Evaluation of alternative ABC harvest control rules for Mid-Atlantic fisheries

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A total of ten control rules were explored in the management strategy evaluation (MSE) model for scup, summer flounder, and butterfish. There were five approaches for adjusting the target P* as a function of the estimated biomass (Figure 1), and each approach was evaluated using an assumed CV of the OFL distribution of 0.6 and 1.0. The control rule was applied to each stock for 25 years, with variability introduced in the population dynamics of each species through variability in recruitment and natural mortality, as well as variability in the data collected that are used in the stock assessment model. At the end of each 25 year run in the model, a series of performance measures were calculated, summarizing average population size, average short-term catch (over the first 5 years following control rule implementation), average long-term catch (over the final 15 years), the average fishing mortality rate, the probability of overfishing, the probability of becoming overfished, and variability in yield. The model was run for each stock and each control rule 1000 times, and performance across control rule options compared to identify overall performance as well as the tradeoffs associated with each control rule.

Result were explored both across all model runs (called the baseline results), as well as by separating out the runs by what occurred over the years the control rule was applied, based on the different possible "states of nature" of the future. The separate states of nature explored include runs where natural mortality (*M*) and recruitment were lower or higher than average, and where the stock assessment under- or overestimates biomass, on average. All combinations of these different states were possible in the model (e.g., *M* could be low, but with poor recruitment), but things were combined into "bad" (*M* higher, assessment overestimates biomass) and "really bad" (*M* higher, assessment overestimates biomass, *and* recruitment is low) possible futures.

Under the baseline results, all control rules were able to limit overfishing, resulting in a median probability of overfishing below the 50% threshold for each stock. Control rules that had a higher target P* (0.45) resulted in a higher risk of overfishing, as did assuming a higher CV for the OFL distribution (Figure 2). When runs were separated out by the different states of nature, however, the threshold-based control rules that reduced the target P* linearly as biomass declines were better suited for keeping the risk of overfishing below the 50% level when future conditions were poor across stocks (Figure 3).

The amount of short-term and long-term yield across control rules varied by stock, in part because summer flounder is currently below the biomass target, whereas scup and butterfish are not (triggering initially lower target P* for summer flounder). Under the baseline results for summer flounder, there was an 8-12% difference in the short-term yield between control rules (for a given CV), with the threshold-based options having the lower catch, and a 3-5% difference in short-term catch for the different CVs for a given control rule (Table 1). There was a 5% difference in long-term yield for summer flounder, with the threshold-based options resulting in the higher catch, and only a 0-1% difference in long-term yield based on the OFL CV. The threshold-based options had a risk of overfishing between 12 and 23%, compared to 23-31% for the other fixed P* or stepped P* control rules, and they also reduced the risk of becoming overfished by more than half (13-17% compared to 34-37%). Variability in yield was similar across control rules for summer flounder, with the threshold-based control rules having slightly more variable yield (14-15% change per year compared to 11-13%). Tradeoffs between some of the performance measures for summer flounder are shown in Figures 4-6 (middle panel).

For butterfish, there was a 4-11% difference in short-term catch between control rules (for a given CV), with the threshold-based options having the lower catch, and a 3-5% difference in short-term catch for the different CVs for a given control rule (Table 1). There was a 4-10% difference in long-term yield for butterfish, with the threshold-based options being more conservative, and a 3-6% difference in long-term yield for a given control rule based on the OFL CV. The threshold-based options had a risk of overfishing between 21 and 23%, compared to 37-44% for the other fixed P* or stepped P* control rules, although the difference in the risk of becoming overfished was not as large compared to summer flounder (between 17-37% for the threshold-based options compared to 45-48%). Variability in yield was higher compared to summer flounder, but was similar across control rules, with the threshold-based control rules having slightly more variable yield (28-29% change per year compared to 26-27%). Tradeoffs between some of the performance measures for butterfish are shown in Figures 4-6 (left panel).

For scup, there was a 0-6% difference in short-term catch between control rules (for a given CV), with the difference being largely driven by the maximum target P* (Table 1). There was only 1-3% difference in long-term yield for scup, with the threshold-based options being comparable or slightly more conservative, and a 1-2% difference in long-term yield for a given control rule based on the OFL CV. All control rules had a risk of overfishing between 19 and 31%, with the risk of becoming overfished about half for the threshold-based option (8-10% compared to 18-22%). Variability in yield was similar to summer flounder, although values were comparable across control rules (13-14% change per year). Tradeoffs between some of the performance measures for butterfish are shown in Figures 4-6 (right panel).

