EFFECT OF ALTERNATIVE MSY PROXIES ON THE PROJECTED OVERFISHING LIMITS AND ALLOWABLE BIOLOGICAL CATCHES FOR THE RED SNAPPER FISHERY IN THE U.S. GULF OF MEXICO

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1. INTRODUCTION

During the January 2015 Gulf of Mexico Fishery Management Council (hereafter referred to as 'the Council') meeting, the Council recommended developing a new amendment to the reef fish management plan that would consider various red snapper maximum sustainable yield (MSY) proxies based on alternative spawning potential ratios (SPR). To aid the development of this amendment, the council requested projections of annual overfishing limits (OFL) and acceptable biological catches (ABC) for a range of MSY proxies:

- 40% SPR
- 30% SPR
- 26% SPR (status quo)
- 24% SPR
- 22% SPR
- 20% SPR
- The SPR proxy (if below 20% SPR) that results in the highest annual OFL and ABC.

All projections were to be completed assuming a rebuilding year of 2032. Projections assuming a rebuilding year of 2026 were also requested for MSY proxies less than 26% SPR, because a new rebuilding plan would be required in the event that a less conservative SPR proxy was adopted as the basis of management advice. In addition, the Council requested a projection of the time to rebuild to each SSB_{Proxy} in the absence of fishing mortality.

2. METHODS

The results presented in this paper were based on determinist projections conditioned on the base model from the 2014 update of the SEDAR 31 Gulf of Mexico red snapper assessment with catches updated through 2014 (as reviewed and approved by the GMFMC SSC on February 19, 2015). The projections were implemented using Stock Synthesis (SS3, V3.24U; Methot and Wetzel, 2013).

The projections assumed that fishery selectivity, discarding, and retention practices would continue as they had in the three most recent years of the assessment (2011 – 2013). Forecasted recruitments were assumed to continue at the average of the recent time period (1984 - 2013). The fishing mortality levels for the 6 bycatch fleets (shrimp, recreational closed season, and commercial without IFQ allocation, each with an eastern and western component) were held constant at the 2013 estimated level for all years of the projections. The fishing mortality rates for the directed fleets were constrained so as to maintain the current catch allocations of 51% to the commercial sector and 49% to the recreational sector. In addition, the relative distribution of fishing mortality for fleets within each sector was assumed to remain in a constant proportion based on the average distribution from 2011-2013. The total fishing mortality rate for the directed fleets was then scaled up or down until the projections equilibrated at the target SPR.
The fishing mortality rate proxies (F_{Proxy}) corresponding to the requested SPR targets, expressed as the fraction of the stock removed by fishing (total removals in numbers divided by total abundance), were set

to the values that maintained the SPR target on average over the last ten years of the projections (approximate equilibrium removal rate). The corresponding proxies for MSY (equilibrium OFL) and spawning stock (egg production) were averaged over the same years. MSST was calculated as (1-M)*SSB_{Proxy}, where M is the assumed natural mortality rate of 0.086 representing the average value across all fully selected age classes (SEDAR 31, 2013). The annual OFL and ABC values were calculated as stipulated by the GMFMC SSC during their 2015 meeting in Tampa, Florida for each of the requested SPR proxies. The time series of annual OFLs was taken as the forecasted landings (millions of pounds) given the F_{Proxy}, which represented the median (50^{th} percentile) of the probability density function (PDF) of retained yield in each year of the long-term projection (2015-2074).

The ABC values were calculated assuming a P* value of 0.427 (the 42.7^{th} percentile) of the PDF of the landings (retained yield) based on projections of $F_{Rebuild}$. Because the stock is currently below the management target (SPR 26%), a rebuilding plan is in place with the goal of attaining a gulfwide SPR of 26% by 2032. Therefore, ABCs are based on short-term projections with a $F_{Rebuild}$ that will attain the SPR target by that date (i.e., ABCs are based on the 42.7^{th} percentile of the MLE of retained yield that results from an $F_{Rebuild}$, which rebuilds the stock to the given SPR target in 2032). However, a shorter rebuilding timeline (i.e., an end year of 2026) was required for SPR management targets that were less conservative than the current SPR 26% target, which required a second set of ABC calculations. For ABC projections, a given target SPR was achieved when the gulfwide spawning potential ratio of X% was reached in the terminal year (i.e., 2026 or 2032 depending on the scenario), where X was equal to 40, 30, 26, 24, 22, or 20.

The "SPR proxy that results in the highest annual OFL and ABC" is essentially equivalent to the SPR corresponding to the global MSY, which is achieved when fishing is restricted to an optimal age class, and is difficult to achieve in practice. For this reason, the SEDAR 7 and 31 assessments used an approximation to the global MSY referred to as 'MSY-link', which was calculated as the maximum sustainable landings when all sources of fishing mortality (directed, closed-season, and bycatch) were scaled up or down by the same proportion. The SPR corresponding to the MSY-link scenario was then used as the SPR proxy that results in the highest yield. Note that while the ABCs under the MSY-link case are listed for comparison with the 2032 and 2026 rebuilding scenarios, they are calculated from the 42.7^{th} percentile of the yearly OFL and not based on a $F_{Rebuild}$.

The value of optimal yield (OY) was calculated assuming the fishing mortality rates on the directed fleets were reduced by 25% [i.e., F_{OY}(directed)=0.75*F_{Proxy}(directed)]. Although multiple possibilities exist for determining OY depending on the assumptions regarding bycatch, considering the difficulties in controlling bycatch mortality it was deemed that only directed effort should be scaled for OY calculations. For the MSY-link run, because fishing mortality rates on all fleets were scalable, the optimal yield fishing mortality is actually scaled to 0.75 for all fleets. An additional run was completed with no fishing mortality (F=0 for all directed and bycatch fleets) to determine rebuilding times in the absence of fishing pressure.

Uncertainty in derived quantities (including retained yield) is carried through the projections from the parameter estimation phase in the stock assessment model and represents the approximate variance obtained from the inversion of the Hessian matrix. The PDF and 95% confidence bands are calculated assuming a normal distribution of the derived quantity.

3. RESULTS

The MSY-link (equilibrium OFL from the link scenario) is 11.41 million pounds (mp; Table 1, second to last row) and results in an SPR proxy of 23% (Figure 1). The corresponding OFLs for the MSY-link run are 15.2 mp in 2015, 14.5 mp in 2016, and 13.9 mp in 2017 (Table 1). The resulting ABCs (42.7th percentile of OFL) are 15.0 mp in 2015, 14.3 mp in 2016, and 13.7 mp in 2017 (Tables 2-3). The associated harvest and SSB proxies (equilibrium levels) were 1.12E+12 eggs for SSB and a harvest rate of 0.07 (Table 4). In the absence of fishing mortality the SSB proxy was attained in 2018 (Table 5). Equilibrium optimum yield was projected to be 98% of the MSY (Table 1, last row).

Both OFL and ABC (retained yield in millions of pounds whole weight) increased as the magnitude of the SPR_{Proxy} target value was reduced (Table 1-3, Figures 2-9). For long-term equilibrium runs, the most conservative SPR of 40% resulted in an OFL of 8.94 million pounds (mp) in 2015, 9.54 mp in 2016, and 10.1 mp in 2017 (Table 1, Figures 2-3). Maintaining the status quo and applying an SPR of 26% resulted in annual OFLs of 16.1 mp in 2015, 15.3 mp in 2016, and 14.8 mp in 2017. The least conservative SPR (SPR 20%) resulted in OFLs of 20.7 mp in 2015, 18.3 mp in 2016, and 16.8 mp in 2017. Equilibrium OFL (average retained yield from 2065-2074) for the various SPR targets ranged from a low of 10.6 mp for an SPR of 40% to a high of 13.6 mp for an SPR of 20% (Table 1).

ABCs (retained yield in millions of pounds whole weight) were also inversely related to the magnitude of the SPR target for both a rebuilding year of 2032 (Table 2, Figures 4-6) and 2026 (Table 3, Figures 7-9). Status quo rebuilding (SPR 26%) projections produced estimated ABC values of 14.3 mp in 2015, 14.0 mp in 2016, and 13.7 mp in 2017. The lowest annual ABCs were achieved with an SPR of 40% and resulted in annual yields of 6.55 mp in 2015, 7.26 mp in 2016, and 7.91 mp in 2017. The highest annual ABCs were obtained at SPR 20% and were equal to 18.9 mp in 2015, 17.1 mp in 2016, and 16.0 mp in 2017. Because this was a less conservative SPR proxy, it required a shorter projection terminal year of 2026. Equilibrium yield for ABC projections also increased as SPR proxy declined.

Both SSB and F proxies were calculated for each SPR target along with associated MSST values (Table 4). SSB proxies increased as the SPR target became more conservative, while F proxies were inversely related to the SPR target level. Estimated values of the SSB proxy ranged from 9.83E+11 eggs at SPR 20% to 1.97E+12 eggs at SPR 40%, and F proxies (as a total harvest rate defined by the fraction of total removals to total abundance) ranged from 0.052 to 0.045 for the same SPR targets. Proxies for the status quo SPR 26% target were 1.28E+12 eggs for SSB and a harvest rate of 0.049.

The time to rebuild increased as the SPR proxy became more conservative (Table 5). By definition the SSB proxy must be achieved in the same year as the SPR target, which meant either the terminal year for ABC projections (2026 or 2032) or 2070 for equilibrium OFL projections (i.e., the mid-point over which the average SPR values were taken). The starting (2015) gulfwide SPR for the projections was 0.16, which resulted in the stock being below each SPR target and requiring rebuilding regardless of projection scenario. In the absence of fishing mortality, rebuilding times for SSB proxies ranged from 2017 for the least conservative SPRs (i.e., 20% and 22%) to 2022 for the most conservative SPR 40% proxy (Table 5 and Figure 10). Rebuilding to the status quo SPR 26% target occurred in 2018 when there was no harvesting. The time to rebuild to MSST was also determined (Table 5). The estimated generation time (fecundity weighted mean age) was 15 years.

