) and Figure 2b for Case 3 (domed selectivity after 1994). Comparisons of these two model fits to the Juvenile Abundance Index (JAI) and pound net (PN) abundance indices, which are used as input for the likelihood maximisation, are shown in Fig. 3 with the corresponding residuals in Fig. 4. Evident in these plots is the poor fit to recent PN data which show an upward trend in contrast to the downward trend exhibited by the model. The smaller residuals since about 1980 for the JAI for Case 3 in comparison to those for the Base case is again evidence of the better fit to the data which is achieved with the introduction of doming.

Evidence for the doming is not only statistical. It is reflection of emigration of the older menhaden to areas outside (primarily to the north of) the customary fishing grounds. The presence of an appreciable abundance of menhaden in this area was recently confirmed through aerial surveys (Sulikowski *et al*., 2012).

Fig. 5 shows fully selected fishing mortality trajectories for the Base case and for Case 3 with its doming, which results in decreased fishing mortality estimates, while Fig. 6 shows how the F30% fishing mortality reference point (often used as a proxy for F_{MSY}) are calculated using the approach detailed in the Appendix.

Fig. 7 compares the time series of F values for the fishery with the values of F30% and F15% reference points determined in this way for first the Base case and then for Case 3. What is noteworthy is that under the Base case, the F values were below the overfishing threshold reference point, F15%, during the first decade of the 2000s, although F was above the target reference point of F30%. This contrasts with the results of Case 3, which finds F at or below the F30% target level. (For 2010 and 2011 the assessment results for Case 3 reflect F values above even the F15% reference point; note however that the assessment model is is such that the most recent estimates of F are poorly determined, and further that their values depend on the somewhat arbitrary choice made for a shrinkage factor used in the estimation of recent recruitment.)

Table 2 shows the results for the values of F15% and F30% calculated in different ways: averages of natural mortality, selectivity and mass taken from 1955 rather than over the last 10 years only, and with fecundity replacing spawning biomass as the measure of reproductive potential. Values of F15% and F30% are appreciably lower under both of these alternatives for the Base case. In our view the last 10 years is a more appropriate choice for the period over which to average, as reference points should relate to a period more likely to reflect the present. This is the reason for our finding that F during the first decade of the century was below F15% for the Base case differs from the reported update assessment findings. Furthermore under the domed selectivity Case 3 situation, the reference point estimates are fairly insensitive to either the averaging period or whether spawning biomass or fecundity is chosen to reflect reproductive potential.

4. Conclusions

This paper has first shown that an assessment of Atlantic menhaden which admits the possibility of domed selectivities at age is statistically superior to the currently accepted Base case, which assumes these to be flat at larger ages, and also indicates higher biomasses than for the Base case.

Secondly, given such doming, this model provides evidence that overfishing did not take place during the first decade of the 2000's, when fishing mortality is estimated to have been less than the target F30% level..

The current assessment model assumes dome-shaped selectivity only from 1994, but it seems unrealistic to assume that selectivity was flat at large ages and that migration beyond the region fished commenced only from 1994. A clear priority is to investigate the implications of some selectivity doming in the years prior to 1994; information regarding possible changes in past fishery operations would be desirable to inform such an exercise.

Acknowledgements

We would like to Amy Schueller who kindly assisted in providing the code and data sets used in the 2012 routine update of the Menhaden assessment.

References

Anon. 2010. Stock Assessment Report No. 10-02 of the Atlantic States Marine Fisheries Commission. May 2010.

Burnham, K.P. and D.R. Anderson. 1998. Model selection and inference – A practical information-theoretic approach. Springer-Verlag, New York. 355pp.

Sulikowski, J, Morgan, A, Carlson, A and D.S. Butterworth. 2012. Inferences from aerial surveys on the abundance of Atlantic menhaden from outside the normal fishery range: Implication for improved management of the resource. Document presented at the ASFMC Menhaden Technical Committee meeting, June 2012.

	Case 1: Base case Asymptotically flat S for both fisheries	**Case 2:** Asymptotically flat S for both fisheries Small effective age sample size	**Case 3:** Domed S after 1994 for both fisheries and small effective age sample size
JAI_index	245.324	153.392	130.354
PN_index	19.461	19.453	20.346
reduction_agec	2035.360	169.123	166.629
L_reduction	11.320	1.259	0.808
bait_agec	125.570	66.581	56.992
L_bait	1.936	0.130	0.080
R_dev	17.647	14.113	13.833
R_dev_end	0.834	0.254	0.249
$-\ln L_{TOTAL}$	2457.460	424.304	389.291
p=no of pars estimated	189	189	197
AIC	5292.920	1226.608	1172.582

Table 1: Negative log likelihood contributions for the Base case and two sensitivities considered.

	Spawning biomass per recruit		**Fecundity per recruit**	
	Average over last 10 years (see Appendix)	Average over all years	Average over last 10 years	Average all years
Base Case:	**F15%=1.96** **F30%=0.87**	F15%=1.56 F30%=0.72	F15%=1.69 F30%=0.75	F15%=1.34 F30%=0.62
Case 3:	**F15%=1.17** **F30%=0.67**	F15%=1.11 F30%=0.65	F15%=1.09 F30%=0.64	F15%=1.05 F30%=0.62

Table 2: F15% and F30% fishing mortality reference points based on spawning biomass per recruit and fecundity per recruit calculations when averaging over the most recent 10years (left hand columns) or all years from 1955 (right-hand columns) to obtain the mortality, selectivity and weight at age vectors used in the per recruit analyses. The values advocated and plotted in Fig. 7 are shown in bold.

