Catch Advice Methods for the Northeast Multispecies Fishery:

Report of Phase 4 Work

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Executive Summary

Previous work identified a number of approaches for setting catch advice from age-based assessments for New England groundfish stock that were substantial improvements to the historical approach, often greatly reducing the overestimation in target catches. These were those that 1) used a fixed catch target in the years between assessments, and 2) adjusted the most recent estimate of population size downward to account for the pattern of frequent overestimation. Threshold-based control rules that decreased the harvest rate as the population biomass fell below the MSY level were effective at reducing harvest rates, but were overly conservative in many circumstances. These conclusions were based on five stocks which had problems of frequent, large overestimation of historical catch targets (Georges Bank cod, Gulf of Maine cod, Georges Bank yellowtail flounder, witch flounder, and Southern New England / Mid-Atlantic winter flounder), such that the effectiveness of such approaches may not be the same for other stocks in the groundfish complex.

Here we tested the performance of the successful methods for setting catch advice on a new set of groundfish stocks. Stocks included in this analysis were Georges Bank haddock, Gulf of Maine haddock, Cape Code / Gulf of Maine yellowtail flounder, Southern New England / Mid-Atlantic yellowtail flounder, and American plaice.
The successful combination of approaches previously identified was also effective for these stocks at reducing target catches, and in most years for these stocks the target catch would have been below the overfishing limit, or OFL. Across all stocks evaluated here and in the previous analysis, both the low and moderate adjustments factors we explored greatly reduced the frequency of overfishing. The original approach would have resulted in overfishing more than 50% of the time for 9 out of 10 stocks (if the actual catch equaled the target catch), whereas the low, moderate, and high abundance adjustments would have resulted in overfishing more than 50% of the time for 5, 4, and 2 stocks, respectively. Although the small and moderate adjustment factors had more frequent overfishing associated with them, they also resulted in less potential forgone yield for stocks with greater accuracy in historical assessment estimates. Thus, using a small to moderate abundance adjustment factor without doing projections may be an effective strategy for most stocks for setting catch targets from age-based assessments.

We also evaluated the performance of data-limited alternatives for setting catch advice. In agreement with previous work, performance of many of these methods was highly variable across stocks and assessments. Two of the methods (one catch-curve and one index-based approach) were consistently the better-performing options explored and often were improvements over the original method for setting catch targets. Such approaches may be particularly relevant in cases where an assessment does not pass review and data-limited methods may be needed to set catch targets.

Introduction

For many stocks in the New England groundfish complex, overfishing continues despite efforts to reduce harvest rates and rebuild overfished populations. Understanding why this occurred and potential ways this could have been avoided is of paramount importance to the resource stakeholders so that the frequency of overfishing is reduced for these stocks. Herein we detail work that is part of a larger project with the overall goals of 1) understanding how catch advice was set since 2004 and the role that scientific uncertainty played in achieving target harvest rates for New England groundfish stocks, and 2) quantifying how alternative approaches for setting catch advice would have performed in the face of this uncertainty. Work addressing the first objective found that overestimation of catch targets occurred for many groundfish stocks, such that the achieved harvest rates exceeded the target level despite catches being at or below the specified target in most years for most stocks (Wiedenmann and Jensen 2015a). The cause of this discrepancy between the target and achieved harvest rates resulted primarily from overestimation of terminal abundance in the stock assessment used as the basis for setting catch advice, but also from declining recruitment. Work addressing the second objective was divided into two parts, first testing a wide range of alternative methods for setting catch advice using a subset of groundfish stocks (Gulf of Maine (GOM) cod, Georges Bank (GB) cod, GB yellowtail flounder, witch flounder, Southern New England / Mid Atlantic (SNE/MA) winter flounder, and pollock). For these stocks a number of successful alternatives were identified, including methods that used a fixed catch target in the years between assessments, adjusted the most recent estimate of population size downward to account for the pattern of frequent overestimation, and used a threshold-based control rule that decreased the harvest rate as the population biomass fell below the MSY level (Wiedenmann and Jensen 2015 b).

The original request for proposals (RFP) for this project called for four Phases of work. Phases 1 and 2 were detailed in Wiedenmann and Jensen 2015a, and Phase 3 work was detailed in Wiedenmann and Jensen (2015b). The RFP called for work in Phase 4 to use simulation-based testing of decisions rules for a number of groundfish stocks based on the results of the Phase 3 analysis, with the overall aim to determine the robustness of these approaches. Simulation testing of a range of options under different scenarios (e.g., climate change impacts on recruitment or changes in survey catchability) tailored to specific groundfish stocks would be a large undertaking. Recent simulation work tested many of the options explored in Phase 3 for a range of general scenarios (not tailored to a specific stock), and took more than two years to complete (Wilberg et al. 2015), making such an analysis for this project unfeasible given the one year time constraint. Furthermore, it is often very difficult to account for all of the potential sources of scientific uncertainty in the assessment process when testing different harvest policies. For example, Wilberg et al. (2015) found that even in cases of high uncertainty in stock assessment estimates, using 75% of F_{MSY} as fixed harvest rate was effective at limiting overfishing in most simulation runs, and also found little difference in the frequency and magnitude of overfishing when setting catch targets with or without projections. These conclusions were based on the long-term dynamics of model simulations where assessments over- and underestimated biomass with a similar frequency, which was not the case for New England groundfish. Therefore even if sufficient time were available to conduct a full simulation study on the effectiveness of the catch advice methods identified in Phase 3, the future performance of these methods on groundfish stocks would depend on whether or not the pattern of overestimation of terminal biomass continued, and to what extent in the model.

Because of these issues with simulation testing we proposed to use the overall modeling approach used in Phase 3 to test the successful approaches identified therein on a new set of groundfish stocks as a way of determining the robustness of different approaches. Although this approach does not test the performance of methods across a range of hypothetical situations, it does test historical performance over a wider range of conditions captured across the different stocks in the groundfish complex, such as the species life histories, recruitment variability, and the magnitude of scientific uncertainty in assessment estimates. Testing these methods across a wider range of stocks has the potential to support or refute the utility of certain methods and determine whether or not any approaches can be applied across groundfish stocks.

The successful methods identified by Wiedenmann and Jensen (2015b) were based on stocks with a history of consistent, large overestimation of catch targets. Not all groundfish stocks have had a similar magnitude or frequency of overestimation, so using those methods across all groundfish stocks could have been too conservative in some cases. Here we tested the performance of the successful approaches identified in the previous analysis on five additional groundfish stocks: GB haddock, GOM haddock, American plaice, Cape Cod / Gulf of Maine (CC/GOM) yellowtail flounder, and SNE/MA yellowtail flounder. Performance of each alternative method was evaluated as before with respect to the ability to set target catches each year close to the level that would have achieved F_{MSY} in each year (estimated using the most recent stock assessment), the frequency in which overfishing would have occurred, and also in the interannual variability in catch targets for each method. The most recent assessments for both haddock stocks and plaice indicate that biomass for each has increased above the target level (NEFSC 2015), such that some of the effective approaches identified in Phase 3 may have been too conservative overall, resulting in potential yield lost to the fishery. We therefore also calculate the amount of forgone yield associated with the different methods for setting catch advice. Finally, for all stocks in this analysis and those from the Phase 3 work, we calculated the frequency with which overfishing would have occurred since 2004 under alternative methods for setting catch advice to quantify the risk of overfishing associated with each method.

Methods

This analysis uses the same approach of the Phase 3 work (Wiedenmann and Jensen 2015b) to evaluate the performance of alternative methods for setting catch advice for GB haddock, GOM haddock, plaice, CC/GOM yellowtail flounder, and SNE/MA yellowtail flounder. A full description of the methods can be found therein, but we provide a brief description of the overall approach here.

For each stock, we used the most recent assessment as the source of best available estimates of the population and fishery dynamics over time (NEFSC 2015), and focused on the catch advice following the GARM 1, 2, and 3 assessments for each stock (NEFSC 2002, 2005, 2008). GARM 1 was the basis for catch targets for 2004 and 2005, GARM 2 the basis for catch targets from 2006 through 2008, and GARM 3 the basis for catch targets starting from 2009 through 2012. When catch targets were derived from age-based assessments (GB haddock, SNE/MA and CC/GOM yellowtail flounder and plaice for GARM 1-3, and GOM haddock for GARM 3 only), we used an age structured projection model developed in R (R Core Team, 2015) that mimics the AGEPRO model (Brodziak et al. 1998), and modified the inputs when testing alternative methods. We also evaluated a variety of data-limited methods available in the R package DLMtool (Carruthers 2014) to compare performance with the more data-intensive projections. We first describe the age-structured projection model and all of the modifications we explored, and then describe the data-limited approaches.

In Phase 3 work we evaluated a range of alternative methods for setting catch targets. These methods included modifying the initial abundance-at-age, using a different way of forecasting recruitments in the projections, alternative harvest control rules, whether or not to do projections, and methods for "smoothing" the target catch time series. Of these, the smoothing methods tended to exacerbate the overestimation of catch targets, and modifying recruitment in the projections had little to no effect in most cases (Wiedenmann and Jensen 2015b). We therefore excluded these options from this analysis. A full description of the suitable methods tested here is listed in Table 2. Methods for modifying the initial abundance-at-age either modified the terminal estimate from an assessment with an adjustment factor ϕ,

$$N_{mod}(a) = \frac{N(a)}{1+\phi} \qquad (1)$$

or used the estimated abundance a number of years prior to the terminal year. The latter approach resulted in variable performance across stocks, and was excluded from this analysis. We tested using stock- and assessment-specific values of ϕ from the original assessment (Table 2), or fixed levels across stock and assessments (Table 3).

In addition to the modification of abundance, we evaluated the performance of six control rules on the new subset of stocks. The baseline run (run 1) used the historical F_{target}. For run 2 the F_{target} was set to 75% of F_{MSY} in each projection. Control rule runs 3-6 were variations of the threshold-based P^* control rule that increases the buffer size between the acceptable biological catch (ABC) and the overfishing limit (OFL) as the estimated spawning biomass falls below the target level (i.e., $S < S_{MSY}$). This control rule is currently used by the Mid-Atlantic Fishery Management Council, and was selected for the Phase 3 and current analysis because it performed very well across a range of uncertainties in the simulation work of Wilberg et al. (2015). The general P^* approach uses the point estimate of the overfishing limit, or OFL (the catch at F_{MSY}), and assumes that the point estimate of the OFL is the median of a lognormal distribution with a specified coefficient of variation (C.V.). The catch target (also called the acceptable biological catch, or ABC) is determined by selecting a percentile of the OFL distribution below the median. Selecting the 40th percentile of the OFL as the ABC implies a 40% chance of overfishing, or $P^* = 0.4$. This approach results in the catch target being lower than the median (point estimate) of the OFL, and the size of the buffer increases with a lower percentile for a given C.V., or a higher assumed C.V. for a given percentile. The MAFMC uses a C.V. of 1.0 to generate the OFL distribution, and the target P^* varies with the estimated stock size:

$$P^* = \begin{cases} 0.4 & \frac{S}{S_{MSY}} \geq 1 \\ int + slope * \frac{S}{S_{MSY}} & S_{thresh} < \frac{S}{S_{MSY}} < 1 \\ 0 & \frac{S}{S_{MSY}} \leq S_{thresh} \end{cases} \qquad (2)$$

When biomass is at or above S_{MSY}, a fixed P^* of 0.4 is used. As the biomass falls below S_{MSY}, P^* declines linearly until the S / S_{MSY} reaches some threshold level (S_{thresh}), where P^* is set to 0 and the fishery is closed. The MAFMC uses an $S_{thresh} = 0.1$ for their control rule. For control rule runs 3 and 4 we used a C.V. = 1.0, and S_{thresh}= 0.1 and 0.2, respectively. For runs 5 and 6 we used a CV = 1.2, and S_{thresh}= 0.1 and 0.2, respectively.

The final set of methods we explored for setting catch targets using age-based assessment estimates was to fix the catch over the management interval, with different ways of calculating this fixed catch target. Originally we evaluated two alternatives to the status quo of using projections. The first approach was to calculate the target catch in the first year of the management interval under the target F, and fix the target catch at this level for the remainder of the management period. For GARM 1, this requires doing projections from 2002 to 2004, and fixing the target catch for the management period (2004-2005) at the estimated target catch in 2004. The second option we explored avoids doing projections to the first year of the management period. Using GARM 1 again as an example, this would mean that the target catch in 2004-2005 was set using the estimated abundance in 2002 and the target F for the management period. Both these approaches proved successful for the stocks explored in Phase 3, as increases in biomass, and therefore catches, were predicted for most stocks following most assessments. These predicted increases often did not occur or were of smaller magnitude than originally projected, such that using a target catch that avoids using projections was more conservative (Wiedenmann and Jensen 2015b). If the estimated biomass for a stock is above the target biomass (S_{MSY}), or if there is a large cohort comprising a significant portion of the biomass (e.g., Wiedenmann et al. 2009), declines in projected biomass may result under an $F \leq F_{MSY}$. In such cases using a fixed catch based on an early part of the time period, where the predicted biomass is higher than at the end of the time period, could result in target catches being too high. Of the stocks we explored here, GB Haddock had predicted declines in biomass following the GARM 3 assessments (under a fixed target *F*; Figure 1). We therefore explored two alternative options for setting a fixed catch target: use the average target catch over the management period (PR run 4), or use the projected target catch in the final year of the management period (PR run 5; Table 3). Although GB haddock largely motivated these options, we tested their performance for all stocks following each age-based assessment.

In addition to the age-based methods for setting catch targets detailed above, we explored a range of data-limited approaches that utilize either age structured information from the catch to perform catch curve analyses, or indices of relative abundance over time to adjust the target catch based on the recent trend in the survey index. In total we evaluated 10 data-limited approaches available in the DLMtool R package (Carruthers 2014), with a description of the different methods provided in Table 4 and the specific inputs to the DLMtool package for each stock are presented in Appendix A. The data-limited methods require estimates of uncertainty in input parameters to create distributions for these inputs, and we assumed the same CV for a given input parameter across stocks, although different CVs were assumed for different inputs for a stock (Appendix A). Because of this uncertainty, a distribution of catch targets is produced for each method, and we assumed the target catch was the median of the estimated distribution. We used the data-limited methods to set catches following the GARM 1, 2, and 3 assessment, and the target catch was fixed over the management period.

Performance of the Alternative Methods

For all combinations of alternative methods we evaluated performance using four metrics. The first metric was the ratio of the estimated fishing mortality (*F*) from a given method to the catch that would have achieved F_{MSY} in a given year (the *F*-ratio). F-ratios close to 1.0 indicate that the method would have set the target catch close to achieving F_{MSY}. This metric only measures the ability of a method to limit overfishing, and does not measure the ability to rebuild overfished populations within a specified time period. We avoided quantifying the rebuilding timeline for alternate methods primarily due to the observed declines in recruitment for many stocks, such that rebuilding may not occur (or take longer than mandated) even with $F < F_{MSY}$ (unless reference points are updated).

We explored three methods for calculating $F(t)$, with each method differing by the manner in which abundance changes annually in response to the fishing intensity earlier in the time period. Each approach for calculating *F* assumed that the target catch from an alternative method was removed each year, such there was no implementation uncertainty. The first method for calculating *F* (which we call the static approach) used the fixed abundance-at-age estimates from the most recent assessment, and did not account for possible changes in abundance that may have occurred if a particular approach was more or less conservative than the catches that that occurred for a stock. The second and third approaches allowed for changes in abundance over time resulting from more or less conservative catches over time. The difference between these dynamic approaches was the way in which recruitments were handled. In the first dynamic method, recruitment in each year was fixed at the observed value from the most recent assessment (called the dynamic with fixed recruitment). This method assumes recruitment is independent of stock size, as fishing under a lower *F* would result in increased spawning biomass, yet the recruitments each year remain the same. The second dynamic approach we explored was to estimate a Beverton-Holt stock-recruit relationship for each stock, and calculate the relative deviations in each year around the predicted recruitments (called the dynamic approach with variable recruitment). With a model to predict recruitment from spawning biomass (lagged by the age at recruitment) and estimates of the relative deviations in recruitment each year, we were able to predict changes in recruitment following changes in spawning biomass under the different levels of *F*. A caveat to both of the dynamic approaches is that large changes in biomass (up or down) are not reflected in changes in the assessment estimates used to set catch targets.

The second performance measure we calculated was the frequency of years in which the target catch from an alternative method would have resulted in overfishing (if the actual removals equaled the target). The frequency (P_{OF}) was calculated as the proportion of years (2004 – 2012) in which $F(t) > F_{MSY}$. This metric was sensitive to the resulting *F* from a method, and we calculated it using the static and dynamic abundance methods described above.

The third metric we calculated was a relative measure of the interannual variation in catch, or AAV. This metric was proposed by Punt (2003), and is calculated with

$$AAV = \frac{\sum_{t>1} |C_{target}(t) - C_{target}(t-1)|}{\sum_t C(t)} \qquad (3)$$

Large values of AAV indicate a method resulted in larger interannual changes in the C_{target}.

The effective options identified by Wiedenmann and Jensen (2015b) were conservative because the stocks used in that analysis had a history of large overestimation of target catches. Although overestimation of target catches occurred for stocks in the current analysis, the magnitude of the overestimation was generally not as great (Wiedenmann and Jensen 2015a), such that some of the alternative methods explored here may be overly conservative for the current subset of stocks. We therefore calculated the potential yield that could be lost to the fishery if such approaches were used. This potential lost, or forgone yield in a given year $Y_{FG}(t)$ was calculated with

$$Y_{FG}(t) = OFL(t) - C_{target}(t) \qquad (4)$$

Positive values of $Y_{FG}(t)$ indicate that the target catch set using an alternative method was below the catch that would have achieved F_{MSY}, and thus potential yield would have been forgone if such an approach were followed. We calculated Y_{FG} using the OFL estimated using static and dynamic approaches.

