Executive Summary of Evaluation of Alternative Harvest Control Rules for New England Groundfish

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June 21 2021

Rationale

Management of the New England groundfish complex is challenging because of the multispecies nature of the fishery and aspects of groundfish population dynamics that are not completely understood. The majority of groundfish stocks that have analytical assessments exhibit a similar 'retrospective pattern' whereby the addition of new data results in reduced estimates of past stock size and increased estimates of fishing mortality. Retrospective patterns represent a large source of uncertainty and pose challenges in the classification of Northeast groundfish stock status, evaluation of rebuilding progress, and determination of catch advice.

The determination of the Acceptable Biological Catch (ABC) for each groundfish stock is currently based on the New England Fishery Management Council's (NEFMC) harvest control rule (HCR), also known as the ABC control rule. The ABC control rule states that : a) ABC should be determined as the catch associated with 75% of F_{MSY}; b) if fishing at 75% of F_{MSY} does not achieve the mandated rebuilding requirements for overfished stocks, ABC should be determined as the catch associated with the F that meets rebuilding requirements ($F_{rebuild}$); c) for stocks that cannot rebuild to B_{MSY} in the specified rebuilding period, even with no fishing, the ABC should be based on incidental bycatch, including a reduction in bycatch rate (i.e., the proportion of the stock caught as bycatch); and d) interim ABCs should be determined for stocks with unknown status according to case-by case recommendations from the SSC. In hindsight it has been recognized that application of the groundfish HCRs did not always prevent overfishing (Brooks & Legault, 2016; Wiedenmann & Jensen, 2018). The accuracy of the stock assessment, retrospective patterns, and the quality of projections have been identified as potential contributors to these issues with management performance. In response to the issues raised regarding the performance of the current ABC control rule, the NEFMC initiated an evaluation of the performance of the current HCR and possible alternatives through simulation testing.

Goal

The goal of this analysis was to evaluate the performance of alternative HCRs for New England groundfish stocks using management strategy evaluation (MSE). We structured scenarios to address a series of research questions:

a) How do alternative HCRs perform when a stock is overfished?
b) How do alternative HCRs perform when a stock is not overfished?

c) How do alternative HCRs perform when there is a stock assessment misspecification and retrospective patterns?
d) When retrospective patterns exist, do retrospective adjustments result in better performance than no retrospective adjustments?

Approach

MSE, a general framework aimed at simulation testing management strategies, was used to evaluate the performance of alternative HCRs for a suite of New England groundfish species. In the MSE framework, the operating model (OM) represented the true fish population dynamics and was the basis for evaluating performance relative to the 'true' values for the stock and fishery. Through an observation model, simulated trawl survey data and catch data were generated with plausible random error to represent the information available for groundfish assessment and management. The simulated survey and catch data informed a stock assessment model used to estimate stock attributes and biological reference points (BRPs) were calculated with the same assumptions of the stock assessment. The stock assessment output and estimated BRPs were compared to produce estimated stock status. A HCR then determined fishing mortality (F) based on the estimated stock status. Both the F from the HCR and output from the stock assessment were used in projections to determine catch advice. This catch advice was then applied to simulate harvest in the OM. Catch advice was assumed to be fully caught. Performance of the alternative HCRs were evaluated at each timestep. The stock was assessed every two years unless otherwise noted. The GOM cod and GB haddock historical trajectories were reconstructed by incorporating recruitment and F time series (1982-2018 for cod, 1931-2018 for haddock) from the most recent stock assessments (NEFSC 2019) and calculating SSB and catch as emergent properties. The MP period began in 2019. Scenarios were composed of different operating models, stock assessment specifications, rho-adjustment options, stock assessment frequencies, and harvest control rules (Table 1).

We evaluated HCR performance in the context of two groundfish stocks: Gulf of Maine (GOM) cod and Georges Bank (GB) haddock because these stocks typified a range of conditions currently experienced by groundfish stocks. Scenarios with different combinations of stock size, recruitment, and natural mortality assumptions as well as stock assessment model specifications were simulated to evaluate the performance of HCRs when a stock was overfished, not overfished, and when a stock assessment model had a misspecification, which could result in retrospective patterns.

Stock assessment misspecifications included incorrect natural mortality, recruitment, and survey catchability assumptions. For the natural mortality stock assessment misspecification, natural mortality was 0.2 in the OM at the beginning of the historical period and increased over time to 0.4 (2003) where it remained to the end of the MP period. The stock assessment assumed natural mortality was constant at 0.2. For the recruitment misspecification, the OM assumed recruitment was a function of a stock-recruit relationship which incorporated a negative impact of temperature on recruitment. The stock assessment model did not account for the negative impact of temperature. For the survey catchability misspecification, survey catchability declined with increasing temperature to half of what it originally was by the end of the MP period. The stock assessment assumed survey catchability was constant over time.

Four different HCRs were evaluated: ramp, P*, F-step and constrained ramp HCRs (Fig. 1). The ramp HCR was designed to emulate the basic structure of the current ABC control rule and promoted rebuilding and optimal yield by decreasing F gradually with SSB if SSB was below the threshold (50% SSB_{MSY}). The P* HCR emulated the P* method, which also ramps down F as SSB decreases below a threshold but avoids overfishing by accounting for uncertainty with a probabilistic approach. The F-step HCR emulated a step in F between 75% F_{MSY} and 70% F_{MSY} which is the rebuilding F for several New England groundfish stocks. The constrained ramp HCR emulated a ramp HCR that includes a catch variation constraint (i.ecatch advice cannot change more than 20% from the previous year's catch). All HCR alternatives included a constraint that prevented catch advice from exceeding the catch corresponding to the estimated overfishing limit (OFL). However, in misspecified scenarios, the true catch could exceed the catch that corresponds to the true OFL due to assessment error. For the correctly specified GOM cod scenario, we also simulated catch advice with two-year projections and with year-one projection held constant.

The F associated with maximum sustainable yield (F_{MSY}) proxy used in these HCRs was $F_{40\%}$, or the F expected to maintain 40% of the unfished SSB per recruit, which was determined with spawner per recruit (SPR) analysis. The SSB_{MSY} proxy was the long-term equilibrium SSB that corresponded to the F_{MSY}. For the estimated and true SSB_{MSY} proxies, recruitment used in the equilibrium calculation was the mean of the previous 20 years of estimated or true recruitment values. These recruitment values were dynamic and changed as the years accumulated. Both true and estimated reference points are estimated with natural mortality at 0.2, even if natural mortality increases to 0.4 in the OM, because the stock is at a lower productivity (Legault and Palmer 2016).

Table 1. Summary of operating model and stock assessment misspecification scenarios, rho-adjustment scenarios, stock assessment frequencies, and harvest control rule alternatives simulated in this study.