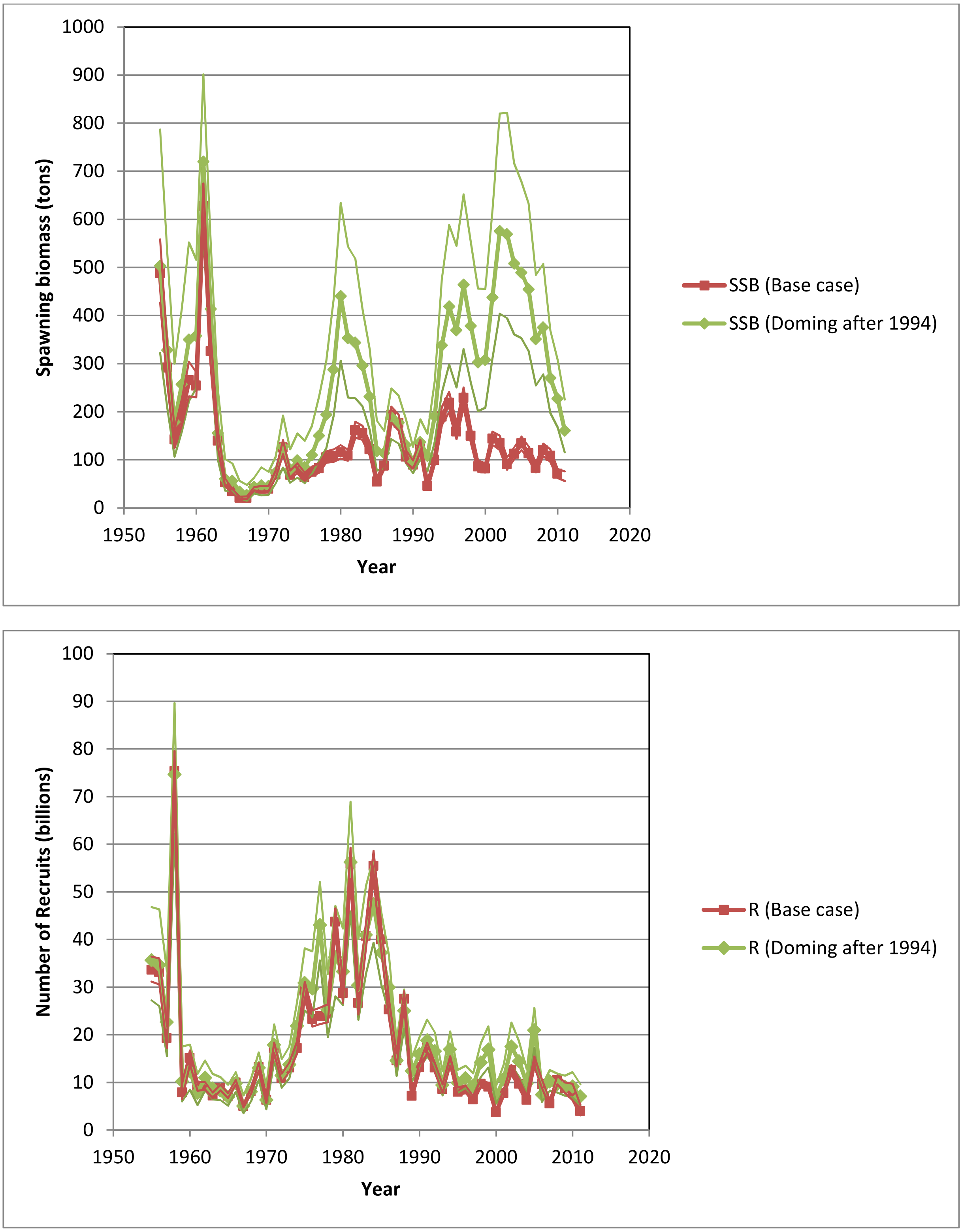


Figure 1: Annual spawning biomass (top) and recruitment estimates (bottom) with associated 95% confidence intervals for the Base case (red) and domed selectivity case 3 (green).

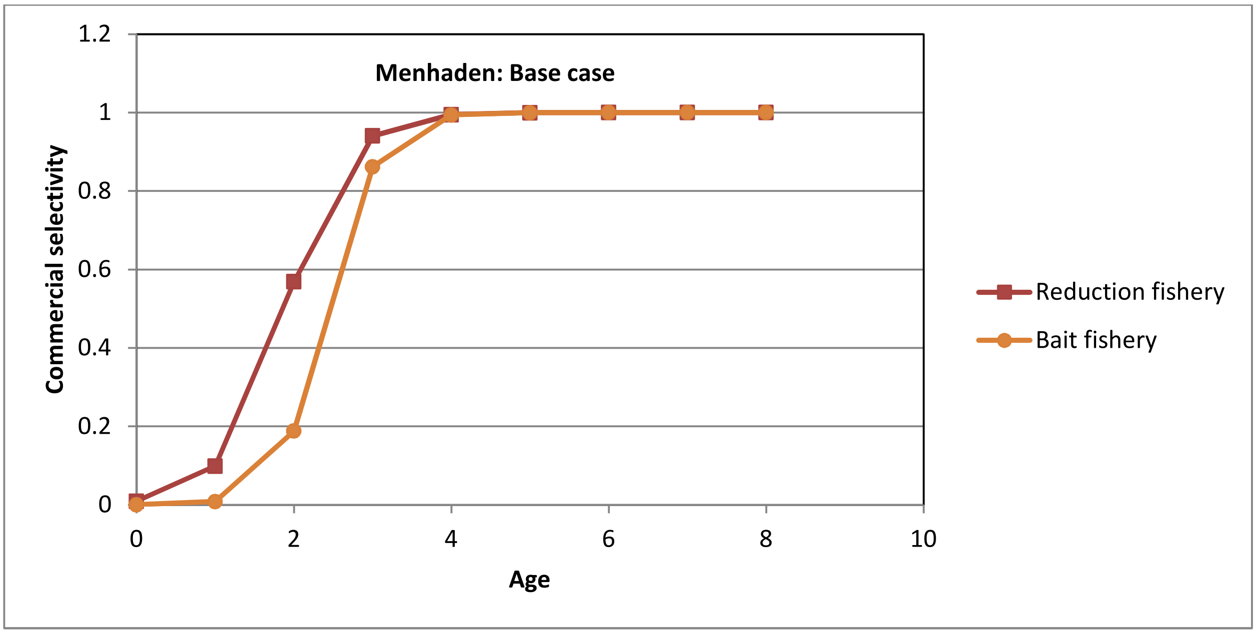


Figure 2a: Selectivity vectors estimated for the reduction and bait fisheries for the Base case.

