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Catch Advice Methods for the Northeast Multispecies Fishery: Report of Phase 1 and Phase 2 Work

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Executive Summary

In New England, overfishing continues for many stocks in the groundfish complex despite efforts to constrain harvest rates and rebuild overfished populations. We evaluated the magnitude and sources of scientific uncertainty in catch advice for stocks in the New England groundfish complex, and found that since 2004, annual catches have generally been at or below the target catch in most years for most stocks, yet harvest rates often exceeded the target, suggesting that target catches have been overly optimistic for many stocks. Methods for setting catch advice were generally similar (either age-based or index-based projections depending on the assessment model for a stock), but the magnitude of uncertainty and the impact it had on the ability of the catch advice to achieve the target harvest rate varied widely across stocks. For a number of stocks with age-based projections, the annual achieved harvest rates were between 2-10 times higher than the target harvest rates, despite catches being below the target catch in those years. These stocks included witch flounder, Gulf of Maine cod, Georges Bank cod, Georges Bank yellowtail flounder, and Cape Cod / Gulf of Maine yellowtail flounder.

Multiple sources of scientific uncertainty contributed to the overestimation of catch targets since 2004, but the largest contributing factors were overestimated abundance and below expected future recruitments. By evaluating population estimates over time from sequential assessments for each stock, we found that for many groundfish stocks, previous assessments overestimated biomass and recruitment in many years, particularly in terminal year of the assessment. Estimated abundance in the terminal year is the starting point for projections used to calculate future catch targets, and overestimated terminal abundance generally resulted in an overestimation of future catch targets. Additional uncertainty in catch advice has resulted from recent recruitments being below historical levels for many stocks. Historical recruitments estimates are used to predict future recruitments (influencing future stock biomass), and below expected recruitment can cause or exacerbate the overestimation of future biomass (and therefore future catch targets). Metrics often used to represent assessment uncertainty (i.e., retrospective error and variation in the estimate of terminal biomass) were poor predictors of the true uncertainty, indicating these metrics do not accurately reflect the total uncertainty in stock assessment estimates.

The causes of the overestimation of stock biomass and the observed declines in recruitment for many stocks remain unknown. Because these patterns occurred for many stocks, there may be some common mechanisms in the region influencing assessment estimates (e.g., underreported catches, increasing natural mortality, changes in survey catchability), and stock productivity (e.g., environmentally-induced regime shifts), and future work to identify and address these possible sources of scientific uncertainty in assessments models and projections is warranted.

Introduction

Modern fisheries management in the United States aims to keep the annual harvest rates (F) for a population at or below some threshold limit that defines overfishing (F_{MSY}). While the goal for a particular fishery is a target F, managers must try to achieve that F by setting catch limits based on output from a stock assessment model. Calculating catch limits is straightforward, but having those catches achieve the target F is not. Uncertainty in both the science and the management processes is common, and can have a large impact on the realized F for a stock. In some cases, realized Fs are far from the target (both above and below), which can have dire consequences for both the resource and the stakeholders. Identifying the reasons for such discrepancies is essential if we are to effectively manage our fish stocks.

Discrepancies between the target and realized F can result from uncertainty in both the science and management processes (Figures 1 and 2). On the management side, uncertainty typically manifests in the ability of the fishery to achieve the catch limits, also called implementation error. On the science side, uncertainty manifests in two areas: 1) the current estimates of population size, and 2) future dynamics. In other words, how accurate are the estimates, and how predictable are the stock dynamics? For 1) data issues (e.g., age-length key error or misreported catches) and model assumptions (e.g., fixed natural mortality rate or survey catchability) may interact to produce strong retrospective patterns in the assessment (Mohn 1999). Even in the absence of such issues, uncertainty can arise from using estimates from the terminal year of the model. Estimates of recruitment in the terminal year of an assessment generally have higher uncertainty, and errors in terminal recruitment estimates, when used, in a projection model can heavily influence the target catch limits. Similarly, projection models also use assumed future levels of recruitment to calculate future stock size and therefore future catch limits. Recruitment is highly variable and prone to environmental influence (Vert-pre et al. 2013), such that the actual recruitments may differ greatly from the levels used in the projection model. Projections that are done over a number of years also assume a target harvest rate, such that error early in the projected time series can propagate over the entire period, exacerbating the discrepancy between the target and realized F for a given stock.

The groundfish complex in New England currently comprises 20 stocks (Table 1), many of which support large fisheries that are of great economic and cultural importance to the region (NEFSC 2002). The assessment history of stocks belonging to the groundfish complex is varied in the number of times a stock has been assessed (determined by when it was first assessed and the number of years between assessments) and the methods used to assess stock status. In 2002 a comprehensive assessment of groundfish stocks was concluded at the Groundfish Assessment Review Meeting (herein called GARM 1; NEFSC 2002). The GARM 1 assessment relied on virtual population analysis (VPA), production models, and index-based approaches to assess status for 19 stocks, and concluded that 11 (58%) were overfished (when biomass or the index-based proxy for biomass is less than half the target level) and 9 stocks (47%) were experiencing overfishing (F or its proxy > F_{MSY}). After more than a decade of subsequent assessments and management actions aimed to reduce harvest rates, many groundfish stocks have shown little sign of recovery, and others stocks once classified in good condition are now overfished (Figure 3).

The overall aim of this project is to 1) better understand how catch advice was set since 2004 and the role that scientific uncertainty has played in achieving target harvest rates for New England groundfish stocks, and 2) how alternative approaches for setting catch advice would have performed in the face of this uncertainty. This report focuses on the former, while future work will address the latter. We selected 2004 as the first year for our analyses as it represents the first year target catches were specified, and because files necessary for our analyses were not available for years prior to 2004. Specific objectives for this phase of project are listed below (as specified in the request for proposals, or RFP):

1. Identify the methods used to set groundfish catch advice for all groundfish stocks since FY 2004.
2. Identify key assumptions used in each instance of setting catch advice. For example, when evaluating catches set using AGEPRO, identify the basis for recruitment assumptions, selectivity, weights-at-age, etc.
3. Quantify the lag between information used in the assessment and implementation of catch advice. Summarize assumptions about estimated catches in year T+1 when projecting catches in year T+2, T+3 etc. Evaluate potential consequences of conducting assessments on a calendar year basis and implementing catches on an offset fishing year.
4. Compare realized catches to projected catches with measures of uncertainty.
5. Evaluate the performance of the catch advice with respect to achieving the desired fishing mortality rate and predicted changes in stock size. Consider the joint effects of the uncertainty of the forecast and precision of the abundance estimate. This analysis should include a review of adjustments used to improve the projections, such as the retrospective adjustments applied for some stocks.
6. Identify the reasons for the success or failure of the catch advice. This should include exploring whether changes in environmental conditions influence projection performance.
7. Identify changes that will improve the performance of catch advice (for example, by modifying inputs used in the projection model).

Objectives 1 through 3 aim to give a clearer picture of how catch targets were set for groundfish, while Objectives 4 through 7 aim to determine the effectiveness of the catch advice, and identify possible sources of error in cases where catch advice has been overly optimistic or conservative. Note that the original scope of this work was to include all groundfish stocks in the analyses for Objectives 1 and 2, and use a subset of stocks for the remaining Objectives. We gathered as much information for as many stocks as possible, such that some of the analyses for Objectives 3-5 were done for as many groundfish stocks as possible, not just for a selected subset.

Our analysis expanded on these objectives to better understand scientific uncertainty in the catch advice for groundfish stocks. Specifically, we explored how estimates from repeated stock assessments (across model uncertainty) changed over time, and how well measures of uncertainty from an assessment (within model uncertainty) captured the true uncertainty in terminal estimates. This additional work is related to Objective 5, and our findings in this area are included therein.

Sources of Information

The focus of this work is on catch advice set for 2004 onward for groundfish stocks. We obtained a large number of documents pertaining to the assessment and management of these stocks from the New England Fisheries Management Council (NEFMC). These documents include, but are not limited to, management measures (Amendments and Frameworks from Amendment 13 onward; Table 1), stock assessments (Table 2), reports from the Scientific and Statistical Committee (SSC) and from the groundfish Plan Development Team (PDT). In addition, we obtained the files used in the projection model AGEPRO (Brodziak et al. 1998), which was the primary basis for the catch advice for stocks with age-based assessments covering this time period.

Objective 1) Identify the methods used to set groundfish catch advice for all groundfish stocks since FY 2004.

We first provide an overview of the general methods used to set catch advice, and then discuss specific details associated with individual management measures.

Overview

The methods used to set catch advice varied across stocks and in some cases across management measures for a given stock. This variation in approaches was largely due to the type of assessment model used, although there were some exceptions. Stock assessments for New England groundfish can be classified into 3 broad categories: Data-poor approaches, production models, and age-structured models. For data-poor stocks, the index-based assessment program AIM was used in nearly all cases. Although a production model was explored as an option in the assessments of many stocks, only for GB winter flounder in GARM 1 and GARM 2 (NEFSC 2002, 2005) was this approach the primary basis for determining stock status and reference points (using the ASPIC program). Age-based assessment approaches were virtual population analysis (VPA), and statistical catch at age analysis (SCAA), primarily using the programs ADAPT and ASAP, respectively, to perform the analyses (details on all the models listed, as well as software downloads, can be found at http://nft.nefsc.noaa.gov/).

Groundfish stocks for which index-based assessments were done include pollock, GOM haddock, white hake, pout, and north and south windowpane flounder. Pout and both windowpane stocks were assessed using index-based methods for the entirety of the time period, whereas age-based assessments were developed for pollock, GOM haddock, and white hake. The focus of this study is primarily on the age-based assessment methods, so discussion of index-based projection methods is limited in this report. For a summary of the AIM projection approach see NEFSC 2002b.

Wolffish was first assessed as part of as part of a data-poor working group (NDPSWG 2009), which explored AIM, depletion-corrected average catch (DCAC; MacCall 2009) and a statistical catch-at-length model (SCALE; http://nft.nefsc.noaa.gov/). The SCALE model has been the basis for setting catch advice for wolffish from 2010 onward, although projections were not performed for this stock (NEFMC 2010, 2013).

For stocks with age-based assessments, catch advice was based primarily on the AGEPRO model (Brodziak et al. 1998), although there were some exceptions (detailed below). AGEPRO is an age-structured projection model that uses output from the most recent assessment (terminal abundance, recruitment estimates or an estimated stock-recruit relationship, and estimated fishery selectivities) combined with assumed natural mortality-, maturity-, and weight-at-age to project the population biomass forward in time under an assumed fishing mortality rate. Uncertainty in AGEPRO projections is largely determined by uncertainty in the initial abundance at age in the projection (based on bootstrapped estimates from VPA models or Markov chain Monte Carlo estimates from SCAA models) and the future recruitment dynamics. Uncertainty in other inputs (natural mortality-, weight-, maturity-, and fishery selectivity-at-age) is also possible to include in AGEPRO, but this feature was not available until recently (Version 4.2.2., 2013). As a result, catch advice evaluated in this study was based on AGEPRO projections assuming fixed inputs for these quantities. Setting catch advice using AGEPRO also requires assumptions about how future recruitments are calculated and about the catches or F in the interim years between the terminal year of the assessment and the year a target harvest rate is applied in the model. The assumed AGEPRO inputs used to set catch advice for groundfish are discussed in detail in response to Objective 2 below. Once inputs are specified, AGEPRO is run for a number of iterations over a set time period to produce a distribution of stock size and catch at the target F over time. In addition to calculating a target catch, AGEPRO can be used to determine the target F that achieves some objective, such as the F that results in the rebuilding of a stock ($F_{rebuild}$) by some time in the future with some probability (generally the F that results in at least a 50% probability that the biomass will exceed the target in the specified year).

AGEPRO was the most frequently used projection method for groundfish stocks with age-based assessments, but alternative methods were also used in some cases. For GOM winter flounder, no projections were done following GARM 2 and GARM 3 due to uncertainty in the assessment model results (NEFSC 2005, 2008). As a result of this uncertainty a target catch was not specified in Framework 42 (NEFMC 2006), and the target catch for 2010-2012 specified in Framework 44 was based on a 3-year average of the most recent catches (NEFMC 2010). For white hake and halibut following GARM 3, age-structured projections were completed using an alternative projection model, although the details of the specific models used were not specified in NEFMC (2010). Finally, catch advice for GB yellowtail flounder has been updated annually based on annual TRAC assessments (Table 3), but in some years AGEPRO is used, while in others, an alternative projection model was used (e.g. TRAC 2007).

