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Sensitivity of the Georges Bank Yellowtail Flounder Stock Assessment to Alternative Estimates of Discard Mortality Including Gear Dependent Sensitivity

Adam Barkley[1], Christopher M. Legault[2], Larry Alade[2], and Steven X. Cadrin[2]

[1] University of Massachusetts Dartmouth
School for Marine Science & Technology
200 Mill Road, Suite 325, Fairhaven, MA 02719
u_abarkley@umassd.edu
scadrin@umassd.edu
(508) 910-6394

[2] National Marine Fisheries Service,
Northeast Fisheries Science Center
166 Water Street, Wood's Hole, MA, 02543
Chris.Legault@noaa.gov
Larry.Alade@noaa.gov

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ABSTRACT

Sensitivity analyses were used to evaluate the sensitivity of the Georges Bank yellowtail flounder stock assessment to alternative discard mortality assumptions. Recent stock assessment results were the basis for initial input data and analyses. A range of discard mortality assumptions (0%, 25%, 50%, 75% and 100%) were used to simulate different catch estimates for the Virtual Population Analysis (VPA) and reference point calculations. Sensitivity of the assessment to differing assumptions of discard mortality by capture method was also analyzed. Results from the 100% mortality analyses represent the assumption used in the current stock assessment. Abundance at-age, spawning stock biomass (SSB) and, fishing mortality rate-at-age (F), were estimated by the VPA. Yield and Spawner per Recruit analyses were used to calculate reference point $F_{40\%}$ as a proxy for F_{MSY}, while projection analyses were used to characterize long-term maximum sustainable yield (MSY) and the associated spawning stock biomass at MSY (SSB_{MSY}). Results indicated nonlinear, positive relationships between discard mortality rate, abundance estimates and F estimates. However, statuses of the stock show subtle changes relative to the current assumption. Therefore, these analyses indicate that alternative discard mortality assumptions do not substantially affect determination of stock status for Georges Bank yellowtail flounder.

RÉSUMÉ

Des analyses de sensibilité ont servi à évaluer la sensibilité de l’évaluation du stock de limande à queue jaune du banc Georges à divers taux hypothétiques de mortalité par rejets. Les données d’entrée et analyses initiales ont été fondées sur les résultats de l’évaluation récente du stock. On a utilisé une gamme de taux hypothétiques de mortalité par rejets (0 %, 25 %, 50 %, 75 % et 100 %) pour simuler différentes estimations de captures en vue de l’analyse de population virtuelle (APV) et des calculs des points de référence. On a aussi analysé la sensibilité de l’évaluation à divers taux hypothétiques de mortalité par rejets selon la méthode de capture. Les résultats des analyses portant sur une mortalité de 100 % correspondent à l’hypothèse utilisée actuellement dans l’évaluation du stock. L’abondance selon l’âge, la biomasse du stock de reproducteurs (BSR) et le taux de mortalité par pêche selon l’âge (F) ont été estimés d’après l’APV. Des analyses de la production et des reproducteurs parmi les recrues ont servi à calculer le point de référence F40 %, indicateur approximatif de FPME, tandis que des analyses de projection ont permis d’établir la production maximale équilibrée (PME) à long terme et la biomasse du stock de reproducteurs connexe (BSRPME). Les résultats reflétaient des relations non linéaires positives entre le taux de mortalité par rejets, les estimations de l’abondance et les estimations de F. Toutefois, l’état du stock présente des changements subtils par rapport aux hypothèses actuelles. Il ressort donc des analyses que des taux hypothétiques différents de mortalité par rejets n’influent pas sensiblement sur l’appréciation de l’état du stock de limande à queue jaune du banc Georges.

INTRODUCTION

By-catch is one of the most prominent problems in marine fisheries today (Hall et al. 2000, Davis and Ryer 2003). The survival of discarded by-catch is unknown, under-studied and a large source of uncertainty for many fisheries, posing a large source of uncertainty in stock assessments and fisheries management (Davis 2002). Most assessment models assume a discard mortality rate of 100%, but it is thought to be less. By-catch reduction devices are useful in reducing the amount of unwanted by-catch, but in fisheries that discard large portions of the target species, conservation engineering solutions are limited. The yellowtail flounder trawl fishery is an example, with a high rate of discarded catch of the target species in recent years (Table 1). An sensitivity analysis of the Virtual Population Analysis (VPA) for southern New England-Mid Atlantic yellowtail flounder showed nonlinear, positive relationships between discard mortality rates, abundance estimates and fishing mortality (F) as well as maximum sustainable yield (MSY) reference points, and the stock status determination (overfishing or not) was sensitive to the assumed discard mortality rate (Barkley, in prep.). Recent assessments show that the Georges Bank (GB) yellowtail flounder stock is currently overfished, although overfishing is not occurring (Legault et al. 2009). The crude assumption of 100% discard mortality in the GB yellowtail flounder assessment, as well as the high observed discard level, indicate that including an empirical estimate of discard mortality rate may be beneficial to this stock assessment.

The current assumption is that the majority of fish discarded die. However, Robinson and Carr (1993) reported that discarded yellowtail flounder exhibited high survival rates with survival estimated to be 67% or greater. Similarly, Carr et al. (1995) showed that yellowtail flounder had the greatest survival rates of the three flatfish species studied with survival rates from 66% and higher. Additionally, Carr et al. (1995) studied the effects of escapee mortality (those fish that are not caught, but interact with the net). They reported yellowtail flounder escapee survival to be between 68% and 99%. If this type of non-catch mortality does occur, then the total impact of fishing could be underestimated even with an assumption of 100% discard mortality. Discard mortality rates have been included in several stock assessments in the northeast United States. The majority of those stocks have substantial recreational fishing, and estimates are for both recreational catch and release fishing and commercial fishing. The southern New England-Mid Atlantic winter flounder and summer flounder stock assessments include discard mortality rates for recreational and commercial fisheries (NEFSC 2008b, Terceiro 2008). Including this information allows for a more accurate estimate of the stock abundance as well as more representative MSY reference points. In this study, we examine the sensitivity of the GB yellowtail flounder population estimates from VPA to alternative assumptions of discard mortality rates and their implication on biological reference points.

METHODS

Virtual Population Analysis

The base case for these analyses is considered 100% discard mortality. The initial input data is from the 2009 GB yellowtail flounder TRAC assessment including the DFO 2008 and 2009 values, but downweighting these years due to high coefficients of variation (CVs) caused by single large tows. All analyses were done using the NOAA Fisheries Toolbox programs: VPA version 3.0.3, AGEPRO version 3.3.9 and Yield per Recruit (YPR) version 2.7.2. For the total discard mortality sensitivity analyses five different assumptions were tested: 100% discard mortality, 75% discard mortality, 50% discard mortality, 25% discard mortality and 0% discard mortality. In the gear dependent discard mortality sensitivity analyses two additional assumptions were tested using two different allocation methods (constant proportion and variable-at-age proportion): 1) 50% discard mortality for trawls and 100% discard mortality for dredges, and 2) 0% discard mortality for trawls and 50% discard mortality for dredges.

Total commercial removals for the VPA were calculated as a function of landings-at-age, discard-at-age and the proportion discard mortality using the following process equation:

$$C'_{a,t} = L_{a,t} + \sum_{g} D_{a,t,g} M_g \qquad [1]$$

Where *C'* is the dead catch at age *a* and time *t*, $L_{a,t}$ is the landings-at-age, $D_{a,t,g}$ is the discards-at-age for gear *g*, and M_g is the discard mortality rate for gear *g*, expressed as a proportion (i.e. 100% = 1.0). This is the method of including a discard mortality rate, by assuming that a certain percentage of all fish discarded will survive. The catch number-at-age values were updated with the values calculated using each discard mortality rate and used for alternative VPAs.