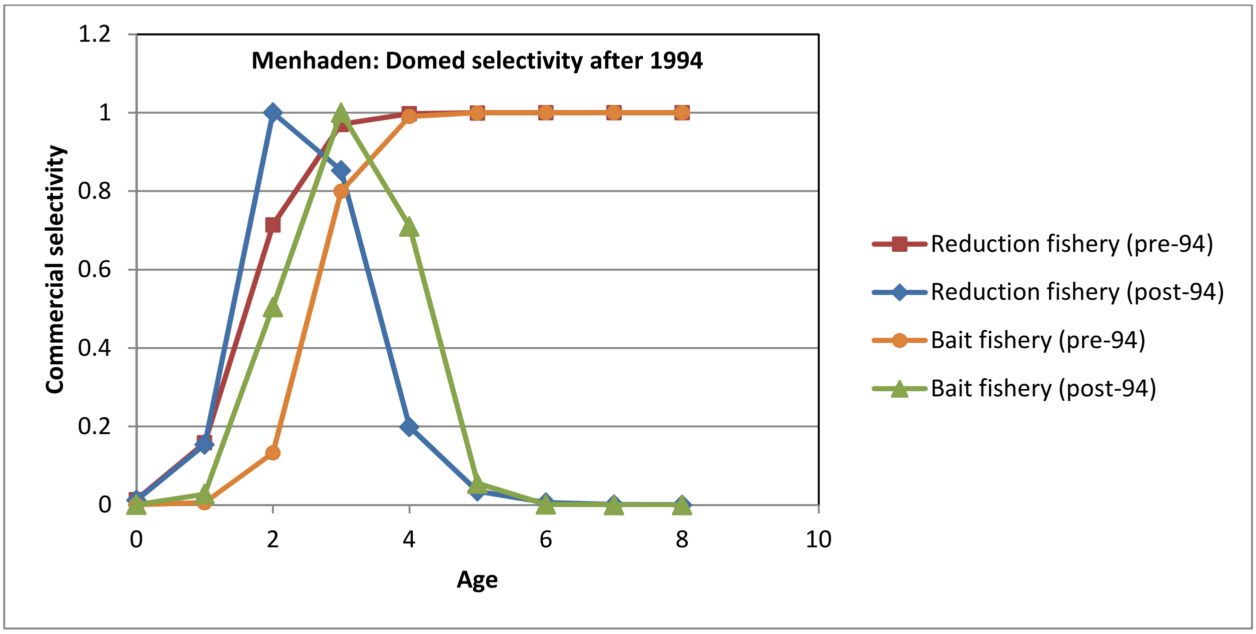
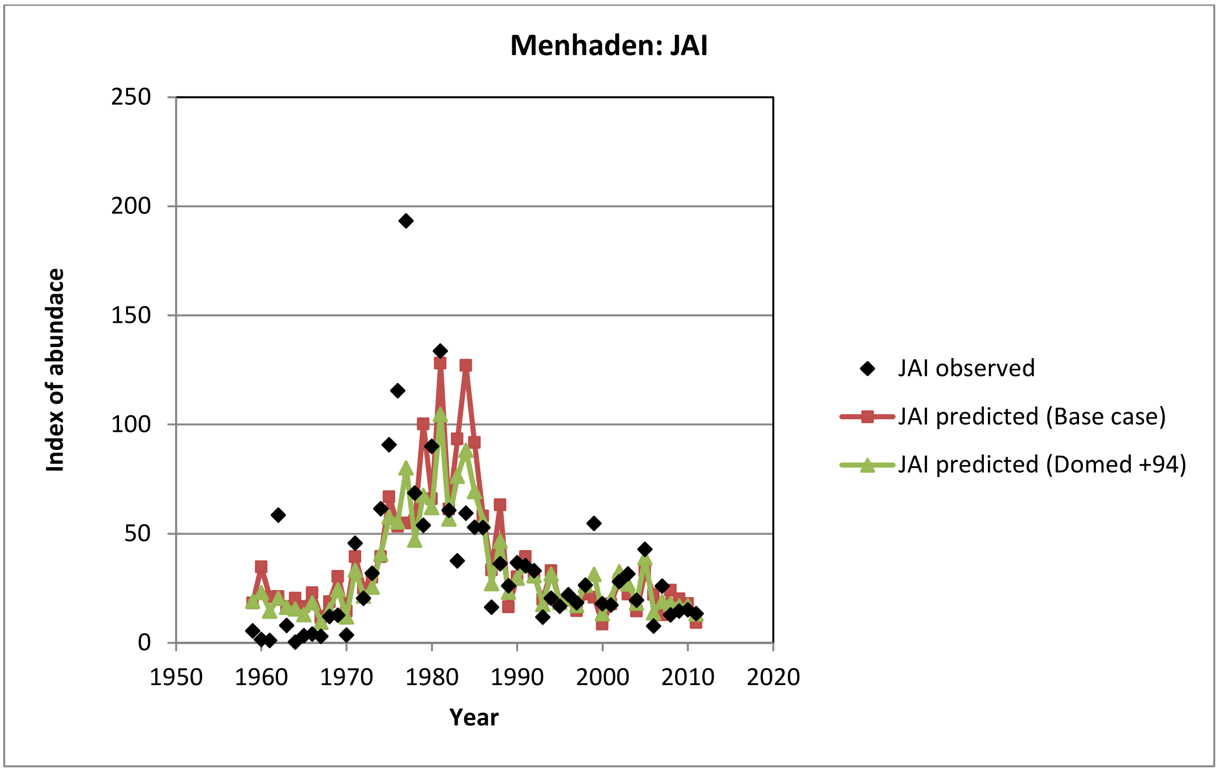