Equilibrium yields achieved at the optimum yield fishing mortality rate ($0.75* F_{Direct\ at\ SPRtarget}$) were between 88% and 95% of the equilibrium yields obtained at the target SPR (Table 1, last row). The difference was greatest for the more conservative SPR target values. At the status quo of SPR 26%, equilibrium optimum yield was projected to be 93% of the equilibrium yield.

4. DISCUSSION

The projections indicate that as the target SPR for red snapper becomes more conservative, the associated F_{Proxy} declines, SSB_{Proxy} increases, the time to rebuild becomes longer, and associated OFL, ABC, and equilibrium yields decrease. The MSY-link scenario resulted in an SPR of 23%, but produced lower equilibrium landings than when shrimp bycatch and closed-season discarding are assumed to remain at recent levels. This is because, under the linked scenario, any increase in directed fishing mortality is assumed to be accompanied by a proportionate increase in non-directed fishing mortality. Accordingly, the MSY-link scenario does not appear to be a robust proxy for the global MSY when there is substantial bycatch mortality. Alternative approaches to calculating MSY proxies should be considered.

It is important to reiterate that the forecasts of optimal yield assumed the fishing mortality by the directed fisheries would be reduced by 25% (i.e., $F_{OY, Directed} = 0.75 * F_{SPRtarget, Directed}$), but not that of the bycatch fleets (the latter's F values were input and held constant). The result was that the realized total harvest rate (i.e., total removals in numbers/total abundance) in the OY projections was around 95% of F_{Proxy} instead of 75% (Table 6). The disparity between realized and intended harvest rate is due to the substantial contribution of the bycatch fleets to the total annual removals (i.e., resulting in high relative F in comparison to some directed fleets; Figure 11 top left panel). However, the total instantaneous fishing mortality was closer to 85% of the total fishing mortality at SPR 26% (Figure 11, bottom panel), which better reflects the decrease in directed fishing mortality. The degree of difference in mortality is also a function of the metric used (e.g., because shrimp bycatch is mostly juvenile red snapper, an F metric that looked at age 3+ mortality would better reflect the 0.75 mortality scalar).

There was interaction within the model between fishing mortality and fleet allocation. To achieve F_{OY} (75% of F SPR_{REF}) and retain the desired allocation for the recreational and commercial sectors, the realized fishing mortalities at F_{OY} were around 80% of F SPR 26% for each of the commercial fisheries and 70% for each of the recreational fisheries, which averaged to 75% of the F SPR 26% for the directed fisheries (Table 6, Figure 11 top right panel). Given the many approaches to calculating optimal yield when multiple directed and bycatch fleets exist (e.g., average directed F is 75% of F at the SPR target, average F across all directed and bycatch fleets is 75% of F at the SPR target or total harvest rate is 75% of that at the SPR target), consideration of a standard OY approach should be undertaken in the future to avoid further confusion.

An important caveat for these projections is that SPR is calculated for the entire gulfwide stock (estimated to be 0.16 in 2015), which ignores the regional impact that a given SPR target might have on the eastern or western component of the stock complex individually. When SPR values are viewed regionally (Figure 12; ABC projections with a 2032 rebuild date are shown for illustrative purposes**)**, quite disparate effects are seen. In 2015, the western Gulf of Mexico red snapper SPR was 0.19, but the eastern Gulf of Mexico SPR was only 0.11. Additionally, the SPR (and spawning stock biomass) is projected to increase in the western Gulf of Mexico for all SPR target values. However, the eastern Gulf of Mexico is forecasted to decline even further for all but the most conservative SPR target (e.g., SPR 40%). Even the forecast with the status quo (SPR 26% target) demonstrates continual declines in the eastern Gulf of Mexico stock unit to an SPR ratio of 0.07 in 2032.

The differential response in SPR ratio by region is a function of four major assumptions of the projection: the allocation by sector (commercial v. recreational), assumed regional recruitment, fixed bycatch rates, and relative distribution of F by fleet. SEFSC (2015) demonstrated that increasing allocation to the commercial fishery could increase SPR ratios, but this result is also a function of the latter three assumptions in the Stock Synthesis projections. For instance, the eastern stock receives only half of the recruitment of the western stock in each year of the projection (Figure 13; fixed at recent timeseries averages for the length of the projections), but encounters nearly three times the fishing pressure (Figure

11, top left panel). Relative F by fleet (for the directed fisheries) is fixed at the 2011-2013 average values, which results in much higher fishing mortality from the eastern Gulf of Mexico recreational (MRIP) fishery and the commercial handline fishery, in comparison to the associated western Gulf of Mexico counterparts. Additionally, the bycatch fishing mortality is held constant at the average rates from 2011-2013. The consequence is a high closed season F from the recreational fishery in the eastern Gulf of Mexico that nearly matches the associated open season fishing mortality, and is much larger than any F experienced by the western Gulf of Mexico stock.

The large discrepancy between recruitment and removals (fishing mortality) within the eastern stock is the major factor causing a decline in SPR throughout the projections. However, because recruitment and mortality is more balanced in the western stock, the SPR ratio is able to increase. The outcome is a gulfwide average SPR that more closely reflects the western trend than that in the eastern region. Although the projection assumptions (i.e., constant recruitment, constant relative F, and constant bycatch F) are unlikely to remain stationary in the long-term, it may be reasonable to assume that they will remain at or near recent averages during the short-term forecasts (i.e., three years) used to develop management advice.

The projection results should therefore be treated cautiously, especially considering that gulfwide SPR ratios and other proxy values do not accurately reflect the fine-scale (e.g., regional) dynamics in the Gulf of Mexico. Additionally, if allocation to the recreational sector is increased (e.g., SEFSC, 2015) in combination with a reduction in management target SPR, the impacts on the regional spawning potential will be more severe than indicated by either action individually.

5. LITERATURE CITED

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6. TABLES

Table 1. OFL (retained yield in millions of pounds whole weight) as a function of spawning potential ratio proxy for long-term equilibrium runs. OFL was calculated as the median (50th percentile) of the probability density function of retained yield (millions of pounds). All runs achieve target SPR values over the last ten years of the model (2065-2074) where the average SPR over that time frame equaled the target value. Equilibrium yield was the average OFL over the last ten years. Equilibrium optimal yield (OY) was the average retained yield over the last ten years with $F_{Direct}=0.75*F_{Direct\ at\ SPRtarget}$ for the directed fisheries. The MSY-link run maximizes equilibrium yield assuming all fisheries are scalable, while maintaining proportional Fs, and does not aim for any prespecified target SPR.

OFL (Retained Yield Million Pounds Whole Weight)							
YEAR	**MSY-LINK**	**SPR 40%**	**SPR 30%**	**SPR 26%**	**SPR 24%**	**SPR 22%**	**SPR 20%**
2015	15.24	8.94	13.63	16.10	17.49	19.00	20.65
2016	14.45	9.54	13.49	15.31	16.26	17.24	18.25
2017	13.91	10.08	13.42	14.80	15.47	16.14	16.79
2018	13.31	10.34	13.18	14.26	14.76	15.24	15.70
2019	12.56	10.24	12.71	13.60	14.02	14.41	14.78
2020	12.03	10.07	12.36	13.17	13.55	13.90	14.24
2021	11.71	9.94	12.14	12.93	13.29	13.64	13.96
2022	11.52	9.87	12.03	12.79	13.14	13.47	13.78
2023	11.46	9.91	12.03	12.77	13.11	13.42	13.72
2024	11.45	9.98	12.05	12.77	13.10	13.41	13.69
2025	11.44	10.03	12.08	12.78	13.10	13.39	13.67
2026	11.43	10.08	12.10	12.78	13.09	13.38	13.64
2027	11.42	10.13	12.11	12.79	13.09	13.37	13.62
2028	11.42	10.17	12.13	12.79	13.08	13.36	13.61
2029	11.41	10.21	12.14	12.79	13.08	13.35	13.60
2030	11.40	10.24	12.16	12.80	13.08	13.35	13.59
2031	11.40	10.27	12.17	12.80	13.08	13.34	13.58
2032	11.40	10.30	12.18	12.81	13.08	13.34	13.57
Equil	11.41	10.57	12.34	12.91	13.17	13.40	13.60
Equil OY	11.20	9.29	11.29	12.00	12.33	12.64	12.93

Table 2. ABC (retained yield in millions of pounds whole weight) as a function of spawning potential ratio (SPR) target for a 2032 rebuilding date. ABC was calculated using a P* of 0.427 (the 42.7th percentile) of the probability density function of retained yield obtained from the projection of $F_{Rebuild}$ (the harvest rate that achieves the specified gulfwide spawning potential ratio (SPR) in 2032). A P* of 0.427 implies a 42.7% probability of overfishing in any given year. Less conservative SPR proxies than currently used for management (e.g., values below SPR 26%) may require a new rebuilding plan (i.e., rebuilding date of 2026). The values provided here may not be appropriate for use in setting allowable harvest levels for those target proxies. The MSY-link run maximizes equilibrium yield assuming all fisheries are scalable, while maintaining proportional Fs, and does not aim for any prespecified target SPR. ABCs for the MSY-link are calculated directly from the OFL and not a $F_{Rebuild}$.