The total commercial removals for the gear sensitivity analysis were calculated using two different schemes. First, the constant proportion (CP) analyses were derived by calculating the proportion of discards from both the U.S. trawl fleet and the U.S. dredge fleet for each year (i.e. trawl proportion= U.S. trawl discards/total U.S. discards). Those proportions were then used with the discards-at-age data for the U.S. discards. The Canadian discards were assumed to be 100% dredge discards for all gear sensitivity analyses and were added to the U.S dredge discards. For the variable-at-age proportion (VP) analyses a proportion-at-age was used. The assumed values used for trawl discards were 70, 60, 50, 40, 40, 40 percent for age-1 to ages-6+ respectively and the values for dredge discard proportion were 1- trawl proportion-at-age. These values were used based on exploratory data searches. The proportions-at-age were held constant for all years and consistent for all ages (i.e. age-1 trawl was always 70%). These values were then used with the U.S. discards-at-age and Canadian discards were again considered dredge discards.

Biological Reference Point Analyses

Biological reference points, F_{MSY}, MSY and B_{MSY} were calculated using AGEPRO and YPR. YPR analyses were based on the last five-year average partial recruitment calculated by the VPA, and constant maturity and weight-at-age to estimate $F_{40\%}$ as a proxy for F_{MSY}. Subsequently, a 50-year stochastic projection using the recent 5-year average of partial recruitment was used to calculate median MSY and SSB_{MSY} while sampling recruitment from a non-parametric distribution in AGEPRO. MSY reference points for GB yellowtail flounder were most recently estimated in 2008 (NEFSC 2008a), and were not updated in the 2009 assessment (Legault et al. 2009).

For the YPR analyses, the initial input data used was borrowed from the 2009 Georges Bank yellowtail Transboundary Resources Assessment Committee (TRAC) assessment. This was modified to account for the discard mortality rates by changing the parameter values for partial recruitment (PR). The partial recruitment values used were taken from the output file produced by each discard mortality rate corresponding VPA.

To run the age projection analyses, estimates of January 1st population size-at-age in the terminal year and recruitment abundances were obtained from VPA bootstrap results. Assumptions regarding weights-at-age, maturity, natural mortality, and partial recruitment were the same as in the YPR analyses. The recruitment series were split into two stanzas, based on

SSB. For the base case recruitment, values produced by SSB less than 5,000 mt were in the first stanza and all recruitment values produced by SSB of 5,000 mt or greater were in the second stanza. For all subsequent model runs the years in which SSB was less than 5,000 mt in the base case were kept in the 1st stanza regardless of the "updated" value of SSB and those years with SSB greater then 5,000 mt were kept in the second stanza. Updated hindcast recruitment values were used in the sensitivity analyses, by dividing the survey indices during 1963-1972 by the calculated catchability of the age-1 index from the Northeast Fisheries Science Center autumn research bottom trawl survey.

RESULTS AND DISCUSSION

Total Discard Mortality Sensitivity

The results from the VPA analyses showed comparable trends to the recent 2009 TRAC results with nonlinear, positive relationships between discard mortality rates, abundance estimates and F. Changes seen in SSB, F and recruitment are found throughout the time series due to the method of including a discard mortality rate (including the same rate for all years in the time series). Trends in SSB were similar to the base discard mortality assumption (100%), all showing an increase in stock size since 2005 (Figure 1) and reductions in fully recruited F since 2004 (Figure 2). Similarly, trends in the age-1 abundance results were consistent with large year classes in 1970's, early 1980's and 2005 (Figure 3). The SSB in 2008 decreased from 19,785 mt to 16,368 mt between 100% discard mortality and 0% discard mortality respectively. The F was reduced from 0.0901 to 0.0757, between 100% and 0% discard mortality rate, respectively. The age-1 abundance values in 2009 decrease from 17,267,000 (100% discard mortality) to 13,624,000 (0% discard mortality) (Table 2). The 2009 recruitment value is calculated as the geometric mean of the previous ten years and thus reflects the central tendency of recent recruitment values. The biological reference point results showed larger changes compared to the VPA results. The SSB_{MSY} decreased from 119,504 mt (100%) to 95,623mt (0%). The MSY reference point decreased from 11,295 mt to 8,154 mt and the F_{MSY} reference point increased from 0.2593 to 0.2750 between 100% to 0% discard mortality respectively (Table 2). In comparison to the VPA that assumed 100% discard mortality, estimates from the VPA that assumed 0% discard mortality were:

- 18% less for 2008 SSB,
- 20% less for SSB_{MSY},
- 16% less for 2009 F, and
- 6% greater for F_{MSY}.

The SSB in 2008 changed in all model runs because of how the model treats the catch-at-age data. When the discard mortality rate was imposed on the dead catch-at-age data it is only effecting the discard-at-age data (i.e. using 0% discard mortality would return the landings-at-age). Although there was a difference of about three thousand metric tons in the SSB_{2008} between 100% (19,785 mt) and 0% (16,368 mt) discard mortality it was offset by the large shift in SSB_{MSY} (119,504 mt to 95,623 mt, 100% to 0% discard mortality, respectively), so the ratio of SSB to SSB_{MSY} was less sensitive. A PR plot for ages 1- 2 is shown in Figure 4.

The results from the biological reference point analyses show the implications of including discard mortality rate in stock assessments more clearly. The F_{MSY} reference point change was different then the other reference points. The SSB_{MSY} and MSY were positively correlated with discard mortality rate, while the F_{MSY} was negatively correlated with discard mortality rate. This is due to the use of the dead catch-at-age data, the model is allowing a higher F at low discard mortality rates, because not all of the fish that are discarded die, so you can fish the stock harder because some discarded fish survive.

The status of the stock plots (Figures 5-6), show that under all assumptions of discard mortality rate overfishing is not occurring and there is a negative relationship between discard mortality rate and relative magnitude of overfishing. The overfished reference point also showed a negative relationship with discard mortality rate, showing that as discard mortality rate decreased so did the relative magnitude of overfishing. While there is a change in the overfishing and overfished reference points the changes are very small. The slight changes in the overfished reference point can be attributed to the history of the fishery, in the case of GB yellowtail flounder including a discard mortality rate won't change decades of overfishing. For overfishing this may indicate that while discarding is taking place, the magnitude of discarding may not be large enough to dramatically impact the relative stock size. In comparison, a similar study performed on the Southern New England Mid-Atlantic yellowtail flounder stock indicated that including a discard mortality of 0% would substantially reduce the overfishing reference point and change the status of the stock from overfishing is occurring to overfishing is not occurring (Figure 7; Barkley, *in prep.*). A potential reason for the differences between this study and that performed by Barkley (*in prep.*) is the proportion of discards to total stock size. The proportion of the stock being discarded in the Southern New England Mid-Atlantic stock was 5.331% (187 mt/3508 mt; Barkley, *in prep.*) compared to 2.461% in the GB stock (487 mt/19785 mt). This may indicate that a discard to catch ratio, may not be the most appropriate indicator of a “highly discarded” stock.

Gear Dependant Discard Mortality Sensitivity

The results from the alternative gear dependant VPA analyses showed similar trends to the total discard mortality sensitivity with nonlinear, positive relationships between discard mortality rates, abundance estimates and F. Trends in SSB were consistent with the base discard mortality assumption (100%), all showing an increase in stock size since 2005 (Figure 8) and reductions in fully recruited F since 2004 (Figure 9). Similarly, trends in the age-1 abundance results were consistent with large year classes in 1970’s, early 1980’s and 2005 (Figure 10). The SSB in 2008 changed from 19,771 mt to 18,030 mt between the constant proportion trawl 50% dredge 100% run and the constant proportion trawl 0% dredge 100% run, respectively. The F was reduced from 0.0827 to 0.0763, between the same two runs. The age-1 abundance values in 2009 decrease from 16,898,000 fish (CP Trawl 50% Dredge 100%) to 15,067,000 fish (CP Trawl 0% Dredge 50%) (Table 4). The differences between the constant proportion runs and the variable at age proportions runs were minimal and are only shown in the tables and figures (Tables 4-5; Figures 8-10). The biological reference point results showed smaller changes compared to the total discard mortality results and the results between the constant proportions and the variable at age proportions were again very similar. The SSB_{MSY} decreased from 112,152 mt (CP Trawl 50% Dredge 100%) to 97,941 mt (CP Trawl 0% Dredge 50%). The MSY reference point decreased from 10,551 mt to 9,134 mt and the F_{MSY} reference point increased from 0.2621 to 0.2697 between CP Trawl 50% Dredge 100% to CP Trawl 0% Dredge 50% respectively (Table 5). As stated previously, the results between constant proportions and variable at age proportions were very similar, the variable at age proportions results are only shown in tables and figures (Tables 4-5; Figures 8-10). A PR plot for ages 1 and 2 is shown in Figure 11.