A subset of performance measures is shown in Table 2 for the baseline model run compared to bad and really bad future dynamics. As expected when conditions deteriorate, the risk of overfishing and the risk of becoming overfished increase and yield decreases. Under really bad future conditions, nearly all runs (81-100%) resulted in the population becoming overfished at some point, although the risk was lower for the threshold-based control rules. Only the threshold-based control rules were able to keep the median risk of overfishing below 50% under the bad and really bad scenarios, depending on the stock, the maximum P*, and the assumed CV. For butterfish and scup, long-term yield under the bad and really bad scenarios was lower for the threshold-based options, but for summer flounder the threshold-based control rules resulted in similar or higher yield compared to the fixed and stepped P* options (Table 2).

An important caveat to this work is that the performance measures summarizing the benefits to the fishery are measured in terms of short- and long-term yield, and do not account for the different economic factors of each fishery. Model results can be used, however, in an economic analysis to better quantify the risk versus reward of the different control rules, and discussions of doing so are currently under way.

Table 1. Median values for each performance measure (across 1000 model runs) for each control rule and assumed CV of the OFL for each stock.

Stock	Control Rule	CV	Mean S / S_{MSY}	Short-Term Average Catch	Long-term Average Catch	Mean F / F_{MSY}	Risk of Overfishing	Risk of Becoming Overfished	Vairiability in Catch
	P* fixed = 0.4	0.60	1.04	0.84	0.90	1.02	0.42	0.46	0.26
	P* fixed = 0.4	1.00	1.08	0.80	0.86	0.95	0.37	0.44	0.26
	Two step P*	0.60	1.03	0.87	0.93	1.04	0.42	0.48	0.26
	Two step P*	1.00	1.06	0.83	0.90	0.99	0.42	0.46	0.26
	Three step P*	0.60	1.06	0.85	0.91	0.99	0.42	0.47	0.27
Butterfish	Three step P*	1.00	1.09	0.82	0.88	0.93	0.37	0.45	0.27
	Threshold P* (max = 0.45)	0.60	1.12	0.80	0.86	0.83	0.26	0.44	0.28
	Threshold P* (max = 0.45)	1.00	1.15	0.76	0.83	0.76	0.21	0.41	0.29
	Threshold P* (max = 0.40)	0.60	1.15	0.74	0.82	0.77	0.21	0.41	0.28
	Threshold P* (max = 0.40)	1.00	1.20	0.69	0.76	0.68	0.21	0.37	0.28
	P* fixed = 0.4	0.60	0.75	0.76	0.78	0.88	0.31	0.36	0.11
	P* fixed = 0.4	1.00	0.79	0.73	0.77	0.82	0.23	0.34	0.11
	Two step P*	0.60	0.73	0.76	0.78	0.91	0.31	0.37	0.12
	Two step P*	1.00	0.76	0.73	0.78	0.86	0.27	0.35	0.12
Summer	Three step P*	0.60	0.75	0.73	0.79	0.87	0.31	0.36	0.12
Flounder	Three step P*	1.00	0.78	0.70	0.78	0.83	0.23	0.34	0.13
	Threshold P* (max = 0.45)	0.60	0.80	0.69	0.82	0.81	0.23	0.17	0.14
	Threshold P* (max = 0.45)	1.00	0.82	0.65	0.82	0.77	0.19	0.15	0.15
	Threshold P* (max = 0.40)	0.60	0.84	0.66	0.80	0.76	0.19	0.15	0.14
	Threshold P* (max = 0.40)	1.00	0.88	0.61	0.80	0.71	0.12	0.13	0.14
	P* fixed = 0.4	0.60	0.97	1.00	0.80	0.84	0.27	0.20	0.14
	P* fixed = 0.4	1.00	1.02	0.96	0.78	0.78	0.19	0.18	0.13
	Two step P*	0.60	0.90	1.07	0.81	0.91	0.31	0.23	0.14
	Two step P*	1.00	0.93	1.05	0.80	0.87	0.31	0.21	0.14
	Three step P*	0.60	0.91	1.07	0.80	0.90	0.31	0.22	0.14
Scup	Three step P*	1.00	0.94	1.05	0.79	0.87	0.31	0.21	0.14
	Threshold P* (max = 0.45)	0.60	0.93	1.07	0.81	0.88	0.31	0.10	0.14
	Threshold P* (max = 0.45)	1.00	0.97	1.05	0.80	0.85	0.27	0.10	0.14
	Threshold P* (max = 0.40)	0.60	1.00	1.01	0.79	0.81	0.23	0.09	0.14
	Threshold P* (max = 0.40)	1.00	1.05	0.97	0.77	0.76	0.19	0.08	0.13