For the data-limited approaches, performance was evaluated in a slightly different manner. For each approach we calculated the ratio of the target catch to the estimated OFL (calculated using the static approach), and refer to this metric as the *C*-ratio (*C*-ratio (t) $=C_{\text{target}}(t)/\text{OFL}(t)$). As with the *F*-ratio, we are looking for methods that result in a *C*-ratio close 1.0 across years for a stock.

Results

The effects that the alternative methods had on the performance metrics for a stock depended on whether or not we assumed abundance in each year changed in response to changes in the estimated F (the dynamic or static approaches). We show results from both the static and dynamic approaches (with fixed recruitment), except for GOM haddock where we did not use the dynamic approaches due to the shorter time period for which we were evaluating catches (from the GARM 3 assessment only). Estimates of the F-ratio (F / F_{MSY}) grouped by each method are shown in Figures 2 - 6 for each assessment period for each stock (plaice, SNE/MA and CC/GOM yellowtail flounder, GB and GOM haddock). Each of these Figures has a panel a) and b), corresponding to the results from the dynamic approach with fixed recruitment and the static approach, respectively. Estimates of the relative interannual variability in catches (AAV; equation 3) across methods for each stock are shown in Figures 7 - 11. The run numbers correspond to those listed in Table 3, with the run numbered 1 for a given method representing the approach originally used for a stock. For example NAA 1 refers to the model run where abundance-at-age was not modified, and PR1 the model run where projections were used in the calculation of target catches. The distribution of estimates of the F-ratio for a given run represents all other combinations of alternative methods explored (e.g., all combinations of the runs listed in Table 2 for NAA 1). The key to interpreting these plots is to compare the distribution of alternative methods relative to the original method (e.g., are NAA runs 2-7 improvements over NAA run 1?), and whether or not patterns are consistent across assessments. Also, it is important to identify which runs for a given method are the most successful, resulting in target catches close to the OFL (F-ratio close to 1.0) in majority of years ($P_{OF} < 0.5$) and with greater stability (lower AAV).

We evaluated methods for modifying the estimated abundance, alternative control rules, and different ways of fixing catches during the management period. Other methods explored previously in Phase 3 were omitted, as they proved largely ineffective at reducing target catches for the first subset of stocks explored (Wiedenmann and Jensen 2015b). Similar to the previous work, using the Mohn's ρ estimated from each assessment (NAA run 2; Table 2) to adjust the abundance was generally not as effective as using fixed adjustments ($\phi = 0.38$, 0.66 and 1.0; NAA runs 3, 4, and 5, respectively; Figures 2 -6). The largest adjustment factor was often too conservative following some assessments for SNE/MA and CC/GOM yellowtail, and GB and GOM haddock, while the small and moderate adjustment factors (NAA runs 3 and 4) tended to result in F-ratios closer to 1.0 for these stocks. For plaice, the largest adjustment factors resulted in the F-ratio closer to 1.0. Using fixed catches also proved effective, with PR runs 2 and 3 reducing catch targets in many instances. For GB haddock, however, these fixed catch runs performed poorly following the GARM 3 assessment due to a declining biomass resulting from the large 2003 cohort moving out of the population. In this instance, the projected catches were higher than the final part of the time series, and target catches based on the projected catch in the final year of the management period was an effective alternative (Figure 5b). Threshold-base control rules (CR runs 3-6) were also effective at reducing catch targets and getting F-ratios closer to 1.0 in many instance, but these approaches alone were generally not sufficient at reducing catch targets below the OFL. As we found in the previous analysis, methods that fixed the target catch during the management period resulted in greater stability in catches (lower AAV) compared to changing catch targets based on projections (Figures 7-11).

Thus far we have discussed the individual performance of the alternative approaches, but it is important to identify the effectiveness of combinations of these approaches at setting catch targets close to the OFL in most years. In Phase 3 work we used regression trees to help identify effective combinations of methods. Because we previously identified effective combinations of approaches, our focus here is in quantifying the effectiveness of these approaches on this new subset of stocks. For GOM cod, GB cod, GB yellowtail flounder, witch flounder, and SNE/MA winter flounder the most successful approaches overall were those that together used a fixed abundance adjustment factor (assuming biomass following each assessment was overestimated by 38, 66 or 100%; NAA runs 3, 4, and 5, respectively), fixed the catch without projections (PR run 3), and used the original control rule (CR run 1; see Table 3 for details). In Table 5 we show the mean *F*-ratio for each stock in the current analysis following the GARM 1, 2, and 3 assessments for some of the more effective approaches identified by Wiedenmann and Jensen (2015b). Combining the threshold-based control rules with the abundance modifications without doing projections was very effective at limiting overfishing across stocks, although this combination was often very conservative, resulting in mean *F*-ratios between 0 and 0.73, depending on the stock and the size of the abundance adjustment. For SNE/MA and CC/GOM yellowtail, the threshold-based control rules triggered the closure of the fishery in some cases (Table 5). Without a threshold-based control rule, using fixed abundance modifications and not doing projections (NAA runs 3, 4, and 5) were often effective at setting catches below the OFL, although *F*-ratios varied by stock and by assessment depending on the size of the adjustment (and on whether or not the static or dynamic abundance approach was used). For the lowest adjustment factor ($\phi = 0.38$ the F-ratios ranged between 0.73 and 3.29 on average, for SNE/MA yellowtail and GB haddock, respectively. For the moderate adjustment factor ($\phi = 0.66$) target catches ranged from 0.56 to 2.59 of the OFL, while for the largest adjustment factor considered ($\phi = 1.0$), they ranged from 0.43 to 1.67, on average, for SNE/MA yellowtail and GB haddock, respectively. (Table 5).

Following the GARM 3 assessment for GB haddock, a decline in biomass occurred as the very large 2003 year-class dwindled. In this case, not doing projections to calculate the target catch was not an effective strategy, as it would have kept catches higher than the projected target catches (Figure 1). In this case, using the projection-estimated target catch in the last year of management period was a much more effective option (*F*-ratio = 1.67 compared to 6.99, for example, when $\phi = 0.66$ and without using a threshold-based control rule; Table 5).

In many instances using the larger abundance adjustments would have kept the target catch below the OFL. National Standard 1 requires catch limits be set that have a low probability of overfishing (Federal Register 2009). Even under conservative harvest policies, overfishing is likely to occur in some years for a stock. If a harvest policy results in the target catch exceeding the OFL more than half the time, than the policy is more likely than not to result in overfishing (if the target catch is removed). For each stock from the current and previous (Phase 3) analysis, we calculated the proportion of years in which $F > F_{MSY}$ as a measure of the frequency of overfishing. Under the original catch targets, overfishing would have occurred more than 50% of the time for 9 of the 10 stocks evaluated with age-based catch targets (Table 6). When catch targets were fixed without using a threshold-based control rule, using fixed abundance adjustments of 0.38 and 0.66 resulted in between 4 and 7 of 10 stocks having overfishing more than 50% of the time, depending on whether or not the static or dynamic abundance approaches were used. Using the largest adjustment factor here reduced the number to 2 and 4 stocks out of 10 for the dynamic and static approaches, respectively (Table 6). When using a threshold-based control rule, 0 stocks had overfishing in more than 50% of the years for ϕ = 0.66 and 1.0, and only 2 stocks when ϕ = 0.38.

Although many of the alternative catch-setting methods would have reduced the frequency of overfishing for many stocks relative to original approach, the target catch was conservative ($F << F_{MSY}$) in some cases. For example, with the moderate fixed adjustment ($\phi = 0.66$) without a threshold-based control rule, the estimated F would have been 22% of F_{MSY} for SNE/MA yellowtail flounder following the GARM 2 assessment, and between 40 and 74% of F_{MSY} for GB haddock following the GARM 1 and 2 assessments (Table 5). Target catches for GB haddock were higher than all other groundfish stocks evaluated here and in the previous analysis, such that overly conservative approaches for this stock could have resulted in a substantial amount of forgone yield to the fishery. For all stocks we calculated the potential forgone yield (Y_{FG}) each year as the difference between the OFL and the target catch (equation 4).
In Table 7 we show the target catches and the resulting Y_{FG} when using the fixed abundance modifications (NAA runs 3, 4, and 5) without projections (PR run 3) and the original control rule (CR run 1). In this example, Y_{FG} values are based on the OFL calculated using the fixed abundance-at-age estimates from the most recent assessment (the static approach). Our purpose here is to illustrate the theoretical potential for forgone yield based on some alternative methods, and we note that different values of Y_{FG} would result when using the dynamic approach to calculate the OFL. Positive values of Y_{FG} indicate target catches were below the OFL, and negative values indicate target catches were above the OFL. Forgone yield varied considerably across stocks, and over time for a given stock. For GB haddock, for example, the total target catch (2004-2012) for adjustment factors of 0.66 and 1.0 was 206,100, and 171,917 mt, representing a theoretical amount of forgone yield of 32,030 and 66,213 mt relative to the OFL. It is important to point out that even though these methods were conservative for GB haddock, the actual catches for this stock were similar in magnitude (166,526 mt caught based on a total target catch of 569,419 mt), such that the forgone yield under these alternative approaches (if the target catches could have been fully removed from the population) would be less than what actually occurred for the stock (Table 7).

Performance of the data-limited methods we evaluated was variable across stocks and assessments. Some methods were consistent improvements to the original target catches, but many would still have resulted in overfishing (C-ratio > 1). Wiedenmann and

Jensen (2015b) identified two methods that performed well across stocks, the catch-curve method Fratio_CC, and the index-based method Itarget4 (see Table 4 for details). One or both of these approaches performed well for each stock relative to the other data-limited methods, indicating consistency in these methods across stocks. However, target catches for both of these methods were still high in some cases, particularly for CC/GOM and SNE/MA yellowtail flounder, where catches were between 1.6 and 2.35 times the OFL, on average.

Conclusions

Previously we evaluated a number of alternative methods for setting catch advice for a subset of New England groundfish stocks to identify possible methods, or combinations of methods, that would have reduced the frequency of overfishing since 2004. For these stocks (GB and GOM cod, GB yellowtail founder, witch flounder, and SNE/MA winter flounder), we identified a number of approaches using information from age-based assessments that were substantial improvements over the original target catches. The most successful approaches were those that 1) used a fixed catch target in the years between assessments, and 2) adjusted the most recent estimate of population size downward to account for the pattern of frequent overestimation. We tested fixed adjustments (ϕ) of 0.38, 0.66, and 1.0, and found they were significant improvements relative to the original catch target, resulting in F closer to F_{MSY} in many years when used in conjunction with fixing the target catch (without doing projections) and the original control rule. Despite the improvements in the target catches, however, frequent overfishing would still have occurred for GOM cod, GB yellowtail flounder, and witch flounder using these methods. Using a threshold-based control rule that decreases the harvest rate as the population biomass declines below the MSY level was also effective to a lesser degree, but when used in combination with the abundance modification methods it was overly conservative and on occasion would have resulted in the closure of the fishery.

In this analysis we tested these successful methods on another set of groundfish stocks (plaice, CC/GOM and SNE/MA yellowtail flounder, GB and GOM haddock) to determine their broader effectiveness. The combination of approaches was also effective for these stocks at reducing target catches, and in many years for these stocks F would have been below F_{MSY}. As in the previous analysis, the threshold-based control rule was overly conservative in many cases when used in combination with the abundance adjustment methods, resulting in F well below F_{MSY}. While not doing projections and fixing the target catch over the management period was generally effective at reducing overfishing, using this strategy is not recommended when the biomass of a stock is projected to decline over the management period (for a fixed target harvest rate) because the fixed target catch would be higher than the projected catch. Fixing the target catch over the management period using the projected catch at the end of the management period was a successful alternative in such a case, as it occurred for GB haddock following the GARM 3 assessment.

No single management option will prevent overfishing from occurring in all years, but to comply with federal guidelines a harvest policy that results in frequent overfishing should be reevaluated. Across stocks under the original method for setting catch targets, overfishing would have occurred more than 50% of the time for 9 of the 10 stocks evaluated (if the actual catch equaled the target catch). Based on our results, the important question from a management perspective is what size adjustment factor should be used to reduce overfishing, and should a single value be used across stocks? When combined with the original control rule without doing projections, adjustment factors of 0.38, 0.66 and 1.0 would have resulted in overfishing more than half the time for 5, 4 and

2 out of the 10 stocks, respectively (when accounting for changes in biomass in response to the different catch targets). These options were significant improvements over the original method for setting catch targets, with the lower adjustment factor resulting in more frequent overfishing (50% of the stocks had overfishing in more than 50% of the years), but less potential forgone yield for many stocks, while the largest adjustment factor had less overfishing (20% of the stocks) but greater potential foregone yield, particularly for GB haddock. Thus, an adjustment factor of $\phi = 0.38$ or 0.66 (representing 27.5 and 37.5% declines in the estimated abundance, respectively) may be preferred for most groundfish stocks except those with a history of very high overestimation of terminal biomass, such as GOM cod, GB yellowtail flounder, and witch flounder.

We also evaluated performance of data-limited alternatives for setting catch advice, and found considerable variation in catch targets across methods for each stock. Many of these methods were improvements over the original catch targets, although the reductions in catches were not always sufficient to prevent overfishing. Two of the methods (one catch-curve approach called Fratio_CC, and one index-based approach called Itarget4) were consistently some of the better-performing options explored. Further exploration of the factors affecting the performance of these methods for New England groundfish stocks could prove insightful. Such methods may become particularly relevant in cases where an assessment does not pass review (such as the recent GB cod assessment) and data-limited methods are needed as a fallback approach for setting catch targets.

All the methods evaluated herein are temporary fixes to a larger problem. The frequency, magnitude and direction of the uncertainty in catch targets may change with subsequent assessments, such that the successful approaches we identified in this work may no longer be effective for setting future catch targets. We therefore recommend that this sort of retrospective analysis on the performance of catch advice be done on a regular basis to determine the performance of recent catch advice. Furthermore, an exploration into why catch advice since 2004 has been overestimated for the majority of groundfish stocks is warranted. Identifying the sources of this uncertainty, and potential ways to address them in the assessment or projection models is of paramount importance for the setting of sustainable future catch targets.

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Table 1. Stocks used in this analysis and the most recent assessments that passed review that were the sources of best available (updated) information for each stock.

Full Stock Name	Abbreviated Name	Most Recent Assessment
American plaice	Plaice	NEFSC 2015
Cape Cod / Gulf of Maine Yellowtail Flounder	GOM Cod	NEFSC 2015
Southern New England / Mid-Atlantic Yellowtail Flounder	SNE / MA Yellowtail	NEFSC 2015
Georges Bank Haddock	GB Haddock	NEFSC 2015
Gulf of Maine Haddock	GOM Haddock	NEFSC 2015

Table 2. Estimated Mohn's ρ (a measure of the mean retrospective error in terminal assessment estimates; Mohn 1999) for biomass and the fishing mortality rate for each stock by assessment. GOM haddock was assessed with an index-based assessment in GARM 1 and 2 and therefore does not have estimates of Mohn's ρ for these assessments.

			Mohn's ρ	
Stock	Variable	GARM 1	GARM 2	GARM 3
GB	Biomass	-0.06	-0.10	0.07
Haddock	Fishing mortality	0.03	-0.05	0.10
GOM	Biomass	-	-	0.08
Haddock	Fishing mortality	-	-	0.65
CC / GOM	Biomass	0.42	0.20	0.13
Yellowtail Flounder	Fishing mortality	-0.51	0.15	-0.03
SNE / MA	Biomass	1.02	0.39	0.11
Yellowtail Flounder	Fishing mortality	-0.64	0.30	0.46
American	Biomass	-0.01	-0.14	0.41
Plaice	Fishing mortality	0.11	-0.10	-0.31

Table 3. Description of the alternative methods used to calculate target catches from age-based stock assessments. The abbreviations in parenthesis are used identify the different approaches in the Figures.

Modification	Run	Description
	1	Use the model-estimated terminal abundance estimates
Initial	2	Adjust the terminal estimates with the ϕ = estimated Mohn's ρ (Table 3)
Abundance-	3	Adjust the terminal estimate with a fixed $\phi = 0.37$
at-age (NAA)	4	Adjust the terminal estimate with a fixed $\phi = 0.66$
	5	Adjust the terminal estimate with a fixed $\phi = 1.00$
	1	Use the original target F in each year
	2	Use 75% FMSY in all years as the control rule
Control	3	Use the threshold P* control rules with a max P*=0.4; CV = 1.0; minimum $S / S_{MSY} = 0.1$
Rules (CR)	4	Use the threshold P* control rules with a maximum P*=0.4; CV = 1.0; minimum $S / S_{MSY} = 0.2$
	5	Use the threshold P* control rules with a maximum P*=0.4; CV = 1.2; minimum $S / S_{MSY} = 0.1$
	6	Use the threshold P* control rules with a maximum P*=0.4; CV = 1.2; minimum $S / S_{MSY} = 0.2$
Projections	1	Use projections to estimate target catch each year
(PR)	2	Set a fixed target catch using the projection-estimated abundance in the first year of the management period
	3	Set a fixed target catch using the terminal estimate of abundance (no projections)
	4	Set a fixed target catch using the mean projected catch over the management period
	5	Set a fixed target catch using the projection-estimated abundance in the final year of the management period

Table 4. A list of the data-limited methods used in this analysis to predict catch targets for all stocks. Each method is available in the DLMtool R package developed by Carruthers (2014).