Category	Scenarios	Purpose
Operating model and stock assessment misspecification scenarios	Base Case Overfished Scenario	To emulate a groundfish stock in poor status
	Base Case Not Overfished Scenario	To emulate a groundfish stock in good status with large recruitment events
	Overfished Mortality Misspecified Scenario	To emulate a groundfish stock in poor status with a natural mortality misspecification in the stock assessment
	Overfished Recruitment Misspecified Scenario	To emulate a groundfish stock in poor status with a recruitment misspecification in the stock assessment
	Not Overfished Catchability Misspecified Scenario	To emulate a groundfish stock in good status with a survey catchability misspecification in the stock assessment
Rho-adjustment scenarios	Rho Scenario 1	To not apply rho-adjustments
	Rho Scenario 2	To apply rho-adjustments
Assessment frequency scenarios	Frequency Scenario 1	To update the assessment every two years, which is currently done for New England groundfish
	Frequency Scenario 2	To update the assessment annually
Projection scenarios	Projection Scenario 1	To determine catch advice with two-year projections
	Projection Scenario 2	To determine catch advice with year one of the projection held constant
Harvest control rule alternatives	Ramp	To emulate a ramped harvest control rule, which promotes rebuilding and optimal yield
	P*	To emulate the P* method, which avoids overfishing by accounting for uncertainty with a probabilistic approach
	F-step	To emulate a step in fishing mortality (between 75% F_{MSY} and 70% F_{MSY}) harvest control rule, which has recently been applied to some New England groundfish
	Constrained ramp	To emulate a ramped harvest control rule that includes a catch variation constraint

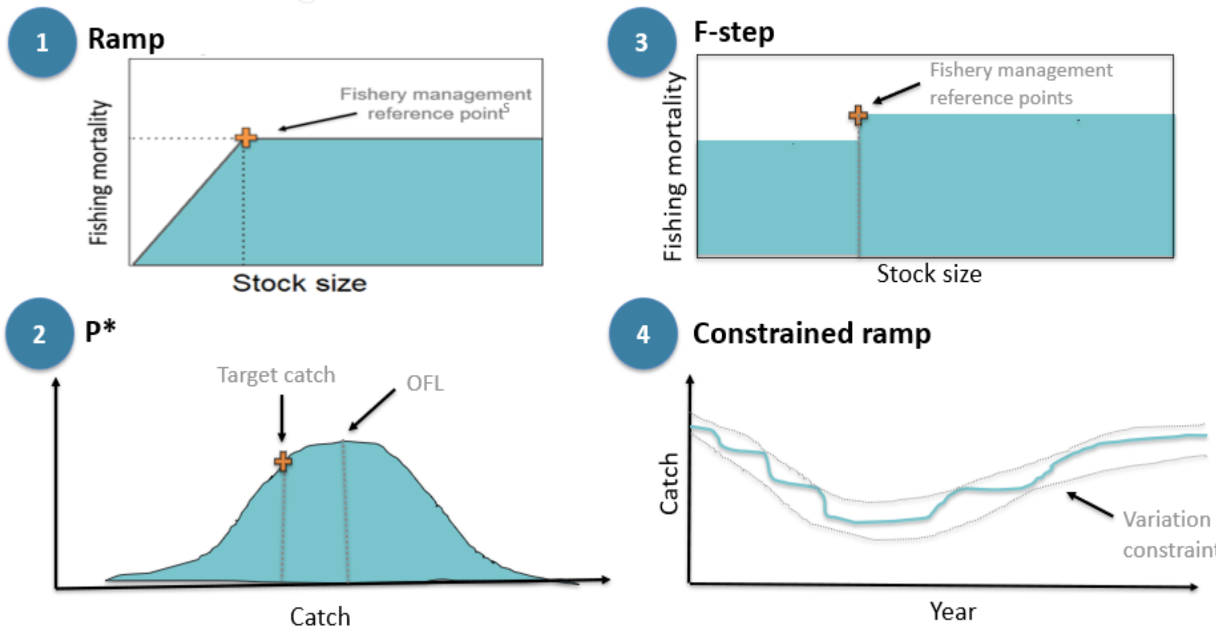


Figure 1. Harvest control rule forms evaluated in this study.

Take Home Results

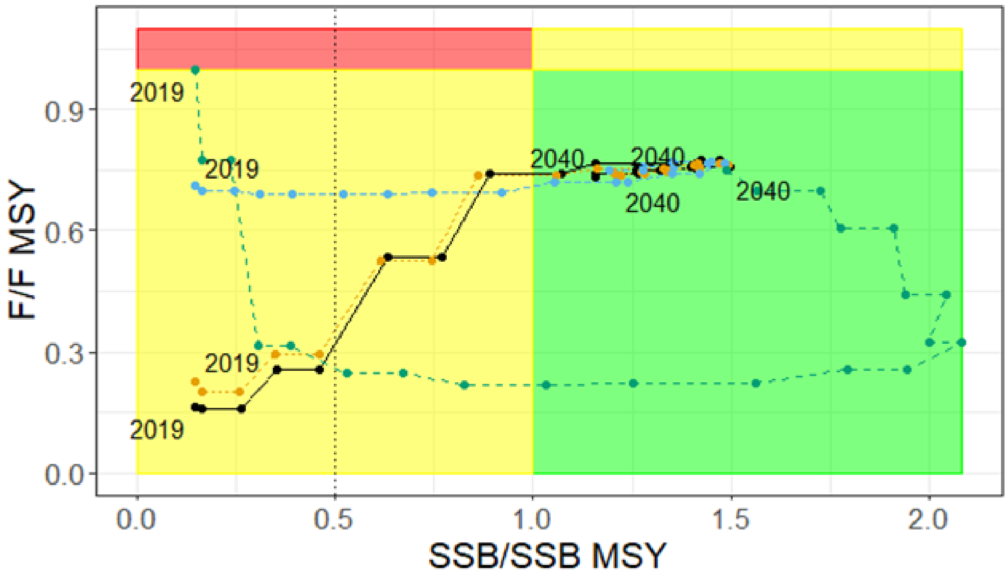
This analysis provides information on the performance of alternative HCRs across a range of conditions currently experienced by groundfish stocks. Scenarios with different combinations of stock size, recruitment, and natural mortality assumptions as well as stock assessment model specifications were simulated to evaluate the performance of HCRs when a stock was overfished, not overfished, and when a stock assessment model had a misspecification and retrospective patterns. Overall, the ramp, P*, and F-step HCRs resulted in different catch advice when a stock was overfished, but performed relatively similarly when not overfished. There were trade-offs in the performance of HCRs in the short- , medium- and long-term relative to key metrics (e.g., SSB, catch, catch stability, and frequency of overfished and overfishing status). For an overfished stock, the choice of HCRs was most influential in the short- and medium-term, as there were more significant differences in HCR performance during this period. In the long-term, the ramp, P*, and F-step HCRs typically performed similarly because stock size increased over the SSB threshold and thus catch advice was similar among HCRs.

