Response to Council's Request for Additional Red Snapper Projections

August 22, 2016

The SAFMC requested additional Red Snapper projections (memorandum dated June 22, 2016). The request was generated as a result of Motion #11 of the SAFMC meeting that took place June 13-17, 2016 in Cocoa Beach, FL. Motion #11 states "Request the SSC review additional runs at F_{max} and $F_{20\%SPR}$ at October 2016 meeting. Provide advice regarding risk of these as reference points for overfishing." What follows is the response to each request made in the memo.

Request 1) "For management benchmarks of F_{max} and $F_{20\%}$, provide the associated fishing mortality rate and MSST, as well as equilibrium stock biomass, spawning stock biomass proxy (expressed in egg production as used in the SEDAR 41 assessment) and yield in pounds and numbers. For F_{max}, also provide the associated %SPR."

F_{max} is 0.217, and $F_{20\%}$ is 0.212. F_{max} corresponds to $F_{19.5\%SPR}$. A new set of management benchmarks is provided using F_{max} and $F_{20\%}$, as requested:

	MSST	SSB(1E8)	B (mt)	R(num)	L.klb	L.knum	D.klb	D.knum
F_{max}	159318	212424	2858.006	446465	446.214	36.539	391.831	63.701
$F_{20\%}$	163684	218245	2899.811	446276	446.27	36.336	388.766	62.75

Yield is separated into landings (L) and dead discards (D).

Request 2) "Provide projections to 2044 (the end of the rebuilding period) based on fixed fishing mortality at F_{max} and $F_{20\%SPR}$. Include the full suite of projection outputs as provided for SEDAR 41 projections."

The full suite of projection outputs for the two constant F projections ($F_{20\%}$ and F_{max}) are contained in Tables 1 and 2, and in Figures 1 and 2. Management was assumed to begin in 2017 and the projection methodology is identical to that which was used for projections based on $F_{30\%}$ (report dated April 12, 2016). Both projection scenarios show that the stock does not rebuild with 50% probability by 2044.

Request 3) "Provide projections of $F_{rebuild}$ based on a 50% probability of rebuilding the stock by 2044 based on MFMT proxies of F_{max} and $F_{20\%SPR}$. Include the full suite of projection outputs as provided for SEDAR 41 projections."

The full suite of projection outputs for the two $F_{rebuild}$ to 50% probability of recovery projections are contained in Tables 3 and 4, and in Figures 3 and 4. Management was assumed to begin in 2017 and the projection methodology is identical to that which was used for projections based on $F_{30\%}$ (report dated April 12, 2016). The fishing mortality that allows the stock to rebuild with 50% probability to $F_{20\%}$ benchmarks is 0.2087. The fishing mortality that allows the stock to rebuild with 50% probability to F_{max} benchmarks is 0.214.

The memo and SAFMC motion request ‘additional runs,’ which were interpreted to mean projection analyses. The SEFSC further interpreted the motion language ‘provide advice regarding risk’ as a request for a scientific analysis of the probability of overfishing for the various reference points, including F_{max} and $F_{20\%SPR}$. The Council did not have their current control rule when developing the rebuilding plan for Red Snapper. The rebuilding plan was set to recover to $F_{30\%}$ with 50% probability by 2044. In the following analysis, the SEFSC provides a more complete picture of other potential reference points for Red Snapper and their associated probability of overfishing, which has not been provided to date. We also provide rebuilding projections to F_{max} and $F_{20\%SPR}$ benchmarks to a rebuilding probability consistent with the SAFMC’s current control rule.

The SEDAR 41 assessment of Red Snapper did not estimate steepness; rather, the assessment estimated mean recruitment, and deviations around that mean. The available stock-recruitment observations for Red Snapper in the South Atlantic (SA) were insufficient to uniquely identify a stock-recruitment relationship to directly estimate MSY-based benchmarks for stock size and fishing mortality. This is a property common to many fish stocks around the world. For both Red Snapper stocks in southeast (SA and Gulf of Mexico), and in line with the National Standard Guidelines, the Councils’ SSCs have recommended use of SPR as proxies for the purpose of estimating MFMT and MSST levels. Throughout the nation, SPR proxies have been widely adopted for a broad range of stocks. Initial scientific guidance (in the mid-90s) indicated that SPRs in the range of 30-40% were reasonable proxies for MSY quantities for a range of fish stocks, although the precise SPR associated with MSY could be higher or lower depending on the actual underlying stock-recruitment relationship and fishery characteristics. Additionally, standard practices in determining appropriate proxy reference points are used in other regions of the United States (Clark 2002, Dorn 2002). For the last benchmark assessment and subsequent rebuilding plan, the SA Council set a proxy of 30% SPR.

The meta-analysis of Shertzer and Conn (2012) provides a good basis to judge what an approximate value of steepness would be for a Red Snapper-like species. The probability of overfishing assumed in a choice of the F_{msy} proxy can be determined using the SEDAR41 assessment and the Shertzer and Conn (2012) meta-analysis. The mean steepness of 0.84 in the meta-analysis corresponds to $F_{27\%}$ (Figure 5), but we need a distribution of F_{msy} to account for the uncertainty in that F proxy. Drawing values of steepness from the beta distribution described in Shertzer and Conn (2012), we calculated F_{msy} holding all other model parameters to the base model values. Figure 6 shows the distribution of F_{msy} using this approach. We illustrate where F_{max}, $F_{20\%}$, $F_{27\%}$, $F_{30\%}$ and $F_{40\%}$ falls on the distribution. The further into the tails the F_{msy} proxy, the higher the probability of under or overfishing. A proxy in the portion of the curve with more probability density would lower the probability of overfishing or underfishing. Therefore, an appropriate SPR proxy for Red Snapper that also takes into account both the biology and similarity with species represented in the meta-analysis and the probability of over or underfishing would be $F_{27\%SPR} = 0.1624$. Figure 7 shows the yield per recruit and fecundity per recruit curves with the suite of F_{msy} proxies under consideration plotted for comparison.

Next, we consulted the SAFMC's control rule, as well as the value calculated for Red Snapper for the last benchmark assessment (P*=0.3, implying 70% probability of rebuilding). Using the descriptions of the tiers within each dimension, we scored the current Red Snapper assessment as follows: Dimension I – 2.5, Dimension II – 2.5, Dimension III – 7.5, and Dimension IV – 5, which comes to a 67.5% probability of rebuilding. If when reviewing this document, the SSC calculates a different value, an additional analysis will be provided. Using the new value, we carried out two additional rebuilding projections. The fishing mortality that allows the stock to rebuild with 67.5% probability to the $F_{20\%}$ SSB benchmark is 0.189. The fishing mortality that allows the stock to rebuild with 67.5% probability to the F_{max} SSB benchmark is 0.1927. Tables 5 and 6 provide the suite of projection outputs for these runs respectively.

Request 4) "Evaluate the impacts of 18" and 20" total length minimum size limits on future selectivity and current reference point values and rebuilding projections. Provide management benchmark info as requested in #1, and projection results as requested in #2 and #3, based on the selectivity patterns associated with the alternative size limits."

In brief, this request needs to be clarified before a thorough analysis can be provided. The current assessment has selectivities in three time blocks: before the 20" size limit, during the 20" size limit, and during the mini-season and moratorium. All fish are discarded during the moratorium, and there is no size limit during the mini-season. Request #4 asks that an 18" size limit be used with current reference points and rebuilding projections. We assumed that to mean the reference points requested in their most recent memo, and we assumed that the 18" size limit would act more as a size limit did during the 20" size limit rather than during a mini-season. The 20" size limit has been represented in the current assessment, but we do not have any data to investigate how the selectivity or fishing behavior would be effected if there was a size limit during a mini-season with a bag limit. We consulted with Council staff, but no clarity was offered besides this was a curiosity of the Council, and the proposed regulation regime was unclear. There was no explanation of why 18" or even a 20" size limit during a mini-season would be considered to help us better understand and investigate the request. Additionally, a change in selectivities causes a change in benchmarks, and new benchmarks are being considered. A more comprehensive analysis of a change in size limit would have to be done once the proposed regulations are clarified (e.g. Is there a bag limit? Is it during an open season or a mini-season? Is there an anticipated biological benefit to 18" or 20"? etc.)

We addressed this request using the variability in size at age. Figure 8 shows the distribution of size at age for ages 2, 3, and 4. An 18" fish is approximately 2.5 years old, and a 20" fish is approximately 3 years old. There is no probability of a 457 mm (18 inch) fish being one year old. The overlap of the distributions in Figure 8 show that either size limit can correspond to age 2, 3, or 4 with different probabilities. We used the change in probability of being each age at each size limit and adjusted the total landings and discards selectivity curves accordingly. This is not what would be done for a more comprehensive analysis, as these curves are a combination of all three time blocks combined. However, for this thought experiment, adjusting the total selectivity curve shows the maximum effect of a change in size limit. It shows a maximum effect because a smaller proportion of the total selectivity would be affected if this exercise were completed for each fleet's selectivity in only the terminal time block (mini-season selectivity). The new landings selectivity is shown in Figure 9 and the new discards selectivity is shown in Figure 10. There was a slight increase in the selectivity of landings at ages 2 and 3 and a decrease in the selectivity of discards of the same ages. We conducted a deterministic projection using these new selectivity curves (methodology identical to that used for all other projections provided for SEDAR 41) and the results are shown in Table 7. These cursory and simplified projections show that the effect of a change in size limit from 20" to 18" is minimal. There is a slight increase in the overall landings taken by the end of the projections (460 klb v. 446 klb), but a larger decrease in the allowable discards (362 klb v. 392 klb).