Control rule abbreviation	Description	Source
BK_CC	Beddington and Kirwood life history method combined with catch curve analysis. Calculates the OFL using a catch curve estimate of current F and an approximation of FMSY based on length at first capture.	Beddington and Kirkwood 2005
Fdem_CC	Demographic MSY method using catch-curve analysis to estimate recent Z	McCallister et al. 2001; Carruthers 2014
Fratio_CC	Calculates the OFL based on a fixed F_{MSY} / M ratio and a catch curve estimate of current stock size	Gulland 1971; Martell and Froese 2012; Carruthers 2014
GB_slope	A harvest control rule similar to SBT1 that modifies a time-series of catch recommendations aiming for stable catch rates, keeping annual changes within + / - 20%	Geromont and Butterworth (2014)
Islope1	The least biologically precautionary of two constant index / CPUE methods proposed by Geromont and Butterworth 2014	Geromont and Butterworth 2014
Islope4	The most biologically precautionary of two constant index / CPUE methods proposed by Geromont and Butterworth 2014	Geromont and Butterworth 2014
Itarget1	The least biologically precautionary of two index/CPUE target management procedures proposed by Geromont and Butterworth 2014.	Geromont and Butterworth 2014
Itarget4	The most biologically precautionary of two index/CPUE target management procedures proposed by Geromont and Butterworth 2014.	Geromont and Butterworth 2014
SBT1	A harvest control rule that makes incremental adjustments to quota recommendations based on the apparent trend in surplus production.	http://www.ccsbt.org/site/recent_assessment.php
DCAC_40	A method for adjusting average catches based on an assumed fixed change in biomass over the time period.	Carruthers 2014

Table 6. The mean *F*-ratio (F / F_{MSY}) across a subset of alternative methods. Results are shown for runs where no projections, smoothing, or recruitment modification methods were used (PR run 3, AVG run 1, R run 1, respectively) using different adjustment factors (ϕ = 0, 0.37, 0.68, and 1.0), control rules (CR runs 1 and 3), and when *F* was calculated either using static abundance-at-age estimates from the most recent assessment, or dynamic abundance-at-age estimates (with fixed recruitment) that change in response to different catch targets. See Table 3 for details on the specific model runs. Values in bold represent the method where the frequency of overfishing (proportion of years when $F > F_{MSY}$) was less than 0.5.

	Adj. Factor (ϕ)	0.00	0.38	0.38	0.66	0.66	1.00	1.00	0.38	0.38	0.66	0.66	1.00	1.00
	Abundance Static (S) or Dynamic (D)?	S	S	D	S	D	S	D	S	D	S	D	S	D
Stock	Control rule run	1	1	1	1	1	1	1	3	3	3	3	3	3
Plaice	GARM 1	5.55	3.20	3.40	2.53	2.55	2.00	1.95	0.78	0.70	0.55	0.50	0.38	0.33
	GARM 2	3.57	1.78	2.53	1.42	1.67	1.17	1.17	0.35	0.28	0.27	0.18	0.18	0.13
	GARM 3	2.05	0.93	1.38	0.74	0.90	0.61	0.65	0.49	0.40	0.34	0.26	0.25	0.19
	Mean	3.72	1.97	2.44	1.56	1.71	1.26	1.26	0.54	0.46	0.38	0.32	0.27	0.22
	P_{OF}	1.00	0.67	0.78	0.67	0.67	0.33	0.56	0.00	0.00	0.00	0.00	0.00	0.00
CC/GOM Yellowtail	GARM 1	5.34	3.14	2.48	2.43	1.86	1.93	1.45	0.30	0.21	0.21	0.16	0.14	0.11
	GARM 2	11.95	2.10	0.89	1.68	0.61	1.33	0.46	0.00	0.00	0.00	0.00	0.00	0.00
	GARM 3	3.48	1.21	0.67	0.97	0.50	0.80	0.39	0.36	0.16	0.25	0.12	0.18	0.09
	Mean	6.92	2.15	1.35	1.69	0.99	1.36	0.77	0.22	0.13	0.15	0.09	0.11	0.07
	P_{OF}	1.00	0.78	**0.33**	0.67	**0.22**	0.67	**0.22**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
SNE/MA Yellowtail	GARM 1	16.84	1.79	1.47	1.41	1.13	1.13	0.89	0.00	0.00	0.00	0.00	0.00	0.00
	GARM 2	0.70	0.38	0.29	0.31	0.22	0.26	0.18	0.00	0.00	0.00	0.00	0.00	0.00
	GARM 3	2.17	0.63	0.43	0.51	0.34	0.41	0.27	0.23	0.14	0.13	0.08	0.00	0.00
	Mean	6.57	0.93	0.73	0.75	0.56	0.60	0.45	0.08	0.05	0.04	0.03	0.00	0.00
	P_{OF}	0.56	**0.22**	**0.22**	**0.22**	**0.22**	**0.11**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
GB Haddock	GARM 1	1.26	0.53	0.50	0.42	0.40	0.35	0.33	0.13	0.12	0.08	0.08	0.06	0.06
	GARM 2	4.57	0.92	0.81	0.74	0.62	0.60	0.48	0.43	0.32	0.30	0.21	0.21	0.15
	GARM 3	5.01	8.42	15.12	6.99	13.83	4.06	8.09	7.92	9.58	4.84	7.58	2.89	1.93
	GARM 3*	5.01	2.25	-	1.67	-	1.30	-	1.62	-	1.24	-	0.99	-
	Mean	3.61	3.29	5.48	2.72	4.95	1.67	2.97	2.82	3.34	1.74	2.62	1.05	0.71
	Mean*	3.61	1.23	-	0.95	-	0.75	-	0.73	-	0.54	-	0.42	-
	P_{OF}	1.00	0.56	0.56	0.56	**0.44**	**0.44**	**0.44**	**0.44**	**0.33**	**0.33**	**0.33**	**0.33**	**0.22**
GOM Haddock	GARM 3	1.01	0.76	-	0.61	-	0.50	-	0.53	-	0.36	-	0.26	-
	P_{OF}	**0.33**	**0.00**	-	**0.00**	-	**0.00**	-	**0.00**	-	**0.00**	-	**0.00**	-

Table 6. Similar to Table 5, but showing the proportion of years (2004-2012) in which $F > F_{MSY}$ for all stocks with age-based assessments evaluated in this analysis and in Phase 3 work. Results are shown for runs where no projections were used (PR run 3) using different adjustment factors (ϕ = 0, 0.37, 0.68, and 1.0), control rules (CR runs 1 and 3), and when F was calculated either using static abundance-at-age estimates from the most recent assessment, or dynamic abundance-at-age estimates (with fixed recruitment) that change in response to different catch targets. See Table 3 for details on the specific model runs.

Stock	Adj. Factor (ϕ) Abundance Static (S) or Dynamic (D)? Control rule run	0.00 S 1	0.38 S 1	0.38 D 1	0.66 S 1	0.66 D 1	1.00 S 1	1.00 D 1	0.38 S 3	0.38 D 3	0.66 S 3	0.66 D 3	1.00 S 3	1.00 D 3
GB Cod		1.00	0.75	0.25	0.75	0.25	0.25	0.25	0.00	0.00	0.00	0.00	0.00	0.00
GOM Cod		1.00	1.00	0.56	1.00	0.33	0.89	0.22	0.33	0.00	0.11	0.00	0.11	0.00
GB Haddock		1.00	0.56	0.56	0.56	0.44	0.44	0.44	0.44	0.33	0.33	0.33	0.33	0.22
GOM Haddock		0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Witch		1.00	0.78	0.67	0.56	0.56	0.56	0.33	0.56	0.56	0.44	0.11	0.33	0.00
Plaice		1.00	0.67	0.78	0.67	0.67	0.33	0.56	0.00	0.00	0.00	0.00	0.00	0.00
SNE/MA Winter		0.56	0.22	0.22	0.22	0.22	0.11	0.11	0.00	0.00	0.00	0.00	0.00	0.00
GB Yellowtail		1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.56	0.22	0.44	0.22	0.11	0.00
CC/GOM Yellowtail		1.00	0.78	0.33	0.67	0.22	0.67	0.22	0.00	0.00	0.00	0.00	0.00	0.00
SNE/MA Yellowtail		0.56	0.22	0.22	0.22	0.22	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Proportion of stocks with overfishing > 50% of the time		0.9	0.7	0.5	0.7	0.4	0.4	0.2	0.2	0.2	0	0	0	0

Table 7. Original target catch (mt) and the observed catch compared to the target catches set using abundance adjustment factors of 0.38, 0.66, and 1.0 (equation 1) without a threshold-based control rule (CR run 1) and without projections (PR run 3) for all stocks except GB haddock following GARM 3 (where the catch is based on PR run 5). The estimated OFL was calculated using the fixed abundance-at-age estimates from the most recent assessment for each stock., and forgone yield (Y_{FG} was calculated using the fixed OFL using equation 3). Negative values of Y_{FG} indicate the target catches were higher than the OFL, and vice-versa.

Stock	Year	Original Target	Observed	OFL	New Target $\phi = 0.38$	Y_{FG} $\phi = 0.38$	New Target $\phi = 0.66$	Y_{FG} $\phi = 0.66$	New Target $\phi = 1.0$	Y_{FG} $\phi = 1.0$
Plaice	2004	3,695	2,070	855	2,536	-1,681	2,093	-1,238	1,737	-882
	2005	3,625	1,636	1,033	2,536	-1,503	2,093	-1,060	1,737	-704
	2006	3,666	1,402	1,041	2,363	-1,322	1,950	-909	1,618	-577
	2007	4,104	1,238	1,882	2,363	-481	1,950	-68	1,618	264
	2008	5,121	1,358	1,627	2,363	-736	1,950	-323	1,618	9
	2009	3,614	1,770	1,712	2,496	-784	2,060	-348	1,710	2
	2010	3,156	1,796	2,510	1,915	595	1,581	929	1,312	1,198
	2011	3,444	1,568	2,658	1,915	743	1,581	1,077	1,312	1,346
	2012	3,632	1,747	2,574	1,915	659	1,581	993	1,312	1,262
	Total	30,425	12,838	13,320	18,486	-5,168	15,256	-1,938	12,663	655
CC/GOM Yellowtail	2004	881	1,186	298	709	-411	585	-287	485	-187
	2005	1,233	997	257	709	-452	585	-328	485	-228
	2006	650	620	167	374	-207	309	-142	256	-89
	2007	1,078	633	213	374	-161	309	-96	256	-43
	2008	1,406	699	222	374	-152	309	-87	256	-34
	2009	608	639	278	497	-219	410	-132	340	-62
	2010	863	633	391	382	9	315	76	262	129
	2011	1,041	758	373	382	-9	315	58	262	111
	2012	1,159	1,092	402	382	20	315	87	262	140
	Total	8,919	7,257	2,601	4,183	-1,582	3,452	-851	2,865	-264
SNE/MA Yellowtail	2004	707	619	230	313	-83	258	-28	214	16
	2005	1,982	346	166	313	-147	258	-92	214	-48
	2006	146	396	206	116	90	96	110	80	126
	2007	213	502	318	116	202	96	222	80	238
	2008	312	583	400	116	284	96	304	80	320
	2009	272	453	375	235	140	194	181	161	214
	2010	493	291	353	245	108	202	151	168	185
	2011	687	390	389	245	144	202	187	168	221
	2012	1,002	563	359	245	114	202	157	168	191
	Total	5,814	4,143	2,797	1,944	852	1,604	1,192	1,331	1,465
GB Haddock	2004	24,855	18,253	21,111	12,116	8,995	9,999	11,112	8,299	12,812
	2005	27,692	21,814	22,106	12,116	9,990	9,999	12,107	8,299	13,807
	2006	49,829	15,989	19,093	23,949	-4,856	19,765	-672	16,405	2,688
	2007	103,329	16,815	26,320	23,949	2,371	19,765	6,555	16,405	9,915
	2008	121,681	21,021	41,820	23,949	17,871	19,765	22,055	16,405	25,415
	2009	92,888	23,126	42,909	64,769	-21,860	53,492	-10,583	44,382	-1,473
	2010	62,515	25,903	31,793	29,262	2,531	24,438	7,355	20,574	11,219
	2011	46,784	16,670	23,089	29,262	-6,173	24,438	-1,349	20,574	2,515
	2012	39,846	6,935	9,889	29,262	-19,373	24,438	-14,549	20,574	-10,685
	Total	569,419	166,526	238,130	248,632	-10,502	206,100	32,030	171,917	66,213
GOM Haddock	2009	1564	946	1,526	1,140	386	941	585	781	745
	2010	1,265	958	1,349	891	458	736	613	611	738
	2011	1,206	744	1,161	891	270	736	425	611	550
	2012	1,013	739	924	891	33	736	188	611	313
	Total	5,048	3,387	4,960	3,814	1,146	3,148	1,812	2,613	2,347

Table 7 continued.

Stock	Year	Original Target	Observed	OFL	New Target $\phi = 0.38$	Y_{FG} $\phi = 0.38$	New Target $\phi = 0.66$	Y_{FG} $\phi = 0.66$	New Target $\phi = 1.0$	Y_{FG} $\phi = 1.0$
GOM Cod	2004	4,850	5,769	1,995	3,508	-1,513	2,895	-900	2,403	-408
	2005	6,372	5,258	1,511	3,508	-1,997	2,895	-1,384	2,403	-892
	2006	5,146	4,207	1,341	2,561	-1,220	2,113	-772	1,754	-413
	2007	10,020	5,485	1,749	2,561	-811	2,113	-364	1,754	-5
	2008	10,491	7,187	1,894	2,561	-667	2,113	-219	1,754	140
	2009	10,839	8,247	1,984	4,730	-2,746	3,904	-1,920	3,240	-1,256
	2010	8,530	7,517	1,781	3,625	-1,844	2,991	-1,211	2,483	-702
	2011	9,012	6,673	1,292	3,625	-2,332	2,991	-1,699	2,483	-1,191
	2012	9,018	3,472	621	3,625	-3,004	2,991	-2,370	2,483	-1,862
	Total	65,260	50,343	13,547	26,677	-13,129	22,016	-8,469	18,273	-4,726
GB Cod	2004	3,949	5,171	1,974	3,496	-1,522	2,886	-911	2,395	-421
	2005	4,830	5,071	1,695	3,496	-1,801	2,886	-1,191	2,395	-700
	2006	7,458	4,442	1,820	2,343	-523	1,934	-114	1,605	215
	2007	9,822	5,665	1,880	2,343	-463	1,934	-54	1,605	275
	2008	11,855	5,164	1,838	2,343	-505	1,934	-96	1,605	233
	2009	11,368	4,646	2,131	2,956	-826	2,440	-309	2,025	106
	2010	4,812	3,959	2,542	2,268	274	1,872	671	1,554	989
	2011	5,616	4,448	3,559	2,268	1,291	1,872	1,687	1,554	2,005
	Total	59,710	38,566	17,439	21,515	-4,076	17,756	-317	14,738	2,702
Witch	2004	5,174	3,247	1,196	2,532	-1,335	2,089	-893	1,734	-538
	2005	6,992	2,810	1,113	2,532	-1,419	2,089	-977	1,734	-622
	2006	5,511	1,957	759	1,697	-938	1,400	-641	1,162	-403
	2007	5,075	1,175	644	1,697	-1,052	1,400	-756	1,162	-518
	2008	4,331	1,075	515	1,697	-1,181	1,400	-885	1,162	-647
	2009	3,558	1,068	566	556	10	459	107	381	185
	2010	944	855	403	425	-22	351	52	291	112
	2011	1,369	947	467	425	42	351	116	291	176
	2012	1,639	1,110	473	425	48	351	122	291	182
	Total	34,593	14,244	6,137	11,985	-5,848	9,891	-3,754	8,210	-2,073
GB Yellowtail	2004	7,900	6,400	1,464	7,185	-5,720	5,929	-4,465	4,921	-3,457
	2005	6,000	4,100	881	7,185	-6,304	5,929	-5,049	4,921	-4,041
	2006	3,000	2,500	438	2,330	-1,892	1,923	-1,485	1,596	-1,158
	2007	1,300	1,100	398	2,330	-1,932	1,923	-1,525	1,596	-1,198
	2008	2,500	1,700	629	2,330	-1,701	1,923	-1,294	1,596	-967
	2009	2,100	1,900	570	993	-424	820	-250	680	-111
	2010	2,000	1,300	427	1,233	-806	1,018	-591	845	-418
	2011	2,700	1,100	479	1,233	-755	1,018	-539	845	-366
	2012	1,200	600	524	1,233	-709	1,018	-493	845	-320
	Total	28,700	20,700	5,810	26,052	-20,243	21,501	-15,691	17,846	-12,036
SNE/MA Winter	2004	2,860	1,942	1,588	1,902	-314	1,570	18	1,303	285
	2005	3,550	1,563	1,510	1,902	-393	1,570	-60	1,303	207
	2006	2,481	2,023	1,767	954	812	788	979	654	1,113
	2007	3,016	1,867	1,861	954	907	788	1,073	654	1,207
	2008	3,577	1,298	1,572	954	618	788	784	654	918
	2009	3,309	532	1,412	0	1,412	0	1,412	0	1,412
	2010	644	363	1,585	35	1,550	29	1,556	24	1,561
	2011	897	531	1,722	35	1,687	29	1,693	24	1,698
	2012	626	650	1,780	35	1,745	29	1,751	24	1,756
	Total	20,960	10,769	14,797	6,773	8,024	5,589	9,208	4,639	10,158

Table 8. The ratio of the target catches from each data-limited method (see Table 5 for descriptions of each method) to the catch at F_{MSY} (the OFL) for each stock, where the OFL was calculated using the fixed abundance-at-age estimates from the most recent assessment (the static approach). For each assessment, the fall NEFSC index of abundance and the estimated catch at age in the fishery were used through the terminal year (2001, 2004, and 2007 for GARM 1, 2, and 3 respectively). Base is the original catch target ratio for each stock.