Comparing correctly specified scenarios to those with stock assessment misspecifications allowed us to understand how stock assessment bias and unaccounted for changes in population dynamics can impact HCR performance. With stock assessment misspecifications, the relative HCR performance sometimes differed from that with a correctly specified stock assessment. The frequency of overfished and overfishing stock status depended more on the type of stock assessment misspecification, rather than the HCR. HCR performance depended upon OM and stock assessment assumptions. With a natural mortality misspecification, retrospective patterns appeared. Retrospective patterns are a sign that there is a stock assessment misspecification that has greatly impacted our perception of reality. The scenario with the combined natural mortality and recruitment misspecification simulates retrospective patterns similar in scale to what are seen in several groundfish assessments. The classification of which control rule performs best across a range of conditions will depend on the definition and prioritization of management objectives for the groundfish fishery which was outside the scope of this study.

How do alternative harvest control rules perform when a stock was overfished?

All HCRs were able to rebuild the stock above SSB_{MSY} in the long-term, although the unique features of HCRs resulted in different pathways to achieve this stock status (Fig. 2a). With no bias and nearly perfect information provided to the stock assessment, all HCRs were able to produce sustainable catch advice. The ramp and P* HCRs performed similarly and resulted in reduced catch and catch stability in the short-term (Fig. 2b). The F-step HCR tended to provide the highest catch and also the highest catch stability in the beginning of the MP period, because the fishing mortality did not change much with changes in SSB. The trajectories under the constrained ramp HCR differed the most from all other HCRs. This HCR resulted in the lowest F and catch in the medium-term and resulted in the highest SSB in the long-term. However, the constrained ramp HCR did not always result in the highest catch stability. This variability constraint prevented the catch from increasing as fast as under other HCRs in the short- to medium-term. However, in the long-term, this HCR resulted in more variable catch as a 20% difference in catch became larger as catch increased at the end of the MP period. None of the HCRs for GOM cod allowed catch to increase to the level of the 1980s and 1990s, because F was not allowed to get as high as it had in the past. HCRs performed differently for an overfished stock because the prescribed F across HCRs differed in response to the SSB being below the overfished threshold at the start of the MP period. However, in these scenarios, there were negligible REE and retrospective patterns, which is not what is experienced in most groundfish stocks.

a



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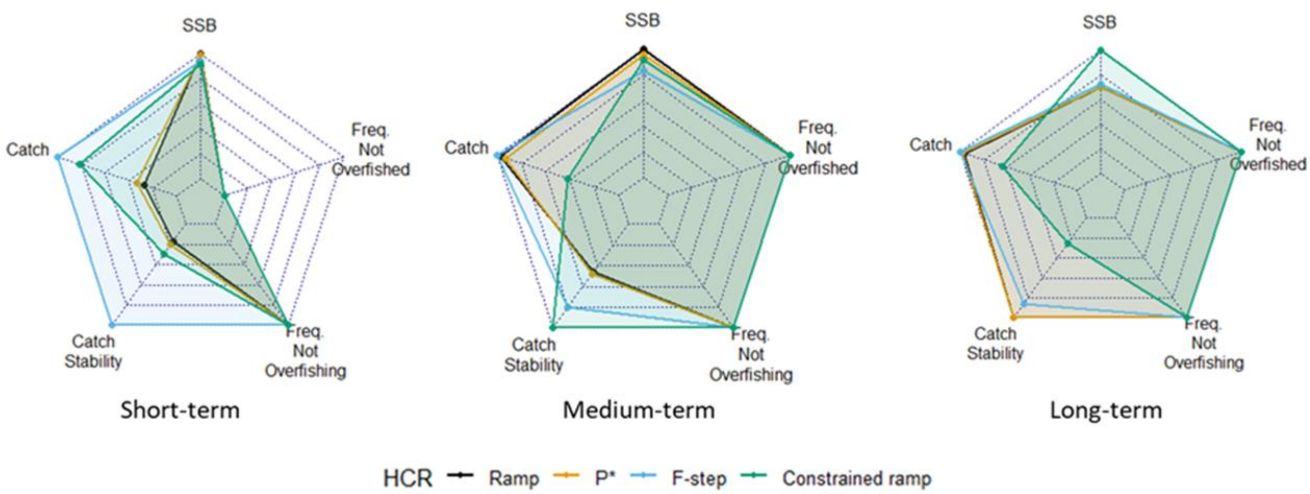


Figure 2. a) True stock status trajectories (ratio of fishing mortality to the fishing mortality reference point (F/F_{MSY}) versus ratio of spawning stock biomass to the spawning stock biomass reference point (SSB/SSB_{MSY})) for Gulf of Maine cod with no stock assessment model misspecification (Base Case Overfished Scenario). The dashed line represents the overfished threshold. b) Harvest control rule (HCR) performance for Gulf of Maine cod with no stock assessment model misspecification (Base Case Overfished Scenario) in the short- (1-5 years), medium- (6-10 years), and long-term (11-21 years). Metrics are standardized to the maximum value for each metric attained by the different HCRs and equally weighted. Spawning stock biomass (SSB) and catch are median SSB and catch for the time period.

How do alternative harvest control rules perform when a stock was not overfished?

Overall, the ramp, P*, and F-step HCRs performed similarly for a stock that was not overfished because the prescribed F was often the same since SSB was above the overfished threshold throughout the MP period (Fig. 3). The ramp, P*, and F-step HCRs allowed the fishery to take advantage of large recruitment events. In contrast, the constrained ramp HCR did not enable taking full advantage of the large recruitment events that resulted in a high catch in the short- to medium-term for other HCRs. However, catch was similar among HCRs in the long-term and the constrained ramp HCR conserved SSB, provided high catch stability in the short-term, and provided the highest catch in the long-term. Conditioning these simulations on haddock provided a contrast to those conditioned on Gulf of Maine cod and captured unique features of haddock population dynamics (i.e. influence of large recruitment events). A large recruitment event occurred near the end of the historical period for all haddock scenarios and the high catch at the beginning of the MP period depended on that recruitment event.

