1.0 OVERVIEW OF TECHNICAL METHODS USED IN MSE MODELS

This management strategy evaluation includes three parts: a Gulf of Maine/Georges Bank Atlantic herring model, a model of Atlantic herring predators, and an economic model. This section briefly describes the methods used for these models to help inform the discussion of results, a more detailed descriptions of the technical methods can be found in Appendix ???. Staff at the Northeast Fisheries Science Center developed these models using any and all available data on herring and other species in this region. While there are limitations on what data could be included in the models, this MSE was reviewed by an external panel of experts, " that deemed the Atlantic herring MSE represents the *best available science* at this time for evaluating the performance of herring control rules and their potential impact on key predators."

Multiple age-structured operating models, eight in all, were created to evaluate the effects of the uncertainties identified through the first workshop: herring recruitment (high or low?), natural mortality (high or low?), growth (good or poor?), assessment error/bias (yes or no?). Several basic control rules were evaluated first as well as several variations in the time frame applied (i.e. annual, 3 year blocks, etc.). For each combination of control rule shapes and operating model, 100 simulations were conducted, each for 150 years, and the results are presented in terms of the proportion of the last 50 years (i.e. proportion of years overfishing occurs).

The predator modelling component of this MSE was based on interests expressed at the first workshop, as well as the scope and timeline specified by the Council, specifically an annual, stock-wide control rule that considered herring's ecological role as forage, to be completed in one year. The primary predators types identified at the workshop included highly migratory species (tuna), groundfish, seabirds, and marine mammals. The time constraints of this MSE did not permit development of integrated multispecies models, or spatial and seasonal models accounting for migrations of wide-ranging predators in and out of this ecosystem. Through this MSE, three predator population models (for Bluefin tuna, common tern, and spiny dogfish) were developed and an existing food web model (for marine mammals), with several noted data limitations and assumptions. For example, the predator models were not fully age structured (unlike the herring models). A purpose here was to help compare the relative performance of control rules, not necessarily to create perfect population models for the predators. What this MSE identifies is how a predator may react to having different amounts of herring in the ecosystem, based on how a given control rule performs. Not all of the predator metrics reacted to the control rules, in some cases because of data/model limitations and in other cases there was evidence to support that they would not react.

The initial economic model evaluated two economic based metrics: maximizing yield and profit for the herring fleet and ensuring herring catch is stable over time. Later in the process additional work was done to update the model of herring prices and costs, as well as improvements to the methods to assess stationarity, or stability.

Some Caveats

This MSE assumed that the reference points used to define controls rules are known without error (Fmsy and SSBmsy). There is also error in these reference points, but incorporating that step in this MSE was not practical due to time constraints. While some life-history parameters varied among operating models in this MSE, they were all treated as time invariant, so did not change within the same operating model, those conditions remained constant for 150 years.

The predator models are informed by data from the Northeast US shelf only. This is a benefit in some sense because it is specific to this region, but in some cases there was not sufficient information to inform a stock recruit relationship in this area. Furthermore, the Northeast is a very complex food web with many diverse predators and prey; therefore, isolating a clear herring predator relationship from observations is difficult or impossible when accounting for all the other factors affecting predators. Predator responses to aggregate prey dynamics are likely to have clearer responses, but that is a more complex, and time consuming process.

Fixed costs were not included in the economic models, and average variable costs are the same as the marginal costs. In addition, the model does not estimate if firms will enter or exit the fishery; which is possible if long-run conditions improve or decline compared to current levels. Furthermore, landings can be less than ABC.

2.0 OUTLINE OF MSE RESULTS

MSE generally produces a large volume of output in terms of results to compare alternatives. These results have been synthesized in two main ways. First, decision support tables have been developed that enable control rule alternatives to be compared for individual subject or metric across a series of potential operating models, or estimations of resource conditions. Section 3.0 summarizes these results for over a dozen individual metrics. The control rule alternatives are listed across the top along the first row of the table (Alternatives 1, 2, 3, and 4a-4f), and the eight different operating models are listed down the first column on the left hand side (A through H). The numeric results for each alternative is included in the individual bar charts, and the alternatives are ranked from highest to lowest with dark green representing the highest ranked alternative compared to the others, and the taller the bar the better that alternative performed for that metric.

A summary row has been added to the bottom of each decision support table that sums up the individual ranking across all eight operating models. The best possible ranking (performs the best across all operating models) would be a total score of 72, and the worst possible ranking (performs the worst across all operating models) would be a total score of 8. Section 4.0 includes a summary table of all the results and rankings for each metric individually (Table 1).

These results have also been summarized by valued ecosystem component (VEC) to aid with summarizing potential impacts under requirements of the Magnuson Stevens Act (MSA) and the National Environmental Protection Act (NEPA). Section 5.0 has identified a handful of individual metrics for each VEC, and combined the results, to produce an overall summary of potential impacts per component of the ecosystem. For example, the results for several metrics that represent potential impacts on the herring resource have been combined, as well as protected resources and ecotourism, predator species, herring fishery impacts including mackerel and lobster fisheries, and predator fisheries. Several metrics have been identified to characterize the overall potential impacts on a particular VEC, but it is possible to modify these lists if a different combination of metrics would better reflect the potential effects.

Section 7.0 has been included to summarize the associated tradeoffs across different VECs. Rather than consider the impacts individually, radar plots or web diagrams have been developed to help evaluate the potential effects of control rule alternatives across VECs, or on several aspects of the ecosystem at once. Again, several metrics have been selected to highlight how these results can be used, but different metrics could be included if the Council is interested in considering additional tradeoff plots. Finally, Section 8.0 summarizes the potential short term impacts of the control rule alternatives, compared to the previous results which are long-term.

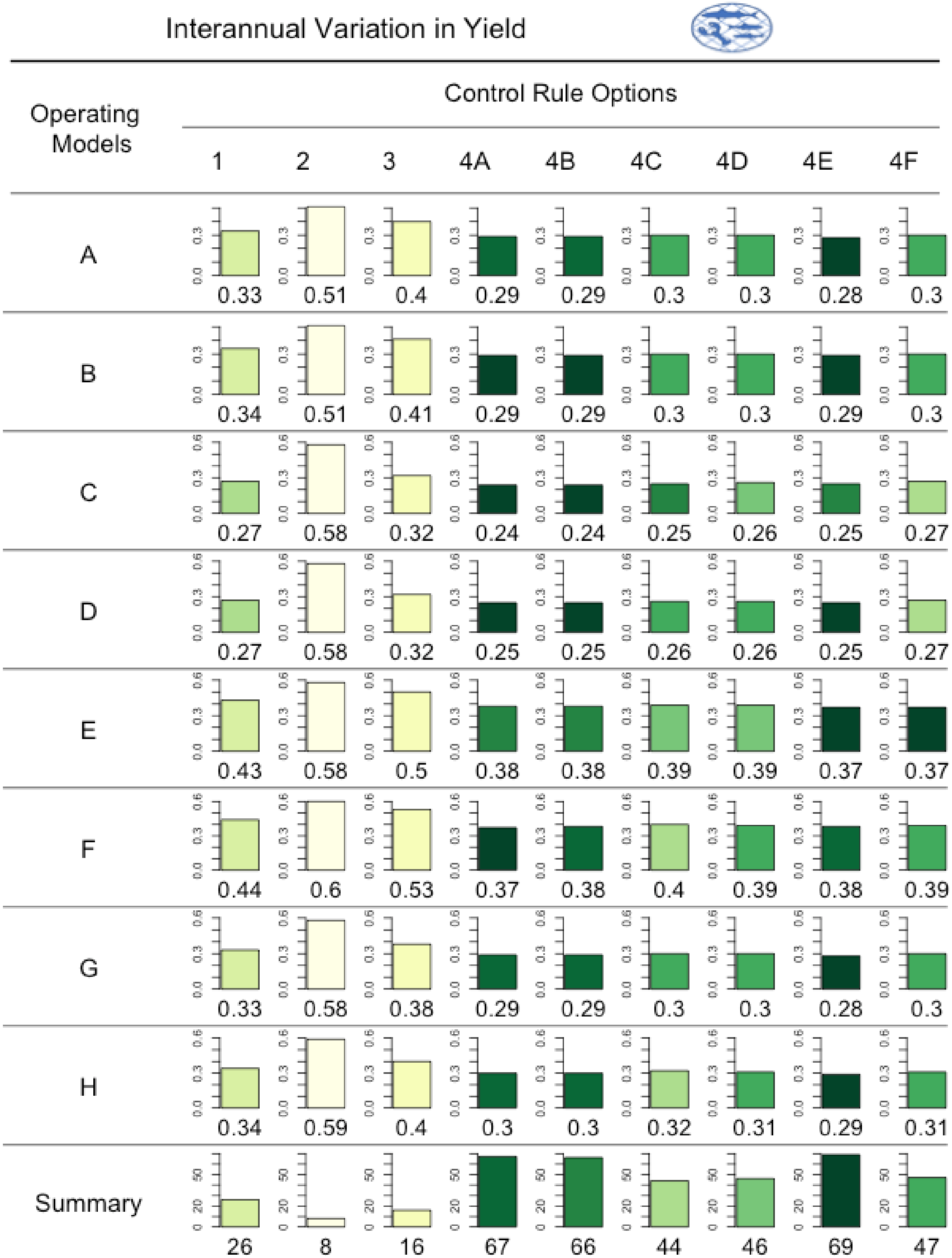
3.0 MSE RESULTS: METRIC BY METRIC

3.1 INTERANNUAL VARIATION IN YIELD (IAV)

- For this metric, the *lower* the value the better the performance; lower values translate into lower variation in fishery yields from year to year which is considered to be positive for the fishery and businesses that rely on herring as bait to help stabilize the supply.
- Overall, the six options of Alternative 4 rank the highest in terms of smallest variation in annual yield. Alternative 1 (Strawman A) ranks second, then Alternative 3, and finally Alternative 2 ranks last.
- For most of the operating models (6 out of 8 operating models), Alternative 4E ranks first, with variation in annual yield between 25-30%. It is not surprising that most of the alternatives perform relatively well for this topic because this is one of the four primary metrics the Council selected to identify alternative control rule shapes for Alternative 4. The Council recommended that annual variation in yield should ideally be less than 10%, but if necessary as high as 25%; therefore, most of the results for Alternative 4 will fall in that range for most of the operating models.
- Alternatives 1 and 3 have 30-40% variation in yield for most of the operating models, but a few reach 50% for Alternative 3, pulling the overall rank for Alternaitve3 behind Alternative 1.
- On average, Alternative 2 estimates 50-60% variation in yield across operating models; therefore, ranks consistently last for this metric.
- Alternative 4E ranks the highest overall with a total score of 69/72, and Alternatives 4A and 4B are not far behind.

Figure 1 – Summary results for metric "<u>Interannual variation in yield (IAV)</u>" for ABC control rule alternatives across all eight operating models developed for Herring Amendment 8 MSE

Units are in terms of average variation in herring yields from one year to the next, a value of 0.25 means that on average ABC could change up to 25% from one year to the next.