ABC (Retained Yield Million Pounds Whole Weight)							
YEAR	**MSY-LINK**	**SPR 40%**	**SPR 30%**	**SPR 26%**	**SPR 24%**	**SPR 22%**	**SPR 20%**
2015	15.00	6.55	11.54	14.28	15.87	17.63	19.59
2016	14.25	7.26	11.79	13.96	15.11	16.31	17.55
2017	13.72	7.91	12.02	13.74	14.61	15.45	16.28
2018	13.10	8.32	11.99	13.38	14.05	14.67	15.26
2019	12.36	8.37	11.67	12.85	13.40	13.91	14.39
2020	11.86	8.31	11.40	12.49	12.99	13.46	13.90
2021	11.56	8.24	11.24	12.29	12.78	13.23	13.64
2022	11.38	8.21	11.15	12.18	12.65	13.08	13.48
2023	11.33	8.27	11.17	12.17	12.62	13.04	13.42
2024	11.31	8.35	11.22	12.19	12.63	13.03	13.40
2025	11.30	8.41	11.25	12.21	12.63	13.02	13.37
2026	11.29	8.47	11.29	12.22	12.63	13.01	13.35
2027	11.28	8.53	11.31	12.23	12.64	13.00	13.34
2028	11.28	8.58	11.34	12.24	12.64	13.00	13.32
2029	11.27	8.62	11.36	12.25	12.64	12.99	13.31
2030	11.26	8.66	11.38	12.26	12.64	12.99	13.30
2031	11.26	8.70	11.40	12.26	12.65	12.99	13.29
2032	11.25	8.73	11.41	12.27	12.65	12.99	13.29
Equil	11.26	9.05	11.61	12.40	12.74	13.04	13.30

Table 3. ABC (retained yield in millions of pounds whole weight) as a function of spawning potential ratio (SPR) target for a 2026 rebuilding date. ABC was calculated using a P* of 0.427 (the 42.7th percentile) of the probability density function of retained yield obtained from the projection of $F_{Rebuild}$ (the harvest rate that achieves the specified gulfwide spawning potential ratio (SPR) in 2026). A P* of 0.427 implies a 42.7% probability of overfishing in any given year. Current rebuilding plans stipulate a terminal date of 2032, therefore SPR proxies at or above the levels currently used for management (e.g., SPR 26% or greater) do not require a 2026 rebuilding date. The values provided here may not be appropriate for use in setting allowable harvest levels for those target proxies. The MSY-link run maximizes equilibrium yield assuming all fisheries are scalable, while maintaining proportional Fs, and does not aim for any prespecified target SPR. ABCs are calculated directly from the OFL and not a $F_{Rebuild}$.

ABC (Retained Yield Million Pounds Whole Weight)							
YEAR	**MSY-LINK**	**SPR 40%**	**SPR 30%**	**SPR 26%**	**SPR 24%**	**SPR 22%**	**SPR 20%**
2015	15.00	4.27	9.71	12.78	14.59	16.63	18.91
2016	14.25	4.92	10.23	12.80	14.19	15.64	17.14
2017	13.72	5.54	10.67	12.84	13.92	14.98	16.01
2018	13.10	5.98	10.84	12.67	13.52	14.33	15.07
2019	12.36	6.14	10.66	12.25	12.97	13.63	14.24
2020	11.86	6.16	10.47	11.93	12.59	13.20	13.76
2021	11.56	6.13	10.34	11.75	12.39	12.98	13.51
2022	11.38	6.13	10.27	11.66	12.28	12.84	13.35
2023	11.33	6.19	10.31	11.67	12.27	12.81	13.30
2024	11.31	6.27	10.37	11.70	12.28	12.81	13.28
2025	11.30	6.34	10.42	11.72	12.30	12.81	13.26
2026	11.29	6.40	10.46	11.75	12.31	12.81	13.24
Equil	11.26	7.03	10.88	12.00	12.47	12.88	13.22

Table 4. Rebuilding proxies for each SPR target. All proxies are equilibrium values averaged over the last ten years of the projection (2065-2074) for the given parameter and are obtained from runs that achieve the target SPR on average over the last ten years. Fishing mortality proxies are yearly harvest rates (total removals/total abundance), which account for all removals from the commercial, recreational, and bycatch fleets (bycatch fishing mortality rates are held constant at 2014 terminal year assessment model estimates). Spawning stock biomass (SSB) is in number of eggs and minimum stock size threshold (MSST) is equivalent to SSB_{Proxy}*(1-M) where M is natural mortality rate (equal to 0.086).

F and SSB Proxies			
SPR	**F (Removals/Abundance)**	**SSB (Eggs)**	**MSST (Eggs)**
MSY-LINK	0.07	1.12E+12	1.03E+12
0.20	0.05	9.83E+11	8.98E+11
0.22	0.05	1.08E+12	9.88E+11
0.24	0.05	1.18E+12	1.08E+12
0.26	0.05	1.28E+12	1.17E+12
0.30	0.05	1.47E+12	1.35E+12
0.40	0.04	1.97E+12	1.80E+12

Table 5. The time required to rebuild based on the projection year that SSB_{Proxy} is achieved for each SPR target. F=0 runs indicate the time to rebuild in the absence of any fishing mortality. For the MSY-link run only one projection was undertaken (i.e., there were no rebuilding scenarios), so the 2032 and 2026 terminal year runs were not applicable (NA).

Year that Rebuilding Target is Reached								
SPR	**F=0**		**OFL (Reach SPR by 2074)**		**2032 (Reach SPR by 2032)**		**2026 (Reach SPR by 2026)**	
	SSB	**MSST**	**SSB**	**MSST**	**SSB**	**MSST**	**SSB**	**MSST**
MSY-LINK	2018	2017	2070	2023	NA	NA	NA	NA
0.2	2017	2016	2070	2022	2032	2020	2026	2019
0.22	2017	2017	2070	2026	2032	2023	2026	2021
0.24	2018	2017	2070	2029	2032	2024	2026	2022
0.26	2018	2018	2070	2031	2032	2025	2026	2023
0.3	2019	2019	2070	2034	2032	2026	2026	2023
0.4	2022	2021	2070	2037	2032	2028	2026	2024

Table 6. Retained yield and relative fishing mortality for optimal yield (OY) runs where the directed fishing mortality was equivalent to 0.75 multiplied by the F at SPR 26%. Proportions are given as the OY run value divided by the SPR 26% run value. Harvest rate is total removals (in numbers) divided by total abundance. The total F proportions and harvest rate proportions differ because total F is average instantaneous fishing mortality across all directed and bycatch fleets, whereas harvest rate is total removals divided by total abundance. Retained yield is in millions of pounds. Equilibrium values are averages over the last ten years (2065-2074) of the projection.

Optimal Yield (OY) Run Results						
YEAR	**Retained Yield (mp)**	**Yield Proportion**	**Harvest Rate**	**Harvest Rate Proportion**	**Total F Proportion**	**Directed F Proportion**
2015	12.49	0.78	0.0493	0.93	0.84	0.75
2016	12.59	0.82	0.0493	0.95	0.84	0.75
2017	12.70	0.86	0.0491	0.95	0.84	0.75
2018	12.60	0.88	0.0487	0.96	0.84	0.75
2019	12.22	0.90	0.0483	0.96	0.84	0.75
2020	11.90	0.90	0.0480	0.96	0.84	0.75
2021	11.71	0.91	0.0479	0.96	0.84	0.75
2022	11.60	0.91	0.0478	0.96	0.84	0.75
2023	11.61	0.91	0.0477	0.96	0.84	0.75
2024	11.65	0.91	0.0477	0.96	0.84	0.75
2025	11.68	0.91	0.0476	0.96	0.84	0.75
2026	11.71	0.92	0.0476	0.96	0.84	0.75
2027	11.73	0.92	0.0476	0.96	0.84	0.75
2028	11.75	0.92	0.0475	0.96	0.84	0.75
2029	11.77	0.92	0.0475	0.96	0.84	0.75
2030	11.79	0.92	0.0475	0.96	0.84	0.75
2031	11.81	0.92	0.0475	0.96	0.84	0.75
2032	11.82	0.92	0.0475	0.96	0.84	0.74
Equil	12.00	0.93	0.05	0.96	0.83	0.74

7. FIGURES

Figure 1. Equilibrium yield verse equilibrium SPR assuming scalability of all fisheries and constant recruitment (i.e., MSY-link scenario). MSY-proxy is 11.41 million pounds and results in an SPR of 23%.

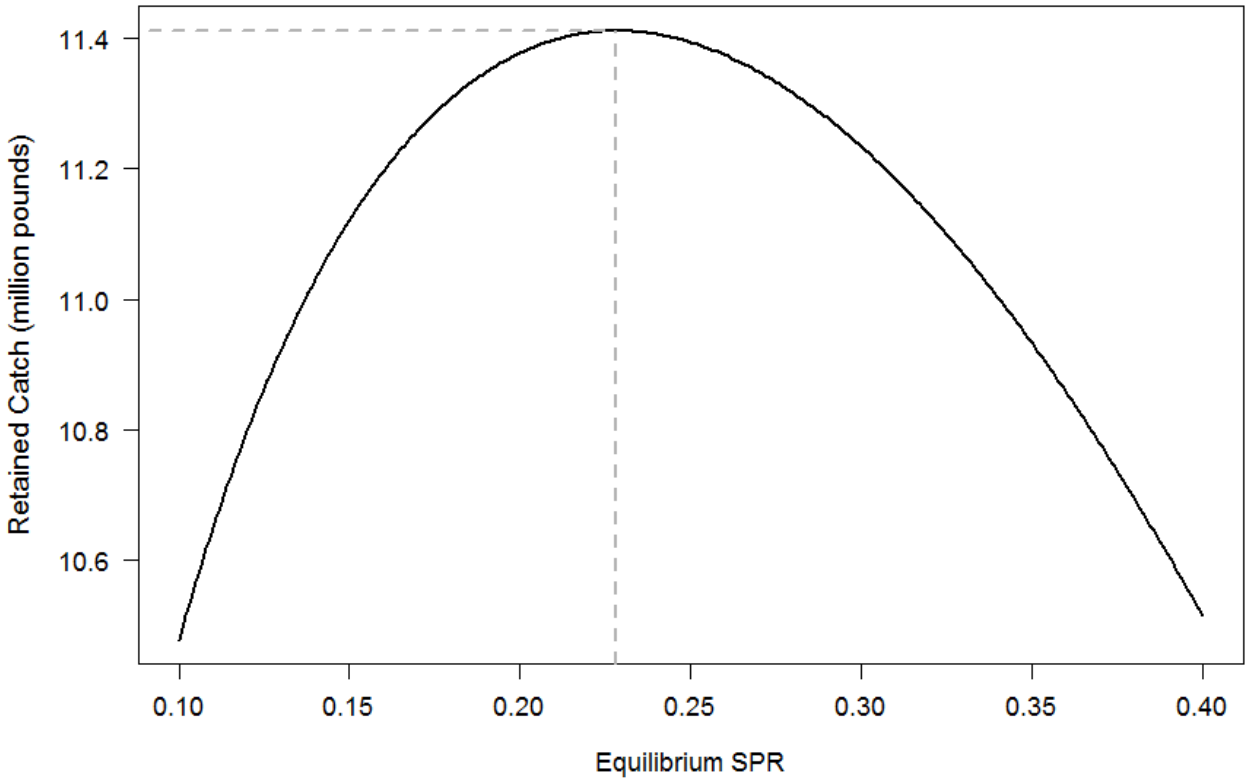


Figure 2. Timeseries plots of overfishing limits (OFLs) with associated symmetrical 95% confidence intervals (grey shaded region) and corresponding SPR levels for each SPR target.