Table 2. Similar to Table 1, but with a subset of performance measures, and comparing the baseline scenario with cases where the future state of nature is bad (assessment overestimates biomass and *M* is higher) and really bad (assessment overestimates biomass, *M* is higher and recruitment is poor).

Stock	Control Rule	CV	Baseline Short-Term Average Catch	Bad Short-Term Average Catch	Really Bad Short-Term Average Catch	Baseline Long-term Average Catch	Bad Long-term Average Catch	Really Bad Long-term Average Catch	Baseline Risk of Overfishing	Bad Risk of Overfishing	Really Bad Risk of Overfishing	Baseline Risk of Becoming Overfished	Bad Risk of Becoming Overfished	Really Bad Risk of Becoming Overfished
	P* fixed = 0.4	0.60	0.84	1.30	0.94	0.90	1.22	0.58	0.42	0.68	0.89	0.46	0.78	1.00
	P* fixed = 0.4	1.00	0.80	1.21	0.95	0.86	1.19	0.62	0.37	0.63	0.89	0.44	0.79	1.00
	Two step P*	0.60	0.87	1.27	0.93	0.93	1.24	0.54	0.42	0.68	0.95	0.48	0.83	1.00
	Two step P*	1.00	0.83	1.21	0.92	0.90	1.20	0.56	0.42	0.63	0.89	0.46	0.81	1.00
	Three step P*	0.60	0.85	1.26	0.90	0.91	1.22	0.53	0.42	0.68	0.89	0.47	0.81	1.00
Butterfish	Three step P*	1.00	0.82	1.25	0.91	0.88	1.18	0.54	0.37	0.63	0.89	0.45	0.77	1.00
	Threshold P* (max = 0.45)	0.60	0.80	1.18	0.91	0.86	1.13	0.49	0.26	0.53	0.63	0.44	0.79	1.00
	Threshold P* (max = 0.45)	1.00	0.76	1.16	0.83	0.83	1.07	0.47	0.21	0.53	0.53	0.41	0.75	0.99
	Threshold P* (max = 0.40)	0.60	0.74	1.18	0.86	0.82	1.09	0.51	0.21	0.53	0.58	0.41	0.75	1.00
	Threshold P* (max = 0.40)	1.00	0.69	1.20	0.80	0.76	1.03	0.47	0.21	0.47	0.47	0.37	0.72	0.98
	P* fixed = 0.4	0.60	0.76	0.78	0.77	0.78	0.75	0.26	0.31	0.62	0.73	0.36	0.59	1.00
	P* fixed = 0.4	1.00	0.73	0.76	0.74	0.77	0.74	0.29	0.23	0.54	0.65	0.34	0.57	0.97
	Two step P*	0.60	0.76	0.78	0.77	0.78	0.75	0.26	0.31	0.62	0.73	0.37	0.64	1.00
	Two step P*	1.00	0.73	0.76	0.74	0.78	0.74	0.28	0.27	0.58	0.69	0.35	0.62	0.97
Summer	Three step P*	0.60	0.73	0.77	0.75	0.79	0.74	0.27	0.31	0.62	0.65	0.36	0.64	0.98
Flounder	Three step P*	1.00	0.70	0.74	0.72	0.78	0.73	0.29	0.23	0.54	0.60	0.34	0.60	0.97
	Threshold P* (max = 0.45)	0.60	0.69	0.73	0.71	0.82	0.76	0.28	0.23	0.54	0.38	0.17	0.63	0.98
	Threshold P* (max = 0.45)	1.00	0.65	0.69	0.68	0.82	0.75	0.28	0.19	0.50	0.31	0.15	0.61	0.97
	Threshold P* (max = 0.40)	0.60	0.66	0.70	0.68	0.80	0.76	0.29	0.19	0.46	0.35	0.15	0.58	0.96
	Threshold P* (max = 0.40)	1.00	0.61	0.65	0.64	0.80	0.74	0.30	0.12	0.42	0.31	0.13	0.52	0.90
	P* fixed = 0.4	0.60	1.00	1.20	1.13	0.80	0.97	0.45	0.27	0.58	0.75	0.20	0.32	0.92
	P* fixed = 0.4	1.00	0.96	1.15	1.08	0.78	0.95	0.47	0.19	0.50	0.69	0.18	0.28	0.88
	Two step P*	0.60	1.07	1.28	1.20	0.81	0.97	0.42	0.31	0.62	0.81	0.23	0.39	0.94
	Two step P*	1.00	1.05	1.25	1.18	0.80	0.97	0.42	0.31	0.58	0.81	0.21	0.35	0.91
	Three step P*	0.60	1.07	1.28	1.20	0.80	0.95	0.41	0.31	0.58	0.77	0.22	0.38	0.91
Scup	Three step P*	1.00	1.05	1.25	1.18	0.79	0.95	0.42	0.31	0.58	0.73	0.21	0.34	0.90
	Threshold P* (max = 0.45)	0.60	1.07	1.29	1.22	0.81	0.95	0.36	0.31	0.58	0.54	0.10	0.35	0.93
	Threshold P* (max = 0.45)	1.00	1.05	1.26	1.19	0.80	0.94	0.36	0.27	0.54	0.50	0.10	0.30	0.92
	Threshold P* (max = 0.40)	0.60	1.01	1.20	1.14	0.79	0.93	0.39	0.23	0.50	0.50	0.09	0.29	0.89
	Threshold P* (max = 0.40)	1.00	0.97	1.15	1.09	0.77	0.92	0.41	0.19	0.46	0.42	0.08	0.21	0.81