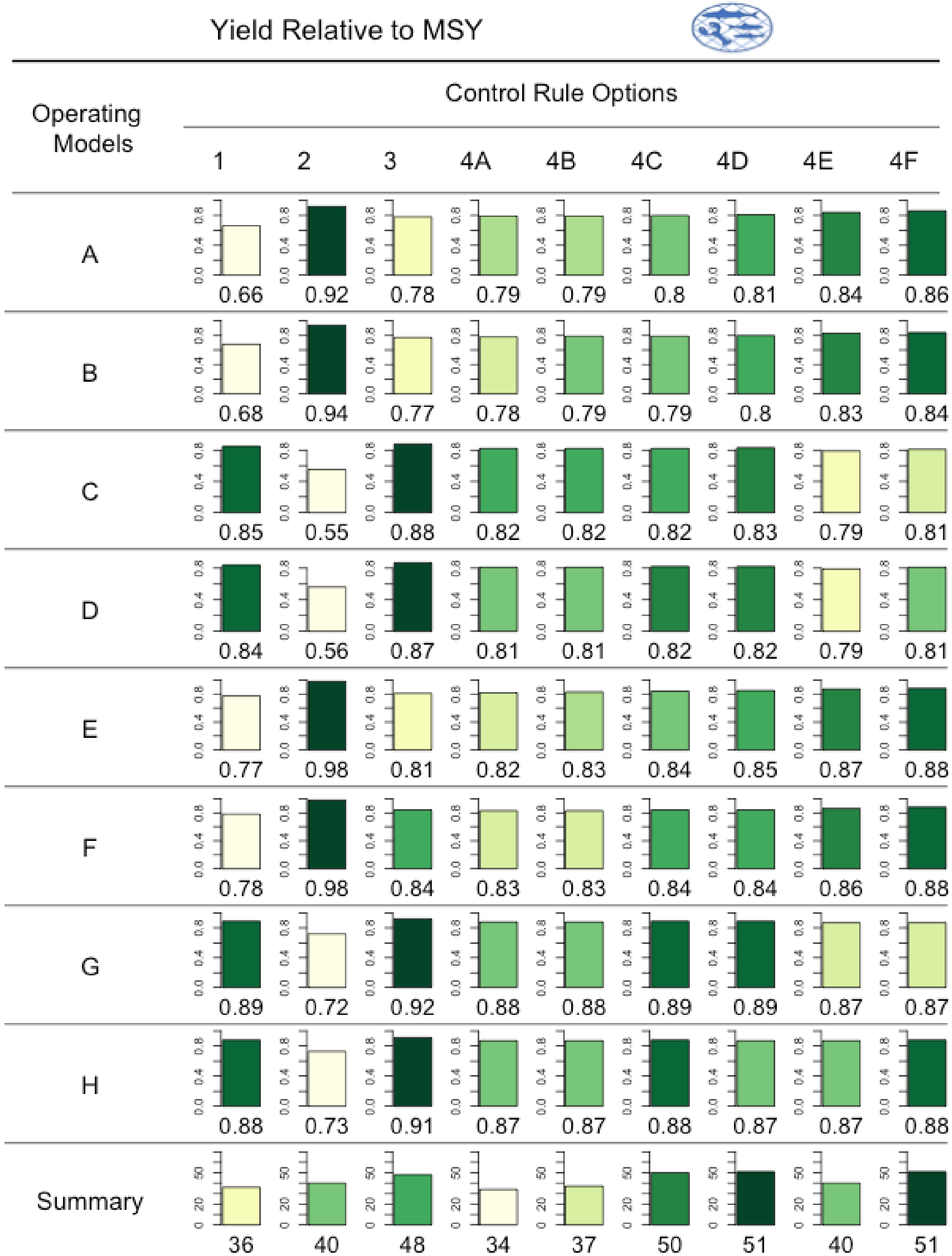


3.2 YIELD RELATIVE TO MSY

- For this metric, the *higher* the value the better the performance; higher values mean fishery yields are projected to be closer to MSY (the maximum catch that is expected to produce a sustainable resource long-term).
- Overall, Alternative 4F ranks the highest across all operating models, but for the most part Alternative 3 and Alternatives 4A-4F have similar results for projected long-term yields relative to MSY. It is not surprising that most of the alternatives perform relatively well for this topic because this is one of the four primary metrics the Council selected to identify alternative control rule shapes for Alternative 4. The Council recommended that alternatives be considered that set yield at 100% MSY, with an acceptable level as low as 85%. Therefore, for most cases the results for all Alternative 4 options have values over 85% for this metric, except for a few of the operating models where yield relative to MSY falls closer to 80% (i.e. operating models with high natural mortality – models A, B, C and D).
- Alternative 3 performs the best for this metric (about 90%) under some of the operating models (i.e. Models C, D, G and H that assume the assessment is unbiased), but lower for the remaining operating models. Therefore, it ranks second overall when the results for all operating models are combined because it ranks on the higher end for some, but not as low as others for remaining operating models.
- The results for Alternative 1 (Strawman A) are similar to Alternative 3; they are relatively high for some operating models (almost 90% of MSY), but they fall under 70% for operating models that assume the assessment is biased (A and B), while Alternative 3 remains closer to 80% under those conditions. Overall, Alternative 1 does *not* perform well under operating models with a biased assessment.
- Conversely, Alternative 2 ranks the highest for some of the operating models, and lowest for others. The results vary the greatest for this metric, ranging from about 55% for operating models C and D (which assume the assessment is unbiased) to 98% for operating models E and F that assume the assessment is biased. This control rule is relatively sensitive to operating model for this metric.
- Alternatives 4F and 4D rank the highest overall with a total score of 51/72, and Alternative 4C is not far behind with 50/72.

Figure 2 – Summary results for metric "<u>Yield relative to MSY</u>" for ABC control rule alternatives across all eight operating models developed for Herring Amendment 8 MSE

Units are in terms of average yield as a proportion of maximum sustainable yield, or the fraction of MSY that ABC would be set at, a value of 0.90 means that on average ABC would be set at 90% of MSY.

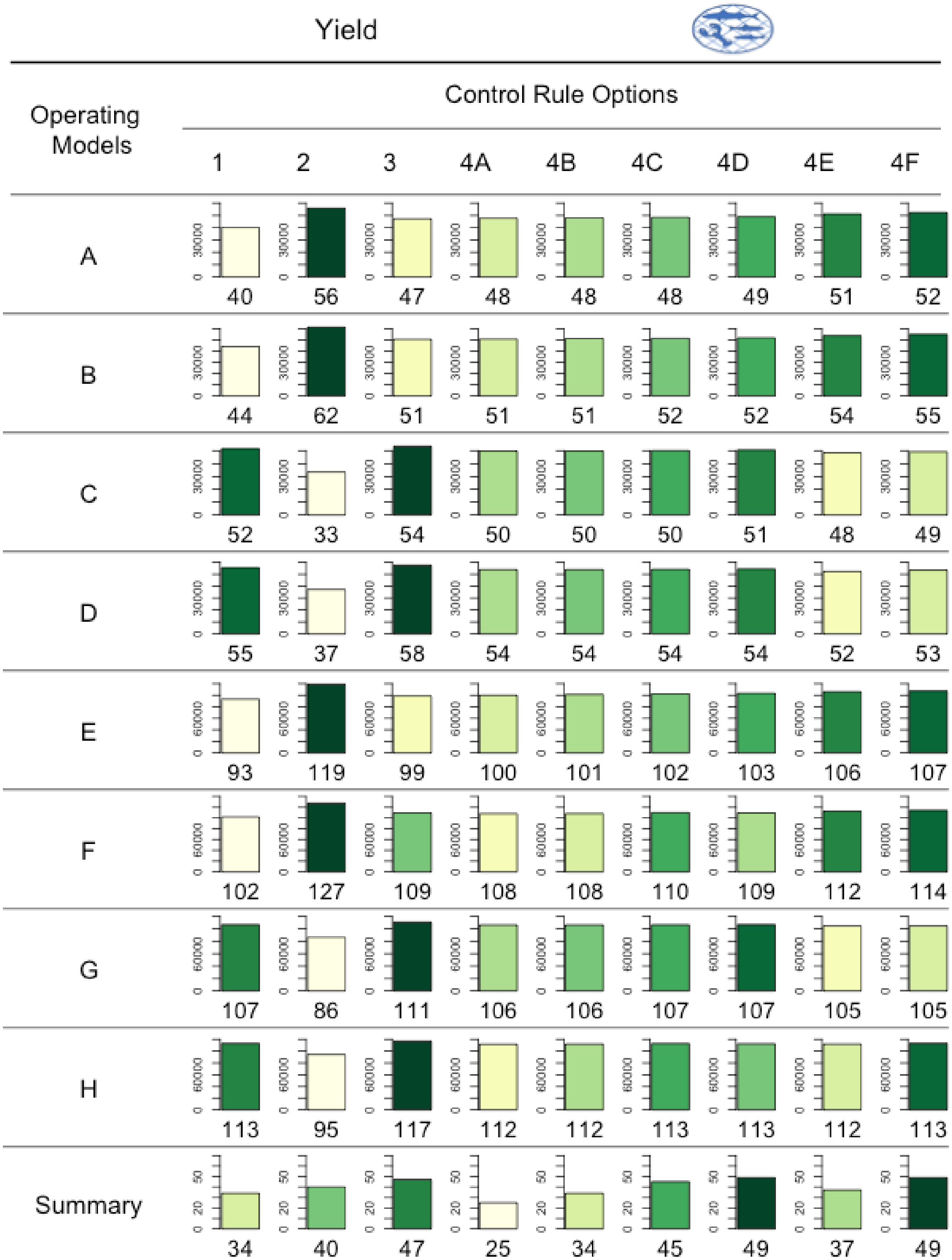


3.3 ABSOLUTE YIELD

- For this metric, the *higher* the value the better the performance; higher values mean projected yields are higher for the herring fishery. The units are in 1,000 mt.
- Overall, Alternative 4F ranks the highest across all operating models, and the results are essentially the same as they were for the metric "yield relative to MSY:' Alternative 3 is ranked second, followed by the other Alternative 4 options (4A-4E).
- Alternative 3 ranks second because it is the highest performer for some of the operating models with an unbiased assessment (C, D, G and H), but falls behind most of the Alternative 4 options for the other operating models.
- Alternative 1 is generally similar to Alternative 3, but consistently has about 5,000 mt less yield than Alternative 3.
- Alternative 2 again ranks the highest for some of the operating models, 111-127,000 mt, but falls well behind the others for other operating models. It ranks #8 out of 9 overall because it projects about 20,000 mt less yield than the other alternatives for some of the operating models. Also, while some of the options for Alternative 4 rank behind Alternative 2 for some of the operating models, in some cases it is not by much in terms of absolute yields.
- A larger driver of differences in estimated yields is operating model rather than control rule alternative; the four operating models with high productivity (models E, F, G, and H) have higher yield estimates well over 100,000 mt for all alternatives, and the operating models with low productivity (models A, B, C, and D), have much lower yields for all control rule alternatives, about 40-55,000 mt.
- Alternatives 4F and 4D rank the highest overall with a total score of 49/72, and Alternative 3 is not far behind with 47/72.

Figure 3 – Summary results for metric "<u>Absolute Yield</u>" for ABC control rule alternatives across all eight operating models developed for Herring Amendment 8 MSE

Units are in terms of average annual yield in 1,000 metric tons (mt), values range from 33,000 mt to 127,000 mt for the same control rule alternative under different operating models.

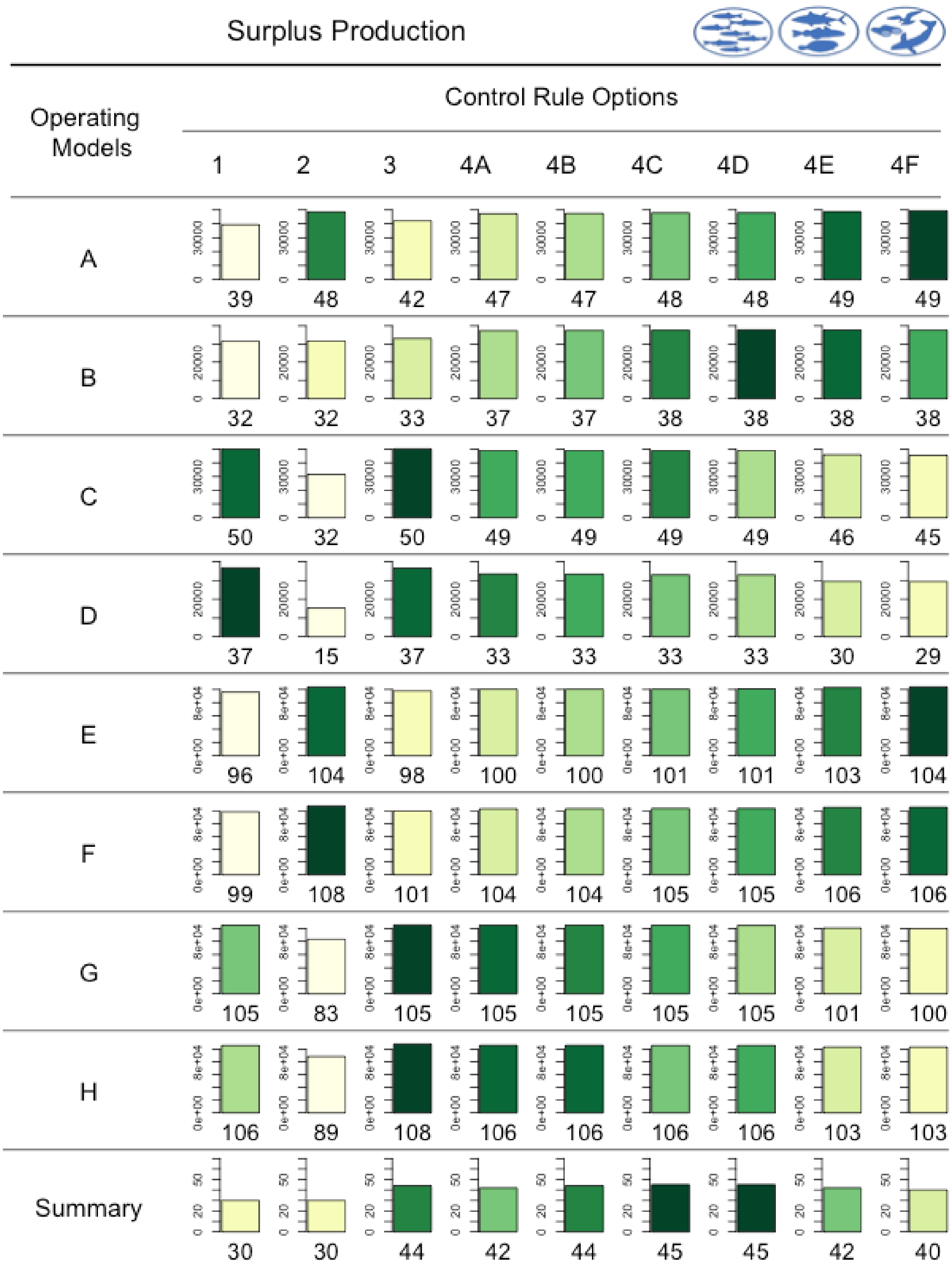


3.4 SURPLUS PRODUCTION

- For this metric, the *higher* the value the better the performance; higher values mean the control rule alternative produces higher surplus production, or biomass above the amount needed to sustain a population.
- Overall, Alternative 4D ranks the highest across all operating models; however, for the most part the results are very similar across all alternatives and the differences are very small; differences primarily due to different productivity scenarios.
- The overall results in terms of total surplus production are more driven by operating model than control rule alternative. For example, all the alternatives produce about 1 million mt of biomass under high production operating models (E, F, G, and H), but much lower estimated surplus production for operating models with low production (A, B, C, and D).
- When the results for all operating models are combined, the only alternative with noticeable lower results is Alternative 2, because the estimated surplus production for that alternative is substantially lower for some of the operating models when compared to other alternatives (C and D).
- All the options for Alternative 4 are relatively close (5.8 million mt) when results for all operating models are combined. The results are essentially the same for Alternatives 4A – 4D, and Alternatives 4E and 4F and close behind. Alternative 3 ranks jut lower than Alternative 4 (5.74 million mt), followed by Alternative 1 (Strawman A) at 5.63 million mt, and finally Alternative 2 at 5.11 million mt.
- Alternatives 4C and 4D rank the highest overall with a total score of 45/72, and Alternatives 3 and 4B are not far behind with 44/72.

Figure 4 – Summary results for metric "Surplus Production" for ABC control rule alternatives across all eight operating models developed for Herring Amendment 8 MSE

Units are in terms of estimated herring biomass in 1,000 metric tons (mt), values range from under 50,000 mt to over 1,000,000 mt for the same control rule alternative under different operating models.