Overall Caveats

All projections provided here should be interpreted in light of the model assumptions and key aspects of the data. Some major considerations are the following:

- In general, projections of fish stocks are highly uncertain, particularly in the long term (e.g., beyond 5–10 years).
- Although projections included many major sources of uncertainty, they did not include structural (model) uncertainty. That is, projection results are conditional on one set of functional forms used to describe population dynamics, selectivity, recruitment, etc.
- Fisheries were assumed to continue fishing at their estimated current proportions of total effort, using the estimated current selectivity patterns. New management regulations that alter those proportions or selectivities would likely affect projection results.
- The projections assumed no spawner-recruit relationship applies in the future and that past deviations represent future uncertainty in recruitment. If future recruitment is characterized by runs of large or small year classes, possibly due to environmental or ecological conditions, stock projections may be affected. If future average recruitment increases with increasing stock size, benchmarks and projections will be affected.
- Projections apply the Baranov catch equation to relate F and landings using a one-year time step, as in the assessment. The catch equation implicitly assumes that mortality occurs throughout the year. This assumption is violated when seasonal closures or small intensive fishing seasons are in effect, introducing additional and unquantified uncertainty into the projection results.

References:

Clark, W.G. 2002. F35% revisited 10 years later, *North American Journal of Fisheries Management*, 22:251-257.

Dorn, M.W. 2002. Advice on west coast rockfish harvest rates from Bayesian meta-analysis of stock-recruit relationships, *North American Journal of Fisheries Management*, 22:280-300.

Shertzer, K.W. and P.B. Conn 2012. Spawner-recruit relationships of demersal marine fishes: prior distribution of steepness, *Bulletin of Marine Science*, 88(1) 39-50.

Table 1. Projection results with fishing mortality rate fixed at $F_{20\%}$ starting in 2017. R = number of age-1 recruits (in 1000s), F = fishing mortality rate (per year), B = biomass (mt), S = spawning stock (1E8 eggs), L = landings expressed in numbers (n, in 1000s) or whole weight (w, in 1000 lb), and D = dead discards expressed in numbers (n, in 1000s) or whole weight (w, in 1000 lb), pr.rebuild = proportion of stochastic projection replicates with SSB greater than or equal to $SSB_{F20\%}$. The extension .base indicates expected values (deterministic) from the base run; the extension .med indicates median values from the stochastic projections.

year	R.base (1000)	R.med (1000)	F.base	F.med	B.base(mt)	B.med(mt)	S.base(1E8)	S.med(1E8)	L.base (1000)	L.med (1000)	L.base (1000 lb)	L.med (1000 lb)	D.base (1000)	D.med (1000)	D.base (1000 lb)	D.med (1000 lb)	pr.rebuild
2015	434	313	0.27	0.29	1849	1743	65721	59735	2	2	19	14	169	167	644	653	0.009
2016	437	313	0.28	0.31	2006	1839	85574	74996	2	2	20	16	169	167	773	774	0.031
2017	440	315	0.21	0.22	2054	1820	105040	89582	28	25	270	246	57	50	303	268	0.063
2018	442	315	0.21	0.22	2220	1963	123534	103752	29	26	306	273	58	52	324	285	0.092
2019	443	317	0.21	0.22	2356	2083	139876	115987	30	27	329	293	59	53	337	298	0.121
2020	444	316	0.21	0.22	2470	2184	154043	127367	32	28	352	312	60	53	348	308	0.151
2021	445	324	0.21	0.22	2563	2276	166337	137284	33	29	372	330	61	54	357	317	0.18
2022	445	319	0.21	0.22	2638	2349	176870	145720	34	30	388	345	61	55	364	324	0.211
2023	445	320	0.21	0.22	2698	2404	185483	153703	34	31	401	356	62	55	370	331	0.242
2024	446	318	0.21	0.22	2744	2453	192542	159997	35	31	411	368	62	56	375	336	0.271
2025	446	324	0.21	0.22	2780	2494	198148	165445	35	32	419	376	62	56	378	339	0.297
2026	446	322	0.21	0.22	2808	2522	202595	169855	35	32	425	382	62	56	381	341	0.319
2027	446	327	0.21	0.22	2829	2548	206164	173374	36	32	430	386	62	56	383	344	0.341
2028	446	321	0.21	0.22	2846	2567	208917	176318	36	33	434	391	63	56	384	346	0.359
2029	446	325	0.21	0.22	2858	2580	211055	179183	36	33	437	394	63	56	385	347	0.374
2030	446	322	0.21	0.22	2868	2596	212747	180901	36	33	439	397	63	57	386	348	0.387
2031	446	323	0.21	0.22	2876	2604	214047	182523	36	33	441	398	63	56	387	349	0.397
2032	446	320	0.21	0.22	2881	2612	215035	183711	36	33	442	401	63	56	387	349	0.407
2033	446	320	0.21	0.22	2886	2619	215795	184059	36	33	443	402	63	56	388	350	0.414
2034	446	321	0.21	0.22	2889	2618	216372	184015	36	33	444	402	63	56	388	349	0.421
2035	446	321	0.21	0.22	2892	2622	216816	184655	36	33	444	403	63	56	388	349	0.426
2036	446	323	0.21	0.22	2894	2630	217155	185192	36	33	445	404	63	56	388	349	0.429
2037	446	322	0.21	0.22	2895	2634	217414	185653	36	33	445	405	63	56	388	351	0.427
2038	446	321	0.21	0.22	2896	2630	217611	186162	36	33	445	405	63	56	388	350	0.432
2039	446	319	0.21	0.22	2897	2633	217762	186378	36	33	446	406	63	56	389	350	0.432
2040	446	323	0.21	0.22	2898	2632	217877	186331	36	33	446	406	63	56	389	351	0.432
2041	446	322	0.21	0.22	2898	2631	217964	186757	36	33	446	406	63	56	389	350	0.434
2042	446	323	0.21	0.22	2899	2632	218031	186869	36	33	446	406	63	57	389	351	0.432
2043	446	323	0.21	0.22	2899	2634	218082	186422	36	33	446	406	63	56	389	351	0.433
2044	446	322	0.21	0.22	2899	2636	218121	186991	36	33	446	406	63	57	389	351	0.438

Table 2. Projection results with fishing mortality rate fixed at F_{max} starting in 2017. R = number of age-1 recruits (in 1000s), F = fishing mortality rate (per year), B = biomass (mt), S = spawning stock (1E8 eggs), L = landings expressed in numbers (n, in 1000s) or whole weight (w, in 1000 lb), and D = dead discards expressed in numbers (n, in 1000s) or whole weight (w, in 1000 lb), pr.rebuild = proportion of stochastic projection replicates with SSB greater than or equal to SSB_{Fmax}. The extension .base indicates expected values (deterministic) from the base run; the extension .med indicates median values from the stochastic projections.

year	R.base (1000)	R.med (1000)	F.base	F.med	B.base(mt)	B.med(mt)	S.base(1E8)	S.med(1E8)	L.base (1000)	L.med (1000)	L.base (1000 lb)	L.med (1000 lb)	D.base (1000)	D.med (1000)	D.base (1000 lb)	D.med (1000 lb)	pr.rebuild
2015	434	313	0.27	0.29	1849	1743	65721	59735	2	2	19	14	169	167	644	653	0.014
2016	437	313	0.28	0.31	2006	1839	85574	74996	2	2	20	16	169	167	773	774	0.041
2017	440	315	0.22	0.22	2054	1820	104743	89297	28	26	275	251	58	51	310	273	0.076
2018	442	315	0.22	0.22	2213	1956	122684	102892	30	27	311	278	59	53	329	290	0.107
2019	443	317	0.22	0.22	2343	2073	138404	114461	31	27	333	297	60	54	343	302	0.137
2020	444	316	0.22	0.22	2452	2164	151944	125319	32	29	355	315	61	54	353	313	0.163
2021	445	324	0.22	0.22	2541	2250	163634	134528	33	30	375	332	62	55	362	321	0.191
2022	445	319	0.22	0.22	2611	2323	173607	142656	34	30	391	347	62	56	369	328	0.222
2023	445	320	0.22	0.22	2667	2377	181721	149903	35	31	403	358	63	56	374	334	0.251
2024	445	318	0.22	0.22	2711	2425	188345	155881	35	32	413	368	63	56	379	339	0.277
2025	446	324	0.22	0.22	2744	2460	193579	161163	35	32	421	377	63	57	382	342	0.302
2026	446	321	0.22	0.22	2770	2494	197715	165448	36	32	427	382	63	57	384	344	0.323
2027	446	327	0.22	0.22	2790	2517	201024	168669	36	32	431	386	63	57	386	346	0.343
2028	446	321	0.22	0.22	2806	2537	203566	171617	36	33	435	391	64	57	388	348	0.361
2029	446	325	0.22	0.22	2817	2547	205533	174202	36	33	437	394	64	57	389	350	0.374
2030	446	322	0.22	0.22	2827	2566	207085	175775	36	33	440	397	64	57	389	351	0.386
2031	446	323	0.22	0.22	2833	2568	208274	176816	36	33	441	398	64	58	390	352	0.397
2032	446	320	0.22	0.22	2839	2574	209174	177870	36	33	442	401	64	57	391	352	0.407
2033	446	320	0.22	0.22	2843	2582	209864	178125	36	33	443	402	64	57	391	353	0.413
2034	446	321	0.22	0.22	2846	2587	210386	178724	36	33	444	402	64	57	391	352	0.419
2035	446	321	0.22	0.22	2848	2591	210787	179159	36	33	445	403	64	57	391	351	0.426
2036	446	323	0.22	0.22	2850	2594	211092	179847	36	33	445	403	64	57	392	352	0.428
2037	446	322	0.22	0.22	2851	2599	211324	180296	37	33	445	404	64	57	392	353	0.426
2038	446	321	0.22	0.22	2852	2595	211501	180184	37	33	445	405	64	57	392	353	0.432
2039	446	319	0.22	0.22	2853	2596	211635	180196	37	33	446	406	64	57	392	352	0.431
2040	446	322	0.22	0.22	2854	2598	211737	180343	37	33	446	406	64	57	392	353	0.431
2041	446	322	0.22	0.22	2854	2597	211815	180795	37	33	446	406	64	57	392	353	0.434
2042	446	323	0.22	0.22	2854	2598	211874	180748	37	33	446	406	64	58	392	353	0.431
2043	446	323	0.22	0.22	2855	2600	211918	180815	37	33	446	406	64	57	392	354	0.433
2044	446	322	0.22	0.22	2855	2606	211953	181100	37	33	446	406	64	57	392	354	0.439