Figure 2b: Pre and post-1994 selectivity vectors estimated for the reduction and bait fisheries when allowing for decreasing selectivity at older ages in the latter period together with a small effective sample size for the age data in the likelihood.



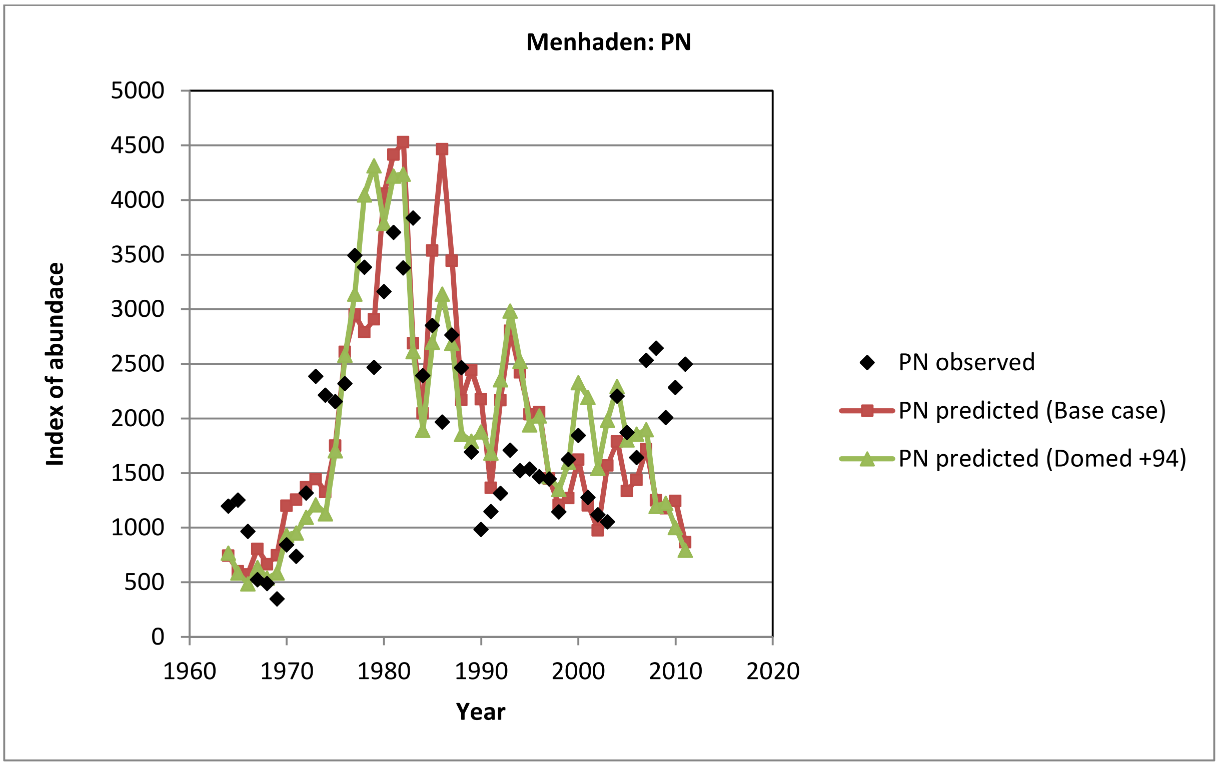


Figure 3: Observed (black diamonds) and predicted JAI (top) and PN estimates (bottom) for the Base case (red) and domed selectivity case 3 (green).