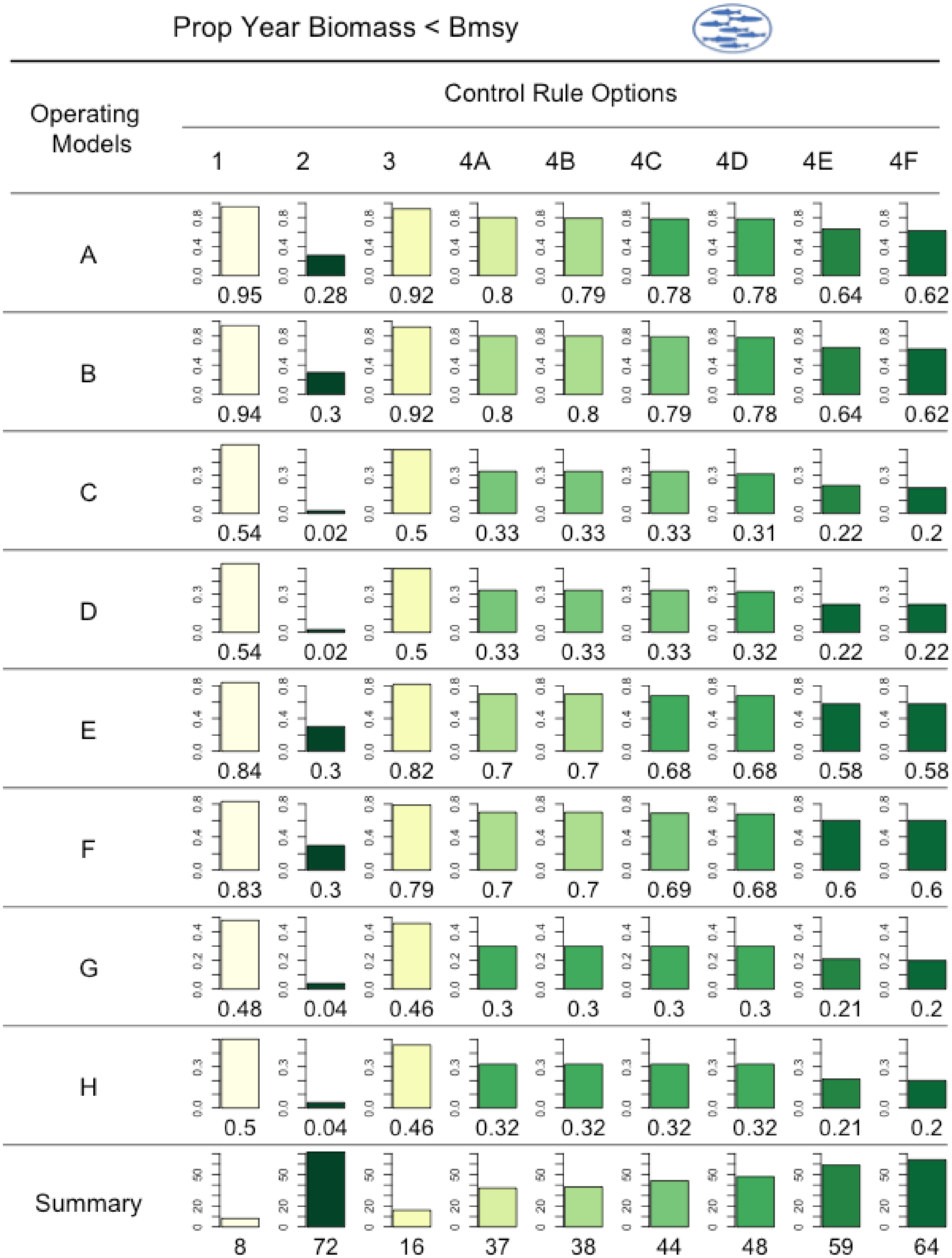


3.5 PROPORTION OF YEARS BIOMASS LESS THAN BMSY

- For this metric, the *lower* the value the better the performance; lower values mean the proportion of years that biomass is projected to be lower than Bmsy is small.
- Overall, Alternative 2 (Strawman B) ranks the highest across all operating models, and for many operating models the proportion of years that biomass is projected to be below Bmsy is less than 5%. It is only 30% for operating models A and B which have low productivity and a biased assessment.
- The difference between the results for Alternative 2 and all the other alternatives is notable. In some cases Alternative 2 will have a very low proportion of years that biomass may fall below Bmsy, while many of the other alternatives have high results, well over 50%.
- Alternatives 4E and 4F rank next with results that range from about 20% - 60% in terms of the number of years that biomass could be less than Bmsy. And Alternatives 4A – 4D follow next with results between 30% for operating models C, D, G and H and 70-80% for operating models A, B, E and F when the assessment is assumed to be biased.
- Alternative 3 and Alternative 1 (Strawman A) rank the lowest, with estimates of 50% to 95% depending on the operating model.
- Alternative 2 ranks the highest overall with a total score of 72/72, and Alternative 4F is the next ranked alternative with 64/72.

Figure 5 – Summary results for metric "<u>Proportion of years biomass greater than Bmsy</u>" for ABC control rule alternatives across all eight operating models developed for Herring Amendment 8 MSE

Units are in terms of proportion of years that average biomass is less than Bmsy, a value of 0.50 means that average biomass is estimated to be 50% of Bmsy.

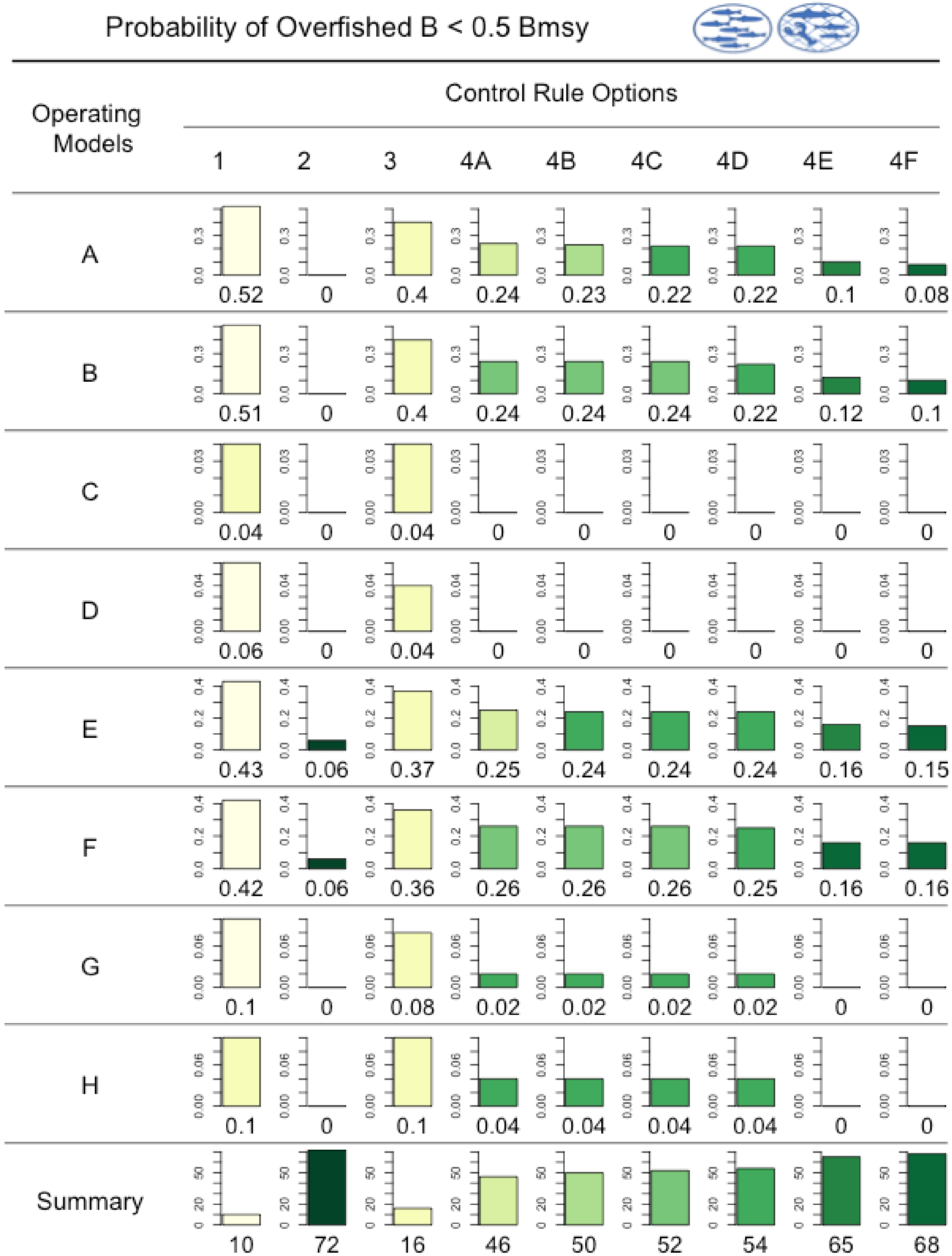


3.6 PROBABILITY OF OVERFISHED (B< 0.5 BMSY)

- For this metric, the *lower* the value the better the performance; lower values mean the probability that a control rule alternative will lead to the stock being overfished is low.
- Overall, Alternative 2 (Strawman B) ranks the highest across all operating models. This alternative has essentially a zero chance of causing the stock to be overfished except under two operating models (E and F) which assume the assessment is biased and the stock productivity is high, and those results are very low as well, about 6%.
- For half of the operating models that assume the assessment is unbiased (C, D, G and H), essentially all of the control rule alternatives have zero or very little change of causing the stock to be overfished (less than 10%).
- Alternatives 4E and 4F rank next with results that are 0% for half the operating models, and 8-16% for the other half. And Alternatives 4A – 4D follow next with low values for probability of overfished for half of the operating models, and about 25% for the operating models that assume the assessment is biased (A, B, E, and F). It is not surprising that most of the alternatives perform relatively well for this topic because this is one of the four primary metrics the Council selected to identify alternative control rule shapes for Alternative 4. The Council recommended that alternatives be considered with a probability of overfished equal to zero, but could increase to 25% under certain conditions. Therefore, most of the results for Alternative 4 options will fall between 0-25% under various operating models.
- Alternative 3 and Alternative 1 (Strawman A) rank the lowest, with generally similar results overall, but Alternative 3 consistently scoring a little better than Alternative 1 across the board. For some of the operating models the probability of overfished is low for both alternatives (less than 10%) and for some it is 40-50%. Therefore, the range of results across operating models is relatively large for both Alternative 1 and 3 for this metric.
- Alternative 2 ranks the highest overall with a total score of 72/72, and Alternative 4F is the next ranked alternative with 68/72.

Figure 6 – Summary results for metric "Probability of overfished" for ABC control rule alternatives across all eight operating models developed for Herring Amendment 8 MSE

Units are in terms of the probability the stock becomes overfished, or biomass is less than 0.5 of Bmsy, a value of 0.50 means that average biomass is estimated to be 50% of Bmsy.

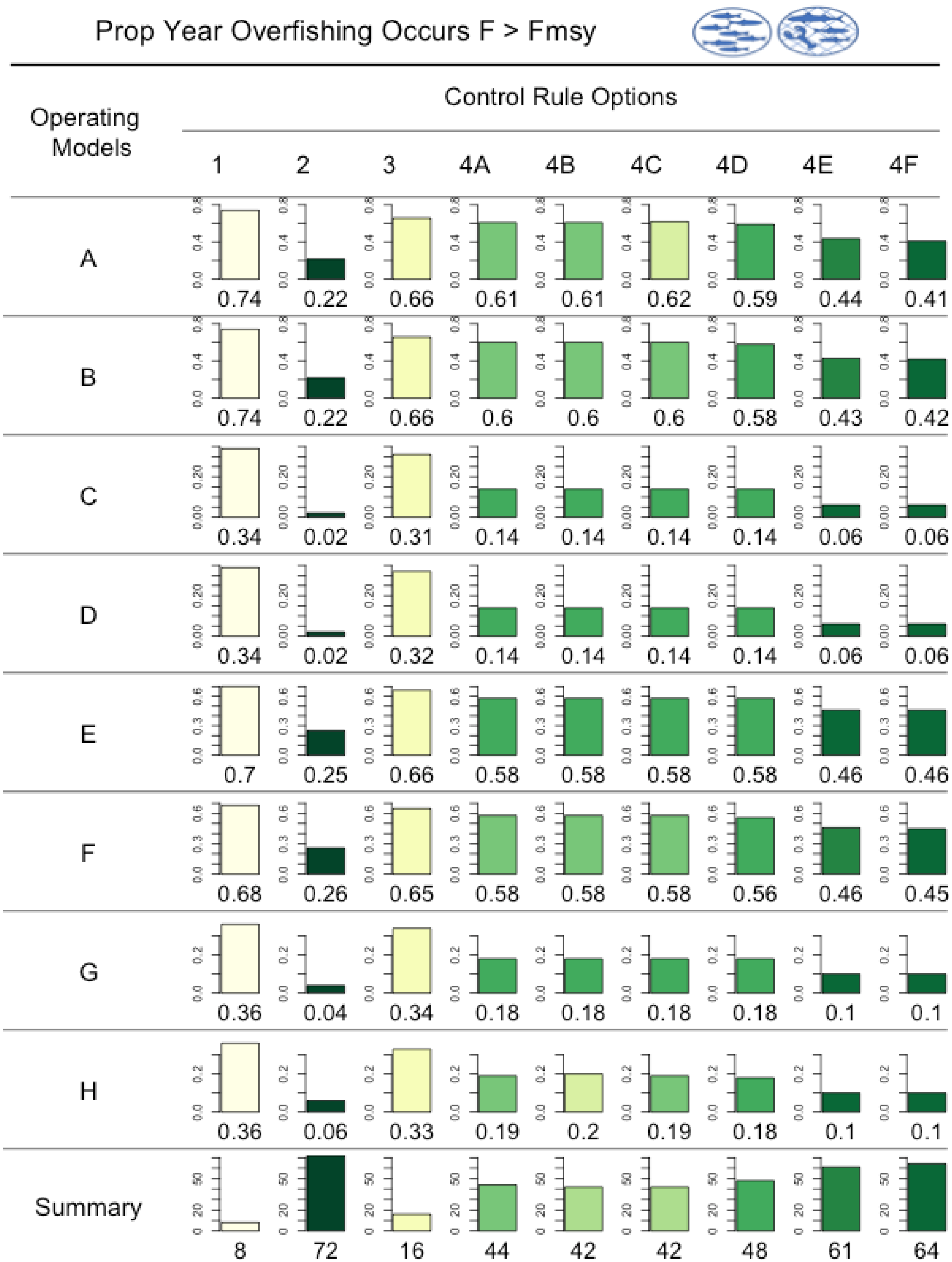


3.7 PROBABILITY OF OVERFISHING (F > FMSY)

- For this metric, the *lower* the value the better the performance; lower values mean the probability that a control rule alternative will lead to overfishing is low.
- Overall, Alternative 2 (Strawman B) ranks the highest across all operating models. This alternative has a very low probability of causing overfishing for half of the operating models, and a relatively low probability for the other half (about 22-26% proportion of years).
- For half of the operating models that assume the assessment is unbiased (C, D, G and H), essentially all of the control rule alternatives have very little or well below a 50% probability of causing overfishing; the options of Alternative 4 are between 6-20% for these operating models and that increases to about 40-60% for the other operating models that assume the assessment is biased (A, B, E, and F). The ranked order of the Alternative 4 options is generally the same, Alternative 4F performs slightly better than Alternative 4E, followed by Alternatives 4A-4D, which are about the same.
- Alternative 3 and Alternative 1 (Strawman A) rank the lowest, and have very similar results, with Alternative 3 consistently scoring a little better than Alternative 1 for all operating models. For the operating models that assume the assessment is unbiased, the estimated probability of overfishing for these alternatives is about 35%, and for the other operating models that assume the assessment is biased, that increases to about 65-75% depending on the alternative and operating model.
- Some of the alternatives (i.e. 2 and 4E) are below 50% even where there is bias in the assessment; therefore, the risk of overfishing is likely very low.
- Alternative 2 rank the highest overall with a total score of 72/72, and Alternative 4F is the next ranked alternative with 64/72.