Amendment 13

A summary of the approaches used in Amendment 13 is presented in Table 4 along with the target harvest rate (F_{target}) or the target catch / index (C/I_{target}) for index-based assessments. Many of the stocks were in need of rebuilding, so the target harvest rate was based on a rebuilding analysis. Two different types of rebuilding strategies were explored, termed the "phased" and "adaptive" rebuilding plans (details of these plans are provided in NEFMC 2003) and the plan that was used varied for each stock (Table 4). For stocks not in need of rebuilding, F_{target} was the estimated F_{MSY} or proxy (herein we use F_{MSY} to represent the F reference point, regardless of whether or not is in an actual estimate of F_{MSY} or a proxy such as $F_{35\%}$). The target catch calculated at F_{target} was called the target total allowable catch, or TTAC, although this was not a "hard" catch target (i.e., no closures or accountability measures if exceeded).

Framework 42

Following the GARM 2 assessments in 2005 (NEFSC 2005), Framework 42 was developed to set catch advice for 2006-2009 based on the updated status for each stock (NEFMC 2006). For most stocks, the target harvest rates remained unchanged from Amendment 13, although for some stocks F_{target} was modified to account for the updated status of the stock and new rebuilding schedule (Table 5).

Framework 44

Framework 44 (NEFMC 2009) was developed to update the catch advice starting in 2010 based on the GARM 3 assessment, which estimated population status and exploitation rates through 2007 (NEFSC 2008). Reference points were updated, and age-based stock assessments were conducted for GOM haddock and white hake, previously assessed using an index-based approach (NEFSC 2008). Framework 44 marked a transition to setting acceptable biological catch limits (ABCs) for each stock as mandated in the revised Magnuson Act (NEFMC 2009). The NEFMC ABC control rule specified in Amendment 16 (NEFMC 2009) is to set the ABC using 75% F_{MSY} in the absence of rebuilding. In cases where rebuilding is required, the control rule specifies that F_{target} is to be set at the smaller of 75%F_{MSY} or $F_{rebuild,}$ when rebuilding is possible in the specified timeframe (see Appendix A for more details). As a result, the basis for the F_{target} shifted for a number of stocks from $F_{rebuild}$ in Framework 42 to 75%F_{MSY} in Framework 44 (Tables 5 and 6). The ABC was set using AIM for index-based stocks (without projections), and AGEPRO primarily for stocks with age-based assessments, although the ABC for GOM winter flounder was based on the average catch in the previous three years due to assessment uncertainty, and for white hake an alternative projection model was used (NEFMC 2010).

Frameworks 45 and 47

ABCs were updated in Frameworks 45 and 47 for 10 stocks (Table 7) starting in 2011 and 2012, respectively (NEFMC 2011, NEFMC 2012). The ABC specification for three stocks (pout, and North and South windowpane) was index-based, but without projections. AGEPRO was used for GB yellowtail flounder (based on TRAC 2010 and 2011), pollock (based on NEFSC 2010), GB winter flounder, and SNE/MA winter flounder (based on NEFSC 2011), and white hake (based on NEFSC 2008). White hake was included in Framework 45 to correct an error in the Federal Register, so projections were not based on updated information. The ABC for GOM winter flounder was also updated, but the assessment relied on a swept area estimate of total biomass and projections were not used. The F_{target} was set using the ABC control rule. In the case of SNE / MA winter flounder, the population could not rebuild in the specified timeline, so the F_{target} was based on the 2009-2010 average estimate of F when landings were prohibited (NEFMC 2012).

Framework 50

In 2012, assessments were conducted for a number of groundfish stocks, and Framework 50 was implemented to update the catch advice (starting in 2013) based on the updated assessment results (NEFMC 2013). For stocks with age-based projections, the ABC was estimated in 2013 using the NEFMC ABC control rule, although there were exceptions. The F_{target} for GOM cod in 2013 was based on an F between 75% F_{MSY} and F_{MSY}, and the recommended ABC for GB yellowtail was based on the 2012 ABC. In addition, projections using AGEPRO for many stocks were used to only calculate the ABC in 2013, after which the ABC was fixed due to uncertainty in the accuracy of previous projections (NEFMC 2013; Table 8). As a result, F_{target} for these stocks in 2014 and 2015 is lower than the values specified in Table 8 for stocks predicted to grow. Projections were not used for stocks with index-based assessments (Table 8).

Framework 51

The ABCs in 2014 for GB yellowtail and white hake were updated with Framework 51 (NEFMC 2014). The ABC for white hake was calculated with AGEPRO using output from NEFSC (2012) and a target F of 75% F_{MSY}. The ABC was only calculated for 2014 and fixed through 2016. Assessment uncertainty for GB yellowtail prevented a reliable estimate of the overfishing limit (the catch at F_{MSY}), so the SSC recommended that the catch should not exceed 500 mt, and the ABC was set at 400 mt for 2014 (NEFMC 2014).

Objective 2) Identify key assumptions used in each instance of setting catch advice. For example, when evaluating catches set using AGEPRO, identify the basis for recruitment assumptions, selectivity, weights-at-age, etc.

For this Objective we focused on the catches set using projections from the AGEPRO model. Specific details for the cases in which index-based approaches were used were limited. As a result, we focus on the assumptions used in the age-based projection methods, noting however that a summary of the AIM projection approach is provided in NEFSC (2002b).

A brief summary of the AGEPRO model and required assumptions is provided in response to Objective 1 above. The assumptions we identified for this Objective are: 1) the number years used in calculating the average weight-, maturity-, and selectivity-at-age, 2) the assumed recruitment distribution that determined future recruitments in the projections, and 3) the assumed catch or F in the interim years between the terminal assessment year and the year when catch advice is set. A summary of these assumptions is provided for all stocks (when available) in Table 9. Here we discuss patterns regarding 1 and 2, and discuss 3 in response to Objective 3 below.

The number of years used to calculate the average weight-, maturity-, and selectivity-at-age varied across stocks and across projections for a given stock. These estimates were often (but not always) reported in the assessment documents. Although earlier assessments (GARM 1 and GARM 2) provided the estimated values for these inputs for all stocks, the number of years used to calculate these values was not always reported. In such cases we also explored the 2002 NEFSC reference point document (NEFSC 2002b) since projections and reference points likely used the same inputs. Despite these efforts, we were unable to determine the number of years used to calculate the mean weight-, maturity-, and selectivity-at-age for a number of projections for some stocks. Reported values generally ranged from 3-5 years, although longer intervals were also used (Table 9). Shorter (3 year) intervals were often used when trends were apparent in recent years (e.g., declining mean weight-at-age).

Future recruitments are a key source of uncertainty in future stock size and catch levels predicted in any projection model. The current version of AGEPRO has 21 different methods for predicting future recruitments, although the earlier versions had fewer options. Despite the large number of options, only four methods were used for predicting future recruitments; one parametric and three non-parametric models (Table 9). The only parametric recruitment relationship used was the Beverton-Holt stock-recruitment curve with lognormal variability (recruitment model 5 in AGEPRO). Parameters controlling the shape of the relationship and the level of variability were estimated for certain stocks and specified in the AGEPRO model. The remaining three recruitment models are non-parametric, and rely on drawing recruitments from an empirical cumulative distribution functions (ECDF) created using the estimated recruitments over a specified number of years (not necessarily the entire time period). The specific non-parametric models used were a 1-stage ECDF, where a single ECDF is used to predict all recruitments (AGEPRO model 14), a 2-stage ECDF (AGEPRO model 15) where two recruitment periods are used to create separate ECDFs for a low and high recruitment period (a threshold biomass is specified to determine which ECDF is used), and finally a 1-stage ECDF that allows recruitment to go to 0 (AGEPRO model 21). The Beverton-Holt model, which was used more widely for Amendment 13 and Framework 42 projections, was only used recently for GB and SNE/MA winter flounder stocks (Table 9). When non-parametric approaches were used, we obtained the number of years of recruitment estimates used to create the 1- and 2-stage ECDFs, which varied widely across stocks (from 3 to 53 years; Table 9).

Objective 3. Quantify the lag between information used in the assessment and implementation of catch advice. Summarize assumptions about estimated catches in year T+1 when projecting catches in year T+2, T+3 etc. Evaluate potential

consequences of conducting assessments on a calendar year basis and implementing catches on an offset fishing year.

Catch advice for a given year is based on estimates from the terminal year of the most recent stock assessment model. For a multitude of data, assessment, and management reasons, there is a delay (or lag) in the information available to set target catches for a stock. The number of years between the terminal year of an assessment and the year in which catch advice is set is called data-management lag (DML), and can be considerable for stocks with many years between assessments.

We calculated DML for a given year as the difference between the year that the catch advice is set and the terminal year of the assessment used to inform the catch advice. As an example, catch targets specified in Amendment 13 were set for 2004 and 2005, and for most stocks were based on assessments with a terminal year of 2001 (last year with catch estimates). Therefore, DML for Amendment 13 catch advice ranged between 3 and 4 years for most stocks (Table 9). Since 2004, DML has ranged from 2 to 6 years, although the 6-year interval occurred only once for white hake. A 5-year DML was the longest period for most stocks, occurring for 2009 catch targets based on the GARM 2 assessment with a terminal year of 2004 (Table 9). We explored the impact that DML had on catch advice further in response to Objective 5 below.

Because of DML, setting catch advice in a given year requires assumptions about the fishing mortality in the interim years. When DML is 2 years, an assumption is only needed for one year, whereas an assumption for an additional year is needed when DML is 3 years. A summary of the assumed methods for determining F in the interim years is presented in Tables 4 - 8. For stocks using AGEPRO, the approach typically used was to estimate the catch in the first interim year (terminal year from the assessment, TY, + 1) and calculate the F resulting from that catch in the projection model. If an assumption was needed for the following year (TY +2), the F in that year was based on the estimated F in the previous year, either by setting them equal or adjusting it by some factor (see below). In more recent years, assumptions were only required for one interim year (Tables 7, 8).

Amendment 13 projections required assumptions for the harvest rates in 2002 and 2003 to specify the catch in 2004. For age-based stocks, catch for 2002 was estimated and used in the projection model to determine the resulting F. The 2002 estimate of F was then assumed to be the same in 2003. For index-based stocks, a fixed C/I was assumed for 2002 and 2003 (NEFMC 2003). For Framework 42, target catches in 2006 onward were based on a terminal assessment year of 2004, so an assumption for harvests in 2005 was needed, and F in 2005 was assumed to equal the assessment-estimated F in 2004 for each stock (NEFMC 2006). Target catches in 2010 were based on the GARM 3 assessments (NEFSC 2008) with a terminal year of 2007. The F in 2008 in the projection model was calculated using an estimate of the total catch for each stock, and the F in 2009 was set by adjusting the estimated F in 2008 by a factor that was developed "after considering the expected impacts of the Northeast Multispecies interim action that was implemented May 1, 2009" (NEFMC 2010), although the specific adjustments and the methods used in calculating them were not presented.

Interim year F assumptions for Frameworks 45-51 generally followed the same approach (Tables 7, 8), although there were some exceptions. An estimate of the catch for pollock in TY +1 (2011) was not available for Framework 45, so the sensitivity of catch advice in 2012 was evaluated for a range of catch estimates in 2011. Projection results were largely insensitive to the assumed catch in 2011, so the assumed catch in 2011 was based on $F = 75\% F_{MSY}$ (NEFMC 2012). For GB yellowtail in Frameworks 45 and 47, interim year catches were based on the catch targets (U.S. and Canada combined) from the previous year and not an estimate of the actual catch that occurred (NEFMC 2012, 2013). Increasing uncertainty in assessment results for GB yellowtail resulted in catch advice in Frameworks 50 and 51 not being based on projections.