Stock	Assessment	Base	BK_CC	Fratio_CC	Fdem_CC	SBT1	GB_slope	Itarget1	Itarget4	Islope1	Islope4	DCAC_40
Plaice	GARM 1	3.94	2.31	1.57	6.22	4.62	3.77	2.50	1.58	2.52	1.72	4.66
	GARM 2	2.64	0.86	0.56	2.23	1.08	1.31	1.45	0.85	3.31	1.79	2.69
	GARM 3	1.69	0.29	0.19	0.76	0.38	0.31	0.44	0.25	0.20	0.18	1.53
	Mean	2.75	1.15	0.78	3.07	2.03	1.80	1.46	**0.89**	2.01	1.23	2.96
CC/GOM Yellowtail	GARM 1	3.38	8.20	2.87	8.38	9.41	9.41	4.71	2.83	5.78	4.28	4.80
	GARM 2	4.25	5.71	2.06	5.78	5.24	4.31	4.55	3.21	6.01	5.12	6.19
	GARM 3	2.50	1.85	0.66	1.92	1.59	1.92	1.48	1.00	2.40	1.74	3.35
	Mean	3.38	5.26	**1.86**	5.36	5.41	5.21	3.58	2.35	4.73	3.72	4.78
SNE/MA Yellowtail	GARM 1	7.09	41.57	3.35	7.60	7.24	5.86	6.19	3.14	4.24	3.55	27.45
	GARM 2	0.72	14.29	1.13	2.52	1.90	1.52	1.82	1.17	2.08	1.71	15.47
	GARM 3	1.91	16.89	1.27	2.88	1.35	1.64	0.82	0.52	1.26	0.88	12.82
	Mean	3.24	24.25	1.92	4.34	3.50	3.01	2.94	**1.61**	2.52	2.05	18.58
GB Haddock	GARM 1	1.22	0.80	1.05	2.88	0.53	0.65	0.30	0.16	0.70	0.36	0.29
	GARM 2	2.83	0.40	0.55	1.41	0.55	0.67	0.47	0.22	6.49	2.57	0.22
	GARM 3	2.30	0.59	0.78	2.11	0.77	0.62	0.88	0.41	-	-	0.37
	Mean	2.12	0.59	**0.79**	2.13	0.62	0.65	0.55	0.26	3.59	1.47	0.29
GOM Haddock	GARM 1	-	3.71	0.44	0.51	0.45	0.37	0.41	0.21	0.09	0.12	0.63
	GARM 2	-	5.53	0.68	0.78	0.72	0.59	0.65	0.33	0.14	0.19	1.02
	GARM 3	0.94	44.05	4.22	4.56	1.15	0.99	0.50	0.35	0.90	0.69	1.53
	Mean	0.94	17.76	1.78	1.95	0.78	0.65	0.52	0.30	0.38	0.33	**1.06**

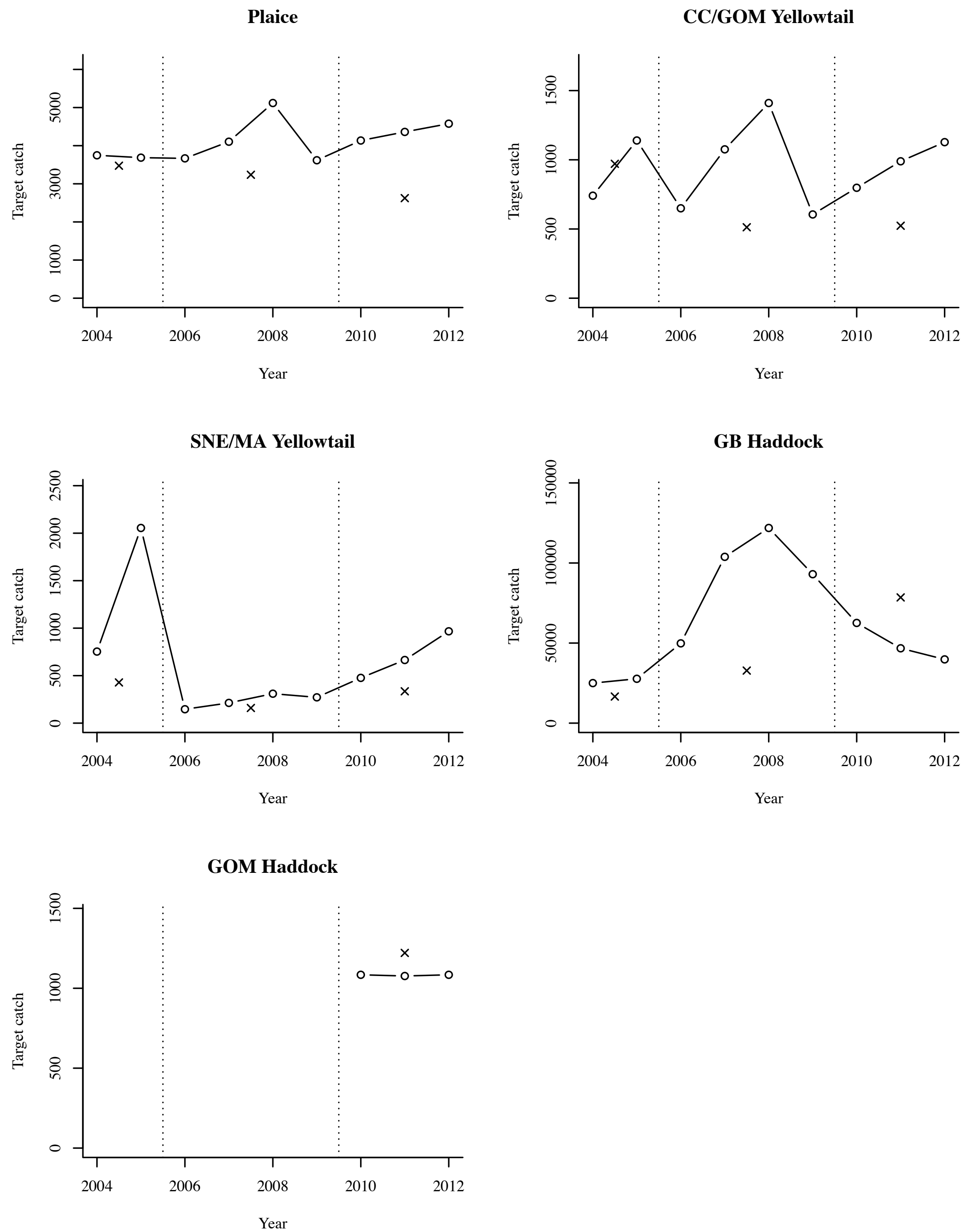

Figure 1. Projected catch (mt) under the original target *F* using the unmodified abundance at age estimates. Dashed vertical lines separate the catch advice from the GARM 1, 2, and 3 management periods, and the X in the middle of each management period is the estimated target catch under the target *F* without doing any projections.

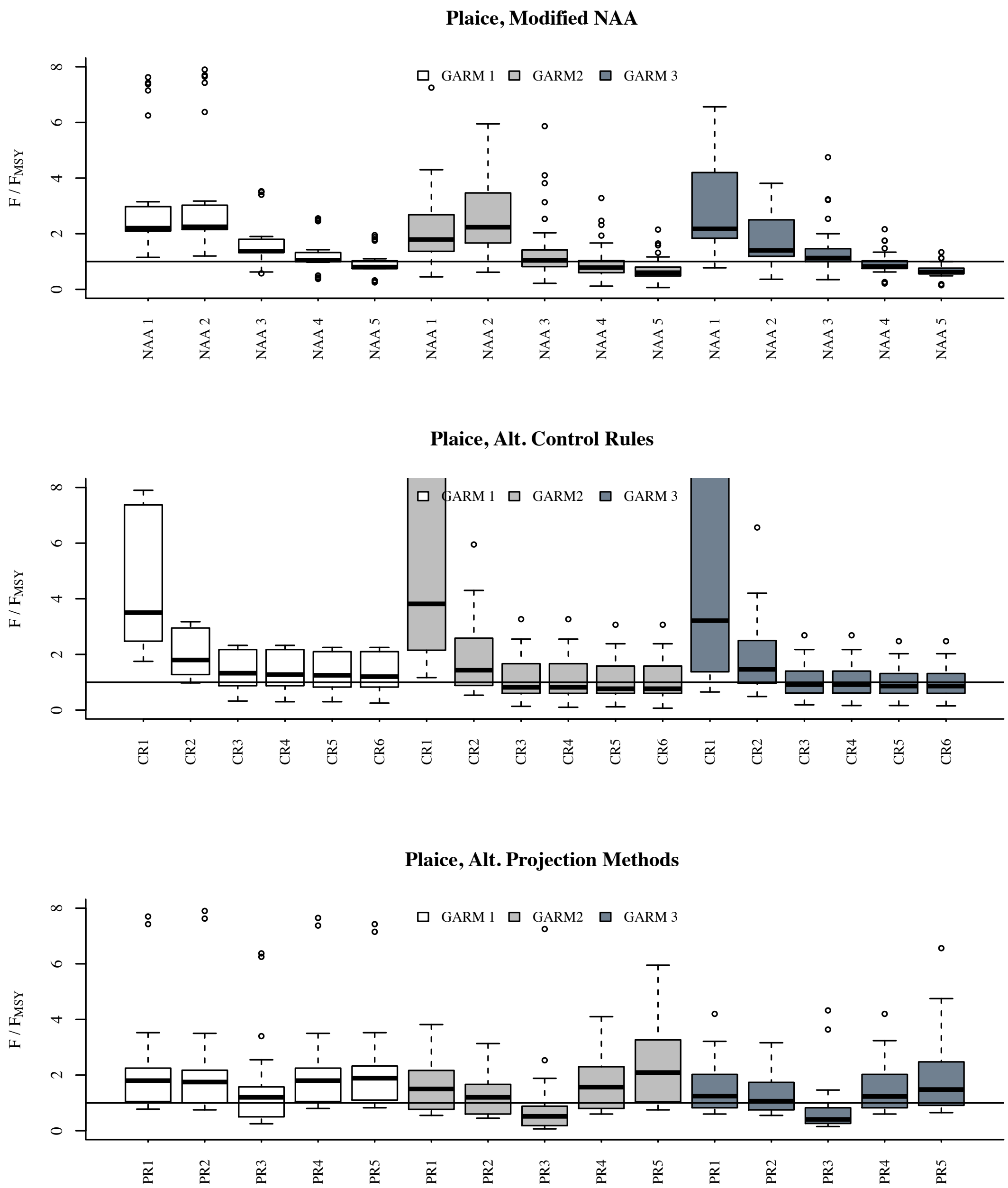

Figure 2a. Boxplot of the distribution of the *F*-ratio for a given modification in the way the target catch is calculated using information from the GARM 1 – 3 assessments for plaice (NEFSC 2002; 2005; 2008). The *F*-ratio is the estimated F / F_{MSY} where F is calculated allowing for changes in biomass due to the altered catch targets (the dynamic approach with fixed recruitment). The solid line at 1 indicates catch targets that would have achieved F_{MSY}. For a given modification (see Table 3 for details of each modification), the distribution is based on estimates across all modifications combined.

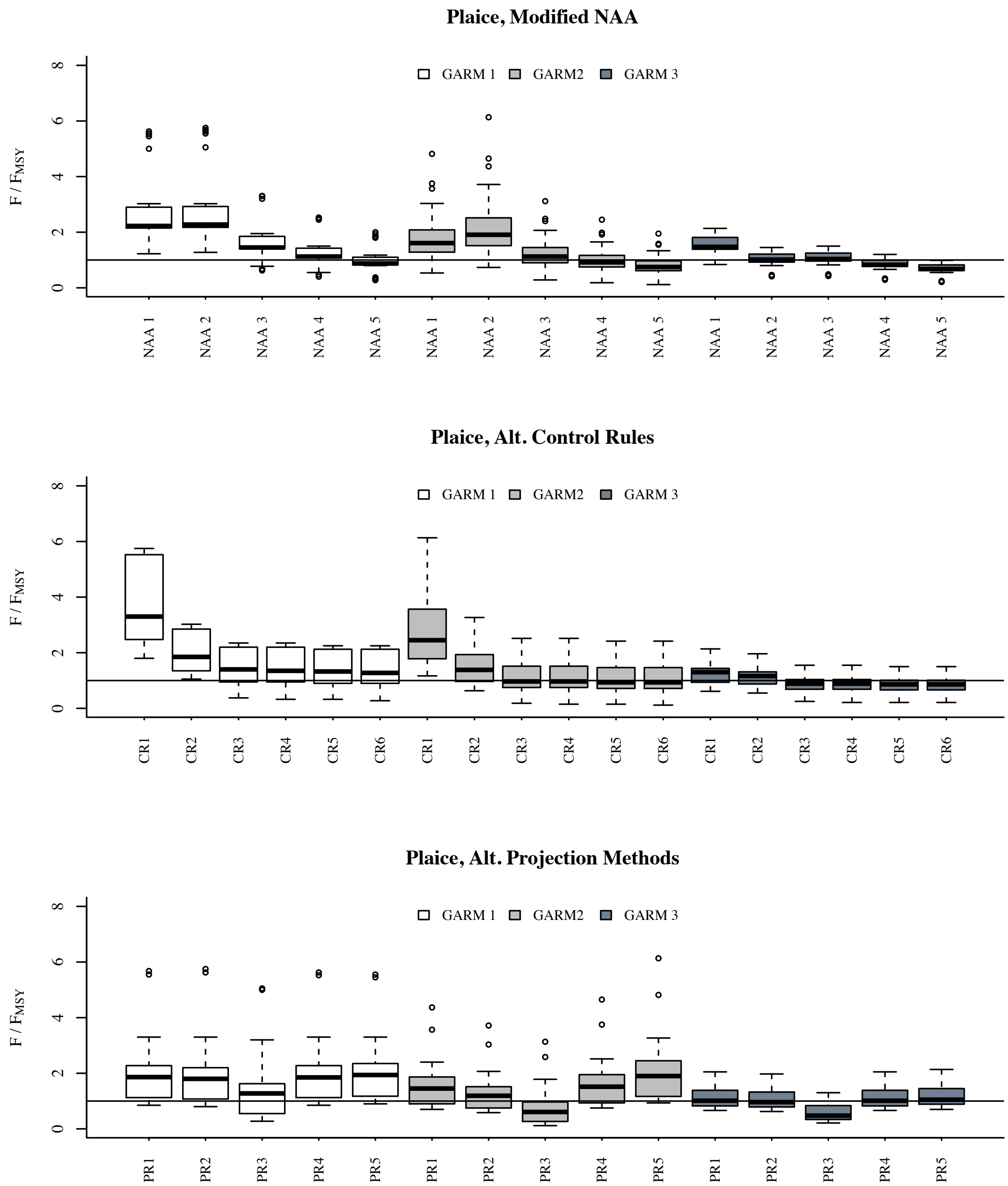

Figure 2b. Boxplot of the distribution of the *F*-ratio for a given modification in the way the target catch is calculated using information from the GARM 1 – 3 assessments for plaice (NEFSC 2002; 2005; 2008). The *F*-ratio is the estimated F / F_{MSY} where F is calculated using the fixed abundance-at-age estimates from the most recent assessment (the static approach). The solid line at 1 indicates catch targets that would have achieved F_{MSY}. For a given modification (see Table 3 for details of each modification), the distribution is based on estimates across all modifications combined.

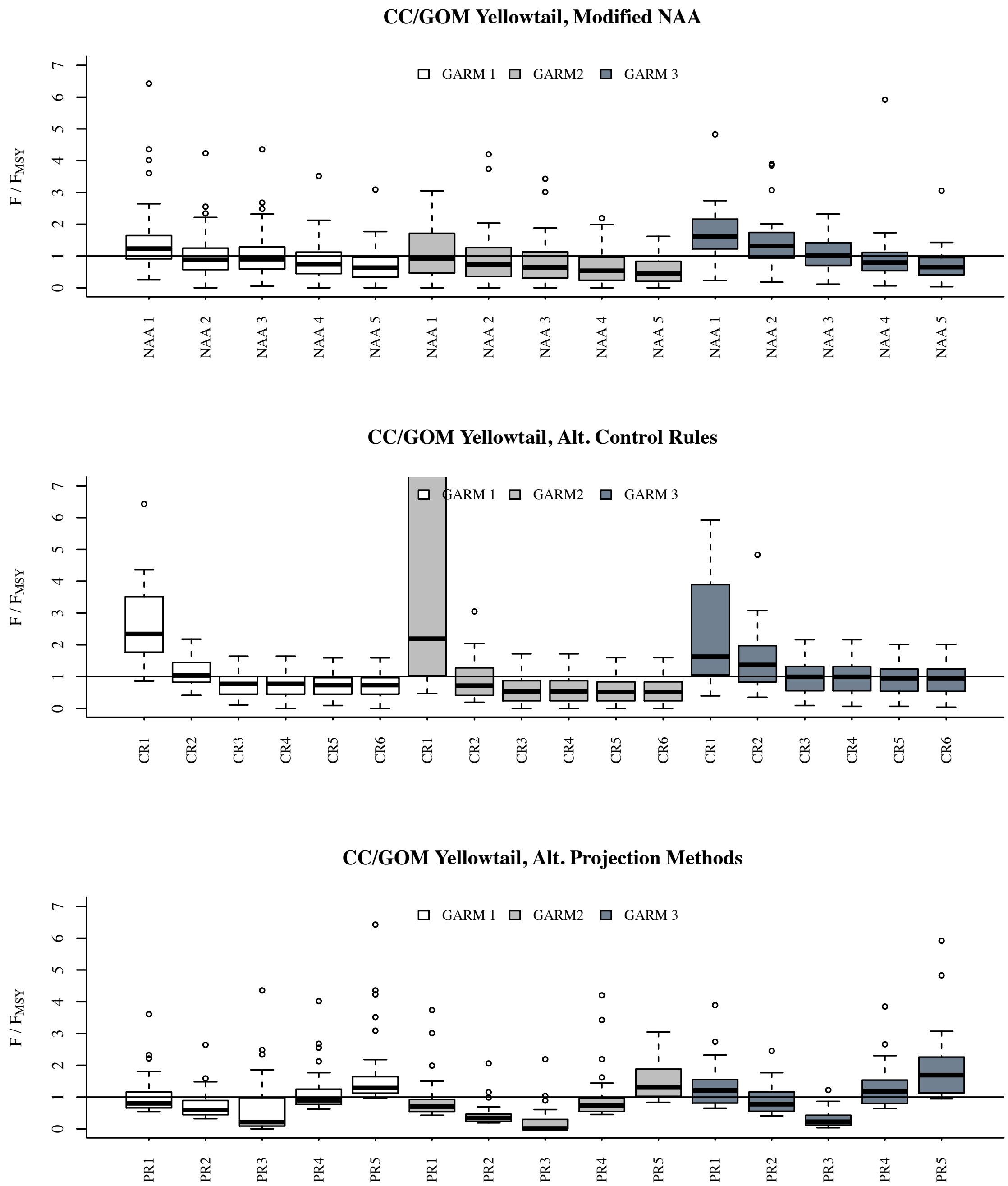

Figure 3a. Boxplot of the distribution of the *F*-ratio for a given modification in the way the target catch is calculated using information from the GARM 1 – 3 assessments for Cape Cod / Gulf of Maine (CC / GOM) yellowtail flounder (NEFSC 2002; 2005; 2008). The *F*-ratio is the estimated F / F_{MSY} where F is calculated allowing for changes in biomass due to the altered catch targets (the dynamic approach with fixed recruitment). The solid line at 1 indicates catch targets that would have achieved F_{MSY}. For a given modification (see Table 3 for details of each modification), the distribution is based on estimates across all modifications combined.