The biological reference point results for the gear sensitivity showed similar results to that of the total discard mortality rate runs. There was a negative relationship between discard mortality rate and relative magnitude of the overfishing and overfished status. The status of the stock plots (Figures 12-13), show that under all assumptions of discard mortality rate overfishing is not occurring and there is a negative relationship between discard mortality rate and relative magnitude of overfishing. The results from the constant proportion and variable proportion were similar and showed that with a trawl discard mortality rate of 0% and a dredge discard mortality rate of 50% you would maximize the effect on the overfished reference point status. This can again be attributed to how the model is using the discard mortality rate described above.

CONCLUSIONS

These sensitivity analyses indicate that including a discard mortality rate in the Georges Bank yellowtail flounder stock assessment would not change the current status of the stock (overfished, overfishing is not occurring), but do suggest that including a discard mortality rate would affect estimates of stock size, fishing mortality and MSY reference points. ,

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Table 1. Table of landings, discards, total catch and proportion of the total catch that is discards. Adapted from Legault et al. 2009.

Year	US Landings	US Discards	Canada Landings	Canada Discards	Other Landings	Total Catch	% discards
1973	15899	364	12	378	300	16953	4%
1974	14607	980	5	619	1000	17211	9%
1975	13205	2715	8	722	100	16750	21%
1976	11336	3021	12	619	0	14988	24%
1977	9444	567	44	584	0	10639	11%
1978	4519	1669	69	687	0	6944	34%
1979	5475	720	19	722	0	6935	21%
1980	6481	382	92	584	0	7539	13%
1981	6182	95	15	687	0	6979	11%
1982	10621	1376	22	502	0	12520	15%
1983	11350	72	106	460	0	11989	4%
1984	5763	28	8	481	0	6280	8%
1985	2477	43	25	722	0	3267	23%
1986	3041	19	57	357	0	3474	11%
1987	2742	233	69	536	0	3580	21%
1988	1866	252	56	584	0	2759	30%
1989	1134	73	40	536	0	1783	34%
1990	2751	818	25	495	0	4089	32%
1991	1784	246	81	454	0	2564	27%
1992	2859	1873	65	502	0	5299	45%
1993	2089	1089	682	440	0	4300	36%
1994	1431	148	2139	440	0	4158	14%
1995	360	43	464	268	0	1135	27%
1996	743	96	472	388	0	1700	28%
1997	888	327	810	438	0	2464	31%
1998	1619	482	1175	708	0	3985	30%
1999	1818	577	1971	597	0	4963	24%
2000	3373	694	2859	415	0	7341	15%
2001	3613	78	2913	815	0	7419	12%
2002	2476	53	2642	493	0	5663	10%
2003	3236	410	2107	809	0	6562	19%
2004	5837	460	96	422	0	6815	13%
2005	3161	414	30	246	0	3851	17%
2006	1196	384	25	504	0	2109	42%
2007	1061	503	17	94	0	1675	36%
2008	748	370	41	117	0	1275	38%

Table 2. VPA results from the Total Discard Mortality Sensitivity Analyses including: Fishing mortality in 2008 (F_{2008}), Spawning Stock Biomass in 2008 (SSB_{2008}), and January 1st abundance values for age-1 fish (R_{2009}).

	F_{2008}	SSB_{2008} (mt)	R_{2009} (000's)
0% discard mortality	0.0757	16368	13624
25% discard mortality	0.0796	17228	14545
50% discard mortality	0.0833	18085	15460
75% discard mortality	0.0869	18932	16365
100% discard mortality	0.0901	19785	17267

Table 3. Biological Reference Point results from the Total Discard Mortality Sensitivity analyses including: Spawning stock biomass corresponding to maximum sustainable yield (SSB_{MSY}), maximum sustainable yield (MSY), fishing mortality rate at maximum sustainable yield (F_{MSY}), relative fishing mortality rate (F_{2008}/F_{MSY}), and relative spawning stock biomass (SSB_{2008}/SSB_{MSY}).

	SSB_{MSY}	MSY	F_{MSY}	F_{08}/F_{MSY}	SSB_{08}/SSB_{MSY}
0% discard mortality	95623	8154	0.275	0.2753	0.1712
25% discard mortality	98760	9193	0.2697	0.2951	0.1744
50% discard mortality	105734	9.895	0.2655	0.3138	0.1710
75% discard mortality	112702	10598	0.2622	0.3314	0.1680
100% discard mortality	119504	11295	0.2593	0.3475	0.1656

Table 4. VPA results from the Gear Dependent Sensitivity analyses including: Fishing mortality in 2008 (F_{2008}), spawning stock biomass in 2008 (SSB_{2008}), and January 1st abundance values for age-1 fish (R_{2009}).

	F_{2008}	SSB_{2008} (mt)	R_{2009} (000's)
CP Trawl 50% Dredge 100%	0.0827	19771	16898
VP Trawl 50% Dredge 100%	0.0861	19579	16849
CP Trawl 0% Dredge 50%	0.0763	18030	15067
VP Trawl 0% Dredge 50%	0.0797	17820	15008
100% discard mortality	0.0901	19785	17267

Table 5. Biological Reference Point (results from the Gear Dependent Sensitivity analyses including: spawning stock biomass corresponding to maximum sustainable yield (SSB_{MSY}), maximum sustainable yield (MSY), fishing mortality rate at maximum sustainable yield (F_{MSY}), relative fishing mortality rate (F_{2008}/F_{MSY}), and relative spawning stock biomass (SSB_{2008}/SSB_{MSY}).

	SSB_{MSY}	MSY	F_{MSY}	F_{08}/F_{MSY}	SSB_{08}/SSB_{MSY}
CP Trawl 50% Dredge 100%	112152	10551	0.2621	0.3155	0.1763
VP Trawl 50% Dredge100%	114749	10789	0.2621	0.3285	0.1706
CP Trawl 0% Dredge 50%	97941	9134	0.2697	0.2831	0.1968
VP Trawl 0% Dredge 50%	100867	9388	0.2695	0.2957	0.1767
100% discard mortality	119504	11295	0.2593	0.3475	0.1656