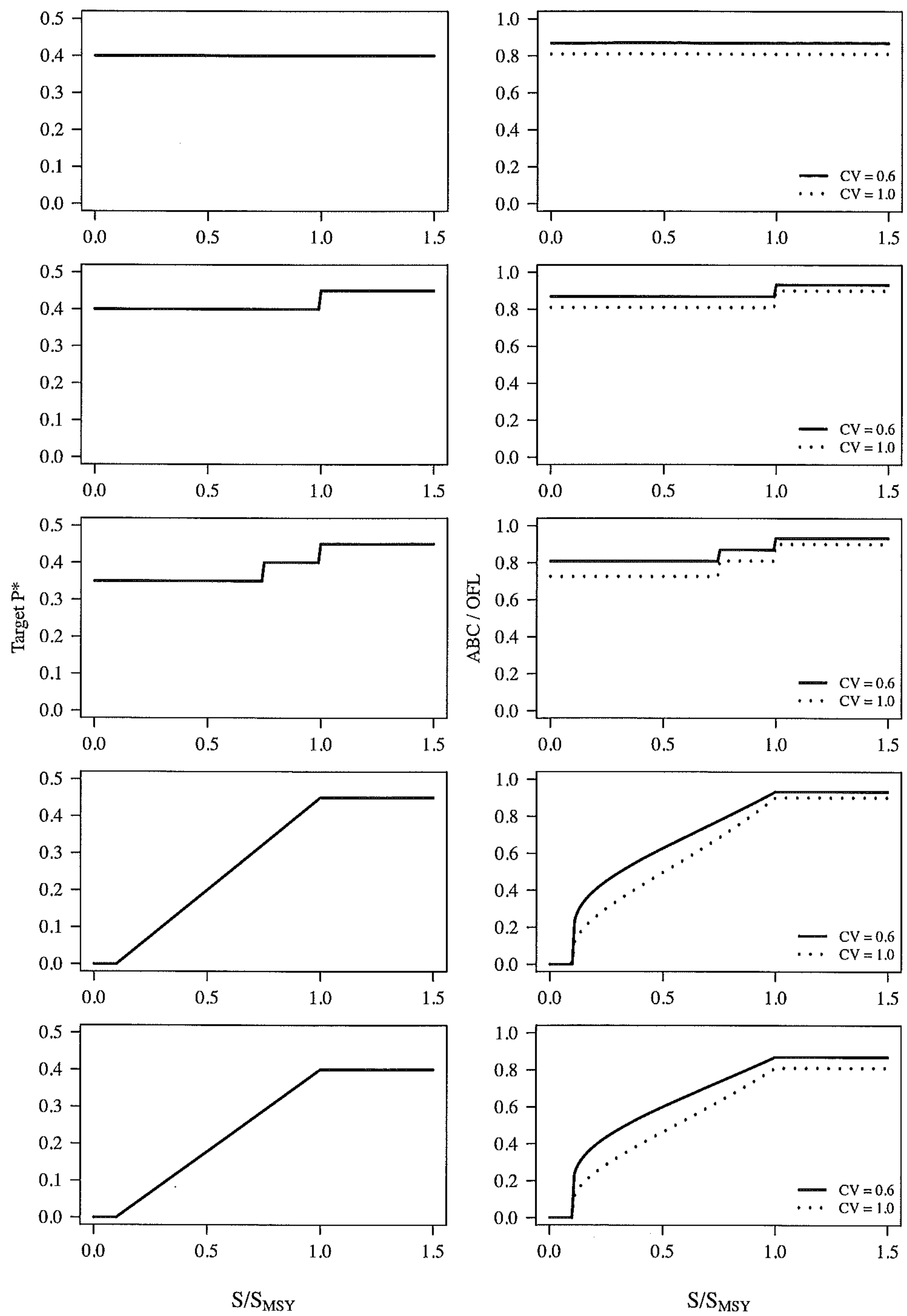

Figure 1. Five different ways of setting the target P* are explored in this analysis, with each P* control rule explored assuming an OFL CV of 0.6 and 1.0. Left: the target P* as a function of the estimated stock spawning biomass. Right: the ABC / OFL ratio as function of biomass and the assumed CV of the OFL.

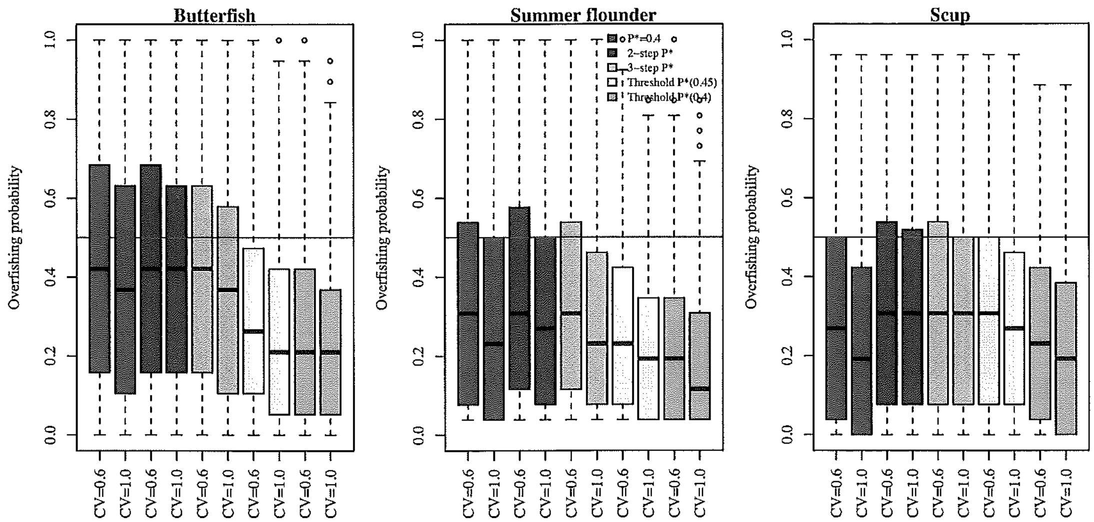

Figure 2. The risk of overfishing by control rule for each stock, with horizontal line at 0.5 representing the 50% threshold, above which overfishing is more likely to occur than not.