One potentially problematic assumption in the setting and evaluation of catch advice is that catch targets are estimated for the start of the calendar year (January 1st), yet the management year for New England fisheries starts May 1st. Therefore, the projected biomass at the start of a given year used in the projection calculation could potentially be dramatically lower if the harvest were larger prior to May (based on a target catch set for the previous year). Evaluating the impact of this assumption on the success of catch advice was not feasible given the time constraints of this project.

Objective 4. Compare realized catches to projected catches with measures of uncertainty, and

Objective 5. Evaluate the performance of the catch advice with respect to achieving the desired fishing mortality rate and predicted changes in stock size.

Objectives 4 and 5 aim to identify how well catch advice from projections performed. Our analysis of projections was based on a subset of stocks, but we conducted a broader analysis of the performance of catch advice at achieving F_{target} for all groundfish stocks with the necessary information. We first describe this broader analysis for all groundfish stocks, and then detail the projection analysis for the subset of stocks.

To determine how well catch advice performed in a given year with respect to achieving the target harvest rate, we need to know what the actual harvest rate was over the time of the catch advice. The true annual harvest rates are unknown for all groundfish stocks, but we have estimates of these harvest rates from stock assessment models. We used the most recent assessment that passed review for a given stock as the source of estimates of "true" harvest rates. Herein we refer to estimates obtained from the most recent assessments as the "updated" estimates. A caveat to this approach is that these are still estimates from an assessment model, and may be revised in future assessments. We also obtained estimates of annual total catches from the most recent assessment for comparison with the catch targets.

For some stocks, earlier assessments passed the review process (i.e., results could be used to set catch targets) while later assessments did not, and we did not use information from the failed assessments in our analyses. Both GB yellowtail and GOM winter flounder are stocks where this occurred. Age structured models for both stocks showed considerable uncertainty in the estimates, and the assessment ultimately used survey-based estimates of the swept-area biomass to estimate abundance (NEFSC 2012; TRAC 2014). For these stocks we used previous assessments that passed review (NEFSC 2005 for GOM winter and TRAC 2013) as the basis for the updated estimates, cautioning that many of the uncertainties present in the failed assessments were also present in these assessments.

From management documents (listed in Table 2) we obtained the annual target catch and harvest rates for each stock from 2004 onward, including stocks with index-based estimates. Prior to 2010 the target catch was called the target total allowable catch (TTAC), and from 2010 onward the catch was the acceptable biological catch (ABC). Both the TTAC and ABC were calculated using the F_{target} specified in each management measure, and we considered them comparable for our analysis. Target and observed catches and harvest rates are presented in Table 10.

With estimates of the true harvest rates, we calculated the ratio of the observed harvest rate to the target, as well as the ratio of the observed total catch to the target total catch in all available years. In Figure 4 we plot the annual F-based harvest ratio for stocks in all years where we have estimates of F_{target} and the observed F. The observed F (F_{obs}) we used in a given year was the average estimate of F on fully-selected age classes in that year from the assessment. We also evaluated using an F multiplier (the largest F estimated across age classes) as Fobs, but results were similar, so we only discuss results using the average F on fully-selected ages. The observed catch (in weight; C_{obs}) exceeding the catch target was not a common occurrence, as most stocks had at most 1 or 2 years when the catch was above the target. When overages occurred, the size of the overage was generally less than 50% above the target. An exception was SNE/MA yellowtail flounder, which had catch overages in 4 years, all more than 50% above the target catch (Figure 4). Despite the relative infrequency of catch overages, most annual estimates of the fishing mortality rates were above the target set in those years. Averaged annual estimates of F_{obs}/F_{target} and C_{obs}/C_{target} for each stock are shown in Figure 5.

Deviations in the estimated C_{obs}/C_{target} away from 1 can result from implementation uncertainty, but can also result from misreported catches (Figure 2). The majority of the total catches were estimated to be below the target catch in most years, but whether or not this was the result of the true catch being below the target or if a large number of catches went unreported cannot be determined. Misreported catches may be an important source of scientific uncertainty for New England groundfish (King and Sutinen, 2010), but we cannot determine the relative contribution of misreported catches in the deviations of C_{obs} / C_{target} shown in Figures 4 and 5 with the available information.

An $F/F_{\text{target}} > 1$ when $F/F_{\text{target}} < 1$ (or vice-versa) could result from scientific uncertainty, but it could also result from management uncertainty. For example, a stock with $F/F_{\text{target}} = 2$ when $C/C_{\text{target}} = 2$ is different from a stock with $F/F_{\text{target}} = 2$ when $C/C_{\text{target}} = 0.5$. In the former case, an overage in the total catch resulted in the higher F. In the latter case, total catch was only half the target, yet F was double F_{target}, indicating that scientific uncertainty played an important role in $F > F_{\text{target}}$. We therefore calculated a relative measure of error in achieving F_{target} as a quantitative measure of scientific uncertainty:

$$F_{error} = \frac{\left(\frac{F_{obs}}{F_{target}} - \frac{C_{obs}}{C_{target}}\right)}{\frac{C_{obs}}{C_{target}}}$$

Values close to 0 imply that the discrepancies between the observed and target F are largely the result of the achieved catch (relative to the target), and are examples of low scientific uncertainty (e.g., Figure 2). In contrast, values farther away from 0 (positive and negative) indicate that F_{obs}/F_{target} is disproportionately large or small for a given C_{obs}/C_{target}, , respectively, and are examples of high scientific uncertainty. This measure assumes proportional changes in F in response to changes in catch, which is not true across the entire range of C_{obs}/C_{target}, particularly as this ratio approaches 0 or becomes very large (>>1). Furthermore, this measure does not distinguish between the different sources of uncertainty in a given year (which we explored for a subset of stocks; see Objective 6 below). For example, an $F_{obs}/F_{target} > 1$ when $C_{obs}/C_{target} = 1$ could result from overestimation of terminal abundance, below forecast recruitments, or declining mean weight-at-age. Nevertheless, F_{error} is a useful measure for identifying cases where the achieved F was impacted by scientific uncertainty. An additional caveat to this metric is that it assumes catches were accurately estimated, which may not be true for some stocks. The mean F_{error} for each stock is shown in Figure 6. Only two stocks had negative mean estimates (pollock and redfish), and 9 stocks had high mean estimates of F_{error} (> 2), with 4 stocks (CC/GOM and GB yellowtail flounder, GOM cod, and witch flounder) having very high estimates (>5).

We also evaluated the performance of catch advice for index-based stocks by plotting the observed harvest ratio (C/I_{obs}) / (C/I_{target}) as a function of C_{obs} / C_{target}. Catch overages were larger and more frequent for index-based stocks, although the achieved C/I-ratio was often close to the 1:1 line, suggesting a large degree of implementation uncertainty for these stocks (Figure 7) for achieving C/I_{target}.

Index-based methods calculate proxies for the OFL, so that while target catches for these stocks may be able to achieve the target C/I, whether or not these catch targets are close to the true OFL is unclear. We explored this question using information from three stocks formerly assessed using index-based methods that were later assessed using age-structured models (GOM haddock, white hake, and pollock). For these stocks we calculated the F_{obs} / F_{MSY} from the age-based assessment and compared it to C_{obs} / C_{target} in years when the target catch was based on an index approach. We used F_{MSY} here instead of F_{target} because F_{target} was not calculated in these years. We could have used 75% of F_{MSY}, but chose F_{MSY} to determine whether or not the index-based approaches resulted in overfishing (i.e., $F_{obs} > F_{MSY}$). For GOM haddock, overfishing did not occur, and values were clustered around the 1:1 indicating reasonably effective index-based catch advice (Figure 8). For white hake and pollock, index-based catch advice was less effective, being too conservative ($F_{obs} < F_{MSY}$) for pollock, and both conservative in some years and optimistic for white hake (Figure 8).

For most stocks where catch advice came from age-based assessments, that advice often resulted in $F_{obs} > F_{target}$ (Figures 4 - 6). To better understand the influence of some potential factors, we explored the relationship between F_{error} and 1) the data-management lag (DML; detailed in Objective 3 above), 2) the assumed recruitment distribution used in the projection model (also detailed in Objective 3), and 3) the error in terminal biomass estimates. Estimates of F_{error} were highest for a DML of 2 years, but this was largely due to GB yellowtail and GOM cod (Figure 9). When these stocks were excluded, F_{error} was similar across the length of observed DML (2-5 years). Thus, greater error in catch advice did not necessarily occur when catch advice was based on increasingly out of date information. The assumed recruitment model used in the projection was also a poor predictor of F_{error} (Figure 10).

To explore the impact that error in terminal spawning biomass estimates had on F_{error} we obtained biomass estimates from all available assessments (from GARM 1 onward) and compared the historical estimates with the most recent (updated) estimates. Recruitment and F estimates were also obtained, and all estimates across assessments are found in Appendix B. For stocks that required an adjustment to the terminal estimates based on a retrospective pattern (i.e., a rho adjustment), we used the adjusted values in the terminal year for that assessment. In some cases, multiple models with different estimates were put forward as plausible in an assessment. For GOM cod, recent assessments explored two formulations where natural mortality was constant or increased in recent years, and for GB yellowtail following the GARM 3 assessment, models were run including or omitting a very high annual estimate of relative abundance from the Canadian survey (NEFSC 2008). We used assessment estimates from the models assuming a constant natural mortality rate for cod, and omitting the large survey estimate for GB yellowtail. Error in terminal estimates is not the only potential source of error in catch advice from a projection model, however, and we conducted a more thorough evaluation of projection advice for a subset of groundfish stocks (detailed below).

Using annual estimates of biomass and recruitment across multiple stock assessments for a given stock we calculated the across-model uncertainty in the assessment estimates. Raltson et al. (2011) used a variety of approaches for calculating the across-model uncertainty for stocks in the Pacific, but we focus on the relative error in estimates using the most recent (or updated) estimate as the true value (B_{up}). For example, the relative error in a biomass estimate from assessment j in year t ($REB(j,t)$) is calculated with:

$$REB(j,t) = \frac{(B(j,t) - B_{up}(t))}{B_{up}(t)} \qquad (2)$$

The analysis of Ralston et al. (2011) only considered uncertainty across benchmark (or "research track") assessments for a given stock, where data inputs may have been modified (e.g., updated catch estimates) and model assumptions changed (e.g., adjusted natural mortality rate or differently-shaped selectivity curve) from the previous assessment. We included both benchmark and update assessments (where only the data are updated to the most recent year and the model rerun) in our analysis because we wanted to include the possibility for large changes in the perception of stock status following an update assessment.

We calculated the relative error in biomass and recruitment estimates from 1999 to the terminal year of the second to last assessment. For most stocks the most recent assessment was completed in 2015, with updated biomass and fishing mortality estimates through 2014 (NEFSC 2015). Assessment-estimated biomass and recruitment trajectories for each stock are shown in Appendix B. Estimates of *REB* (across years) are shown by stock in Figures 11 and 12, and *REB* and *RER* based only on the terminal year estimates are shown in Table 11 (by stock) and Figure 13 (aggregated across stocks). The general pattern across assessments for most stocks has been to overestimate biomass and recruitment (the median *REB* is positive for 11 stocks and negative for 3 stocks; Figure 12). The median *REB* and *RER* for terminal assessment estimates aggregated across stocks) is 0.37 and 0.24, respectively (means of 0.66 and 0.6), indicating that terminal estimates from previous assessments were often overestimated. Error in terminal biomass estimates is a good predictor of error in achieving F_{target}, with higher values of REF_{target} occurring for higher values of *REB* (Figure 14).