Figure 7 – Summary results for metric "<u>Probability of overfishing</u>" for ABC control rule alternatives across all eight operating models developed for Herring Amendment 8 MSE

Units are in terms of the probability of overfishing, of when fishing mortality is greater than Fmsy, a value of 0.50 means that average fishing mortality is estimated to be 50% of Fmsy.

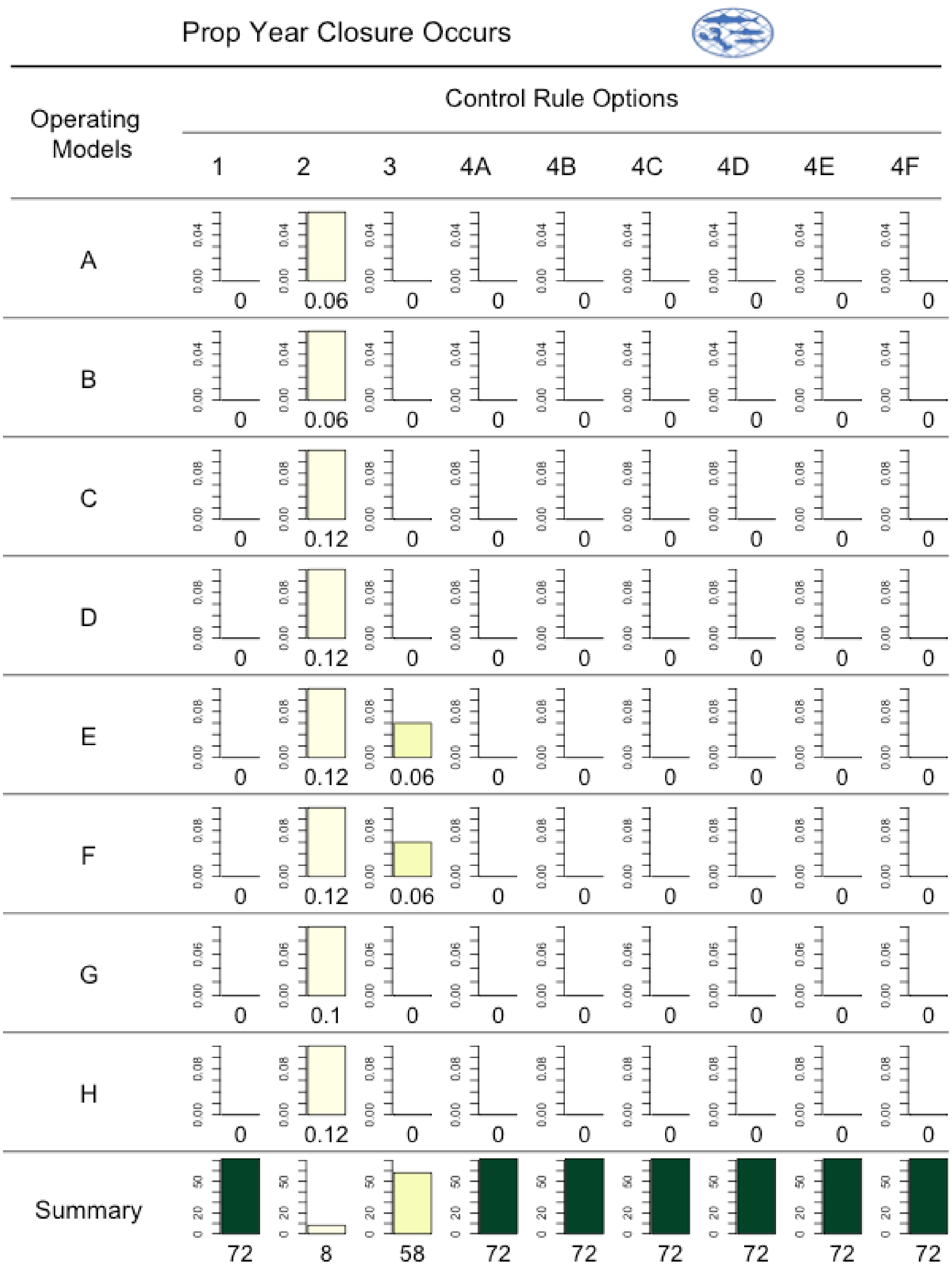


3.8 PROPORTION OF YEARS A FISHERY CLOSURE OCCURS (ABC=0)

- For this metric, the *lower* the value the better the performance; lower values mean the probability that a control rule alternative will lead to a fishery closure, or the need to set ABC equal to zero is low.
- For this metric, the frequency of years ABC would potentially be set to zero is generally very low. It is not surprising that the results for most of these control rule alternatives is zero. This is one of the primary metrics identified by the Council for Alternative 4 control rule shapes; that the probability of ABC=0 be set to 0%. Therefore, all of the Alternative 4 options are zero for all operating models. Even though two of the six options for Alternative 4 include a fishery cutoff, the likelihood of biomass falling below the level that would set SBC=0 is essentially zero.
- The results for Alternative 1 (Strawman A) are also zero for all operating models, there is essentially no chance of a fishery closure under this alternative for any of the operating models.
- For Alternative 3 three is only one set of operating models that has a relatively small chance of causing a fishery closure; operating models E and F are estimated to cause ABC to equal zero 6% of the time, or about 3 times out of 50 years.
- Alternative 2 ranks last for this metric, but the number of years that ABC is estimated to equal zero is also relatively small, ranging from 6% to 12% depending on the operating model, or 3 to 6 times in fifty years.
- Many alternatives tie for the highest rank for this metric, Alternative 1 and all options of Alternative 4 rank the highest overall with a total score of 72/72, and Alternative 3 is next behind them with 58/72.

Figure 8 – Summary results for metric "<u>Proportion of years the fishery would be closed (ABC=0)</u>" for ABC control rule alternatives across all eight operating models developed for Herring Amendment 8 MSE

Units are in terms of the proportion of years biomass would be low enough that ABC would be set to zero and the fishery would be closed, a value of 0.1 means that the model estimates that the fishery would be closed about 10% of the years under that control rule alternative.

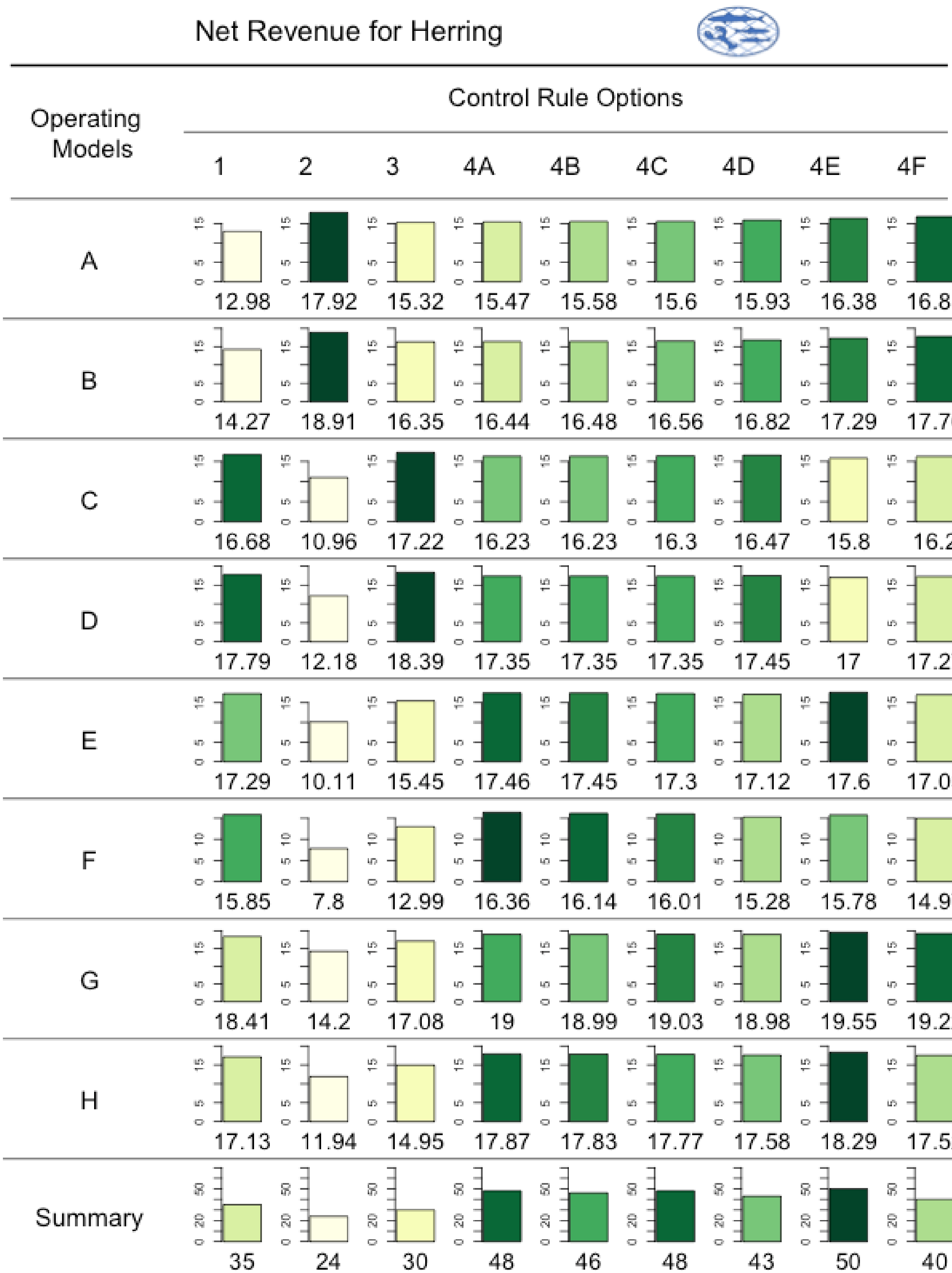


3.9 NET REVENUE FOR HERRING FISHERY

- For this metric, the *higher* the value the better the performance; higher values mean the control rule alternative produces higher estimates of net revenue for the herring fishery.
- Overall, Alternative 4E ranks the highest across all operating models; however, for the most part the results are very similar across all alternatives and the differences are very small, except for Alternative 2, which is ranked last and has the lowest results under all scenarios except when the operating model ??? (A and B operating models). For Alternative 4E, it ranks very high under most operating models, except models C and D when it falls second to last.
- Alternative 2 (Strawman B) has the highest estimated net revenues than all the other alternatives for operating models A and B, when ???. However, this alternative ranks last for all the other operating models. On average, Alternative 2 is estimated to have 3-6 million less in annual net revenues under most control rules and operating models, and 1-5 million higher net revenues under operating models A and B.
- The overall differences between Alternative 1, Alternative 3, and all the Alternative 4 options are relatively small.
- Alternative 4E ranks the highest overall with a total score of 50/72, and Alternatives 4A and 4C are close behind with scores of 48/72.

Figure 9 – Summary results for metric "<u>Net revenue for herring</u>" for ABC control rule alternatives across all eight operating models developed for Herring Amendment 8 MSE

Units are estimated average net revenue for the herring fishery in millions of dollars, a value of 16.0 means the model estimates that average annual net revenue would be 16 million dollars for the fishery overall.