Table 3. Projection results with fishing mortality rate fixed at $F_{rebuild50\%}$ starting in 2017. R = number of age-1 recruits (in 1000s), F = fishing mortality rate (per year), B = biomass (mt), S = spawning stock (1E8 eggs), L = landings expressed in numbers (n, in 1000s) or whole weight (w, in 1000 lb), and D = dead discards expressed in numbers (n, in 1000s) or whole weight (w, in 1000 lb), pr.rebuild = proportion of stochastic projection replicates with SSB greater than or equal to $SSB_{F20\%}$. The extension .base indicates expected values (deterministic) from the base run; the extension .med indicates median values from the stochastic projections.

year	R.base (1000)	R.med (1000)	F.base	F.med	B.base(mt)	B.med(mt)	S.base(1E8)	S.med(1E8)	L.base (1000)	L.med (1000)	L.base (1000 lb)	L.med (1000 lb)	D.base (1000)	D.med (1000)	D.base (1000 lb)	D.med (1000 lb)	pr.rebuild
2015	434	313	0.27	0.29	1849	1743	65721	59735	2	2	19	14	169	167	644	653	0.009
2016	437	313	0.28	0.31	2006	1839	85574	74996	2	2	20	16	169	167	773	774	0.031
2017	440	315	0.21	0.21	2054	1820	105237	90092	27	24	266	236	56	48	299	256	0.068
2018	442	315	0.21	0.21	2225	1975	124098	105342	29	25	302	264	57	50	320	275	0.106
2019	443	317	0.21	0.21	2364	2110	140856	118693	30	26	326	284	59	51	334	289	0.146
2020	444	316	0.21	0.21	2482	2217	155447	130919	31	28	349	306	60	52	345	300	0.185
2021	445	324	0.21	0.21	2579	2314	168149	141890	33	29	369	325	60	53	354	311	0.222
2022	445	319	0.21	0.21	2656	2394	179062	151040	33	30	386	341	61	53	361	318	0.263
2023	445	320	0.21	0.21	2718	2451	188015	159317	34	30	399	353	61	54	367	325	0.304
2024	446	318	0.21	0.21	2766	2500	195374	166637	35	31	410	365	61	54	372	330	0.335
2025	446	324	0.21	0.21	2803	2537	201235	172288	35	31	418	374	62	54	376	334	0.364
2026	446	322	0.21	0.21	2832	2568	205896	176871	35	32	425	380	62	55	378	336	0.389
2027	446	327	0.21	0.21	2855	2594	209645	180334	35	32	430	385	62	55	380	339	0.412
2028	446	321	0.21	0.21	2872	2619	212545	183484	36	32	433	390	62	55	382	341	0.429
2029	446	325	0.21	0.21	2886	2630	214803	186012	36	32	436	393	62	55	383	342	0.446
2030	446	322	0.21	0.21	2896	2647	216592	187876	36	32	439	396	62	55	384	343	0.458
2031	446	323	0.21	0.21	2904	2653	217971	188849	36	32	440	397	62	55	384	343	0.467
2032	446	321	0.21	0.21	2910	2664	219021	190439	36	33	442	400	62	55	385	344	0.478
2033	446	320	0.21	0.21	2915	2664	219830	191080	36	33	443	401	62	55	385	344	0.484
2034	446	321	0.21	0.21	2918	2665	220446	191414	36	33	444	401	62	55	386	344	0.489
2035	446	321	0.21	0.21	2921	2669	220921	191808	36	33	444	402	62	55	386	345	0.493
2036	446	323	0.21	0.21	2923	2676	221284	192574	36	33	445	403	62	55	386	344	0.494
2037	446	322	0.21	0.21	2925	2681	221562	193167	36	33	445	403	62	55	386	346	0.495
2038	446	321	0.21	0.21	2926	2685	221775	193487	36	33	445	404	62	55	386	345	0.497
2039	446	319	0.21	0.21	2927	2680	221937	193483	36	33	446	405	62	55	386	345	0.497
2040	446	323	0.21	0.21	2928	2680	222061	193288	36	33	446	405	62	55	386	346	0.497
2041	446	322	0.21	0.21	2928	2677	222156	193236	36	33	446	405	62	55	386	345	0.498
2042	446	323	0.21	0.21	2929	2679	222228	193576	36	33	446	405	62	55	386	346	0.5
2043	446	324	0.21	0.21	2929	2684	222283	194073	36	33	446	405	62	55	386	346	0.499
2044	446	322	0.21	0.21	2929	2689	222326	194107	36	33	446	404	62	55	386	346	0.5

Table 4. Projection results with fishing mortality rate fixed at $F_{rebuild50\%}$ starting in 2017. R = number of age-1 recruits (in 1000s), F = fishing mortality rate (per year), B = biomass (mt), S = spawning stock (1E8 eggs), L = landings expressed in numbers (n, in 1000s) or whole weight (w, in 1000 lb), and D = dead discards expressed in numbers (n, in 1000s) or whole weight (w, in 1000 lb), pr.rebuild = proportion of stochastic projection replicates with SSB greater than or equal to SSB_{Fmax}. The extension .base indicates expected values (deterministic) from the base run; the extension .med indicates median values from the stochastic projections.

year	R.base (1000)	R.med (1000)	F.base	F.med	B.base(mt)	B.med(mt)	S.base(1E8)	S.med(1E8)	L.base (1000)	L.med (1000)	L.base (1000 lb)	L.med (1000 lb)	D.base (1000)	D.med (1000)	D.base (1000 lb)	D.med (1000 lb)	pr.rebuild
2015	434	313	0.27	0.29	1849	1743	65721	59735	2	2	19	14	169	167	644	653	0.014
2016	437	313	0.28	0.31	2006	1839	85574	74996	2	2	20	16	169	167	773	774	0.041
2017	440	315	0.21	0.21	2054	1820	104945	89846	28	25	271	241	57	49	305	262	0.084
2018	442	315	0.21	0.21	2218	1969	123261	104640	29	26	308	269	58	51	325	280	0.127
2019	443	317	0.21	0.21	2352	2099	139403	117479	30	27	330	288	60	52	339	294	0.168
2020	444	316	0.21	0.21	2464	2201	153368	129215	32	28	353	309	61	53	350	304	0.207
2021	445	324	0.21	0.21	2556	2293	165467	139720	33	29	373	327	61	54	359	315	0.248
2022	445	319	0.21	0.21	2630	2368	175818	148292	34	30	389	344	62	54	366	322	0.289
2023	445	320	0.21	0.21	2688	2423	184269	156237	34	31	402	355	62	55	371	329	0.324
2024	446	318	0.21	0.21	2733	2470	191187	163051	35	31	412	367	62	55	376	334	0.354
2025	446	324	0.21	0.21	2768	2505	196672	168460	35	32	420	376	63	55	379	337	0.379
2026	446	322	0.21	0.21	2796	2534	201017	172611	36	32	426	382	63	56	382	339	0.403
2027	446	327	0.21	0.21	2817	2559	204501	175842	36	32	431	386	63	56	384	342	0.422
2028	446	321	0.21	0.21	2833	2582	207185	178846	36	32	434	391	63	56	385	344	0.439
2029	446	325	0.21	0.21	2845	2593	209268	181275	36	33	437	394	63	56	386	345	0.453
2030	446	322	0.21	0.21	2855	2609	210914	183058	36	33	439	397	63	56	387	346	0.464
2031	446	323	0.21	0.21	2862	2615	212178	183831	36	33	441	397	63	56	388	346	0.472
2032	446	320	0.21	0.21	2868	2625	213137	185302	36	33	442	401	63	56	388	347	0.48
2033	446	320	0.21	0.21	2872	2625	213873	185941	36	33	443	402	63	56	389	347	0.486
2034	446	321	0.21	0.21	2875	2625	214432	186220	36	33	444	401	63	56	389	347	0.492
2035	446	321	0.21	0.21	2878	2629	214862	186668	36	33	444	402	63	56	389	347	0.492
2036	446	323	0.21	0.21	2879	2636	215190	187193	36	33	445	403	63	56	389	347	0.496
2037	446	322	0.21	0.21	2881	2641	215440	187878	36	33	445	403	63	56	389	349	0.498
2038	446	321	0.21	0.21	2882	2643	215631	188127	36	33	445	404	63	56	390	348	0.498
2039	446	319	0.21	0.21	2883	2639	215776	188038	36	33	446	405	63	56	390	348	0.5
2040	446	323	0.21	0.21	2883	2639	215886	187781	36	33	446	405	63	56	390	348	0.498
2041	446	322	0.21	0.21	2884	2636	215970	187801	36	33	446	404	63	56	390	348	0.498
2042	446	323	0.21	0.21	2884	2637	216035	188028	36	33	446	405	63	56	390	348	0.497
2043	446	324	0.21	0.21	2885	2642	216083	188607	36	33	446	405	63	56	390	349	0.499
2044	446	322	0.21	0.21	2885	2647	216121	188628	36	33	446	404	63	56	390	349	0.5

Table 5. Projection results with fishing mortality rate fixed at $F_{rebuild67.5\%}$ starting in 2017. R = number of age-1 recruits (in 1000s), F = fishing mortality rate (per year), B = biomass (mt), S = spawning stock (1E8 eggs), L = landings expressed in numbers (n, in 1000s) or whole weight (w, in 1000 lb), and D = dead discards expressed in numbers (n, in 1000s) or whole weight (w, in 1000 lb), pr.rebuild = proportion of stochastic projection replicates with $SSB = SSB_{F20\%}$. The extension .base indicates expected values (deterministic) from the base run; the extension .med indicates median values from the stochastic projections.

