Economic Trade-offs of Alternative ABC Control Rules for Summer Flounder

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Introduction

At the February 2018 Mid-Atlantic Fishery Management Council (MAFMC) meeting, John Wiedenmann presented his results on the "Evaluation of Alternative ABC Control Rules for Mid-Atlantic Fisheries" (Wiedenmann 2018). In that study, control rules were varied as to how the probability of overfishing (P*) was implemented according to whether the estimated spawning stock biomass (SSB) was below the target level for maximum sustainable yield (SSB_{MSY}). The options for P* were fixed, 2-step, 3-step, and ramped. Using a management strategy evaluation (MSE) simulated over 30 years for scup, summer flounder and butterfish; performance of the control rules was evaluated in terms of the average biomass, long-term and initial catch, probability of overfishing, probability of becoming overfished, risk of very low biomass, mean F/F_{MSY}, and year-to-year catch variability. The study found that the chosen control rule's performance mattered more, in term of the variables being evaluated, under poor future conditions such as high natural mortality, low recruitment and overestimates of stock size.

Given the biological consequences of the different control rules, Council members expressed additional interest in the economic trade-offs among control rules or other ways in which economic considerations could be accounted for in harvest control rules. At that time, two of the authors (i.e., Hutniczak and Lipton) were working with Wiedenmann on an economic analysis of the timing of stock assessment updates and data management lags building on another MSE study (Wiedenmann et al. 2017). That study (Hutniczak et al. 2018), used a suite of economic models built around the summer flounder fishery, to demonstrate that annually updating the summer flounder stock assessment produced summer flounder economic benefits greater than the cost of updating. We found that the difference between a two year stock assessment update interval with a data lag of one year (base scenario), and a five year update interval with a two year data lag is only 10,000 metric tons of summer flounder harvested over a 27 year period. Our analysis estimates, however, that the difference in cumulative economic benefits between the two scenarios is about $102.7 million which is more than the added cost of updating every two years. We offered to the Council that, at least for summer flounder, we could modify the harvest control rules in our base scenario to match the simulations in the Wiedenmann (2018) report, and determine the differences in economic benefits from the fishery for the scenarios analyzed in that report.

Methods

Figure 1 shows the conceptual framework by which the output from Wiedenmann (2018) of catch projections and spawning stock biomass (SSB) serve as inputs to three economic submodels to calculate total economic benefits from the fishery. Details of the economic models are available in Hutniczak et al 2018.

The economic welfare estimates are generated from estimating an inverse demand models for summer flounder price. The demand model is used to estimate downstream industry and consumer benefits from changes in summer flounder landings. The demand model also provides revenues estimates, which when coupled with a days at sea cost model produces estimates of commercial fishing net revenue. Finally, a summer flounder travel cost random utility model is estimated to determine recreational fishermen values due to changes in harvest and biomass.

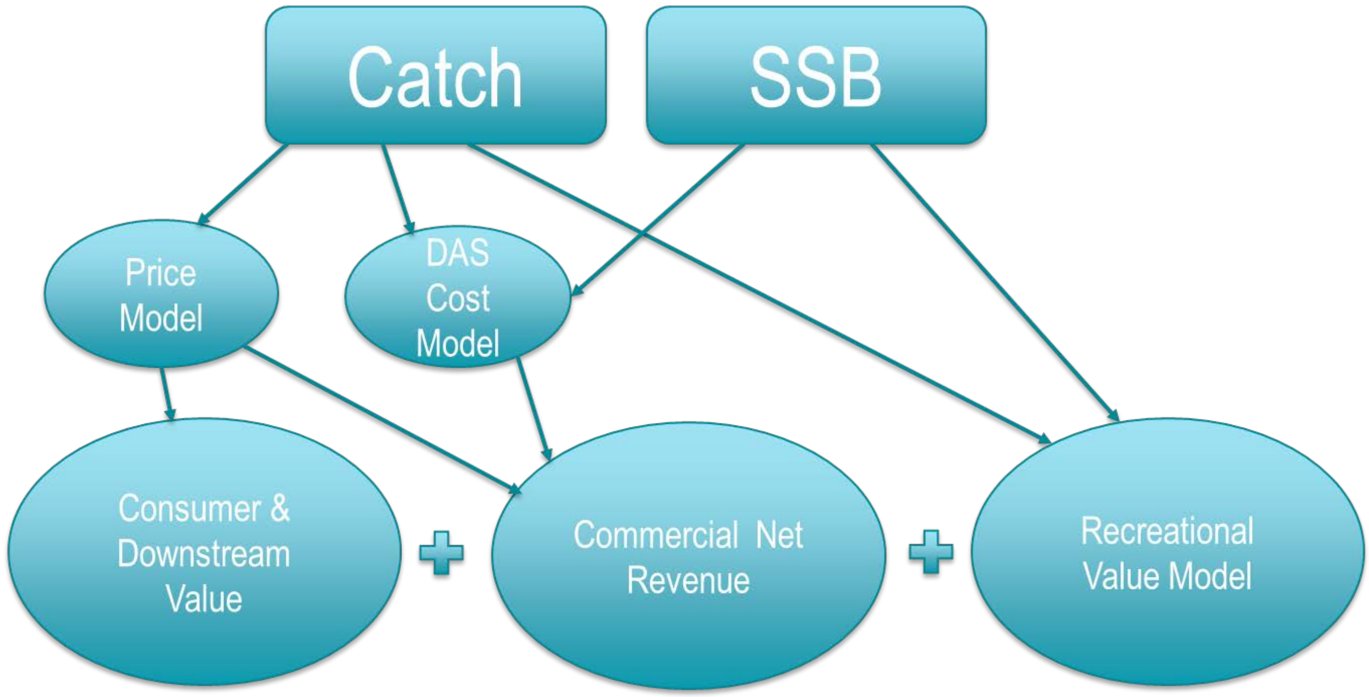

Figure 1. Conceptual approach showing how catch and spawning stock biomass from MSE (Wiedenmann 2018) feed into economic submodels (DAS=days at sea). For details of economic models, see Hutniczak et al. 2018).

The catch and spawning stock biomass estimates that drive the economic models are generated for each of the different summer flounder scenarios analyzed in Wiedenmann (2018). In addition to the base scenario of normal conditions, there are two low productivity conditions corresponding to lower than average recruitment and higher than average natural mortality. There is also a scenario under which the stock is overestimated in the stock assessment. There is a matching set of positive future conditions where productivity is above average and the stock assessment underestimates the true stock. All the scenarios and harvest control rule combinations are shown in Table 1 using the coefficient of variation (CV) currently assigned by the Scientific and Statistical Committee for summer flounder of 0.6. An additional set of model runs used a CV of 1.0.

Wiedenmann provided us with a catch and SSB estimate for 2000 model runs of 30 years for each of the 5 harvest control rules being considered. Each catch and SSB estimate generated a total economic welfare estimate so that we could compare the median performance of the harvest control rule over the 30 year period. The full set of 2000 model runs for each scenario represented “normal conditions”. For each of the 30 year model runs, we calculated the top and bottom quintiles for simulated recruitment, simulated natural mortality, and for runs where the biomass estimates were over or under estimated. We then calculated the economic welfare estimates using only the model runs that fell within those upper and lower quintiles to see how the harvest control rules might differ in performance under worse or better conditions than the average model run.

Table 1. Scenarios and control rule combinations analyzed (from Wiedenmann 2018).