We also explored whether measures of *within*-assessment uncertainty were useful predictors of whether or not catch advice would be successful. In other words, are measures of uncertainty produced from an assessment accurate predictors of how truly uncertain those estimates are and how effective projections will be? Retrospective uncertainty (Mohn's ρ; Mohn 1999) and the coefficient of variation (CV) in the terminal biomass estimate are two metrics often used to quantify within-assessment uncertainty. We obtained estimates of ρ when available[1] from each assessment for each stock, noting that the number of "peel" years used to calculate ρ was not consistent (usually 5-7 years). The CV of the estimated terminal biomass was not always available for each stock from each assessment. Because we have projection outputs for each stock where AGEPRO was used, we have estimates of the CV of the biomass in the first year of the projection (one year after the terminal assessment year) for many of the stocks. We therefore used the biomass CV in the first year of the projection as a proxy for the CV in the terminal estimate. The spawning biomass in the first projection year is based on bootstrapped or MCMC estimates of abundance from the terminal year of the assessment, discounted by the assumed natural mortality rate and the calculated harvest rate resulting from the

[1] Estimates of ρ were not presented in the GARM 1 assessments, but figures showing retrospective estimates were shown for each stock with and age-based assessment. To estimate ρ for each stock we extracted 5 years of estimates of terminal biomass from the retrospective analysis figure for each stock and calculated ρ following Mohn 1999. For GARM 2 assessments, estimates of ρ were also not presented for many stocks, but a summary figure of the estimates ρ for each stock was provided (Figure 5 of NEFSC 2005), so we obtained the mean estimate for each stock in the figure.

observed catch in the terminal year. Thus, uncertainty in the estimated terminal abundance of age 1,2,3,etc. results in uncertainty in the abundance of age 2,3,4, etc. in the first year of the projection. Recruitment in the first projection year is based on an assumed level, often the geometric mean of recent recruitment estimates, but this assumption had little effect on the spawning biomass CV because recruits contributed little to the spawning biomass for most stocks. We caution, however, that the CV of spawning biomass in the first projection year may be an over- or underestimate of the uncertainty in terminal biomass estimate for a variety of reasons. The proxy for the CV in terminal biomass for a given assessment is a poor predictor of the true uncertainty in that estimate, with high *REB* (>1) occurring across the range of CVs (Figure 15). Furthermore, retrospective uncertainty in biomass estimates (ρ) from an assessment is a poor predictor of how accurate the terminal estimates were (Figure 16). High values of *REB* for the terminal year of an assessment for a stock occurred for assessments with negative and positive retrospective patterns in biomass, as well as for assessments with no pattern ($\rho \sim 0$). Therefore, the within-assessment measures for many stocks of terminal uncertainty were often poor predictors of the accuracy of those estimates.

Projections

The analyses described thus far for Objectives 4 and 5 were conducted for all possible stocks to identify stocks where scientific uncertainty has changed the perception of stock status, and also influenced the ability to achieve the target harvest rates. Over- or underestimation of biomass is only one possible source of scientific uncertainty, and a more detailed analysis of potential factors influencing catch advice is needed. Such an analysis requires updating the projections used to set catch advice with our current, best estimates of the relevant parameters, and can determine which factors had the largest impact on overly optimistic or pessimistic projected catch targets.

The accuracy of a projection model is determined by a number of factors, including the assumed initial abundance at age, weight-, maturity- and selectivity-at-age, future recruitments, and also the assumed catch (or *F*) during the interim years between the terminal year of an assessment and the first year that the catch advice is calculated.

With input from NEFMC staff, we selected a subset of 6 stocks for this portion of the analysis: GOM cod, GB cod, SNE / MA winter flounder, witch flounder, GB yellowtail flounder, and pollock. These stocks will also be used in the subsequent analysis exploring the effectiveness of alternative methods for setting catch advice. For all stocks except pollock, we restricted the projection analysis to projections done using estimates from GARM 1, 2, and 3 assessments (NEFSC 2002, 2005, 2008, respectively). Catch advice from GARM 3 covered the period 2010-2012 for most stocks, and GB cod, witch flounder, and SNE / MA yellowtail do not yet have estimates from an assessment beyond 2012. Therefore, there is no way to assess the accuracy of catch advice from projections beyond 2012 for these stocks. GB yellowtail has had annual updates to the assessment and projection models, but redoing projections for all years for this stock was not feasible. We therefore restricted our projection analysis to GARMs 1, 2, and 3 for GOM and GB cod, witch flounder, and SNE/MA winter flounder, GARMs 1 and 3 for

GB yellowtail (projection files were not available for GARM2), and for the SAW 50 (NEFSC 2010) projections for pollock.

It is important to note that the analysis for this part of the work does not use the same assessment as the source for the updated estimates of abundance for most stocks. Work for previous Objectives used the most recent assessments just completed for each stock (NEFSC 2015). The work for this report was completed prior to the completion and review of the 2015 assessments, and a draft of this report was submitted. Subsequently, the 2015 assessments were reviewed and the results made available, so we updated the time series' of biomass, *F*, recruitment, and catch for the analyses and updated the results in this document. However, extracting all of the information necessary to rerun the projections was not feasible given the time constraints of this project, so the basis for the reference estimates of abundance for projection analysis was the assessment prior the 2015 update. For GB cod, the 2015 assessment did not pass the review process, so we did not use any information from the 2015 assessment for this report.

For GARM 1-3, pollock was assessed using an index-based assessment, and catch advice was based on the AIM model. A full description of the index-based projections methods is provided in the NEFSC (2002b). Although it is possible to explore catch predictions from the AIM model using different indices of abundance (e.g., the spring survey index compared to the fall survey index), a more appropriate analysis for this stock requires exploring alternative methods for setting catch advice (i.e., a suite of data-poor methods such as those available in the data-limited toolkit for R; Carruthers 2014) and not alternative inputs to a single model. We therefore focus only on the accuracy of the AGEPRO-based projections for pollock, and reserve analysis of alternative methods for subsequent work. Pollock was first assessed using an age-structured model in 2010 (NEFSC 2010), and was reassessed in 2014 (NEFSC 2014), so we are updating one projection based on the 2010 assessment with information from the 2014 assessment.

We created an age-structured projection model in R (R Core Team, 2015) that mimics the AGEPRO model. We created our own projection model because future work will require a projection model that can be easily modified as needed to test alternative catch advice methods. The equations governing the projection dynamics of our model are presented in Table 12, but we provide a summary of the model here. The projection model uses the same input files created to set catch advice for each stock based on the assessments listed above (obtained from NEFMC staff). The initial abundance at age and all input assumptions are read into the model. The fishing mortality in the first year is either based on the value specified in the input file for that year, or when a catch is specified, *F* is calculated using the Baranov catch equation (equation 5 in Table 12) and the assumed average catch weights and fishery selectivity. In the second year of the projection, recruitment is determined from the specified recruitment model with the appropriate lag in years (either Beverton-Holt, or 1- or 2-stage empirical cumulative distribution functions; see Objective 3 for more details on these recruitment models). For all other age-classes, abundance at age in year 2 is determined by the abundance in the previous year discounted by fishing and natural mortality rates (equation 1 in Table 12).

Spawning biomass is calculated each year using the estimated abundance at age and the specified mean maturity- and spawning weight-at-age, discounted by a specified fraction of the total mortality that occurs before spawning in a year. Spawning biomass determines recruitment when the Beverton-Holt recruitment model is specified, and it also determines which time-series of recruitments should be used when the 2-stage empirical model is used. Total catch in a year is calculated using the Baranov catch equation (Table 12) for a given F_{target}. The stock is projected forward a number of years under the F_{target} specified in the input file, and this process is repeated 1000 times to account for uncertainty in the initial abundance and future recruitments, producing a distribution of predicted spawning biomass, recruitment, and total catch for each year in the model.

The distributions of projected spawning biomass, recruitment and catch are shown in Figures 17 – 22 for each stock alongside the most recent (updated) values. Projected values were calculated using the original projection inputs (e.g., abundance, weights) under the F_{target} for that time period. The current biomass and recruitment each year were based on the most recent assessments for each stock, and the updated catch was calculated using the updated abundance- and catch weight-at-age and the F_{target} specified in Table 10. For GB cod, GOM cod, witch flounder, and GB yellowtail flounder, the updated catch at F_{target} is below the 95% projection intervals for all projections (GARM 1-3) we evaluated (Figures 17, 18, 19, and 21). For these stocks, biomass and recruitment are also overly optimistic in the projections, with the updated values below the median projected value in most years, and often below the lower 95% confidence interval. For SNE/MA winter flounder, projected catches were much higher than the updated values for GARM 1 and GARM 2, but not GARM 3 (Figure 20). Interestingly, for SNE/MA winter flounder the updated biomass was above the median projection estimate at the start of each projection, but below forecasted recruitments resulted in the target catches being overly optimistic from the GARM 1 and 2 projections (Figure 20). For pollock, the updated biomass (from the 2014 assessment) was below the SAW 50 projected median biomass in each year, but the projected catches were close to the updated values (Figure 22).

Objective 6. Identify the reasons for the success or failure of the catch advice. This should include exploring whether changes in environmental conditions influence projection performance.

The projection analysis revealed the catch advice based on projections has been overly optimistic in many cases, with the updated catch (i.e., the estimated catch at F_{target}) often well below the lower 95% confidence bound from the projection for the subset of stocks we explored. To better understand why catch advice from past projections has generally been biased high, we reran each projection for each stock with an updated estimate of key projection inputs and determined whether or not this improved the catch advice from the projection. We ran the projections with the updated

- Initial abundance at age (including the recruited age class in that year)

- Interim fishing mortality (between the assessment terminal year and the first year the target catches are calculated)
- Future recruitments
- Weight-at-age in the catch, and
- Fishery selectivity-at-age

The updated and originally used inputs for each stock projection are presented in Tables 13 - 18. One input was updated for a given projection, and the estimated median catch in each year was compared to the original projected catch, as well as to the updated catch to determine the impact that the input had on the catch advice. Note that this analysis only identifies the sources of the error in catch advice, and not the causes. In other words, this approach may identify that the initial abundance at age was the primary source or error for a projection, but it will not identify why abundance at age was overestimated in an assessment.

We calculated the relative difference in catch advice using the median estimate of the projected catch in a given year $C_{proj}(t)$ and the updated catch ($C_{up}(t)$) using

$$REC_{target}(t) = \frac{C_{proj}(t)-C_{up}(t)}{C_{up}(t)} \qquad (3)$$

The relative differences in catch advice are shown in Table 19. Estimates are averaged across the management periods based on the different assessments used to inform the projections (e.g., GARM 1). Many factors contributed to the discrepancy between the projected and updated catches at F_{target} for many stocks. The initial abundance at age had a large impact on projections for GB cod, GOM cod, GB yellowtail flounder, and witch flounder, although the impact this input had varied by stock and by projection. For example, initial GB cod abundance was influential on catch projections for GARM 2 and 3, but not GARM 1, which was more heavily impacted by updated catch weights, the interim fishing mortality, and future recruitments (Table 19). In fact, updating the GARM 1projection for GB cod with the updated 2002 abundance-at-age results in catch targets higher than the targets from the original projections. For SNE/MA winter, the initial biomass estimates from the original GARM 1 and 2 projections were very close to the updated biomass, yet future recruitments were lower than predicted and the assumed interim fishing mortality was incorrect, greatly influencing the projections of target catch. Updated fishery selectivity had a small to moderate impact in most cases (Table 19).

Catch advice for pollock following the SAW 50 (NEFSC 2010) assessment was largely accurate, with the projected median target catch only 7% above the updated value period, on average. This conclusion is based however on the 2014 assessment (NEFSC 2014), which differs substantially from the 2015 assessment (NEFSC 2015) in the estimated biomass time series (Figure B8). The 2015 assessment (NEFSC 2015) estimates biomass to be much higher than previously estimated, so if we had used these estimates in the projection analysis our conclusions about the accuracy of the catch advice would not likely hold, with the catch advice being too conservative based on the

2015 assessment. Earlier index-based catch advice for pollock (2004-2010) was also too conservative (Figure 8). We did not investigate how catch advice from this period would have differed using alternative indices of abundance in the AIM model, but in later work we will evaluate how alternative data-poor methods would have performed given the information available for pollock.