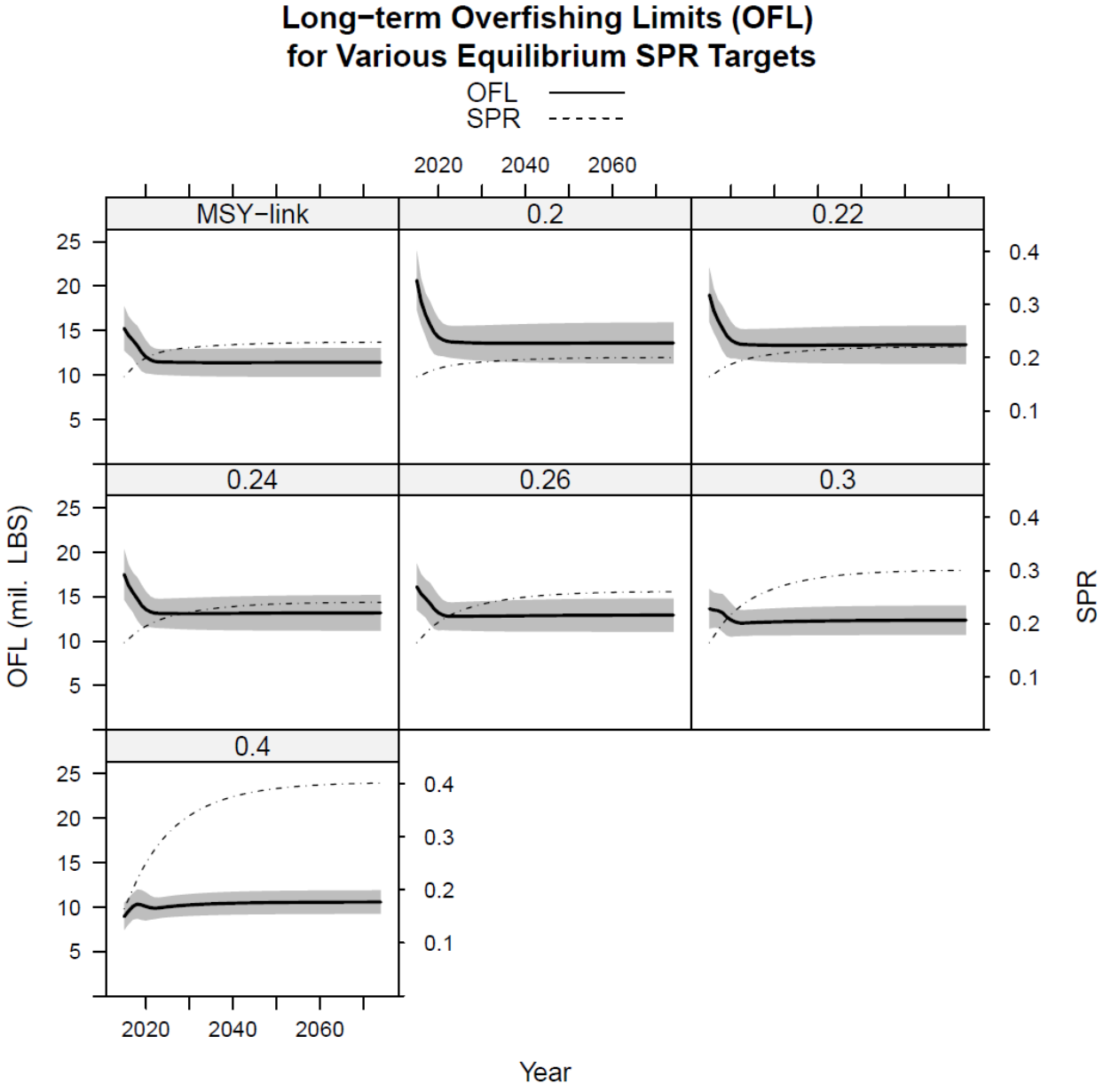
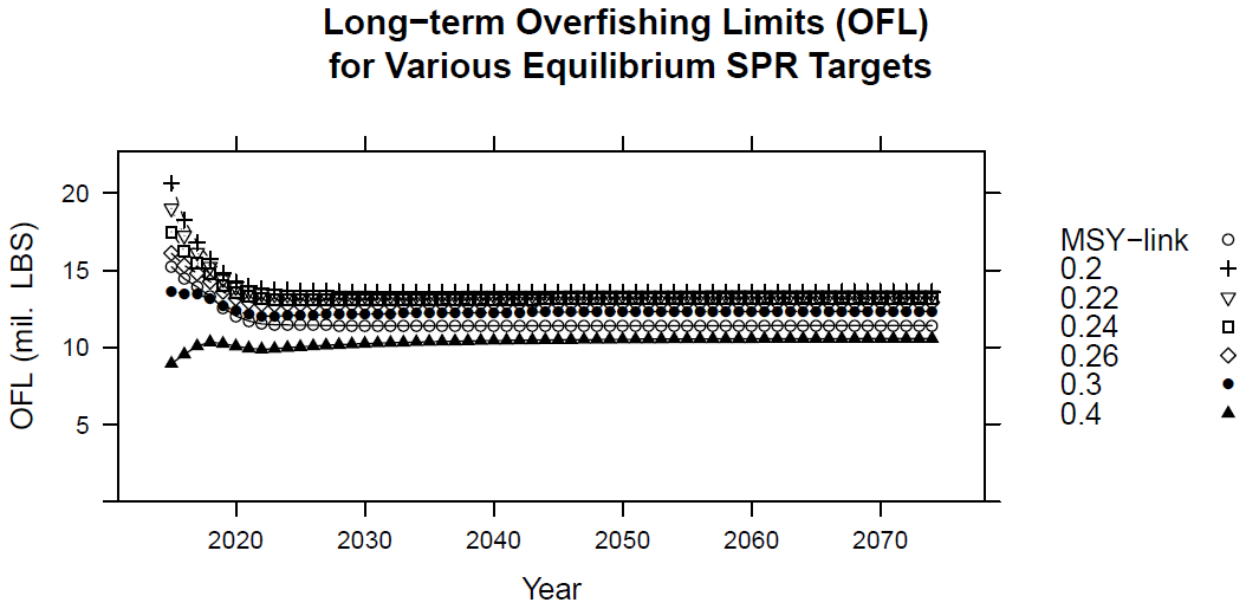


Figure 3. Timeseries plots of OFLs and associated SPR levels for each SPR target.



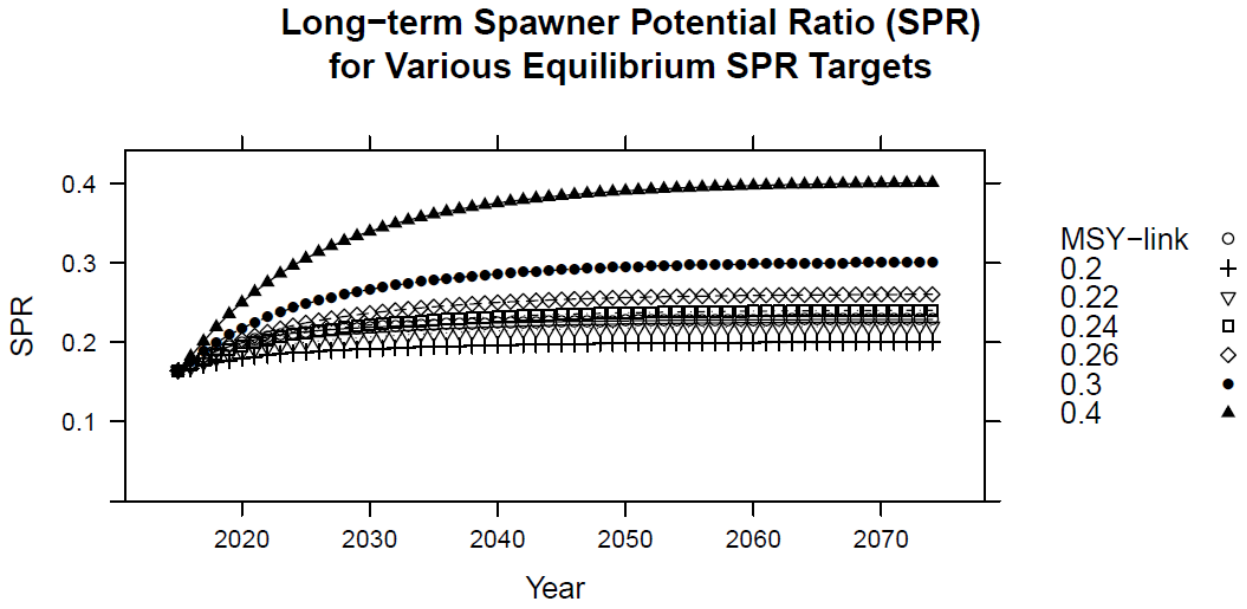


Figure 4. Timeseries plots of acceptable biological catches (ABCs) with associated symmetrical 95% confidence intervals (grey shaded region) and corresponding SPR levels for each SPR target assuming a rebuilding date of 2032. MSY-link runs are shown for comparison, but are not directly applicable because no rebuilding scenarios were undertaken.