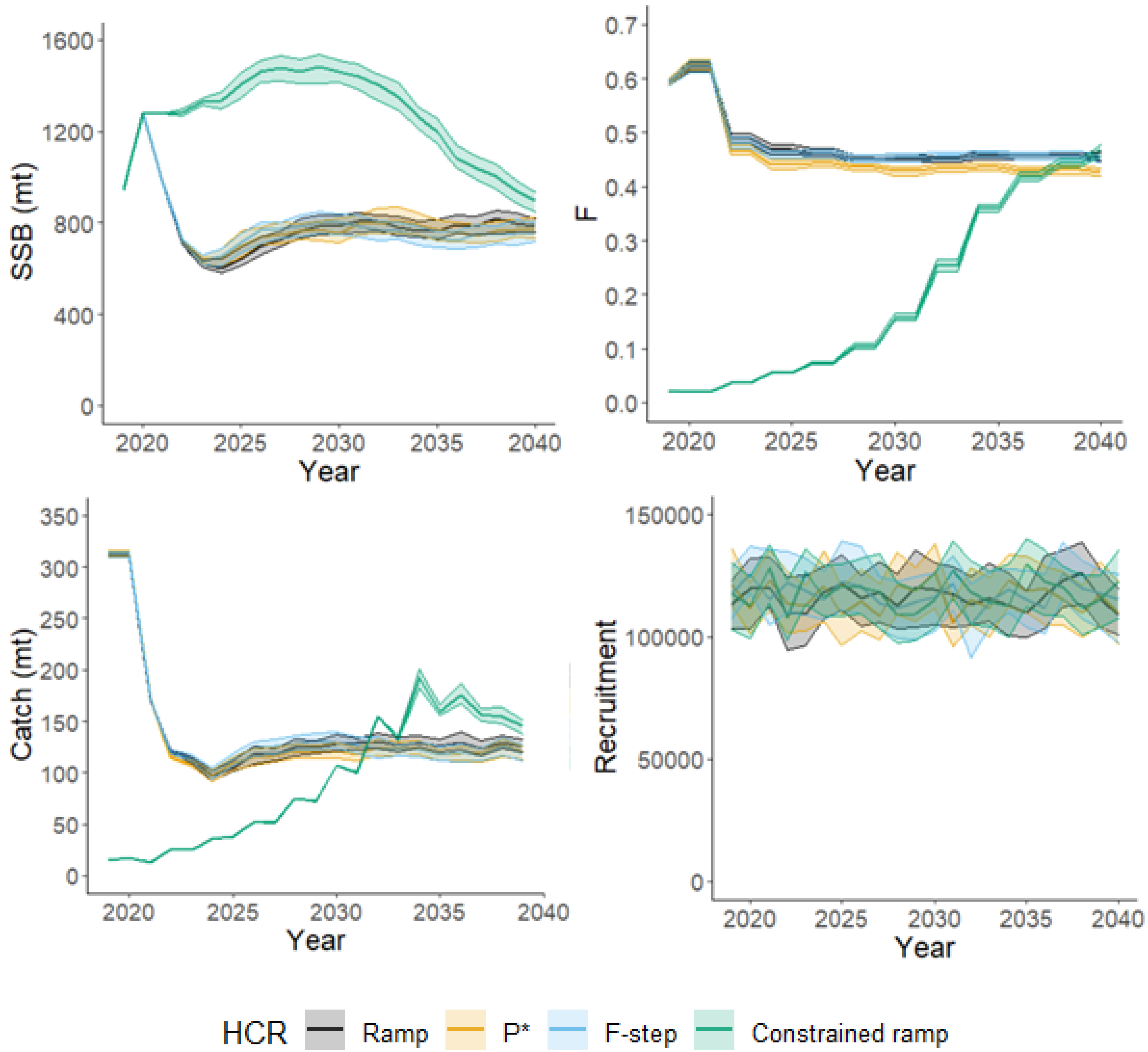


Figure 3. True operating model median spawning stock biomass (SSB), fishing mortality (F), catch (mt), and recruits with 95% confidence intervals for Georges Bank haddock with no stock assessment model misspecification (Base Case Not Overfished Scenario) from 2019 to 2040.

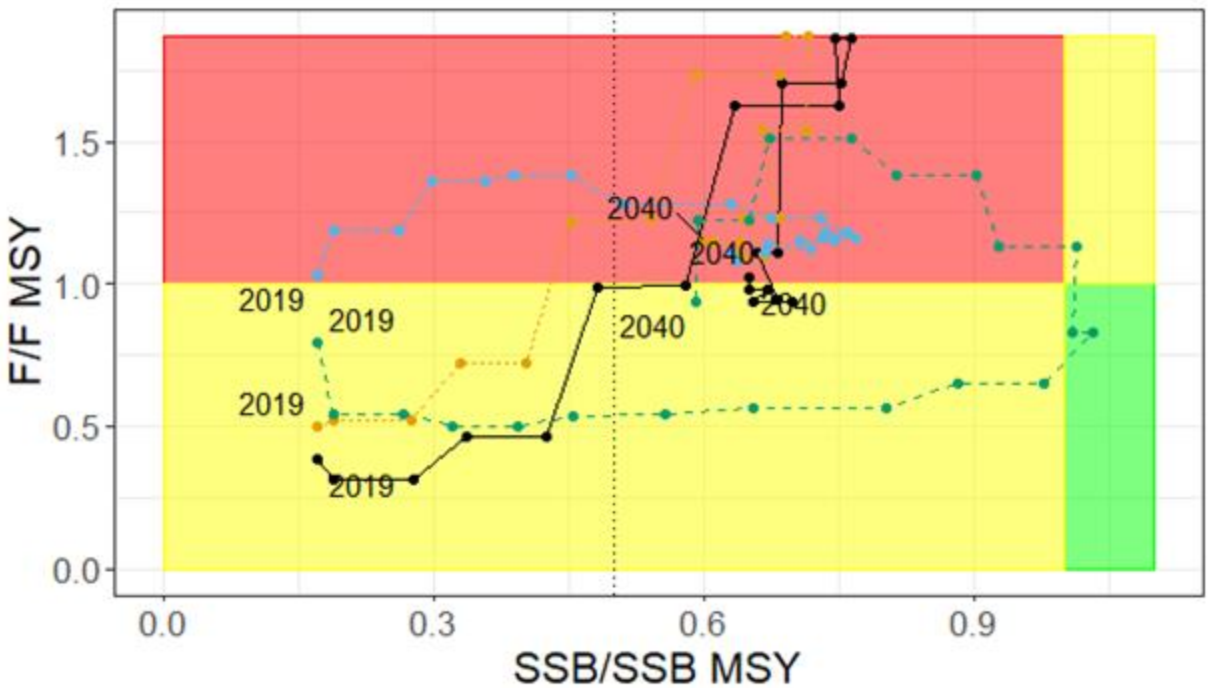
How do alternative harvest control rules perform when stock assessments are misspecified?

In scenarios that incorporate stock assessment misspecifications, stock assessment assumptions were not an accurate reflection of the 'reality' in the OM and fisheries management was informed by imperfect knowledge. As a result, the HCRs did not always perform as well as with no misspecifications. These scenarios are especially important since retrospective patterns are apparent in groundfish stock assessments (NEFSC 2019).

Natural mortality misspecification

In the natural mortality misspecification, natural mortality was higher in the OM than assumed in the assessment model. This contributed to more time spent overfished, more overfishing, lower catch and lower SSB in these misspecified scenarios than in the correctly specified scenarios (Fig. 4a). In the stock assessment, natural mortality was assumed to be lower, and this caused error in the stock assessment (over-and under-estimation of SSB and F) and retrospective patterns (Fig. 4b). With a natural mortality misspecification, the stock was not rebuilt at the end of the MP period under any of the HCRs.

