Rebuilding Projections of Snowy Grouper in the SAFMC Management Area Based on the SEDAR 4 Stock Assessment

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Introduction

A stock assessment of snowy grouper (*Epinephelus niveatus*) in the South Atlantic Fisheries Management Council management area was completed and reviewed in July, 2004, using data through 2002. The primary model used in that assessment was a statistical catch-at-age model. Uncertainty was characterized with a mixed Monte Carlo and bootstrap (MCB) approach. The assessment indicated the snowy grouper population was overfished ($SSB/SSB_{MSY} = 0.18$) and that overfishing was occurring ($F/F_{MSY} = 3.0$).

In September, 2004, the NMFS Southeast Regional Office (SERO) requested recovery projections of snowy grouper. Projections were to include scenarios for constant fishing mortality rate (F); constant catch; and unspecified modified fishing mortality rates during the maximum allowable time for recovery. This original version of this report answered that request, and this revision corrects minor errors and adds more information.

Revision Levels of this Report

The original version of this report was dated November 29, 2004. A revision dated December 6, 2004, added additional explanation of the constant-F rebuilding scenario and added figure 20. Also, figures of relative reference points were provided with reference lines at 1.0. This revision (dated March 31, 2005) adds a minor correction to treatment of 2001–02 recreational landings, a correction that affects only the landings assumed for 2004–05, which were 124 mt/yr (273 klb/yr) [thousand pounds per year] and are now 128 mt/yr (282 klb/yr).

Methods

As requested, projections assume the recovery period for snowy grouper begins in 2006. This necessitates the following preliminary steps:

(1) Obtain tabulated or projected landings estimates by fishery for the years 2003–2005
(2) Re-compute rebuilding time under the assumption that zero fishing could not begin until 2006

Projections were computed using 2000 trials of an MCB method similar to that used in the stock assessment. To arrive at starting conditions for each trial, an assessment run was chosen at random from the set of 1470 MCB runs in the assessment. For each trial, the numbers-at-age in 2002 (the last year in the assessment) were projected forward in time using parameter estimates specific to that MCB run. In the stock assessment model the recreational landings (headboat and MRFSS) input are in numbers and not weight. Therefore, each MCB run chosen will have an associated landings estimate in weight in 2002 that will vary across runs and it is these landings estimates that are part of the projection output in this report. Recruitment in subsequent years was determined using the stock–recruit parameters and a bootstrap sample of the recruitment residuals from that

MCB run. Fishing in 2003–2005 was determined by matching the tabulated fixed landings (see below) exactly. Using these general methods, the following recovery scenarios were computed:

(1) Find the maximum constant fishing mortality rate in 2006 and beyond that will allow the population to recover to SSB_{MSY} in the maximum allowable recovery time.

(2) Find the maximum constant catch rate in years 2006 and beyond that will allow the population to recover to SSB_{MSY} in the maximum allowable recovery time.

Results

Landings Estimates (2003–2005)

Because the assessment model ended in 2002, we compiled or estimated landings for 2003–2005. Landings for 2003 were apparently complete in available databases. Landings estimates for 2004 were not complete in most databases. Therefore, we estimated 2004 and 2005 landings as the average of the three previous years (2001–2003) of landings from each fishery. The 2001 and 2002 landings estimates used for the average calculation were fixed values from the stock assessment input data and not a stochastic calculation. The resulting landings estimates are listed below.

	Commercial		**Recreational**	
Year	**handline (mt)**	**longline (mt)**	**headboat (mt)**	**MRFSS (mt)**
2003	67.1	25.2	0.21	10
2004	77.5	39.3	0.30	11.3
2005	77.5	39.3	0.30	11.3

	Commercial		**Recreational**	
Year	**handline (1000 lbs.)**	**longline (1000 lbs.)**	**headboat (1000 lbs.)**	**MRFSS (1000 lbs.)**
2003	147.9	55.6	0.46	22
2004	170.9	86.6	0.66	24.9
2005	170.9	86.6	0.66	24.9

In all projections, these landings were fit exactly, by solving for the fishery-specific fishing mortality rates in each MCB trial.

Rebuilding Time Under No Fishing

The SEDAR 4 stock assessment report contained projections under a no-fishing scenario; however, those projections assumed that the no-fishing regime started in 2003. Because the rebuilding period is scheduled to start in 2006, instead, the time it takes the snowy grouper population to reach SSB_{MSY} under no fishing was re-computed. In this scenario, landings were matched in 2003–2005, and fishing mortality was set to zero for following years. The stochastic projection was run for 100 years to ensure the population level in all runs could reach SSB_{MSY}. The median rebuilding time from 2000 trials was 13 years. We tested the stability of this result by plotting a running median of rebuilding time over the 2000 trials (Figure 1). The variance about this result is large, with some trials estimating more than 60 years to rebuild and others showing rebuilding before 2006 (Figure 2). The generation time estimated in the stock assessment report was 21 years. Therefore, the maximum allowable recovery time is 34 years, meaning that the under a rebuilding plan, the stock should reach SSB_{MSY} (the rebuilding target) by the beginning of year 2040. Median recruitment, total mature biomass (SSB), and the ratio of SSB/SSB_{MSY} estimates from the 2000 simulation trials under the no-fishing scenario are shown in Tables 1–3 and Figures 3–5, respectively.

Constant-F Scenario

In this scenario, rebuilding was simulated with a constant fishing mortality rate (F) in 2006–2039. In the MCB procedure, each sampled run was projected and iteratively solved to determine the constant F that would allow rebuilding for that trial within the recovery period. A total of 2000 trials were used to determine the distribution of solutions. Recruitment estimates are shown in Table 4 and Figure 6. Total mature biomass (SSB) and SSB/SSB_{MSY} estimates are shown in Table 5–6 and Figures 7–8.

In Figure 8, some individual trials exceeded SSB_{MSY} during the recovery period (year 2040). In such cases, the stochastic recruitment pattern resulted in above average recruitment in the first few years of the projection, which allowed the population to exceed SSB_{MSY} prior to 2040. The same runs experienced average or below average recruitment in later years of the projection, so the result was a population exactly matching SSB_{MSY} in 2040.

The median constant F resulting in recovery to SSB_{MSY} by the start of 2040 was estimated to be 0.103 (yr^{-1}) (Table 7 and Figure 9). The stability of this result was examined by plotting the running median result over the 2000 runs (Figure 10). The constant F for recovery is slightly higher than F_{MSY}, resulting in a median F/F_{MSY} ratio of 1.06 (Table 8 and Figure 11). This occurs because recruitment estimates (which are randomly sampled in the projections) from the stock assessment were slightly above average. The catch resulting from the constant F scenario starts out low, 44 mt (97 thousand lbs.) in 2006, and then rises to 143 mt (315 thousand lbs.) in 2040 (Table 9, Figure 12). For comparison, landings in 2002–2003 were 126 and 103 mt (278 and 227 thousand lbs.), respectively. This suggests that fishery landings would have to be reduced by about 54–65% to achieve this rebuilding scenario. On average, landings would recover to the 2003 value of 103 mt (227 thousand lbs.) by 2023 and to the 2002 value of 126 mt (278 thousand lbs.) around 2030 or 2031 (Table 9).

Constant-Catch Scenario

In this scenario, rebuilding was simulated with constant catch in 2006–2039. In the MCB procedure, each sampled run was projected and iteratively solved to determine the constant catch level that would allow rebuilding within the maximum recovery period. This simulation was more difficult computationally than the constant F scenario, as for each year within a single trial, the F must be found that matches the specified constant catch. This whole process is then iteratively solved to find the constant catch resulting in the population reaching SSB_{MSY} by the start of year 2040. A total of 2000 trials were used to determine the distribution of solutions. Recruitment estimates are shown in Table 10 and Figure 13. Total mature biomass (SSB) and the ratio SSB/SSB_{MSY} estimates are shown in Table 11–12 and Figures 14–15.

In Figure 15, some individual runs exceeded SSB_{MSY} prior to the end of the recovery period (year 2040). In such cases, stochastic recruitment pattern resulted in above average recruitment in the first few years of the projection. This allowed the population to exceed SSB_{MSY} prior to 2040. These runs also experienced average or below average recruitment in later years of the projection, so the result was a population exactly matching SSB_{MSY} in 2040.

The median constant catch resulting in recovery to SSB_{MSY} by the start of 2040 was estimated to be 84 mt/yr (185 thousand lbs.)(Table 15 and Figure 18). We tested the stability of this result by plotting a running median of constant catch over the 2000 runs (Figure 19). The median value of the ratio of constant catch to MSY was 0.60 (not shown). Landings estimates for 2002–2003 are 126 and 103 mt, respectively. This suggests that landings would have to be reduced by about 18–33% to achieve recovery by the constant catch scenario. Fishing mortality rates estimated for the constant catch scenario remain above F_{MSY} until the year 2028 (Tables 13–14 and Figures 16–17).

Comments

Results of the two management scenarios are compared in Table 16. Although the constant-catch scenario has higher initial landings, it is soon surpassed by the constant-F scenario, which has higher landings overall.

In the constant-F projection, the median estimate of F/F_{MSY} was 1.06. This is an unusual result, because in general, $F < F_{MSY}$ is required to bring a depressed population to B_{MSY}. However, this population is estimated to have experienced above-average recruitment in recent years (Fig. 20). This has resulted in an age structure skewed towards younger fish, not vulnerable to fishing. Thus, a slightly higher F than expected can still lead to B_{MSY} in the rebuilding time frame, although the higher F would not be sustainable indefinitely.

As usual, projections should be interpreted in light of the model assumptions and data sources used. Several assumptions merit particular consideration:

• In constant-landings scenarios, it is necessary to reduce the fishing mortality rate as the stock recovers. This implies reductions in fishing effort.

• The projected scenarios assume no increase in proportion of catch that is discarded. To meet that assumption may require management action.

• Projections assume that the estimated stock–recruit relationship applies in the future and that past residuals represent future uncertainty in recruitment. If the stock–recruitment relationship changes, rebuilding may be affected.

Table 1. Recruitment (1000s) estimates from stochastic projections (n=2000) of the SEDAR 4 snowy grouper stock assessment model with no fishing starting in 2006.

Year	10th percentile	Median	90th percentile
2002	30	116	445
2003	34	153	620
2004	36	165	641
2005	38	189	708
2006	39	190	762
2007	25	177	726
2008	28	191	804
2009	30	211	820
2010	35	217	866
2011	42	231	886
2012	46	240	892
2013	51	256	933
2014	50	260	956
2015	58	271	1009
2016	65	291	1023
2017	66	290	1022
2018	71	299	1029
2019	77	307	1081

Table 2a. Total mature biomass (SSB) (mt) estimates from stochastic projections (n=2000) of the SEDAR 4 snowy grouper stock assessment model with no fishing starting in 2006.

Year	10th percentile	Median	90th percentile
2002	275	392	585
2003	288	453	715
2004	324	562	979
2005	269	596	1142
2006	172	564	1211
2007	189	626	1367
2008	216	709	1514
2009	260	800	1684
2010	316	915	1867
2011	383	1037	2051
2012	441	1165	2246
2013	489	1302	2481
2014	540	1445	2676
2015	586	1587	2874
2016	641	1752	3082
2017	706	1908	3277
2018	773	2083	3468
2019	840	2256	3704

Table 2b. Total mature biomass (SSB) (thousand lbs.) estimates from stochastic projections (n=2000) of the SEDAR 4 snowy grouper stock assessment model with no fishing starting in 2006.

Year	10th percentile	Median	90th percentile
2002	607	865	1290
2003	636	999	1576
2004	714	1240	2158
2005	592	1315	2517
2006	378	1242	2671
2007	418	1380	3013
2008	477	1563	3339
2009	572	1765	3713
2010	698	2016	4116
2011	844	2286	4522
2012	972	2569	4951
2013	1078	2870	5469
2014	1190	3186	5900
2015	1293	3499	6336
2016	1413	3862	6794
2017	1557	4207	7224
2018	1703	4591	7645
2019	1851	4973	8165

Table 3. Ratio of total mature biomass to total mature biomass at maximum sustainable yield (SSB/SSB_{MSY}) estimates from stochastic projections (n=2000) of the SEDAR 4 snowy grouper stock assessment model with no fishing starting in 2006.

Year	10th percentile	Median	90th percentile
2002	0.10	0.18	0.37
2003	0.10	0.21	0.46
2004	0.11	0.26	0.62
2005	0.09	0.27	0.74
2006	0.06	0.26	0.80
2007	0.07	0.29	0.91
2008	0.07	0.33	1.02
2009	0.09	0.37	1.14
2010	0.11	0.43	1.27
2011	0.13	0.48	1.42
2012	0.15	0.54	1.58
2013	0.16	0.60	1.72
2014	0.18	0.67	1.87
2015	0.19	0.74	2.03
2016	0.21	0.81	2.19
2017	0.23	0.89	2.33
2018	0.25	0.97	2.47
2019	0.28	1.04	2.58

Table 4. Recruitment (1000s) estimates from stochastic projections (n=2000) of the SEDAR 4 snowy grouper stock assessment model with a constant fishing mortality rate (yr^{-1}) starting in 2006 that allows for rebuilding within 35 years.

Year	10th percentile	Median	90th percentile
2002	31	116	457
2003	39	162	598
2004	40	175	659
2005	41	194	728
2006	37	193	747
2007	27	181	782
2008	30	195	760
2009	32	190	775
2010	32	206	778
2011	38	206	786
2012	42	214	793
2013	50	229	835
2014	52	238	851
2015	53	249	876
2016	56	239	786
2017	56	255	825
2018	63	252	839
2019	64	256	817
2020	65	267	876
2021	72	269	881
2022	71	280	900
2023	75	289	928
2024	80	289	942
2025	78	302	953
2026	89	298	888
2027	84	305	997
2028	84	312	980
2029	96	313	992
2030	94	338	999
2031	93	331	956
2032	94	319	926
2033	94	315	984
2034	101	342	1061
2035	100	324	1032
2036	96	320	1042
2037	104	340	1055
2038	105	338	1044
2039	107	347	1104
2040	110	346	1014

Table 5a. Total mature biomass (mt) estimates from stochastic projections (n=2000) of the SEDAR 4 snowy grouper stock assessment model with a constant fishing mortality rate (yr^{-1}) starting in 2006 that allows for rebuilding within 37 years.