Future productivity / assessment error	Control rule	OFL CV	Average biomass (S/S_{MSY})	Long-term relative catch	Initial relative catch	Prob. of overfishing (P_{OF})	Risk of becoming overfished	Risk of very low biomass	Mean F / F_{MSY}	Catch *AAV*
M below average	P* fixed = 0.4	0.6	1.72	1.24	0.80	0.13	0.06	0.00	0.68	0.14
R above average	P* fixed = 0.4	0.6	1.22	1.02	0.80	0.23	0.34	0.17	0.79	0.14
Assessment under	P* fixed = 0.4	0.6	1.67	1.20	0.79	0.10	0.01	0.09	0.68	0.14
M above average	P* fixed = 0.4	0.6	0.53	0.75	0.81	0.58	0.75	0.42	1.25	0.15
R below average	P* fixed = 0.4	0.6	0.24	0.33	0.80	0.52	0.85	0.71	1.20	0.15
Assessment over	P* fixed = 0.4	0.6	0.53	0.76	0.82	0.58	0.42	0.74	1.26	0.15
M below average	2-step P*	0.6	1.64	1.29	0.80	0.13	0.08	0.00	0.73	0.15
R above average	2-step P*	0.6	1.17	1.05	0.80	0.23	0.35	0.17	0.83	0.15
Assessment under	2-step P*	0.6	1.60	1.25	0.79	0.13	0.01	0.11	0.73	0.15
M above average	2-step P*	0.6	0.52	0.75	0.81	0.58	0.77	0.42	1.29	0.16
R below average	2-step P*	0.6	0.25	0.33	0.80	0.55	0.85	0.71	1.21	0.15
Assessment over	2-step P*	0.6	0.52	0.76	0.82	0.58	0.42	0.75	1.30	0.16
M below average	3-step P*	0.6	1.64	1.29	0.79	0.13	0.08	0.00	0.72	0.15
R above average	3-step P*	0.6	1.16	1.05	0.79	0.23	0.35	0.17	0.82	0.15
Assessment under	3-step P*	0.6	1.59	1.25	0.78	0.13	0.01	0.11	0.73	0.15
M above average	3-step P*	0.6	0.53	0.74	0.79	0.55	0.77	0.41	1.24	0.16
R below average	3-step P*	0.6	0.27	0.33	0.79	0.48	0.83	0.70	1.12	0.16
Assessment over	3-step P*	0.6	0.53	0.75	0.82	0.58	0.41	0.76	1.26	0.16
M below average	Ramped P* (0.45)	0.6	1.64	1.30	0.76	0.13	0.08	0.00	0.72	0.15
R above average	Ramped P* (0.45)	0.6	1.17	1.05	0.76	0.23	0.35	0.15	0.80	0.16
Assessment under	Ramped P* (0.45)	0.6	1.59	1.26	0.74	0.13	0.01	0.11	0.72	0.15
M above average	Ramped P* (0.45)	0.6	0.55	0.74	0.77	0.52	0.77	0.39	1.18	0.18
R below average	Ramped P* (0.45)	0.6	0.32	0.34	0.77	0.32	0.82	0.66	0.92	0.18
Assessment over	Ramped P* (0.45)	0.6	0.54	0.75	0.80	0.55	0.39	0.75	1.20	0.18
M below average	Ramped P* (0.40)	0.6	1.73	1.24	0.73	0.10	0.05	0.00	0.65	0.15
R above average	Ramped P* (0.40)	0.6	1.23	1.02	0.72	0.16	0.32	0.14	0.74	0.16
Assessment under	Ramped P* (0.40)	0.6	1.66	1.20	0.71	0.10	0.01	0.07	0.65	0.16
M above average	Ramped P* (0.40)	0.6	0.56	0.73	0.74	0.45	0.74	0.35	1.10	0.17
R below average	Ramped P* (0.40)	0.6	0.32	0.33	0.73	0.29	0.81	0.63	0.88	0.18
Assessment over	Ramped P* (0.40)	0.6	0.56	0.75	0.76	0.48	0.35	0.73	1.11	0.17
Baseline	3-step P*	0.6	0.96	1.03	0.79	0.32	0.43	0.21	0.94	0.16
Baseline	Ramped P* (0.45)	0.6	0.97	1.04	0.77	0.32	0.43	0.20	0.93	0.16
Baseline	Ramped P* (0.40)	0.6	1.02	1.01	0.73	0.26	0.40	0.18	0.85	0.16
Baseline	P* fixed = 0.40	0.6	1.23	0.98	1.25	0.26	0.38	0.14	0.86	0.13
Baseline	2-step P*	0.6	1.17	1.01	1.34	0.32	0.40	0.16	0.92	0.13
Baseline	3-step P*	0.6	1.18	1.01	1.34	0.32	0.40	0.15	0.91	0.14

Results – 30 Year Projections

In our initial set of projections, we run the economic models using the full 30-year dataset of projections of catches and SSB from the MSE (Wiedenmann 2018). In addition to the base scenario, we present the economic projections for the low and high natural mortality scenarios. These natural mortality scenarios deviated the most from the base scenario, with the recruitment and stock assessment error scenarios following the same pattern, but with a smaller impact.

Base scenario, 30 years

Figures 2 and 3 show the summer flounder harvest and SSB for the base case scenario of normal conditions. In the early years of the simulation, the ramped policies are more conservative in setting the quota and then cross the other policies in years 7, and outperform them in the remaining years of the simulation. The fixed 40% policy has the lowest catch level starting in year 8. The lower harvests for the ramped 40% and fixed 40% policies lead to the ramped 40% policy having the highest SSB levels for the entire projection period, and the fixed 40% policy having the second highest SSB starting in year 10 (Figure 3). Figure 4 shows the annual median net economic benefits. They closely follow the harvest results from Figure 2, with the ramped 45% outperforming all other policies and the fixed 40% policy underperforming all other policy starting in year 7. The ramped 40% policy appears to yield lower harvests but higher economic benefits than the 2-step and 3-step policies in most years. Figure 5 shows the corresponding present value of net economic benefits summed over the 30 years of the simulation. The differences are barely discernable in the graphic, but the current policy has the lowest total net economic value of about $2.051 billion compared with $2.105 billion for the 2-step policy, a difference of about $54 million over the 30 years. At a higher discount rate (7%) the difference in outcomes is $48 million higher for the 2-step policy.

High natural mortality, 30 years

Figure 6 shows the annual median net economic benefits for the different control rules over the 30-year period for model runs where natural mortality is in the top quintile. All policies seem to produce similar patterns after year 5. Figure 7 shows the distribution of cumulative net economic benefits over the 30-year period. Again, it is hard to see the differences among the control rules in the graphs, but the current policy has the lowest net economic value of about $1.487 billion per year compared with $1.535 billion for the 2-step policy, a difference of $48 million. At a 7% discount rate, the fixed 40% policy has the highest net economic at $1,004 billion compared with $959 million for the current policy.

Low natural mortality, 30 years

Figure 8 shows the annual median net economic benefits for the different control rules over the 30-year period for model runs where natural mortality is in the bottom quintile. . In this case, the 2-step, 3-step, and ramped 45% policies all produce the same result starting in year 12 as they are essentially the same policy when relative SSB is above one. Figure 9 shows the distribution of cumulative net economic benefits over the 30-year period. It is hard to see the differences among the control rules in the graphs, but the current policy has the lowest net economic value of about $3,023 billion compared with $3,122 billion for the 2 step policy, a difference of $99 million. At a 7% discount rate, the current policy has the lowest net economic at $1,706 billion compared with $1,776 billion for the 2 step policy. The difference is $70 million.