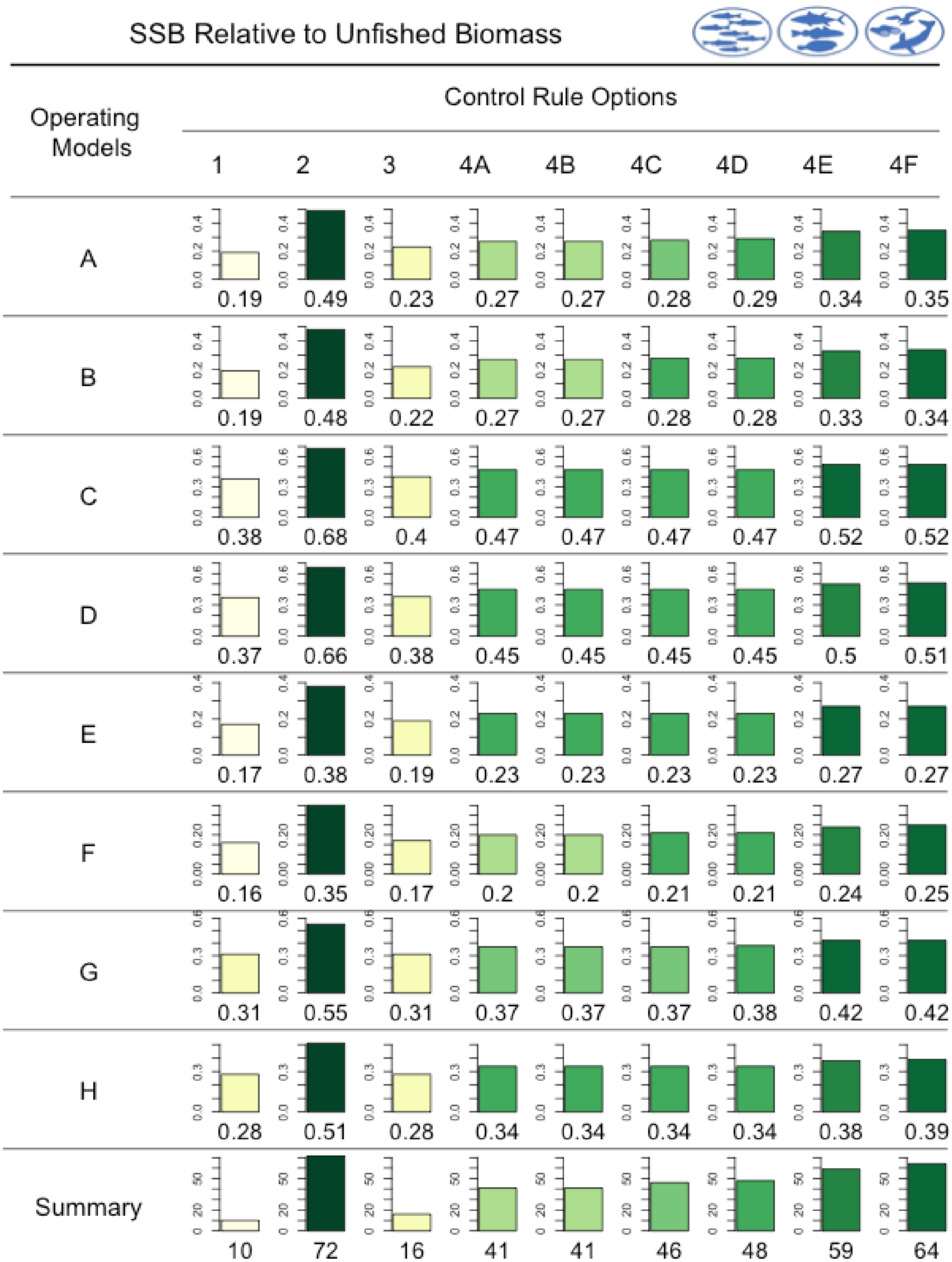


3.10 SSB RELATIVE TO UNFISHED BIOMASS (SSB / SSB0)

- For this metric, the *higher* the value the better the performance; higher values mean the estimated biomass relative to unfished biomass, or biomass level with no directed fishery, is high. For example, a value of 0.3 translates to estimated biomass that is 30% of virgin biomass, or biomass that does not experience fishing pressure.
- Overall, Alternative 2 ranks the highest overall and consistently has the highest results for all operating models. The estimates are between 35 – just under 70% SSB relative to unfished SSB.
- Overall this metric has very stable results across alternatives and operating models, no alternative jumps out of order across operating models. The results are similar for all six Alternative 4 options, ranging from 20-50% of unfished biomass depending on the operating model.
- Alternatives 1 and 3 rank the lowest, having similar results with Alternative 3 slightly ahead of Alternative 1 in all cases; average results range between about 20-40% of unfished biomass.
- Alternative 2 rank the highest overall with a total score of 72/72, and Alternative 4F is the next ranked alternative with 64/72.

Figure 10 – Summary results for metric "SSB relative to unfished biomass" for ABC control rule alternatives across all eight operating models developed for Herring Amendment 8 MSE

Units are in terms of estimated biomass relative to the estimate of unfished biomass for that operating model, a value of 0.40 means that estimated biomass is about 40% of unfished biomass.



3.11 PROPORTION OF YEARS BIOMASS IS GREATER THAN 30% OF UNFISHED BIOMOASS (B ZERO)

- For this metric, the *higher* the value the better the performance; higher values mean herring biomass is expected to be a relatively high fraction of unfished biomass in most years.
- Overall, Alternative ???....
- Alternative ? ranks the highest overall with a total score of ???.

Figure 11 – Summary results for metric <u>“% years biomass between 30-75% unfished biomass</u>” for ABC control rule alternatives across all eight operating models developed for Herring Amendment 8 MSE

Units are in terms of estimated biomass relative to the estimate of unfished biomass for that operating model, a value of 0.20 means that estimated biomass is expected to be above 30% of unfished 20% of the time.

Not available for the mailing

Will be available at the meeting.

3.12 STATIONARITY (STREAKINESS OF NET REVENUES)

- For this metric, the *lower* the value the better the performance; lower values mean the system is in a stable equilibrium or a good year is equally likely to be followed by a good or bad year. A higher value implies the system is not is a stable equilibrium, a good year is more likely to be followd by a good year, and a bad year is more likely to be followed by a bad year.
- Overall, ???

Figure 12 – Summary results for metric "stationarity" for ABC control rule alternatives across all eight operating models developed for Herring Amendment 8 MSE

Units are in terms of ???net revenue over time, a value of

Not available for the mailing

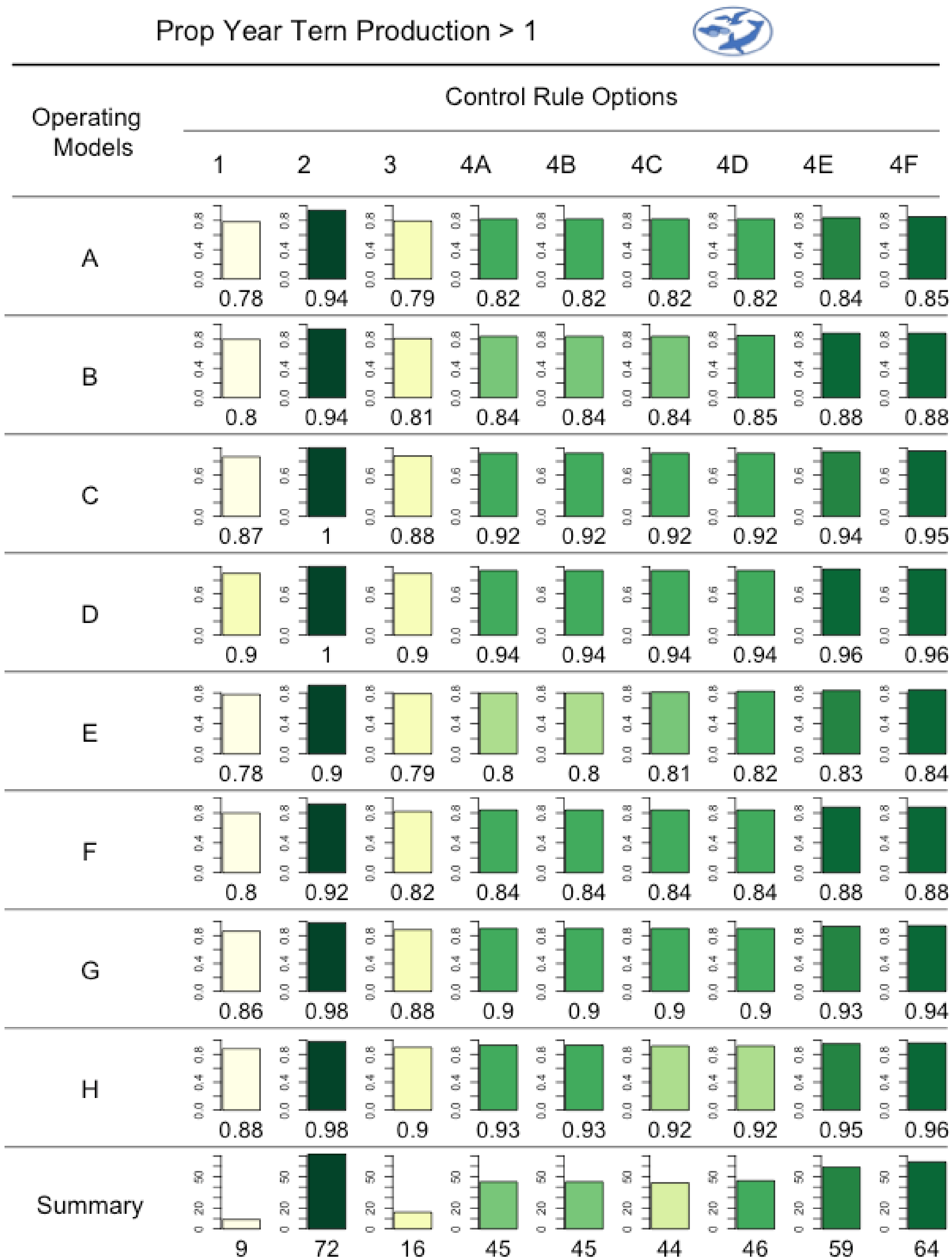
Will be available at the meeting.

3.13 TERN PRODUCTIVITY

- For this metric, the *higher* the value the better the performance; higher values mean the likelihood that tern productivity is high, or the ability for one tern to replace itself is high. The recommended threshold for tern productivity is 0.8, or an 80% chance that terns will have reproductive success. When that threshold was used essentially all of the ABC control rule alternatives ranked very high and it was difficult to see any differences (cite part of appendix that includes results for 0.8). When that threshold is increased from 0.8 to a target of 1.0, or 100% tern productivity, some variation among control rule alternatives is detected, but the differences are still relatively small.
- Overall, Alternative 2 ranks the highest overall and consistently has the highest results for all operating models.
- Alternative 4F is not very far behind, and for the most part all of the control rule alternatives score very high for this metric, with over 90% success rate for tern production under all operating models. The results fall a bit lower under the operating models that assume the assessment is biased, but even in those cases the results are at or above the threshold that is commonly used, 80%.
- In general, all control rules maintain tern productivity above the threshold of 0.8 the majority of the time.
- Alternative 2 rank the highest overall with a total score of 72/72, and Alternative 4F is the next ranked alternative with 64/72.

Figure 13 – Summary results for metric "tern production" for ABC control rule alternatives across all eight operating models developed for Herring Amendment 8 MSE

Units are in terms of estimated biomass relative to the estimate of unfished biomass for that operating model, a value of 0.40 means that estimated biomass is about 40% of unfished biomass.

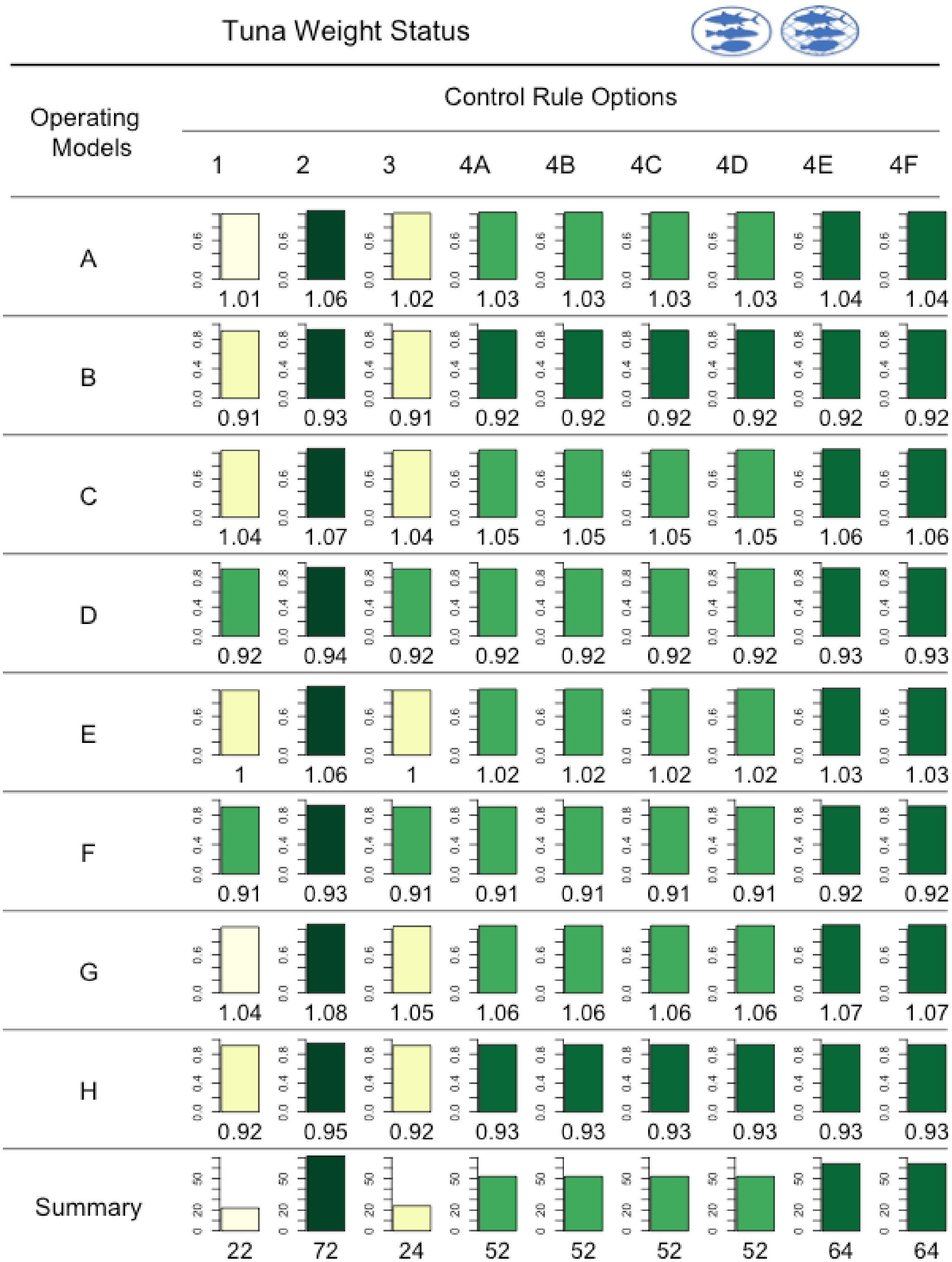


3.14 TUNA WEIGHT

- For this metric, the *higher* the value the better the performance; higher values mean estimated tuna weight is higher than threshold weight, a value of 1.0 means estimated tuna weight is equal to threshold weight. Values greater than 1.0 would have expected positive impacts for tuna growth.
- Overall, Alternative 2 ranks the highest and consistently has the highest results for all operating models. However, the differences are relatively minor.
- The range of values across all control rule alternatives and operating models is 0.92 to 1.08. This is a relatively narrow range in terms of performance. Therefore, even under poor herring conditions (i.e. operating models B and D have recent (slow) growth and low productivity), tuna weights are lower than threshold values (about 0.92), but not drastically lower. Furthermore, even under the best herring conditions (operating model E), the highest ratio of tuna weight is 1.06, or 6% higher than threshold values.
- Alternative 2 rank the highest overall with a total score of 72/72, and Alternatives 4E and 4F are next with 64/72.