Year	10th percentile	Median	90th percentile
2002	278	394	612
2003	289	456	735
2004	325	574	1000
2005	278	609	1173
2006	182	577	1232
2007	194	601	1248
2008	213	624	1223
2009	253	664	1211
2010	296	707	1208
2011	343	759	1236
2012	381	808	1292
2013	419	862	1340
2014	456	906	1397
2015	491	948	1424
2016	526	986	1476
2017	568	1029	1534
2018	613	1070	1577
2019	662	1111	1628
2020	701	1153	1680
2021	750	1205	1739
2022	797	1248	1787
2023	842	1296	1844
2024	885	1334	1904
2025	918	1375	1961
2026	955	1424	2019
2027	989	1467	2098
2028	1033	1522	2165
2029	1076	1566	2223
2030	1108	1624	2283
2031	1145	1682	2320
2032	1176	1738	2397
2033	1204	1784	2478
2034	1223	1828	2538
2035	1253	1872	2614
2036	1262	1918	2693
2037	1293	1967	2796
2038	1320	2007	2872
2039	1336	2043	2957
2040	1361	2088	3092

Table 5b. Total mature biomass (thousand lbs.) estimates from stochastic projections (n=2000) of the SEDAR 4 snowy grouper stock assessment model with a constant fishing mortality rate (yr^{-1}) starting in 2006 that allows for rebuilding within 37 years.

Year	10th percentile	Median	90th percentile
2002	612	869	1349
2003	638	1005	1621
2004	715	1265	2204
2005	613	1344	2586
2006	401	1273	2715
2007	429	1326	2752
2008	469	1377	2697
2009	558	1464	2669
2010	652	1558	2662
2011	756	1673	2724
2012	839	1781	2848
2013	924	1901	2955
2014	1005	1998	3079
2015	1082	2091	3140
2016	1161	2175	3255
2017	1253	2268	3381
2018	1351	2358	3477
2019	1460	2450	3589
2020	1546	2543	3704
2021	1653	2656	3833
2022	1758	2751	3940
2023	1856	2857	4065
2024	1951	2941	4198
2025	2025	3031	4324
2026	2105	3139	4451
2027	2181	3235	4625
2028	2278	3355	4772
2029	2372	3452	4902
2030	2443	3581	5034
2031	2525	3707	5115
2032	2593	3832	5285
2033	2655	3932	5463
2034	2696	4031	5595
2035	2762	4127	5764
2036	2783	4228	5937
2037	2850	4337	6165
2038	2909	4424	6332
2039	2946	4505	6519
2040	3001	4603	6818

Table 6. Ratio of total mature biomass to total mature biomass at maximum sustainable yield (SSB/SSB_{MSY}) estimates from stochastic projections (n=2000) of the SEDAR 4 snowy grouper stock assessment model with a constant fishing mortality rate (yr^{-1}) starting in 2006 that allows for rebuilding within 37 years.

Year	10th percentile	Median	90th percentile
2002	0.10	0.18	0.38
2003	0.10	0.21	0.48
2004	0.12	0.26	0.64
2005	0.10	0.28	0.75
2006	0.07	0.26	0.80
2007	0.07	0.28	0.81
2008	0.08	0.29	0.80
2009	0.09	0.31	0.79
2010	0.11	0.34	0.81
2011	0.12	0.36	0.82
2012	0.14	0.38	0.85
2013	0.15	0.41	0.86
2014	0.17	0.43	0.89
2015	0.18	0.46	0.90
2016	0.19	0.48	0.92
2017	0.21	0.50	0.93
2018	0.23	0.52	0.95
2019	0.24	0.55	0.97
2020	0.26	0.57	0.98
2021	0.28	0.60	1.00
2022	0.31	0.62	1.01
2023	0.33	0.64	1.02
2024	0.35	0.66	1.03
2025	0.37	0.69	1.04
2026	0.40	0.71	1.05
2027	0.43	0.73	1.06
2028	0.46	0.75	1.06
2029	0.49	0.77	1.08
2030	0.52	0.79	1.08
2031	0.55	0.82	1.09
2032	0.59	0.84	1.09
2033	0.62	0.86	1.10
2034	0.65	0.89	1.09
2035	0.70	0.91	1.09
2036	0.75	0.93	1.08
2037	0.80	0.95	1.06
2038	0.85	0.97	1.05
2039	0.92	0.99	1.03
2040	1.00	1.00	1.00

Table 7. Fully selected fishing mortality rate (yr^{-1}) estimates from stochastic projections (n=2000) of the SEDAR 4 snowy grouper stock assessment model with a constant fishing mortality rate (yr^{-1}) starting in 2006 that allows for rebuilding within 37 years.

Year	10th percentile	Median	90th percentile
2002	0.157	0.252	0.380
2003	0.117	0.226	0.450
2004	0.147	0.337	0.970
2005	0.160	0.428	1.860
2006	0.023	0.103	0.178
2007	0.023	0.103	0.178
2008	0.023	0.103	0.178
2009	0.023	0.103	0.178
2010	0.023	0.103	0.178
2011	0.023	0.103	0.178
2012	0.023	0.103	0.178
2013	0.023	0.103	0.178
2014	0.023	0.103	0.178
2015	0.023	0.103	0.178
2016	0.023	0.103	0.178
2017	0.023	0.103	0.178
2018	0.023	0.103	0.178
2019	0.023	0.103	0.178
2020	0.023	0.103	0.178
2021	0.023	0.103	0.178
2022	0.023	0.103	0.178
2023	0.023	0.103	0.178
2024	0.023	0.103	0.178
2025	0.023	0.103	0.178
2026	0.023	0.103	0.178
2027	0.023	0.103	0.178
2028	0.023	0.103	0.178
2029	0.023	0.103	0.178
2030	0.023	0.103	0.178
2031	0.023	0.103	0.178
2032	0.023	0.103	0.178
2033	0.023	0.103	0.178
2034	0.023	0.103	0.178
2035	0.023	0.103	0.178
2036	0.023	0.103	0.178
2037	0.023	0.103	0.178
2038	0.023	0.103	0.178
2039	0.023	0.103	0.178
2040	-	-	-

Table 8. Ratio of fully selected fishing mortality (F) to F at maximum sustainable yield (F/F_{MSY}) estimates from stochastic projections (n=2000) of the SEDAR 4 snowy grouper stock assessment model with a constant fishing mortality rate (yr^{-1}) starting in 2006 that allows for rebuilding within 37 years.

Year	10th percentile	Median	90th percentile
2002	1.23	2.75	5.70
2003	0.97	2.53	6.68
2004	1.16	3.79	14.12
2005	1.25	4.72	28.18
2006	0.35	1.06	1.45
2007	0.35	1.06	1.45
2008	0.35	1.06	1.45
2009	0.35	1.06	1.45
2010	0.35	1.06	1.45
2011	0.35	1.06	1.45
2012	0.35	1.06	1.45
2013	0.35	1.06	1.45
2014	0.35	1.06	1.45
2015	0.35	1.06	1.45
2016	0.35	1.06	1.45
2017	0.35	1.06	1.45
2018	0.35	1.06	1.45
2019	0.35	1.06	1.45
2020	0.35	1.06	1.45
2021	0.35	1.06	1.45
2022	0.35	1.06	1.45
2023	0.35	1.06	1.45
2024	0.35	1.06	1.45
2025	0.35	1.06	1.45
2026	0.35	1.06	1.45
2027	0.35	1.06	1.45
2028	0.35	1.06	1.45
2029	0.35	1.06	1.45
2030	0.35	1.06	1.45
2031	0.35	1.06	1.45
2032	0.35	1.06	1.45
2033	0.35	1.06	1.45
2034	0.35	1.06	1.45
2035	0.35	1.06	1.45
2036	0.35	1.06	1.45
2037	0.35	1.06	1.45
2038	0.35	1.06	1.45
2039	0.35	1.06	1.45
2040	-	-	-

Table 9a. Catch (mt) estimates from stochastic projections (n=2000) of the SEDAR 4 snowy grouper stock assessment model with a constant fishing mortality rate (yr^{-1}) starting in 2006 that allows for rebuilding within 37 years.

Year	10th percentile	Median	90th percentile
2002	–	126	–
2003	–	103	–
2004	–	128	–
2005	–	128	–
2006	3	44	150
2007	4	47	148
2008	5	50	151
2009	5	54	153
2010	6	58	155
2011	7	62	157
2012	7	64	161
2013	8	67	163
2014	8	71	166
2015	9	75	168
2016	10	79	171
2017	11	82	175
2018	11	87	177
2019	12	91	179
2020	14	95	179
2021	14	99	181
2022	15	101	185
2023	16	103	187
2024	17	106	187
2025	18	110	190
2026	20	113	190
2027	21	115	192
2028	22	118	191
2029	24	122	193
2030	26	125	196
2031	27	127	198
2032	28	130	200
2033	29	133	202
2034	31	135	203
2035	33	138	204
2036	35	138	205
2037	36	140	206
2038	38	141	208
2039	39	143	207
2040	–	–	–

Table 9b. Catch (thousand lbs.) estimates from stochastic projections (n=2000) of the SEDAR 4 snowy grouper stock assessment model with a constant fishing mortality rate (yr^{-1}) starting in 2006 that allows for rebuilding within 37 years.

Year	10th percentile	Median	90th percentile
2002	–	278	–
2003	–	226	–
2004	–	283	–
2005	–	283	–
2006	8	97	332
2007	9	104	326
2008	11	111	332
2009	12	119	336
2010	14	127	342
2011	15	136	346
2012	15	142	354
2013	17	148	359
2014	19	157	367
2015	20	166	370
2016	21	174	378
2017	23	182	387
2018	25	192	391
2019	27	200	394
2020	30	209	394
2021	31	218	400
2022	33	222	408
2023	35	228	412
2024	38	235	412
2025	41	242	418
2026	45	249	419
2027	47	255	423
2028	49	261	422
2029	54	269	426
2030	57	275	433
2031	60	280	437
2032	62	287	441
2033	64	292	446
2034	69	298	447
2035	73	304	450
2036	77	304	451
2037	80	309	454
2038	84	312	458
2039	87	315	455
2040	–	–	–

Table 10. Recruitment (1000s) estimates from stochastic projections (n=2000) of the SEDAR 4 snowy grouper stock assessment model with a constant catch starting in 2006 that allows for rebuilding within 37 years.

Year	10th percentile	Median	90th percentile
2002	31	112	433
2003	34	153	558
2004	36	168	645
2005	41	185	711
2006	37	186	734
2007	27	183	753
2008	27	173	742
2009	28	168	743
2010	31	170	749
2011	34	176	726
2012	37	184	691
2013	37	184	725
2014	44	189	726
2015	44	203	763
2016	45	205	744
2017	46	211	752
2018	51	212	781
2019	52	212	786
2020	55	226	774
2021	59	235	824
2022	59	233	811
2023	59	247	813
2024	63	247	841
2025	73	256	807
2026	73	259	861
2027	75	262	775
2028	78	280	918
2029	78	281	883
2030	78	275	917
2031	84	294	895
2032	89	300	939
2033	88	298	911
2034	89	301	976
2035	96	304	973
2036	97	333	930
2037	97	315	1024
2038	102	322	1016
2039	99	338	1050
2040	105	328	1028

Table 11a. Total mature biomass (mt) estimates from stochastic projections (n=2000) of the SEDAR 4 snowy grouper stock assessment model with a constant catch starting in 2006 that allows for rebuilding within 37 years.

Year	10th percentile	Median	90th percentile
2002	277	389	600
2003	289	447	732
2004	324	564	977
2005	277	594	1150
2006	184	561	1220
2007	183	547	1196
2008	188	535	1173
2009	206	540	1149
2010	231	548	1145
2011	254	568	1163
2012	281	590	1180
2013	298	617	1206
2014	317	645	1228
2015	334	670	1254
2016	347	699	1274
2017	366	726	1310
2018	382	755	1332
2019	399	785	1362
2020	427	816	1393
2021	460	864	1436
2022	488	908	1483
2023	524	947	1513
2024	560	989	1575
2025	607	1041	1634
2026	637	1092	1676
2027	677	1154	1725
2028	731	1213	1795
2029	785	1269	1874
2030	838	1332	1941
2031	887	1391	2017
2032	939	1452	2107
2033	1000	1526	2214
2034	1072	1596	2352
2035	1126	1675	2468
2036	1182	1748	2577
2037	1247	1820	2718
2038	1285	1910	2863
2039	1334	1998	3029
2040	1363	2102	3200

Table 11b. Total mature biomass (thousand lbs.) estimates from stochastic projections (n=2000) of the SEDAR 4 snowy grouper stock assessment model with a constant catch starting in 2006 that allows for rebuilding within 37 years.

Year	10th percentile	Median	90th percentile
2002	611	858	1323
2003	638	984	1614
2004	715	1243	2155
2005	610	1310	2536
2006	406	1236	2690
2007	404	1205	2637
2008	415	1180	2586
2009	455	1190	2534
2010	509	1209	2523
2011	560	1252	2565
2012	619	1300	2602
2013	657	1360	2658
2014	699	1422	2708
2015	737	1477	2765
2016	765	1540	2808
2017	808	1601	2887
2018	842	1663	2936
2019	881	1730	3003
2020	941	1800	3072
2021	1015	1905	3166
2022	1077	2002	3270
2023	1156	2088	3335
2024	1235	2181	3472
2025	1338	2296	3602
2026	1405	2407	3695
2027	1493	2545	3802
2028	1612	2675	3957
2029	1730	2797	4130
2030	1847	2936	4279
2031	1955	3066	4448
2032	2070	3200	4646
2033	2204	3363	4882
2034	2364	3519	5185
2035	2483	3693	5441
2036	2606	3853	5680
2037	2750	4012	5992
2038	2833	4211	6311
2039	2941	4406	6677
2040	3006	4635	7054

Table 12. Ratio of total mature biomass to total mature biomass at maximum sustainable yield (SSB/SSB_{MSY}) estimates from stochastic projections (n=2000) of the SEDAR 4 snowy grouper stock assessment model with a constant catch starting in 2006 that allows for rebuilding within 37 years.