year	R.base (1000)	R.med (1000)	F.base	F.med	B.base(mt)	B.med(mt)	S.base(1E8)	S.med(1E8)	L.base (1000)	L.med (1000)	L.base (1000 lb)	L.med (1000 lb)	D.base (1000)	D.med (1000)	D.base (1000 lb)	D.med (1000 lb)	pr.rebuild
2015	434	313	0.27	0.29	1849	1743	65721	59735	2	2	19	14	169	167	644	653	0.009
2016	437	313	0.28	0.31	2006	1839	85574	74996	2	2	20	16	169	167	773	774	0.031
2017	440	315	0.19	0.19	2054	1820	106418	91082	25	22	243	215	51	44	273	234	0.071
2018	442	316	0.19	0.19	2251	1998	127524	108240	27	23	281	245	53	46	295	254	0.117
2019	443	317	0.19	0.19	2416	2156	146862	123677	28	25	307	267	54	47	311	270	0.168
2020	444	316	0.19	0.19	2557	2283	164119	138124	30	26	332	291	55	48	324	282	0.222
2021	445	324	0.19	0.19	2673	2397	179430	151332	31	27	355	312	56	49	335	293	0.277
2022	445	319	0.19	0.19	2768	2495	192807	162608	32	28	373	330	56	50	343	302	0.334
2023	446	321	0.19	0.19	2844	2568	203987	172663	33	29	388	344	57	50	349	309	0.386
2024	446	319	0.19	0.19	2905	2629	213329	181699	33	30	400	357	57	50	355	315	0.434
2025	446	325	0.19	0.19	2953	2674	220902	188926	34	30	410	367	57	51	359	319	0.476
2026	446	322	0.19	0.19	2990	2712	227019	194717	34	31	418	374	57	51	362	322	0.512
2027	446	327	0.19	0.19	3020	2745	232003	199654	34	31	424	380	58	51	364	325	0.546
2028	447	321	0.19	0.19	3043	2773	235920	203484	35	31	428	385	58	51	366	328	0.572
2029	447	325	0.19	0.19	3061	2794	239012	206646	35	31	432	390	58	51	367	329	0.595
2030	447	323	0.19	0.19	3075	2813	241491	209395	35	31	435	393	58	51	368	330	0.612
2031	447	324	0.19	0.19	3086	2821	243428	211199	35	32	437	394	58	51	369	330	0.628
2032	447	321	0.19	0.19	3095	2833	244924	212866	35	32	439	397	58	51	370	331	0.64
2033	447	321	0.19	0.19	3101	2841	246092	213877	35	32	440	399	58	51	370	331	0.65
2034	447	321	0.19	0.19	3106	2840	246993	214495	35	32	441	399	58	51	371	332	0.657
2035	447	321	0.19	0.19	3110	2845	247695	215149	35	32	442	401	58	51	371	332	0.661
2036	447	323	0.19	0.19	3113	2855	248240	216022	35	32	443	401	58	51	371	332	0.666
2037	447	322	0.19	0.19	3116	2858	248662	216908	35	32	443	402	58	51	372	333	0.668
2038	447	321	0.19	0.19	3117	2861	248988	217148	35	32	443	402	58	51	372	333	0.671
2039	447	319	0.19	0.19	3119	2857	249240	217416	35	32	444	403	58	51	372	333	0.674
2040	447	323	0.19	0.19	3120	2856	249435	217104	35	32	444	404	58	51	372	333	0.675
2041	447	323	0.19	0.19	3121	2858	249586	217414	35	32	444	404	58	52	372	333	0.676
2042	447	324	0.19	0.19	3121	2859	249703	217600	35	32	444	404	58	52	372	333	0.674
2043	447	324	0.19	0.19	3122	2865	249793	217940	35	32	444	404	58	51	372	334	0.675
2044	447	323	0.19	0.19	3122	2869	249862	218199	35	32	444	403	58	52	372	334	0.676

Table 6. Projection results with fishing mortality rate fixed at $F_{rebuild67.5\%}$ starting in 2017. R = number of age-1 recruits (in 1000s), F = fishing mortality rate (per year), B = biomass (mt), S = spawning stock (1E8 eggs), L = landings expressed in numbers (n, in 1000s) or whole weight (w, in 1000 lb), and D = dead discards expressed in numbers (n, in 1000s) or whole weight (w, in 1000 lb), pr.rebuild = proportion of stochastic projection replicates with SSB greater than or equal to SSB_{Fmax}. The extension .base indicates expected values (deterministic) from the base run; the extension .med indicates median values from the stochastic projections.

year	R.base (1000)	R.med (1000)	F.base	F.med	B.base(mt)	B.med(mt)	S.base(1E8)	S.med(1E8)	L.base (1000)	L.med (1000)	L.base (1000 lb)	L.med (1000 lb)	D.base (1000)	D.med (1000)	D.base (1000 lb)	D.med (1000 lb)	pr.rebuild
2015	434	313	0.27	0.29	1849	1743	65721	59735	2	2	19	14	169	167	644	653	0.014
2016	437	313	0.28	0.31	2006	1839	85574	74996	2	2	20	16	169	167	773	774	0.041
2017	440	315	0.19	0.19	2054	1820	106195	90894	26	22	247	219	52	44	278	238	0.087
2018	442	316	0.19	0.19	2246	1993	126874	107706	27	24	285	249	53	46	300	258	0.139
2019	443	317	0.19	0.19	2406	2147	145714	122699	28	25	310	270	55	48	316	274	0.192
2020	444	316	0.19	0.19	2543	2271	162451	136727	30	26	335	294	56	49	328	286	0.25
2021	445	324	0.19	0.19	2655	2381	177249	149506	31	28	358	314	57	50	338	297	0.304
2022	445	319	0.19	0.19	2746	2475	190137	160371	32	29	376	332	57	50	346	305	0.361
2023	446	321	0.19	0.19	2820	2545	200871	170153	33	29	391	346	58	51	353	313	0.409
2024	446	319	0.19	0.19	2878	2604	209814	178810	34	30	402	359	58	51	358	318	0.452
2025	446	324	0.19	0.19	2924	2647	217039	185688	34	31	412	369	58	51	362	322	0.492
2026	446	322	0.19	0.19	2959	2683	222859	191232	34	31	419	376	58	52	365	325	0.526
2027	446	327	0.19	0.19	2988	2715	227589	195880	35	31	425	381	58	52	367	328	0.555
2028	446	321	0.19	0.19	3009	2743	231295	199535	35	31	429	386	58	52	369	330	0.581
2029	447	325	0.19	0.19	3027	2763	234213	202521	35	32	433	391	58	52	370	331	0.6
2030	447	323	0.19	0.19	3040	2780	236547	205122	35	32	436	394	59	52	371	332	0.617
2031	447	323	0.19	0.19	3050	2788	238366	206773	35	32	438	395	59	52	372	333	0.628
2032	447	321	0.19	0.19	3058	2800	239768	208395	35	32	440	398	59	52	373	334	0.641
2033	447	321	0.19	0.19	3064	2807	240859	209386	35	32	441	400	59	52	373	334	0.649
2034	447	321	0.19	0.19	3069	2805	241699	209835	35	32	442	400	59	52	374	334	0.655
2035	447	321	0.19	0.19	3073	2810	242352	210492	35	32	443	401	59	52	374	334	0.662
2036	447	323	0.19	0.19	3076	2819	242858	211417	35	32	443	402	59	52	374	334	0.664
2037	447	322	0.19	0.19	3078	2823	243248	212199	35	32	444	403	59	52	374	336	0.668
2038	447	321	0.19	0.19	3080	2826	243549	212527	35	32	444	403	59	52	375	335	0.67
2039	447	319	0.19	0.19	3081	2822	243782	212629	35	32	444	404	59	52	375	335	0.673
2040	447	323	0.19	0.19	3082	2820	243961	212395	35	32	444	404	59	52	375	335	0.674
2041	447	322	0.19	0.19	3083	2823	244099	212545	35	32	445	404	59	52	375	335	0.673
2042	447	323	0.19	0.19	3083	2824	244206	212735	35	32	445	404	59	52	375	336	0.673
2043	447	324	0.19	0.19	3084	2828	244288	213222	35	32	445	404	59	52	375	336	0.674
2044	447	323	0.19	0.19	3084	2834	244352	213363	35	32	445	404	59	52	375	336	0.675

Table 7. Projection results with fishing mortality rate fixed at F_{max} starting in 2017 with an adjusted size limit (18”). R = number of age-1 recruits (in 1000s), F = fishing mortality rate (per year), B = biomass (mt), S = spawning stock (1E8 eggs), L = landings expressed in numbers (n, in 1000s) or whole weight (w, in 1000 lb), and D = dead discards expressed in numbers (n, in 1000s) or whole weight (w, in 1000 lb).

year	R(1000)	F	B(mt)	S(1E8)	L(1000)	L(1000lb)	D(1000)	D(1000lb)
2015	434	0.27	1849	65721	2	19	169	644
2016	437	0.28	2006	85574	2	20	169	773
2017	440	0.22	2054	104743	31	290	53	283
2018	442	0.22	2213	122684	32	323	54	303
2019	443	0.22	2343	138404	33	347	55	314
2020	444	0.22	2452	151944	34	370	56	324
2021	445	0.22	2541	163634	35	389	56	332
2022	445	0.22	2611	173607	36	405	57	339
2023	445	0.22	2667	181721	37	418	57	344
2024	445	0.22	2711	188345	37	428	57	349
2025	446	0.22	2744	193579	38	435	57	352
2026	446	0.22	2770	197715	38	441	58	354
2027	446	0.22	2790	201024	38	446	58	356
2028	446	0.22	2806	203566	38	449	58	358
2029	446	0.22	2817	205533	39	452	58	359
2030	446	0.22	2827	207085	39	454	58	359
2031	446	0.22	2833	208274	39	456	58	360
2032	446	0.22	2839	209174	39	457	58	360
2033	446	0.22	2843	209864	39	458	58	361
2034	446	0.22	2846	210386	39	458	58	361
2035	446	0.22	2848	210787	39	459	58	361
2036	446	0.22	2850	211092	39	459	58	361
2037	446	0.22	2851	211324	39	460	58	362
2038	446	0.22	2852	211501	39	460	58	362
2039	446	0.22	2853	211635	39	460	58	362
2040	446	0.22	2854	211737	39	460	58	362
2041	446	0.22	2854	211815	39	460	58	362
2042	446	0.22	2854	211874	39	460	58	362
2043	446	0.22	2855	211918	39	460	58	362
2044	446	0.22	2855	211953	39	461	58	362