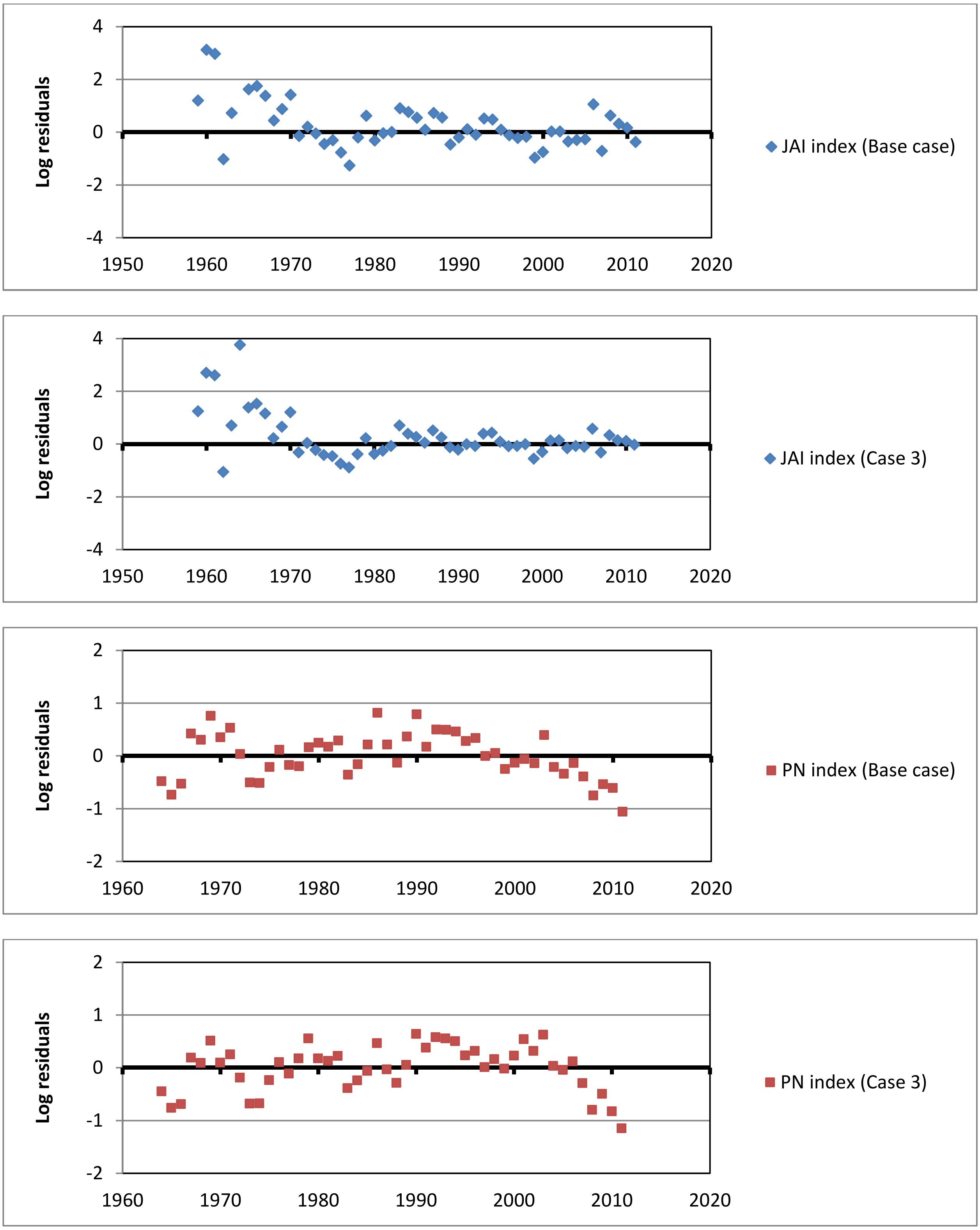
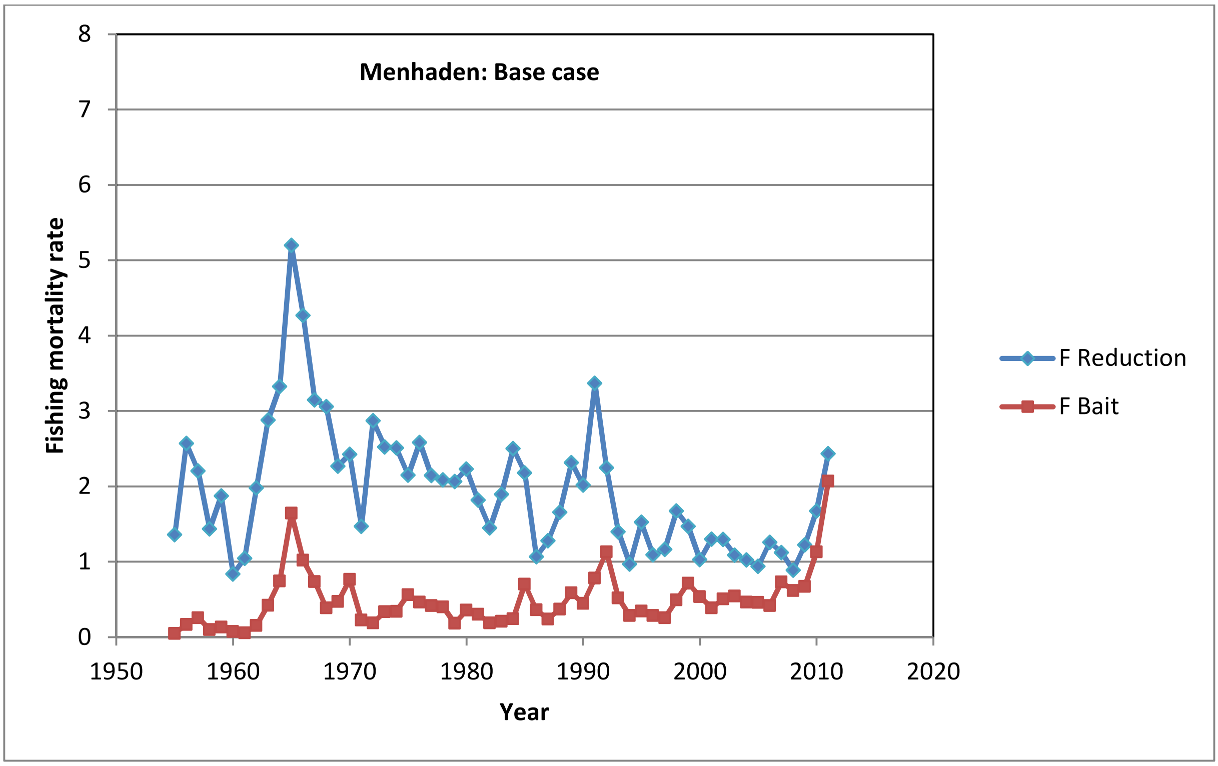


Figure 4: Residuals of the model fit to the JAI (top) and PN (bottom) indices of abundance for the Base case and domed selectivity after 1994 (case 3).