We did not explicitly evaluate the role environmental factors had on projection accuracy, but it is worth noting that they could play an important role in a variety of ways. Forecast uncertainty could result from trends in future recruitments or weight-at-age, or fishery selectivity could change due to environmental fluctuations or changes in management regulations that alter the age structure of the catch. Environmental change can also cause estimation uncertainty in the initial abundance in the projection. This input is based on the terminal assessment estimate, which may exhibit a strong retrospective pattern owing to environmental factors such as changes in natural mortality or changes in stock distribution that might alter catchability in a survey (e.g., offshore movements out of the survey area). Unfortunately, it is not possible to determine the magnitude of the impact environmental factors have had on projection-based catch advice for New England groundfish stocks. Interestingly, projected recruitments have been overly optimistic in many years (Figures 17, 18, 20, and 21) over the period we examined. The mean recruitment for many groundfish stocks from 2004 - present has been lower than the historical mean (from the first available year to 2003; Figure 23) for 11 of 15 stocks (73%) with recruitment estimates, and environmental factors in the region may have contributed the observed declines in productivity for many stocks. Pershing et al. (2015) suggested that rapid warming in the Gulf of Maine has been largely responsible for the decreased recruitment in GOM cod, and warming may be a contributing factor for the declines in recruitment observed in other stocks (although not included in the Pershing et al. analysis)

Our analysis of the impact of forecasted recruitment revealed that although it had an impact on catch advice, the initial abundance-at-age generally had a much larger effect for most stocks, despite actual recruitments often below the forecasted values. The reasons for this effect are twofold. First, when we updated initial abundance-at-age in the projection, we updated all age classes in the first year, including the recruited class, which can be considered a forecasted estimate. Therefore, the impact of an erroneous input value for the first recruited class in the projection was classified as error in the initial abundance-at-age, and not forecast recruitment error. Second, future recruitments often take a few years to become fully available to the fishery, so optimistic recruitment forecasts may not have as large and effect on catch advice for shorter (3-5 year) projection periods.

Objective 7. Identify changes that will improve the performance of catch advice (for example, by modifying inputs used in the projection model).

Scientific uncertainty in assessment and projection estimates has impacted the accuracy of catch advice for many New England groundfish stocks. From a management perspective, the important question is how do you deal with this uncertainty so that future catch targets may be robust to the numerous potential sources of error? Here we describe a variety of ways for dealing with scientific uncertainty in the setting of catch advice. The approaches detailed herein will be evaluated in later work using the same subset of stocks (GOM and GB cod, witch flounder, GB yellowtail flounder, SNE/MA winter flounder, and pollock).

The different approaches we will explore can be broadly classified into four categories: 1) alternative harvest control rules, 2) modified inputs or assumptions in the methods (i.e., projections) used to set the catch advice under a control rule, 3) interim adjustments to catch targets using updated information, and 4) data-limited methods. We will explore 1-3 for all stocks except pollock, and will only explore data-limited approaches for pollock.

Control Rules

A harvest control rule is a method for setting catch targets to meet certain objectives in a fishery. A key objective in the U.S. is to limit overfishing, and the revised National Standard 1 under the Magnuson-Stevens Fishery Conservation and Management Reauthorization Act requires that the SSCs of each Council set ABCs for their stocks that take into account scientific uncertainty (Federal Register 2009). The risk (or probability) of overfishing (denoted P^*) associated with an ABC cannot exceed 50% (i.e., the ABC must not have a high risk of overfishing).

Many control rules to manage a wide range of fisheries have been developed (Deroba and Bence 2008), and some have been evaluated at their ability meet different objectives using management strategy evaluation models (Butterworth and Punt 1999; Punt 2003; Punt et al. 2008). A recent analysis by Wilberg et al. (2015) tested control rules recently developed to comply with the revised Magnuson Act. Many of the approaches tested were variants of the "P^* approach", where the ABC in a given year is calculated based on a distribution for the OFL and a target $P^* < 0.5$ (Shertzer et al. 2008). For example, for a target P^* of 0.4, the ABC is set at the 40th percentile of the OFL distribution. Using this approach, the size of the buffer between the ABC and the OFL increases as the uncertainty in the OFL increases. However, because uncertainty is generally underestimated in assessment models, many of the control rules developed artificially inflate the OFL distribution by assuming the point estimate of the OFL is the median of a lognormal distribution with an assumed CV. The analysis of Wilberg et al. (2015) tested different assumed CVs, as well as whether the target $P*$ was fixed or if it decreased as the estimated biomass fell below the target (called fixed or threshold-based approaches, respectively; Figure 24). Wilberg et al. also include the 75% F_{MSY} control rule used by the NEFMC in their analysis, and found that it performed similarly (with respect to the risk of overfishing) to control rules using a fixed, target $P^* = 0.4$ with an assumed CV of the OFL between 0.7 and 1.0. The 75% F_{MSY} control rule was less conservative than threshold-based P^* control rules in cases where the estimated stock biomass was below the target.

Because the current NEFMC control rule (the lesser of 75% F_{MSY} or $F_{rebuild}$) did not provide a large enough buffer to account for scientific uncertainty for many stocks

(Figure 4), we will explore the more conservative threshold-based P^* approach where the target P^* is 0.4 when biomass is above the target, and declines linearly to $P^* = 0$ when the estimated biomass is at or below 10% of the target. We will initially evaluate OFL CVs of 0.7, and 1.0 for setting the ABC, but higher values may also be explored if the initial values are not conservative enough.

The P^* approach relies on calculating the OFL in a given year, then applying a buffer to set the ABC in that year. The OFL will vary each year as the projected biomass of the population changes, but the ABC can be fixed for a number of years to account for additional uncertainty in the forecast estimates. A fixed ABC was recently implemented for a number of New England groundfish stocks (NEFMC 2014), although the efficacy of this approach cannot be determined yet. The catch advice for most stocks we explored increased in the projection models but current stock assessments indicated that population biomass did not (Figures 17 – 21). Therefore, using a fixed ABC (or TAC prior to 2010) would likely have resulted in lower *F*s for many stocks. We will explore the impact of fixing the ABC for the interim years between management measures. Fixing the ABC can be accomplished in two ways. First, the fixed ABC can be based on the biomass estimated from a projection that bridges the gap between the terminal year of the assessment and the first year of the management measure. Alternatively, the fixed ABC can be based on the terminal estimate of biomass from the assessment. We will explore the latter case because our analysis on the subset of stocks (Objectives 4 - 6) revealed that uncertainty in the gap years (assumed *F* and recruitments) can have a large impact on the accuracy of the catch advice.

Another alternative for setting the ABC is to use a more gradual temporal adjustment to the target catch to account for "noise" in terminal assessment estimates. Using the ABC as an example, the general approach is to average the ABC so that the new ABC for management purposes is a weighted average between the previous and the updated ABC estimate:

$$ABC_{new} = (1 - ø) \cdot ABC_{prev} + ø \cdot ABC_{up} \qquad (4)$$

where ø determines how much weight is given to the updated ABC based on the most recent assessment. Using an averaging approach for the ABC may prevent large increases following an overly optimistic assessment update. However, in cases where an updated assessment correctly identifies a decline in biomass, the averaging approach could limit necessary reductions in catches. In addition to a fixed ø for all updates, a trend-specific approach could also be adopted where the averaging approach is used only when an increase in biomass is predicted.

Modified assessment and /or projection inputs / methods when calculating the OFL

The alternative ABC harvest control rules we will explore rely on setting the ABC using a buffer applied to the point estimate of the OFL in a given year. Calculating the OFL using projections (or not) can be based on the raw assessment output (terminal abundance-at-age and time-series of recruitment estimates), or on modified estimates. Our analysis on the subset of stocks revealed overly optimistic catch advice resulting in part from overestimation of terminal biomass and below forecast recruitments, suggesting that adjustments to these projection inputs may result in more accurate catch advice. One approach for modifying assessment estimates is to use the mean estimate of retrospective uncertainty in biomass estimates (Mohn's ρ) from the assessment, where the updated estimate of terminal biomass is scaled by $1/(1+\rho)$. The same approach can also be done to adjust the terminal biomass by adjusting terminal abundance-at-age estimates by the age-specific ρ estimates. Retrospective adjustments to the terminal abundance were done for some groundfish stocks, but not frequently (Table 9), as the current approach has been to only use an adjusted biomass estimate for setting catch advice when the adjusted biomass outside the 95% uncertainty bounds in terminal biomass estimate. Although the estimates of ρ from assessments were generally positive, they were a poor predictor of the overall magnitude of scientific uncertainty in catch advice (Figure 16) such that doing an adjustment for each stock following an assessment would not likely achieve the necessary reductions in catch advice. Rather than use the ρ from a specific assessment for a stock, we will explore a fixed adjustment factor for terminal biomass estimates based on the median estimated relative in error in terminal biomass for all groundfish stocks (median $REB = 0.38$). The adjusted terminal biomass estimate for each stock following an assessment will be calculated with

$$B_{adj} = B_{est} / (1 + 0.38) \qquad (5)$$

An alternative approach we will explore is use the assessment estimate of ρ when it exceeds the median REB, or

$$B_{adj} = B_{est} / (1 + \max(0.38, \rho)) \qquad (6)$$

Overestimated terminal biomass is one source of optimistic catch advice, and below expected recruitment forecasts is another. For most stocks, recent recruitments have been below historical estimates, and using historical estimates of recruitment (either in the form of an empirical cumulative distribution function (ECDF), or in an estimated stock-recruit functions) can result in overly optimistic recruitment forecasts (Figures 17-21). Without a clear understanding of the factors driving trends in recruitment, however, it is difficult to effectively account for environmental trends when setting catch advice. Punt et al. (2013) reviewed a large number of simulation analyses aimed at developing robust management strategies in the face of environmentally-induced changes in productivity, and found that trying to include environmental variables as predictors of stock dynamics (often assumed driven by recruitment variability) is generally ineffective, except in cases where the underlying mechanisms are well known.

Trying to identify and use specific environmental correlates for predicting recruitments is beyond the scope of this project, and would likely be ineffective according to Punt et al. (2013). However, we can explore methods that seek to identify whether or not recruitment has changed in recent years without trying to identify the causes or predict future changes. The most straightforward approach would be to use a change-point, or moving average, model to identify periods when the mean recruitment has shifted. Such an approach ignores making assumptions about the underlying cause of changes in recruitment, and has been used in a number of studies exploring recruitment dynamics (e.g.,Gilbert 1997; Vert-Pre et al. 2013). Using recruitment estimates from each assessment for a stock, we will estimate whether recent recruitments can be classified as part of a new recruitment regime using the change-point algorithm developed by Rodionov (2004) to detect environmental regime shifts, and used Vert-Pre et al. (2013). If a new recruitment regime is identified in recent years, the mean recruitment (and estimated variability) will be used as the basis for future recruitments in the projections (without updating the reference points). The mean recruitment of a new regime can also be used as the initial abundance of the recruited class that is specified as an input in the projection model.

Interim measures for adjusting target catches.

Long periods of DML result in catch advice being based on out of date information. For most groundfish stocks, the longest DML period since 2004 was 5 years (Table 9). Unexpected changes in the population (relative to the projection estimates) can occur rapidly, and there is an increasing interest among scientists and managers to either increase the frequency of stock assessments (Wilberg et al. 2015), or identify useful indicators of stock status that can be used in lieu of a new assessment to modify catch advice in response to perceived changes in stock status. The latter approach has garnered particular interest because it requires fewer resources than doing annual or biennial updates for a given stock, yet the effectiveness of such an indicator approach remains unknown. The SSC of the Mid-Atlantic Fisheries Management Council recently developed a "rumble strip" approach to help identify cases where catch advice is not performing as expected (i.e., too high; MAFMC 2013) so that new assessments could be requested and the ABC reduced.

An analysis of the rumble strip indicator method is not feasible for the project, but it may be possible to test the performance of a simple index-based approach for updating catch advice in between assessments using average trends in survey indices. The overall approach would be to adjust the target catch in a given year based on the observed trends in the fall or spring survey index of abundance (based on a multi-year average) relative to some reference level. The reference level would be a multi-year average based on the projected biomass multiplied by the estimated catchability coefficient for the survey. The relative deviation in an observed indicator trend, I_{obs}, compared to a reference level, I_{ref}, can be calculated with $\Delta_I = (I_{obs} - I_{ref})/I_{ref}$. The target catch (either the ABC or TAC) can be adjusted with $ABC_{new} = \Delta_I \cdot ABC_{prev}$. Although the catch target can be adjusted up or down using this index-based update method, only cases where decreases in catch are called for is warranted (i.e., $ABC_{new} = \min(\Delta_I, 1) \cdot ABC_{prev}$) given the past performance on catch advice. Testing an indicator approach, however, will likely be labor intensive, and therefore will only be conducted if time permits.