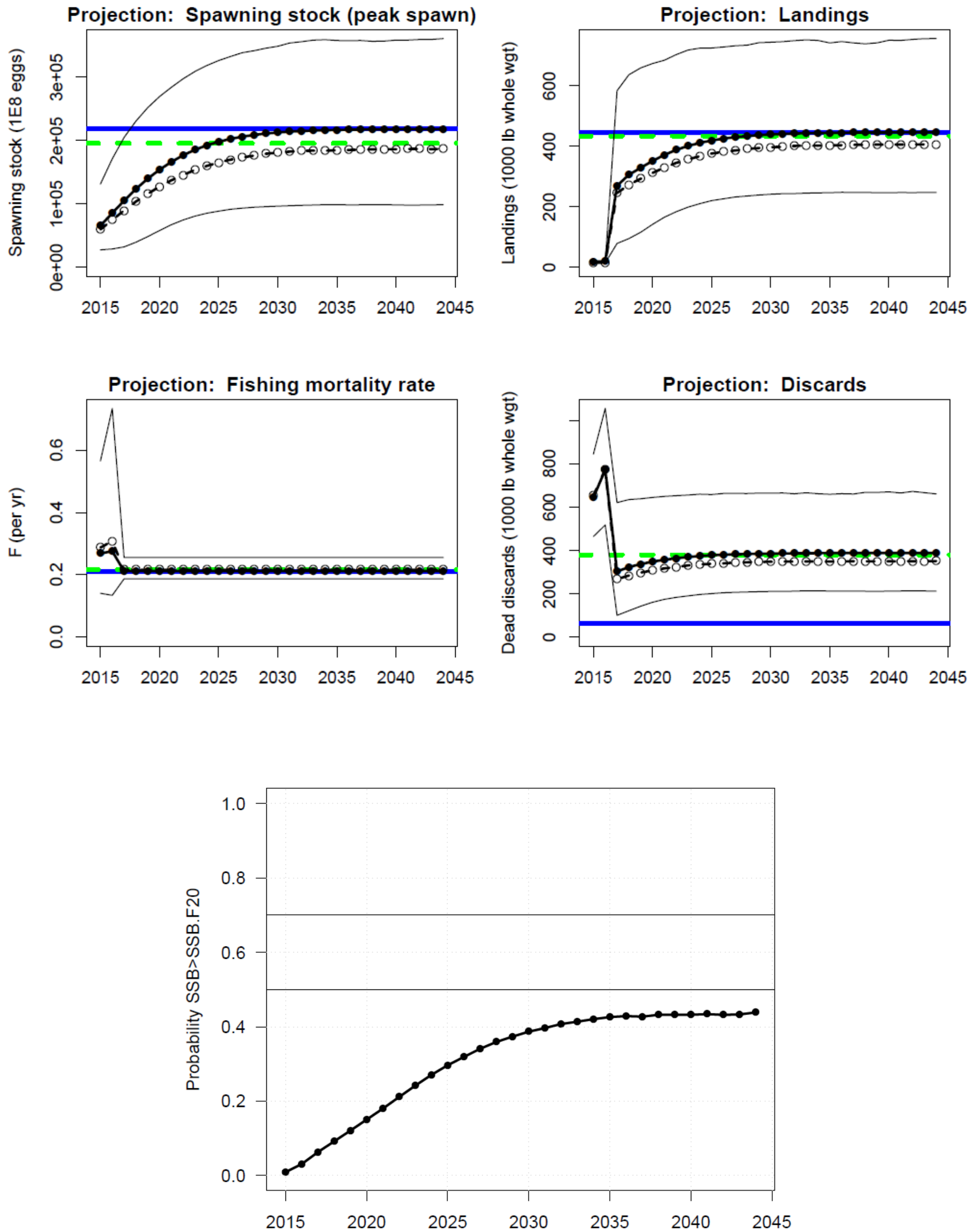

Figure 1. Projection results under the constant fishing mortality rate at $F_{20\%}$. In top four panels, expected values (base run) represented by solid lines with solid circles, medians represented by dashed lines with open circles, and uncertainty represented by thin lines corresponding to 5^{th} and 95^{th} percentiles of replicate projections. Solid horizontal lines mark $F_{20\%}$-related quantities; dashed horizontal lines represent corresponding medians. Spawning stock (SSB) is at time of peak spawning. In bottom panel, the curve represents the proportion of projection replicates for which SSB has reached the replicate-specific $SSB_{F20\%}$.

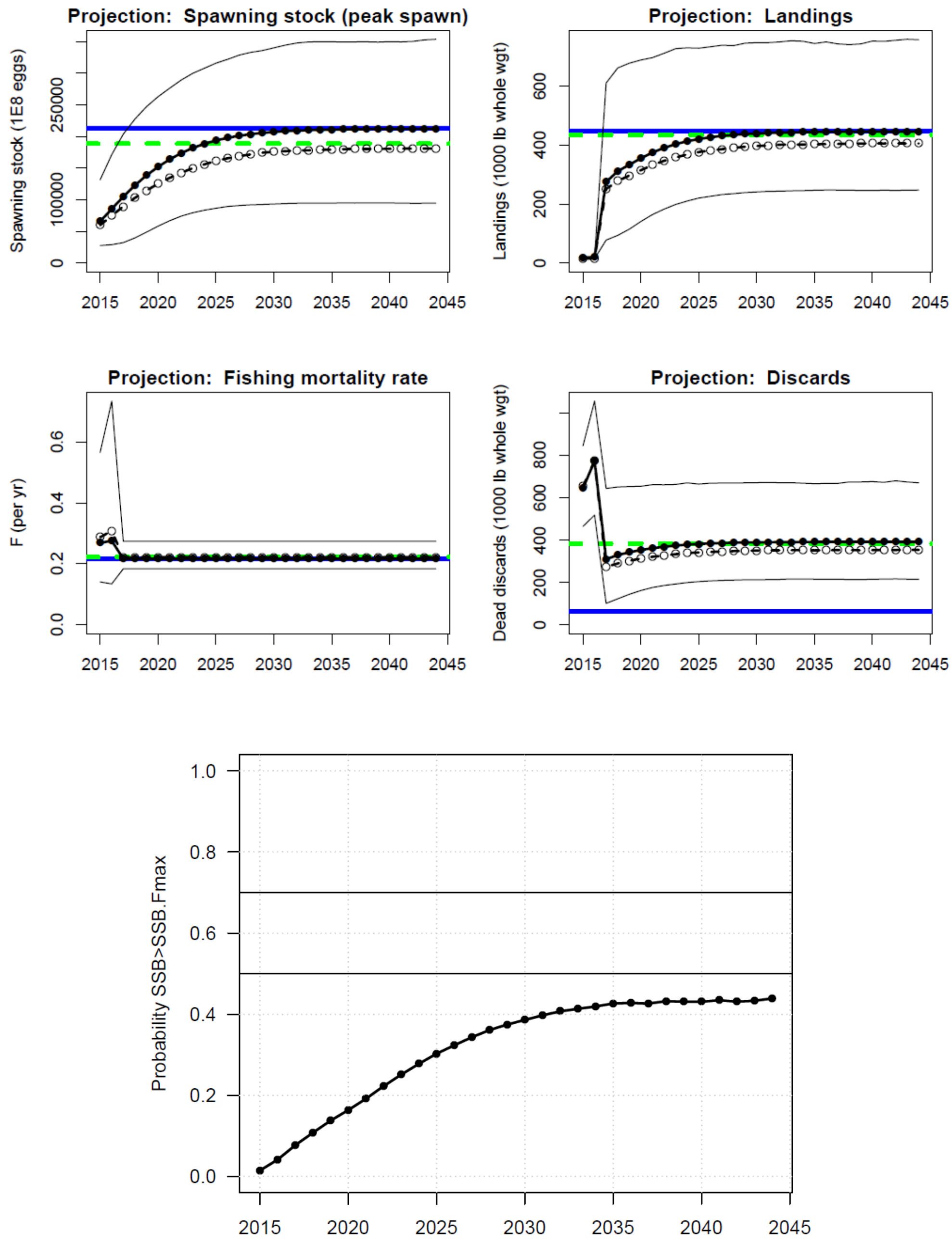

Figure 2. Projection results under the constant fishing mortality rate at F_{max}. In top four panels, expected values (base run) represented by solid lines with solid circles, medians represented by dashed lines with open circles, and uncertainty represented by thin lines corresponding to 5th and 95th percentiles of replicate projections. Solid horizontal lines mark $F_{20\%}$-related quantities; dashed horizontal lines represent corresponding medians. Spawning stock (SSB) is at time of peak spawning. In bottom panel, the curve represents the proportion of projection replicates for which SSB has reached the replicate-specific SSB_{Fmax}.