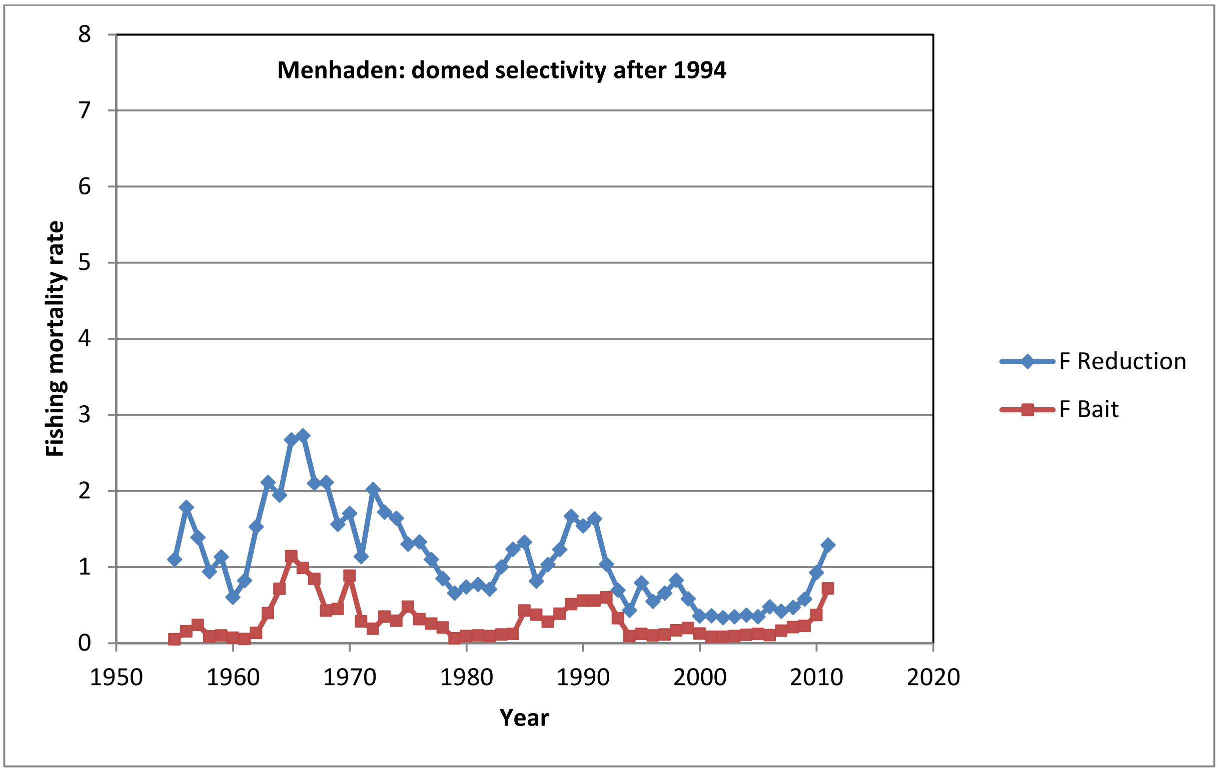


Figure 5: Fishing mortality rates for the reduction and bait fisheries for the Base case (top) and domed selectivity case (bottom).