Figure 14 – Summary results for metric "tuna weight" for ABC control rule alternatives across all eight operating models developed for Herring Amendment 8 MSE

Units are in terms of estimated tuna weight compared to threshold weight, so ideally values close to 1 are ideal for tuna growth, a value of 1.0 means that estimated tuna weight is equal to threshold weights.

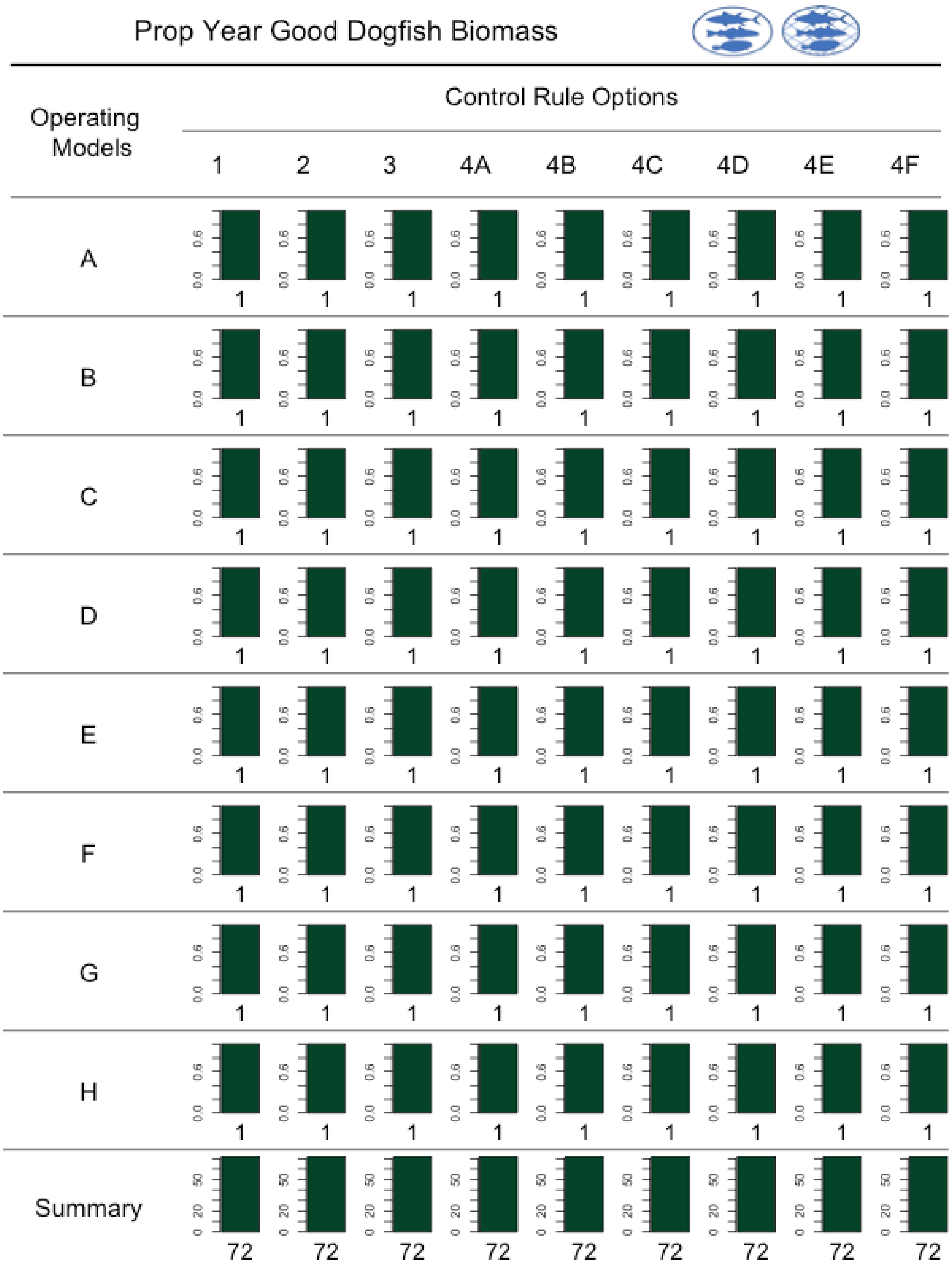


3.15 DOGFISH BIOMASS

- For this metric, the *higher* the value the better the performance; higher values mean estimated dogfish biomass, a proxy for groundfish biomass, is higher than Bmsy for dogfish. A value of 1.0 means estimated dogfish biomass is equal to Bmsy for dogfish.
- Median biomass never exceeds Bmsy under any of the alternatives across all operating models. Therefore, there is essentially no impact detected of the alternatives on estimated dogfish populations.
- All alternatives have the same overall rank since none of them are expected to cause negative impacts on dogfish biomass, the score overall for all alternatives is 72/72.

Figure 15 – Summary results for metric "<u>dogfish biomass</u>" for ABC control rule alternatives across all eight operating models developed for Herring Amendment 8 MSE

Units are in terms of estimated dogfish biomass compared to Bmsy for dogfish, a value of 1.0 means that estimated dogfish biomass is about Bmsy for dogfish.



4.0 MSE RESULTS: SUMMARY OF METRIC BY METRIC RESULTS

Overall rank across all metrics included in bottom row. Does Committee have input on identifying subset of metrics only, weighing certain metrics higher than others, etc.?

Table 1 – Summary of MSE results by metric and rank of Amendment 8 ABC control rule alternatives

Performance Metric	Alt. 1	Alt. 2	Alt. 3	Alt. 4A	Alt. 4B	Alt. 4C	Alt. 4D	Alt. 4E	Alt. 4F
Prop Year B<Bmsy	8	72	16	37	38	44	48	59	64
Prop Overfished B<0.5 Bmsy	10	72	16	46	50	52	54	65	68
SSB relative to Unfished SSB	10	72	16	41	41	46	48	59	64
Surplus Production	30	30	44	42	44	45	45	42	40
Prop overfishing F >Fmsy	8	72	16	44	42	42	48	61	64
Tuna weight status	22	72	24	52	52	52	52	64	64
Prop Year good dogfish biomass	72	72	72	72	72	72	72	72	72
Prop Year Tern production >1	9	72	16	45	45	44	46	59	64
Yield relative to MSY	36	40	48	34	37	50	51	40	51
Absolute Yield	36	40	47	25	34	46	49	37	49
Prop Year Fishery Closure (ABC=0)	72	8	58	72	72	72	72	72	72
Net revenue for herring fishery	35	24	30	48	46	48	43	50	40
Interannual variation in yield	26	8	16	67	66	44	46	69	47
Biomass over 30% of unfished									
Stationarity or streakiness									
ALL METRICS (Overall rank)	**27**	**50**	**31**	**43**	**44**	**47**	**48**	**52**	**55**

5.0 MSE RESULTS: BY VALUED ECOSYSTEM COMPONENT (VEC)

Staff has identified handful of metrics that could be used to describe potential impacts per VEC.

Does Committee have recommendations for any changes?

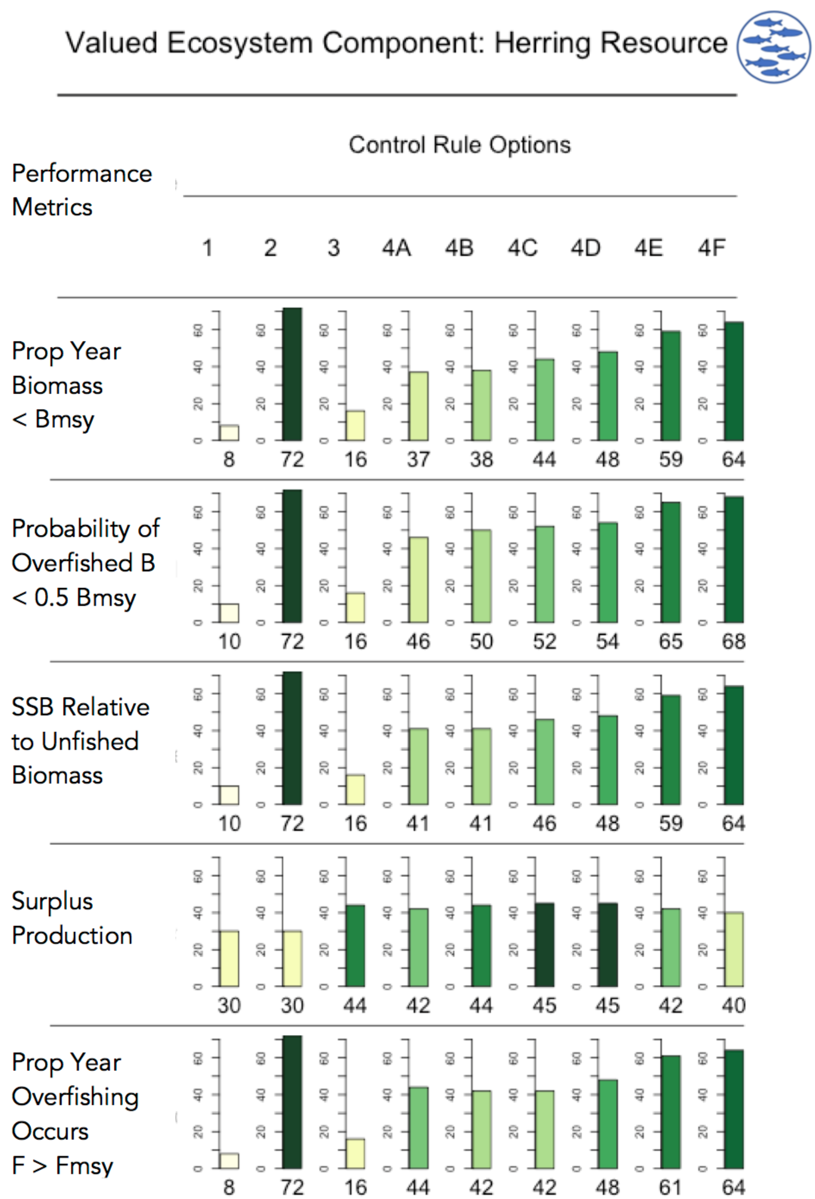
Could add summary table for the 4 metrics the Council used to identify alternatives. Are those the Council's final priority objectives for an ABC control rule, or are those just the priority metrics used for Alternative 4?

If the primary objectives are known, a decision support table could be developed for those metrics separately.

5.1 HERRING RESOURCE

Figure 16 – Summary of the metrics that are indicators of potential impacts on the valued ecosystem metric – herring resource

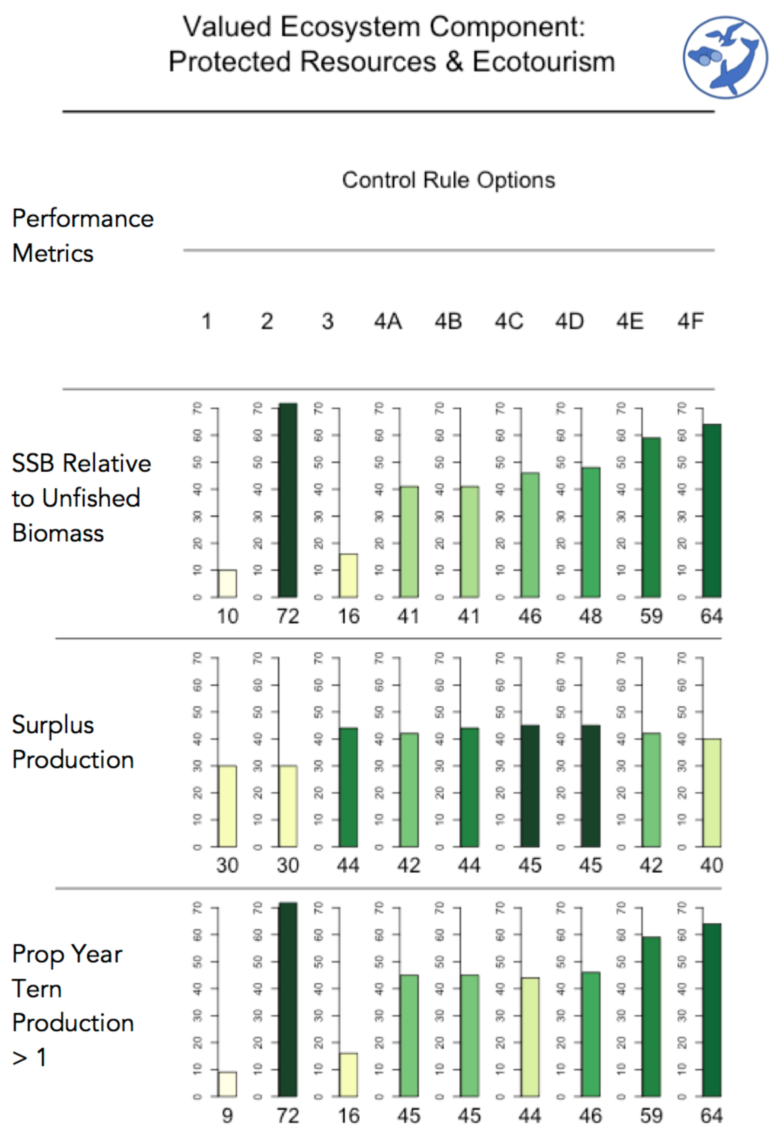
Herring Resource Metrics: Proportion of years B<Bmsy, Probability of overfished, SSB relative to unfished biomass, surplus production, and proportion of years overfishing occurs.