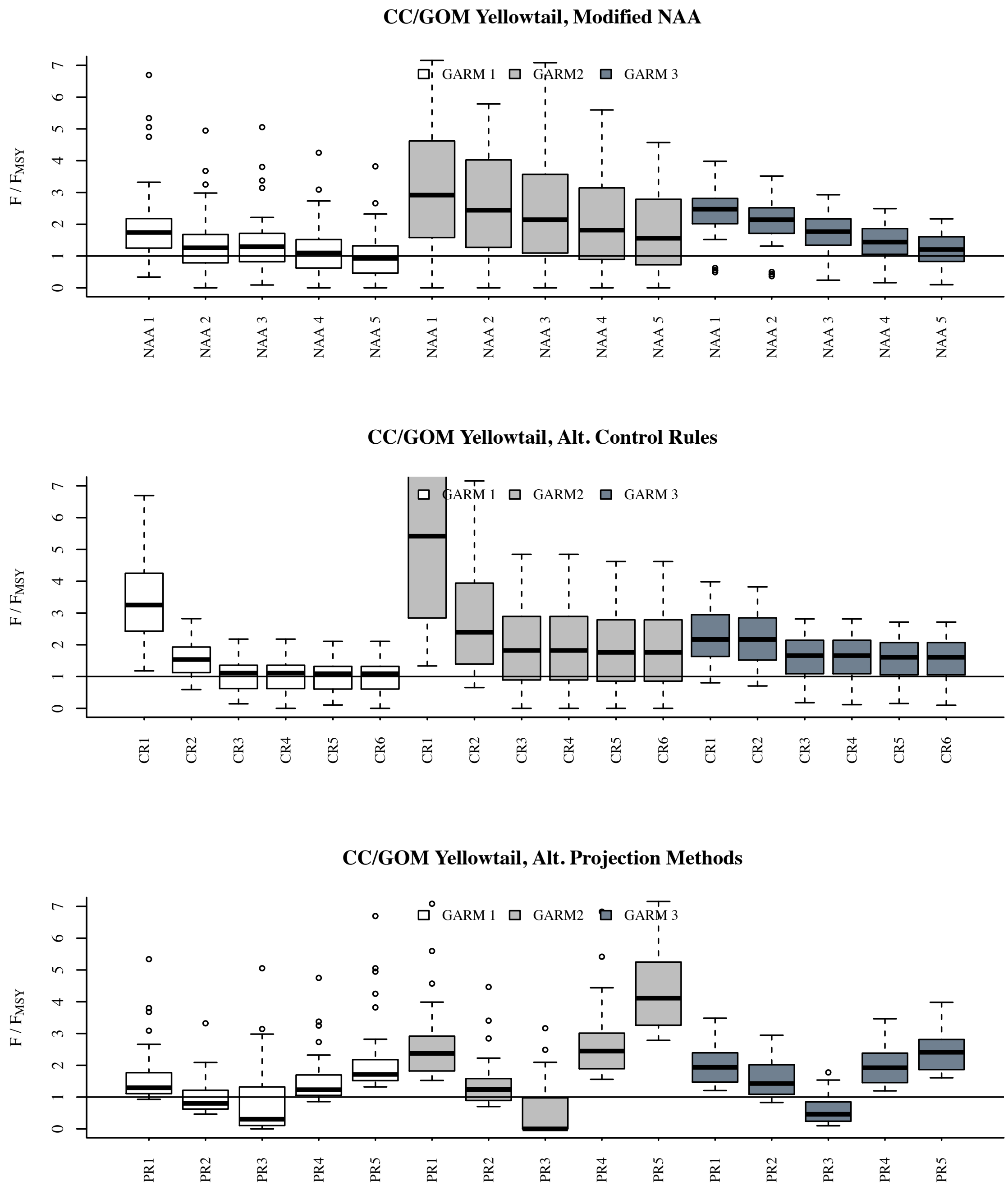

Figure 3b. Boxplot of the distribution of the *F*-ratio for a given modification in the way the target catch is calculated using information from the GARM 1 – 3 assessments for Cape Cod / Gulf of Maine (CC / GOM) yellowtail flounder (NEFSC 2002; 2005; 2008). The *F*-ratio is the estimated F / F_{MSY} where F is calculated using the fixed abundance-at-age estimates from the most recent assessment (the static approach). The solid line at 1 indicates catch targets that would have achieved F_{MSY}. For a given modification (see Table 3 for details of each modification), the distribution is based on estimates across all modifications combined.

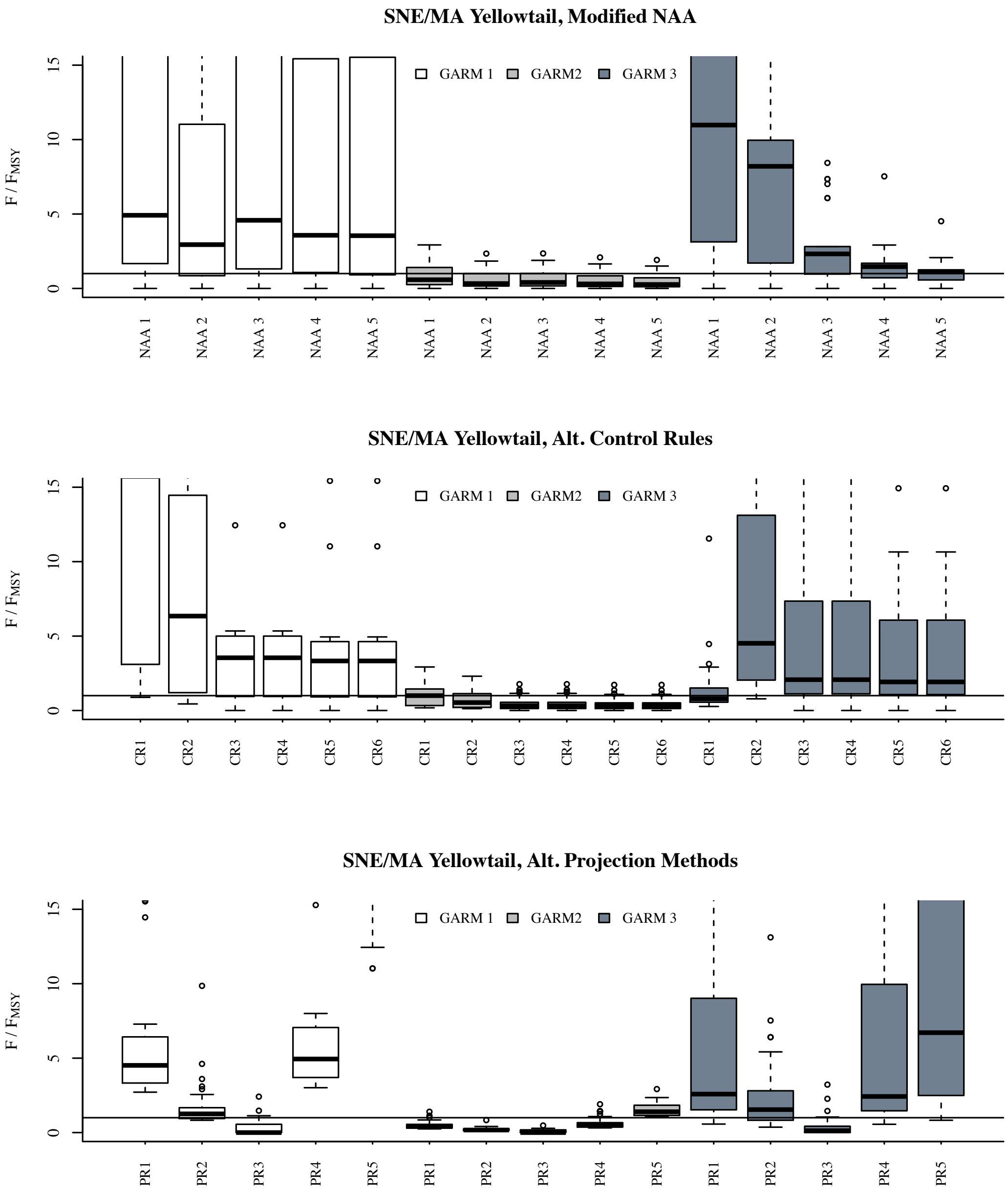

Figure 4a. Boxplot of the distribution of the *F*-ratio for a given modification in the way the target catch is calculated using information from the GARM 1 – 3 assessments for southern New England / Mid-Atlantic (SNE / MA) yellowtail flounder (NEFSC 2002; 2005; 2008). The *F*-ratio is the estimated F / F_{MSY} where *F* is calculated allowing for changes in biomass due to the altered catch targets (the dynamic approach with fixed recruitment). The solid line at 1 indicates catch targets that would have achieved F_{MSY}. For a given modification (see Table 3 for details of each modification), the distribution is based on estimates across all modifications combined.

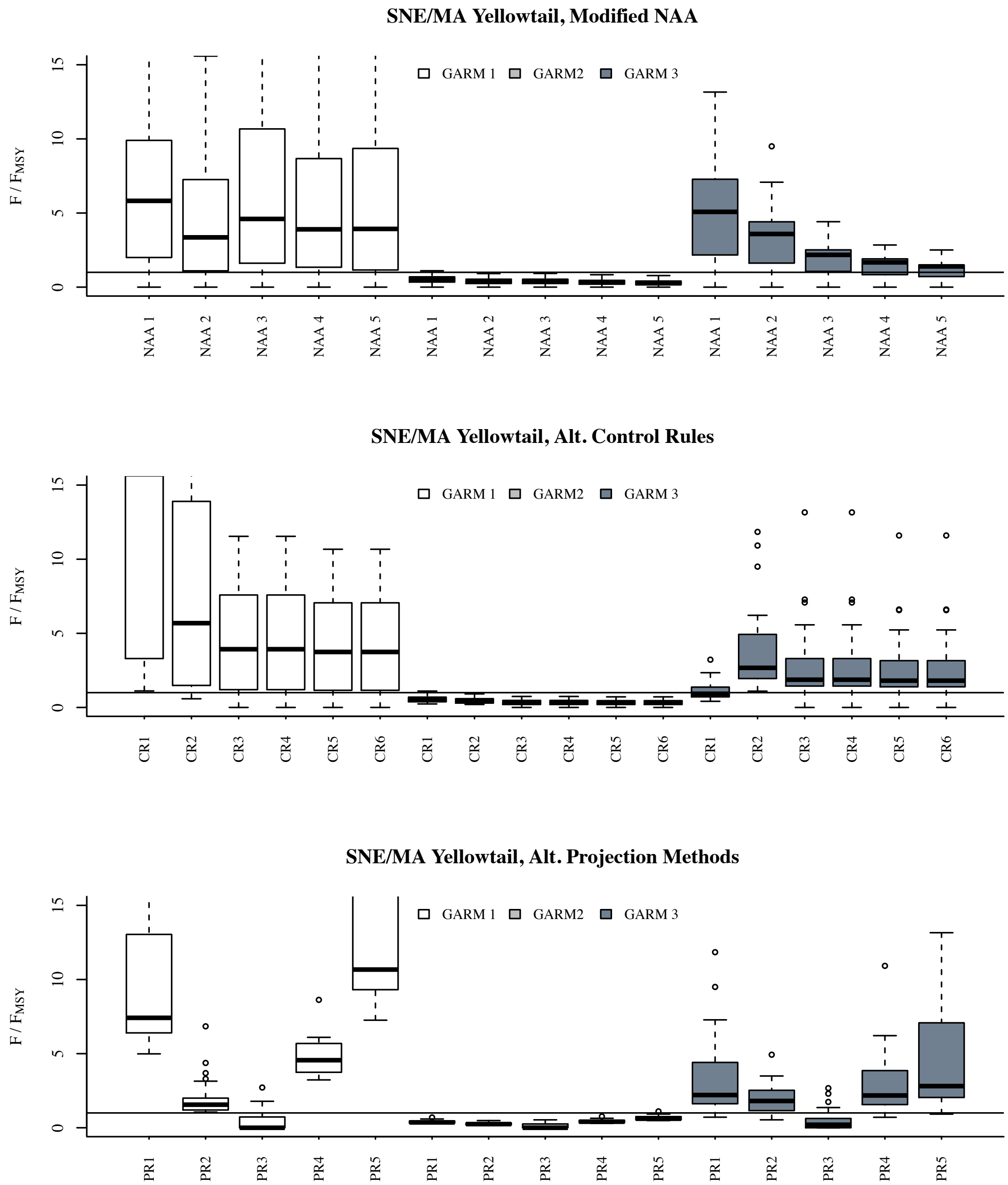

Figure 4b. Boxplot of the distribution of the *F*-ratio for a given modification in the way the target catch is calculated using information from the GARM 1 – 3 assessments for southern New England / Mid-Atlantic (SNE / MA) yellowtail flounder (NEFSC 2002; 2005; 2008). The *F*-ratio is the estimated F / F_{MSY} where F is calculated using the fixed abundance-at-age estimates from the most recent assessment (the static approach). The solid line at 1 indicates catch targets that would have achieved F_{MSY}. For a given modification (see Table 3 for details of each modification), the distribution is based on estimates across all modifications combined.

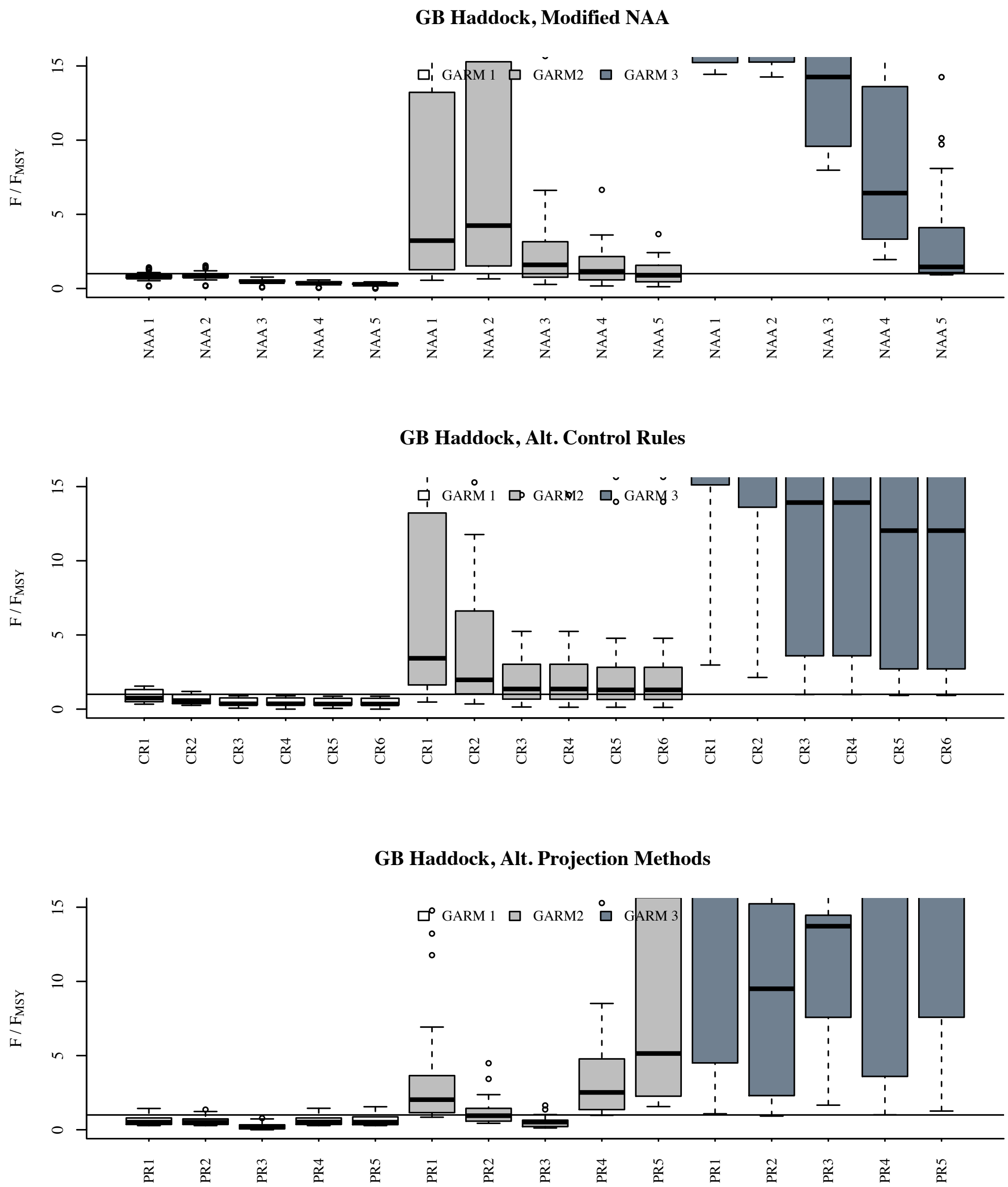

Figure 5a. Boxplot of the distribution of the *F*-ratio for a given modification in the way the target catch is calculated using information from the GARM 1 – 3 assessments for Georges Bank haddock (NEFSC 2002; 2005; 2008). The *F*-ratio is the estimated F / F_{MSY} where F is calculated allowing for changes in biomass due to the altered catch targets (the dynamic approach with fixed recruitment). The solid line at 1 indicates catch targets that would have achieved F_{MSY}. For a given modification (see Table 3 for details of each modification), the distribution is based on estimates across all modifications combined. The y-axis upper limit is set to 15 for comparison with Figure 5b.