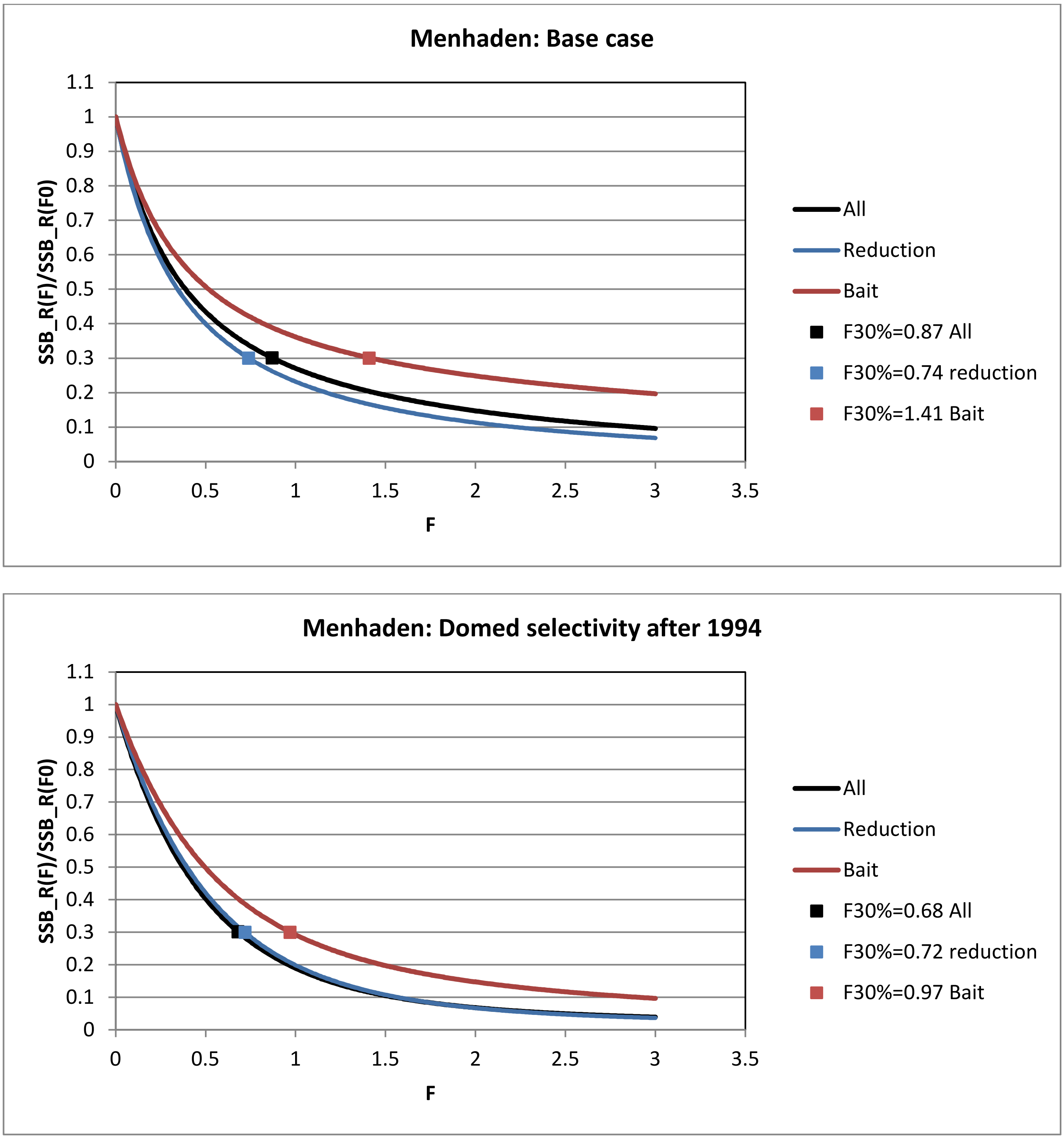
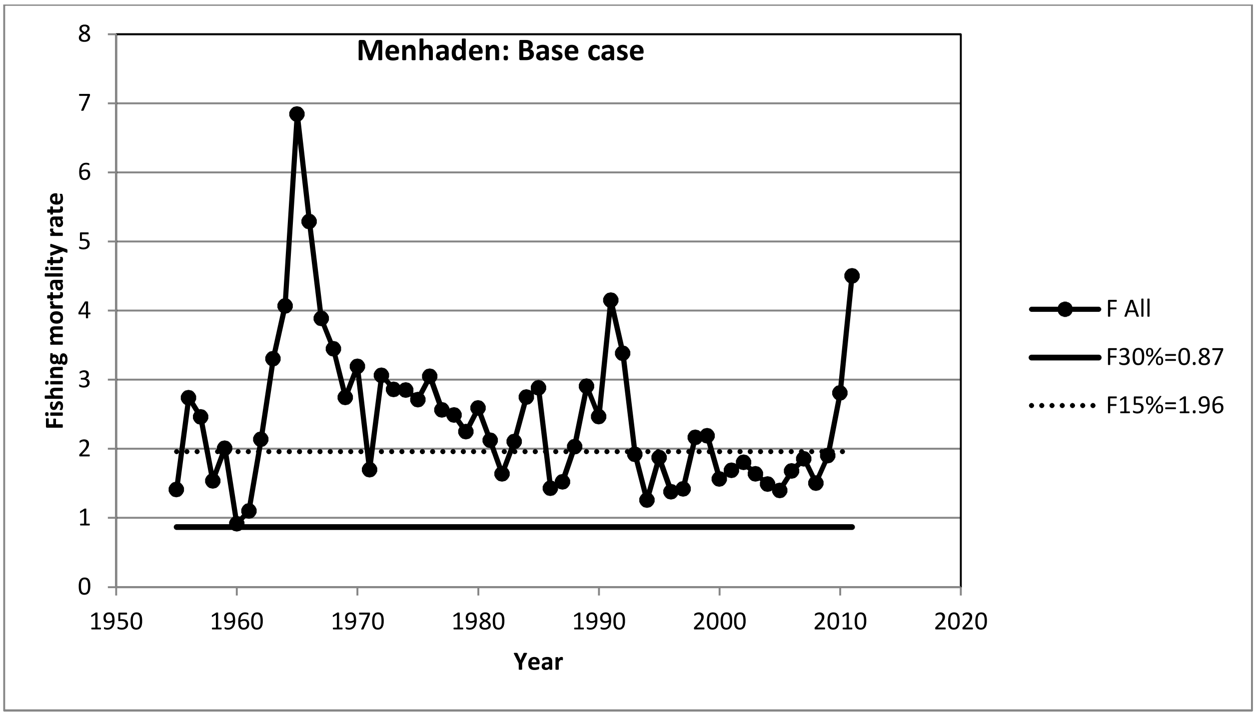


Figure 6: Spawning biomass per recruit plots for the reduction, bait and combined fisheries for the Base case (top) and when allowing for domed selectivity after 1994 (see equations A.1 to A.3).