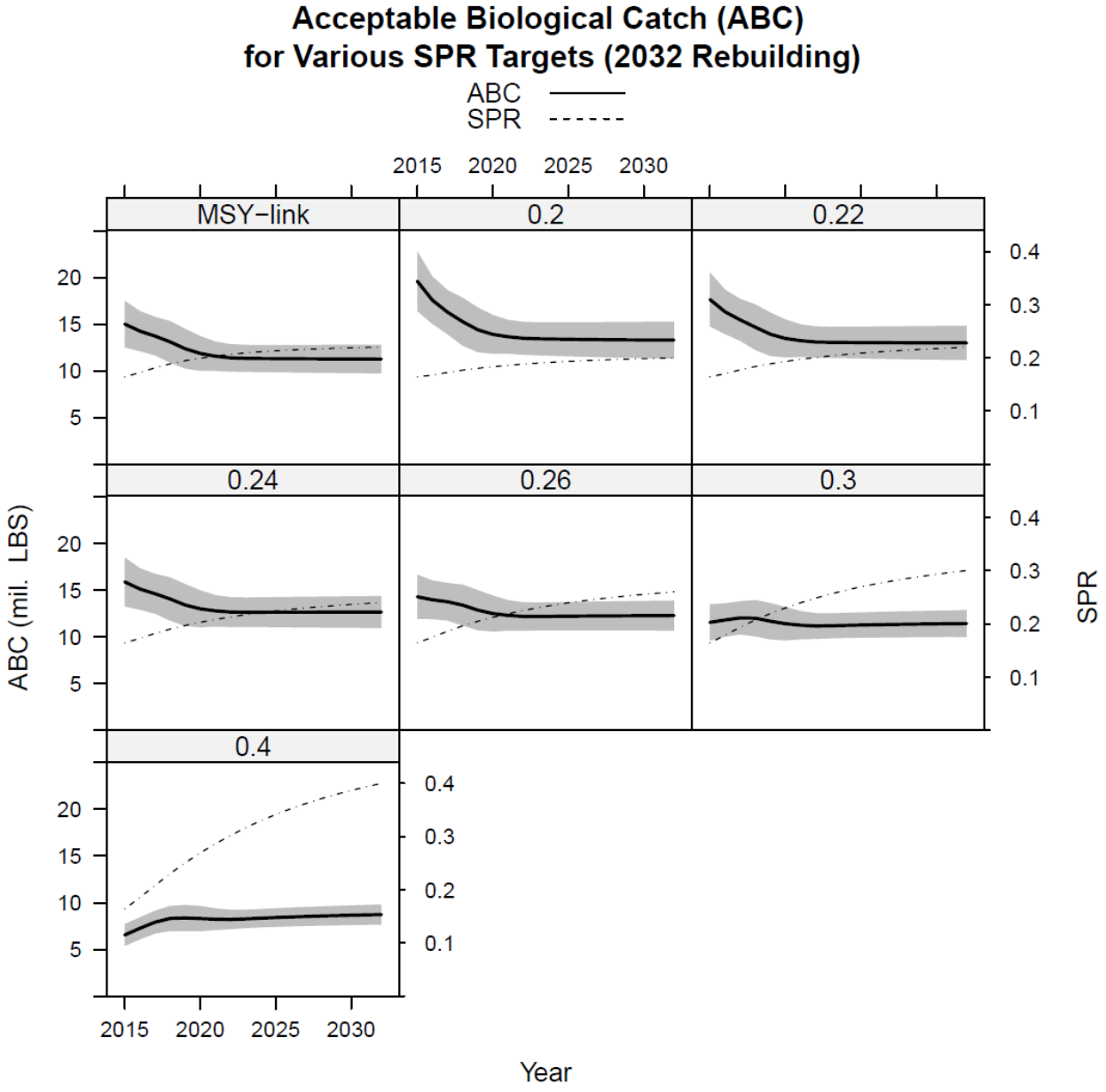
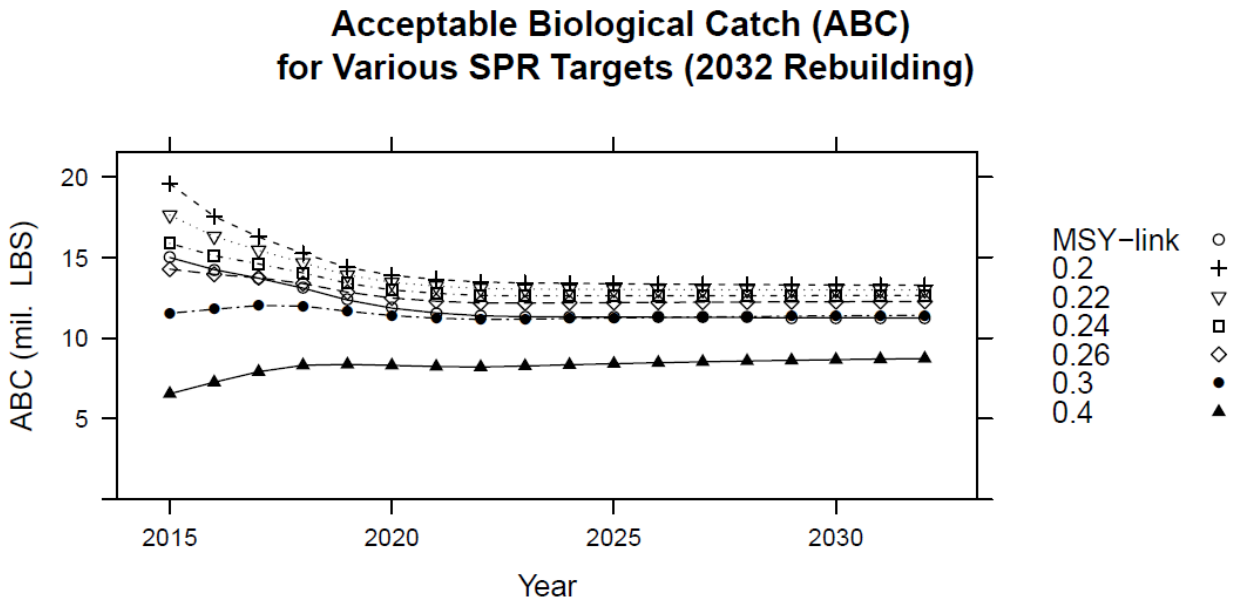


Figure 5. Timeseries plots of ABCs and associated SPR levels for each SPR target assuming a rebuilding date of 2032. MSY-link runs are shown for comparison, but are not directly applicable because no rebuilding scenarios were undertaken.



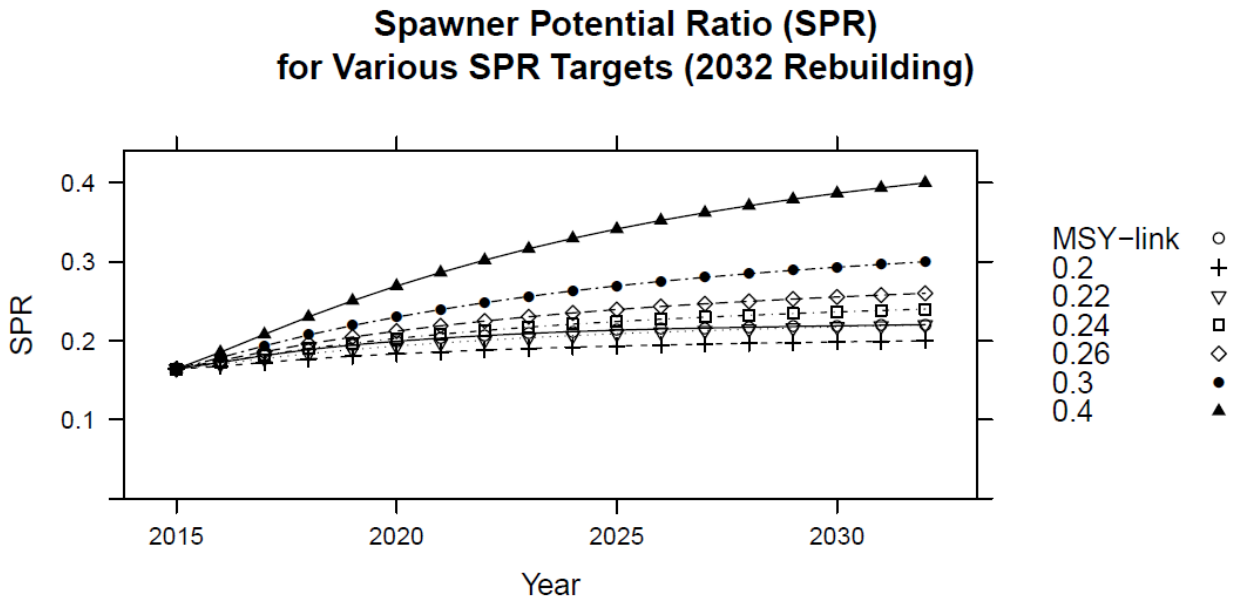


Figure 6. Timeseries plots of retained yield for each SPR target assuming a rebuilding date of 2032. The ABC is calculated from the median (MLE) of retained yield based on a P* of 0.427. MSY-link runs are shown for comparison, but are not directly applicable because no rebuilding scenarios were undertaken.