a



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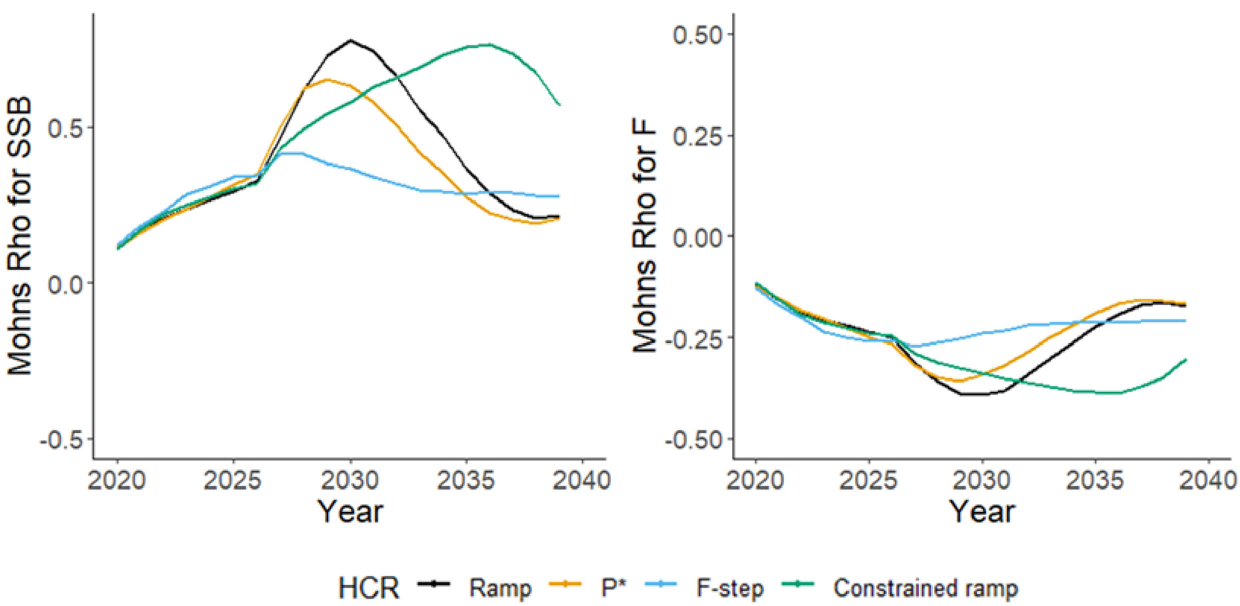


Figure 4. a) True stock status relative to M=0.2 reference points for Gulf of Maine cod with a stock assessment model misspecification (Overfished Mortality Misspecified Scenario). The dashed line represents the overfished threshold. b) Mohn's Rho values for spawning stock biomass (SSB) and fishing mortality (F) for Gulf of Maine cod with a natural mortality stock assessment model misspecification (Overfished Mortality Misspecified Scenario).

Recruitment Misspecification

In the recruitment misspecification, recruitment was a function of SSB and temperature, whereas the assessment assumed recruitment was not negatively impacted by temperature. In this scenario, the ramp and P* HCRs increased SSB at the fastest rate and decreased the frequency of being overfished. However, SSB and catch were lower in this scenario due to the decrease in recruitment over time (Fig. 5). Also, there was overfishing in the long-term due to overestimation of SSB.

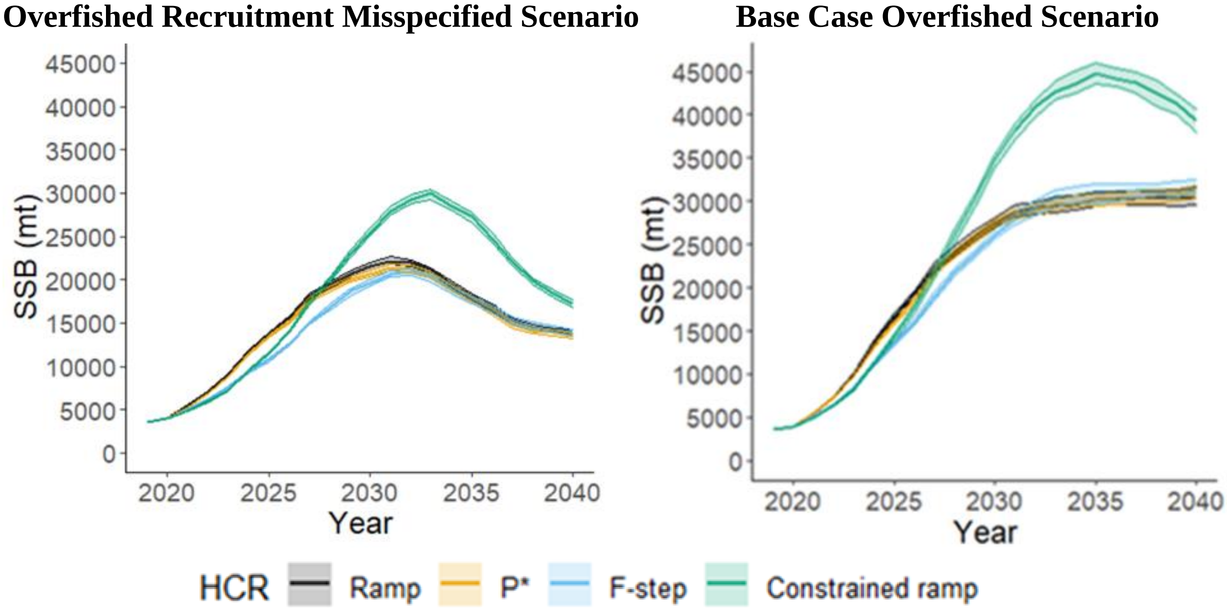
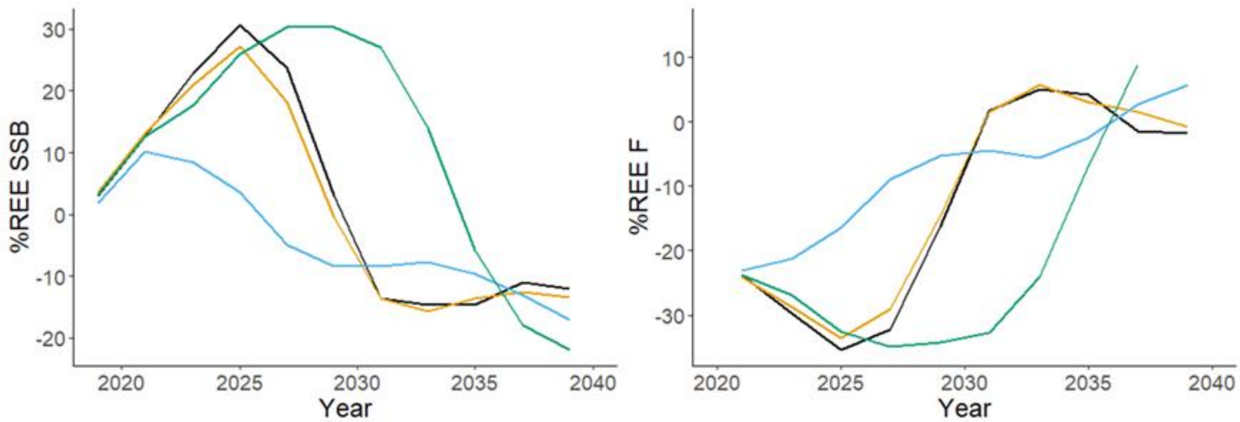


Figure 5. True operating model median spawning stock biomass (SSB) with 95% confidence intervals for Gulf of Maine cod with a recruitment stock assessment model misspecification (Overfished Recruitment Misspecified Scenario) and with no stock assessment model misspecification (Base Case Overfished Scenario) from 2019 to 2040.

