A non-equilibrium surplus production model of black grouper (*Mycteroperca bonaci*) in southeast United States waters

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Introduction

Black grouper are long-lived, late maturing fish that occur primarily in southern Florida but some occur off North Carolina and in the northern Gulf of Mexico. They are caught by recreational anglers and commercial fishers. Spearfishing tournaments frequently produce large (50-80 pounds) black groupers. The State of Florida and the Gulf of Mexico Fishery Management Council instituted a 20-inch (508 mm) total length (TL) minimum size in 1990 and the South Atlantic Fishery Management Council implemented a 20-inch TL minimum size in 1992. The minimum size was increased to 24 inches TL in 1999. There is concern for black grouper because, while the minimum size is 24 inches (610 mm) total length, the size of 50% female maturity is 33 inches TL (856 mm). Thus many black groupers are harvested before they have had an opportunity to reproduce. Hence, the request for a black grouper stock assessment.

A complication is that the common name 'black grouper' has also been applied to gag (*Mycteroperca microlepis*), creating confusion in the historical landing records. A concerted effort in the early 1990s with anglers, fishers, and fish houses has improved the accuracy of the reported landings, but the early records are still dubious.

Given that the early landings are questionable, the emphasis of the assessment effort will be on more recent years. Before applying complex, data-intensive models, the initial step was to apply a simple surplus production model before moving on to age-structured models.

Methods

The data workshop provided the landings by fishery in numbers and biomass, as well as indices of abundance. These data can be entered into a surplus production model to estimate biomass trends and estimates of fishing mortality rates. In its simplest implementation (a logistic or Schaefer (1954) model), there are two

simple equations (Hilborn and Walters 1992). The first relates the biomass at a particular time (t) to the biomass at a future time (t+1):

$$B_{t+1} = B_t + rB_t(1 - B_t / K) - \sum_{f=1}^{fleets} C_{f,t} \qquad (1)$$

where B_t is the biomass at time t, r is a dimensionless net rate of growth in biomass, K is the carrying capacity (biomass) of the environment and $C_{f,t}$ is the catch for fishery f during time t. The second equation relates the catch to the biomass:

$$\hat{C}_{f,t} = q_f E_{f,t} B_t \qquad (2)$$

where q_f is the catchability coefficient (per unit effort) for fishery f, which links effort by sector (fleet) to biomass, and $E_{f,t}$ is the effort expended by that fleet during time t.

The National Marine Fisheries Stock (NMFS) Assessment Toolbox contains the program ASPIC, which is a non-equilibrium, surplus production model (Prager 1994) that allows covariates or tuning indices. The program can be downloaded from http://nft.nefsc.noaa.gov. The version used in the following analyses was ASPIC 5.34.6. ASPIC has been reparameterized to estimate MSY and fishing mortality rates directly instead of the all encompassing net rate of growth, r. Bootstrapping of the residuals, 1000 iterations, provided estimates of uncertainty in the parameters.

The landings in pounds by fishery were taken from the SEDAR 19 black grouper summary spreadsheet, BG_DW_summary_final Sep 11.xls available from SEDAR. The commercial fisheries were analyzed as longline and hook-and-line, the latter also included the dive/spear, trap, and other gears. The commercial landings in the spreadsheet are in gutted weight because that is how most of the fish are landed and these weights were converted to whole weight from gutted weight using WW = 1.061 GW (Table 2.14.7, SEDAR 19 Data Workshop Report). The recreational fisheries estimates were from the NMFS Headboat Survey and the NMFS Marine Recreational Fisheries Statistics Survey (MRFSS). Both of these surveys estimate the whole weight biomass and the number of fish landed

The number of discards came from the same spreadsheet and the release mortality rates were 0.2 for recreational and commercial hook-and-line and 0.3 for the longline fishery (Section 2.5, SEDAR 19 Data Workshop Report). The weight of dead discards was calculated from the lengths of fish smaller than the minimum sizes in earlier years by fishery. This method is an approximation necessitated by the absence of observer data for black grouper. The NMFS shark longline study (Hale and Carlson 2009) observed 50 black groupers during 134 trips in the Gulf of Mexico and South Atlantic during 2005-2008. Two of the black grouper had been

eaten when they were retrieved and were discarded without being measured. Another observer program was the at-sea sampling of headboats in 2005-2007, where observers measured 73 black groupers the plus an additional three fish that were measured in the partial sampling in 2008 (Sauls 2009, SEDAR 19-DW-08). The calculated weight of dead commercial discards differed from the weight given in the spreadsheet because the spreadsheet weights were spread across all sizes and the belief is that only undersized fish were released. The landings and dead discards are shown in Table 1. The large biomass of dead discards for the recreational fisheries in the late 1980s was because there was not a minimum size for black grouper in federal waters; however there was an 18-inch TL minimum size in state waters. Adding to the confusion on discards in the early years is that juvenile gag occur in estuaries and nearshore waters and many of these small gag could have been recorded in the recreational fisheries as discarded black grouper.