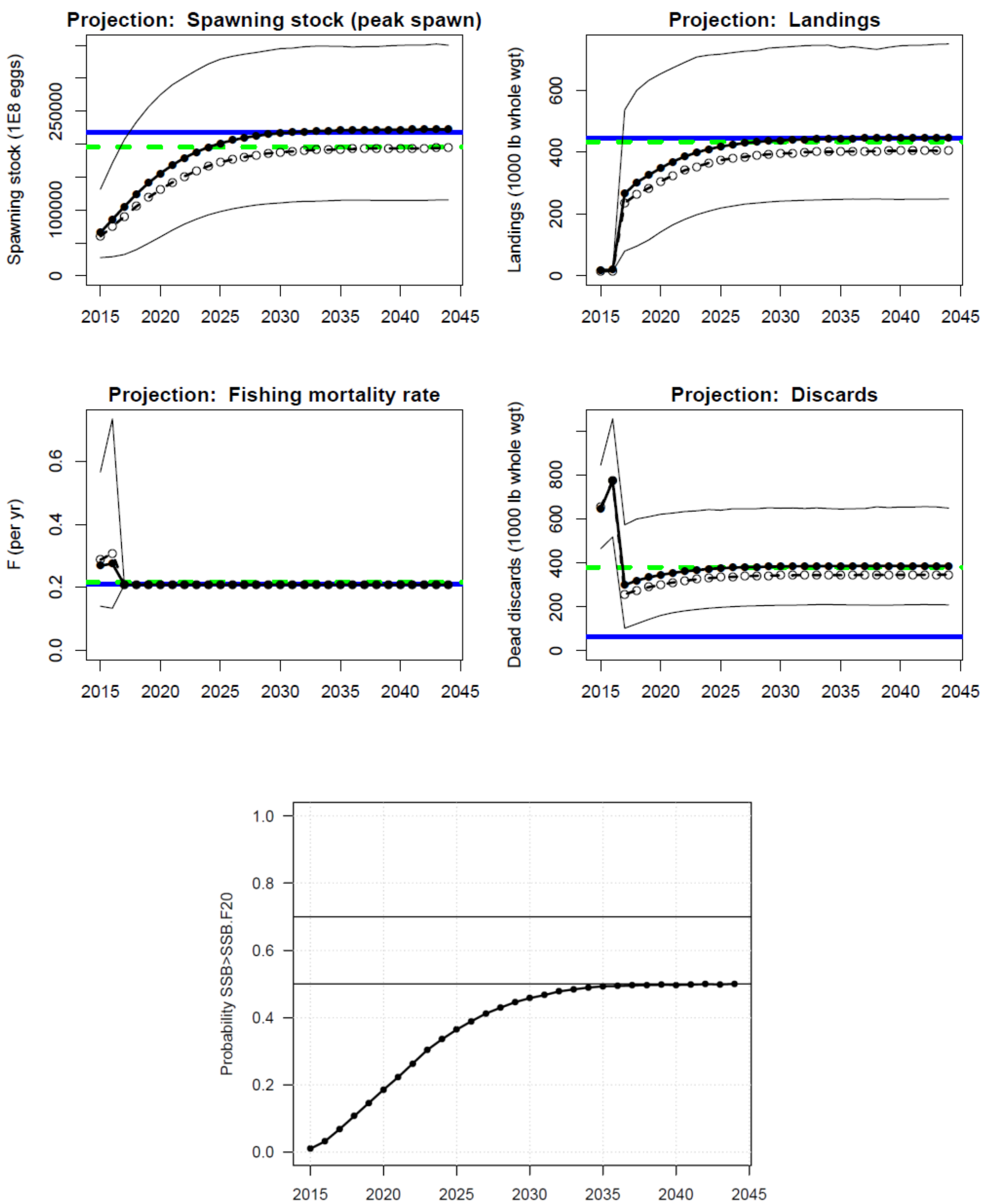

Figure 3 Projection results under a rebuilding fishing mortality rate $F_{rebuild}$, with rebuilding probability of 0.5 in 2044. In top four panels, expected values (base run) represented by solid lines with solid circles, medians represented by dashed lines with open circles, and uncertainty represented by thin lines corresponding to 5^{th} and 95^{th} percentiles of replicate projections. Solid horizontal lines mark $F_{20\%}$-related quantities; dashed horizontal lines represent corresponding medians. Spawning stock (SSB) is at time of peak spawning. In bottom panel, the curve represents the proportion of projection replicates for which SSB has reached the replicate-specific $SSB_{F20\%}$.

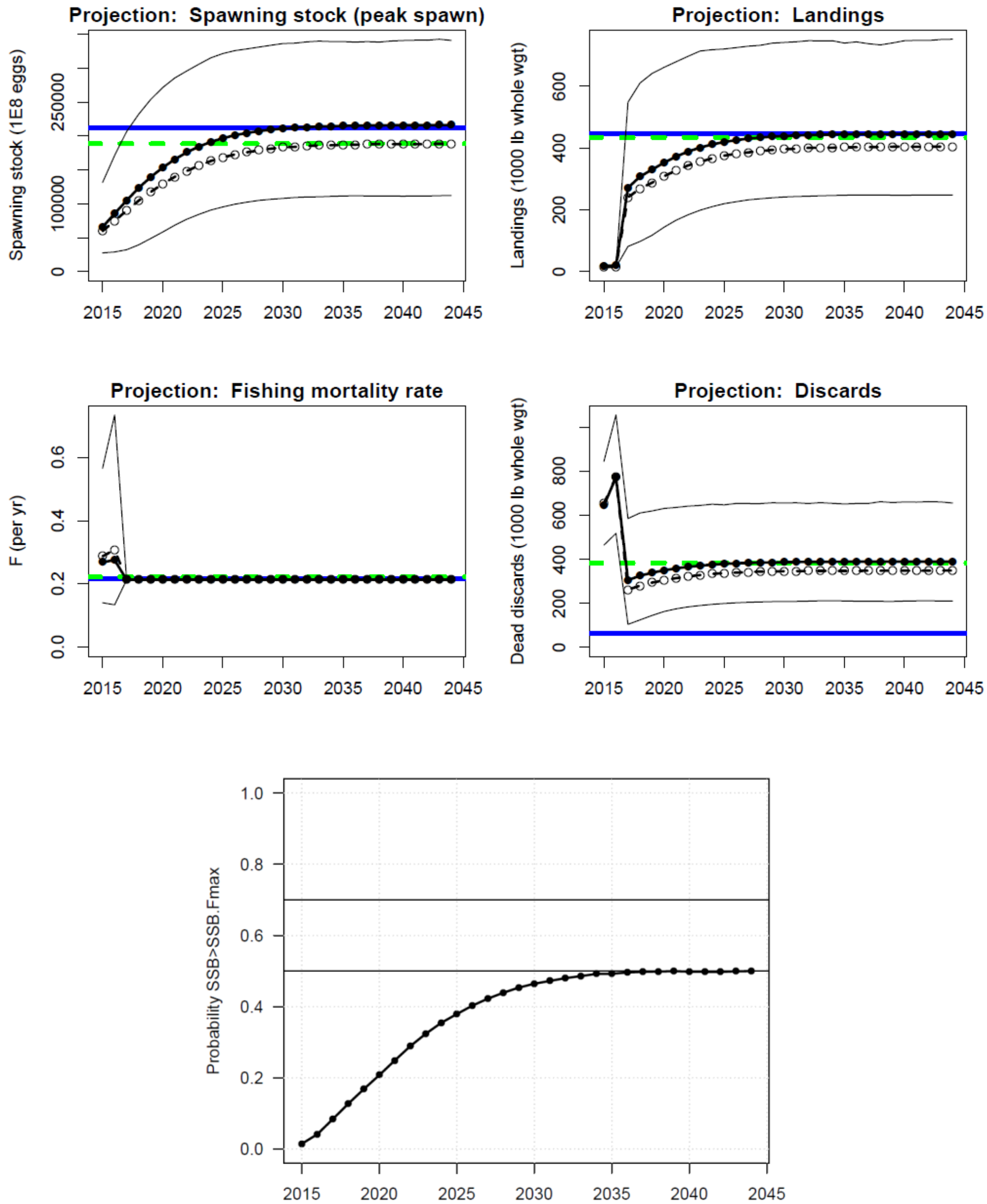

Figure 4 Projection results under a rebuilding fishing mortality rate $F_{rebuild}$, with rebuilding probability of 0.5 in 2044. In top four panels, expected values (base run) represented by solid lines with solid circles, medians represented by dashed lines with open circles, and uncertainty represented by thin lines corresponding to 5^{th} and 95^{th} percentiles of replicate projections. Solid horizontal lines mark $F_{20\%}$-related quantities; dashed horizontal lines represent corresponding medians. Spawning stock (SSB) is at time of peak spawning. In bottom panel, the curve represents the proportion of projection replicates for which SSB has reached the replicate-specific SSB_{Fmax}.