Natural Mortality and Recruitment Misspecification

In previous scenarios, only one parameter was misspecified at a time, but in reality, multiple parameters can be misspecified (Cao et al., 2016). When both a natural mortality and a recruitment misspecification were present, retrospective patterns and stock assessment error were large (Fig. 6a), similar to those in the mortality misspecified scenario. The negative impact of temperature and higher natural mortality combined with the stock assessment misspecifications contributed to lower catch and SSB and more time spent overfished and overfishing (Fig. 6b). These changes in population dynamics and error in the assessment caused the stock to not rebuild under all HCRs. Although the F-step HCR resulted in overfishing in the beginning of the MP period, the error under this HCR was smaller, resulting in higher SSB, catch, catch stability, and less overfishing and time overfished in the long-term compared to the ramp and P* HCRs. The misspecification led to cyclical patterns in stock dynamics in the ramp and P* HCRs, which changed F the most with changes in SSB. Although catch was high under the ramp and P* HCRs in the medium-term, this catch was not sustainable, as it resulted in low SSB and catch in the long-term.

a



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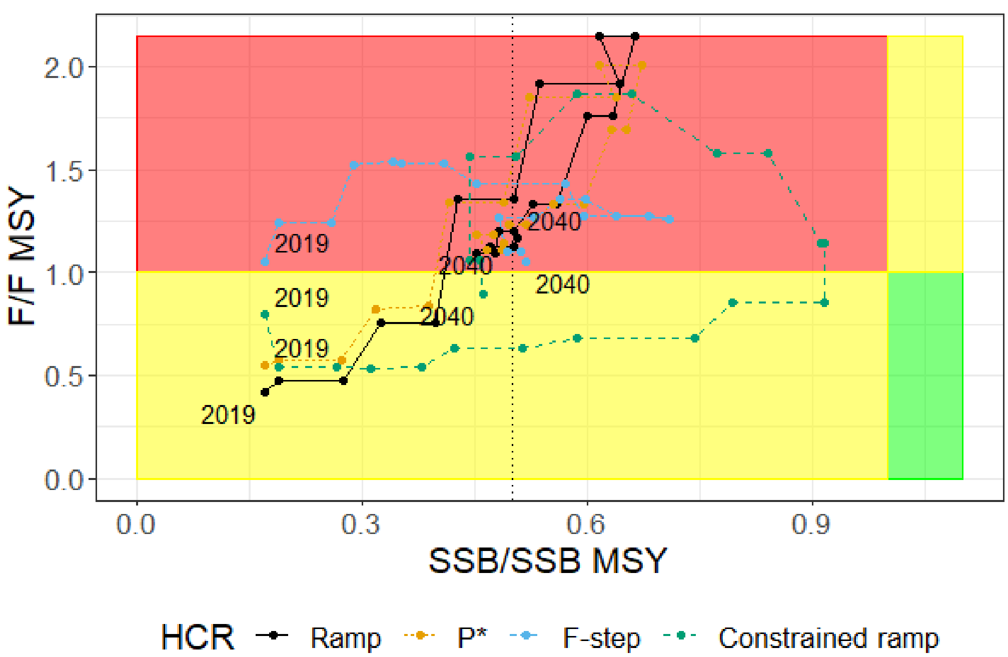

Figure 6. a) Percent relative error (REE) in terminal estimated spawning stock biomass (SSB) and fishing mortality (F) for Gulf of Maine cod with a natural mortality and recruitment stock assessment model misspecification (Overfished Mortality and Recruitment Misspecified Scenario) b) True stock status relative to M=0.2 reference points for Gulf of Maine cod with a natural mortality and recruitment stock assessment model misspecification (Overfished Mortality and Recruitment Misspecified Scenario). The dashed line represents the overfished threshold.

How does HCR performance change when the first year of the projection is held constant for catch advice?

When catch advice was determined holding the first year of the projection constant, the HCRs performed more conservatively than when catch advice was based on two-year projections (Fig. 7). This is because catch from the first year of the projection was often smaller than that of the second year of the projection. In these scenarios, SSB increased faster, stocks rebuilt faster, and F and catch did not increase as fast.

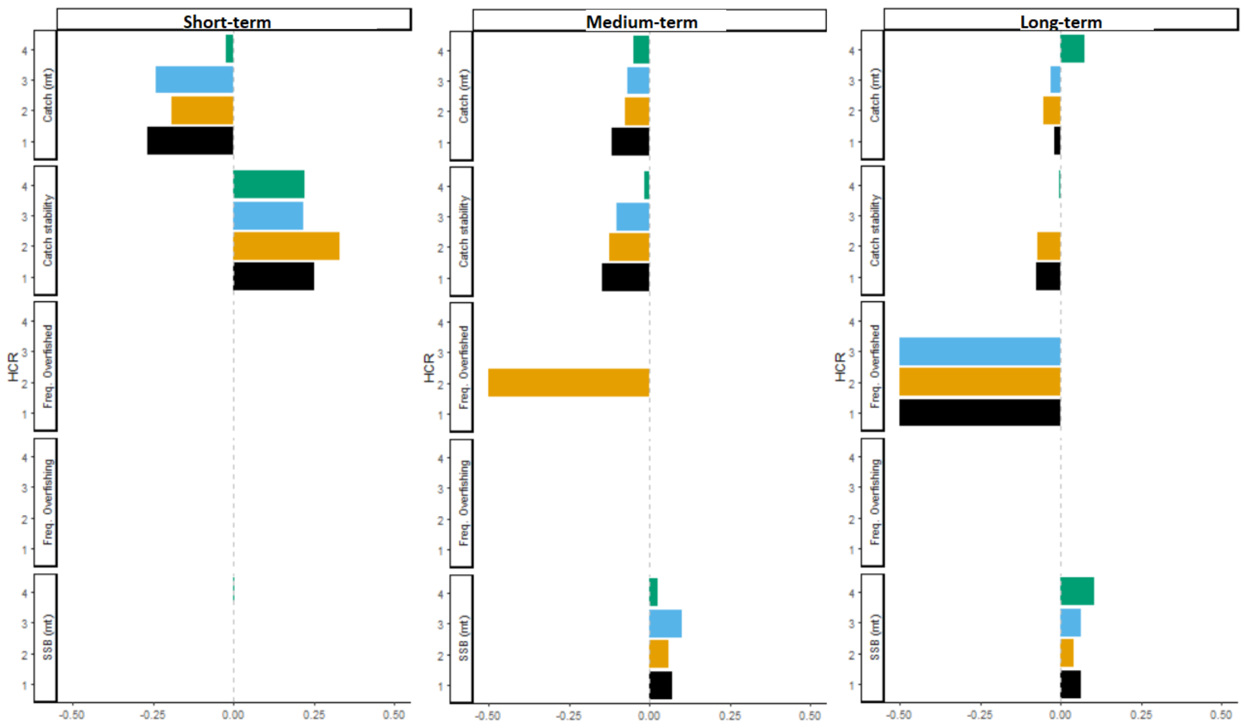

Figure 7. Short- (1-5 years), medium- (6-10 years), and long-term (11-21 years) relative difference in harvest control rule performance with the Overfished Mortality and Recruitment Misspecified Scenario with catch advice based on two-year projections and catch advice based on year one projection held constant.