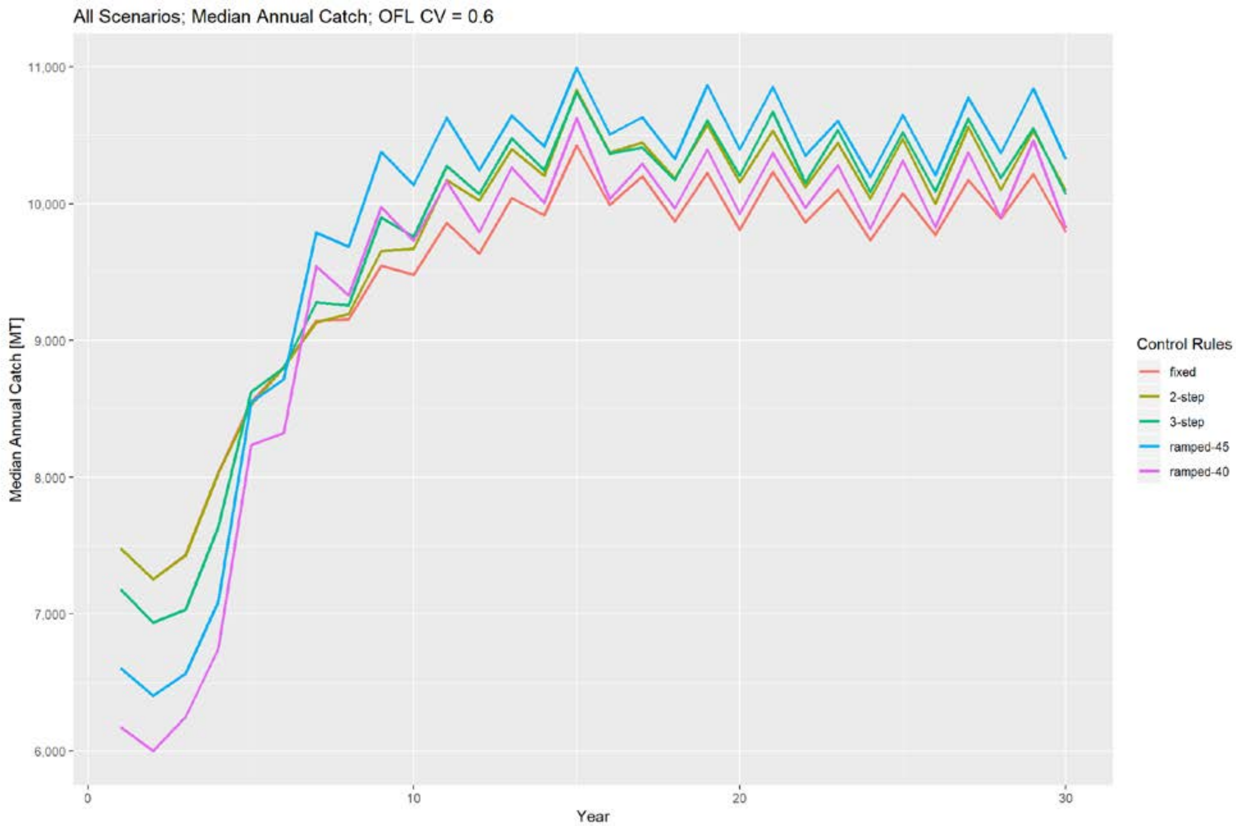

Figure 2. Simulated median annual summer flounder catch for each of the control rule for the base scenario of normal conditions as input to the economic submodels.

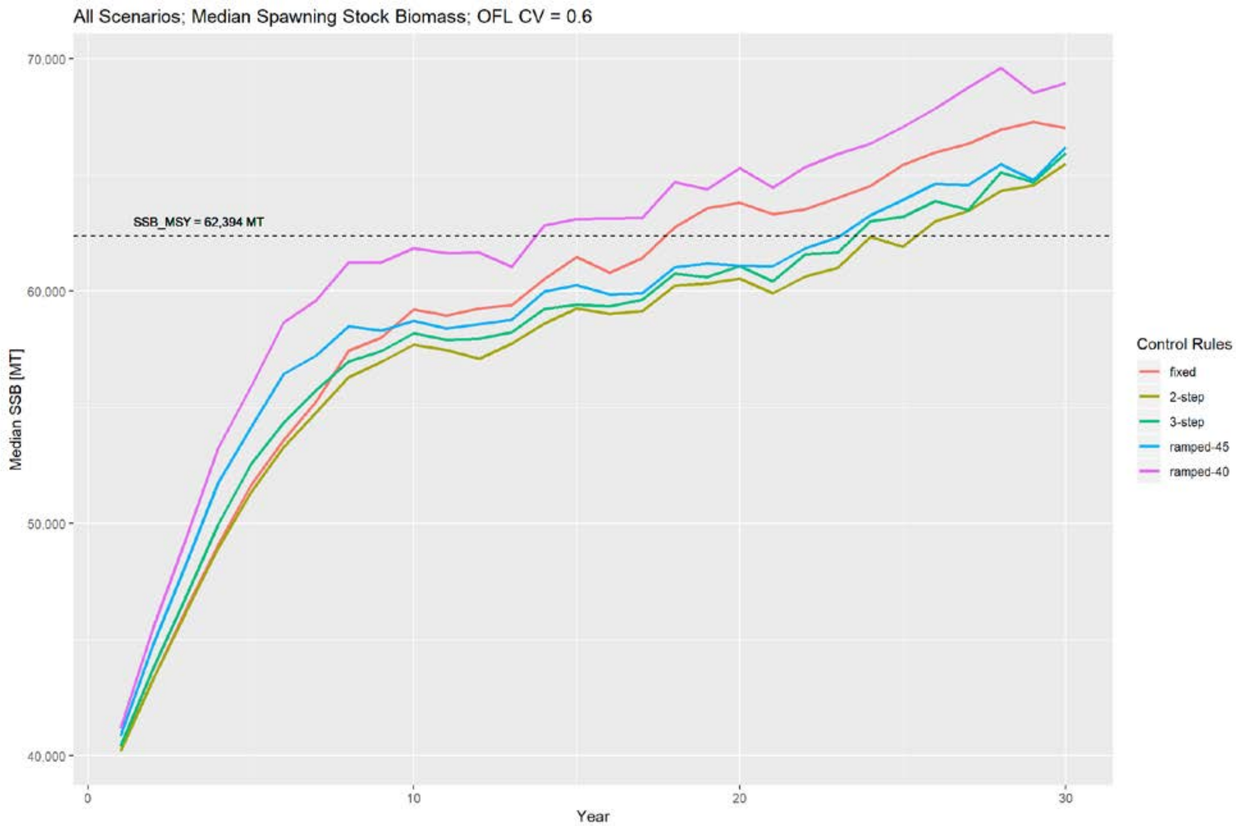

Figure 3. Simulated summer flounder median spawning stock biomass used as input for base scenario of normal conditions as input to the economic submodels.

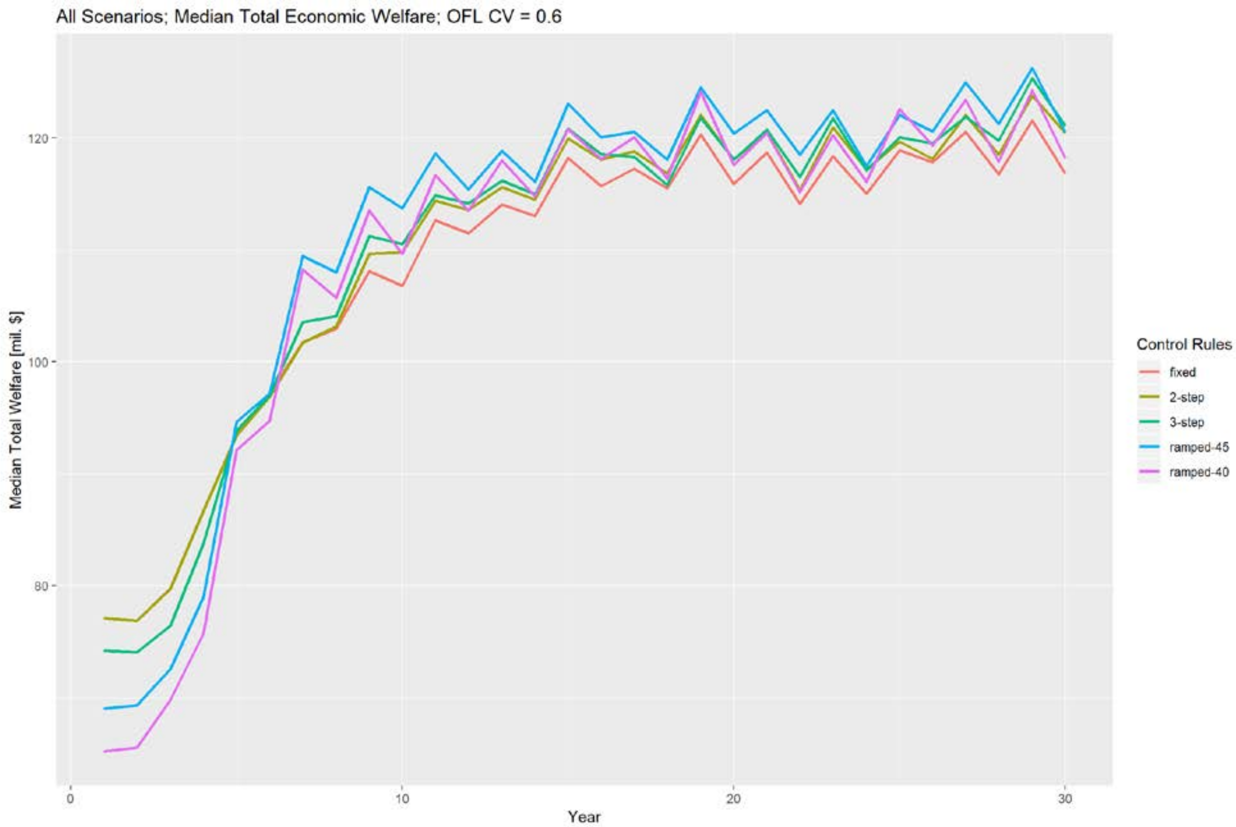

Figure 4. Annual median net economic benefits for the base scenario of normal conditions.