Year	10th percentile	Median	90th percentile
2002	0.10	0.18	0.38
2003	0.10	0.21	0.47
2004	0.12	0.25	0.63
2005	0.10	0.27	0.74
2006	0.065	0.25	0.78
2007	0.064	0.25	0.78
2008	0.066	0.24	0.76
2009	0.07	0.24	0.75
2010	0.08	0.24	0.74
2011	0.09	0.25	0.74
2012	0.10	0.27	0.75
2013	0.11	0.28	0.76
2014	0.12	0.29	0.79
2015	0.13	0.31	0.81
2016	0.13	0.32	0.82
2017	0.14	0.32	0.82
2018	0.15	0.34	0.84
2019	0.16	0.35	0.85
2020	0.17	0.36	0.87
2021	0.19	0.38	0.87
2022	0.20	0.40	0.88
2023	0.22	0.42	0.88
2024	0.24	0.44	0.91
2025	0.26	0.47	0.93
2026	0.28	0.49	0.94
2027	0.30	0.52	0.95
2028	0.33	0.55	0.97
2029	0.36	0.58	0.98
2030	0.40	0.61	0.98
2031	0.43	0.64	0.99
2032	0.47	0.68	0.99
2033	0.51	0.72	1.00
2034	0.56	0.75	1.00
2035	0.61	0.79	1.01
2036	0.66	0.84	1.02
2037	0.72	0.88	1.02
2038	0.80	0.92	1.02
2039	0.89	0.96	1.01
2040	1.00	1.00	1.00

Table 13. Fully selected fishing mortality rate (yr^{-1}) estimates from stochastic projections (n=2000) of the SEDAR 4 snowy grouper stock assessment model with a constant catch starting in 2006 that allows for rebuilding within 37 years.

Year	10th percentile	Median	90th percentile
2002	0.160	0.255	0.385
2003	0.118	0.225	0.458
2004	0.149	0.337	0.970
2005	0.161	0.430	1.806
2006	0.075	0.188	0.293
2007	0.068	0.188	0.297
2008	0.059	0.185	0.294
2009	0.053	0.180	0.284
2010	0.047	0.174	0.278
2011	0.045	0.168	0.274
2012	0.043	0.164	0.263
2013	0.041	0.160	0.261
2014	0.039	0.156	0.261
2015	0.037	0.152	0.258
2016	0.036	0.148	0.251
2017	0.032	0.144	0.249
2018	0.029	0.139	0.244
2019	0.027	0.135	0.239
2020	0.025	0.130	0.231
2021	0.024	0.125	0.226
2022	0.022	0.120	0.222
2023	0.021	0.116	0.218
2024	0.019	0.111	0.213
2025	0.018	0.107	0.207
2026	0.017	0.103	0.201
2027	0.016	0.100	0.197
2028	0.015	0.096	0.193
2029	0.014	0.093	0.189
2030	0.013	0.088	0.187
2031	0.012	0.084	0.179
2032	0.012	0.081	0.174
2033	0.011	0.077	0.170
2034	0.010	0.074	0.168
2035	0.009	0.070	0.166
2036	0.009	0.067	0.164
2037	0.008	0.063	0.161
2038	0.008	0.060	0.160
2039	0.007	0.057	0.157
2040	-	-	-

Table 14. Ratio of fully selected fishing mortality (F) to F at maximum sustainable yield (F/F_{MSY}) estimates from stochastic projections (n=2000) of the SEDAR 4 snowy grouper stock assessment model with a constant catch starting in 2006 that allows for rebuilding within 37 years.

Year	10th percentile	Median	90th percentile
2002	1.27	2.84	5.62
2003	0.94	2.49	6.51
2004	1.22	3.82	13.89
2005	1.29	4.85	27.21
2006	0.87	1.90	3.28
2007	0.83	1.88	3.19
2008	0.80	1.86	3.10
2009	0.74	1.81	2.95
2010	0.70	1.74	2.83
2011	0.66	1.67	2.72
2012	0.65	1.63	2.63
2013	0.63	1.60	2.58
2014	0.61	1.57	2.51
2015	0.60	1.52	2.44
2016	0.55	1.46	2.37
2017	0.51	1.43	2.34
2018	0.48	1.39	2.29
2019	0.44	1.34	2.21
2020	0.40	1.29	2.10
2021	0.38	1.24	2.05
2022	0.35	1.20	2.03
2023	0.33	1.17	1.94
2024	0.32	1.13	1.87
2025	0.29	1.09	1.79
2026	0.27	1.05	1.72
2027	0.25	1.01	1.64
2028	0.24	0.98	1.60
2029	0.22	0.95	1.53
2030	0.21	0.91	1.49
2031	0.20	0.89	1.43
2032	0.18	0.85	1.36
2033	0.17	0.83	1.30
2034	0.16	0.80	1.25
2035	0.15	0.77	1.22
2036	0.14	0.74	1.18
2037	0.13	0.69	1.16
2038	0.12	0.67	1.15
2039	0.12	0.63	1.15
2040	-	-	-

Table 15a. Catch (mt) estimates from stochastic projections (n=2000) of the SEDAR 4 snowy grouper stock assessment model with maximum constant catch starting in 2006 that allows for rebuilding within 37 years.

Year	10th percentile	Median	90th percentile
2002	–	126	–
2003	–	103	–
2004	–	128	–
2005	–	128	–
2006	13	84	172
2007	13	84	172
2008	13	84	172
2009	13	84	172
2010	13	84	172
2011	13	84	172
2012	13	84	172
2013	13	84	172
2014	13	84	172
2015	13	84	172
2016	13	84	172
2017	13	84	172
2018	13	84	172
2019	13	84	172
2020	13	84	172
2021	13	84	172
2022	13	84	172
2023	13	84	172
2024	13	84	172
2025	13	84	172
2026	13	84	172
2027	13	84	172
2028	13	84	172
2029	13	84	172
2030	13	84	172
2031	13	84	172
2032	13	84	172
2033	13	84	172
2034	13	84	172
2035	13	84	172
2036	13	84	172
2037	13	84	172
2038	13	84	172
2039	13	84	172
2040	–	–	–

Table 15b. Catch (thousand lbs.) estimates from stochastic projections (n=2000) of the SEDAR 4 snowy grouper stock assessment model with maximum constant catch starting in 2006 that allows for rebuilding within 37 years.

Year	10th percentile	Median	90th percentile
2002	–	278	–
2003	–	227	–
2004	–	282	–
2005	–	282	–
2006	29	185	379
2007	29	185	379
2008	29	185	379
2009	29	185	379
2010	29	185	379
2011	29	185	379
2012	29	185	379
2013	29	185	379
2014	29	185	379
2015	29	185	379
2016	29	185	379
2017	29	185	379
2018	29	185	379
2019	29	185	379
2020	29	185	379
2021	29	185	379
2022	29	185	379
2023	29	185	379
2024	29	185	379
2025	29	185	379
2026	29	185	379
2027	29	185	379
2028	29	185	379
2029	29	185	379
2030	29	185	379
2031	29	185	379
2032	29	185	379
2033	29	185	379
2034	29	185	379
2035	29	185	379
2036	29	185	379
2037	29	185	379
2038	29	185	379
2039	29	185	379
2040	–	–	–

Table 16. Summary of the estimates from stochastic projections (n=2000) of the SEDAR 4 snowy grouper stock assessment model with management starting in 2006 that allows for rebuilding by the beginning of 2040.

Description	**No. yrs $F>F_{MSY}$**	**No. yrs $F>1.1F_{MSY}$**	**Sum landings 2006–2016, mt**	**Sum landings 2017–2027, mt**	**Sum landings 2028–2039, mt**	**Total landings 2006–2039, mt**
Constant F	34*	0	672	1102	1590	3365
Constant Catch	22	19	920	920	1004	2844
Constant $F=F_{MSY}$**	0	0	632	1093	1599	3324

Description	**No. yrs $F>F_{MSY}$**	**No. yrs $F>1.1F_{MSY}$**	**Sum landings 2006–2016 (1000 lbs.)**	**Sum landings 2017–2027 (1000 lbs.)**	**Sum landings 2028–2039 (1000 lbs.)**	**Total landings 2006–2039 (1000 lbs.)**
Constant F	34*	0	1482	2430	3506	7419
Constant Catch	22	19	2028	2028	2213	6269
Constant $F=F_{MSY}$**	0	0	1393	2410	3525	7328

*****Note: In the constant-F projection, the median estimate of F/F_{MSY} was 1.06. This is an unusual result, because in general, $F < F_{MSY}$ is required to bring a depressed population to B_{MSY}. However, this population is estimated to have experienced above-average recruitment in recent years (Fig. 20). This results in an age structure skewed towards younger fish, not vulnerable to fishing. Thus, a slightly higher F than expected can still lead to B_{MSY} in this time frame, although the higher F would not be sustainable indefinitely without a stock decline.

**Note: This additional scenario (added for illustration) rebuilds by the beginning of year 2036.

Figure 1. Rebuilding time (running median) at F=0 (2006–) from stochastic projections (n=2000) of the SEDAR 4 snowy grouper assessment model.

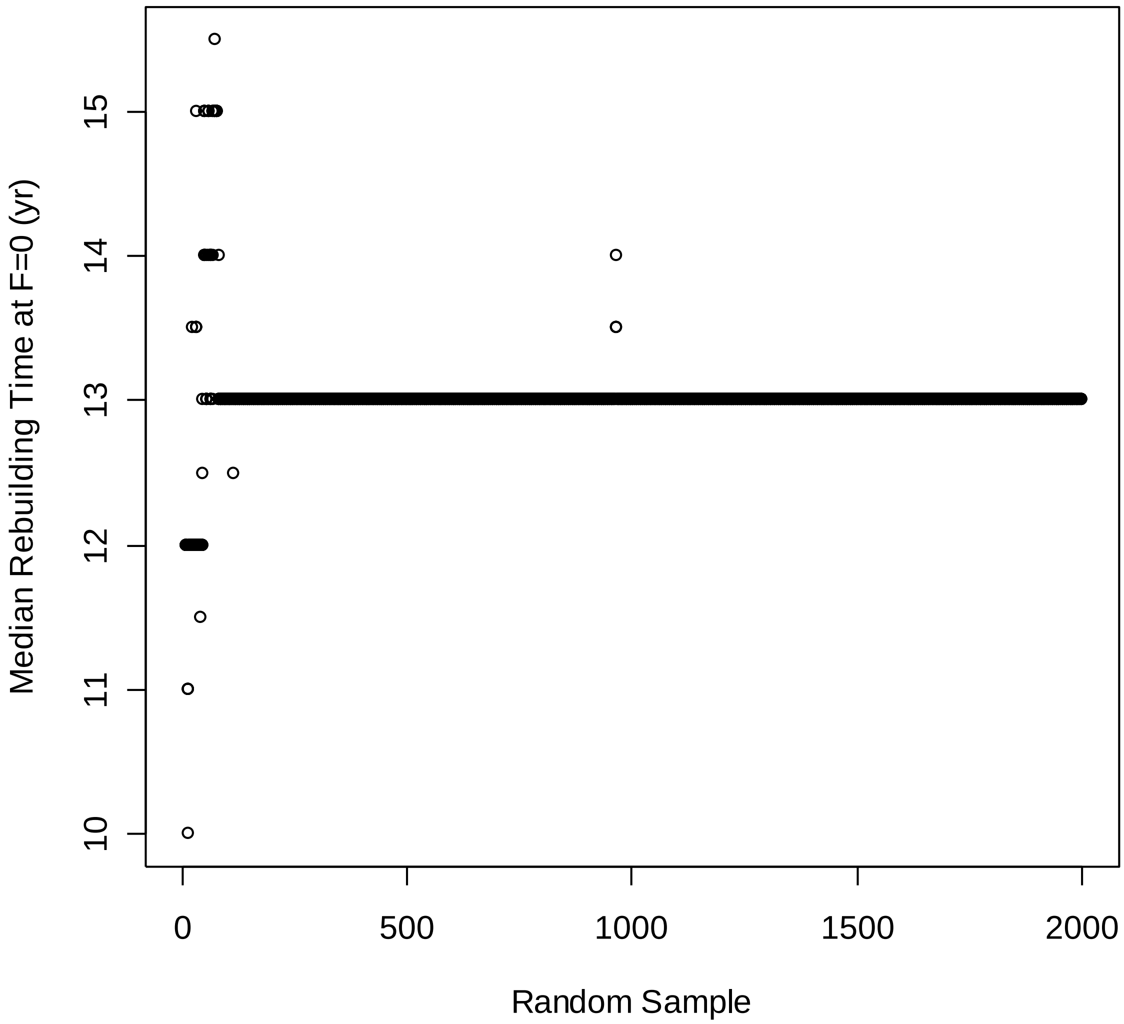

Figure 2. Rebuilding times—probability density of results corresponding to Figure 1. Dashed line represents median rebuilding time of 13 years.