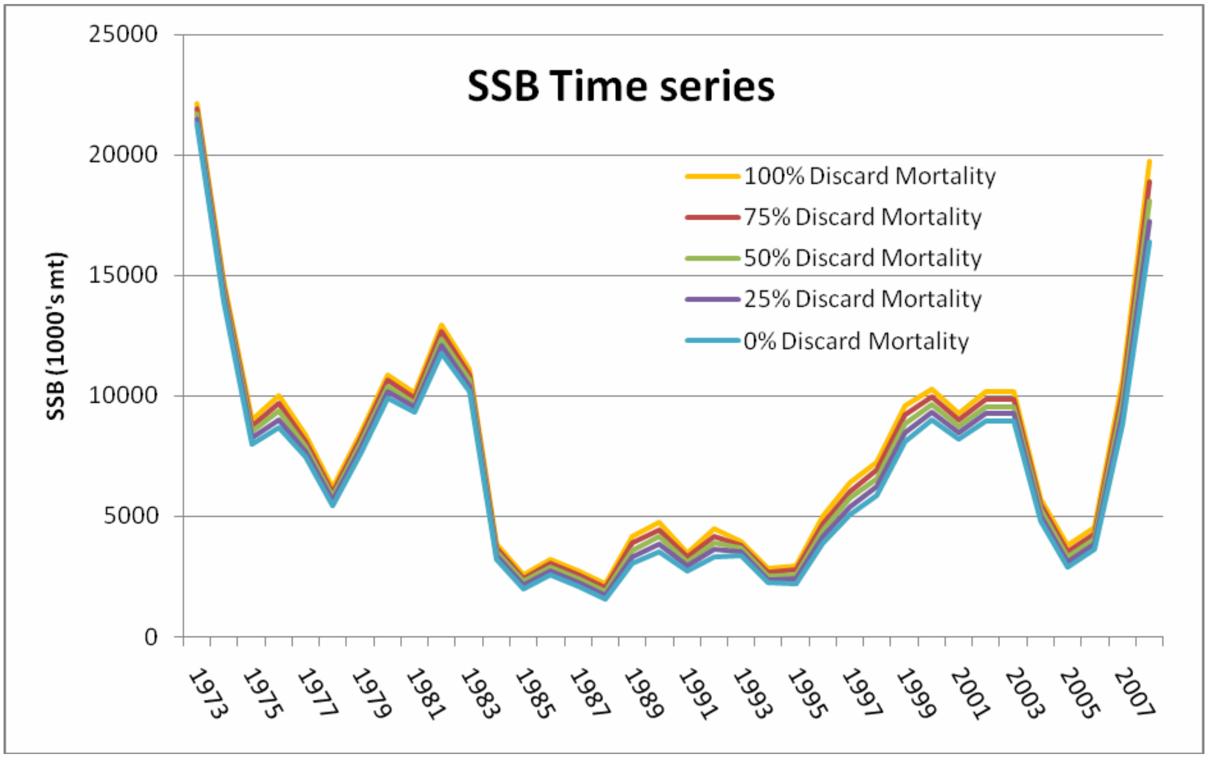

Figure 1. VPA results of estimated spawning stock biomass (SSB) at various discard mortality rates for the Total Discard Mortality Sensitivity analyses.

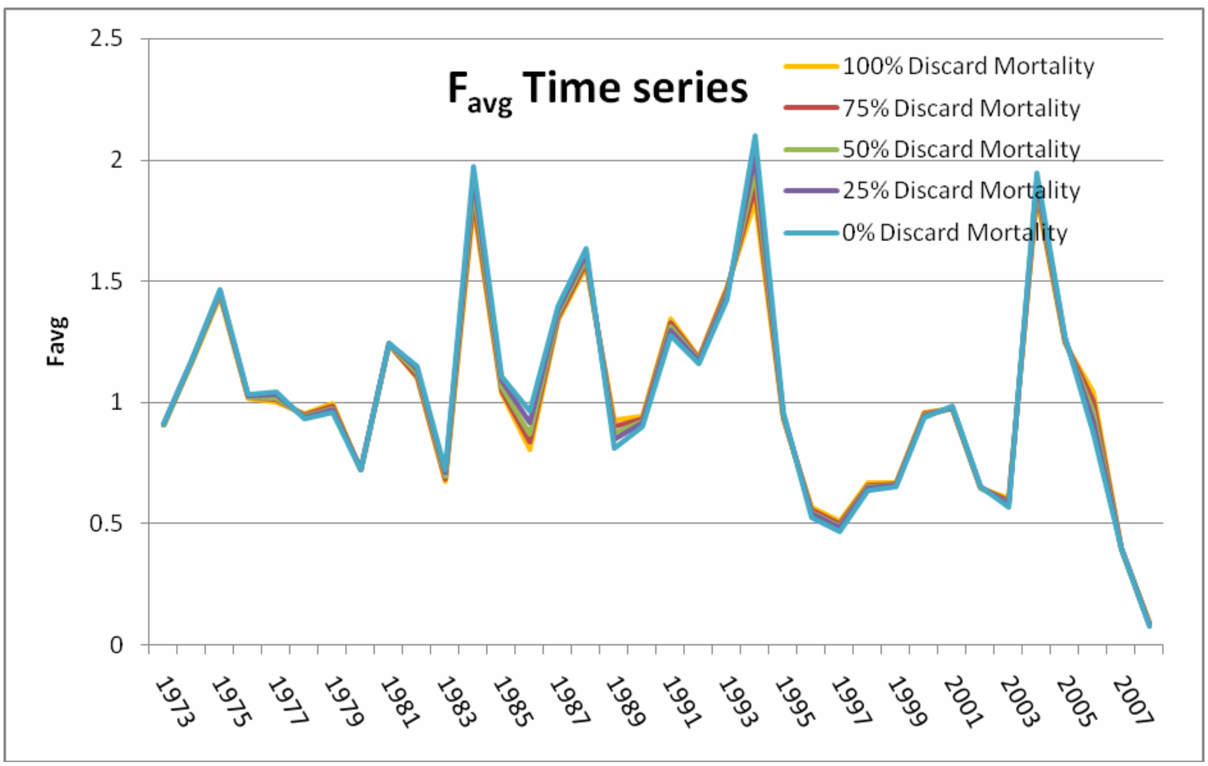

Figure 2. VPA results of estimated average fishing mortality rate (F_{avg}) of ages 4-5 fish for the Total Discard Mortality Sensitivity analyses.

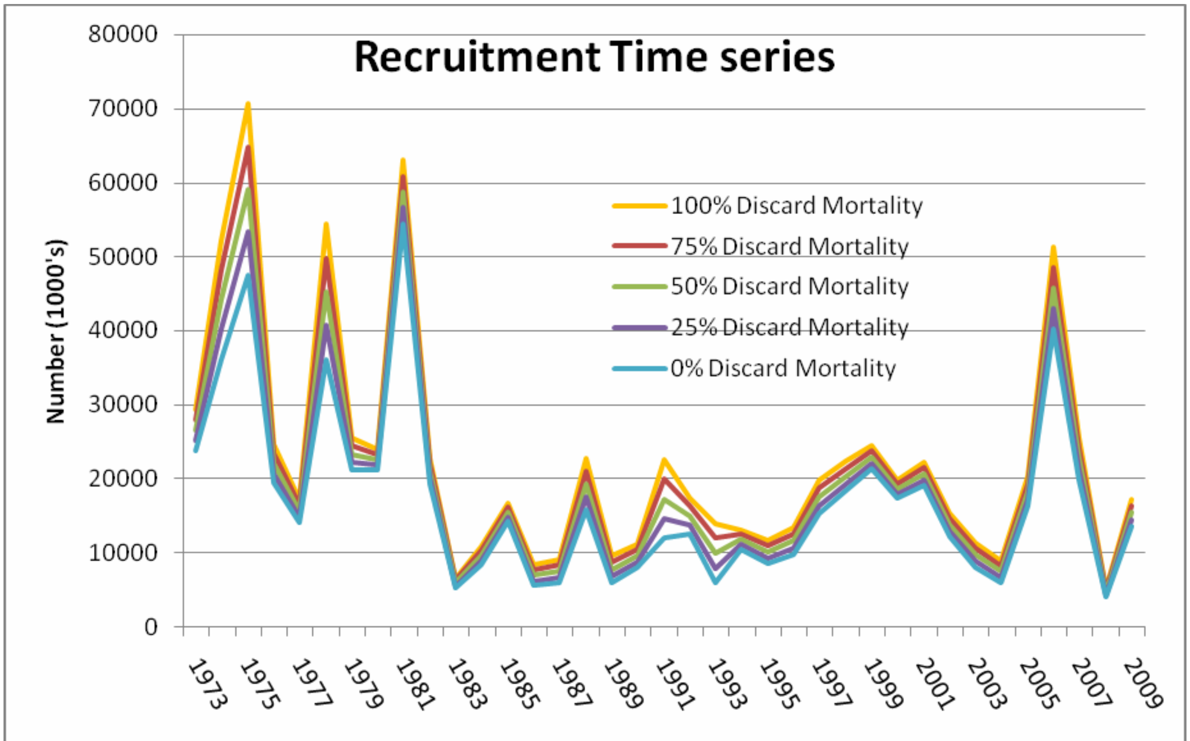

Figure 3. VPA results of estimated January 1st age-1 abundance values for the Total Discard Mortality Sensitivity analyses.