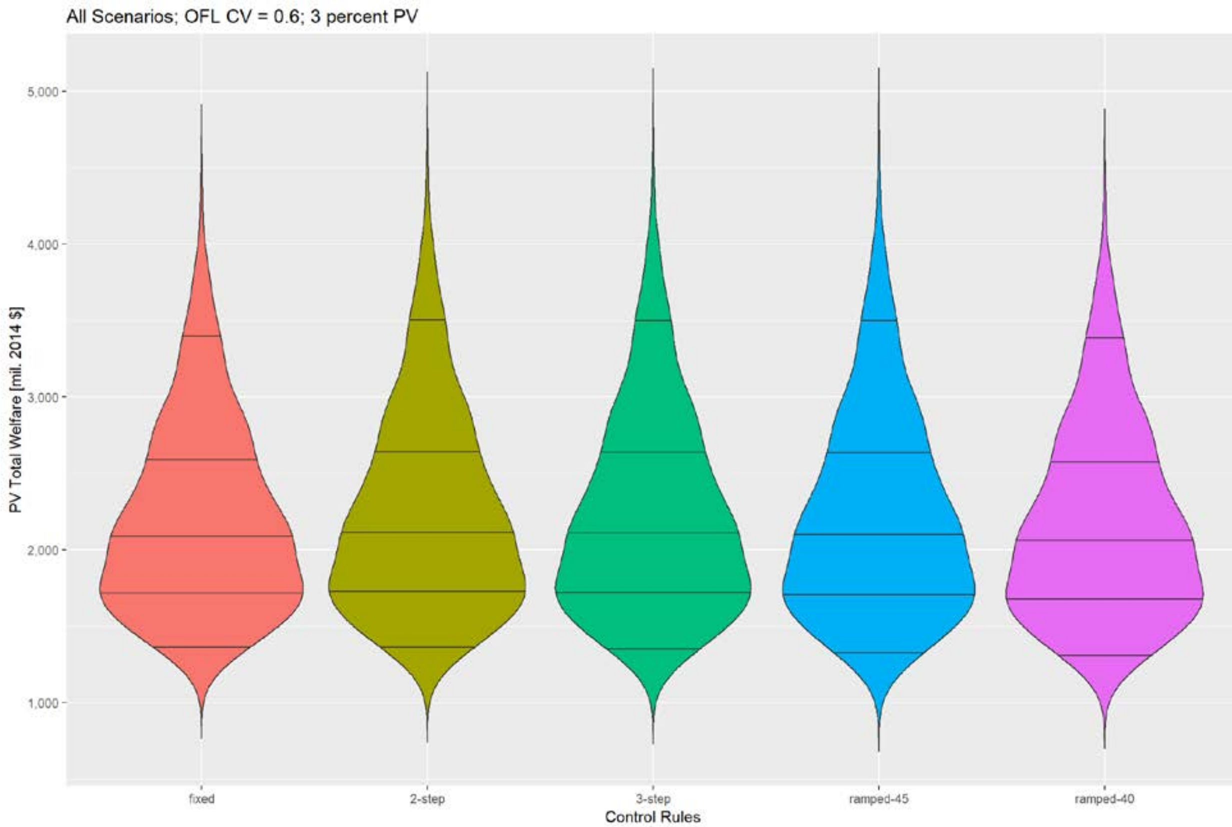

Figure 5. Violin plots of model runs showing quantiles of 5%, 25%, 50%, 75%, 95% for the base scenario showing the present value of total net economic benefit for the base scenario of normal conditions.

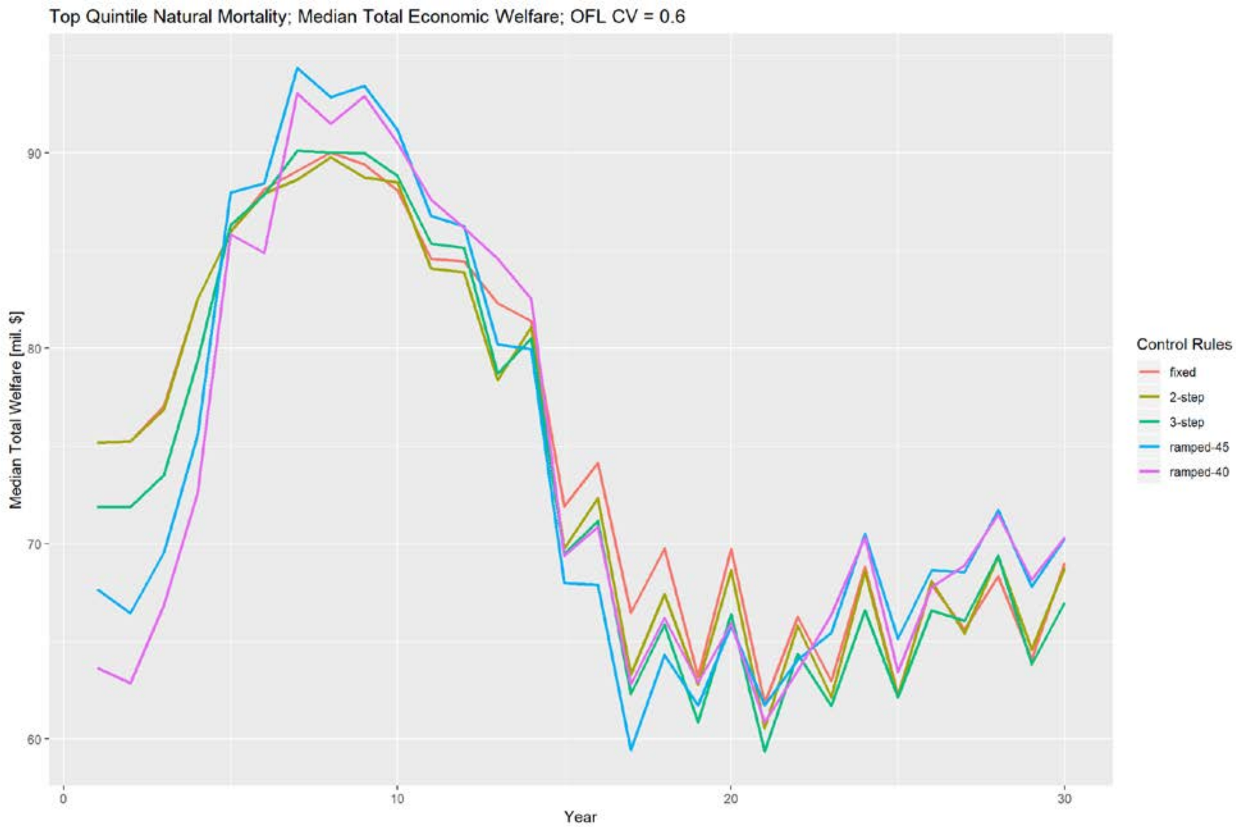

Figure 6. Annual median net economic benefits for simulated runs with natural mortality in the top quintile.