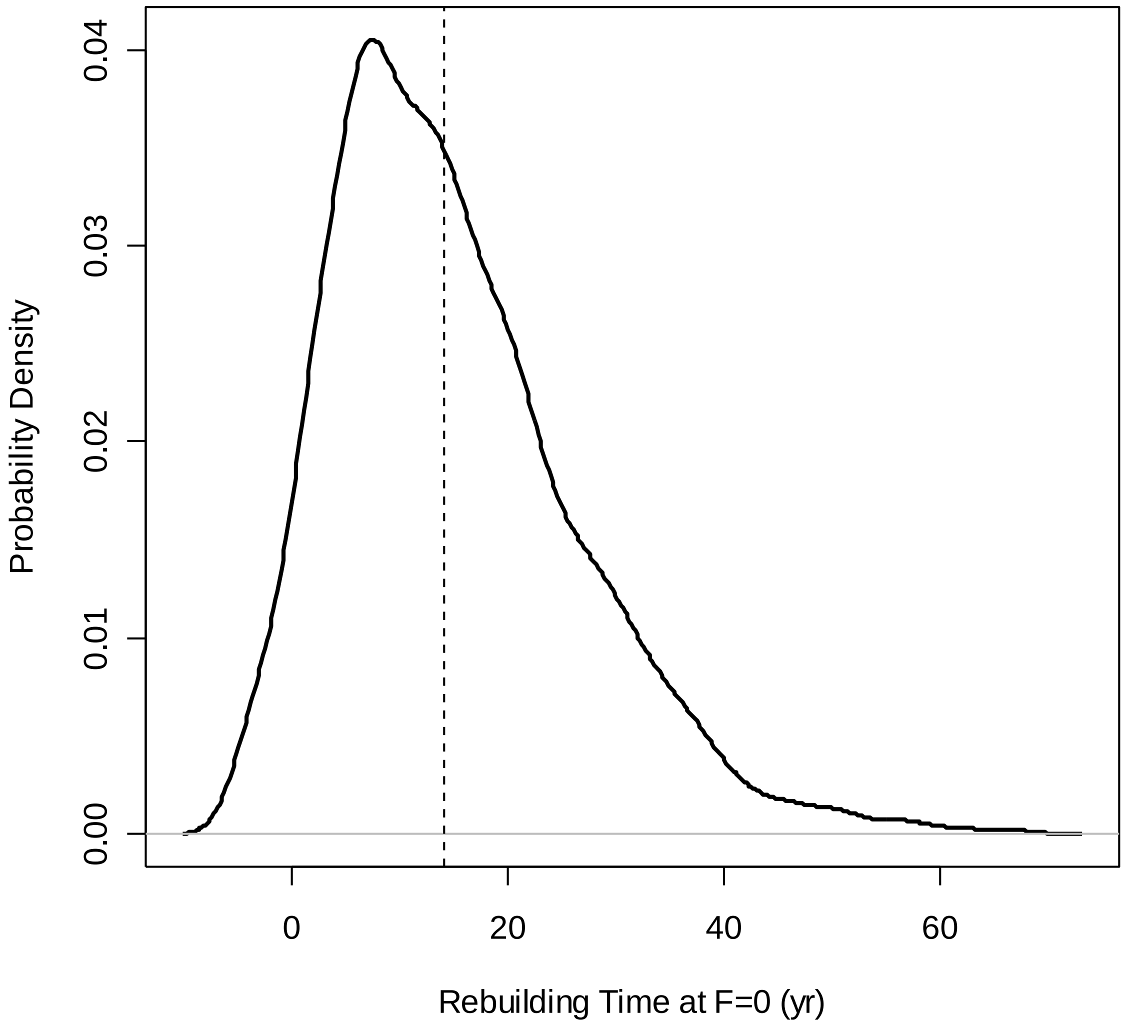

Figure 3. Recruitment estimates from stochastic projections (n=2000) of the SEDAR 4 snowy grouper stock assessment model with no fishing starting in 2006. Solid line represents the median and dashed lines represent 10th and 90th percentiles.

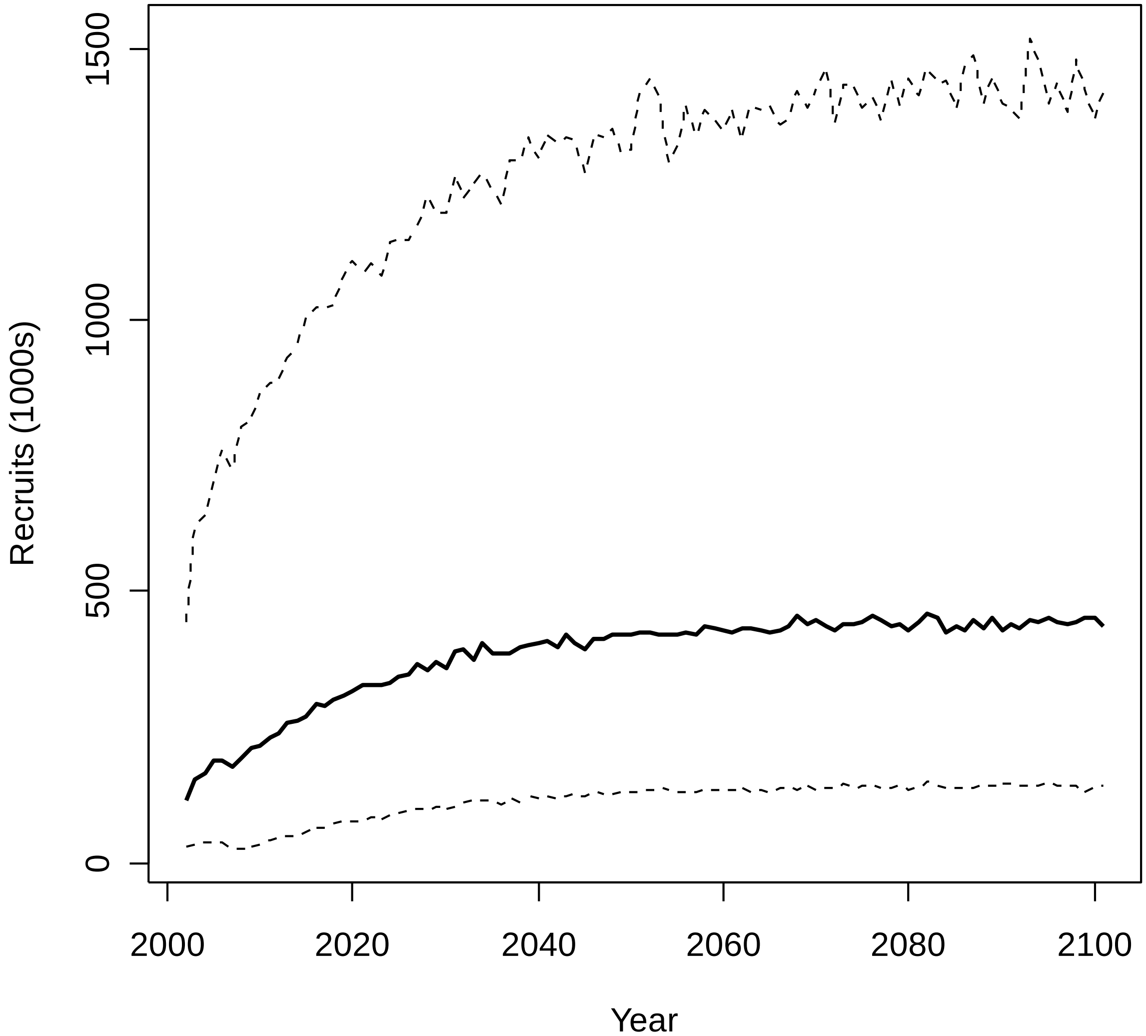

Figure 4. Total mature biomass (SSB) estimates from stochastic projections (n=2000) of the SEDAR 4 snowy grouper stock assessment model with no fishing starting in 2006. Solid line represents the median and dashed lines represent 10th and 90th percentiles.

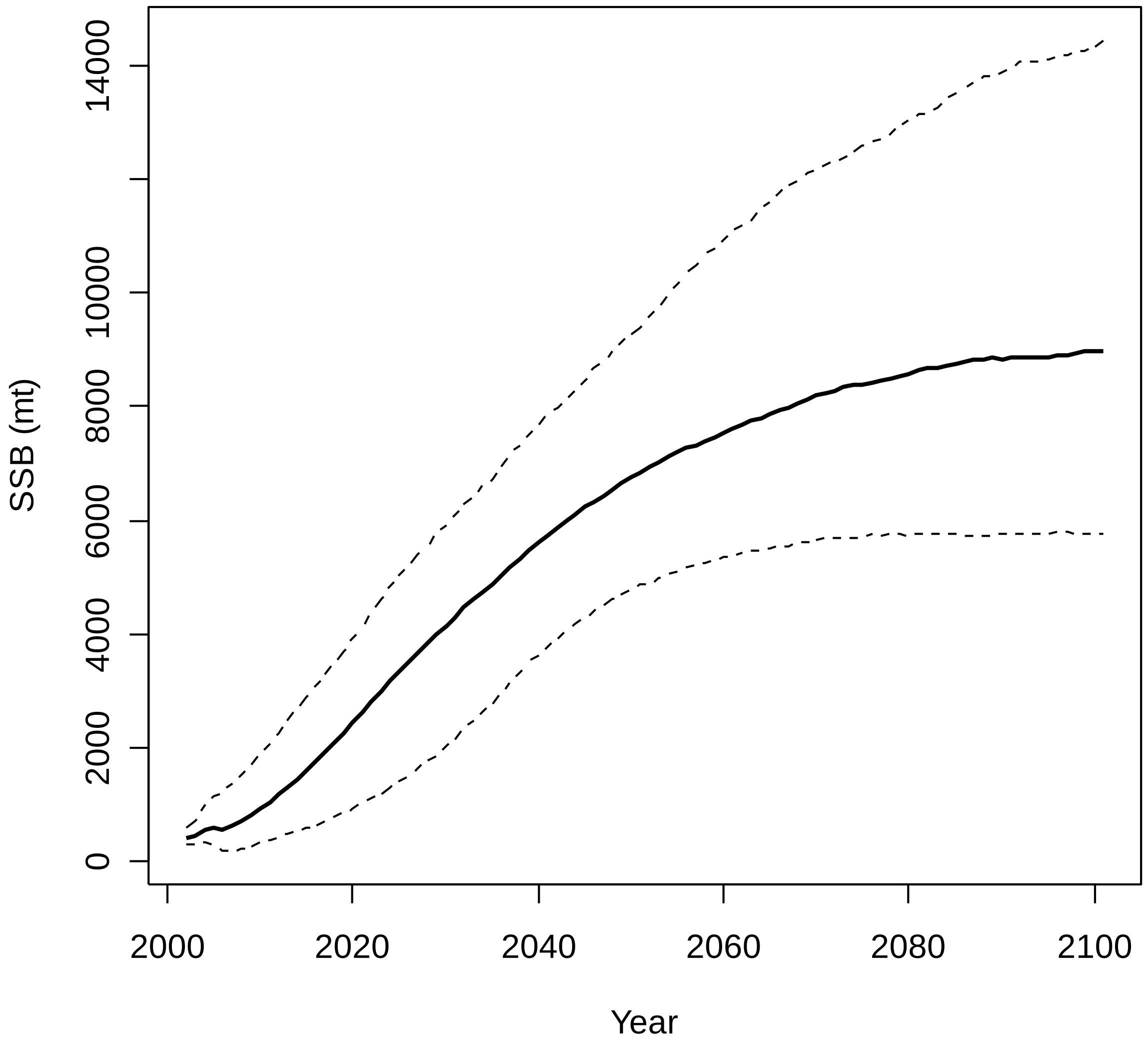

Figure 5. Ratio of total mature biomass to total mature biomass at maximum sustainable yield (SSB/SSB_{MSY}) estimates from stochastic projections (n=2000) of the SEDAR 4 snowy grouper stock assessment model with no fishing starting in 2006. Solid line represents the median and dashed lines represent 10th and 90th percentiles.

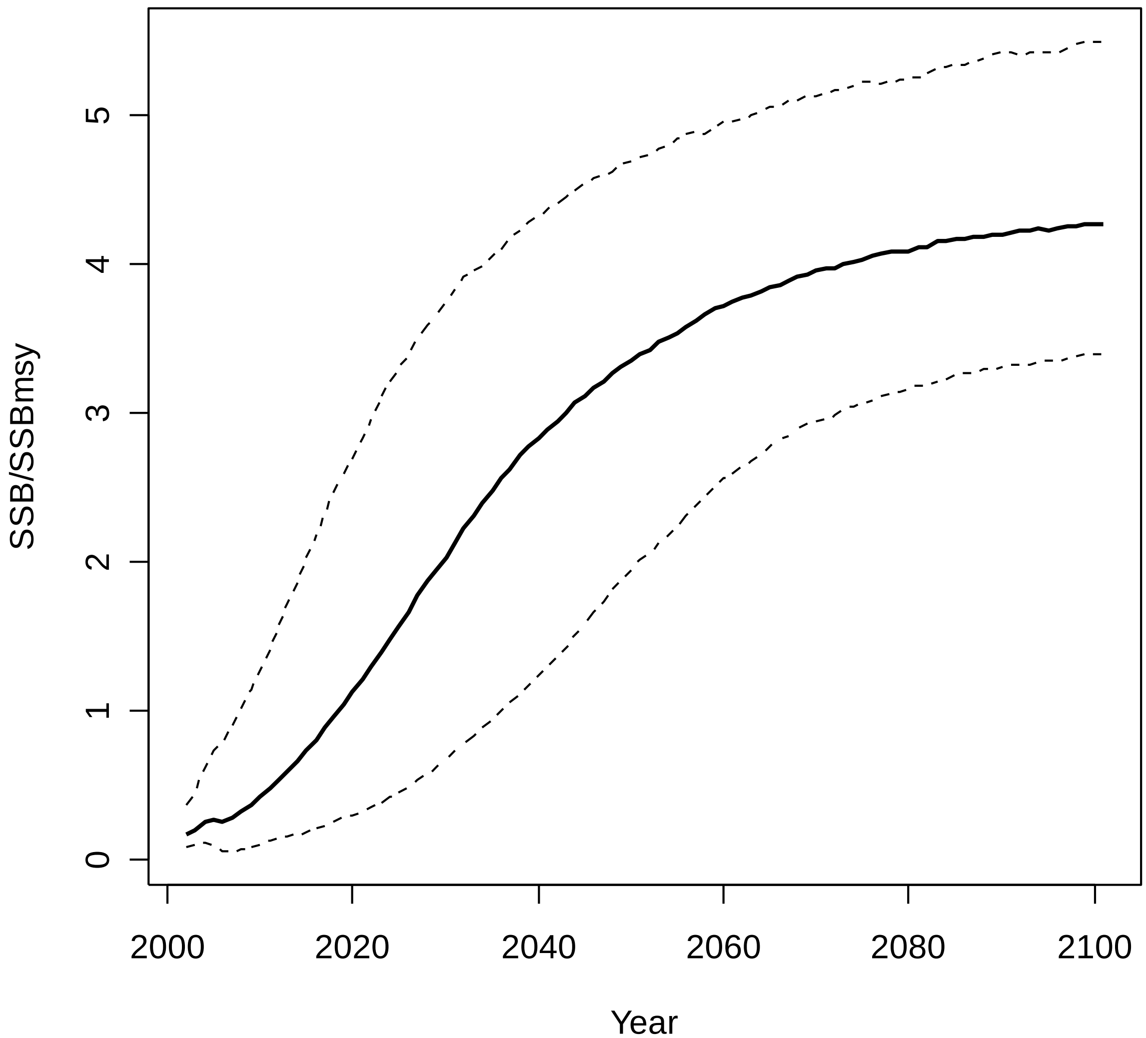

Figure 6. Recruitment (1000s) estimates from stochastic projections (n=2000) of the SEDAR 4 snowy grouper stock assessment model with a constant fishing mortality rate (yr^{-1}) starting in 2006 that allows for rebuilding within 37 years. Solid line represents the median and dashed lines represent 10th and 90th percentiles.