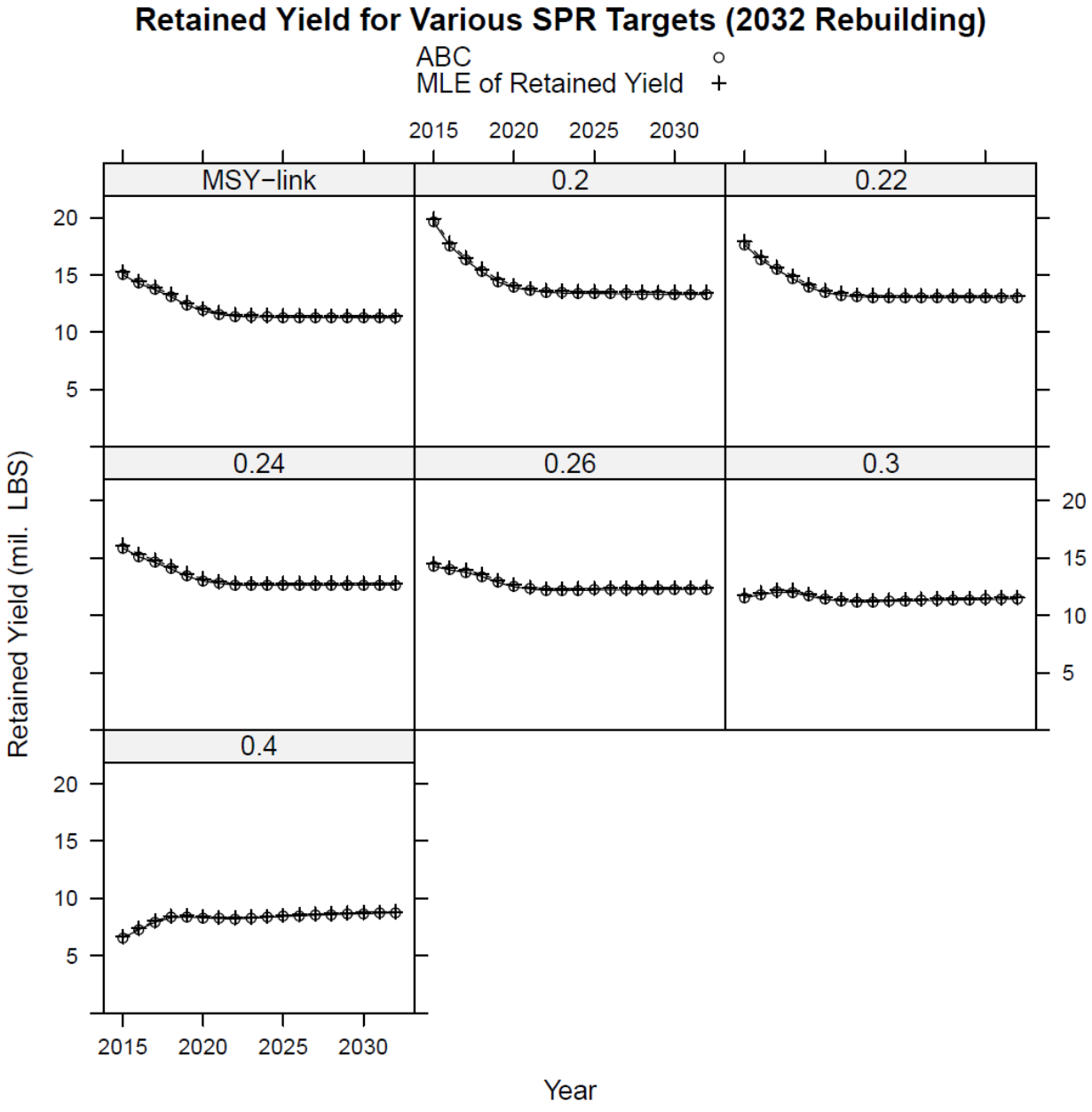


Figure 7. Timeseries plots of ABCs with associated symmetrical 95% confidence intervals (grey shaded region) and corresponding SPR levels for each SPR target assuming a rebuilding date of 2026. MSY-link runs are shown for comparison, but are not directly applicable because no rebuilding scenarios were undertaken.

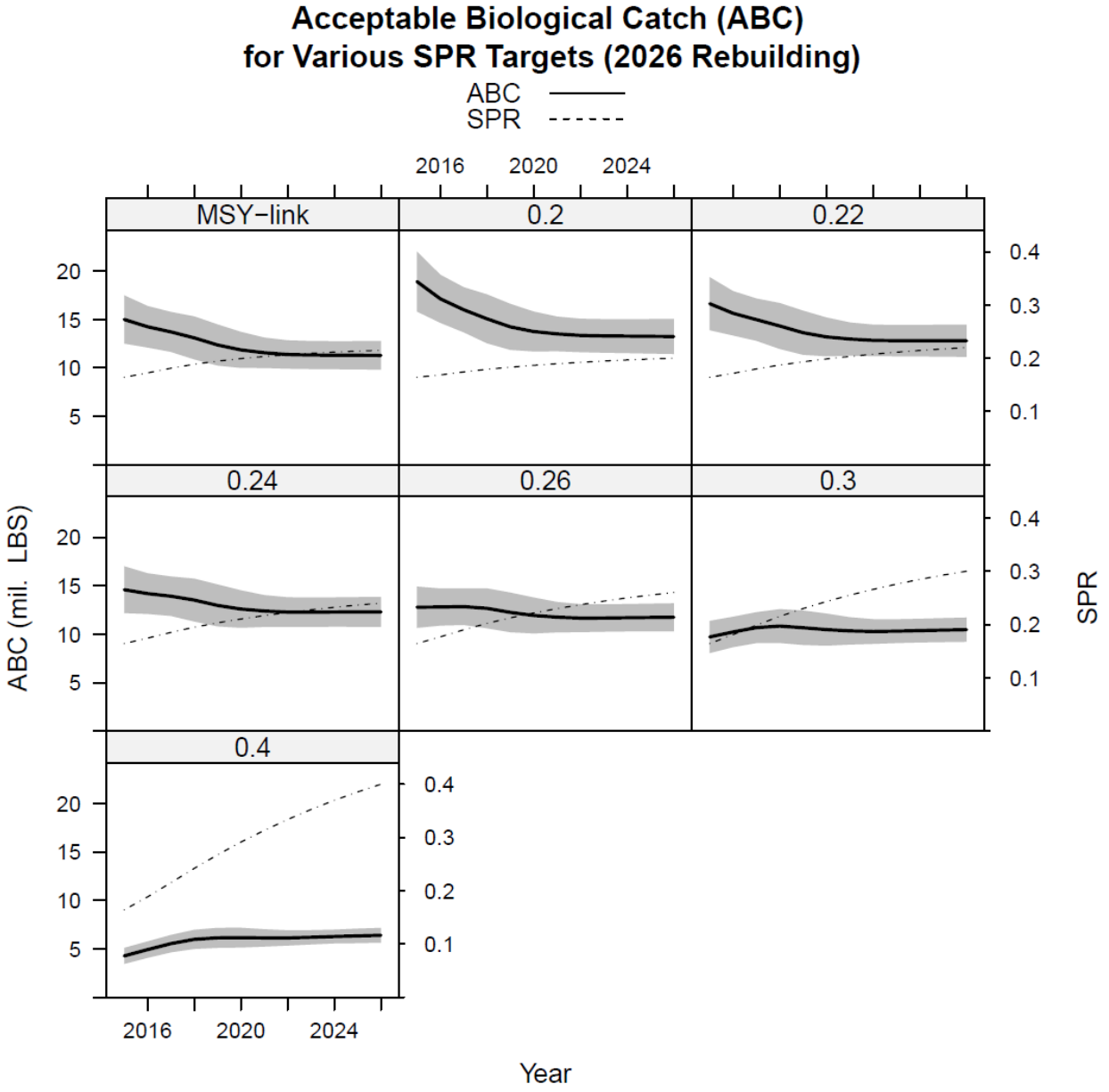


Figure 8. Timeseries plots of ABCs and associated SPR levels for each SPR target assuming a rebuilding date of 2026. MSY-link runs are shown for comparison, but are not directly applicable because no rebuilding scenarios were undertaken.