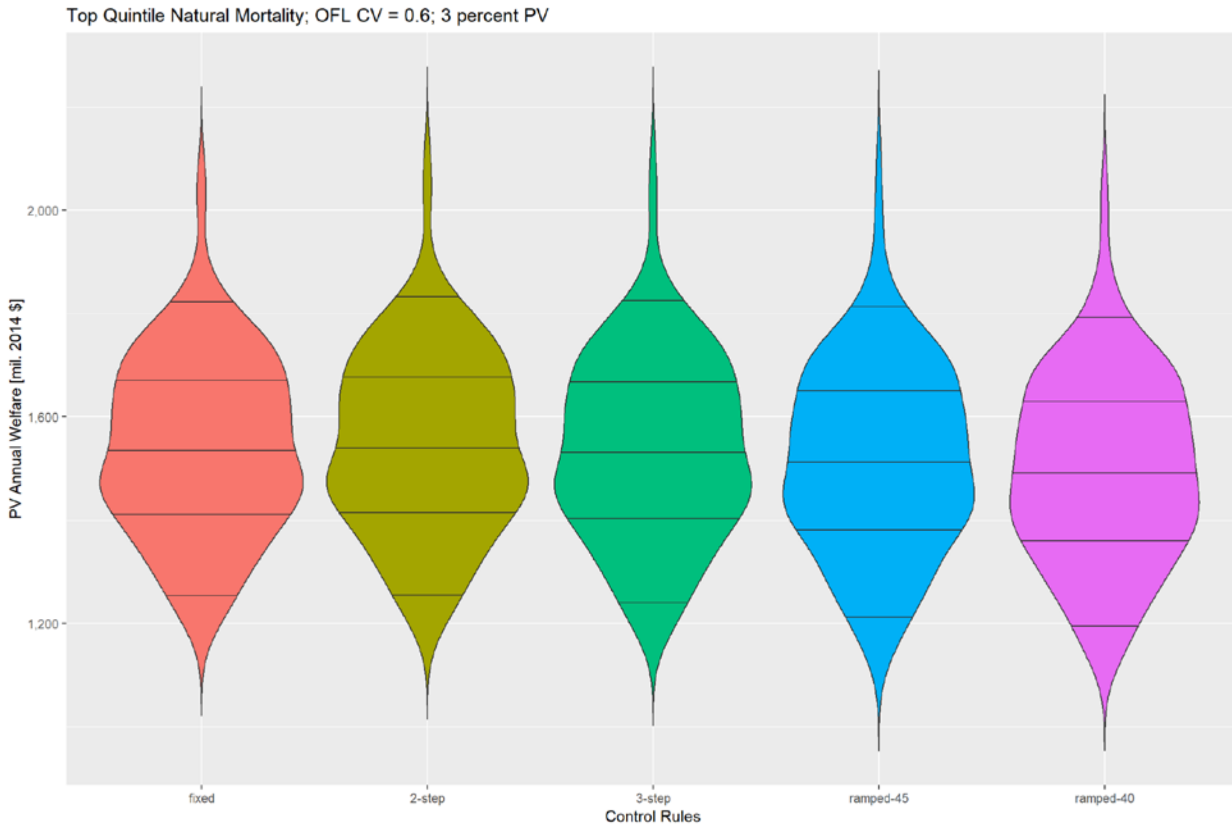

Figure 7. Violin plots of model runs showing quantiles of 5%, 25%, 50%, 75%, 95% of annual net economic benefit under high natural mortality scenarios.

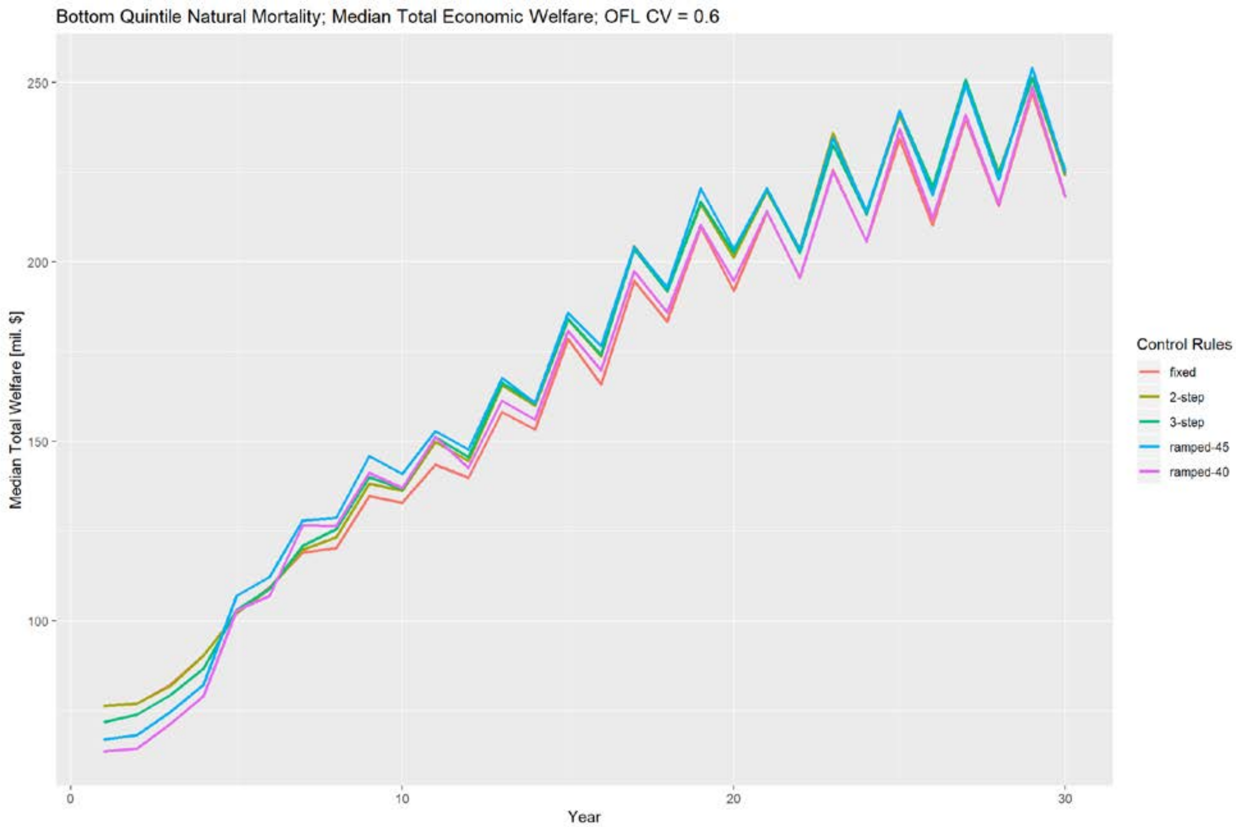

Figure 8. Annual median net economic benefits for simulated runs with natural mortality in the bottom quintile.

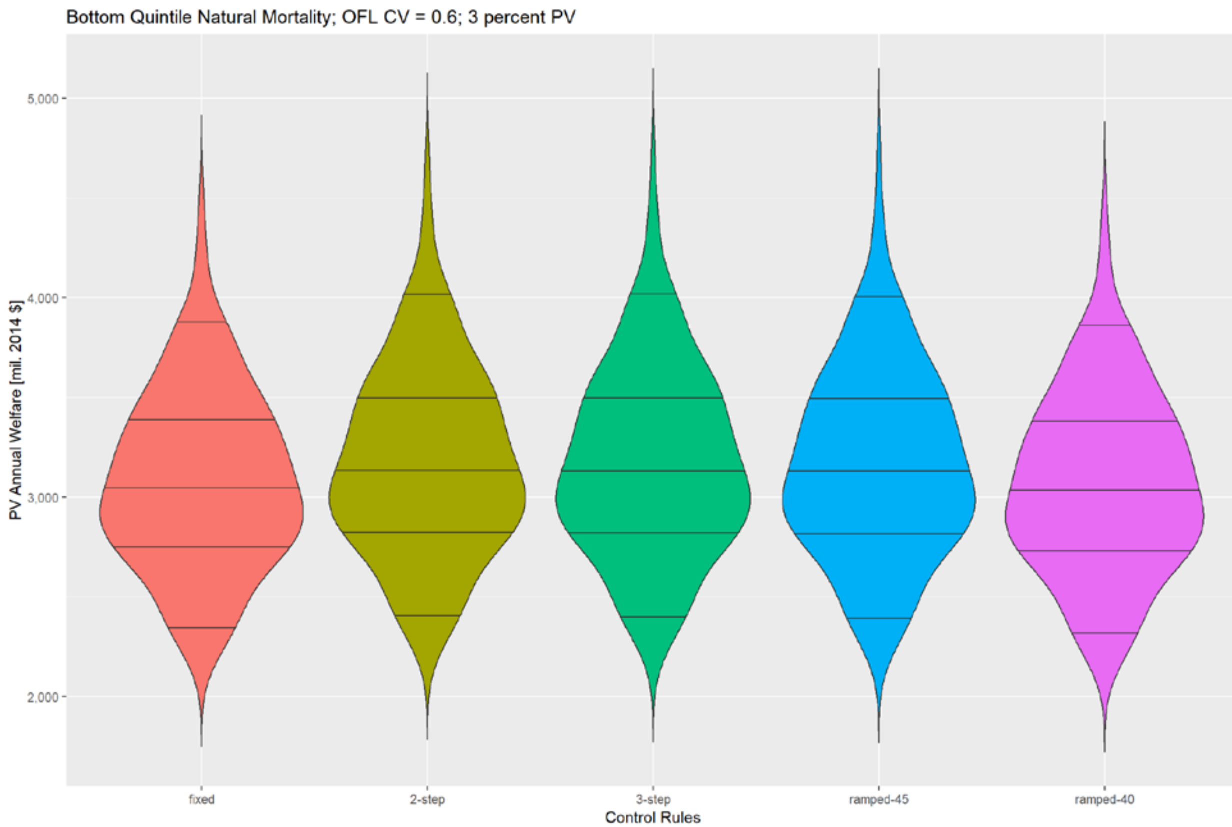

Figure 9. Violin plots of model runs showing quantiles of 5%, 25%, 50%, 75%, 95% of annual net economic benefit under low natural mortality scenarios.