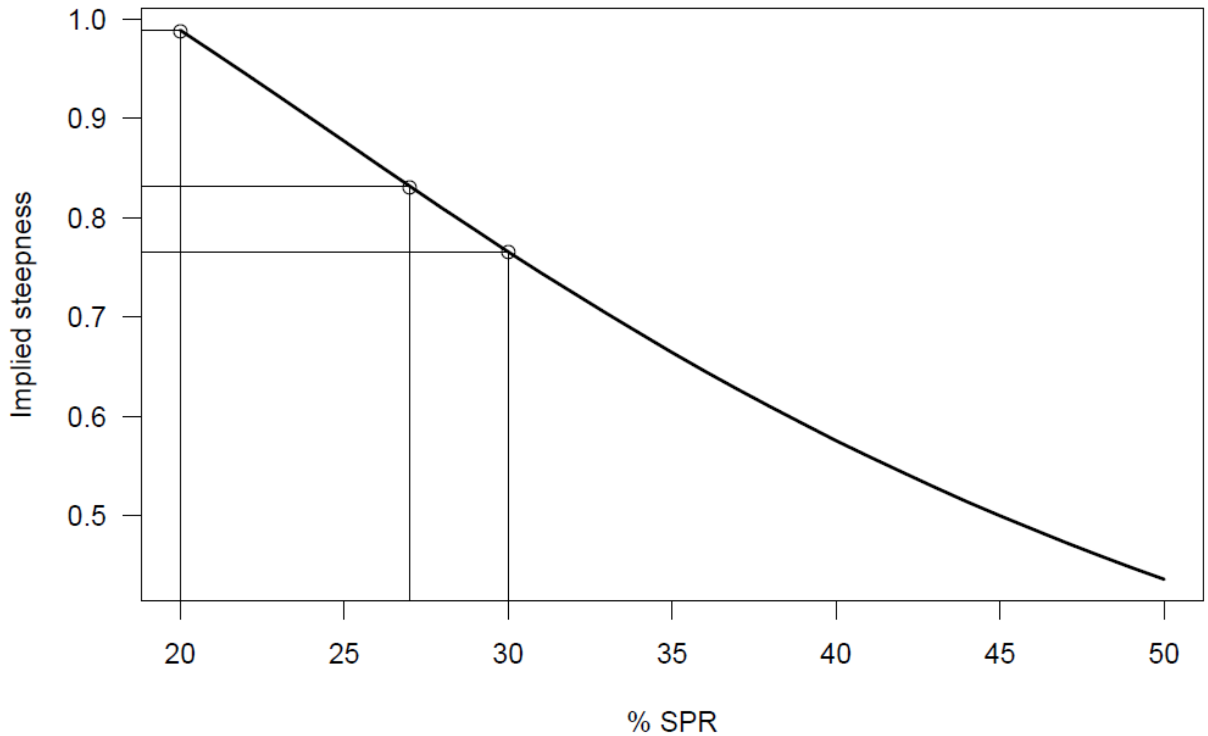

Figure 5. The implied steepness of various %SPR proxies under consideration

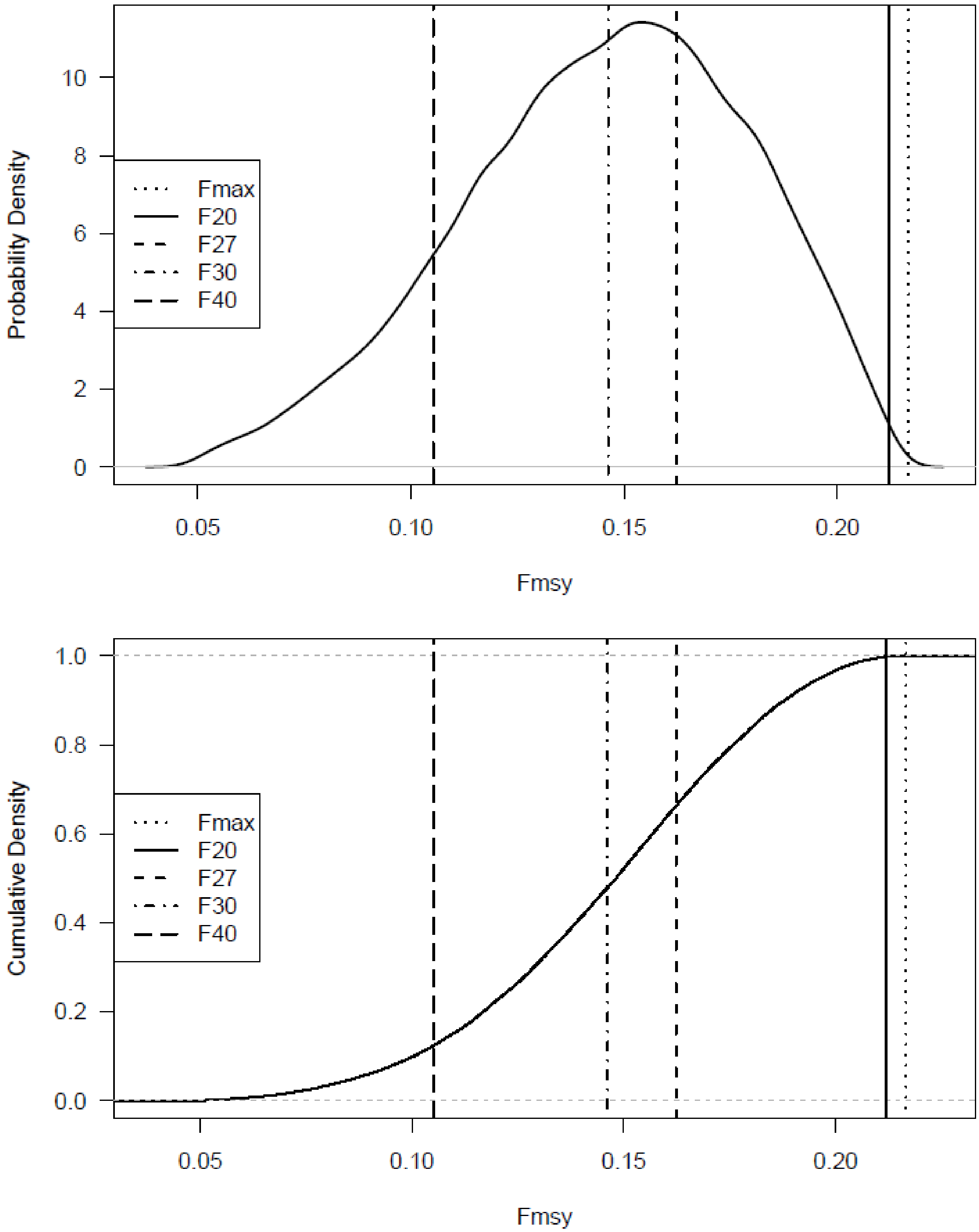

Figure 6. Top Panel: The probability density of F_{msy} given the base parameter estimates using the distribution of steepness values in Shertzer and Conn (2012) plotted against various %SPR proxies under consideration. Bottom panel: The cumulative density of F_{msy} plotted against various %SPR proxies under consideration.

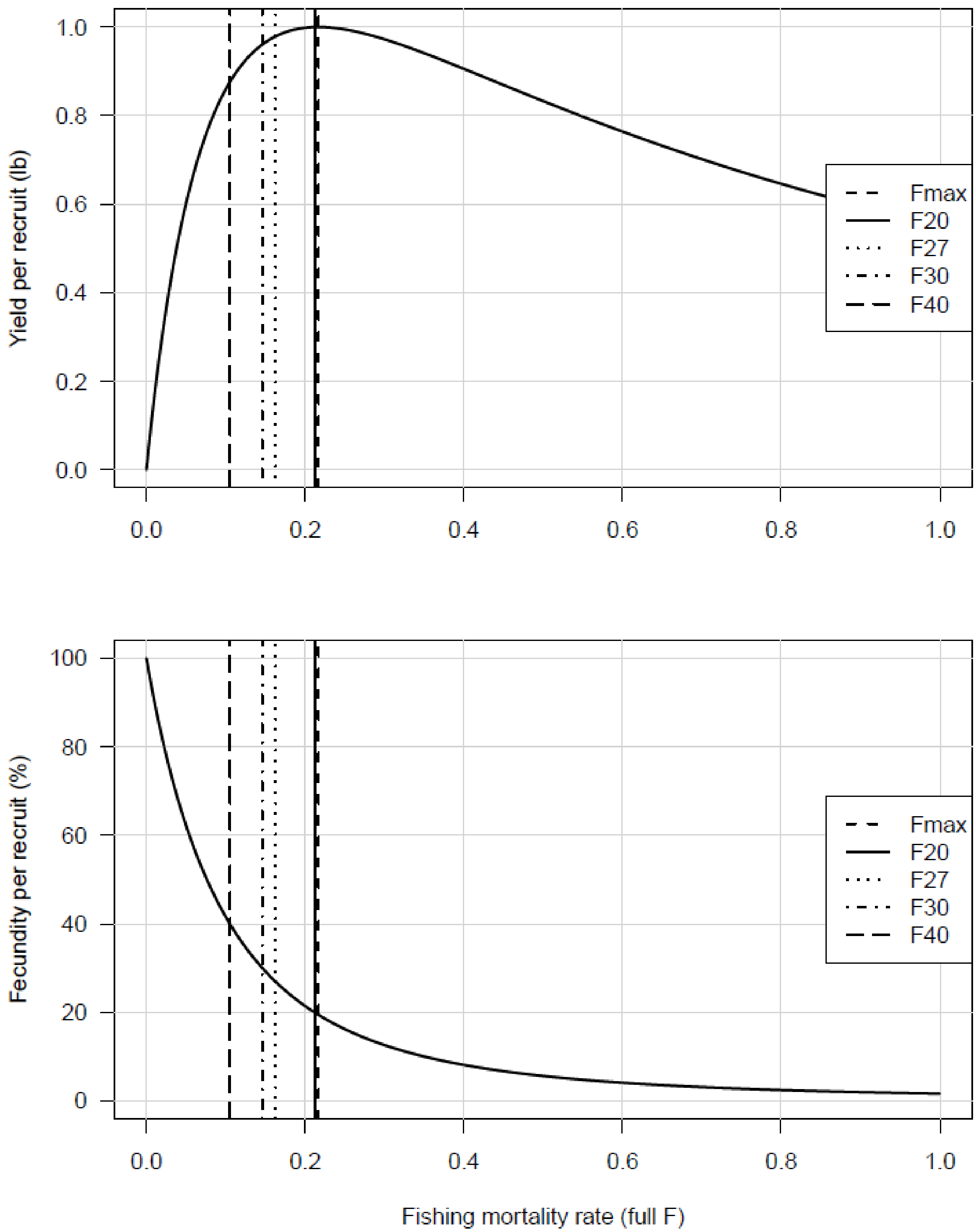

Figure 7. Top Panel: The yield per recruit at various levels of fishing mortality plotted against various %SPR proxies under consideration. Bottom panel: The fecundity per recruit at various levels of fishing mortality plotted against various %SPR proxies under consideration.