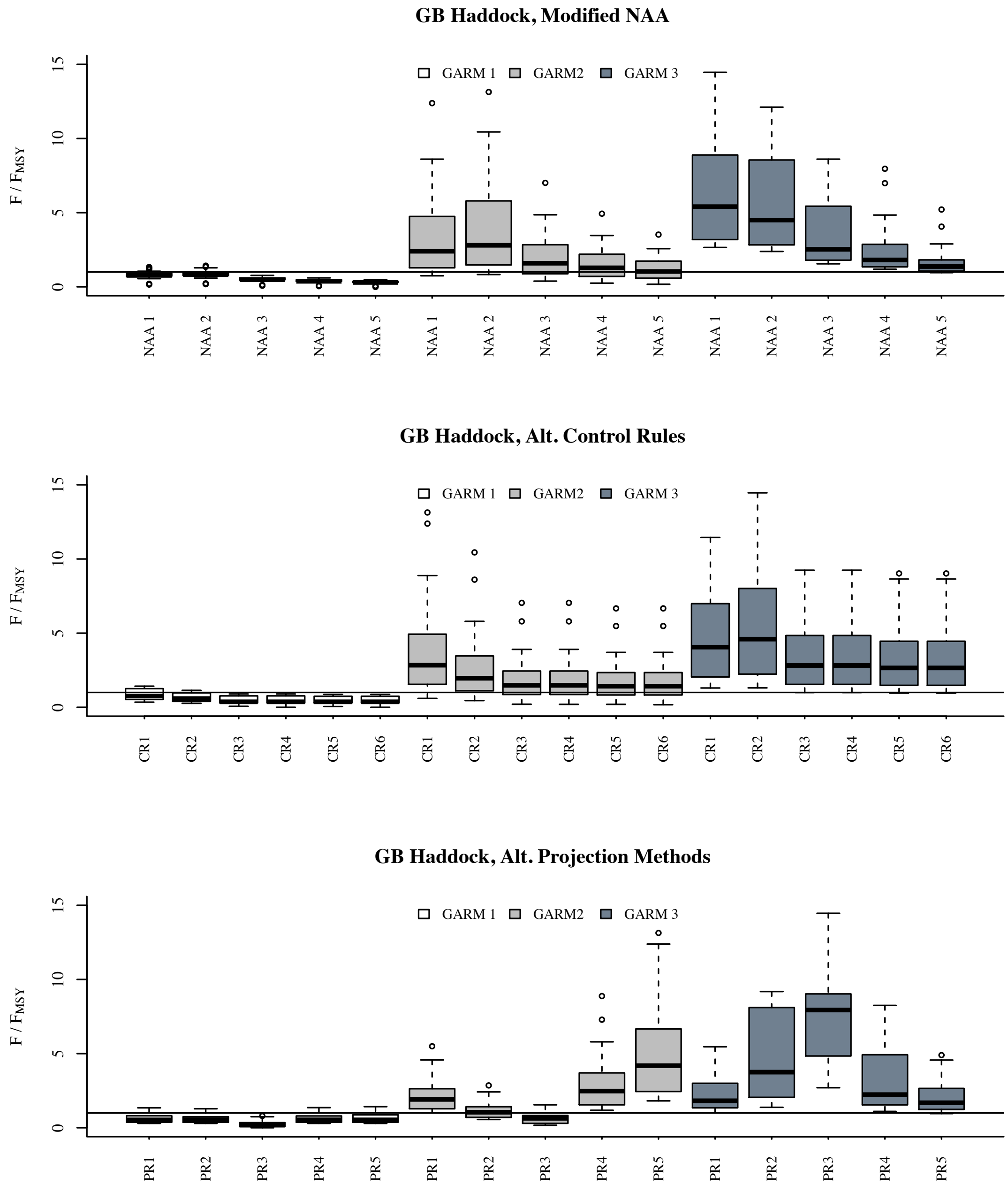

Figure 5b. Boxplot of the distribution of the *F*-ratio for a given modification in the way the target catch is calculated using information from the GARM 1 – 3 assessments for Georges Bank haddock (NEFSC 2002; 2005; 2008). The *F*-ratio is the estimated F / F_{MSY} where F is calculated using the fixed abundance-at-age estimates from the most recent assessment (the static approach). The solid line at 1 indicates catch targets that would have achieved F_{MSY}. For a given modification (see Table 3 for details of each modification), the distribution is based on estimates across all modifications combined.

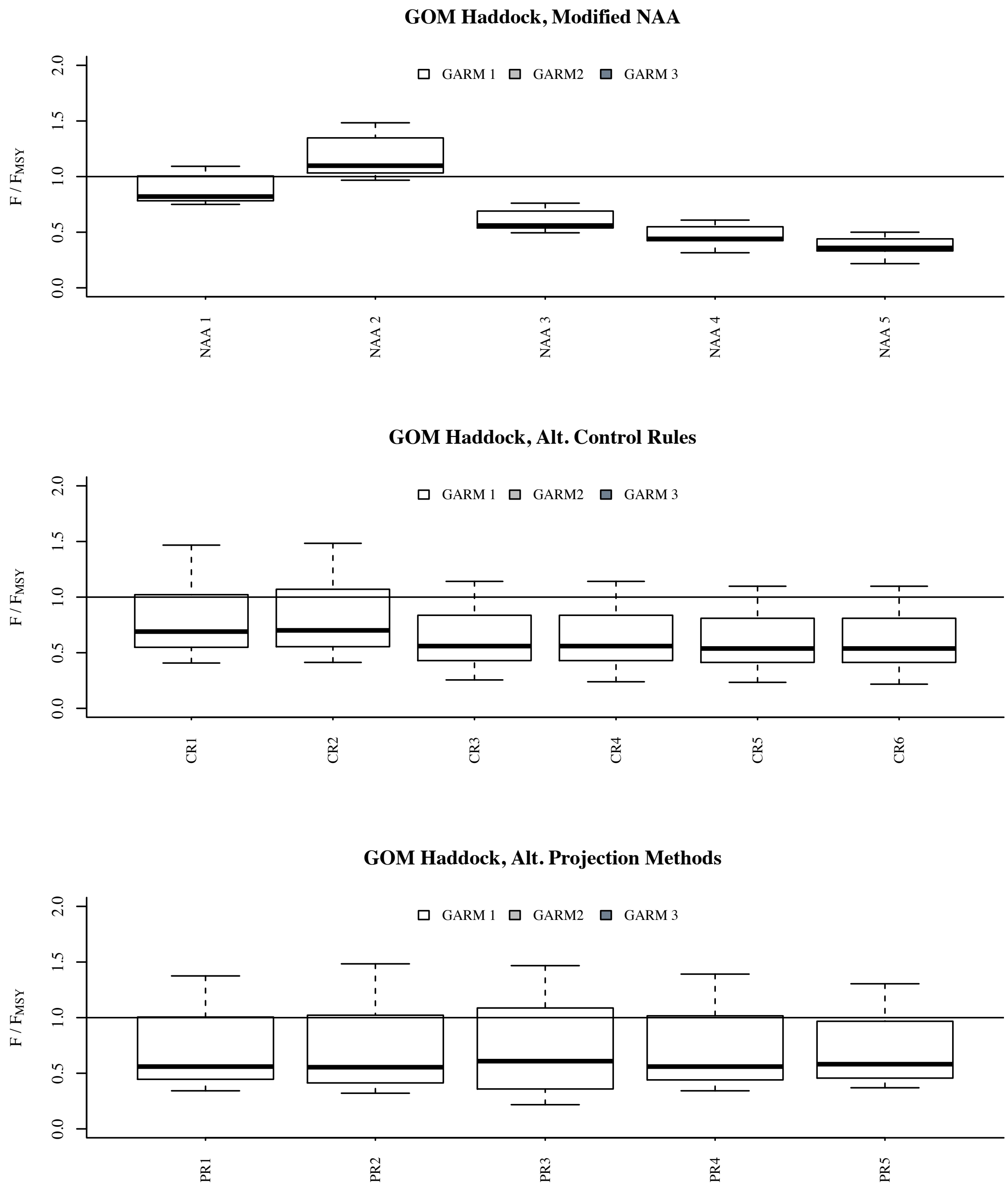

Figure 6. Boxplot of the distribution of the *F*-ratio for a given modification in the way the target catch is calculated using information from the GARM 1 – 3 assessments for Gulf of Maine haddock (NEFSC 2002; 2005; 2008). The *F*-ratio is the estimated F / F_{MSY} where *F* is calculated using the fixed abundance-at-age estimates from the most recent assessment (the static approach). The solid line at 1 indicates catch targets that would have achieved F_{MSY}. For a given modification (see Table 3 for details of each modification), the distribution is based on estimates across all modifications combined.

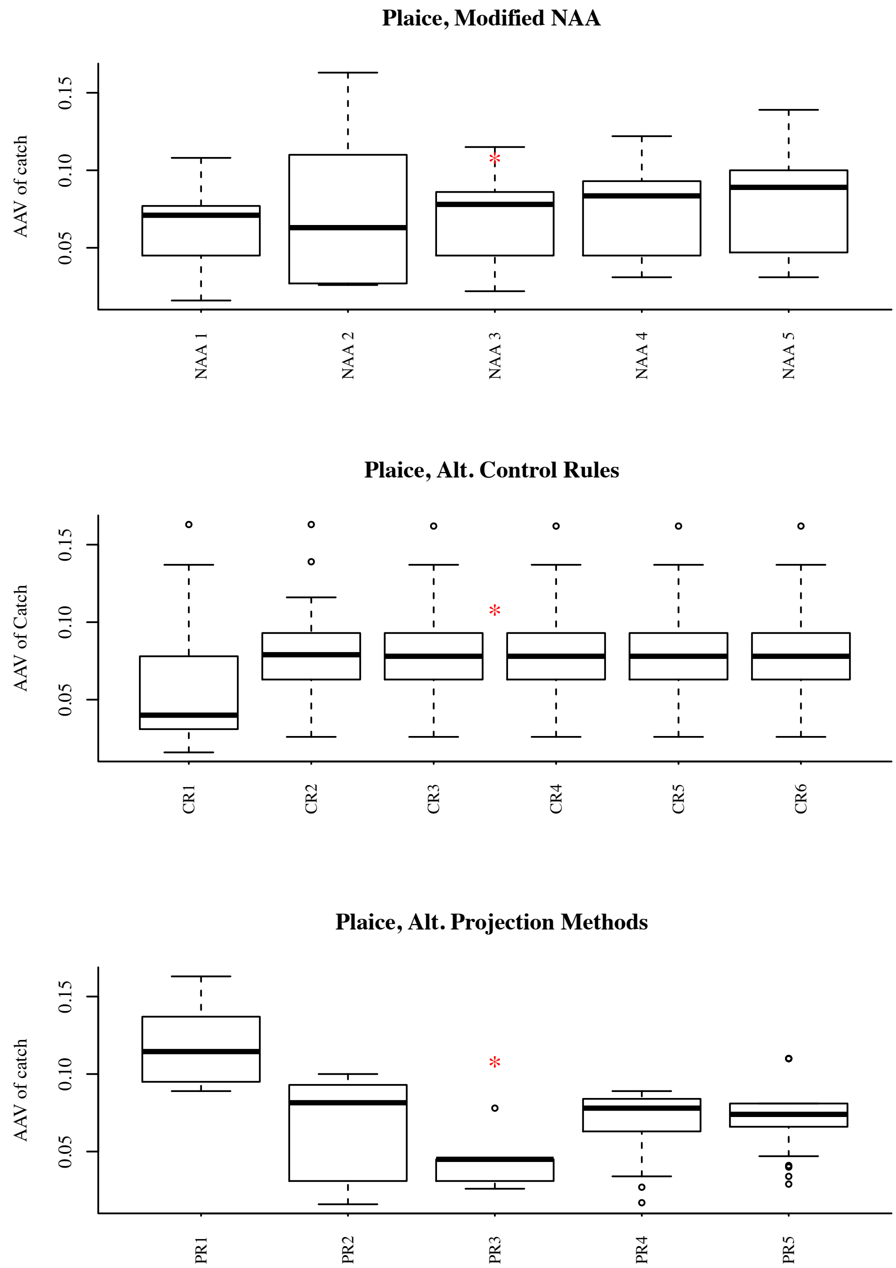

Figure 7. Boxplot of the distribution of the interannual variability (AAV) in the target catch for a given modification in the way the target catch is calculated for plaice. For a given modification (see Table 3 for details of each modification), the distribution is based on estimates across all modifications combined. The red * is the unmodified (i.e., original) AAV.

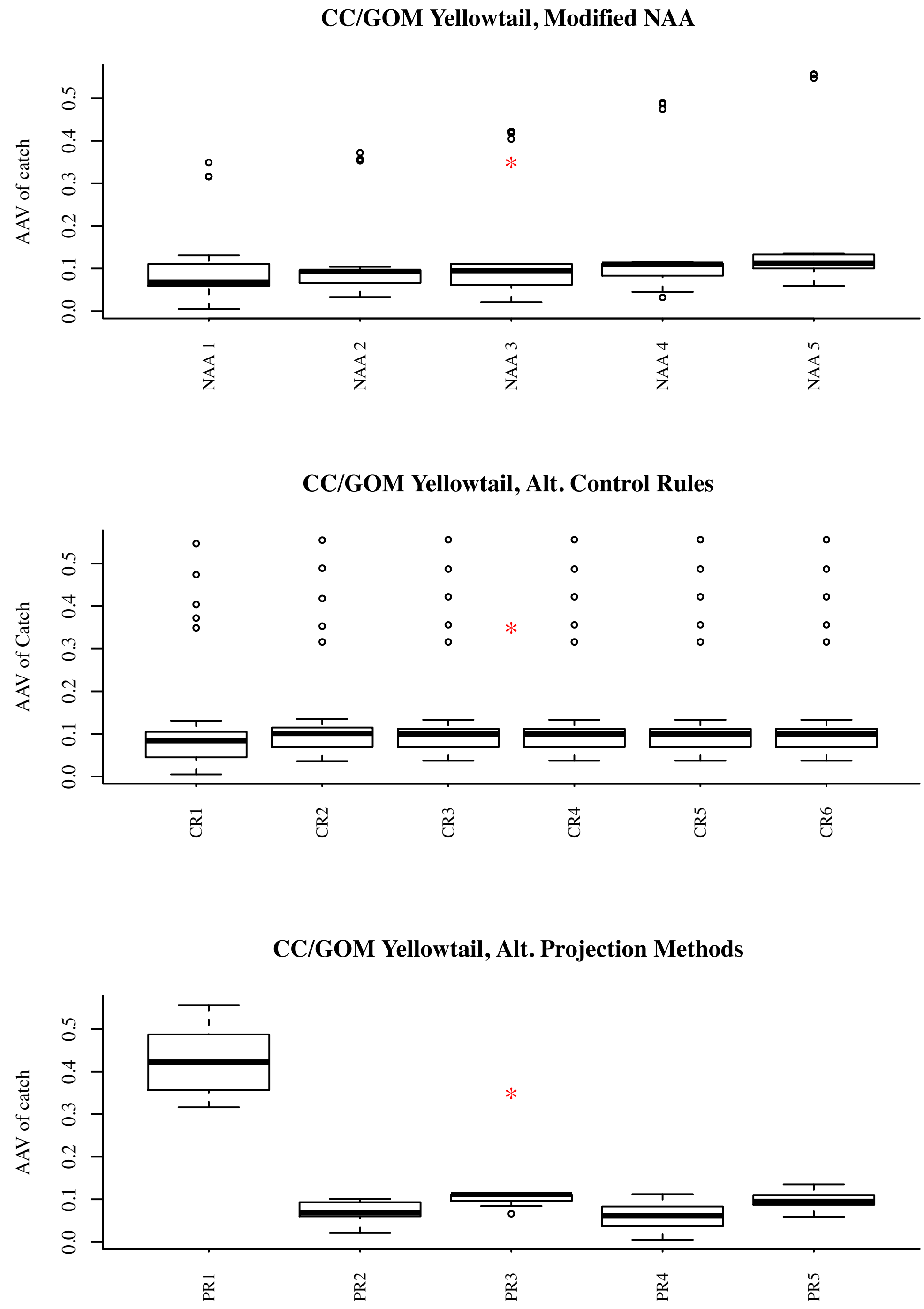

Figure 8. Boxplot of the distribution of the interannual variability (AAV) in the target catch for a given modification in the way the target catch is calculated for CC/GOM yellowtail flounder. For a given modification (see Table 3 for details of each modification), the distribution is based on estimates across all modifications combined. The red * is the unmodified (i.e., original) AAV.