Results – 10 Year Projections

The economic performance of the control rules, as in the biological case, is driven by the initial state of the summer flounder stock in the simulations where $SSB/SSB_{MSY} < 1.0$. During the simulation period, the stock transitions to a state where it fluctuates around $SSB/SSB_{MSY} = 1.0$ and explains the switching of the performance of the different control rules. Therefore, we decided to add an additional analysis that focuses only on the first ten years of the projection period but still encompasses the transition period.

Base scenario – 10 years

Figure 10 shows the annual median net economic benefits for the first 10 years. Figure 11 shows the present value of net economic benefits summed over the first 10 years of the simulation. As before, the current policy has the lowest total net economic value, and it is lower in absolute value at about $760 million because it is calculated over fewer years. In comparison the 2 step policy has a total net economic value of $797 million, a difference of about $37 million over 10 years. At a higher discount rate (7%) the difference in net economic benefits between the current policy, which has the lowest outcome, and the 2 step policy, which has the highest outcome is $35 million.

High natural mortality scenario – 10 years

Figure 12 shows the annual median net economic benefits for the different control rules over the first 10-year period for model runs where natural mortality is in the top quintile. For the first 4 years, the ramped 40%, ramped 45%, and 3-step policies, which allow fewer catches when SSB is low, underperform other policies, but as SSB recovers, they begin to outperform. Figure 13 shows the distribution of cumulative net economic benefits over the 10-year period. The current policy has the lowest net economic value of about $677 million compared with $725 million for the 2-step policy, a difference of $48 million. At a 7% discount rate, this difference decreases to $34 million.

Low natural mortality scenario – 10 years

Figure 14 shows the distribution of annual net economic benefits for the different control rules over the first 10 year period for model runs where natural mortality is in the bottom quintile.. The ramped policies do not perform well initially but start to outperform in year 7. Figure 13 shows the distribution of cumulative net economic benefits over the 10-year period. The current policy has the lowest net economic value of about $848 million compared with $895 million for the 2-step policy, a difference of $47 million. At a 7% discount rate, this difference decreases to $441 million.

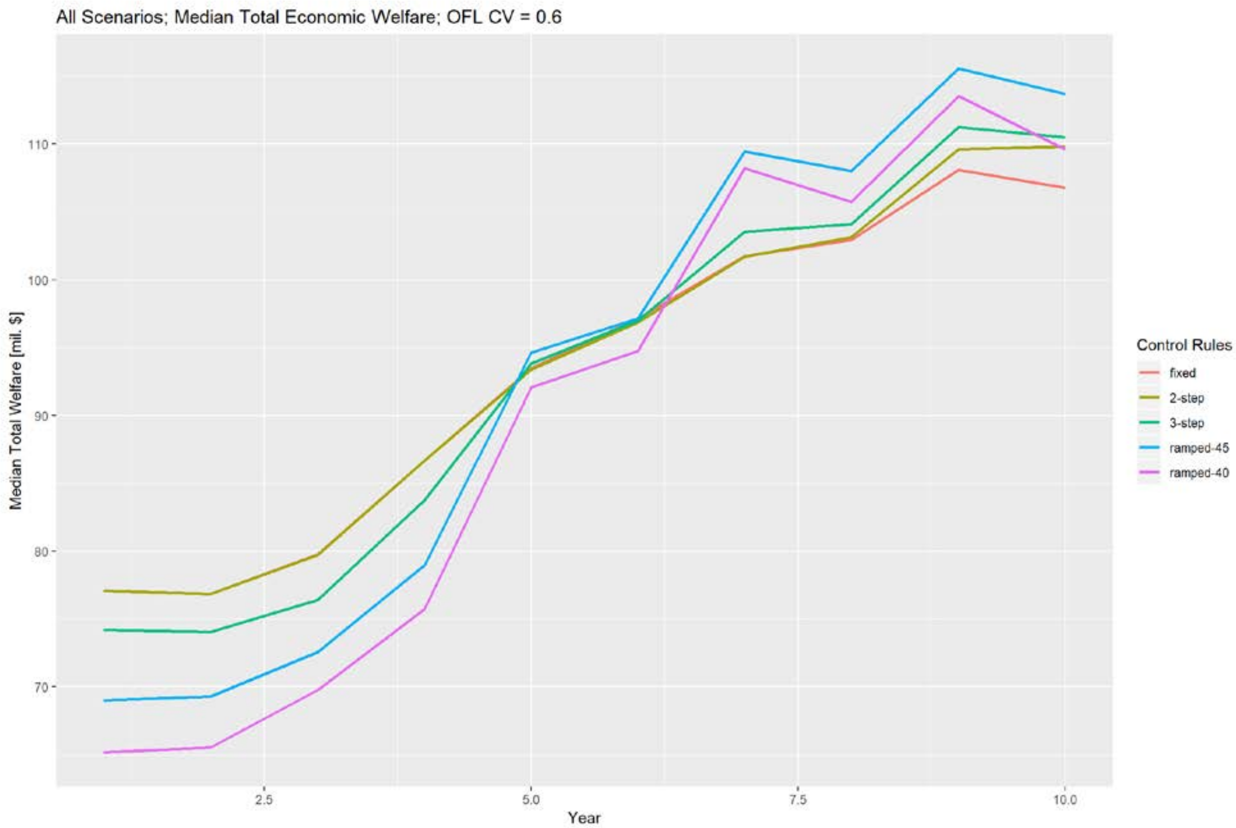

Figure 10. Annual median net economic benefits for the base scenario of normal conditions.

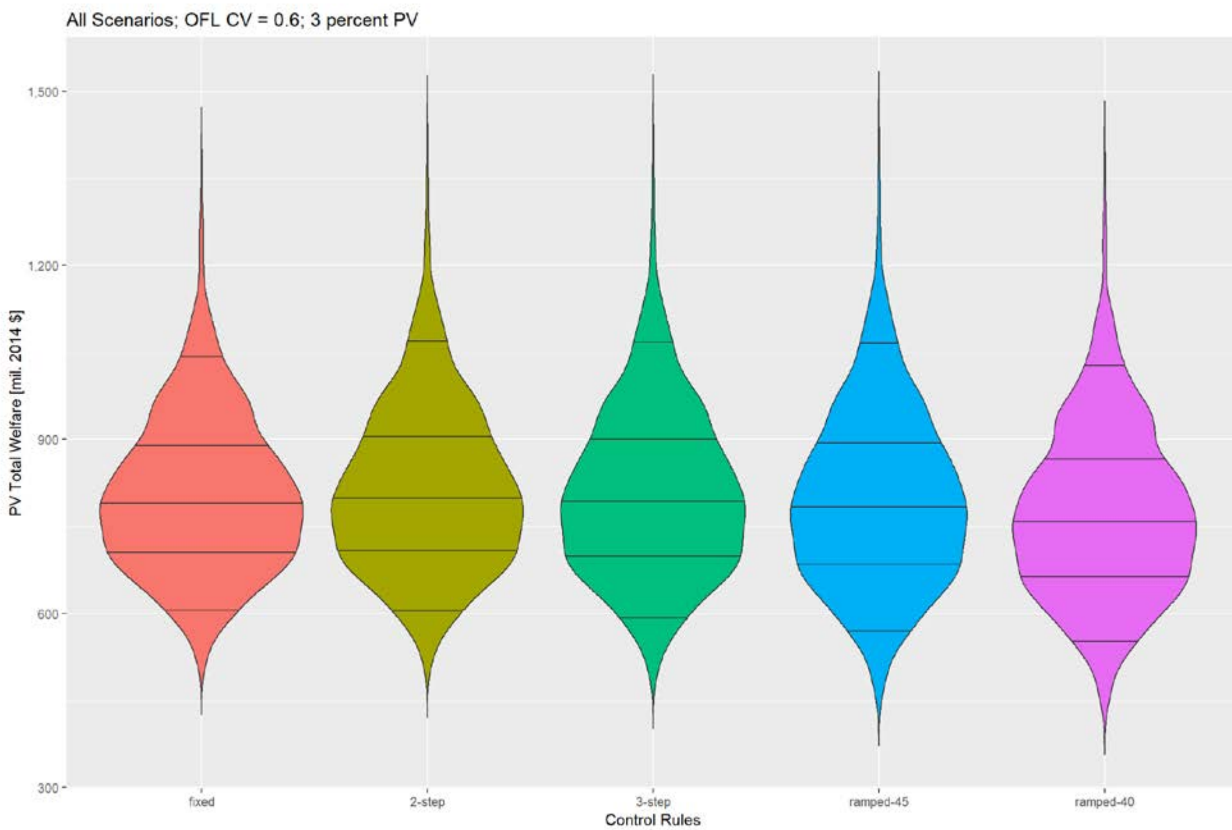

Figure 11. Violin plots of model runs showing quantiles of 5%, 25%, 50%, 75%, 95% for the base scenario showing the present value of total net economic benefit for the base scenario of normal conditions.