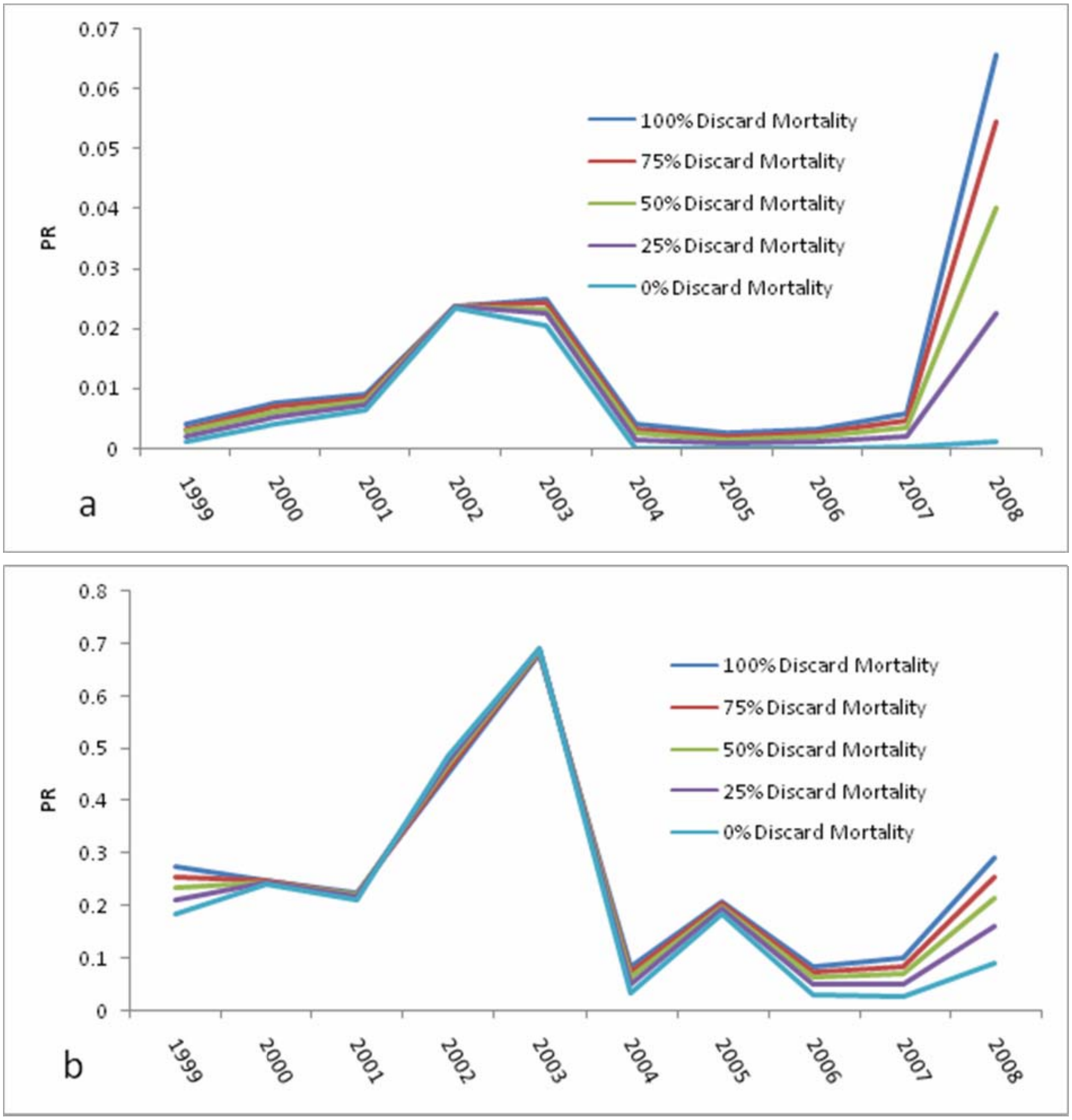

Figure 4. Total Discard Mortality Sensitivity VPA results for the most recent 10 years of partial recruitment (PR) values for age-1 fish (panel a) and for age-2 fish (panel b) at various discard mortality rates

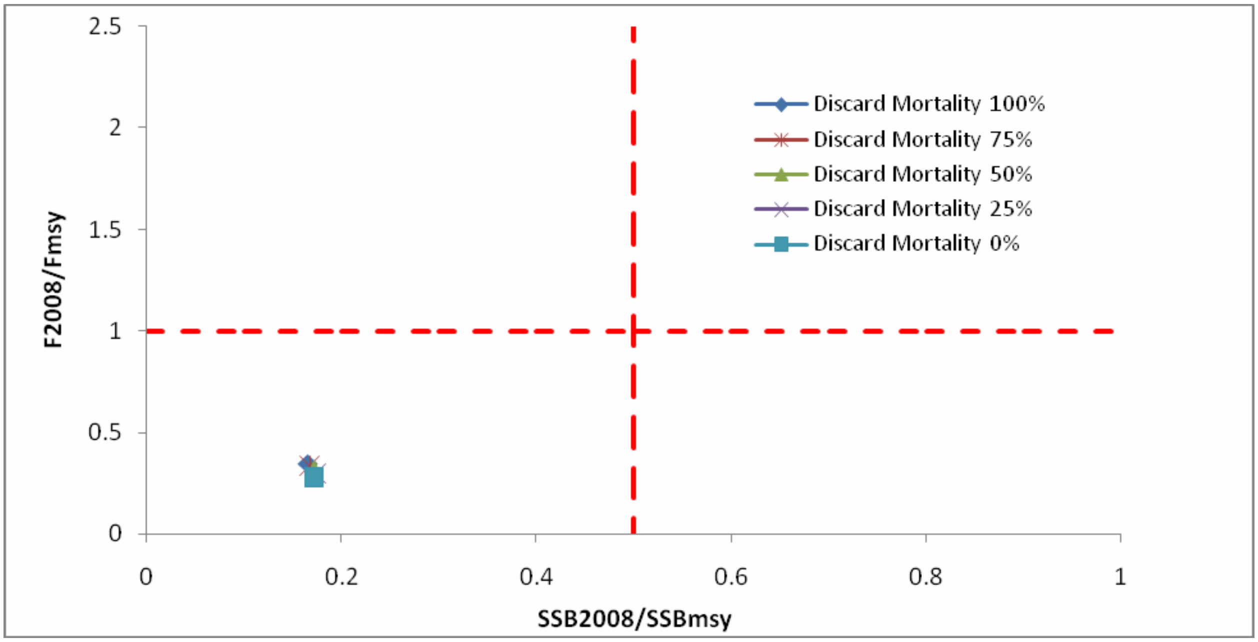

Figure 5. Status of the stock plot for Total Discard Mortality Sensitivity analyses at assumed discard mortality rates. The horizontal dashed line represents the overfishing threshold or F_{2008} equal to F_{MSY}. The vertical dashed line represents the overfished threshold or SSB_{2008} equal to ½ SSB_{MSY}. The upper left quadrant indicates overfished and overfishing is occurring, the upper right quadrant represents not overfished, but overfishing is occurring, the lower left quadrant represents overfished and overfishing is not occurring, and the lower right quadrant represents not overfished and overfishing is not occurring.