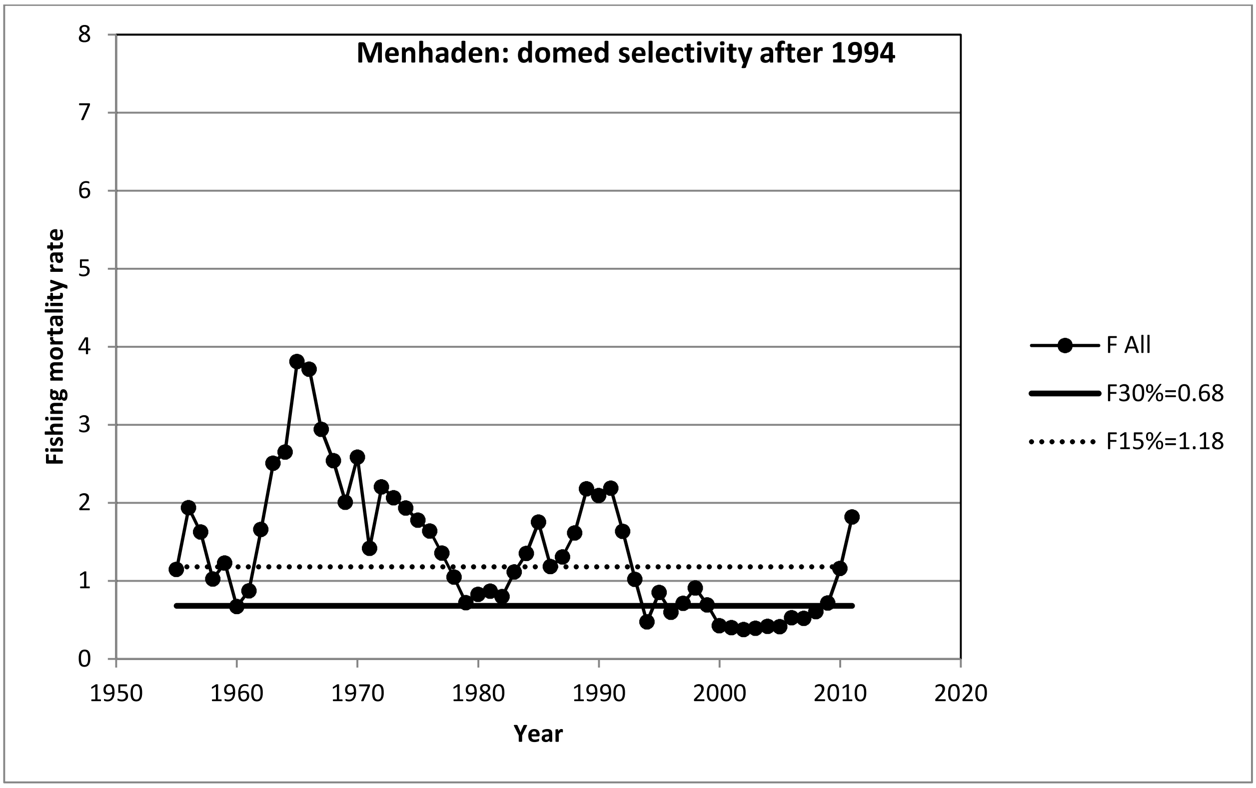


Figure 7: Annual (fully selected) fishing mortality rates for the combined fisheries for the Base case (top) and domed selectivity case (bottom).

Appendix

Spawning biomass per recruit calculations

Let $(N/R)_a$ denote the numbers per recruit at age a such that

$$(N/R)_{a=0} = 1 \quad \text{(A.1)}$$

$$(N/R)_a = (N/R)_{a-1} \exp(-M_{a-1}^{ave} - S_{f,a-1}^{ave} F) \quad \text{(A.2)}$$

where

$M_a^{ave} = 1/10 \sum_{y=2002}^{2011} M_{a,y}$ are the average natural mortality rates for each age over the last 10 years of the assessment period (see Table A.1),

$S_{f,a}^{ave} = 1/10 \sum_{y=2002}^{2011} S_{f,a,y}$ are the average selectivities at age over the last 10 years corresponding to the reduction, bait , or combined fisheries (see Tables A.2 and A.3 for the Base case and the domed selectivity case respectively), and

F is the fully selected fishing mortality rate.

The spawning biomass per recruit corresponding to a fully selected fishing mortality rate F is given by

$$SSB/R = \sum_{a=0}^{8} m_a w_a^{sp} (N/R)_a \quad \text{(A.3)}$$

where

m_a is the female maturity at age vector (see Table A.1), and

$w_a^{sp} = 1/10 \sum_{y=2002}^{2011} w_{a,y}^{sp}$ are the average population weights-at-age (see Table A.1).

For the combined fishery, the total fishing mortality at age is given by

$$F_{a,y}^{all} = \sum_f S_{a,y}^f F_y^f \quad \text{(A.4)}$$

where f denotes the reduction and bait fisheries.

If the fully selected fishing mortality rate for both fisheries combined is given by

$$F_y^{all} = \max(F_{a,y}^{all}) \quad \text{(A.5)}$$

where the maximum is taken over the ages *a*, then the average fishing selectivity for the combined fishery is given by

$$S_a^{all} = 1/10 \sum_{y=2002}^{2009} S_{a,y}^{all} = 1/10 \sum_{y=2002}^{2009} F_{a,y}^{all} / F_y^{all} \tag{A.6}$$

The average natural mortality rates, weights-at-age and selectivities-at-age assumed for the spawning biomass per recruit analyses are given in the Tables below.

Age	0	1	2	3	4	5	6	7	8
Ave mortality	1.115	0.889	0.682	0.579	0.529	0.499	0.476	0.476	0.476
Maturity	0.000	0.000	0.125	0.851	1.000	1.000	1.000	1.000	1.000
Ave weight (g)	26.890	69.160	178.100	291.640	385.080	460.160	521.120	576.170	621.090

Table A.1: Average natural mortality rates and spawning weights for the last 10 years, as well as the female maturity at age vector.

Age	0	1	2	3	4	5	6	7	8
S Reduction	0.009	0.099	0.569	0.941	0.995	1.000	1.000	1.000	1.000
S Bait	0.000	0.009	0.188	0.862	0.994	1.000	1.000	1.000	1.000
S All	0.006	0.067	0.435	0.913	0.995	1.000	1.000	1.000	1.000

Table A.2: Fishing selectivities for the reduction, bait and combined fisheries averaged over the last 10 years for the Base case (flat selectivity at older ages).

Age	0	1	2	3	4	5	6	7	8
S Reduction	0.012	0.154	1.000	0.853	0.199	0.035	0.006	0.001	0.000
S Bait	0.001	0.028	0.504	1.000	0.710	0.055	0.001	0.000	0.000
S All	0.010	0.136	0.972	1.000	0.367	0.044	0.005	0.001	0.000

Table A.3: Fishing selectivities for the reduction, bait and combined fisheries averaged over the last 10 years when allowing for doming after 1994.