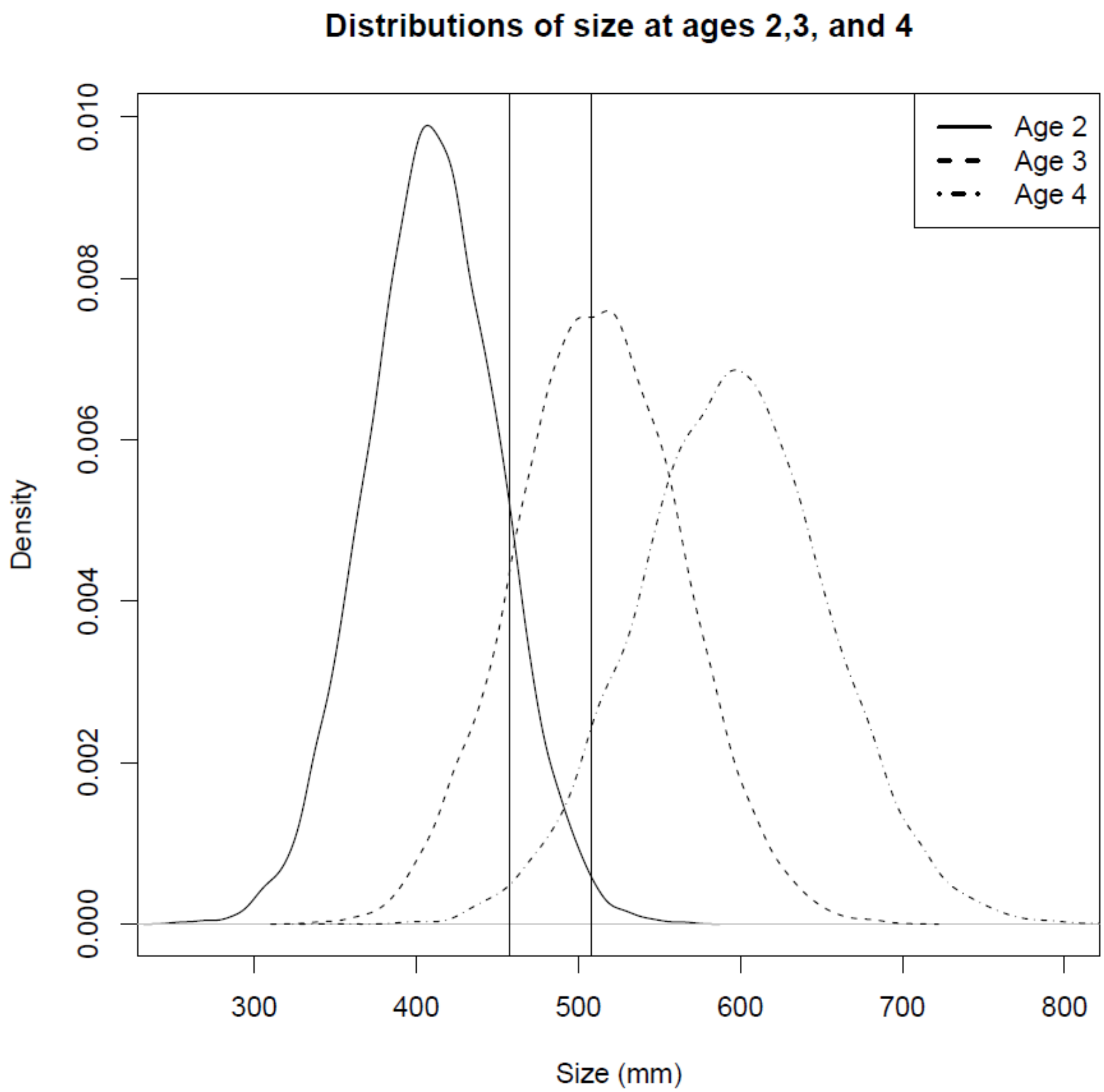

Figure 8. The distribution of sizes at ages 2, 3 and 4. The vertical lines indicate 18 and 20 inches.

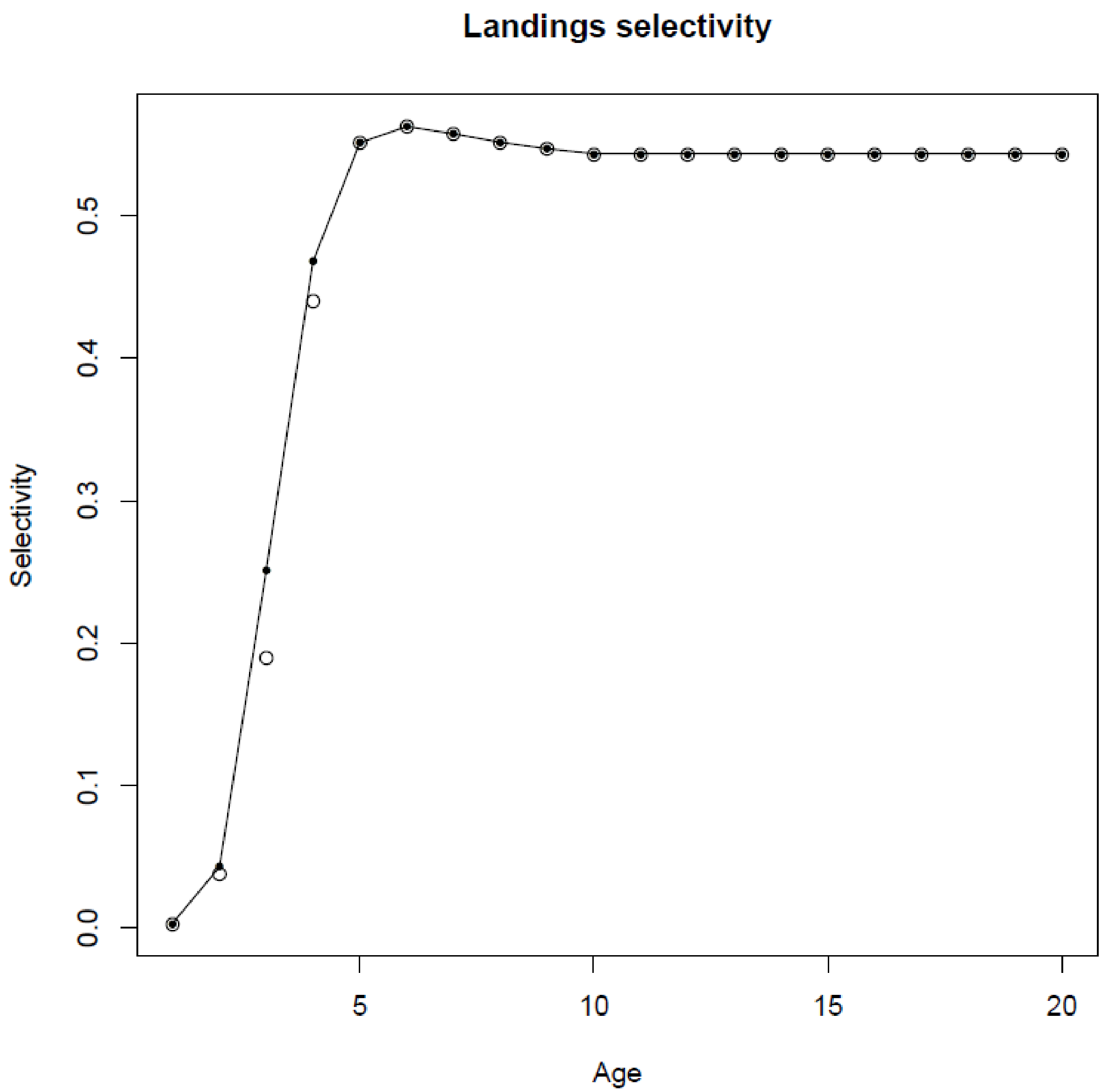

Figure 9. The larger points indicate the current total selectivity of landings, and the solid line with smaller points indicates the assumed change in landings selectivity due to an 18” size limit.

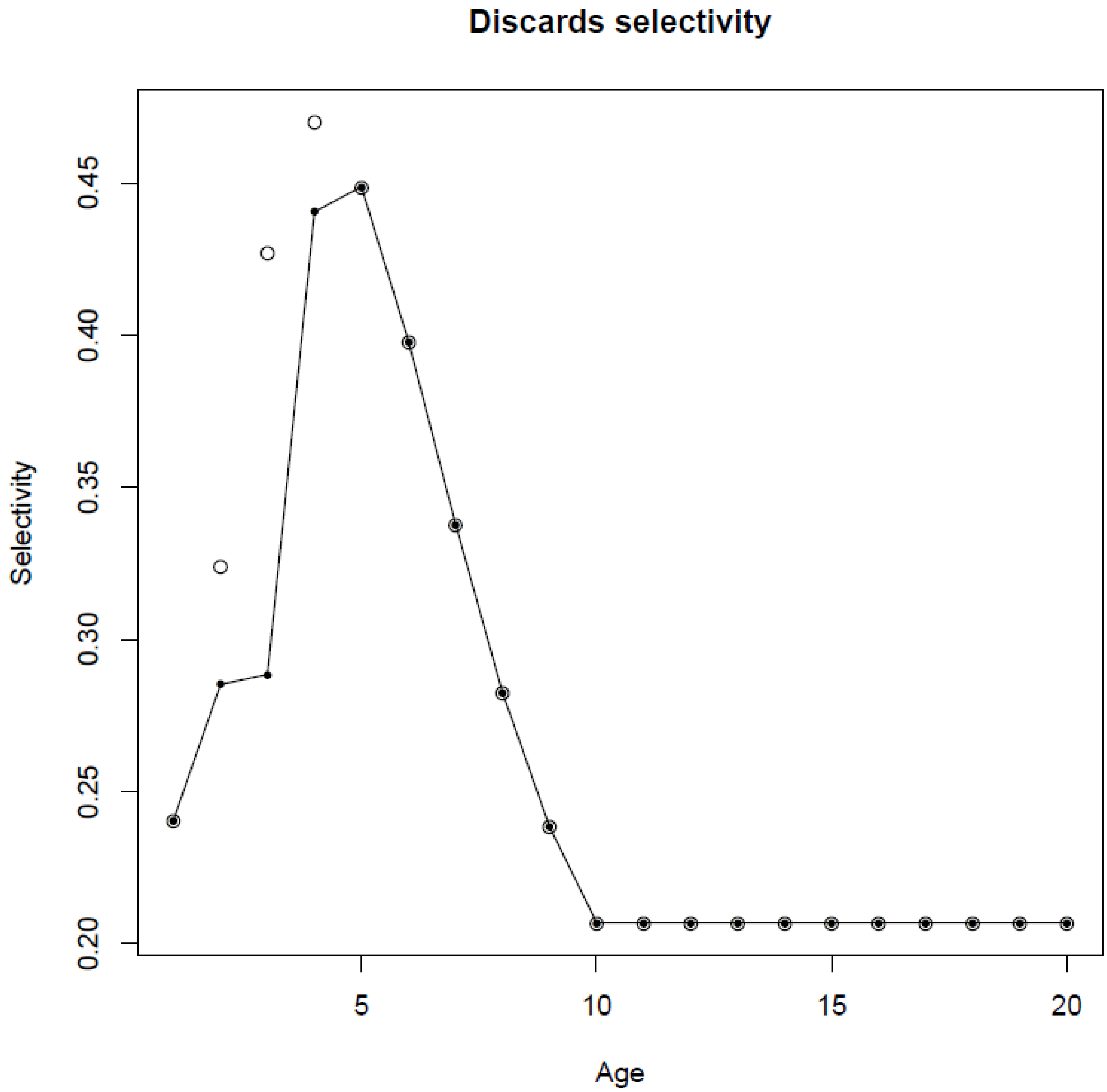

Figure 10. The larger points indicate the current total selectivity of discards, and the solid line with smaller points indicates the assumed change in discards selectivity due to an 18” size limit.