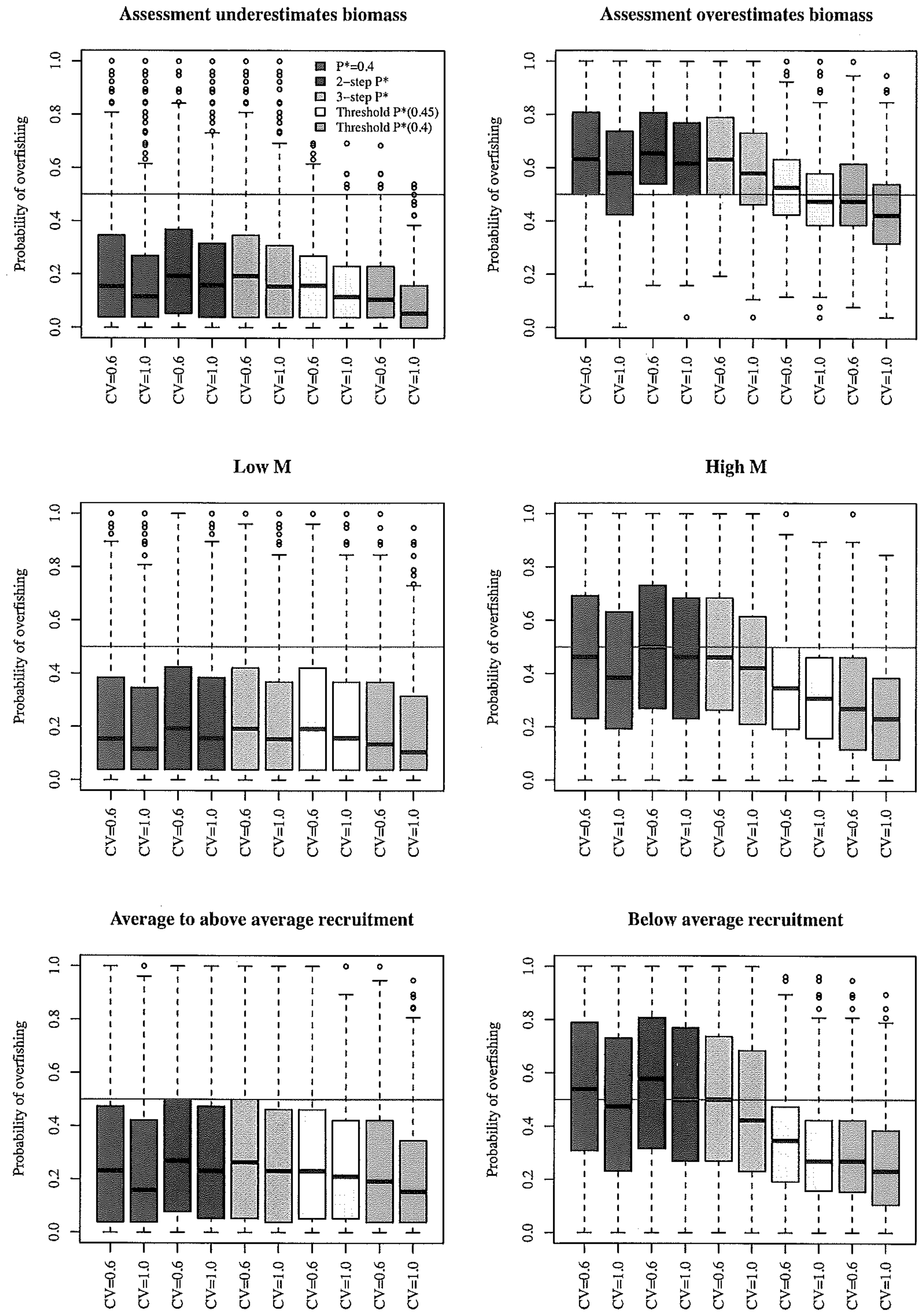

Figure 3. The risk of overfishing aggregated across stocks by control rule, for different scenarios representing good (left column) and bad (right column) future states of nature. The horizontal line at 0.5 represents the 50% threshold, above which overfishing is more likely to occur than not.