5.2 PROTECTED RESOURCES AND ECOTOURISM (MARINE MAMMALS AND BIRDS)

Figure 17 – Summary of the metrics that are indicators of potential impacts on the valued ecosystem metric – protected resources and associated ecotourism businesses that depend on those resources

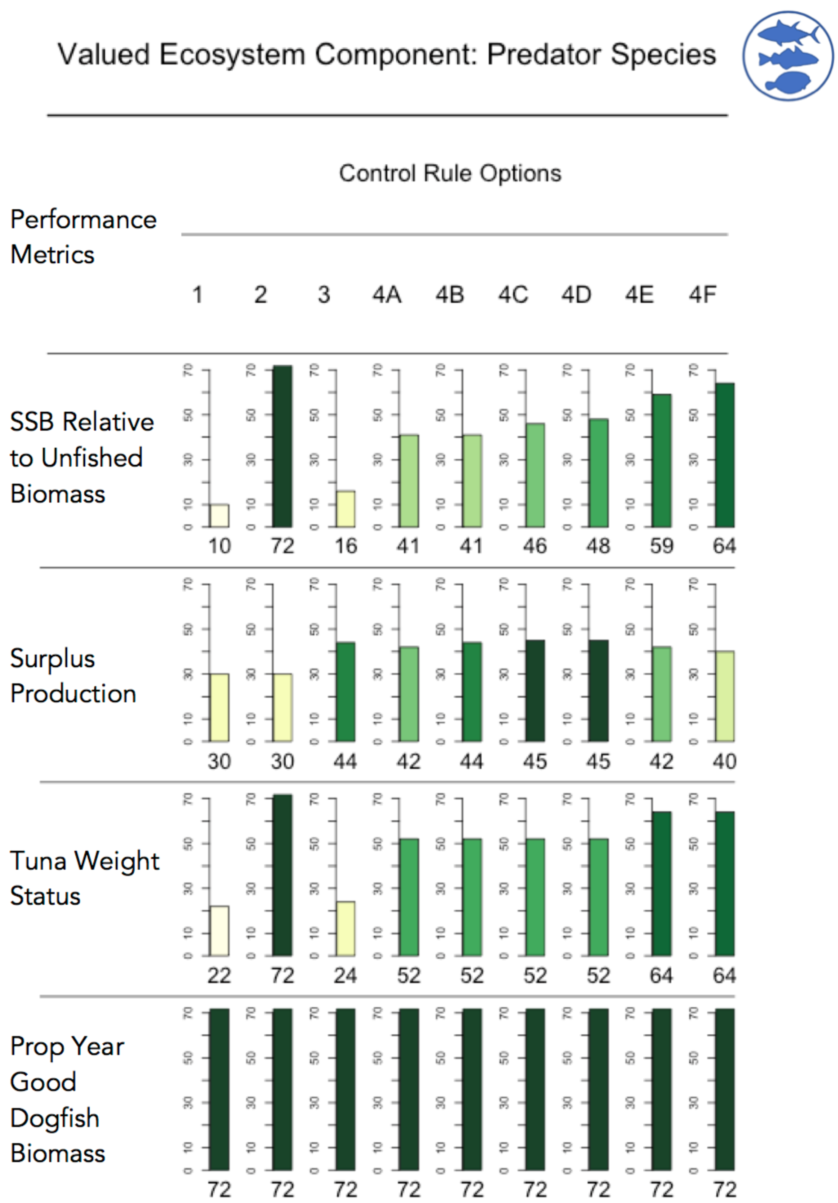
Protected resource Metrics: SSB relative to unfished biomass, surplus production, and tern productivity.



5.3 PREDATOR SPECIES (TUNA, GROUNDFISH)

Figure 18 – Summary of the metrics that are indicators of potential impacts on the valued ecosystem metric – predator species.

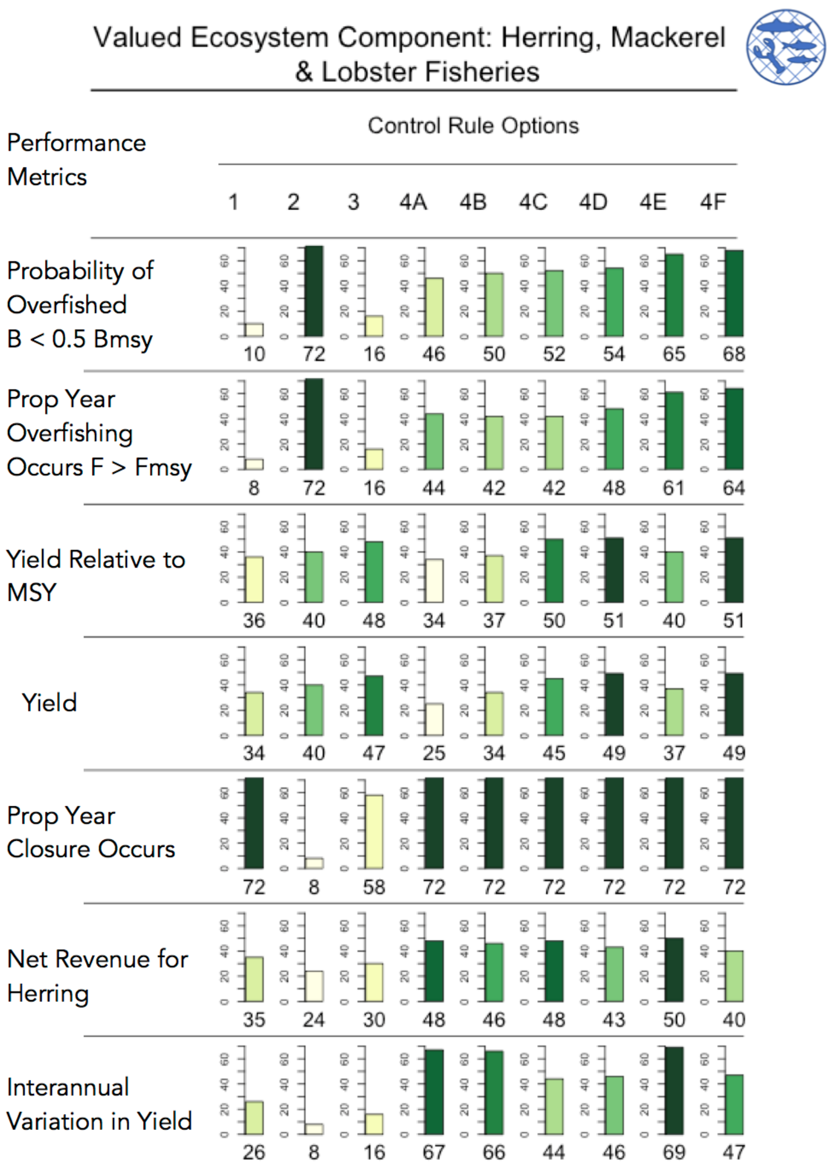
Predator species Metrics: SSB relative to unfished biomass, surplus production, tuna weight, and dogfish biomass.



5.4 HERRING FISHERY (INCLUDING MACKEREL AND LOBSTER FISHERIES)

Figure 19 – Summary of the metrics that are indicators of potential impacts on the valued ecosystem metric – <u>herring fishery and associated businesses (mackerel and lobster fisheries).</u>

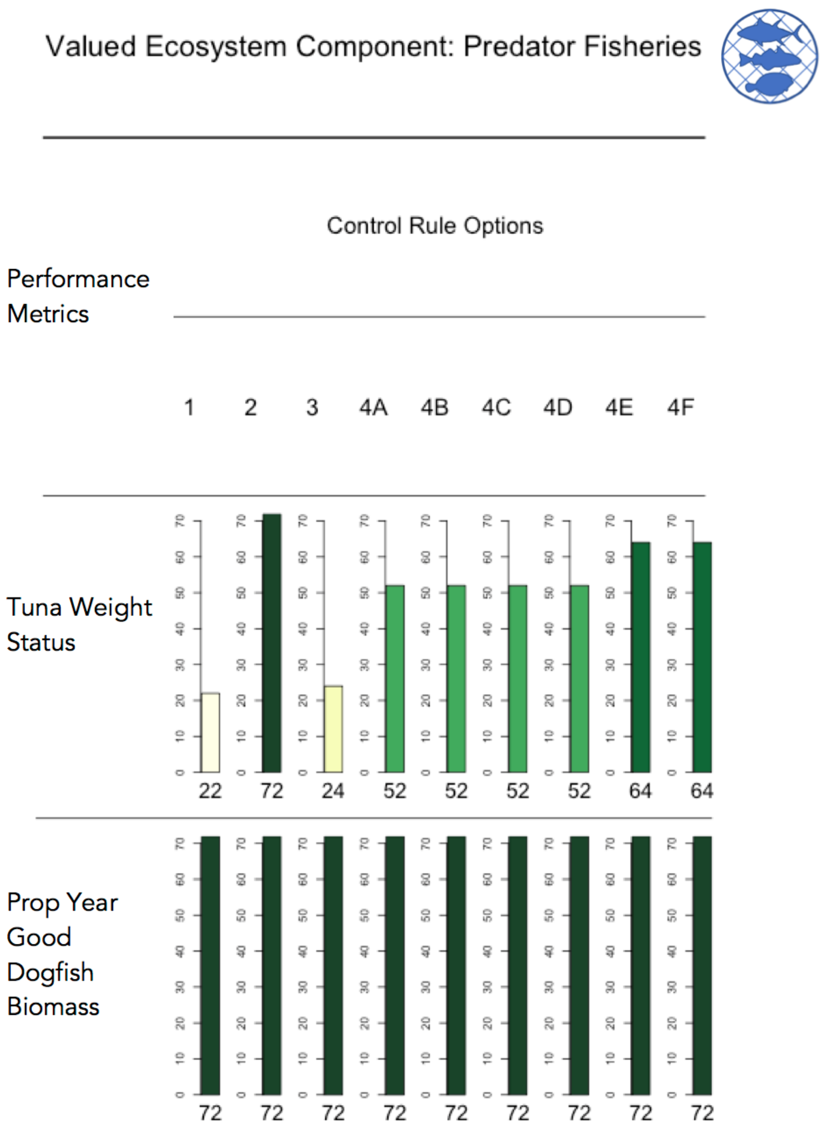
Herring Fishery Metrics: Probability of overfished, probability of overfishing, yield relative to MSY, Yield, Proportion of years no fishery (ABC=0), net revenue, and interannual variation in yield.



5.5 PREDATOR FISHERIES (TUNA, GROUNDFISH)

Figure 20 – Summary of the metrics that are indicators of potential impacts on the valued ecosystem metric – predator fisheries (tuna and groundfish).

Predator Fishery Metrics: Tuna weight status and dogfish biomass.



6.0 MSE RESULTS: ADDITIONAL UNCERTAINTY

All the results above are in terms of the mean. Additional analyses being summarized for the 25% - 75% results. Not complete when documents mailed out – more info at meeting.

7.0 MSE RESULTS: TRADEOFF ANALYSIS

A benefit of MSE analyses is the ability to compare results of different metrics at once. While the quantitative results are in different units, the models enable comparisons of results across the same time frames and conditions. Radar plots or web diagrams are often used in MSE analyses to help compare a handful of metrics at once. These plots are useful to see how alternatives stack up against each other for a handful of metrics at once. The same information that is summarized in Table 1 above can be displayed in web diagrams as well. For some readers, it is easier to see where alternatives differ and where they have similar results when the data are displayed in figures, rather than tables. For example, in

Figure 21 – Example of web diagram displaying MSE results

Good performance has vertex toward the edge of web, and poor performance has vertex toward the center.
(1) Similar results fall under each other; (2) consistent performance has same gradient across alternatives; and (3) variable performance occurs when gradient changes across alternatives – illustrating tradeoffs.

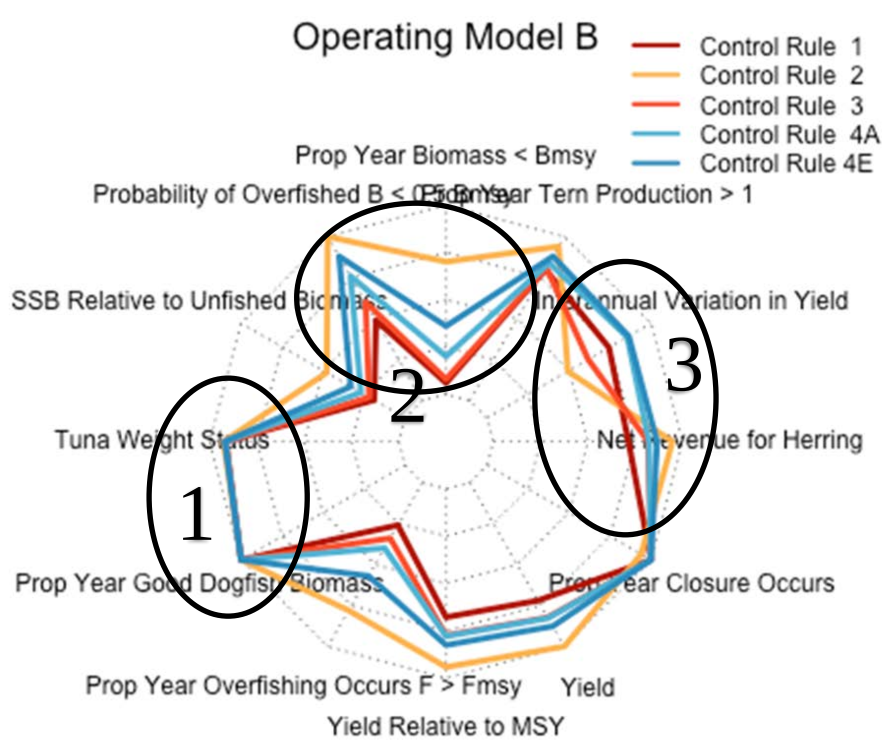


Figure 22 displays the tradeoffs for several herring fishery related metrics with several more ecosystem related metrics across four separate operating models. The performance of some alternatives vary based on the operating model and the overall ranking changes in some cases.