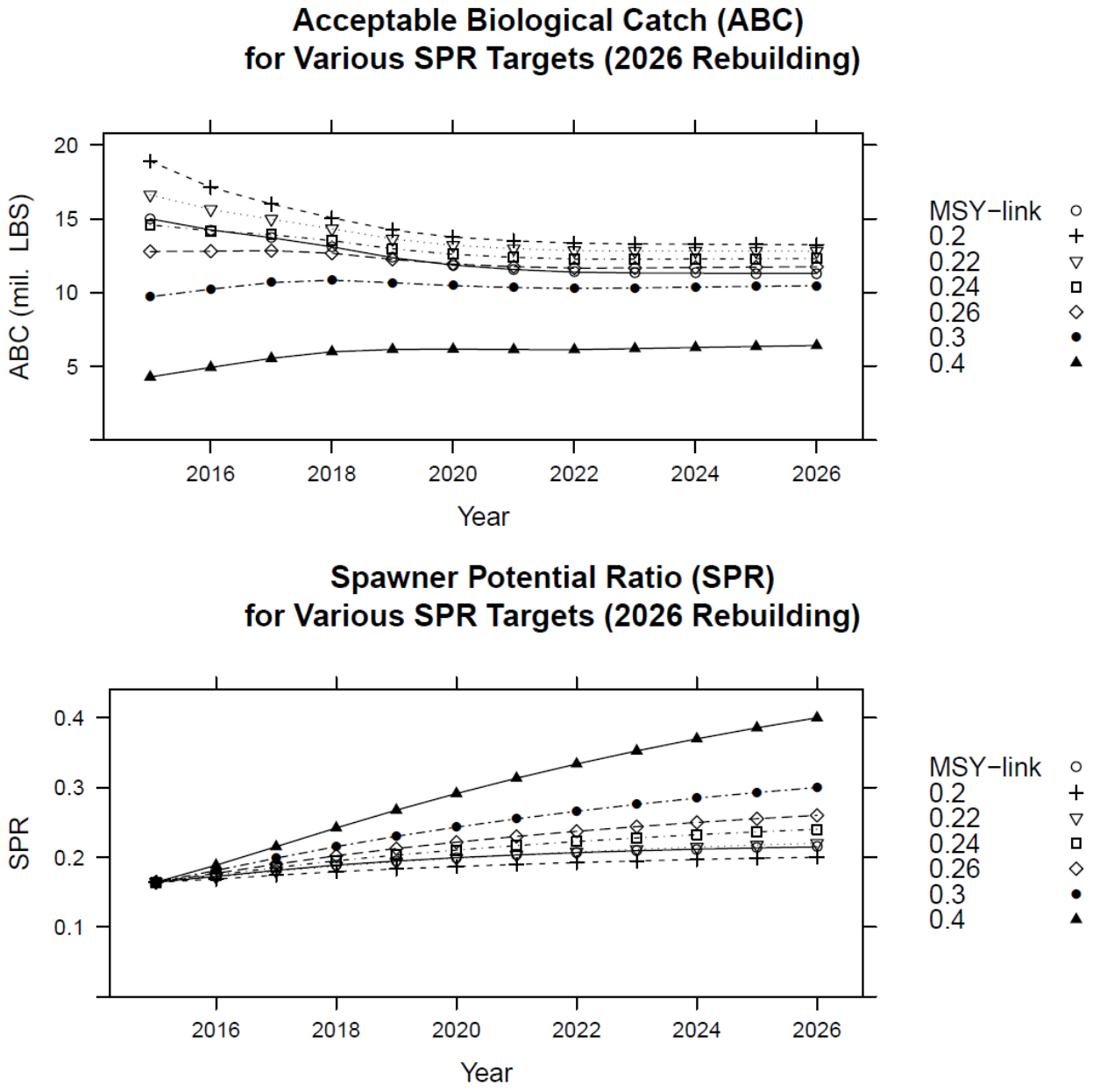


Figure 9. Timeseries plots of retained yield for each SPR target assuming a rebuilding date of 2026. The ABC is calculated from the median (MLE) of retained yield based on a P* of 0.427. MSY-link runs are shown for comparison, but are not directly applicable because no rebuilding scenarios were undertaken.

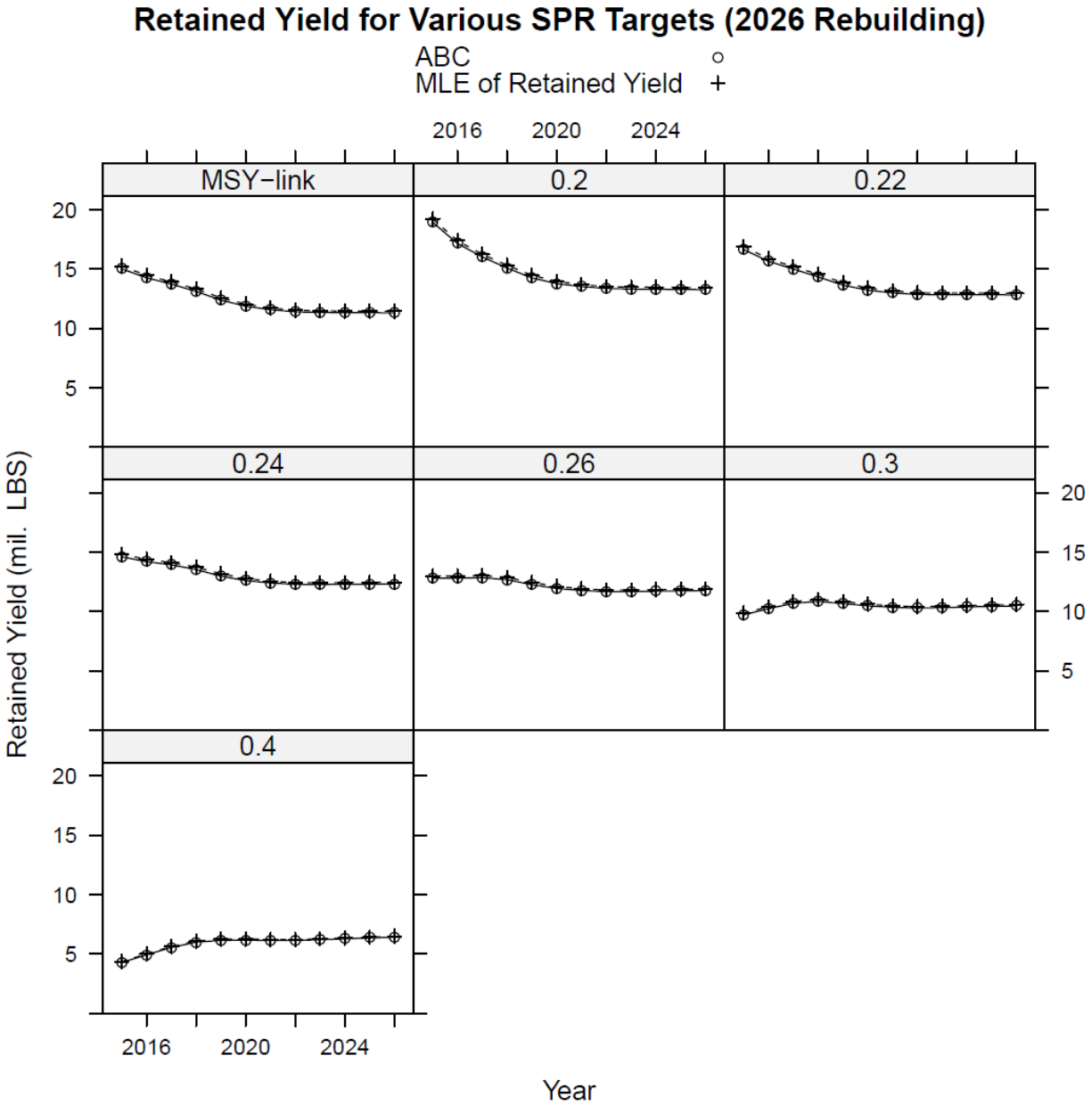


Figure 10. Timeseries of spawning stock biomass in the absence of fishing mortality. The inset provides the time to rebuild to a given target SSB_{Proxy} for each target SPR. Because SSB_{Proxy} is often between $SSB_{F=0}$ values, the intersection of SSB_{Proxy} and rebuilding year line segments occurs just below the actual $SSB_{F=0}$ curve.