Data-Limited Methods

The approaches listed above will all be conducted for GOM and GB cod, SNE/MA winter flounder and GB yellowtail flounder, and witch flounder. For pollock, catch advice from age-based projections was relatively accurate, while the catch targets following index-based assessments were overly conservative ($F_{obs} < F_{MSY}$). Therefore, we will evaluate how catch advice from other data-limited approaches compares to the catch advice from AIM for pollock. Recently, an R package called the data-limited toolkit (DLMtool) was developed (Carruthers 2014), and we will test some of the data-limited approaches available in DLMtool as alternatives to the AIM model for setting catch advice for pollock. Over 30 data-limited options are available in DLMtool, but we will use a small subset (≤ 7) of the more data-intensive approaches that utilize the available information from surveys and the fishery (including age structure of the catch). Methods that require input assumptions of relative depletion (e.g., depletion-based stock reduction analysis, or DB-SRA; Dick and MacCall 2011) will not be explored. The methods we will explore often require assumed distributions for the natural mortality rate, M, and the ratio of F_{MSY} / M, and DLMtool has a built-in option for conducting sensitivity analyses for all input assumptions. The data-limited methods we select from DLMtool will be used to determine alternative catch advice pollock for the GARM 1, 2, and 3 assessments.

Summary of Alternative Methods

The approaches outlined (excluding the data-limited methods) above are not mutually exclusive, as a harvest control rule may include interim adjustments, and modified projection methods may be combined with a harvest control rule to specify catch targets. Furthermore, a single approach may not be completely effective at achieving the target harvest rate, whereas a combination of approaches may be. Therefore, the different approaches will be tested in the subsequent analysis using a factorial design when possible. Because these approaches will be applied following each assessment (maximum of 3) for 5 stocks, the total number of alternative methods for each category must be constrained to keep the total number of model runs reasonable. We will explore 3 control rules (75% F_{MSY}, and the threshold P^* approach using 2 CVs) and 4 different ways of applying the control rules (with and without projections or averaging of the catch target). These options will be evaluated using either no ρ adjustment in terminal biomass or the two options proposed for doing a ρ adjustment, and with or without adjustments to the empirical recruitment distribution in the projection based on a change-point analysis (for a total of 6 runs). Therefore, a total of 72 options will be explored following each assessment for GB cod, GOM cod, GB yellowtail, witch flounder, and SNE/MA winter flounder. If time allows, inclusion of the index-based interim adjustment method will double the total number of runs (144). For pollock, the total number of runs will be determined only by the number of data-limited methods selected, as the other options proposed will not be combined with the data-limited analysis.

Evaluating Performance of Alternative Methods for Setting Catch Advice

For all the alternative approaches for setting catch advice we explore (including the data-limited options), we will quantify the relative performance of each method to determine its suitability. Performance of a harvest method can be measured in a variety of ways, but we will focus on 4 performance measures. For each alternative method we are evaluating, we will calculate the ratio of F/F_{target}, the total catch, and the population biomass each year, and the interannual variability in the catch. The F/F_{target} ratio is a measure of how successful the catch advice is at achieving F_{target}, while the other measures quantify where the population biomass would currently be, and what the total yield to the fishery would have been and how variable would yield have been if an alternative approach were used.

Conclusions

Target catches since 2004 have been overly optimistic for many of the New England groundfish stocks. Scientific uncertainty in estimates from stock assessment models and in the forecasts from projection models resulted in these inflated catch targets. Although many factors contributed to the optimistic catch targets, overestimation of abundance and actual recruitments lower than expected forecasts were important sources of scientific uncertainty. The causes for the overestimation of terminal abundance are unknown, but because this overestimation was frequent for many stocks, there may be some common causal mechanisms in the region (e.g., underreported catches, increasing natural mortality, changes in survey catchability), and future work to identify and address these possible sources in assessments models is warranted.

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Tables 1. List of Groundfish Stocks in New England

Full Stock Name	Abbreviated Name
Georges Bank Atlantic Cod	GB Cod
Gulf of Maine Atlantic Cod	GOM Cod
Georges Bank Haddock	GB Cod
Gulf of Maine Haddock	GOM Cod
Georges Bank Yellowtail Flounder	GB Yellowtail
Cape Cod / Gulf of Maine Yellowtail Flounder	CC / GOM Yellowtail
Southern New England / Mid-Atlantic Yellowtail Flounder	SNE / MA Yellowtail
Georges Bank Winter Flounder	GB Yellowtail
Gulf of Maine Winter Flounder	CC / GOM Yellowtail
Southern New England / Mid-Atlantic Winter Flounder	SNE / MA Yellowtail
Witch Flounder	Witch
American Plaice	Plaice
Acadian Redfish	Redfish
Pollock	Pollock
White Hake	White Hake
Ocean Pout	Pout
Gulf of Maine / Georges Bank Windowpane Flounder	North Windowpane
Southern New England / Mid-Atlantic Windowpane Flounder	South Windowpane
Atlantic Halibut	Halibut
Atlantic Wolffish	Wolffish

Table 2. Management measures that specified target catch and harvest rates for New England groundfish from 2004 onward.

Management Measure	Years*	Source
Amendment 13	2004-2005	NEFMC 2003
Framework 42	2006-2010	NEFMC 2006
Framework 44	2010-2012	NEFMC 2010
Framework 47	2012-2014	NEFMC 2012
Framework 50	2013-2015	NEFMC 2013
Framework 51	2014-2016	NEFMC 2014

Table 3. Groundfish stock assessments that were the basis of the target catch and harvest rates in this analysis.

Assessment Name	Year	Groundfish Stocks	Source
GARM 1	2002	All	NEFSC 2002
GARM 2	2005	All	NEFSC 2005
GARM 3	2008	All	NEFSC 2008
2015 Groundfish Update (GARM 4)	2015	All	NEFSC 2015
2012 Groundfish Update	2012	12 stocks	NEFSC 2012a
SAW 33	2000	Redfish	NEFSC 2001
SAW 36	2003	SNE/MA and CC / GOM yellowtail GOM and SNE/MA winter	NEFSC 2003
SAW 50	2010	Pollock	NEFSC 2010
SAW 52	2011	GB, GOM, SNE/MA Winter	NEFSC 2011
SAW 53	2012	GOM cod	NEFSC 2012a
SAW 54	2012	SNE / MA yellowtail	NEFSC 2012b
SAW 55	2013	GOM cod, GB cod	NEFSC 2013a
SAW 56	2013	White hake	NEFSC 2013b
SAW 59	2014	GOM haddock	NEFSC 2014
2014 GOM Cod Update	2014	GOM cod	Palmer 2014
TRAC 2003	2003	GB yellowtail	Stone and Legault 2003
TRAC 2004	2004	GB yellowtail	Legault et al. 2004
TRAC 2005	2005	GB yellowtail	Stone and Legault 2005
TRAC 2006	2006	GB yellowtail	Legault et al. 2006
TRAC 2007	2007	GB yellowtail	Legault et al. 2007
TRAC 2008	2008	GB yellowtail	Legault et al. 2008
TRAC 2009	2009	GB yellowtail	Legault et al. 2009
TRAC 2010	2010	GB yellowtail	Legault et al. 2010
TRAC 2011	2011	GB yellowtail	Legault et al. 2011
TRAC 2012	2012	GB yellowtail	Legault et al. 2012
TRAC 2013	2013	GB yellowtail	Legault et al. 2013
NDPSWG 2009	2009	Wolffish	NDPSWWG 2009

Table 4. Summary of the methods and target harvest rates for all stocks where catch targets were updated in Amendment 13. TY basis refers to the method assumed to determine the harvest (or harvest rate) in the interim years between the assessment terminal year and the first year of catch advice. See NEFMC (2003) for more details about the adaptive or phase rebuilding strategies.

Management Measure	Stock	Assessment Method	Projection Method	Target *F* basis*	Target *F* (or *C/I*)	Terminal Year (TY) +1 Basis	TY +2 Basis
Amendment 13	GB Cod	Age	AGEPRO	Phased $F_{rebuild}$	0.21	Estimated catch in 2002	*F* in 2003 = *F* in 2002
	GOM Cod	Age	AGEPRO	Adaptive $F_{rebuild}$	0.23	Estimated catch in 2002	*F* in 2003 = *F* in 2002
	GB Haddock	Age	AGEPRO	Adaptive $F_{rebuild}$	0.26	Estimated catch in 2002	*F* in 2003 = *F* in 2002
	GOM Haddock	Index	Index	Adaptive $F_{rebuild}$	0.23	-	-
	CC/GOM Yellowtail	Age	AGEPRO	Phased $F_{rebuild}$	0.26	Estimated catch in 2002	*F* in 2003 = *F* in 2002
	SNE/MA Yellowtail	Age	AGEPRO	Phased $F_{rebuild}$	0.37	Estimated catch in 2002	*F* in 2003 = *F* in 2002
	GB Yellowtail	Age	AGEPRO	F_{lim}	0.25	Estimated catch in 2002	*F* in 2003 = *F* in 2002
	GOM Winter	Age	AGEPRO	F_{lim}	0.43	Estimated catch in 2002	*F* in 2003 = *F* in 2002
	SNE/MA Winter	Age	AGEPRO	Adaptive $F_{rebuild}$	0.32	Estimated catch in 2002	*F* in 2003 = *F* in 2002
	GB Winter	Age	AGEPRO	F_{lim}	0.32	Estimated catch in 2002	*F* in 2003 = *F* in 2002
	Witch	Age	AGEPRO	F_{lim}	0.23	Estimated catch in 2002	*F* in 2003 = *F* in 2002
	Plaice	Age	AGEPRO	Phased $F_{rebuild}$	0.23	Estimated catch in 2002	*F* in 2003 = *F* in 2002
	Redfish	Age	AGEPRO	Adaptive $F_{rebuild}$	0.01	Estimated catch in 2002	*F* in 2003 = *F* in 2002
	White Hake	Index	Index	Phased $F_{rebuild}$	1.03 / 0.23	*C/I* = 0.55	*C/I* = 0.55
	Halibut	-	-	*F* = 0	-	-	-
	Pollock	Index	Index	F_{lim}	5.88	*C/I* = 3.3	*C/I* = 3.3
	Pout	Index	Index	Adaptive $F_{rebuild}$	0.03	*C/I* = 0.01	*C/I* = 0.01
	North Windowpane	Index	Index	F_{lim}	1.11	*C/I* = 0.09	*C/I* = 0.09
	South Windowpane	Index	Index	Adaptive $F_{rebuild}$	0.98	*C/I* = 0.5	*C/I* = 0.5
	Wolffish	-	-	-	-	-	-

Table 5. Summary of the methods and target harvest rates for all stocks where catch targets were updated in Framework 42 (NEFMC 2006). TY basis refers to the method assumed to determine the harvest (or harvest rate) in the interim years between the assessment terminal year and the first year of catch advice. See NEFMC (2003) for more details about the adaptive or phase rebuilding strategies.