Figure 22 – Tradeoff plots for several metrics across operating models

Is Committee interested in seeing any additional tradeoff plots, other metrics included?

As an example, the four metrics the Committee originally used to identify Alternative 4 is included below.

8.0 SHORT TERM ANALYSIS

MSE analyses focus on the potential long-term impacts; they are designed to consider impacts over a wide variety of resource conditions and time. The models developed for the herring MSE were run for 150 years, and the results are generally the mean of the last 50 years. Therefore, the potential impacts concentrate on long-term effects. It is also important to consider the short-term effects of control rules in terms of expected impacts over the next several years. To do this the PDT has taken the numbers of herring at age from the last assessment (2015), as well as three other times in the past to give a range of possible short-term impacts. Because it is relatively uncertain what the herring resource conditions will be in the next several years, a range of possible resource conditions were evaluated to illustrate the range of possible short-term biomass and yield estimates that would result from the various ABC alternaitves. "High (recent)" is the 2015 numbers at age, which is about 2.0*Bmsy, "Poor (1980)" was selected to reflect potential biomass and yield estimates for when the herring resource was at very low numbers (about 0.16*Bmsy), and two "medium" years were selected as well, 1986 (0.5*Bmsy) and 1995 (1.24*Bmsy). Different levels of biomass are used as starting points, and the fishing mortality rates from each control rule alternative is applied to those biomass values. The MSE models used to simulate long-term conditions were *not* used in these analyses; this is a single year estimate.

Spawning stock biomass (SSB) is essentially the estimate of biomass after ABC is removed. These estimates also include an adjustment for the retrospective pattern that was observed in the recent stock assessment. Estimates of biomass for each control rule alternative under the four different scenarios is summarized in Figure 23, and estimates of ABC in Figure 24. Overall biomass is somewhat similar for many of the alternatives, but in some cases Alternative 2 is higher, especially using 1995 numbers at age. The short-term estimates of ABC are quite variable based on the estimate of herring abundance. When herring abundance is high as it has been in recent years the ABC for all the alternatives is 75-well over 100,000 mt, except for Alternative 2 which limits fishing mortality at 0.5. ABC reduces for Alternative 2 before the other alternatives because the upper biomass parameter is set at 2.0, so fishing mortality reduces before other control rules that do not start reducing fishing mortality until biomass falls below 1.0 or lower (0.5-0.7 for other alternatives). The alternatives with fishery cutoffs show zero ABC when herring resource conditions are poor (1980), and Alternative 2 has zero ABC under 1986 as well because the lower biomass parameter is higher than the other alternatives (set at 1.1 compared to 0.1 or 0.3 for some of the other alternatives).

Gross and net revenues under each of the control rules are constructed using the same methods used to construct long-run revenues (Figure 25 and Figure 26). The "new" price model was used for the short-run analyses. The High (recent) biomass scenario is most likely to be in effect in the near future. The results from the other biomass scenarios provide some insight into the sensitivity of the outcomes relative to changes in biomass.

Under the high biomass scenario, the short-run outcomes for the herring fishery are similar for all alternatives except Alternative 2, which results in net revenues that are 2.4-5.8M less than all the other alternatives. Under the Medium biomass scenario, the short-run outcomes for the herring fishery are similar for all alternatives except Alternative 2, which results in net revenues that are approximately 20M less than all the other alternatives. Under the Medium B biomass scenario, there is a good deal of variability in outcomes, although revenues in all scenarios are well below historical averages. Under the Poor biomass scenario, short-run outcomes are similar and reflect nearly no herring fishing under all Alternatives.

Figure 23 – Estimate of spawning stock biomass (SSB) under four different herring resource conditions for the control rules under consideration in Amendment 8

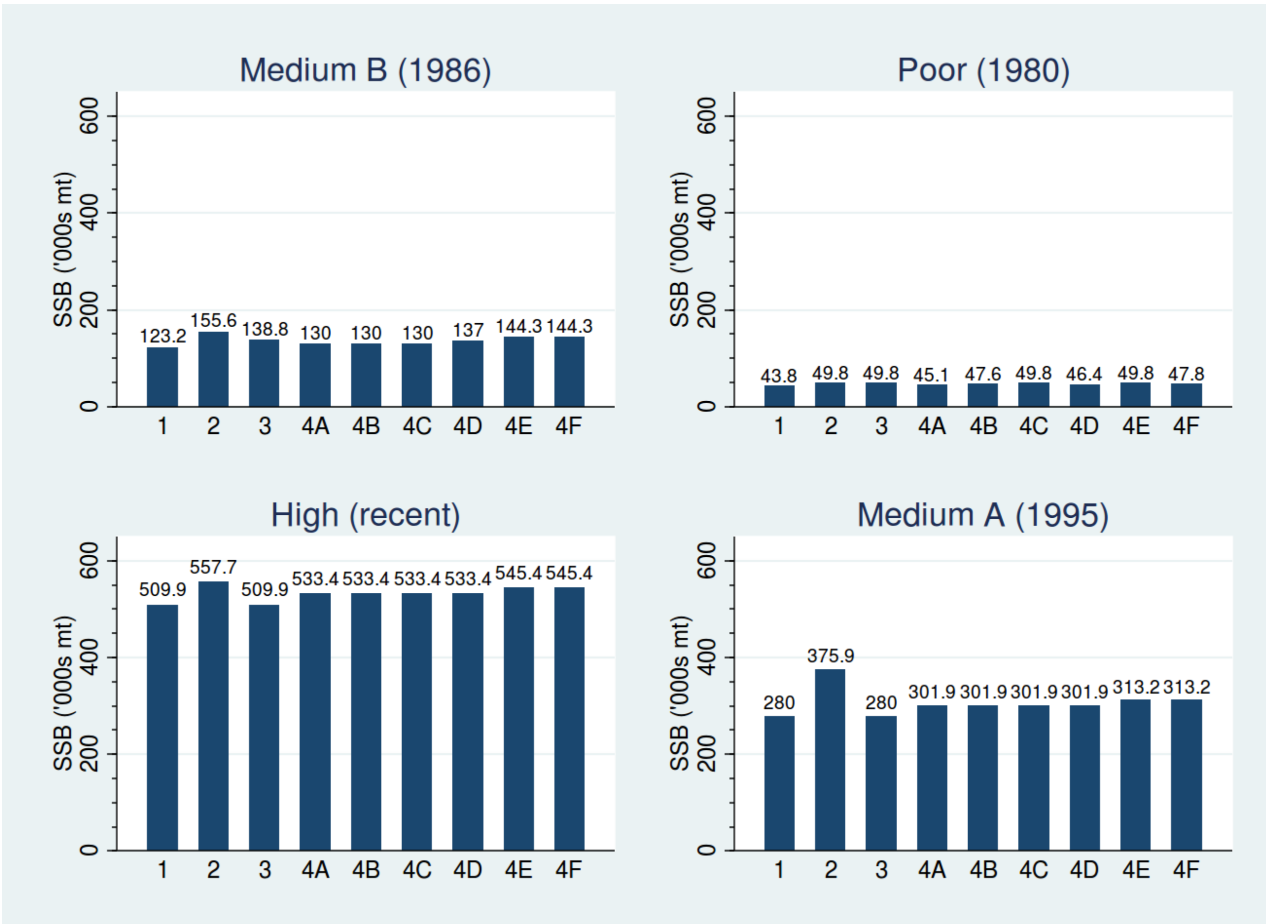


Figure 24 – Estimate of short-term ABC under four different herring resource conditions for the control rules under consideration in Amendment 8

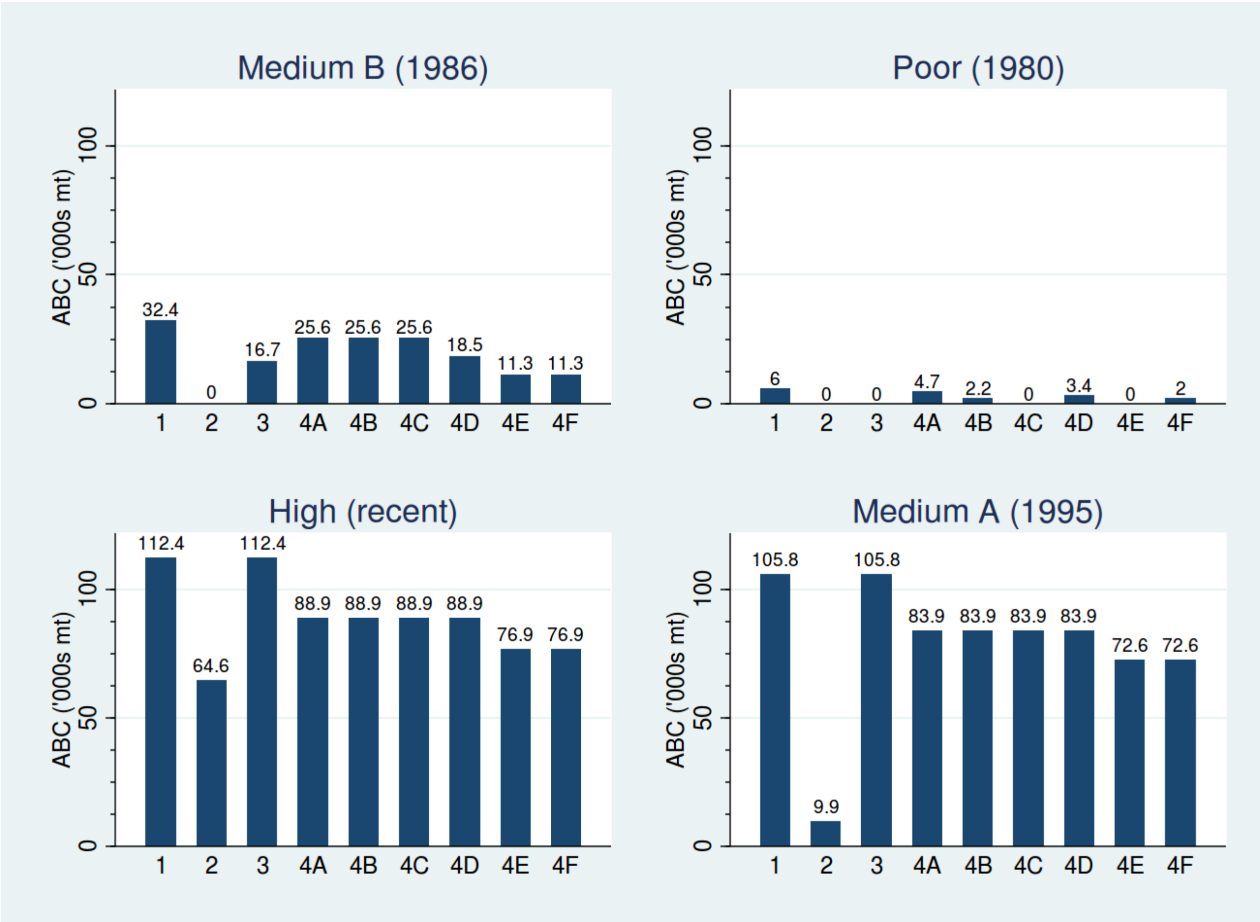


Figure 25 – Estimate of short-term gross revenue under four different herring resource conditions for the control rules under consideration in Amendment 8

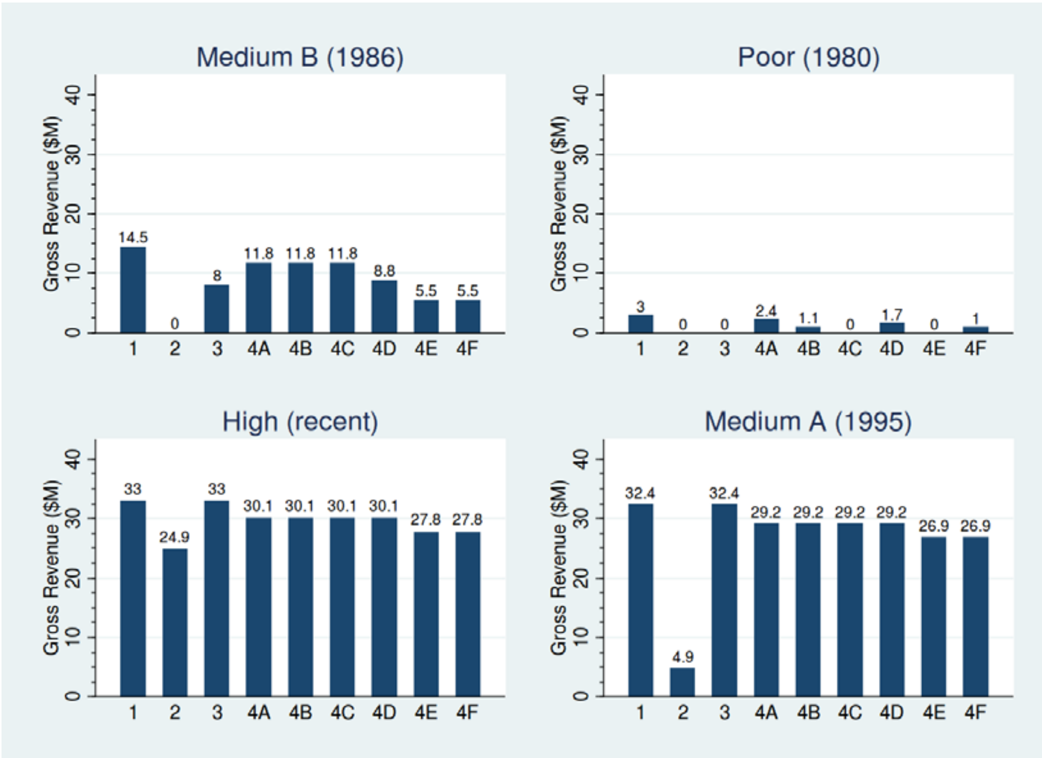


Figure 26 – Estimate of short-term net revenue under four different herring resource conditions for the control rules under consideration in Amendment 8