The model ASPIC can use catch-per-unit-effort (CPUE) and catch as input for the fisheries so two models were configured. The first model used the standardized fishery CPUE indices directly and the second model decremented those index values by 2% per year to approximate increases in catchability (Table 2). Both configurations used the two fishery independent indices.

Results

The first model (constant catchability) converged, with the commercial hook-and-line having the best fit (Mean Squared Error (MSE) = 0.0033) and the Reef Visual Census having the worst fit (MSE = 0.52) (Table 3 and Figure 1). The biomass trajectory initially declined to lows in 1989-93 and then increased afterwards (Figure 2a). Fishing mortality rates were higher in the early part of the time series and then decreased (Figure 2b). After 1000 bootstrap iterations, the fishing mortality rates and ratios were normally distributed while the biomass and yield estimates were log-normally distributed. The mean fishing mortality rate in 2008 was estimated at 0.094 (CV = 0.52) per year and mean biomass in 2008 was estimated at 3.44 million pounds (CV = 0.50). The fishery benchmarks were a mean maximum sustainable yield (MSY) of 683,000 pounds (CV = 0.03), the mean fishing mortality at MSY was 0.38 (CV = 0.58) per year and the biomass as MSY was 2.16 million pounds (CV = 0.70). The mean fishing mortality ratio of F_{2008} to F_{MSY} from the bootstraps was 0.26 (CV = 0.17, Figure 3a) and all 1000 outcomes were less than 1.0. The mean biomass in 2008 to B_{MSY} was 1.61 (CV = 0.12, Figure 3b) and 973 outcomes were 1.0 or greater.

The model with the decremented fishery indices to approximate increasing catchability was unstable in that the results shifted drastically with minute changes in the initial catchability (q) values. For example, the fishing mortality rate in 2008 was estimated at 0.016 per year with a commercial hook-and-line q value of 4.9e-07 and 0.788 per year with a q value of 5.05e-07. Similar large shifts were produced with changing MRFSS initial q values.

Discussion

This exercise was an exploratory endeavor to determine whether the catch and indices together with the underlying quantity and quality of data for black grouper in the southeast US have sufficient signal to provide a reasonable solution. While the fits were poor, the model did converge with four fisheries (standardized fishery dependent CPUE and landings plus dead discards) and two fishery independent indices of abundance. The three levels in the trajectory of fishing mortality correspond to the period without a minimum size in the South Atlantic waters, the 20-inch minimum size limit which was implemented in 1992, and 24 inch-minimum size implemented in 1999. The low fishing mortality values in the years with the 24 inch minimum size is corroborated with catch curve analysis (Muller 2009, SEDAR AW xxx). This model, lacking information on age and reproduction, is not meant to be a definitive assessment but it does indicate that additional investigation is merited.

Literature cited

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Table 1. Landings and dead discards in pounds of black grouper by fishery and year.