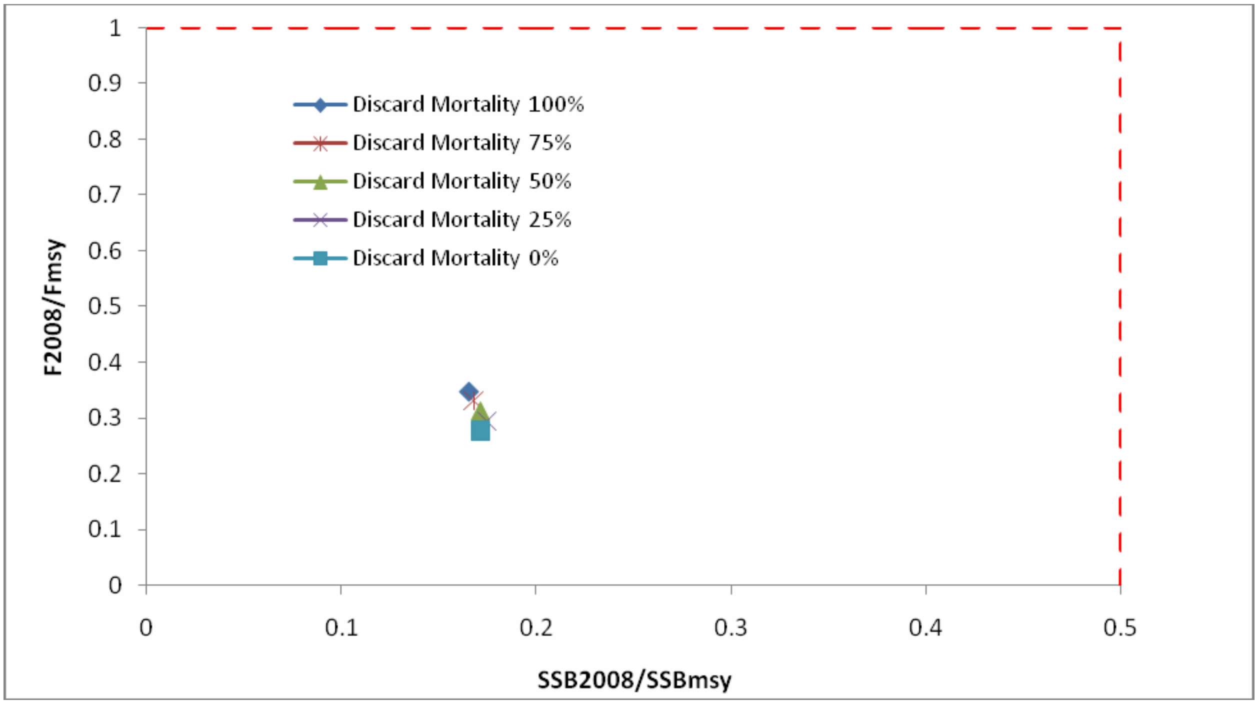

Figure 6. Status of the stock plot for Total Discard Mortality Sensitivity analyses. Zoomed in to the lower left quadrant.

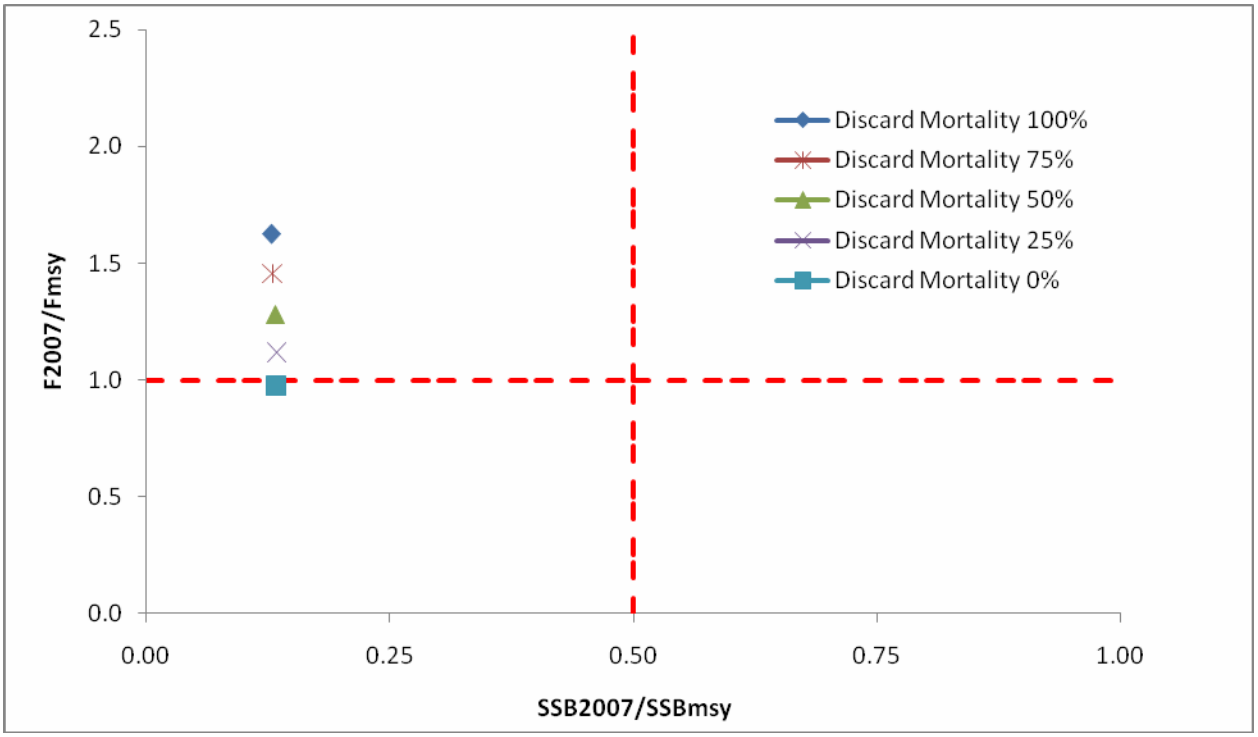

Figure 7. Status of the stock plot for the Southern New England Mid-Atlantic yellowtail flounder stock. Adapted from Barkley, *in prep*.

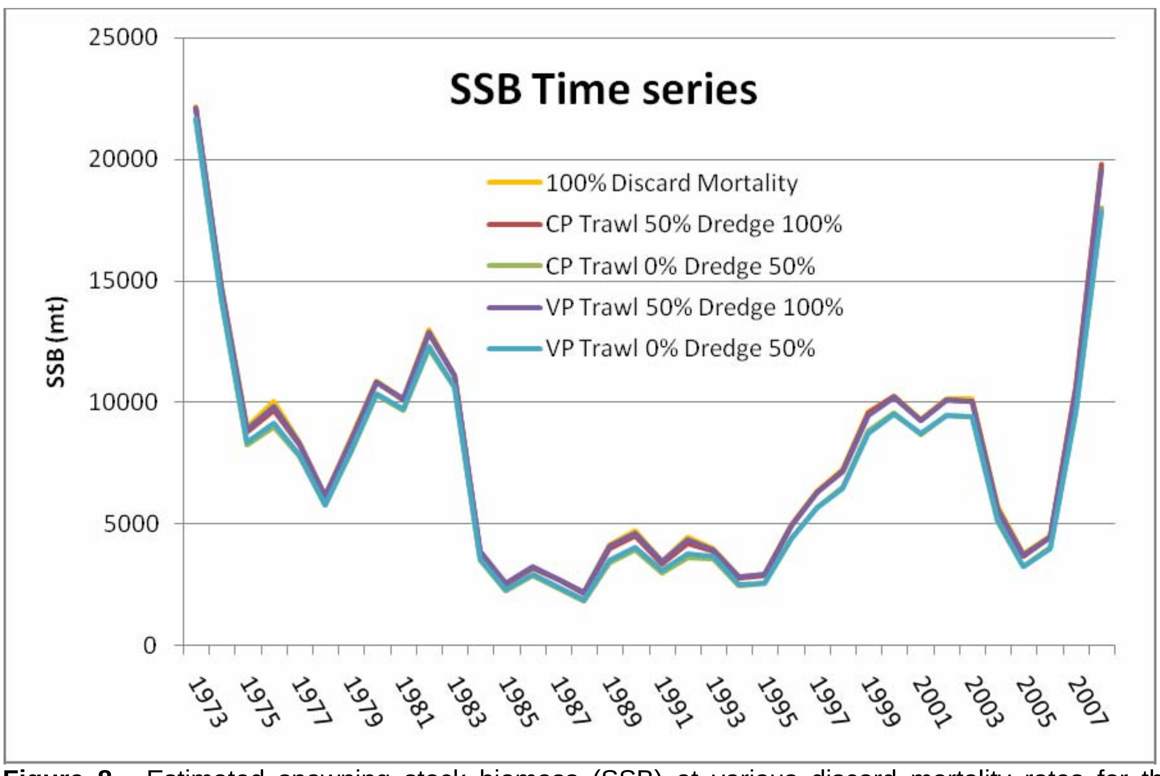

Figure 8. Estimated spawning stock biomass (SSB) at various discard mortality rates for the Gear Dependent Sensitivity analyses.