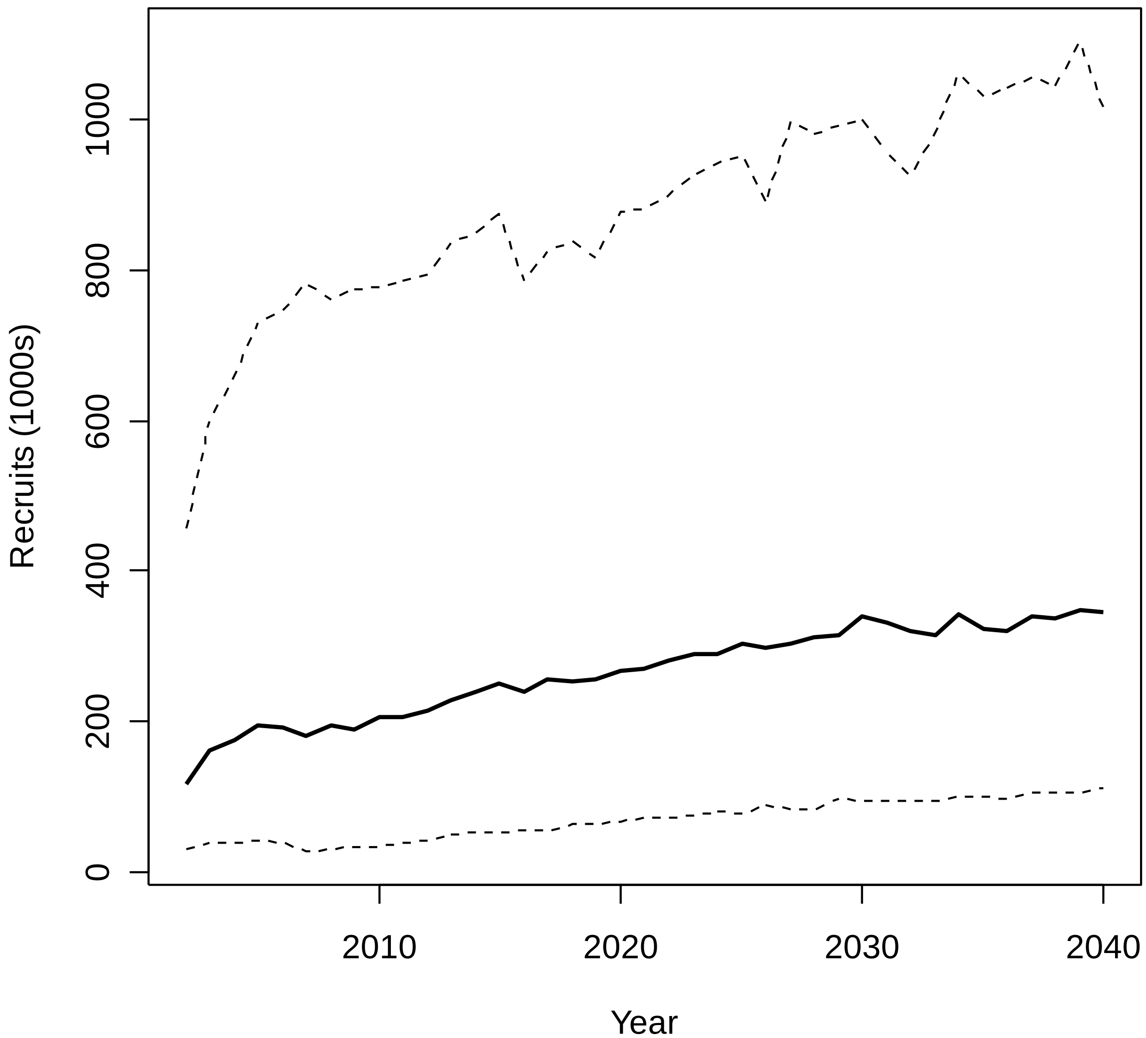

Figure 7. Total mature biomass (SSB) estimates from stochastic projections (n=2000) of the SEDAR 4 snowy grouper stock assessment model with a constant fishing mortality rate (yr^{-1}) starting in 2006 that allows for rebuilding within 37 years. Solid line represents the median and dashed lines represent 10th and 90th percentiles.

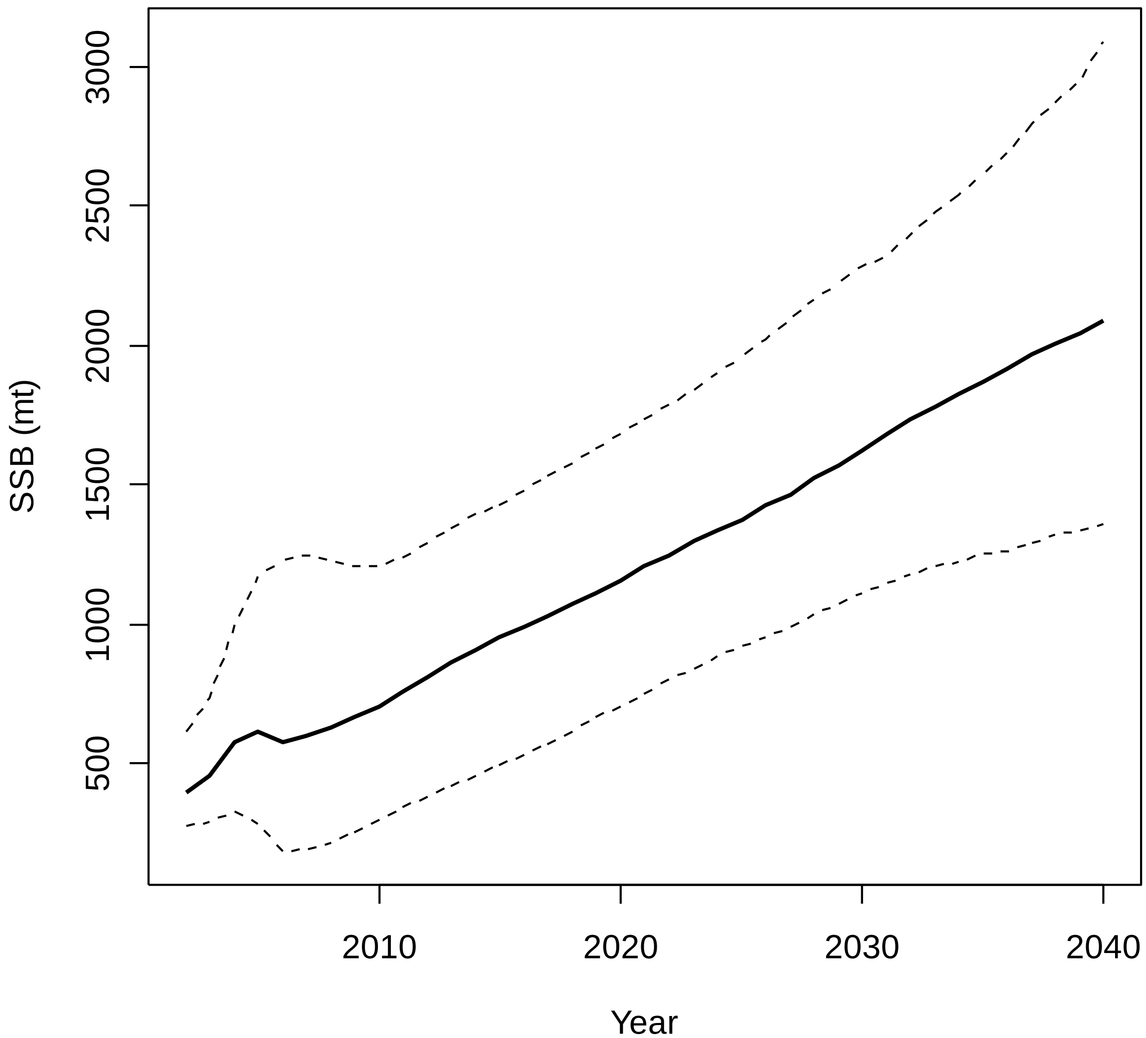

Figure 8. Ratio of total mature biomass to total mature biomass at maximum sustainable yield (SSB/SSB_{MSY}) estimates from stochastic projections (n=2000) of the SEDAR 4 snowy grouper stock assessment model with a constant fishing mortality rate (yr^{-1}) starting in 2006 that allows for rebuilding within 37 years. Solid line represents the median and dashed lines represent 10^{th} and 90^{th} percentiles.

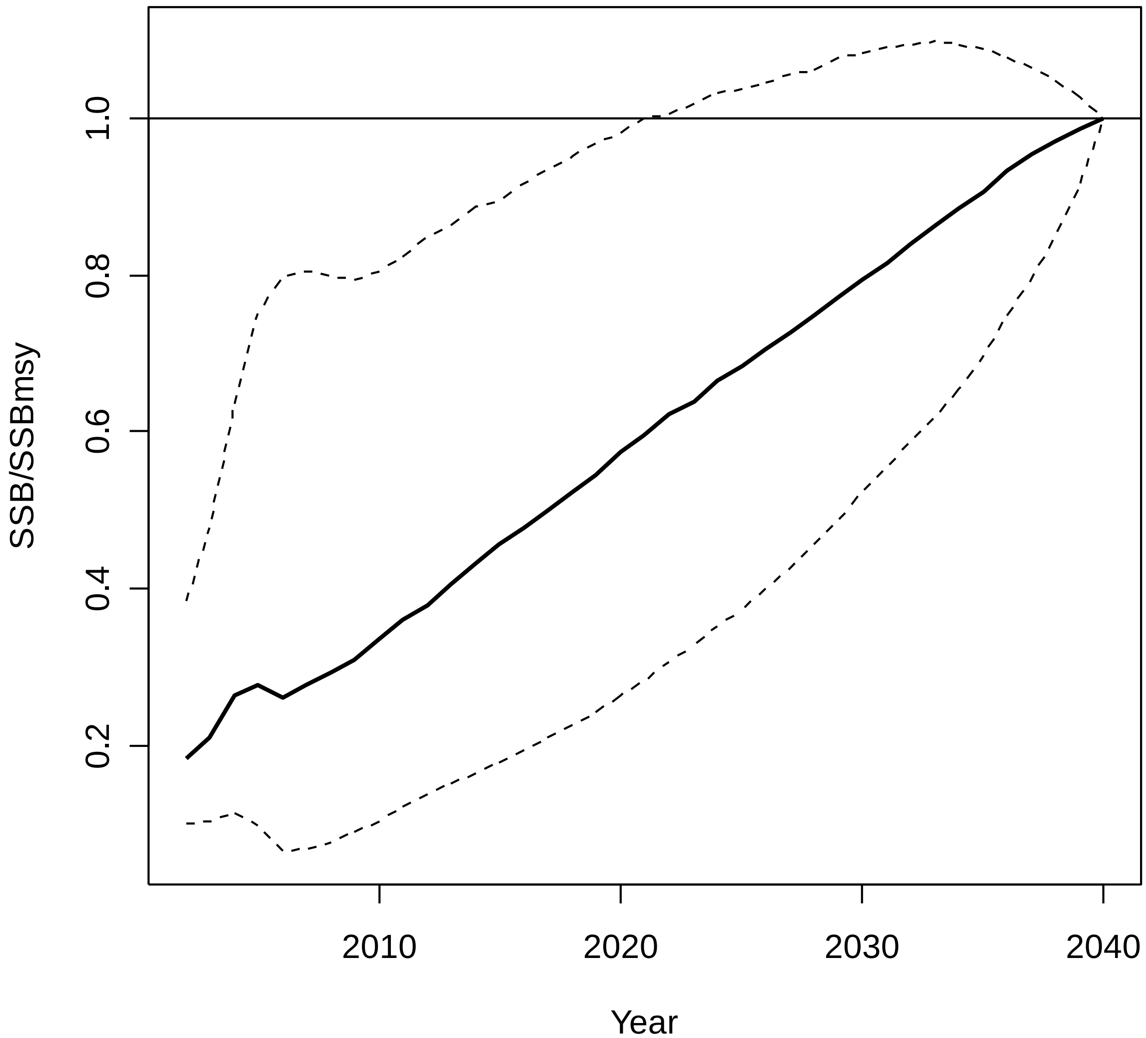

Figure 9. Fully selected fishing mortality rate (yr^{-1}) estimates from stochastic projections (n=2000) of the SEDAR 4 snowy grouper stock assessment model with a constant fishing mortality rate (yr^{-1}) starting in 2006 that allows for rebuilding within 37 years. Solid line represents the median and dashed lines represent 10th and 90th percentiles.