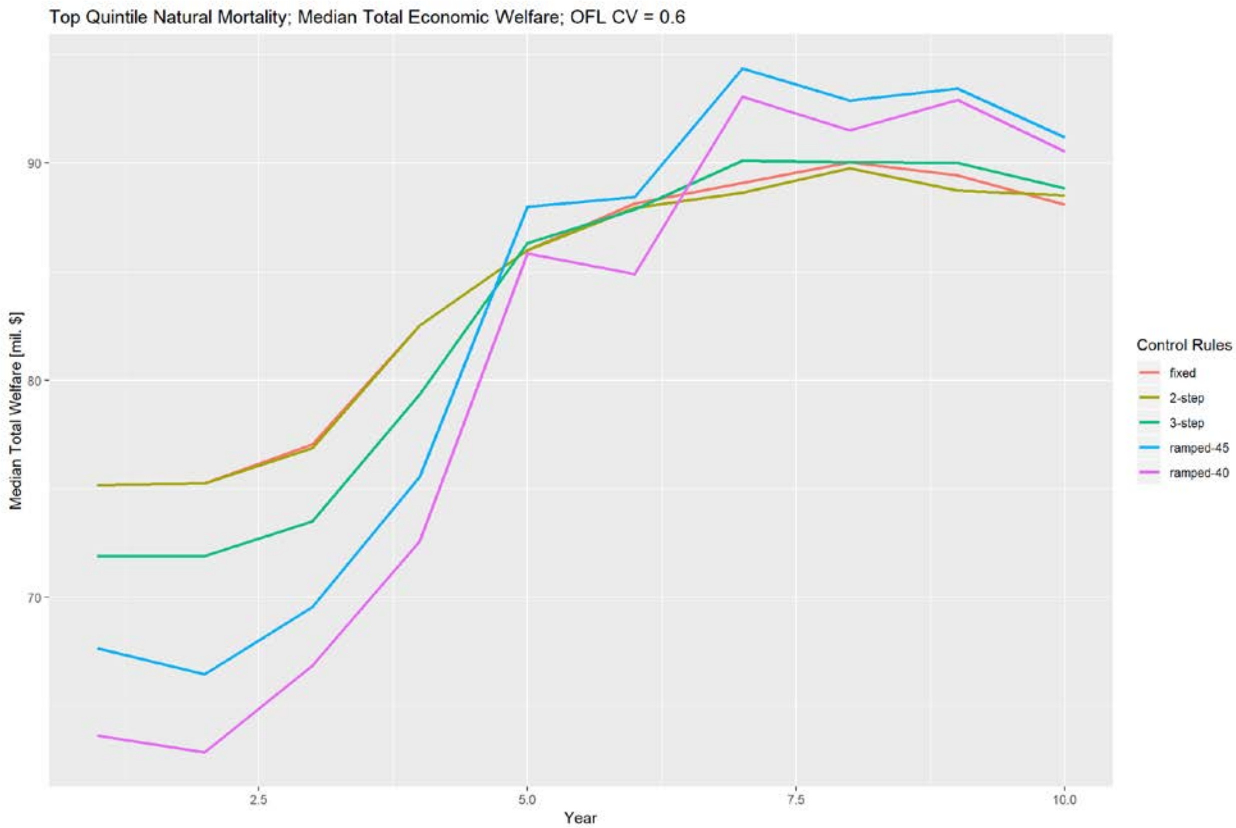

Figure 12. Annual median net economic benefits for simulated runs with natural mortality in the top quintile.

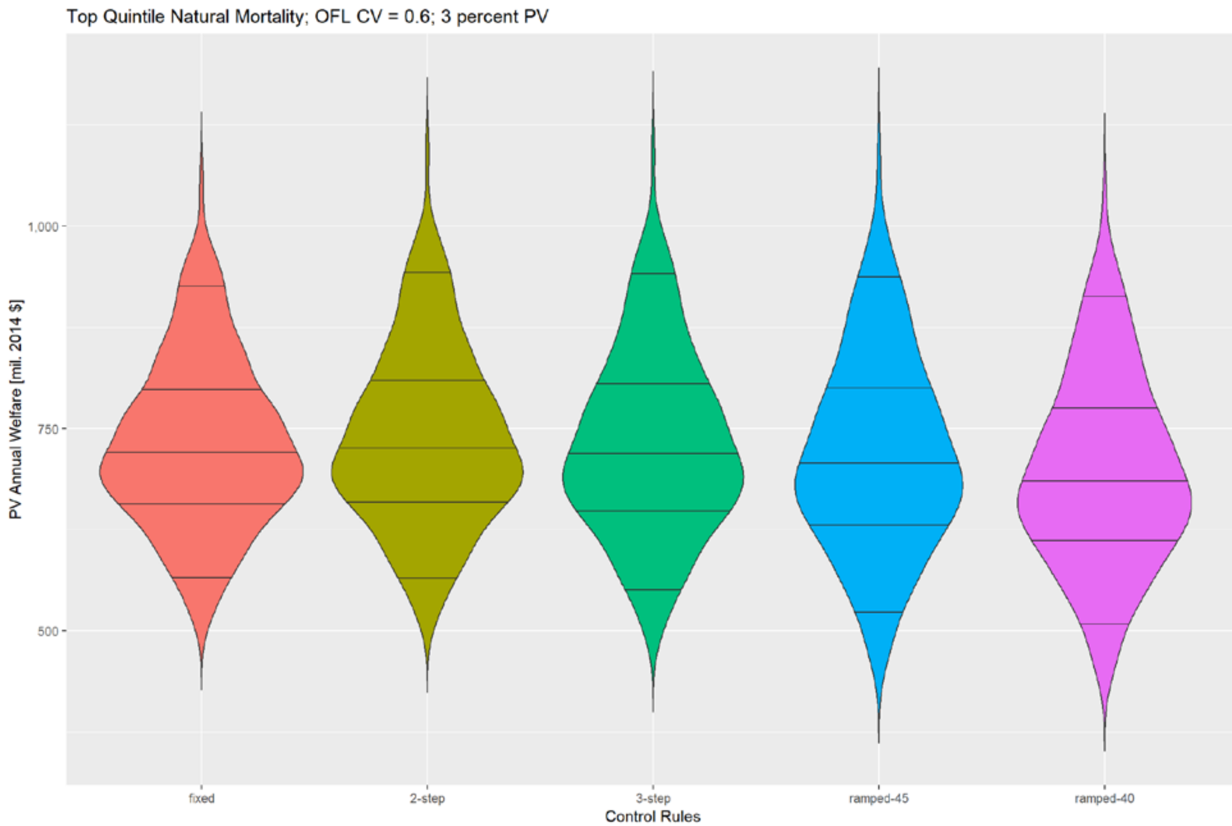

Figure 13. Violin plots of model runs showing quantiles of 5%, 25%, 50%, 75%, 95% of annual net economic benefit under high natural mortality scenarios.