Management Measure	Stock	Assessment Method	Projection Method	Target *F* basis	Target *F* (or *C/I*)	Terminal Year (TY) +1 Basis
	GB Cod	Age	AGEPRO	Phased $F_{rebuild}$	0.21	*F* in 2005 = *F* in 2004
	GOM Cod	Age	AGEPRO	Adaptive $F_{rebuild}$	0.23/0.21	*F* in 2005 = *F* in 2004
	GB Haddock	Age	AGEPRO	Adaptive $F_{rebuild}$	0.26 / 0.24	*F* in 2005 = *F* in 2004
	GOM Haddock	Index	Index	Adaptive $F_{rebuild}$	0.23 / 0.22	-
	CC/GOM Yellowtail	Age	AGEPRO	Phased $F_{rebuild}$	0.26 / 0.09	*F* in 2005 = *F* in 2004
	SNE/MA Yellowtail	Age	AGEPRO	Phased $F_{rebuild}$*	0.26 / 0.17	*F* in 2005 = *F* in 2004
	GB Yellowtail	Age	AGEPRO	F_{lim}	0.25	*F* in 2005 = *F* in 2004
	GOM Winter	Age	None	F_{lim}	0.43	-
Framework 42	SNE/MA Winter	Age	AGEPRO	Adaptive $F_{rebuild}$	0.32	*F* in 2005 = *F* in 2004
	GB Winter	Age	AGEPRO	F_{lim}	0.32	*F* in 2005 = *F* in 2004
	Witch	Age	AGEPRO	F_{lim}	0.23	*F* in 2005 = *F* in 2004
	Plaice	Age	AGEPRO	Phased $F_{rebuild}$	0.23 / 0.14	*F* in 2005 = *F* in 2004
	Redfish	Age	AGEPRO	Adaptive $F_{rebuild}$	0.01	*F* in 2005 = *F* in 2004
	White Hake	Index	Index	Phased $F_{rebuild}$	1.03 / 0.23	-
	Halibut	-	-	$F = 0$	-	-
	Pollock	Index	None	F_{lim}	5.88	-
	Pout	Index	None	Adaptive $F_{rebuild}$	0.03	-
	North Windowpane	Index	None	F_{lim}	1.11	-
	South Windowpane	Index		Adaptive $F_{rebuild}$	0.98 / 0.49	-
	Wolffish	-	-	-	-	-

Table 6. Summary of the methods and target harvest rates for all stocks where catch targets were updated in Framework 44 (NEFMC 2010). TY basis refers to the method assumed to determine the harvest (or harvest rate) in the interim years between the assessment terminal year and the first year of catch advice

Management Measure	Stock	Assessment Method	Projection Method	Target *F* basis	Target *F* (or *C/I*)	Terminal Year (TY) +1 Basis	TY +2 basis *
	GB Cod	Age	AGEPRO	75% F_{MSY}	0.184	Estimated 2008 catch	Assumed *F*
	GOM Cod	Age	AGEPRO	75% F_{MSY}	0.18	Estimated 2008 catch	Assumed *F*
	GB Haddock	Age	AGEPRO	75% F_{MSY}	0.26	Estimated 2008 catch	Assumed *F*
	GOM Haddock	Age	AGEPRO	75% F_{MSY}	0.32	Estimated 2008 catch	Assumed *F*
	CC/GOM Yellowtail	Age	AGEPRO	75% F_{MSY}	0.18	Estimated 2008 catch	Assumed *F*
	SNE/MA Yellowtail	Age	AGEPRO	$F_{rebuild}$	0.072	Estimated 2008 catch	Assumed *F*
	GB Yellowtail	Age	AGEPRO	$F_{rebuild}$	0.018/0.086/(0.068) $	Estimated 2008 catch	Assumed *F*
Framework 44	GOM Winter	Age	None	Avg. catch	-	Estimated 2008 catch	Assumed *F*
	SNE/MA Winter	Age	AGEPRO	75% F_{MSY}	0.01§	Estimated 2008 catch	Assumed *F*
	GB Winter	Age	AGEPRO	$F_{rebuild}$	0.2	Estimated 2008 catch	Assumed *F*
	Witch	Age	AGEPRO	75% F_{MSY}	0.15	Estimated 2008 catch	Assumed *F*
	Plaice	Age	AGEPRO	75% F_{MSY}	0.14	Estimated 2008 catch	Assumed *F*
	Redfish	Age	AGEPRO	75% F_{MSY}	0.03	Estimated 2008 catch	Assumed *F*
	White Hake	Age	ASP	$F_{rebuild}$	0.08	Estimated 2008 catch	Assumed *F*
	Halibut	Age	ASP	$F_{rebuild}$	0.044	Estimated 2008 catch	Assumed *F*
	Pollock	Index	None	75% F_{MSY}	4.25	-	-
	Pout	Index	None	75% F_{MSY}	0.57#	-	-
	North Windowpane	Index	None	75% F_{MSY}	0.375#	-	-
	South Windowpane	Index	None	75% F_{MSY}	1.1#	-	-
	Wolffish	SCALE	None	75% F_{MSY}	< 0.26&	-	-

* F in 2009 was based on the estimated F in 2008*, adjusted by a scaling factor based on expected changes resulting from the Northeast Multispecies interim action implemented in 2009.

$ Multiple targets for GB yellowtail were presented based on multiple models

F target values were not supplied for Pout and N & S window, but the F_{MSY} proxy was, and it was stated that F_{target} = 75% of F_{MSY}

& Wolffish F_{MSY} was deemed < 0.35, although a specific value assumed in the calculation was not specified

§ F target = 0 was set for SNE/MA winter, yet a value of 0.01 was specified in the projection model

Table 7. Summary of the methods and target harvest rates for all stocks where catch targets were updated in Frameworks 45 and 47 (NEFMC 2011, 2012). TY basis refers to the method assumed to determine the harvest (or harvest rate) in the interim years between the assessment terminal year and the first year of catch advice.

Management Measure	Stock	Assessment Method	Projection Method	Target F basis	Target F (or C/I)	Terminal Year (TY) +1 Basis
	GB Yellowtail	Age	AGEPRO	$F_{rebuild}$	0.138	2010 Catch = 2010 Target
Framework	Pollock	Age	AGEPRO	$F_{rebuild}$	0.31	2010 F = 75% F_{lim}
45	White Hake#	Age	AGEPRO	75% F_{MSY}	0.084	Assumed F in 2009
	GB Yellowtail	Age	AGEPRO	$F_{rebuild}$	0.188	Catch = Target
	GOM Winter	Swept area	None	75% F_{MSY}	0.23	
Framework	SNE/MA Winter	Age	AGEPRO	$F_{rebuild}$*	0.07	Estimated catch in 2012
47	GB Winter	Age	AGEPRO	75% F_{MSY}	0.32	Estimated catch in 2012
	Pout	Index	None	75% F_{MSY}	0.57	-
	North Windowpane	Index	None	75% F_{MSY}	0.38	-
	South Windowpane	Index	None	75% F_{MSY}	1.1	-

White hake was included to correct an error publish and the Federal Register, and was based on the GARM 3 assessment.
* The target F forSNE/MA winter was based on the average F for 2009-2010 SAW 56.

Table 8. Summary of the methods and target harvest rates for all stocks where catch targets were updated in Frameworks 50 and 51 (NEFMC 2013, 2014). TY basis refers to the method assumed to determine the harvest (or harvest rate) in the interim years between the assessment terminal year and the first year of catch advice.

Management Measure	Stock	Assessment Method	Projection Method	Target F basis	Target F (or C/I)	Terminal Year (TY) +1 Basis
	GB Cod	Age	AGEPRO	75% F_{MSY}	0.135	Estimated Catch in 2012
	GOM Cod	Age	AGEPRO	75% F_{MSY}	0.17	Estimated Catch in 2012
	GB Haddock	Age	AGEPRO	75% F_{MSY}	0.29	Estimated Catch in 2012
	GOM Haddock	Age	AGEPRO	75% F_{MSY}	0.35	Estimated Catch in 2012
	CC/GOM Yellowtail	Age	AGEPRO	75% F_{MSY}	0.2	Estimated Catch in 2012
	SNE/MA Yellowtail	Age	AGEPRO	75% F_{MSY}	0.24	Estimated Catch in 2012
	GB Yellowtail#	Age	-	-	-	-
Framework 50	SNE/MA Winter	Age	AGEPRO	$F_{rebuild}$	0.18	Estimated Catch in 2012
	Witch	Age	AGEPRO	$F_{rebuild}$	0.17	Estimated Catch in 2012
	Plaice	Age	AGEPRO	75% F_{MSY}	0.14	Estimated Catch in 2012
	Redfish	Age	AGEPRO	75% F_{MSY}	0.03	Estimated Catch in 2012
	White Hake	Age	ASP	$F_{rebuild}$	0.08	Estimated Catch in 2012
	Halibut	Age	ASP	$F_{rebuild}$	0.044	Estimated Catch in 2012
	Pout	Index	None	75% F_{MSY}	0.57#	-
	North Windowpane	Index	None	75% F_{MSY}	0.33	-
	South Windowpane	Index	None	75% F_{MSY}	1.57	-
	Wolffish	SCALE	None	75% F_{MSY}	0.25	-
Framework 51	White Hake	Age	AGEPRO	75% F_{MSY}	0.15	Estimated Catch in 2013
	GB Yellowtail#	Age	None	-	-	-

* The target F for GOM cod was set between 75% of F_{MSY} and F_{MSY} (NEFMC 2013).
# The ABC for GB yellowtail was not based on projections due to uncertainty in assessment estimates.

Table 9. Summary of the methods and assumptions used to set catch advice by stock for each management measure. S.A. stands for stock assessment, term. year is the terminal year of the assessment, DML stands for data-management lag (the minimum and maximum values are reported), rec. model is the assumed recruitment model in the projections and rec. years is the number of years of observations when empirical distributions are created (see text). *W* / *m* / *s* avg. refers to the number of years used to create average age-specific input values of weight (*W*), maturity (*m*) and selectivity (*s*) for the projection, proj. year 1 and 2 are the assumed values for catch (*C*) or (F) in the interim years of the projection, and ρ adj? refers to whether or not the initial biomass was adjusted in the projection due to a strong retrospective pattern that could not be reduced by splitting the survey into different estimation blocks. VPA and SCAA stand for virtual population analysis and statistical catch at age assessment models. RYM is the replacement yield model used for halibut, and ASP stands for age-structured projection model (but not the AGEPRO model). Recruitment models were either based on the Beverton-Holt (B-H) stock-recruit relationship, or on an empirically-derived cumulative distribution function (ECDF). ECDF (2) indicates 2 ECDFs were created for low and high recruitment periods, and ECDF (0) refers to a single distribution that can result in recruitment estimates going to 0. *Terminal recruitment for GB haddock was adjusted, but not based on ρ, and terminal abundance estimates for other age classes were not adjusted.

Stock	Mgmt. Measure	Time Period	S.A. Name	S.A Model	Term. Year	DML (min,max)	Catch Method	Rec. Model	Rec. Years	W / m / s avg. (yrs)	Proj. Year 1	Proj. Year 2	ρ Adj?
	A 13	2004-2005	GARM 1	VPA	2001	3,4	AGEPRO	B-H	-	23 (s = 3)	10764 (C)	0.45 (F)	no
GB	FW 42	2006-2009	GARM 2	VPA	2004	2,5	AGEPRO	B-H	-	3	0.24 (F)	-	no
Cod	FW 44	2010-2012	GARM 3	VPA	2007	3,5	AGEPRO	ECDF (2)	16,14	5	5134 (C)	0.22 (F)	no
	FW 50	2013-2015	SAW 55	SCAA	2011	2,4	AGEPRO	ECDF (2)	21,12	5	2910 (C)	-	yes
	A13	2004-2005	GARM 1	VPA	2001	3,4	AGEPRO	B-H	-	3	7164 (C)	0.36 (F)	no
GOM	FW 42	2006-2009	GARM 2	VPA	2004	2,5	AGEPRO	B-H	-	-	0.58 (F)	-	no
Cod	FW 44	2010-2011	GARM 3	VPA	2007	3,4	AGEPRO	ECDF	26	5	8499 (C)	0.26 (F)	no
	FW 50	2013-2015	SAW 55	SCAA	2011	2,4	AGEPRO	ECDF	21	3	3767 (C)	-	no
	A 13	2004-2005	GARM 1	VPA	2001	3,4	AGEPRO	ECDF (2)	34,36	-	12897 (C)	0.2 (F)	no
GB	FW 42	2006-2009	GARM 2	VPA	2004	2,5	AGEPRO	ECDF (2)	34,40	4 (W = 3)	0.24 (F)	-	no
Haddock	FW 44	2010-2012	GARM 3	VPA	2007	3,4	AGEPRO	ECDF	37	5	20901 (C)	25000 (C)	no
	FW 50	2013-2015	2012 up.	VPA	2011	2,4	AGEPRO	ECDF	39	5	18385 (C)	15697 (C)	no*
	A 13	2004-2005	GARM 1	Index	2001	3,4	Index	-	-	-	-	-	-
GOM	FW 42	2006-2009	GARM 2	Index	2004	2,5	Index	-	-	-	-	-	-
Haddock	FW 44	2010-2012	GARM 3	VPA	2007	3,4	AGEPRO	ECDF	34	5	1197 (C)	0.26 (F)	no
	FW 50	2013-2015	2012 up.	VPA	2010	2,4	AGEPRO	ECDF	36	5	727 (C)	-	no
	A 13	2004-2005	SAW 36	VPA	2001	3,4	AGEPRO	ECDF	17	-	2661 (C)	0.95 (F)	no
CC / GOM	FW 42	2006-2009	GARM 2	VPA	2004	2,5	AGEPRO	ECDF	14	3	0.75 (C)	-	no
Yellowtail	FW 44	2010-2012	GARM 3	VPA	2007	3,4	AGEPRO	ECDF	31	5	727 (C)	0.15	no
	FW 50	2013-2015	2012 up.	VPA	2010	2,4	AGEPRO	ECDF	32	5	747 (C)	950 (C)	yes

Table 9 continued.