	Headboat			MRFSS			Commercial Hook-and-line			Commercial Longline		
Year	Landings	Dead Discards	Combined	Landings	Dead Discards	Combined	Landings	Dead Discards	Combined	Landings	Dead Discards	Combined
1986	19976	7742	27719	447266	10328	457595	426270		426270	129457		129457
1987	39603	5208	44812	382021	47942	429963	567539		567539	125101		125101
1988	24288	4926	29214	188198	4924	193122	365587		365587	83995		83995
1989	19806	3359	23165	181452	6353	187805	384267		384267	82395		82395
1990	17764	3097	20861	74441	5414	79855	299700		299700	109944		109944
1991	15378	2745	18124	398475	23181	421656	163451		163451	53681		53681
1992	20965	7750	28716	281616	54031	335647	218010		218010	58787		58787
1993	25129	6478	31606	140596	28293	168889	165666	3463	169129	35670	102	35772
1994	24053	7531	31584	166073	40010	206083	139558	4216	143774	25401	124	25524
1995	31760	12695	44455	236796	16952	253748	115303	3507	118809	24975	111	25086
1996	36613	8167	44780	316559	44474	361033	120418	3808	124226	29915	131	30046
1997	48274	10557	58831	450156	40694	490850	89464	4028	93492	34644	143	34787
1998	84984	17175	102160	389372	57887	447259	88334	3724	92058	41778	135	41913
1999	25267	8462	33729	169613	67075	236689	79719	6976	86694	51646	255	51900
2000	15118	4812	19929	112952	46920	159873	92434	6898	99332	50077	233	50310
2001	31013	9366	40379	136623	36496	173120	100951	5970	106921	55020	219	55239
2002	15271	3628	18899	139377	34432	173809	89052	4530	93582	53496	283	53779
2003	11940	4114	16054	262670	40167	302837	97394	5735	103129	77142	249	77391
2004	18414	7102	25517	139018	60217	199235	91732	4394	96125	73385	299	73684
2005	25733	6073	31806	135772	15549	151321	73266	6092	79358	45734	163	45897
2006	17862	3541	21403	92165	23869	116034	72223	772	72995	61444	195	61639
2007	17828	4629	22456	156224	39032	195256	54849	6836	61686	43457	198	43655
2008	3930	1464	5393	162408	57402	219810	33236	1191	34427	17843	213	18056

Table 2. Fishery dependent and independent indices for black grouper. The table numbers refer to tables in the SEDAR 19 black grouper Data Workshop Report.

Year	Headboat Scaled Table 5.12	Headboat Decremented by 2% per year	MRFSS Scaled Table 5.14	MRFSS Total catch/ trip Table 5.14	MRFSS Decremented by 2% per year	Comm HL Scaled Table 5.15	Comm HL Decremented by 2% per year	Comm LL Scaled Table 5.16	Comm LL Decremented by 2% per year	NMFS-UM RVC Scaled Table 5.18	FWC VS Scaled Table 5.5	Number/ dive habitat Table 5.5
1986	0.85	0.85										
1987	1.35	1.32										
1988	0.48	0.46										
1989	0.78	0.73										
1990	0.57	0.52										
1991	0.68	0.61	0.49	0.15	0.15							
1992	0.83	0.73	0.43	0.13	0.13							
1993	0.55	0.47	0.52	0.16	0.15	0.76	0.76	0.39	0.39			
1994	0.78	0.66	0.80	0.24	0.22	0.75	0.74	0.30	0.30	1.35		
1995	0.97	0.80	0.75	0.22	0.21	0.81	0.78	0.40	0.39	0.36		
1996	0.82	0.66	1.68	0.50	0.45	0.83	0.78	0.46	0.43	0.11		
1997	0.53	0.41	1.06	0.32	0.28	0.75	0.69	0.46	0.42	0.55		
1998	0.63	0.48	1.06	0.31	0.27	0.97	0.87	0.75	0.68	1.48		
1999	0.44	0.33	1.29	0.38	0.32	0.76	0.67	0.83	0.73	1.18	1.54	0.27
2000	0.39	0.28	0.92	0.27	0.23	0.82	0.70	1.06	0.91	1.46	1.26	0.22
2001	0.41	0.29	1.28	0.38	0.31	1.25	1.05	1.41	1.18	1.50	1.05	0.18
2002	0.59	0.40	0.87	0.26	0.20	1.15	0.94	1.58	1.30	1.49	0.87	0.15
2003	0.52	0.34	1.37	0.41	0.31	1.28	1.02	1.84	1.47	0.68	0.78	0.14
2004	1.00	0.64	1.19	0.35	0.26	1.35	1.05	1.87	1.46	0.92	1.06	0.19
2005	2.97	1.84	0.81	0.24	0.17	1.32	1.00	1.80	1.37	1.40		
2006	1.26	0.76	0.53	0.16	0.11	1.38	1.02	1.11	0.82	0.68	0.80	0.14
2007	1.90	1.10	0.69	0.20	0.14	1.02	0.73	1.05	0.76	0.95	0.85	0.15
2008	0.64	0.36	0.64	0.19	0.13	0.80	0.56	0.69	0.48	0.90		

Table 3. Goodness of fit for the black grouper non-equilibrium, surplus production model, ASPIC, configured for constant catchability.