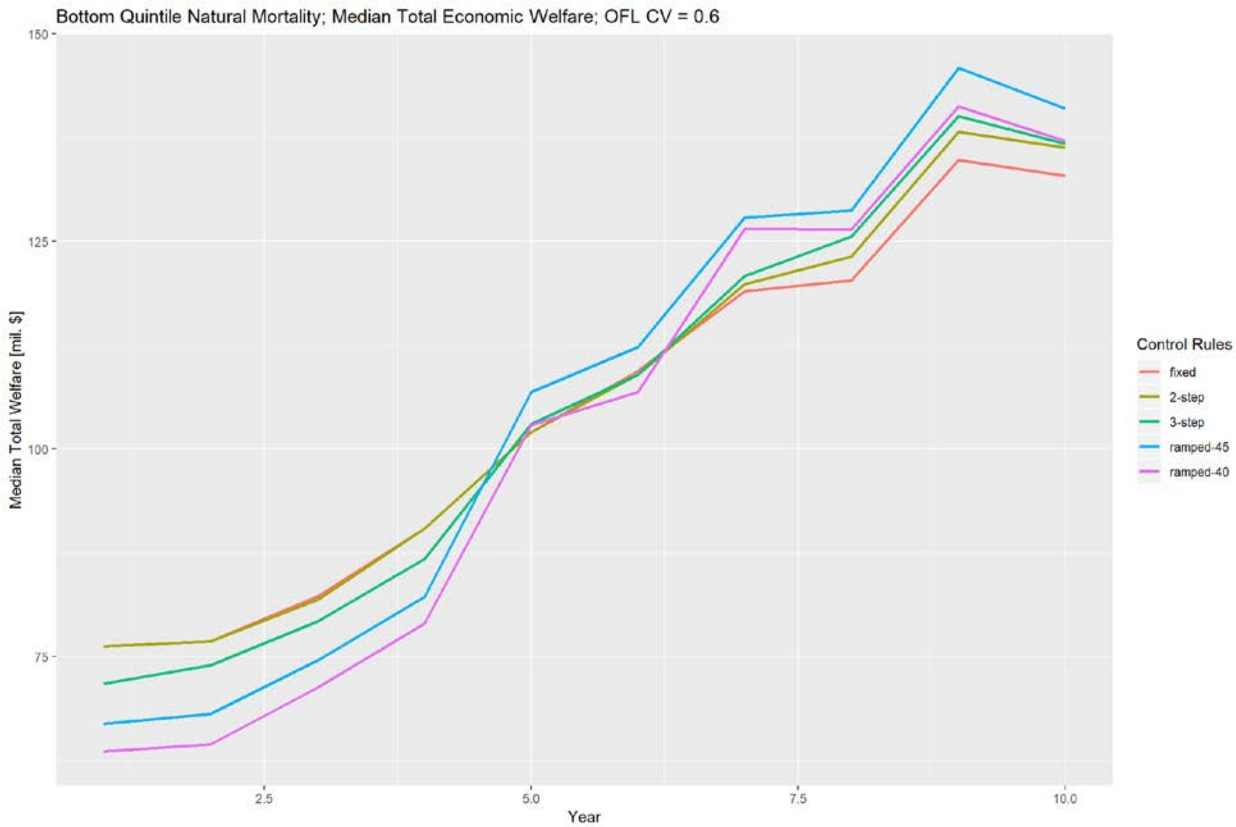

Figure 14. Annual median net economic benefits for simulated runs with natural mortality in the top quintile.

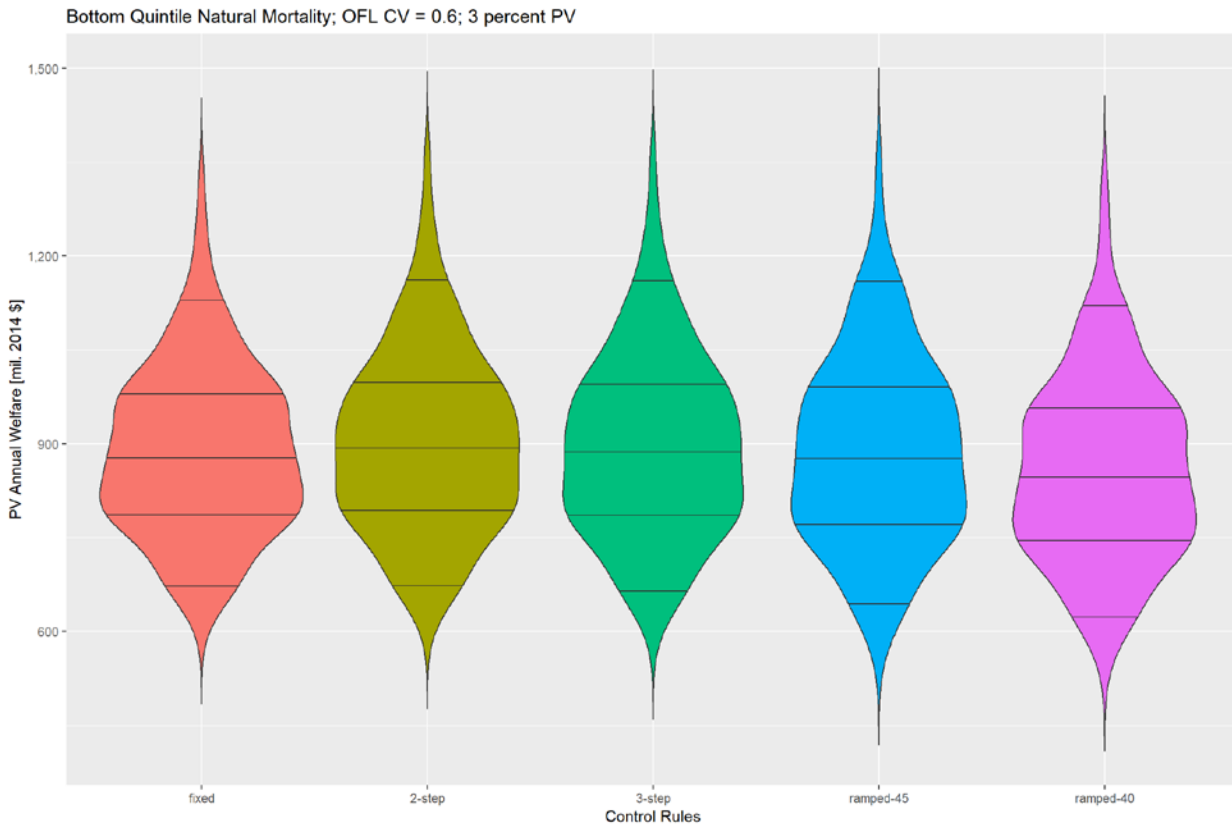

Figure 15. Violin plots of model runs showing quantiles of 5%, 25%, 50%, 75%, 95% of annual net economic benefit under high natural mortality scenarios.

Discussion

Table 2 shows the best and worst performing harvest control rules from the perspective of total net economic benefits for both the 30-year and 10-year scenarios, and for scenarios of high and low natural mortality compared to average conditions. The results for high and low recruitment and for stock assessment error yield similar results with some minor deviations in control rule performance. The current policy (Ramp-40%) is the most conservative and leads to the lowest net economic benefits, while the 2-step policy performs the best. A next step would be to examine the trade-off in terms of realized probability of overfishing that occurs when adopting a less conservative control rule like the 2-step policy which provides greater economic benefits.

The performance of the control rules and their comparison was highly influenced by the starting condition of the summer flounder biomass when the simulation period beings. This can be seen in the 30-year graphs where, as the biomass stabilizes around SSB_{MSY} there appears a much smaller difference in performance between control rules as they become effectively equivalent to each other in most years. In the beginning of the period, when the SSB of the summer flounder resource is below SSB_{MSY}, the Ramp-40 policy restricts harvest which results in its underperformance. In later years, the 2-step policy is better able to take advantage of the increased SSB, again resulting in the underperformance for the Ramp-40 policy.

It is difficult to generalize from the results here as to how the different harvest control rules will perform for other species. As we saw from the shifts in performance of the rules over time within the summer flounder fishery, it is reasonable to assume that when a species SSB is consistently above SSB_{MSY}, the rules will hardly differ in performance. If the SSB randomly slips below SSB_{MSY} in any year and the stock is quickly able to recover even without a reduction in harvest (e.g., where the natural year to year variability has a greater effect than fishing mortality), then the cost (foregone economic benefits) of lowering the harvest would not really gain any future benefit. However, figuring out which stocks this applies to requires a similar analysis as was conducted for summer flounder.

Table 2. Best and worst performing harvest control rule policies, cumulative economic benefit, evaluated over 10 and 30 years (3% discount rate) (millions of dollars).

Term	Scenario	Best Policy	Worst Policy	Cumulative Difference
30 years	Base	2-step ($2,105)	Ramp-40 ($2,051)	$54
30 years	High Natural Mortality	2-step($1,535)	Ramp-40 ($1,487)	$48
30 years	Low Natural Mortality	2 step ($3,122)	Ramp-40 ($3,023)	$99
10 years	Base	2-step ($797)	Ramp-40 ($760)	$37
10 years	High Natural Mortality	2-step ($725)	Ramp-40 ($677)	$48
10 years	Low Natural Mortality	2-step ($895)	Ramp-40 ($848)	$47

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