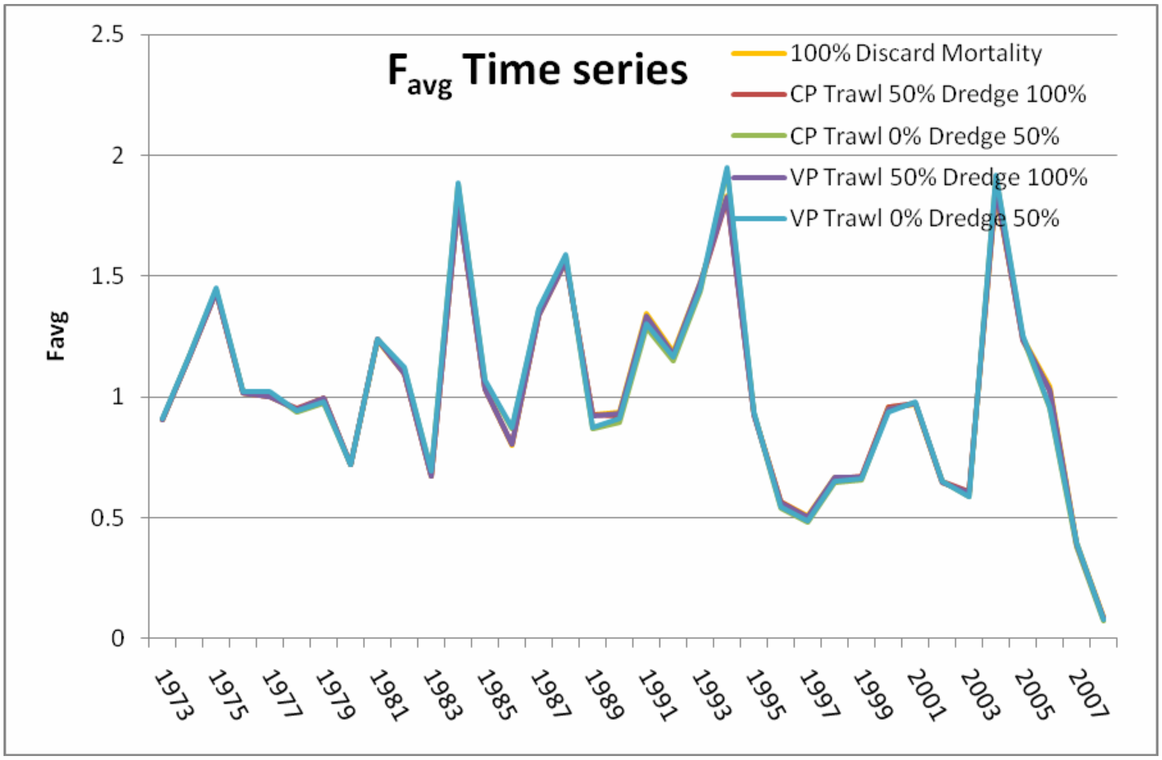

Figure 9. Estimated average fishing mortality rate (F_{avg}) of age 4-5 fish for the Gear Dependent Sensitivity analyses.

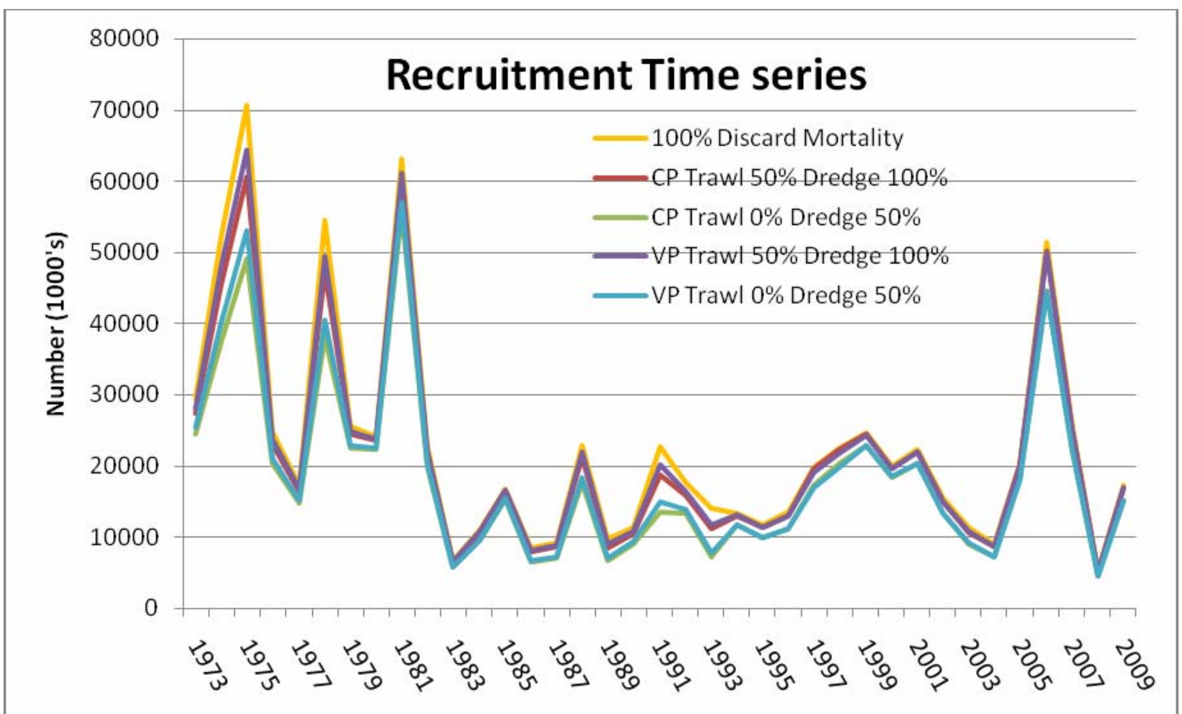

Figure 10. Estimated January 1st age-1 abundance values for the Gear Dependent Sensitivity analyses.