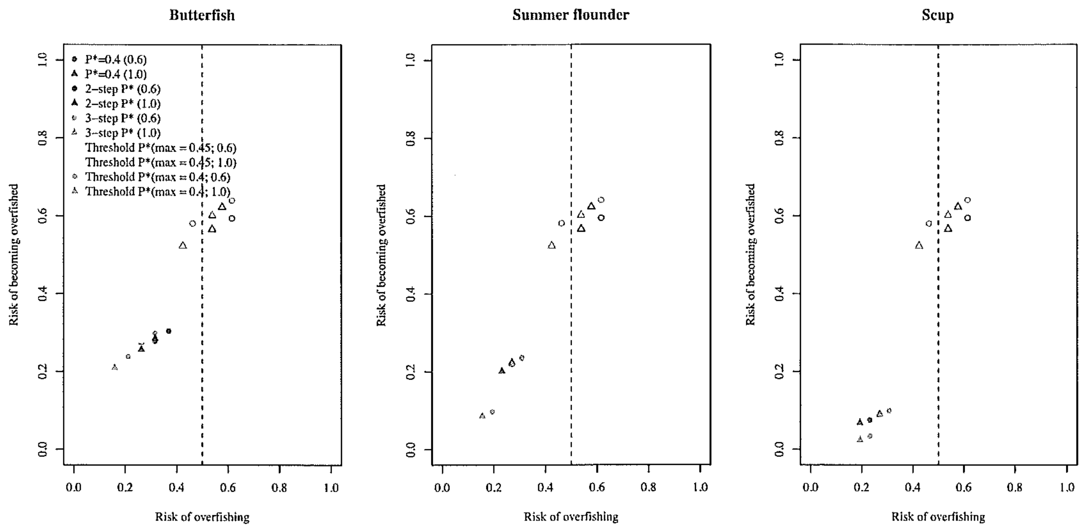

Figure 4. The risk of becoming overfished as a function of the risk of overfishing for each control rule by stock. The colors distinguish the different control rules, and the shapes distinguish the assumed CV of the OFL distribution. Filled shapes represent the median across all model runs, while the open-colored shapes are for run where the future is problematic (above average M, assessment consistently overestimates biomass).

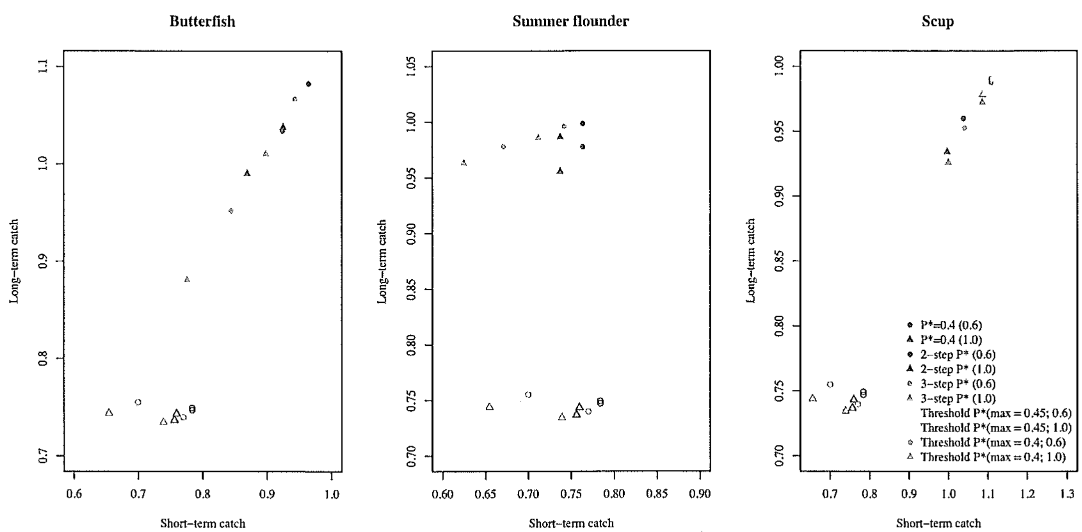

Figure 5. Tradeoffs between relative short-term catch (average in the first 5 years) and relative long-term catch (average over the last 15 years) for each control rule by stock. The colors distinguish the different control rules, and the shapes distinguish the assumed CV of the OFL distribution. Filled shapes represent the median across all model runs, while the open-colored shapes are for run where the future is problematic (above average M, assessment consistently overestimates biomass).