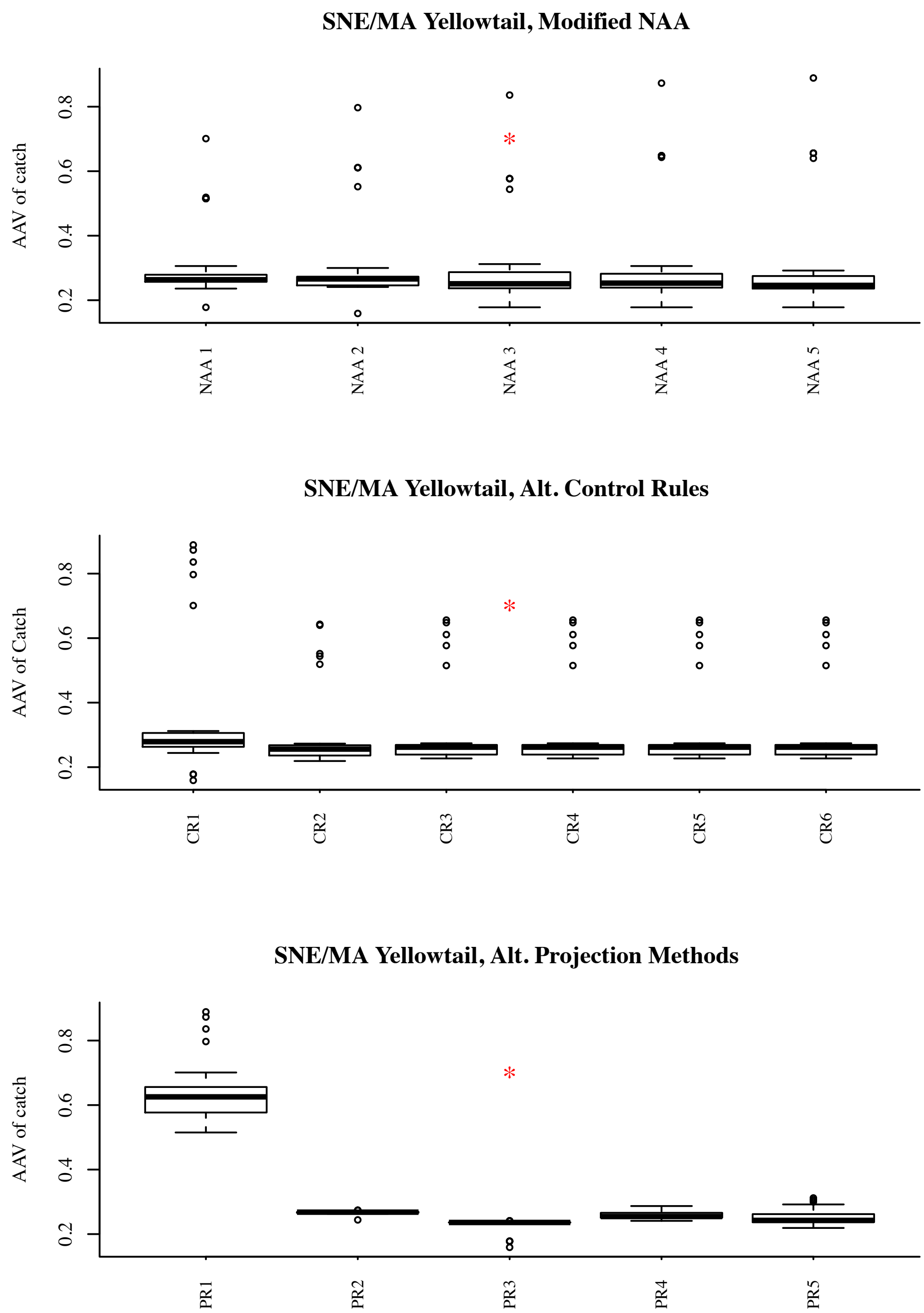

Figure 9. Boxplot of the distribution of the interannual variability (AAV) in the target catch for a given modification in the way the target catch is calculated for SNE/MA yellowtail flounder. For a given modification (see Table 3 for details of each modification), the distribution is based on estimates across all modifications combined. The red * is the unmodified (i.e., original) AAV.

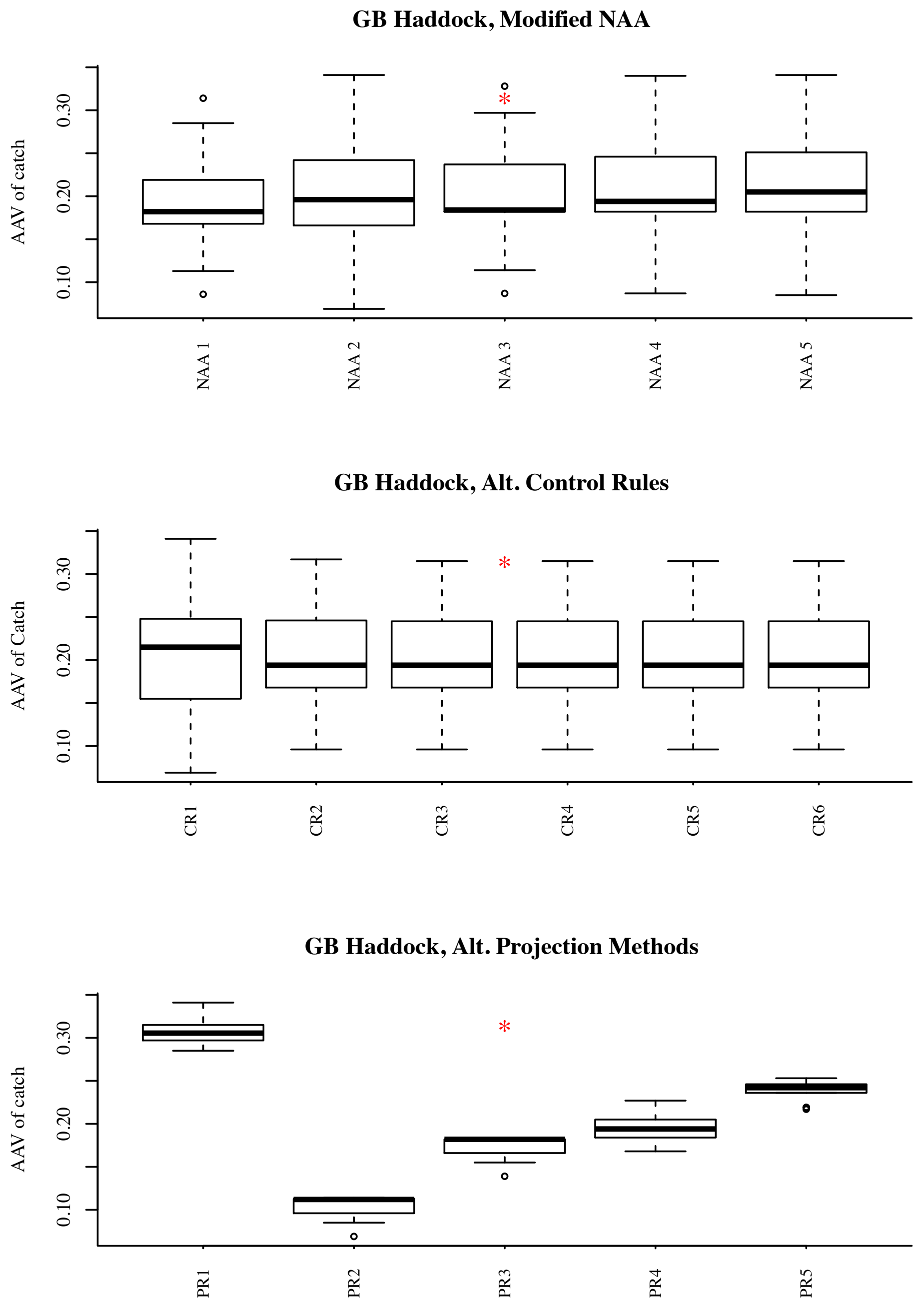

Figure 10. Boxplot of the distribution of the interannual variability (AAV) in the target catch for a given modification in the way the target catch is calculated for GB haddock. For a given modification (see Table 3 for details of each modification), the distribution is based on estimates across all modifications combined. The red * is the unmodified (i.e., original) AAV.

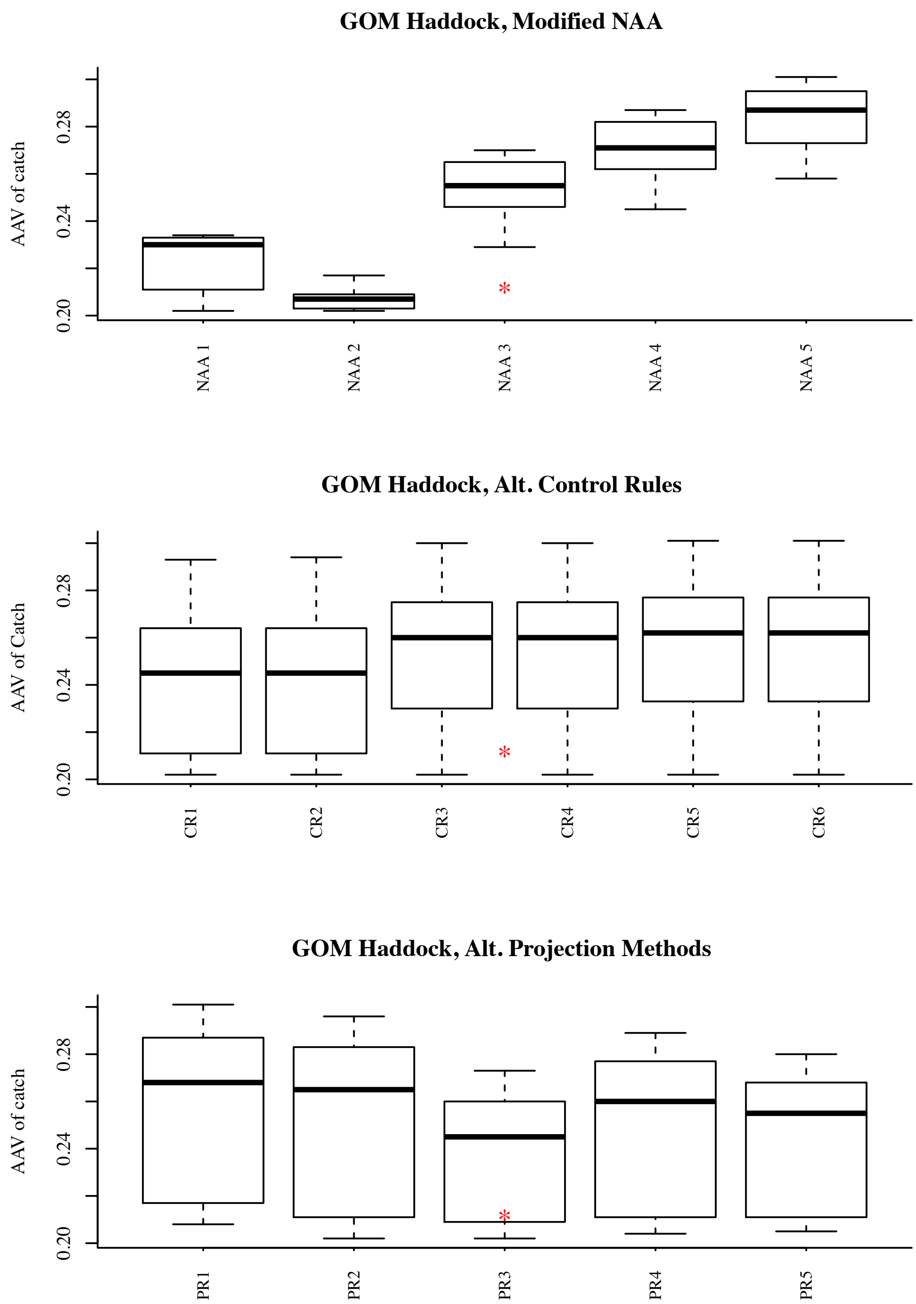

Figure 11. Boxplot of the distribution of the interannual variability (AAV) in the target catch for a given modification in the way the target catch is calculated for GOM haddock. For a given modification (see Table 3 for details of each modification), the distribution is based on estimates across all modifications combined. The red * is the unmodified (i.e., original) AAV.

Appendix A.

Table A1. Input values used in the DLMtool R package for plaice. This file shows the model run using the fall index of abundance with all available years. For runs calculating the catch following GARM 1, 2, and 3, the dataset was truncated using data through 2001, 2004, and 2007, respectively.

Name	plaice_fall											
Year	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
Catch	13597	12881	15156	13178	10142	7070	4506	3849	3490	2421	2497	4287
Abundance index	11.7	13.2	16.4	14.2	13.6	12.7	15.7	12.3	18.1	16.7	13.3	9.7
Year (cont.)	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Catch (cont.)	6419	5720	5007	4619	4365	3955	3651	3231	4339	4451	3498	2487
Abundance index (cont.)	16.2	14.6	16.1	14.5	19.4	16	13.7	18.7	21.9	2.6	21.3	32.1
Year (cont.)	2004	2005	2006	2007								
Catch (cont.)	1713	1343	1105	990								
Abundance index (cont.)	17.2	21.1	15.3	19.1								
Duration t	28											
Average catch over time t	5355.96429											
Depletion over time t	NA											
M	0.2											
FMSY/M	1											
BMSY/B0	0.35											
MSY	NA											
BMSY	NA											
Age at 50% maturity	3.8											
Length at first capture	17.8											
Length at full selection	44.7											
Current stock depletion	NA											
Current stock abundance	NA											
Von Bertalanffy K parameter	0.17											
Von Bertalanffy Linf parameter	64.2											
Von Bertalanffy t0 parameter	0											
Length-weight parameter a	2.86E-06											
Length-weight parameter b	3.31											
Steepness	0.8											
Maximum age	25											
CV Catch	0.2											
CV Depletion over time t	0.5											
CV Average catch over time t	0.221											
CV Abundance index	0.3											
CV M	0.4											
CV FMSY/M	0.3											
CV BMSY/B0	0.045											
CV current stock depletion	0.5											
CV current stock abundance	1											
CV von B. K parameter	0.1											
CV von B. Linf parameter	0.1											
CV von B. t0 parameter	0.1											
CV Age at 50% maturity	0.25											
CV Length at first capture	0.25											
CV Length at full selection	0.25											
CV Length-weight parameter a	0.1											
CV Length-weight parameter b	0.1											
CV Steepness	0.3											
Sigma length composition	0.2											
Units	metric tons											
Reference OFL	NA											
Reference OFL type	NA											
CAA_bins	1	2	3	4	5	6	7	8	9	10		
CAA1980	5.2	98.87	1071.657	2671.5	3938.689	3933.315	3632.03	1185.4	1138.6	849.9		
CAA1981	5.102	981.939	2192.097	5056.235	5338.265	3648.923	2401.297	1581.927	645.24	439.895		
CAA1982	9.603	603.238	3348.502	4574.705	4503.888	3599.226	3297.637	2037.99	1256.34	736.841		
CAA1983	14.549	662.791	1477.918	5174.31	4915.097	3910.459	2268.685	1271.281	700.767	449.3		
CAA1984	2.535	370.467	990.575	2422.061	6031.242	3244.447	1935.634	580.275	273.8	307.2		
CAA1985	64.773	157.827	1217.425	1336.409	2404.572	2872.048	2228.162	1081.289	438.072	267.117		
CAA1986	59.303	638.708	737.977	2283.971	1700.042	1476.463	1307.066	631.5	254.921	104.793		
CAA1987	38.475	589.615	1840.495	1439.239	2282.296	1336.913	895.036	542.855	187.158	61.618		
CAA1988	313.506	785.537	1839.531	1833.411	1597.373	1444.417	552.785	270.313	177.097	88.155		
CAA1989	15.339	2345.54	2713.335	2675.536	1588.668	863.641	857.347	552.118	196.193	103.646		
CAA1990	0	1074.37	4922.563	4022.551	2156.071	739.281	384.131	415.823	193.06	96.094		
CAA1991	0.359	240.424	1010.663	6134.169	4966.221	1275.039	328.661	166.829	202.817	97.59		
CAA1992	9.766	250.208	932.954	1856.278	6147.565	2681.691	862.332	190.76	131.194	117.592		
CAA1993	21.502	278.319	557.057	2209.636	2583.619	2654.356	1386.894	264.937	286.624	151.169		
CAA1994	58.064	883.988	409.31	1778.701	2937.31	1349.242	1160.219	597.926	235.098	149.911		
CAA1995	46.22	2565.414	1889.9	2744.648	3472.854	1913.556	660.821	594.435	210.732	52.663		
CAA1996	12.365	1291.766	1546.109	4118.275	2831.382	1548.134	581.875	244.008	127.342	37.44		
CAA1997	14.65	637.586	388.145	2596.844	3946.186	1780.725	639.622	182.33	85.013	66.355		
CAA1998	37.242	87.381	322.633	849.364	2715.772	2477.323	1066.818	318.888	59.612	56.885		
CAA1999	4.216	216.386	178.225	1192.76	1700.622	2415.365	1393.315	489.87	150.055	42.434		
CAA2000	2.744	308.557	509.593	955.654	1743.314	2273.68	1774.857	568.597	138.304	69.875		
CAA2001	0	93.206	467.597	1142.141	2437.005	2284.723	1609.012	921.546	296.462	56.676		
CAA2002	1.091	13.2	111.339	787.081	1467.924	1826.172	1199.927	519.901	285.239	162.587		
CAA2003	11.933	690.8	48.824	329.359	1327.427	1293.589	732.671	547.936	274.31	150.991		
CAA2004	6.071	138.584	223.825	440.715	938.285	1224.589	519.49	372.48	199.675	79.105		
CAA2005	34.472	285.778	110.118	464.302	1052.713	808.078	459.146	183.894	100.825	43.927		
CAA2006	28.533	87.682	131.434	534.035	822.902	563.144	367.413	195.471	100.621	61.187		
CAA2007	161.479	238.399	225.937	647.237	814.802	505.471	229.307	101.212	58.609	26.314		

Table A2. Input values used in the DLMtool R package for CC/GOM yellowtail. This file shows the model run using the fall index of abundance with all available years. For runs calculating the catch following GARM 1, 2, and 3, the dataset was truncated using data through 2001, 2004, and 2007, respectively.