How does HCR performance change when the stock assessment is updated annually?

With annual updates, the HCRs performed similarly but were more reactive and conservative in the long-term, as catch advice was updated annually (Fig. 8). This caused higher catch stability, higher SSB, less time overfished, and less overfishing in the long-term.

Annual updates **Two-year updates**

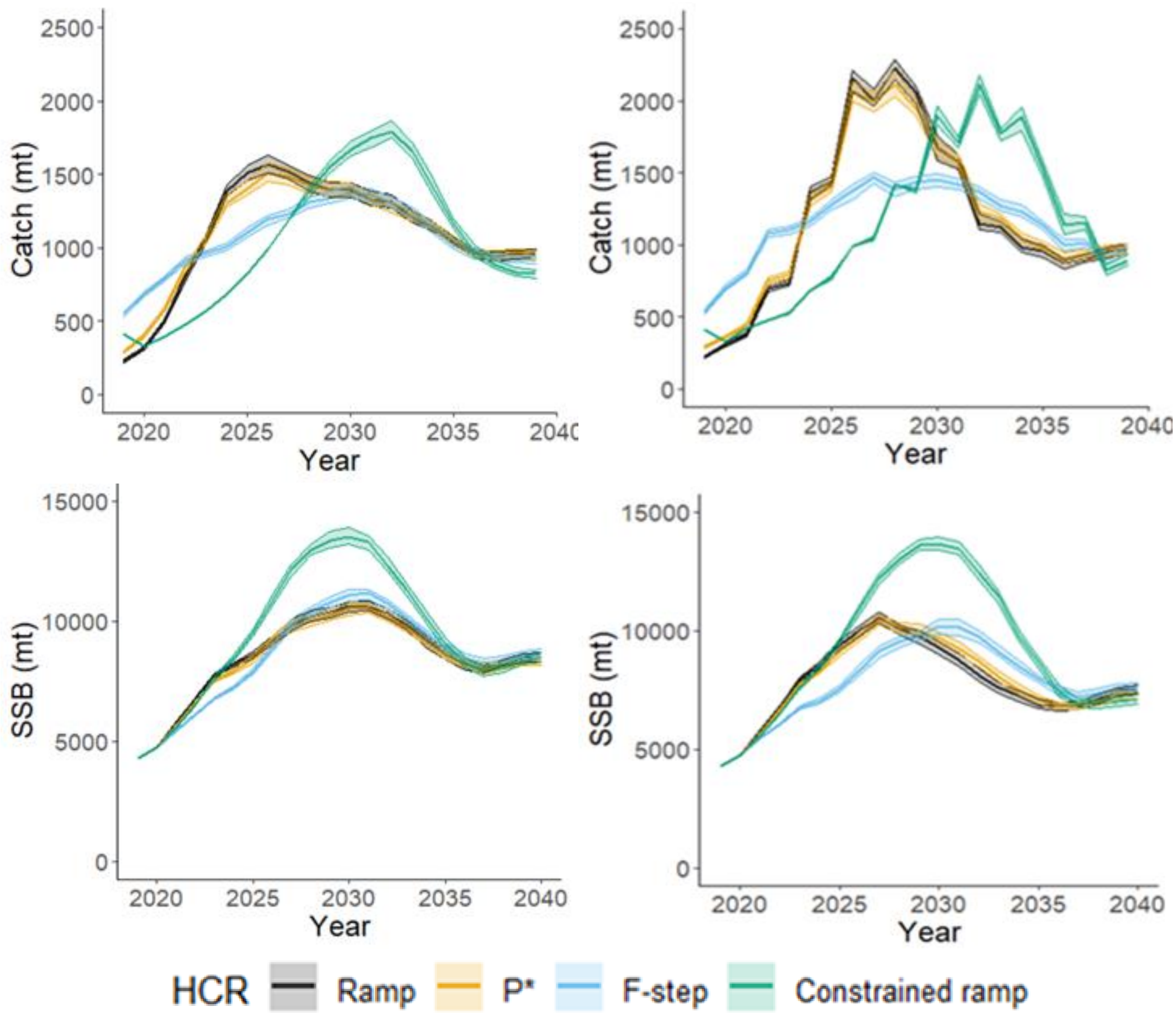

Figure 8. True operating model median spawning stock biomass (SSB) and catch (mt) with 95% confidence intervals for Gulf of Maine cod with a natural mortality stock assessment model misspecification (Overfished Mortality and Recruitment Misspecified Scenario) and annual stock assessment updates (Frequency Scenario 2) and with two-year stock assessment updates (Frequency Scenario 1) from 2019 to 2040.

Survey Catchability Misspecification

In the scenario with a survey catchability misspecification, the population dynamics were not directly altered from the base case scenario, rather survey data from the observation model were altered. In the stock assessment, survey catchability was assumed to be constant, and this caused an underestimation of SSB and overestimation of F. This misspecification caused the HCRs to be more conservative since the estimated SSB was smaller than the true SSB.

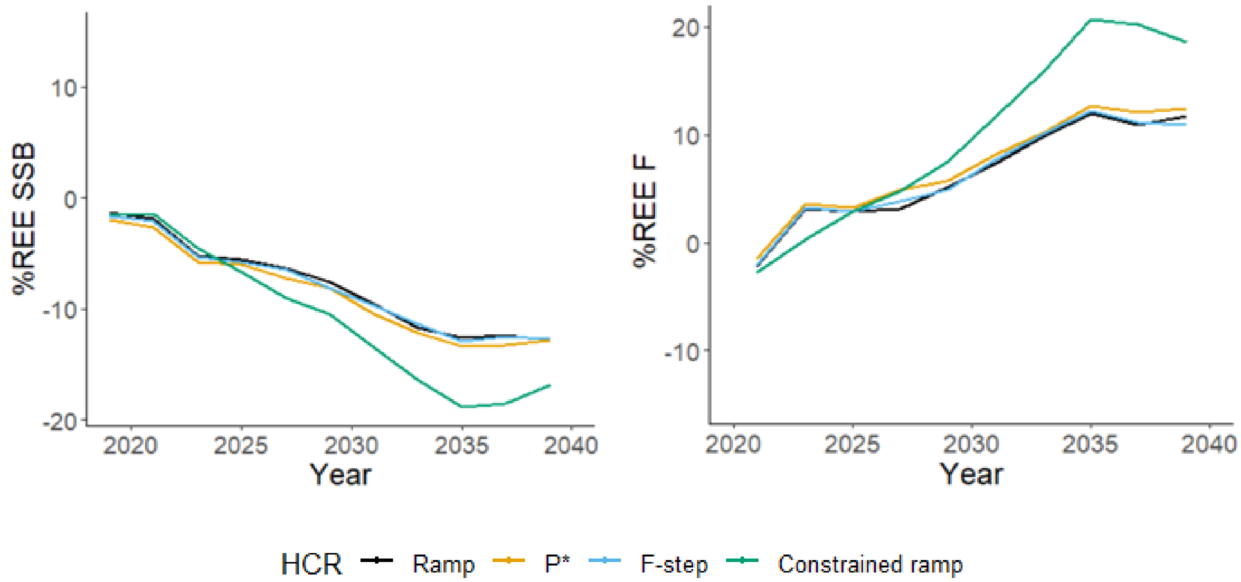

Figure 9. Percent relative error (REE) in terminal estimated spawning stock biomass (SSB) and fishing mortality (F) for Georges Bank haddock with a survey catchability stock assessment model misspecification (Not Overfished Catchability Misspecified Scenario).