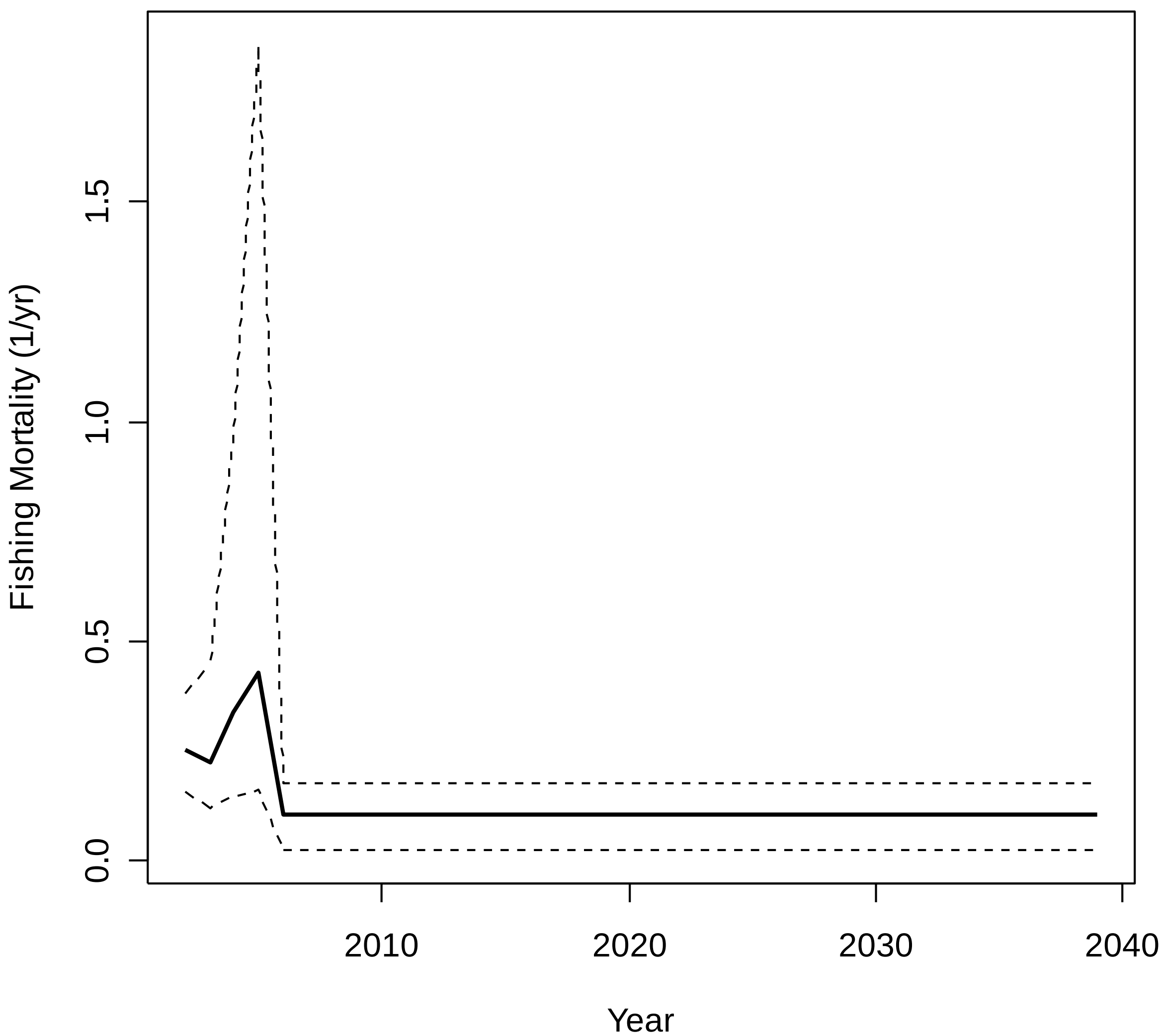

Figure 10. Running median of fully selected fishing mortality rate (yr^{-1}) estimates from stochastic projections (n=2000) of the SEDAR 4 snowy grouper stock assessment model with a constant fishing mortality rate (yr^{-1}) starting in 2006 that allows for rebuilding within 37 years.

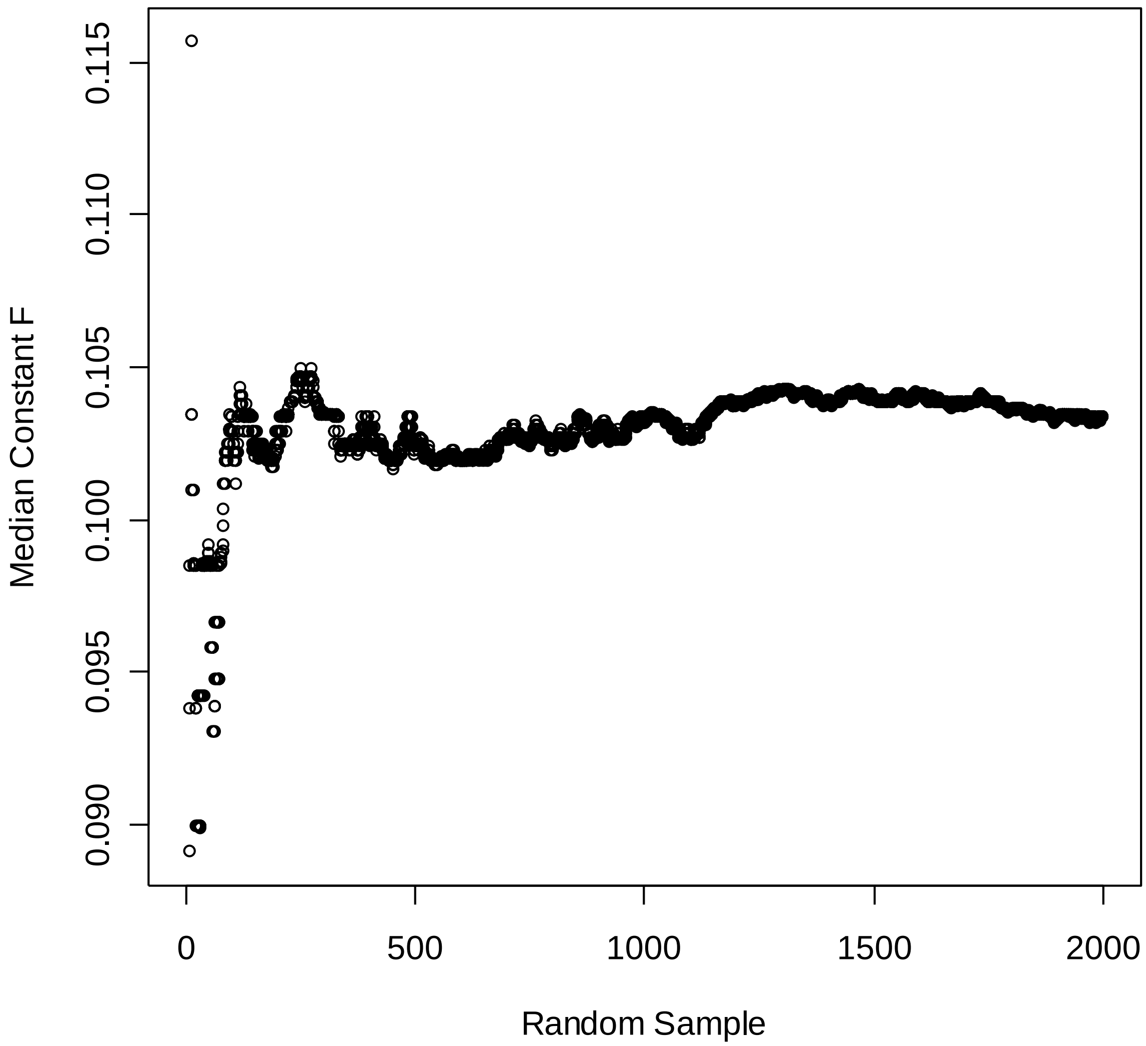

Figure 11. Ratio of fully selected fishing mortality (F) to F at maximum sustainable yield (F/F_{MSY}) estimates from stochastic projections (n=2000) of the SEDAR 4 snowy grouper stock assessment model with a constant fishing mortality rate (yr^{-1}) starting in 2006 that allows for rebuilding within 37 years. Solid line represents the median and dashed lines represent 10^{th} and 90^{th} percentiles.

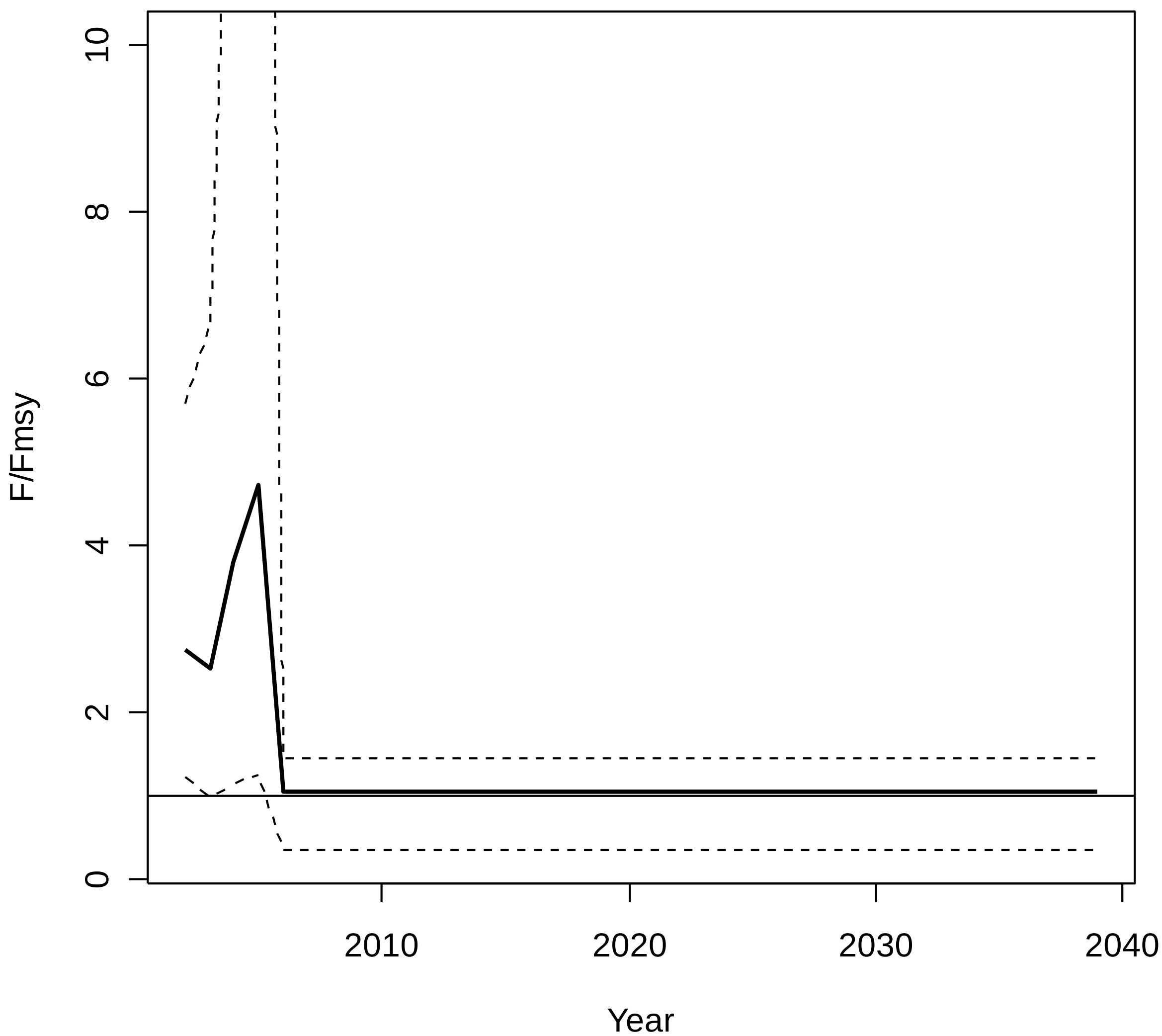

Figure 12. Catch (mt) estimates from stochastic projections (n=2000) of the SEDAR 4 snowy grouper stock assessment model with a constant fishing mortality rate (yr^{-1}) starting in 2006 that allows for rebuilding within 37 years. Solid line represents the median and dashed lines represent 10^{th} and 90^{th} percentiles.

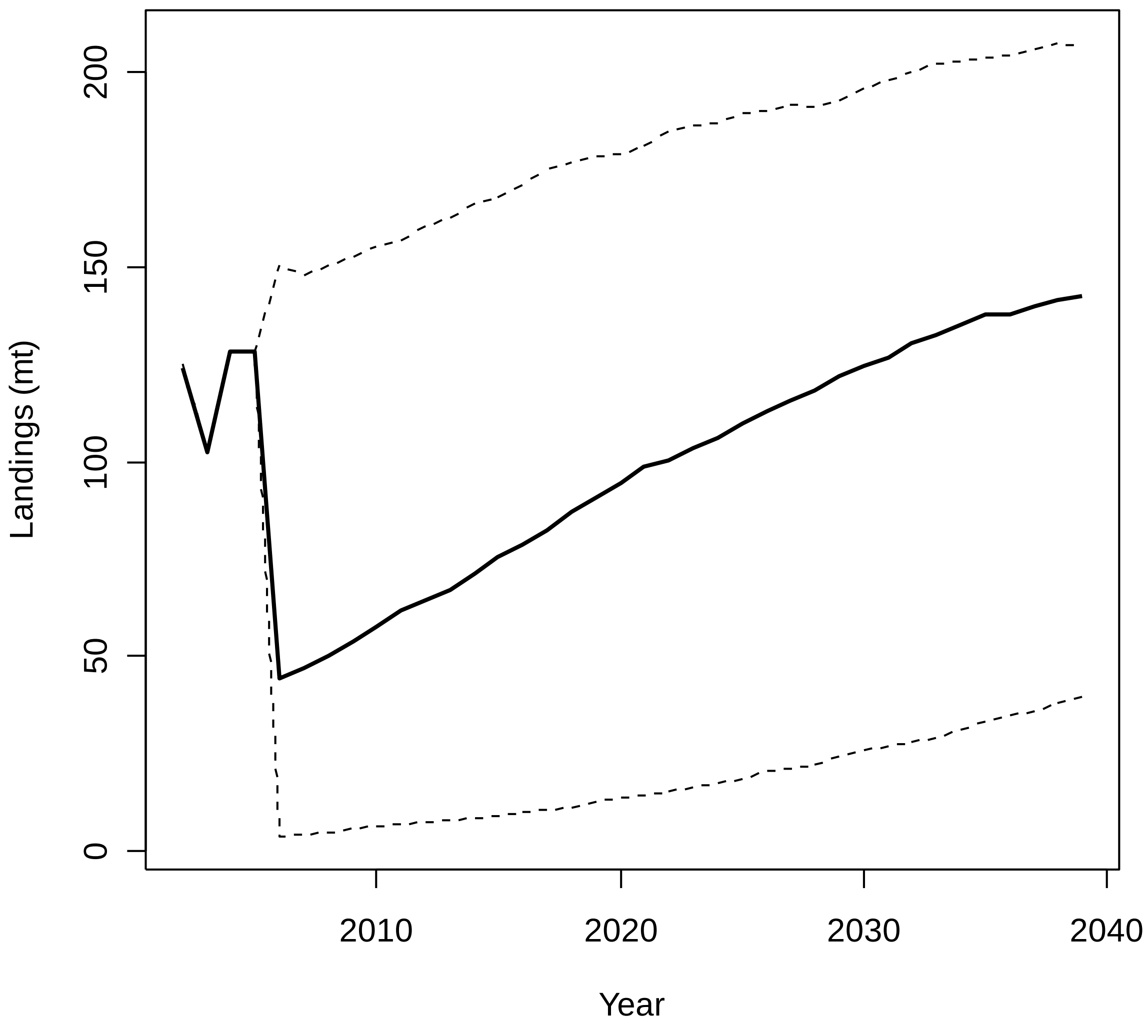

Figure 13. Recruitment (1000s) estimates from stochastic projections (n=2000) of the SEDAR 4 snowy grouper stock assessment model with a constant catch (mt) starting in 2006 that allows for rebuilding within 37 years. Solid line represents the median and dashed lines represent 10th and 90th percentiles.