GOODNESS-OF-FIT AND WEIGHTING (NON-BOOTSTRAPPED ANALYSIS)

Loss component number and title	Weighted SSE	N	Weighted MSE	Current weight	Inv. var. weight	R-squared in CPUE
Loss(-1) SSE in yield	0.000					
Loss(0) Penalty for B1 > K	0.000	1	N/A	1.00E+00	N/A	
Loss(1) Headboat	5.112	23	0.243	1.00E+00	4.72E-01	0.121
Loss(2) MRFSS	2.541	18	0.159	1.00E+00	7.23E-01	-0.154
Loss(3) Comm_HL	0.469	16	0.033	1.00E+00	3.43E+00	0.446
Loss(4) Comm_LL	3.435	16	0.245	1.00E+00	4.68E-01	0.255
Loss(5) FWC VS	0.851	8	0.142	1.00E+00	8.10E-01	-0.991
Loss(6) NMFS-UM RVC	6.769	15	0.521	1.00E+00	2.21E-01	-0.171
TOTAL OBJECTIVE FUNCTION, MSE, RMS	19.177		0.220	0.469		

Estimated contrast index (ideal = 1.0):	0.446	C* = (Bmax-Bmin)/K
Estimated nearness index (ideal = 1.0):	1	N* = 1 - |min(B-Bmsy)|/K

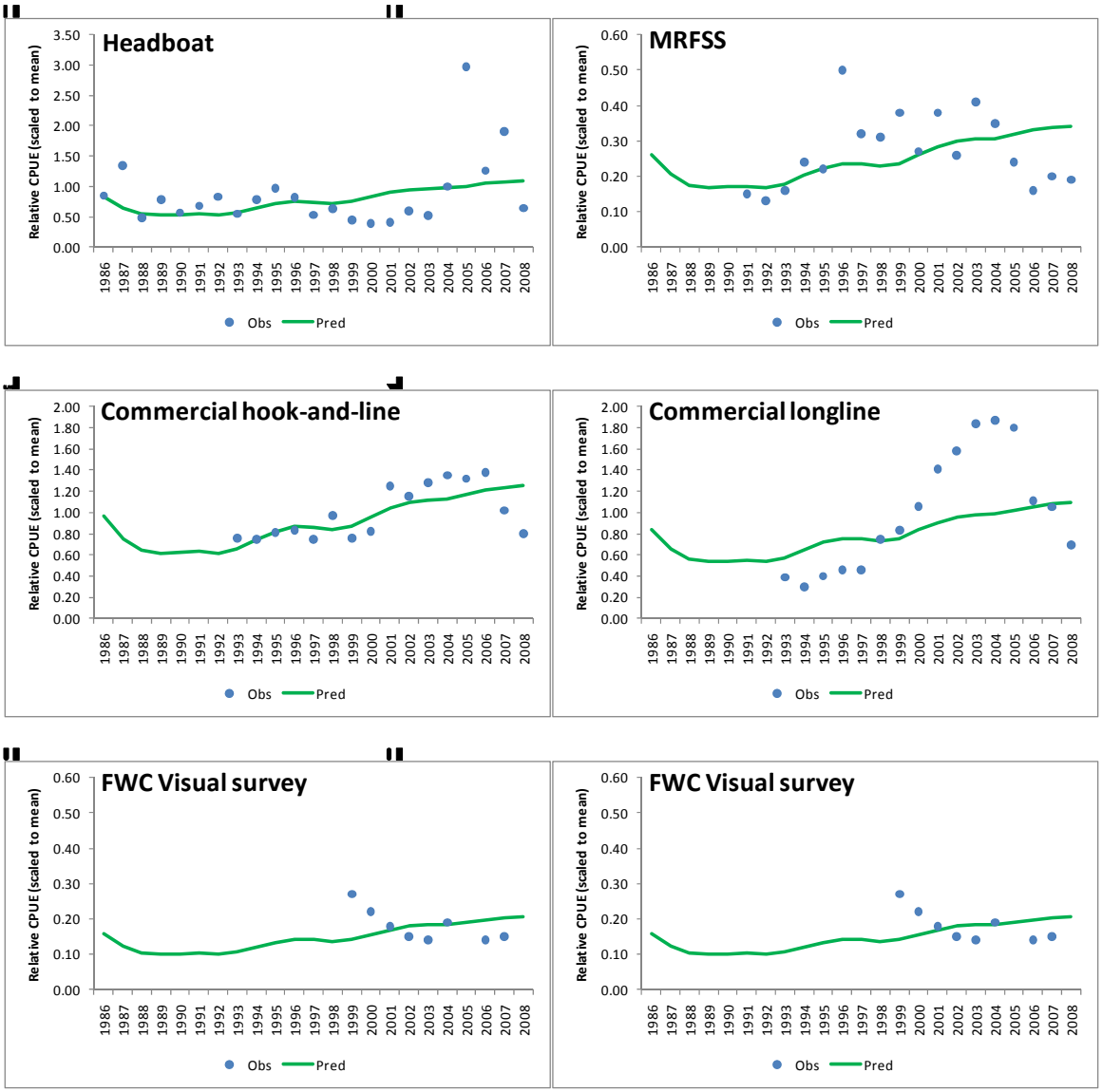
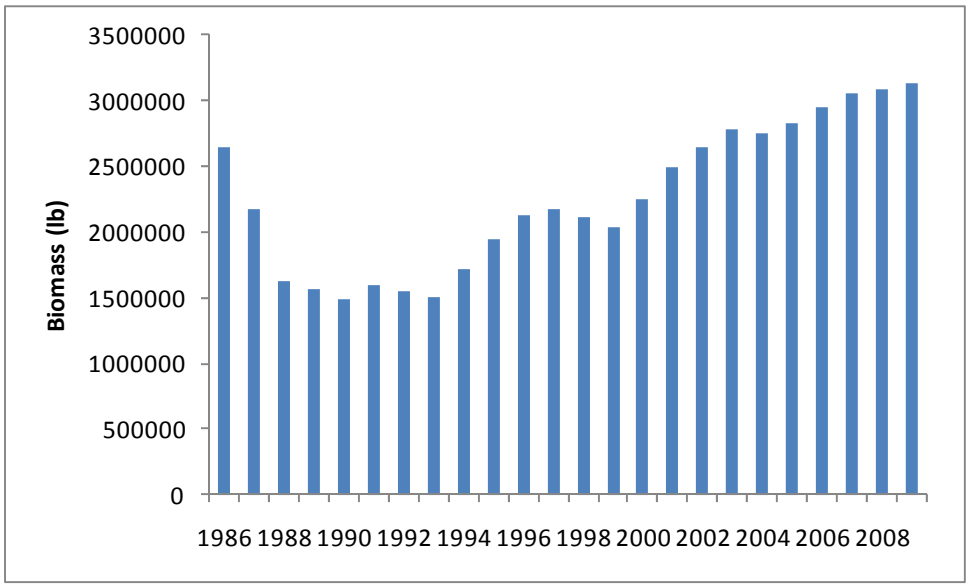