When retrospective patterns exist, do retrospective adjustments result in better performance than no retrospective adjustments?

In the scenario with both a natural mortality and a recruitment misspecification, positive retrospective patterns were present for SSB and implementation of rho-adjustments impacted the performance of HCRs (Fig. 10). A rho-adjustment created more conservative catch advice and caused less overfishing and a lower frequency of overfished stock status. With a rho-adjustment, SSB/SSB_{MSY} was higher and F/F_{MSY} was lower. F and catch were lower, which resulted in a higher SSB.

a

b

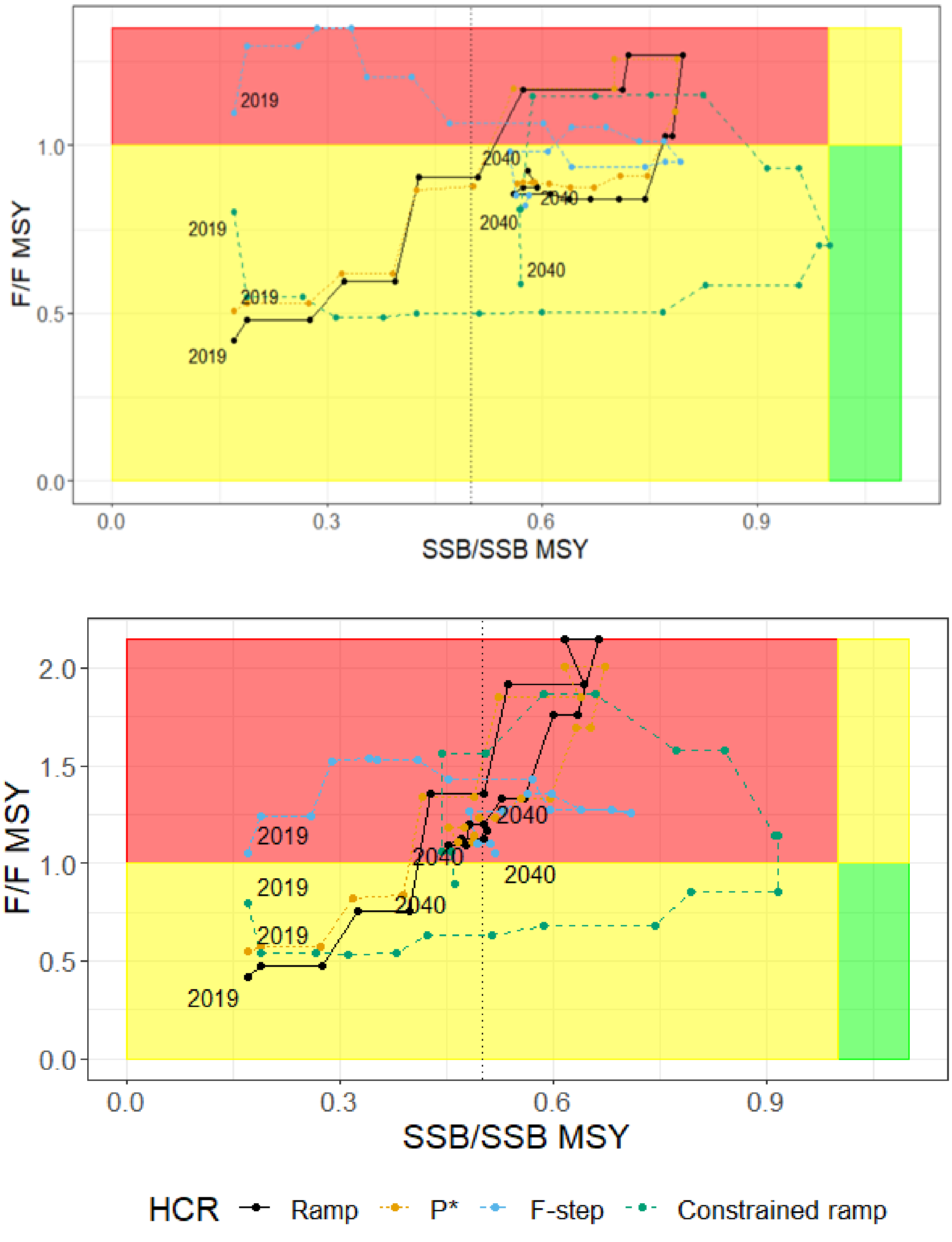

Figure 10. True stock status relative to M=0.2 reference points for Gulf of Maine cod with a natural mortality and recruitment stock assessment model misspecification (Overfished Mortality and Recruitment Misspecified Scenario) with a rho-adjustment (a) and without a rho-adjustment (b). The dashed line represents the overfished threshold.

Caveats

It is important to note some caveats and limitations in this study. The results of this analysis are conditional upon the underlying assumptions of modeled scenarios and the HCRs evaluated. There are additional HCR forms and adjustments to the features of the HCRs evaluated in this study that could be worthwhile exploring in future analyses based on the desired outcomes of groundfish management. One of the limitations of this analysis was that technical interactions were not simulated. We recognize that low catch limits of some groundfish stocks, such as Gulf of Maine cod, impact the realized catch of several other stocks, such as haddock. However, including these realities in the simulation would not have provided a true test of the performance of HCRs. Additionally, HCR performance is dependent upon the reference point calculation and it is important to note that we maintained the status quo approach to defining reference points in this study. OMs can also be further tuned to represent additional complexity in groundfish dynamics and operation of groundfish fisheries.

Conclusions

In summary, scenarios with different combinations of stock status, population dynamics, and stock assessment model specifications were simulated to evaluate the performance of alternative HCRs. HCR performance differed between scenarios, metrics, and time periods. When the stock was overfished, HCRs performed differently in the short-term. HCRs performed differently with a stock assessment misspecification. With a misspecification that creates large errors and retrospective patterns, the stock may not rebuild. The frequency of overfished and overfishing depended more on the type of stock assessment misspecification than the HCR. The classification of an optimal HCR will depend on the definition and prioritization of management objectives for the groundfish fishery.