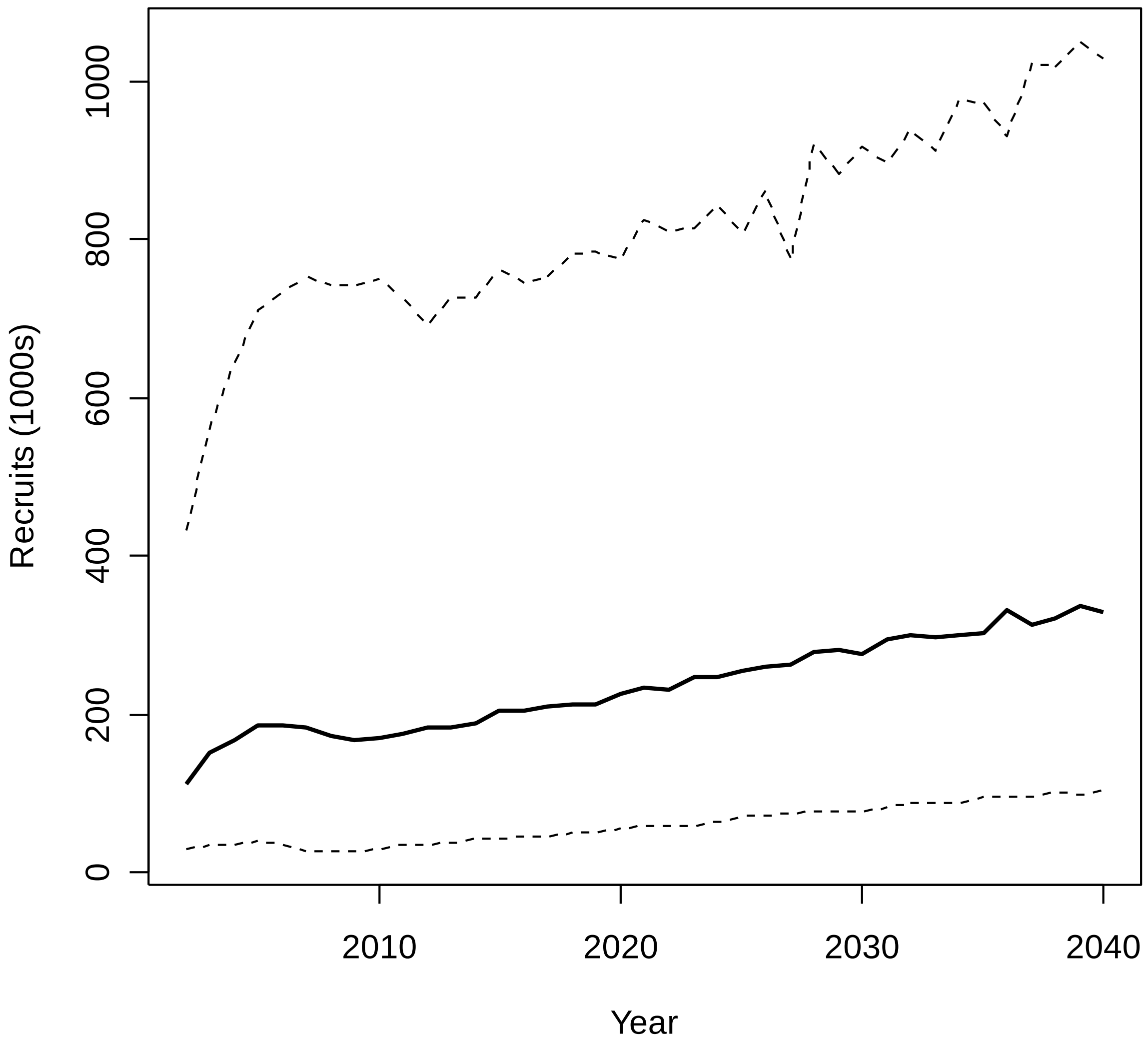

Figure 14. Total mature biomass (SSB) (mt) estimates from stochastic projections (n=2000) of the SEDAR 4 snowy grouper stock assessment model with a constant catch (mt) starting in 2006 that allows for rebuilding within 37 years. Solid line represents the median and dashed lines represent 10th and 90th percentiles.

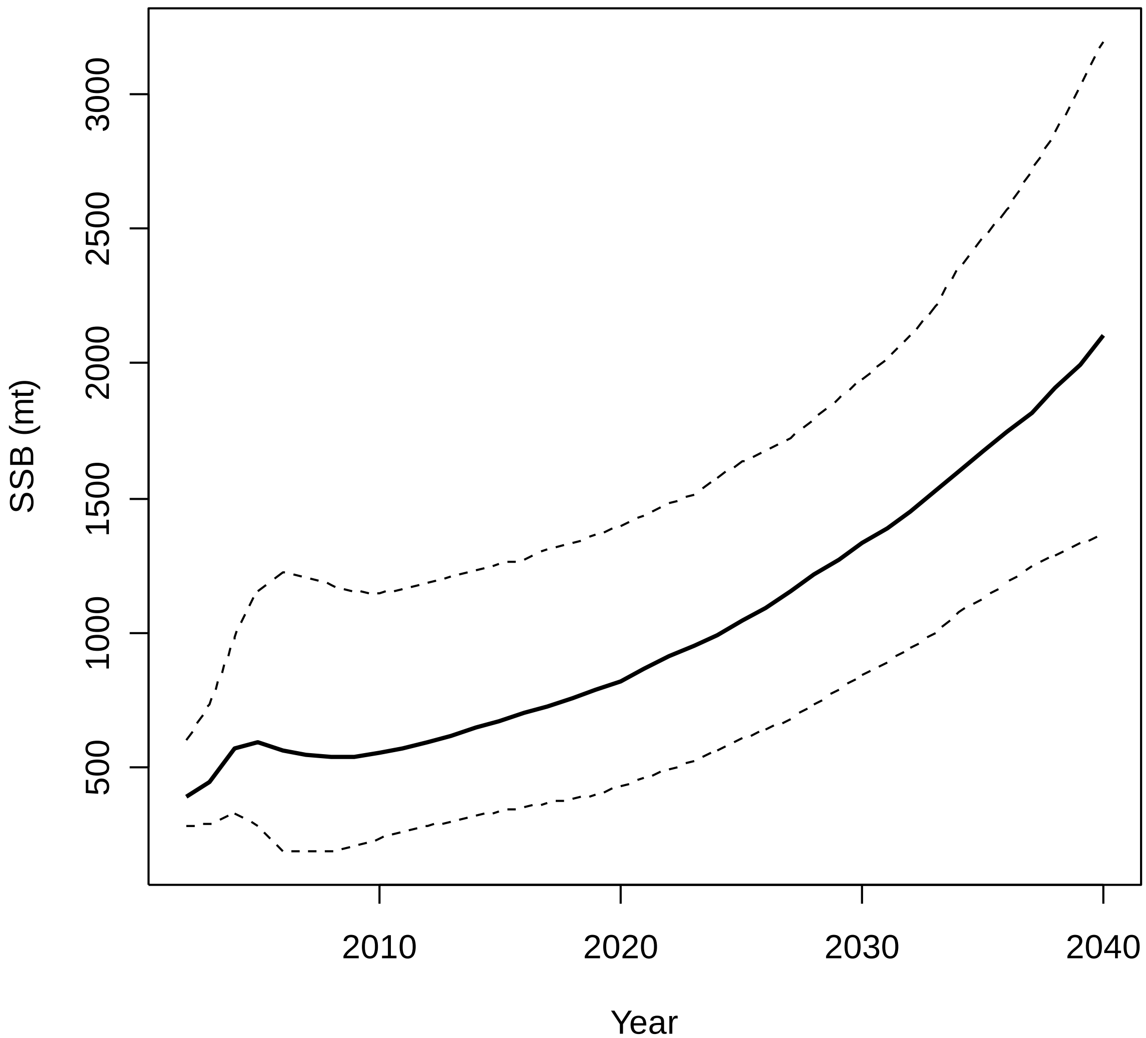

Figure 15. Ratio of total mature biomass to total mature biomass at maximum sustainable yield (SSB/SSB_{MSY}) estimates from stochastic projections (n=2000) of the SEDAR 4 snowy grouper stock assessment model with a constant catch (mt) starting in 2006 that allows for rebuilding within 37 years. Solid line represents the median and dashed lines represent 10th and 90th percentiles.

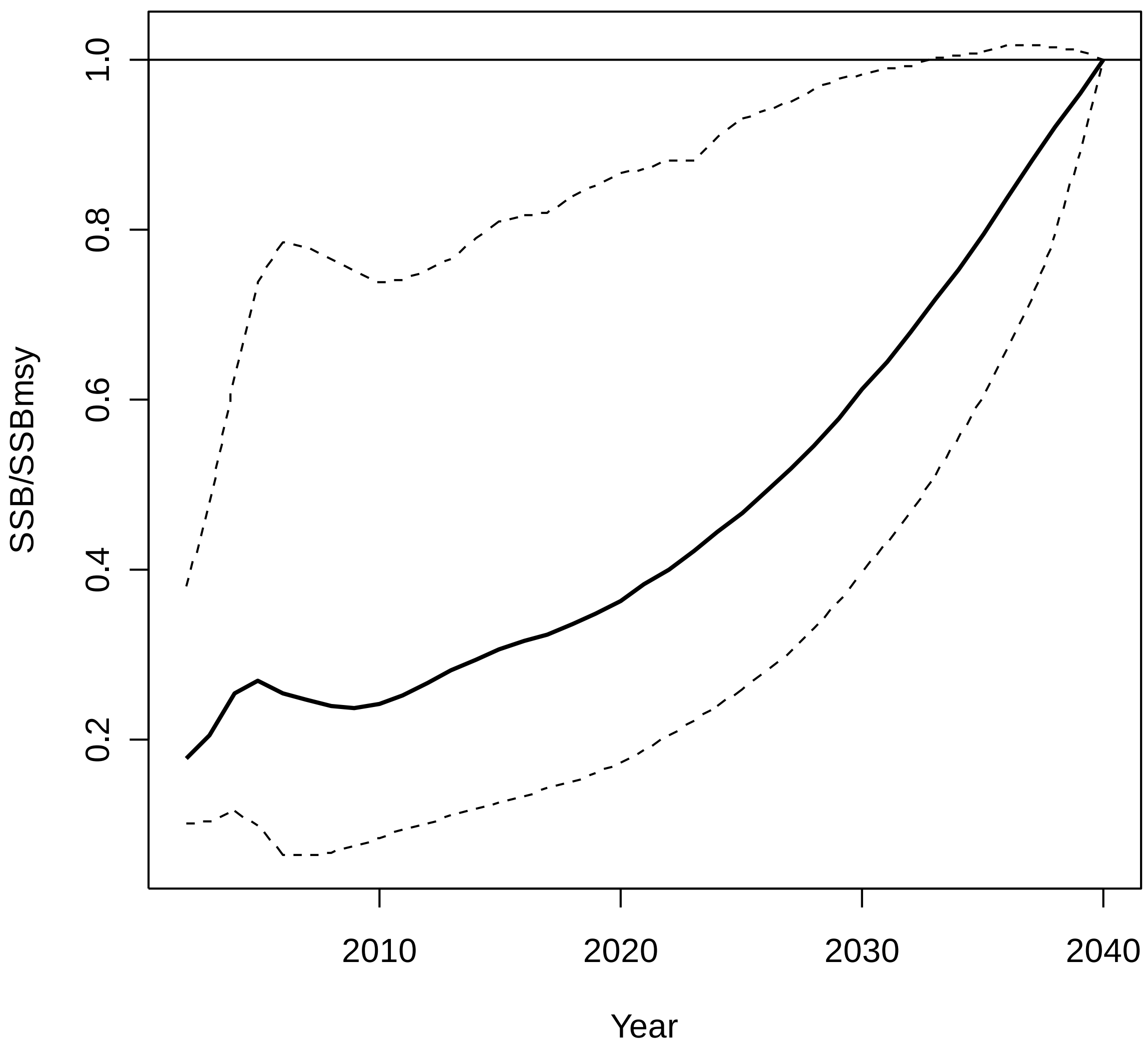

Figure 16. Fully selected fishing mortality rate (yr^{-1}) estimates from stochastic projections (n=2000) of the SEDAR 4 snowy grouper stock assessment model with a constant catch (mt) starting in 2006 that allows for rebuilding within 37 years. Solid line represents the median and dashed lines represent 10th and 90th percentiles.