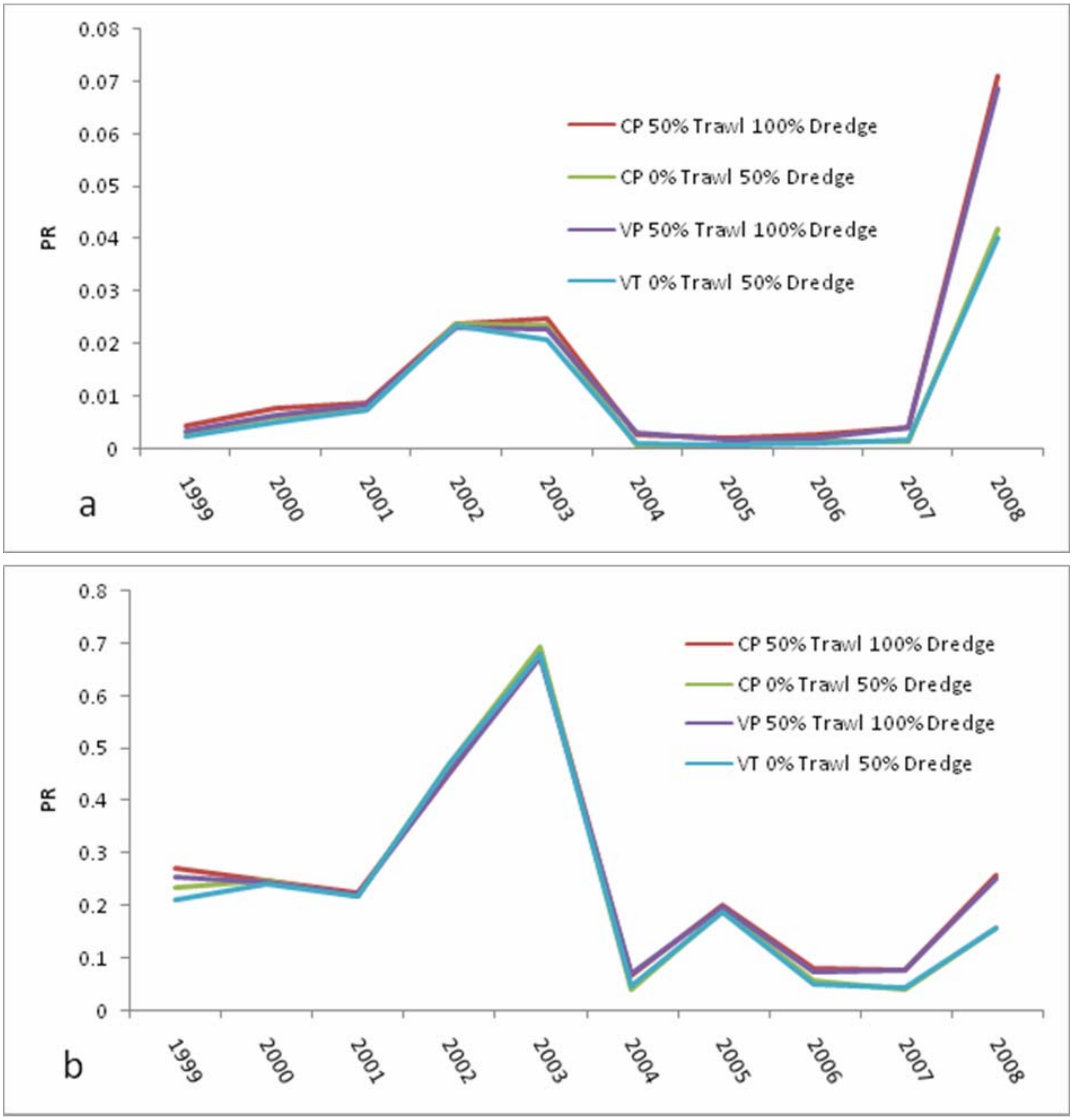

Figure 11. Gear Dependent Sensitivity VPA results for the most recent 10 years of partial recruitment (PR) values of age-1 fish (panel a) and age-2 fish (panel b) at various discard mortality rates.

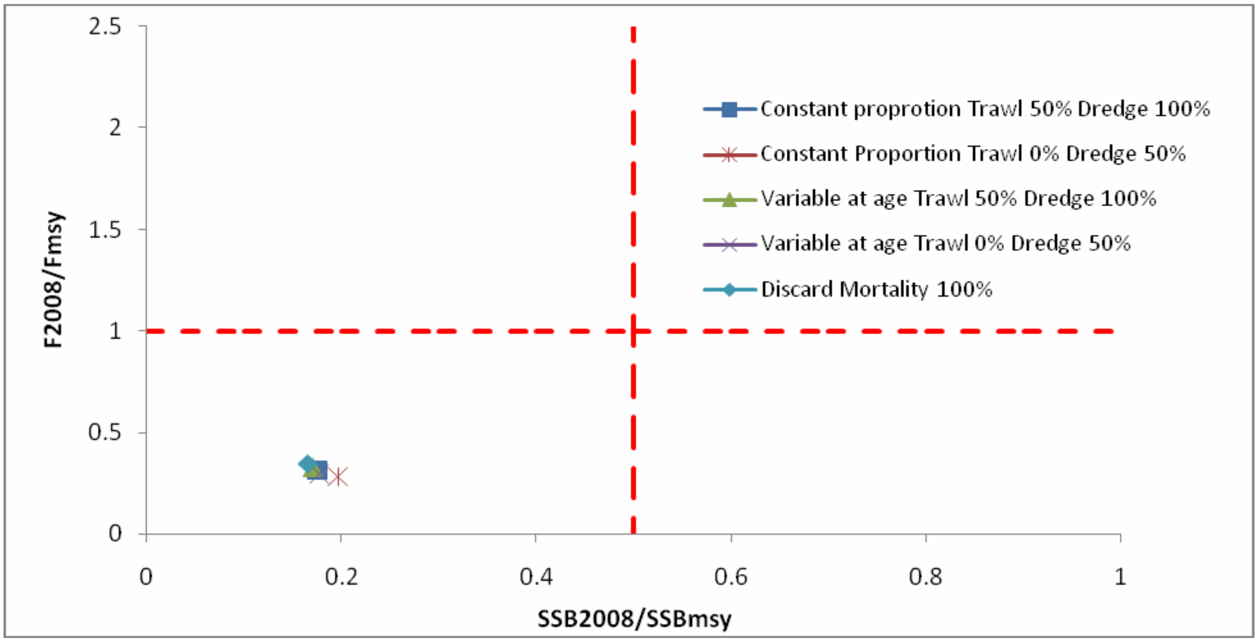

Figure 12. Status of the stock for Gear Dependent Sensitivity analyses. at assumed discard mortality rates. The horizontal dashed line represents the overfishing threshold or F_{2008} equal to F_{MSY}. The vertical dashed line represents the overfished threshold or SSB_{2008} equal to ½ SSB_{MSY}. The upper left quadrant indicates overfished and overfishing is occurring, the upper right quadrant represents not overfished, but overfishing is occurring, the lower left quadrant represents overfished and overfishing is not occurring, and the lower right quadrant represents not overfished and overfishing is not occurring.

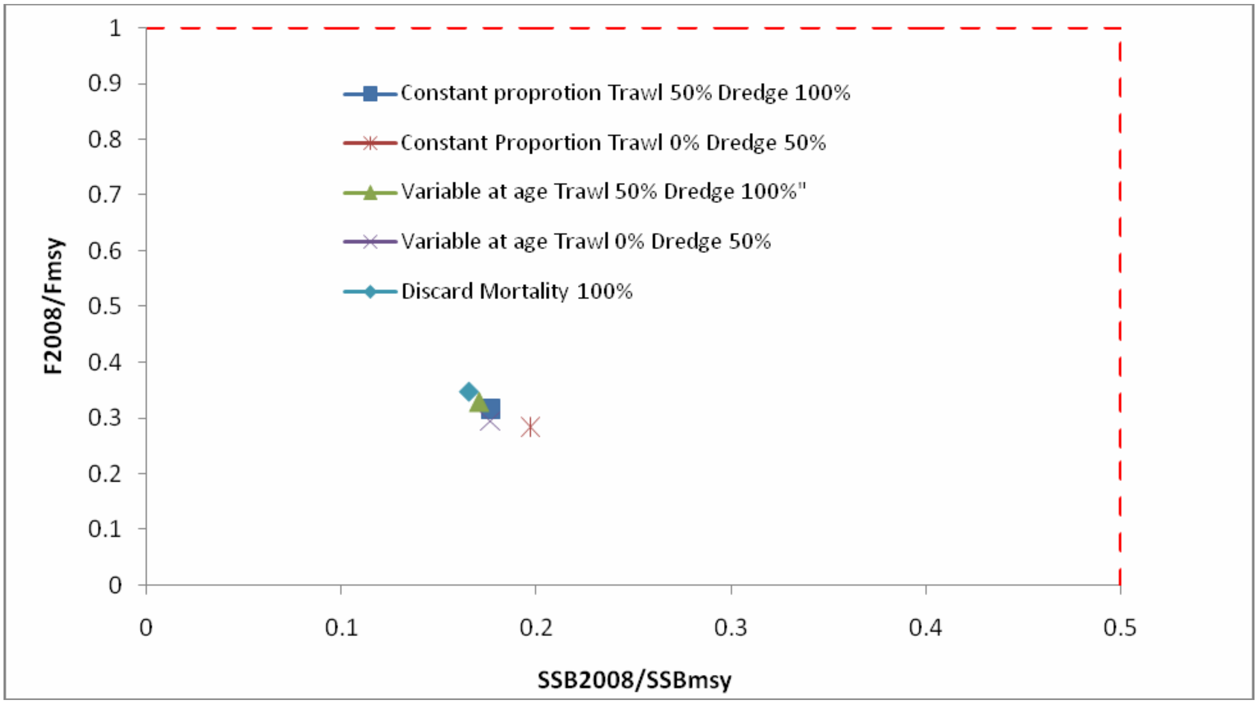

Figure 13. Status of the stock for Gear Dependent Sensitivity analyses. Zoomed in to the lower left quadrant.

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