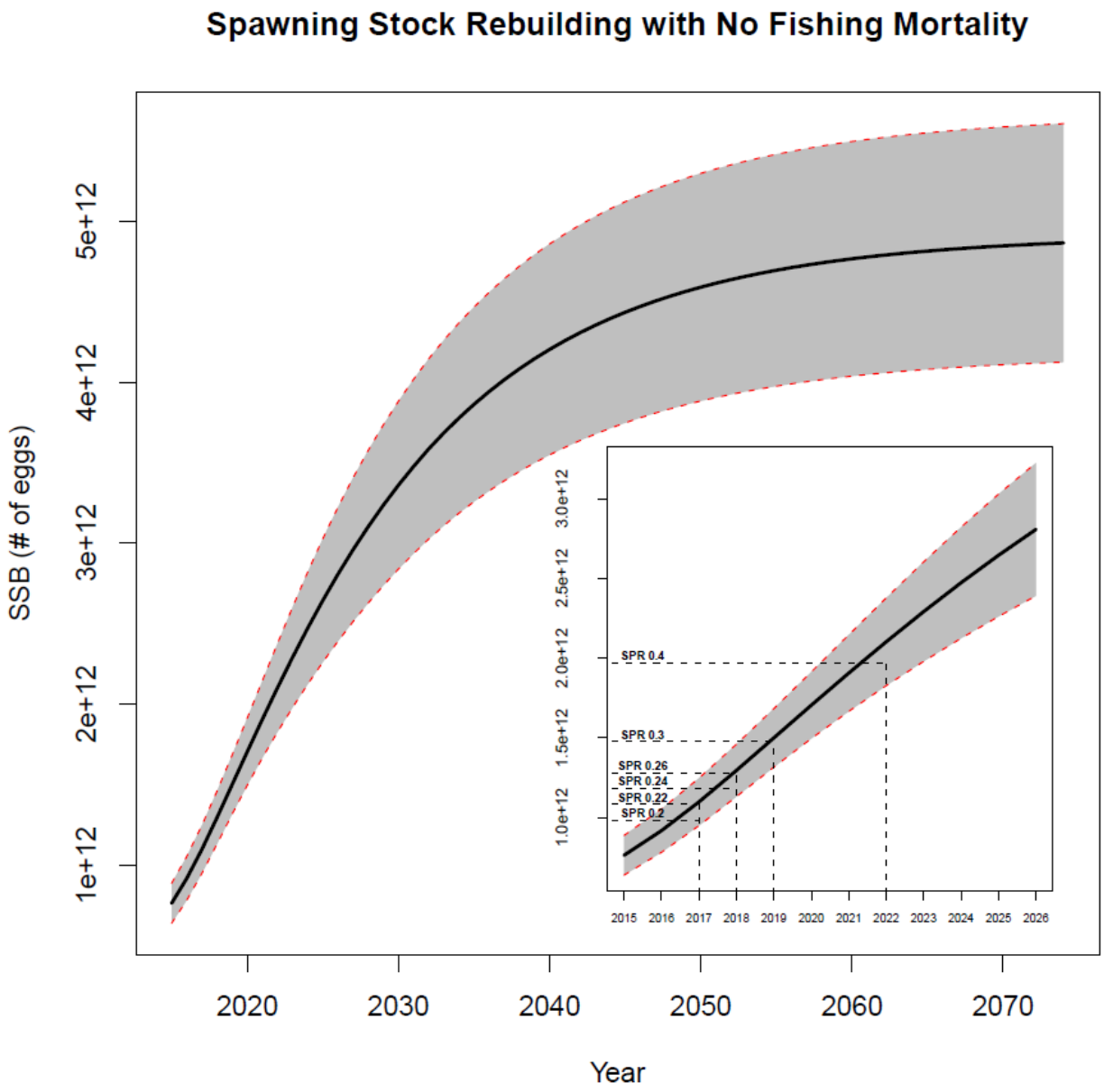


Figure 11. Comparison of relative fishing mortalities for SPR 26% and optimum yield (OY) runs. The top left panel compares equilibrium relative fishing mortality by fleet within a given projection (i.e., relative F is the fleet-specific F divided by the total F in that projection). SPR 26% values represent the relative Fs for all runs (except the optimal yield runs), which are input based on the stock assessment relative Fs from 2011-2013. Because the OY runs only reduce directed F while bycatch fleet Fs are fixed (input directly), the relative Fs for these runs differ from those in the other projections. The top right panel compares the ratio of equilibrium optimal yield fishing mortality by fleet to the associated fishing mortality at SPR 26%. The bottom panel illustrates the timeseries of relative fishing morality (F/F at SPR 26%) for each sector. The OY run aims to reduce directed fishing mortality to $0.75*F_{\text{Direct at SPR 26\%}}$, which results in a realized total fishing mortality that is not reduced by the same 0.75 scalar, because it does not reduce bycatch fishing mortality.

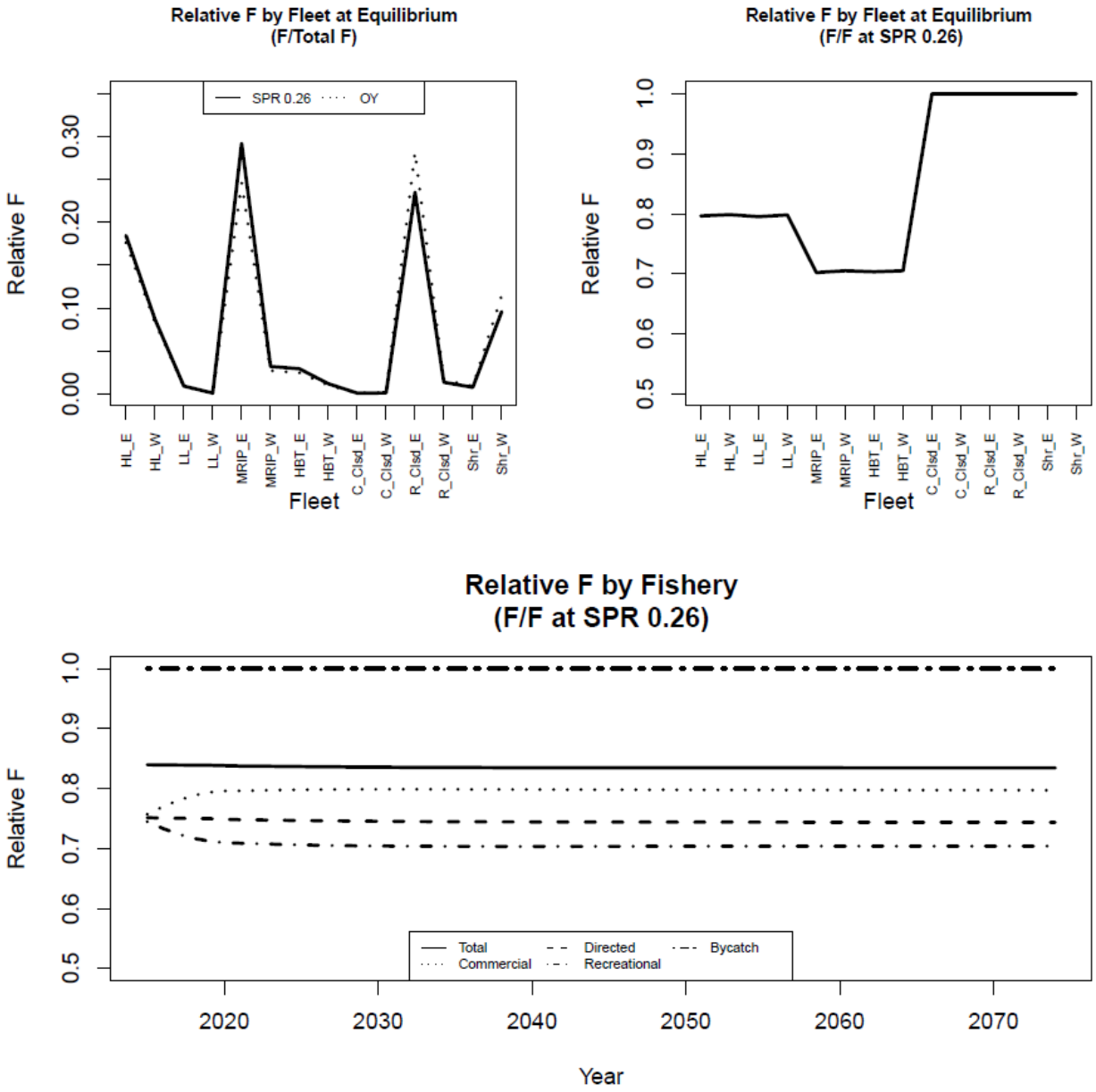


Figure 12. Effect of various gulfwide SPR target values on the regional SPRs for the eastern (top) and western (bottom) Gulf of Mexico. Projected SPR values were obtained from ABC projections with a 2032 rebuild date (except the MSY-link run).

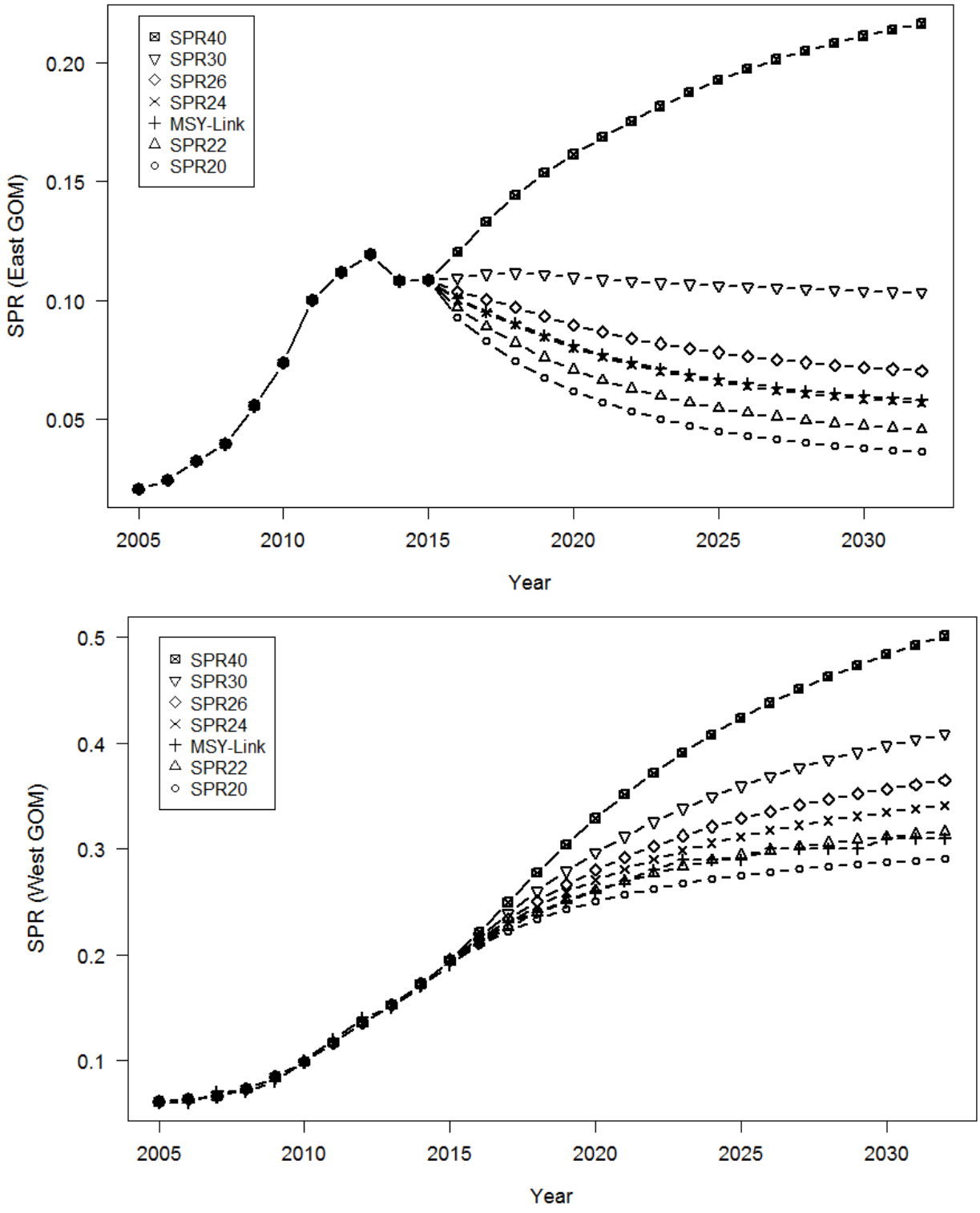


Figure 13. Recruitment by region for red snapper (from SEFSC, 2015). Values used in the projections (2015-2074) are assumed equal to the recent timeseries average (1984-2013), which represent intermediate recruitment levels over the full assessment timeseries.