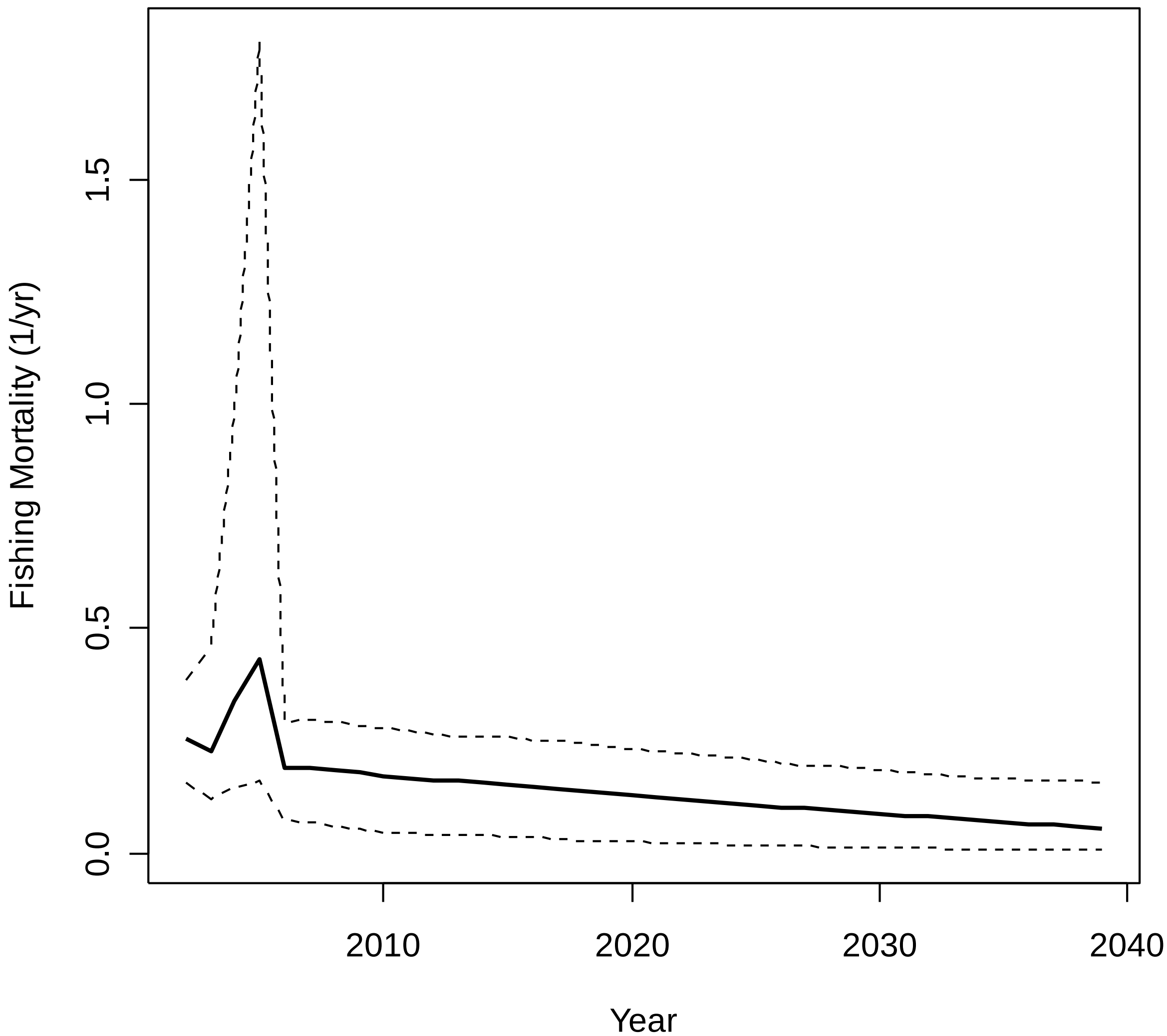

Figure 17. Ratio of fully selected fishing mortality (F) to F at maximum sustainable yield (F/F_{MSY}) estimates from stochastic projections (n=2000) of the SEDAR 4 snowy grouper stock assessment model with a constant catch (mt) starting in 2006 that allows for rebuilding within 37 years. Solid line represents the median and dashed lines represent 10th and 90th percentiles.

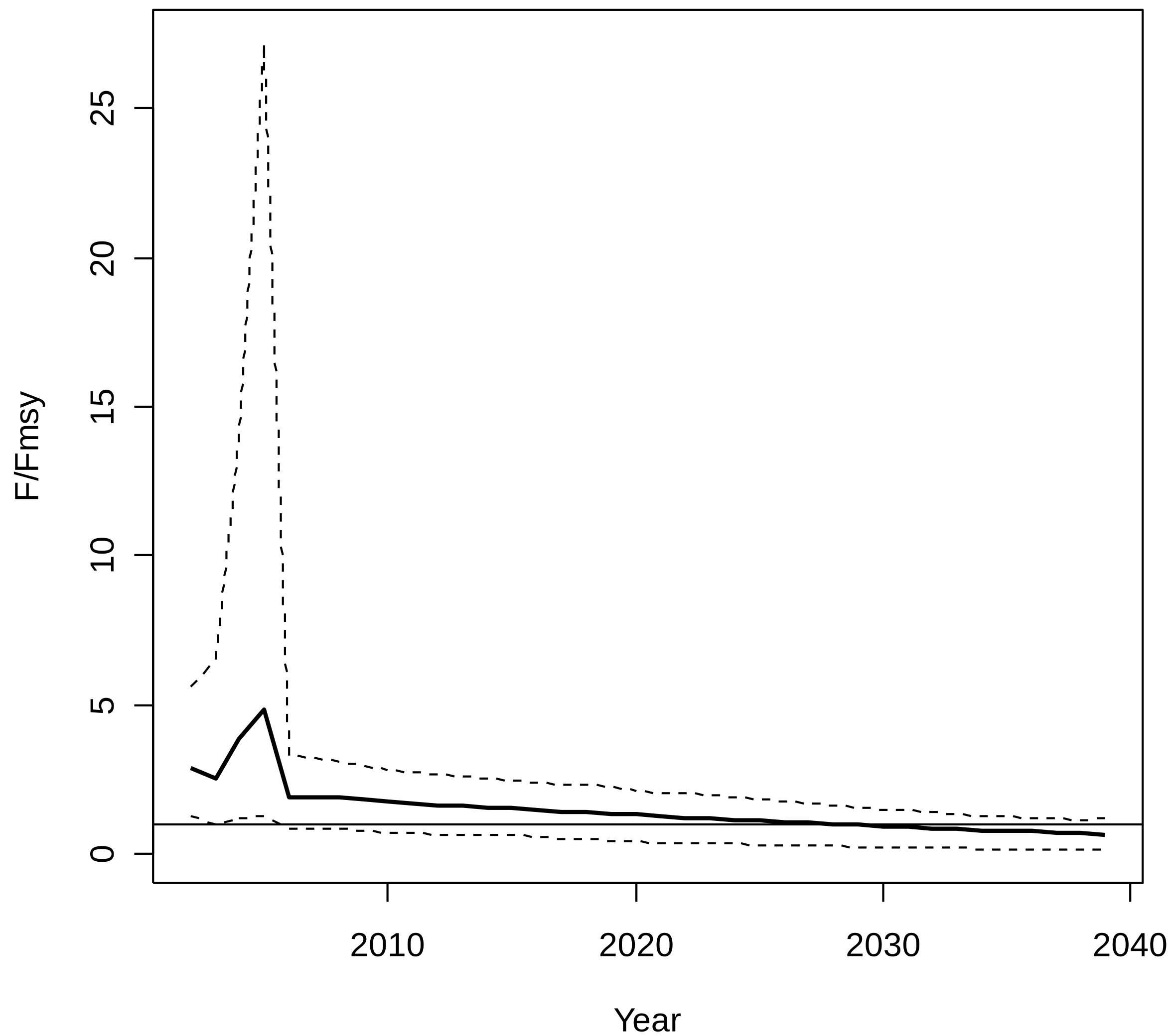

Figure 18. Catch (mt) estimates from stochastic projections (n=2000) of the SEDAR 4 snowy grouper stock assessment model with a constant catch (mt) starting in 2006 that allows for rebuilding within 37 years. Solid line represents the median and dashed lines represent 10th and 90th percentiles.

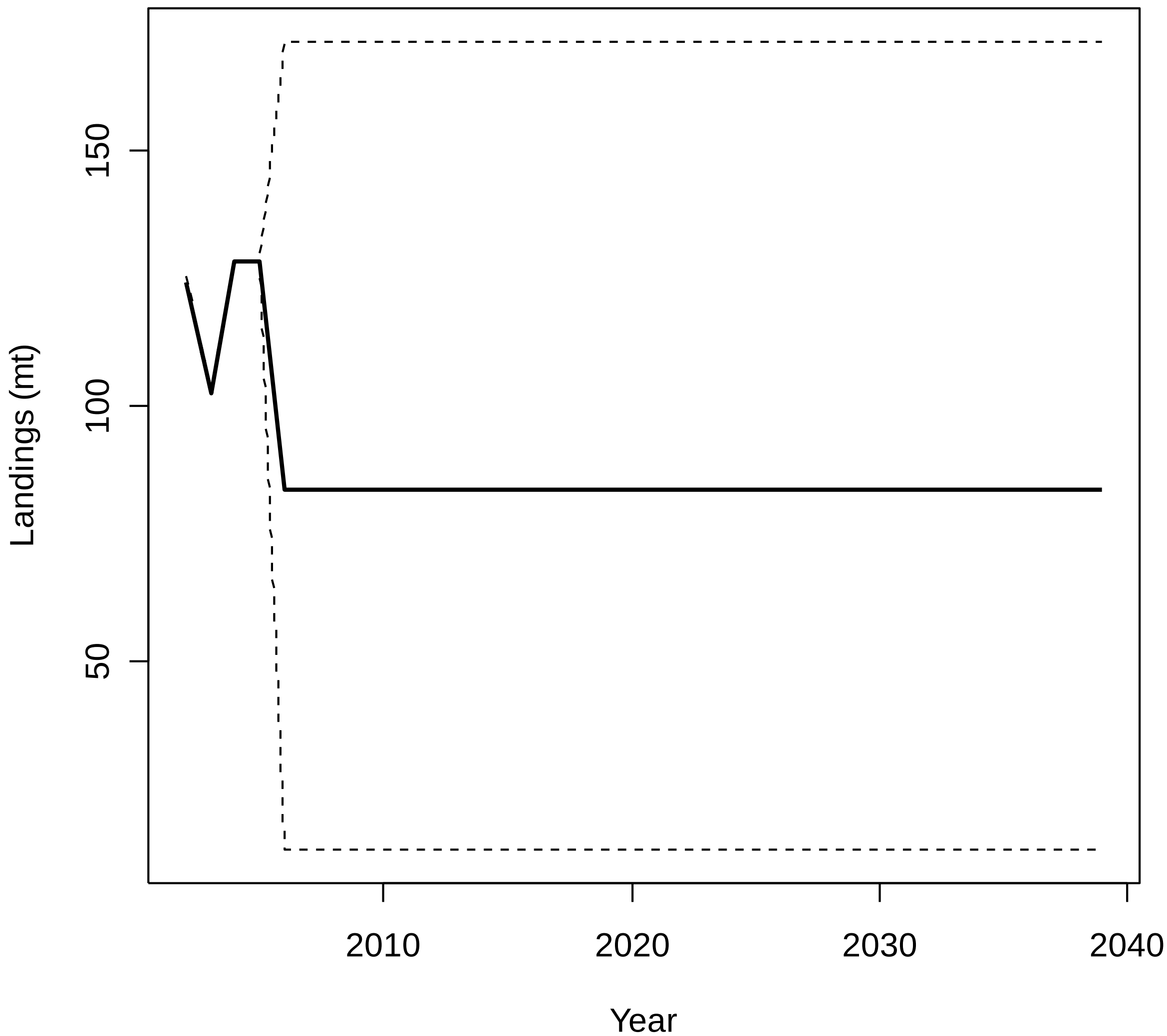

Figure 19. Running median of catch (mt) estimates from 2000 stochastic projections of the SEDAR 4 snowy grouper stock-assessment model with constant catch (mt) starting in 2006 that allows rebuilding within 37 years.

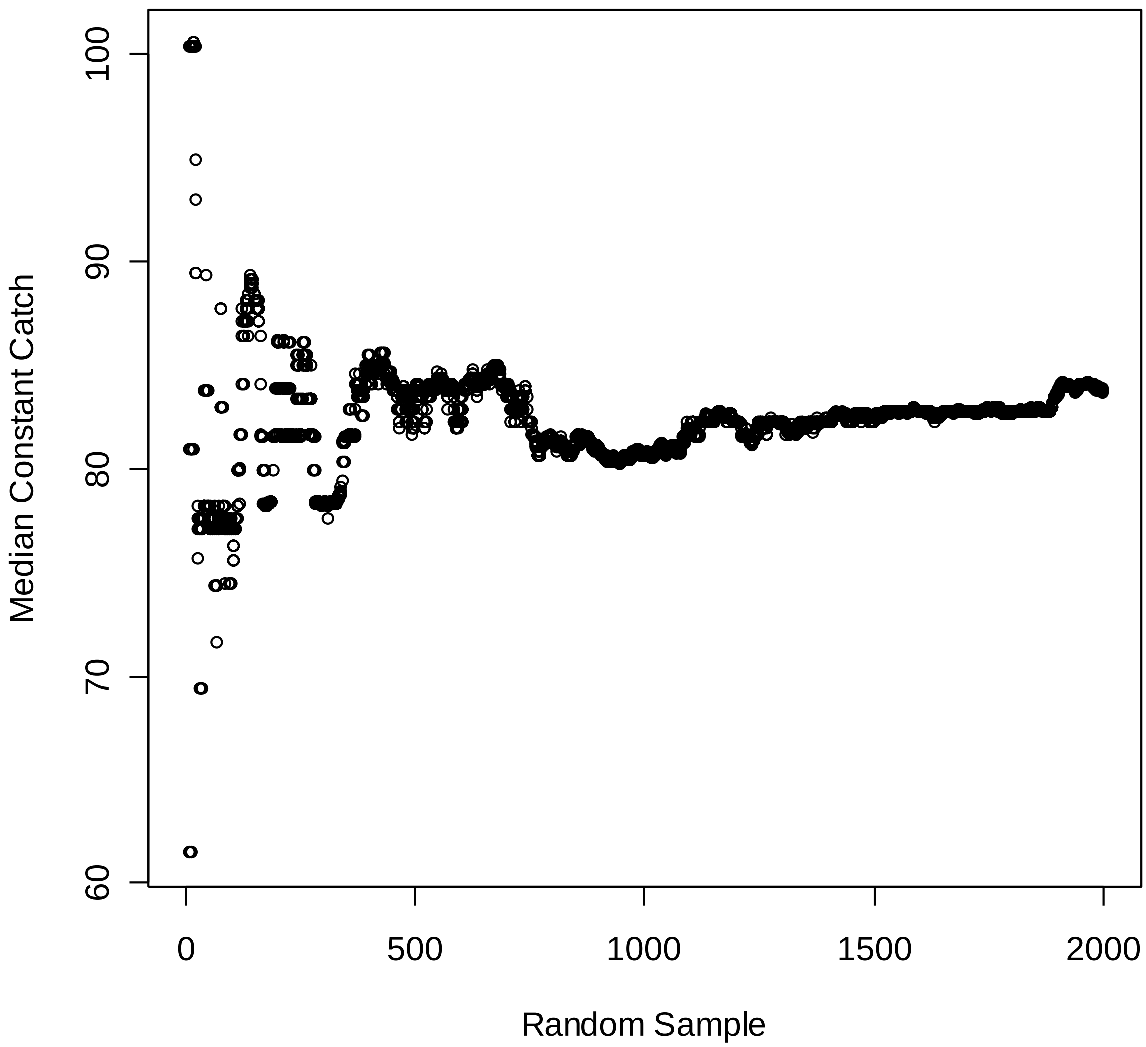

Figure 20. Recruitment deviations (logarithmic) from stock–recruit curve, as estimated by SEDAR 4 snowy grouper assessment. Positive values are recruitments larger than expected. Solid line is median; dashed lines are 10th and 90th percentiles.