Figure 1. Fits of the first model to the four fisheries' catch per unit effort values and two fishery independent indices.

a.



b.

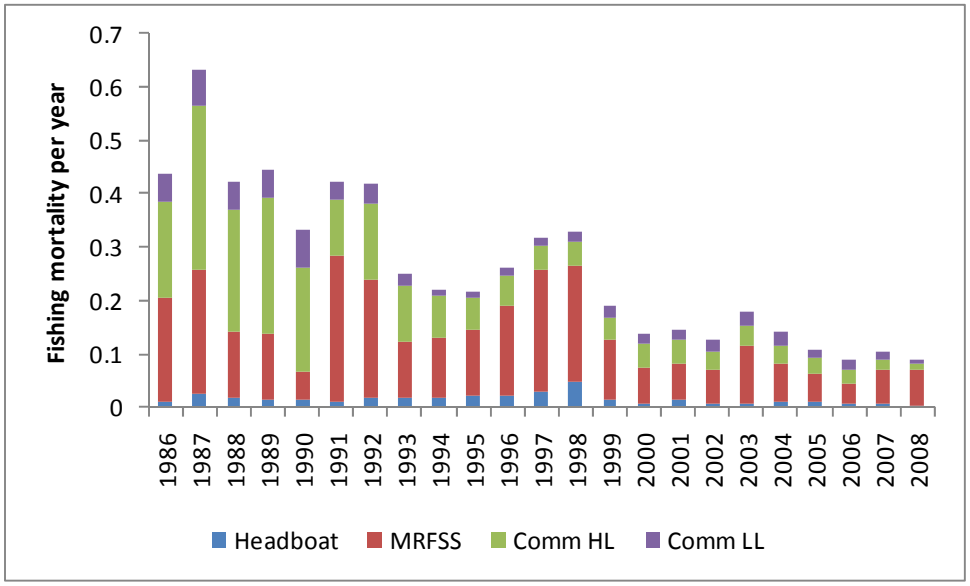
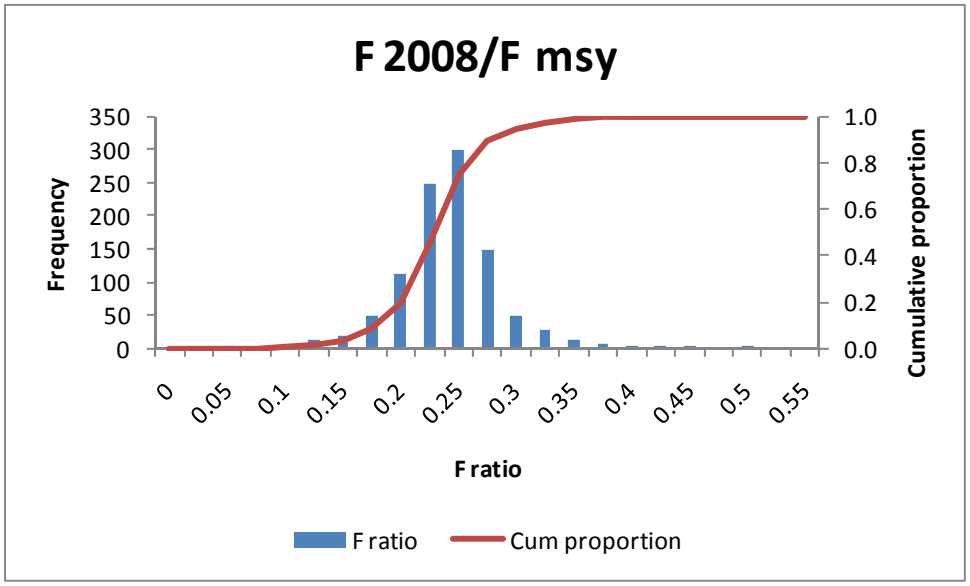


Figure 2. The estimated biomass by year (a) and the estimated fishing mortality rates by fishery and year (b).

a.



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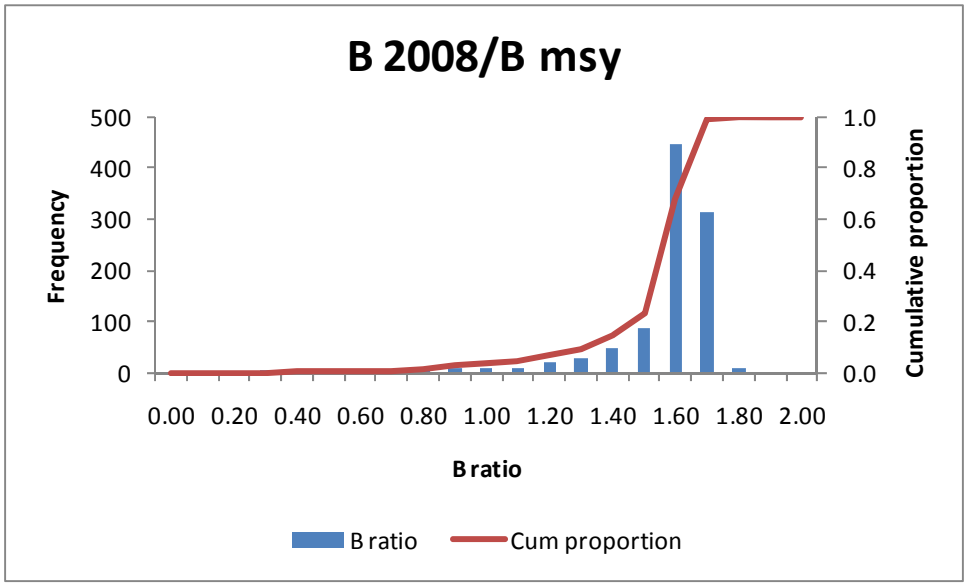

Figure 3. The distribution of outcomes from bootstrapping for the ratio of fishing mortality in 2008 to the fishing mortality at MSY (a) and the ratio of biomass in 2008 to the biomass at MSY.