Name	CCGOM_yellow_fall											
Year	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
Catch	1348.542	1601.519	1647.979	1657.599	1570.225	4547.624	2289.963	1760.453	934.706	1351.255	1517.787	1514.82
Abundance index	2.944663	2.032021	1.434776	3.381303	2.715589	3.554582	1.474601	2.97006	2.731013	4.978761	2.507498	3.57409
Year (cont.)	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	
Catch (cont.)	1686.049	1621.756	1452.103	2585.792	2618.174	2157.171	1968.392	1186.166	997.348	619.919	632.161	
Abundance index (cont.)	2.755304	2.209606	6.536751	4.063338	2.02079	0.920376	3.665869	0.686359	1.216834	1.681081	4.344575	
Duration t	23											
Average catch over time t	1707.28274											
Depletion over time t	NA											
M	0.2											
FMSY/M	1.4											
BMSY/B0	0.35											
MSY	NA											
BMSY	NA											
Age at 50% maturity	2.5											
Length at first capture	19											
Length at full selection	38											
Current stock depletion	NA											
Current stock abundance	NA											
Von Bertalanffy K parameter	0.33											
Von Bertalanffy Linf parameter	50											
Von Bertalanffy t0 parameter	0											
Length-weight parameter a	5.76E-06											
Length-weight parameter b	3.1329											
Steepness	0.8											
Maximum age	20											
CV Catch	0.2											
CV Depletion over time t	0.5											
CV Average catch over time t	0.221											
CV Abundance index	0.3											
CV M	0.4											
CV FMSY/M	0.3											
CV BMSY/B0	0.045											
CV current stock depletion	0.5											
CV current stock abundance	1											
CV von B. K parameter	0.1											
CV von B. Linf parameter	0.1											
CV von B. t0 parameter	0.1											
CV Age at 50% maturity	0.25											
CV Length at first capture	0.25											
CV Length at full selection	0.25											
CV Length-weight parameter a	0.1											
CV Length-weight parameter b	0.1											
CV Steepness	0.3											
Sigma length composition	0.2											
Units	metric tons											
Reference OFL	NA											
Reference OFL type	NA											
CAA_bins	1	2	3	4	5	6						
CAA1985	686	1245	907	635	329	121						
CAA1986	95	4225	785	304	40	8						
CAA1987	19	1885	2331	309	116	53						
CAA1988	452	2582	1503	744	199	41						
CAA1989	118	2297	1812	298	38	9						
CAA1990	84	2897	9400	493	35	28						
CAA1991	465	1372	1765	1953	298	74						
CAA1992	1709	3979	1961	731	191	14						
CAA1993	159	425	1074	795	111	54						
CAA1994	19	817	1697	716	210	109						
CAA1995	37	526	1777	1188	178	170						
CAA1996	26	787	2428	645	104	9						
CAA1997	8	1480	2007	847	180	20						
CAA1998	38	495	2512	650	152	3						
CAA1999	9	743	2292	397	32	7						
CAA2000	2	1114	2981	1408	133	35						
CAA2001	20	1342	3721	849	145	24						
CAA2002	58	1204	2449	905	109	34						
CAA2003	10	859	2122	1200	152	70						
CAA2004	13	475	1594	571	243	75						
CAA2005	15	494	1262	585	82	48						
CAA2006	7	189	662	390	84	54						
CAA2007	6	267	760	396	61	18						

Table A3. Input values used in the DLMtool R package for SNE/MA yellowtail flounder. This file shows the model run using the fall index of abundance with all available years. For runs calculating the catch following GARM 1, 2, and 3, the dataset was truncated using data through 2001, 2004, and 2007, respectively.

Name	SNEMA_yellow_fall											
Year	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
Catch	14549	17088	5732	3436	5223	8085	9883	8021	6607	15764	22211	11225
Abundance index	17.34297	7.06914	3.338	10.01654	5.27903	8.91242	7.91785	6.11182	24.5383	35.00554	27.07059	6.4215
Year (cont.)	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
Catch (cont.)	4817	4620	2652	2782	8349	17916	6430	2695	771	735	343	759
Abundance index (cont.)	1.39752	3.10243	2.33001	5.75422	11.84693	5.56257	2.64975	0.62904	0.57977	1.70484	1.38937	1.06677
Year (cont.)	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	
Catch (cont.)	1222	1087	1403	1397	1449	945	666	619	346	396	502	
Abundance index (cont.)	3.55607	3.10797	2.25689	2.54521	1.41365	3.4434	1.95392	0.30312	3.02586	4.06028	1.98345	
Duration t	35											
Average catch over time t	5449.28571											
Depletion over time t	NA											
M	0.3											
FMSY/M	1.16666667											
BMSY/B0	0.35											
MSY	NA											
BMSY	NA											
Age at 50% maturity	2.05											
Length at first capture	20											
Length at full selection	34											
Current stock depletion	NA											
Current stock abundance	NA											
Von Bertalanffy K parameter	0.91											
Von Bertalanffy Linf parameter	35.4											
Von Bertalanffy t0 parameter	0.245											
Length-weight parameter a	6.60E-06											
Length-weight parameter b	3.194											
Steepness	0.8											
Maximum age	20											
CV Catch	0.2											
CV Depletion over time t	0.5											
CV Average catch over time t	0.221											
CV Abundance index	0.3											
CV M	0.4											
CV FMSY/M	0.3											
CV BMSY/B0	0.045											
CV current stock depletion	0.5											
CV current stock abundance	1											
CV von B. K parameter	0.1											
CV von B. Linf parameter	0.1											
CV von B. t0 parameter	0.1											
CV Age at 50% maturity	0.25											
CV Length at first capture	0.25											
CV Length at full selection	0.25											
CV Length-weight parameter a	0.1											
CV Length-weight parameter b	0.1											
CV Steepness	0.3											
Sigma length composition	0.2											
Units	metric tons											
Reference OFL	NA											
Reference OFL type	NA											
CAA_bins	1	2	3	4	5	6						
CAA1973	201	5333	11815	7973	5226	6286						
CAA1974	788	25853	5477	7366	3687	3347						
CAA1975	8037	3986	1884	1129	1597	1452						
CAA1976	193	6156	1179	327	449	896						
CAA1977	4968	4750	4886	507	278	649						
CAA1978	7830	13181	2163	1470	247	179						
CAA1979	186	17988	8655	1062	438	131						
CAA1980	919	9671	6593	3829	512	167						
CAA1981	34	6627	7546	2926	1111	183						
CAA1982	158	33925	14267	1858	415	86						
CAA1983	2407	18801	42269	3600	385	192						
CAA1984	470	5885	19895	8121	878	276						
CAA1985	2032	7769	2173	1968	1109	246						
CAA1986	421	9594	3322	635	356	149						
CAA1987	1442	3234	2366	926	167	65						
CAA1988	5309	2020	536	506	134	32						
CAA1989	22	18520	3164	449	48	3						
CAA1990	173	1893	40271	2142	89	5						
CAA1991	401	1475	4886	9414	166	51						
CAA1992	429	1338	1989	2674	294	18						
CAA1993	12	436	445	711	145	4						
CAA1994	177	593	539	407	307	96						
CAA1995	1	339	274	273	57	31						
CAA1996	4	491	1131	238	31	30						
CAA1997	17	182	1521	920	115	49						
CAA1998	5	1232	1166	423	78	16						
CAA1999	69	433	2132	482	94	42						
CAA2000	18	1167	1426	558	57	10						
CAA2001	0	494	1946	547	139	43						
CAA2002	7	385	1154	467	34	1						
CAA2003	3	234	731	413	34	13						
CAA2004	291	174	347	305	204	101						
CAA2005	32	185	190	168	117	49						
CAA2006	51	354	304	159	61	72						
CAA2007	9	279	703	176	45	36						

Table A4. Input values used in the DLMtool R package for GB haddock. This file shows the model run using the fall index of abundance with all available years. For runs calculating the catch following GARM 1, 2, and 3, the dataset was truncated using data through 2001, 2004, and 2007, respectively.

Name	GB_haddock_fall											
Year	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
Catch	25011	17627	12009	10394	7943	6846	6997	6689	4915	5574	6997	6244
Abundance index	13.4	5.4	8	5.4	13.2	6.8	3.6	5.3	4.3	2.9	2.9	5.9
Year (cont.)	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Catch (cont.)	4668	4827	2442	4131	3833	5665	6357	8711	11788	13258	12827	18253
Abundance index (cont.)	8	3.5	17.1	4.4	6.1	10.8	23.1	18	22.7	42.1	169.5	187
Year (cont.)	2005	2006	2007									
Catch (cont.)	21814	15989	16815									
Abundance index (cont.)	90.5	57	53.9									
Duration t	27											
Average catch over time t	9949.03704											
Depletion over time t	NA											
M	0.2											
FMSY/M	1.5											
BMSY/B0	0.35											
MSY	NA											
BMSY	NA											
Age at 50% maturity	2.3											
Length at first capture	12											
Length at full selection	40											
Current stock depletion	NA											
Current stock abundance	NA											
Von Bertalanffy K parameter	0.165											
Von Bertalanffy Linf parameter	73.8											
Von Bertalanffy t0 parameter	0.165											
Length-weight parameter a	8.13E-06											
Length-weight parameter b	3.068											
Steepness	0.8											
Maximum age	25											
CV Catch	0.2											
CV Depletion over time t	0.5											
CV Average catch over time t	0.221											
CV Abundance index	0.3											
CV M	0.4											
CV FMSY/M	0.3											
CV BMSY/B0	0.045											
CV current stock depletion	0.5											
CV current stock abundance	1											
CV von B. K parameter	0.1											
CV von B. Linf parameter	0.1											
CV von B. t0 parameter	0.1											
CV Age at 50% maturity	0.25											
CV Length at first capture	0.25											
CV Length at full selection	0.25											
CV Length-weight parameter a	0.1											
CV Length-weight parameter b	0.1											
CV Steepness	0.3											
Sigma length composition	0.2											
Units	metric tons											
Reference OFL	NA											
Reference OFL type	NA											
CAA_bins	1	2	3	4	5	6	7	8				
CAA1981	1	1755.4	11076.4	836.9	943.7	2590.3	333.4	159.1				
CAA1982	1	1173.7	1645.1	3760.7	393.9	573.2	1127.3	106.8				
CAA1983	0	216.1	821.1	696.9	2261.4	274.7	187.9	808				
CAA1984	0	94.1	300.6	735.8	401.8	1499.9	236.8	270.2				
CAA1985	0	2463.7	563.2	198.7	472.1	233.5	538.6	79.9				
CAA1986	6.1	54.7	2848.3	226	148	175.4	152	269.6				
CAA1987	0	2035.1	131.6	1645.5	124.5	74.5	90.8	108.1				
CAA1988	4.1	53.2	2439.1	137.1	952.5	152.4	56.3	65.5				
CAA1989	1.9	1462.2	122.5	1018.7	217.3	477.8	61.7	37				
CAA1990	62.9	11.6	1697	268.9	1124.1	154.3	217.6	55.4				
CAA1991	7	486.1	122.8	2370.1	144.3	517.6	127.9	171.9				
CAA1992	83.6	265.1	407.5	197.2	1960.1	181.2	425.7	46.6				
CAA1993	33	363.3	439.1	340.4	120.1	741.4	62.6	169.2				
CAA1994	27.3	537.5	1191.5	241.5	142.1	73.4	313.4	55.2				
CAA1995	17	93.5	614.3	470.8	58.9	29.4	8.5	61.4				
CAA1996	6.8	56.4	566.3	918.6	450.3	66	22.1	6.9				
CAA1997	14.5	143.3	273	745.1	561.3	217.9	17.5	18.4				
CAA1998	6	230.1	470.9	557.6	767.2	570.7	168.9	23.4				
CAA1999	2.6	43.2	906	541.1	605.7	565.5	383.5	163.2				
CAA2000	1.6	406.6	625.6	1570.9	588	527.7	377	258.1				
CAA2001	14	145.1	2393.3	996.1	1280.6	655.6	437.6	358.8				
CAA2002	2.9	396.7	345.3	3177.4	926.2	1105.4	401.6	306.4				
CAA2003	4.5	17.7	1942.8	461.1	2686.1	604.9	719.1	212.3				
CAA2004	646	33	121.7	5115.6	729.4	2935.4	686.7	562.9				
CAA2005	19.5	612.4	41.8	339	8505.4	777.7	1842.6	315.2				
CAA2006	164.4	18.4	3164.2	70.9	375.2	5418.3	326.5	841.9				
CAA2007	19.2	180.9	231.8	10053.6	176.3	217	1834.9	177.5				

Table A5. Input values used in the DLMtool R package for GOM haddock winter flounder. This file shows the model run using the fall index of abundance with all available years. For runs calculating the catch following GARM 1, 2, and 3, the dataset was truncated using data through 2001, 2004, and 2007, respectively.

Name	GOM_haddock_fall											
Year	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
Catch	3256.1	5023.5	4387.6	6520.6	6264.5	6941.7	7655.6	4101.4	3088.2	1922.2	909.4	438.8
Abundance index	8.296	9.775	6.174	7.152	4.456	2.627	2.598	1.696	4.079	0.623	1.035	0.335
Year (cont.)	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Catch (cont.)	284.6	472.4	446.6	321.4	206.9	186.7	403.7	341	1037.9	988.4	594.1	985.5
Abundance index (cont.)	0.283	0.145	0.142	0.211	0.866	0.325	0.977	2.407	2.688	3.13	6.73	16.589
Year (cont.)	2001	2002	2003	2004	2005	2006	2007					
Catch (cont.)	1232.4	1251.8	1346.7	1307.9	1576.7	1166.9	1343.2					
Abundance index (cont.)	9.96	3.92	4.733	5.704	4.132	3.91	5.153					
Duration t	31											
Average catch over time t	2129.17419											
Depletion over time t	NA											
M	0.2											
FMSY/M	1.5											
BMSY/B0	0.35											
MSY	NA											
BMSY	NA											
Age at 50% maturity	2.5											
Length at first capture	38											
Length at full selection	61											
Current stock depletion	NA											
Current stock abundance	NA											
Von Bertalanffy K parameter	0.395											
Von Bertalanffy Linf parameter	64.15											
Von Bertalanffy t0 parameter	-0.3											
Length-weight parameter a	9.30E-06											
Length-weight parameter b	3.0205											
Steepness	0.8											
Maximum age	25											
CV Catch	0.2											
CV Depletion over time t	0.5											
CV Average catch over time t	0.221											
CV Abundance index	0.3											
CV M	0.4											
CV FMSY/M	0.3											
CV BMSY/B0	0.045											
CV current stock depletion	0.5											
CV current stock abundance	1											
CV von B. K parameter	0.1											
CV von B. Linf parameter	0.1											
CV von B. t0 parameter	0.1											
CV Age at 50% maturity	0.25											
CV Length at first capture	0.25											
CV Length at full selection	0.25											
CV Length-weight parameter a	0.1											
CV Length-weight parameter b	0.1											
CV Steepness	0.3											
Sigma length composition	0.2											
Units	metric tons											
Reference OFL	NA											
Reference OFL type	NA											
CAA_bins	1	2	3	4	5	6	7	8	9			
CAA1977	39.8	1763	53.2	367	184.6	189.3	0	0	2.4			
CAA1978	0	374.7	2291.4	172.4	363	208.7	10.6	0	5.3			
CAA1979	0	67.3	559.6	1577	183.1	99.1	45.3	10.9	0			
CAA1980	0	884.8	104.1	755.8	1366.8	143.8	95.6	27.8	25.8			
CAA1981	2.1	1604.7	721.6	293.7	343	545.1	92.2	117.4	27.1			
CAA1982	30.4	620.6	1519.4	620.7	100.6	301	477.5	107.4	75.9			
CAA1983	10.8	12.4	836.5	976.3	791.3	148.6	253	348.1	115.7			
CAA1984	1.2	89	49.9	598	256.7	365	62.2	64.8	147.6			
CAA1985	0.9	30.2	349.6	85.9	356.2	152	242	47.4	54.6			
CAA1986	4.3	10.8	183.5	358.8	81.3	114	86.4	102.5	14.7			
CAA1987	0	20.6	34.7	106.1	48.8	34.4	56.9	33.8	16.5			
CAA1988	0.3	0.5	12.4	12.3	54.8	55.6	7.6	15	4.1			
CAA1989	1.4	23.2	3.5	42.4	19.3	24	15	0.8	0.9			
CAA1990	7	2	143.1	1.7	28.8	17.6	27.5	4.1	0			
CAA1991	3.1	7.2	16.3	58.6	28.4	27.9	12.6	5.8	3.1			
CAA1992	1.8	13.1	94.4	36.5	19.1	2.2	1.1	0	1.9			
CAA1993	3.7	20.1	36.3	23	9.9	11	4.6	1.7	1.2			
CAA1994	6.5	23.7	44.5	13.6	3.4	9.2	5.7	1.7	0.7			
CAA1995	2.7	71.3	90.5	75.7	10.2	6.3	4.7	4.3	3			
CAA1996	2.8	23.5	129.5	56.5	16.4	4.1	7.1	5.6	1.2			
CAA1997	1.7	7.3	166.8	256.8	90.1	18.9	6.9	2.8	2.3			
CAA1998	5.8	23.8	25.1	132.7	192.8	52.7	17.4	8.6	7.6			
CAA1999	5.3	3.8	39.5	65.8	96.8	69.2	38.5	7.1	5.9			
CAA2000	2.4	68.6	66.1	106.8	65.1	128.5	72.1	31.8	25.7			
CAA2001	0.3	29.5	235.1	133.6	96.8	87.3	80.7	40.4	24.1			
CAA2002	0.4	2.4	27.8	275.3	117.1	110.4	32.1	70.4	68			
CAA2003	0.1	10.8	6.9	54.1	506.9	90.5	63	21.6	70.3			
CAA2004	1.8	1.9	14.1	33	72	512.7	59.7	34	51.1			
CAA2005	0.2	36.5	6.3	49.3	84.8	138.5	534.9	53.7	71.8			
CAA2006	2	2.3	124	8.5	52.7	71.7	83.5	366.7	61.3			
CAA2007	7.8	24.9	17.3	332.7	11.4	54.4	43.2	87.9	371.1			