Stock	Mgmt. Measure	Period	S.A. Name	S.A Model	Term. Year	DML (min,max)	Catch Method	Rec. Model	Rec. Years	W / m / s avg. (yrs)	Proj. Year 1	Proj. Year 2	*r* Adj?
	A 13	2004-2005	SAW 36	VPA	2001	3,4	AGEPRO	ECDF	39	-	748 (C)	0.74 (F)	no
SNE /MA	FW 42	2006-2009	GARM 2	VPA	2004	2,5	AGEPRO	ECDF	10	11	0.99 (F)	-	no
Yellowtail	FW 44	2010-2012	GARM 3	VPA	2007	3,4	AGEPRO	ECDF (2)	22,12	5	504 (C)	0.07 (F)	no
	FW 50	2013-2015	SAW 54	SCAA	2011	2,4	AGEPRO	ECDF	21	5	634 (C)	-	no
	A 13	2004	GARM 1	VPA	2001	2	AGEPRO	ECDF (2)	11,26	-	5500 (C)	0.14 (F)	no
	FW 42	2006	GARM 2	VPA	2004	2	See Note#	ECDF (2)					
GB	FW 44	2009	GARM 3	VPA	2007	2	AGEPRO	ECDF (2)	15,30	3	2500 (C)	-	no
Yellowtail	FW 45	2011	TRAC 2010	VPA	2009	2	AGEPRO	ECDF (2)	15,30	3	1956 (C)	-	no
	FW 47	2012	TRAC 2011	VPA	2010	2	AGEPRO	ECDF (2)	15,30	3	2650 (C)	-	yes
	FW 50	2013	TRAC 2012	VPA	2011	2	AGEPRO	ECDF (2)	19,19	3	1150 (C)	-	yes
	FW 51	2014	TRAC 2013	VPA	2012	2	AGEPRO	ECDF (2)	20,19	3	500 (C)	-	yes
	A 13	2004-2005	GARM 1	Prod.	2001	3,4	Prod.	-	-	-	-	-	no
GB	FW 42	2006-2009	GARM 2	Prod.	2004	2,5	Prod.	-	-	-	-	-	no
Winter	FW 44	2010-2012	GARM 3	VPA	2007	4,4	AGEPRO	ECDF	26	5	963 (C)	0.16 (F)	no
	FW 47	2012-2014	SAW 53	VPA	2010	2,4	AGEPRO	B-H	-	5	2230 (C)	3753 (C)	no
	A 13	2004-2005	GARM 1	VPA	2001	3,4	AGEPRO	B-H	-	5	466 (C)	0.063	no
GOM	FW 42	2006-2009	GARM 2	VPA	2004	-	None	-	-	-	-	-	-
Winter	FW 44	2010-2011	GARM 3	VPA	2007	3,4	Avg Catch	-	-	-	-	-	-
	FW 47	2012-2014	SAW 52	Swept	2010	2	Swept Area	-	-	-	-	-	-
	A 13	2004-2005	GARM 1	VPA	2001	3,4	AGEPRO	B-H	-	-	3524 (C)	0.45 (F)	no
SNE/MA	FW 42	2006-2009	GARM 2	VPA	2004	2,5	AGEPRO	B-H	-	3	.38 (F)	-	no
Winter	FW 44	2010-2011	GARM 3	VPA	2007	3,4	AGEPRO	ECDF (2)		5			no
	FW 47	2012	SAW 52	SCAA	2010	2	AGEPRO	B-H	-	5	363 (C)	626 (C)	no
	FW 50	2013-2015	SAW 52	SCAA	2010	3,5	AGEPRO	B-H	-	5	363 (C)	417 (C)	no
	A 13	2004-2005	GARM 1	VPA	2001	3,4	AGEPRO	ECDF	17	4 (m = 3)	4090 (C)	0.19 (F)	no
Witch	FW 42	2006-2009	GARM 2	VPA	2004	2,5	AGEPRO	ECDF	3	5 (W = 3)	0.2 (F)	-	no
	FW 44	2010-2012	GARM 3	VPA	2007	3,4	AGEPRO	ECDF	27	5	1063 (C)	0.23 (F)	no
	FW 50	2013-2015	2012 up.	VPA	2010	3,5	AGEPRO	ECDF	28	5	1069 (C)	1318 (C)	no
	A 13	2004-2005	GARM 1	VPA	2001	3,4	AGEPRO	ECDF	22	-	3864 (C)	0.26 (F)	no
Plaice	FW 42	2006-2009	GARM 2	VPA	2004	2,5	AGEPRO	ECDF	26	3	0.15 (F)	-	no
	FW 44	2010-2012	GARM 3	VPA	2007	3,4	AGEPRO	ECDF	29	5	1348 (C)	0.09 (F)	yes
	FW 50	2013-2015	2012 up.	VPA	2010	3,5	AGEPRO	ECDF	30	5	1624 (C)	1922 (C)	yes

Table 9 continued.

Stock	Mgmt. Measure	Period	S.A. Name	S.A Model	Term. Year	DML (min,max)	Catch Method	Rec. Model	Rec. Years	W / m / s avg. (yrs)	Proj. Year 1	Proj. Year 2	*r* Adj?
	A 13	2004-2005	SAW 33		2000	4,5	AGEPRO	ECDF	48		360 (C)	468 (C)	no
Redfish	FW 42	2006-2009	GARM 2		2004	2,5	AGEPRO	ECDF	53		0.02 (F)	-	no
	FW 44	2010-2012	GARM 3	SCAA	2007	3,4	AGEPRO	ECDF	38	5	1364 (C)	0.006 (F)	yes
	FW 50	2013-2015	2012 up.	SCAA	2010	3,5	AGEPRO	ECDF	42	5	1852 (C)	2303 (C)	no
	A 13	2004-2005	GARM 1	Index	2001	3,4	Index	-	-	-	-	-	-
White	FW 42	2006-2009	GARM 2	Index	2004	2,5	Index	-	-	-	-	-	-
Hake	FW 44	2010-2012	GARM 3	SCAA	2007	3,5	ASP	-	-	5	-	-	no
	FW 50	2013	GARM 3	SCAA	2007	6	ASP	ECDF	15	5			no
	FW 51	2014-2015	SAW 56	SCAA	2011	3,4	AGEPRO	ECDF (0)	15	5	2900 (C)	2954 (C)	no
	A 13	2004-2005	GARM 1	Index	2001	3,4	Index	-	-	-	-	-	-
Pollock	FW 42	2006-2009	GARM 2	Index	2004	2,5	Index	-	-	-	-	-	-
	FW 44	2010	GARM 3	Index	2007	3	Index	-	-	-	-	-	-
	FW 45	2011-14	SAW 50	SCAA	2009	2,4	AGEPRO	ECDF	38	5	19839 (C)	-	no
	A 13	2004-2005	GARM 1	Index	2001	3,4	Index	-	-	-	-	-	-
North	FW 42	2006-2009	GARM 2	Index	2004	2,5	Index	-	-	-	-	-	-
Windowpane	FW 44	2010-2012	GARM 3	Index	2007	3,5	Index	-	-	-	-	-	-
	FW 47	2013	2012 up.	Index	2010	3	Index	-	-	-	-	-	-
	FW 50	2014-2015	2012 up.	Index	2010	4,5	Index	-	-	-	-	-	-
	A 13	2004-2005	GARM 1	Index	2001	3,4	Index	-	-	-	-	-	-
South	FW 42	2006-2009	GARM 2	Index	2004	2,5	Index	-	-	-	-	-	-
Windowpane	FW 44	2010-2012	GARM 3	Index	2007	3,5	Index	-	-	-	-	-	-
	FW 47	2013	2012 up.	Index	2010	3	Index	-	-	-	-	-	-
	FW 50	2014-2015	2012 up.	Index	2010	4,5	Index	-	-	-	-	-	-
	A 13	2004-2005	GARM 1	Index	2001	3,4	Index	-	-	-	-	-	-
Pout	FW 42	2006-2009	GARM 2	Index	2004	2,5	Index	-	-	-	-	-	-
	FW 44	2010-2012	GARM 3	Index	2007	3,5	None	-	-	-	-	-	-
	FW 47	2013	2012 up.	Index	2010	3	Index	-	-	-	-	-	-
	FW 50	2014-2015	2012 up.	Index	2010	4,5	Index	-	-	-	-	-	-
	A13	-	GARM 1	Swept	2001	-	-	-	-	-	-	-	-
Halibut	FW 42	-	GARM 2	Swept	2004	-	-	-	-	-	-	-	-
	FW 44	2010-2012	GARM 3	RYM	2007	3,5	RYM	-	-	-	-	-	-
	FW 47	2013-2015	2012 up.	RYM	2010	3,5	RYM	-	-	-	-	-	-
Wolffish	FW 44	2010-2012	NDPSWG	SCALE	2008	2,4	None	-	-	-	-	-	-
	FW 50	2013-2015	2012 up.	SCALE	2010	3,5	None	-	-	-	-	-	-

Table 10. Annual observed and target catch and harvest rates (*F* or *C / I*). Note that multiple *F*s for GB yellowtail were presented in FW 44, so the value shown was the largest *F* presented.

Stock	Year	Target Catch	Obs. Catch	Landings Prop.	Target *F*	Est. *F*	Index	Target C/I	Est. C / I
	2004	3949	5171	0.89	0.21	0.54	-	-	-
	2005	4830	5071	0.86	0.21	0.65	-	-	-
	2006	7458	4442	0.87	0.21	0.50	-	-	-
	2007	9822	5665	0.85	0.21	0.65	-	-	-
	2008	11855	5164	0.91	0.21	0.58	-	-	-
GB	2009	11368	4646	0.87	0.18	0.42	-	-	-
Cod	2010	4812	3959	0.91	0.19	0.29	-	-	-
	2011	5616	4448	0.96	0.19	0.23	-	-	-
	2012	6214	2654	0.93	0.19	-	-	-	-
	2013	2506	1825	0.93	0.14	-	-	-	-
	2014	2506	2081	0.98	0.12	-	-	-	-
	2015	2506	-		0.10	-	-	-	-
	2004	4850	5769	0.87	0.23	0.67	-	-	-
	2005	6372	5258	0.92	0.23	0.84	-	-	-
	2006	5146	4207	0.90	0.23	0.72	-	-	-
	2007	10020	5485	0.94	0.23	0.72	-	-	-
	2008	10491	7187	0.93	0.23	0.93	-	-	-
GOM	2009	10839	8247	0.89	0.21	1.04	-	-	-
Cod	2010	8530	7517	0.95	0.18	1.07	-	-	-
	2011	9012	6673	0.96	0.18	1.56	-	-	-
	2012	9018	3472	0.96	0.18	1.78	-	-	-
	2013	1550	1777	0.93	0.17	1.33	-	-	-
	2014	1550	1471	0.92	0.14	0.96	-	-	-
	2015	1550	-		0.10	-	-	-	-
	2004	24855	18253	0.92	0.26	0.34	-	-	-
	2005	27692	21814	0.97	0.26	0.38	-	-	-
	2006	49829	15989	0.91	0.26	0.32	-	-	-
	2007	103329	16815	0.88	0.26	0.24	-	-	-
	2008	121681	21021	0.98	0.26	0.18	-	-	-
GB	2009	92888	23126	0.99	0.24	0.19	-	-	-
Haddock	2010	62515	25903	0.99	0.26	0.31	-	-	-
	2011	46784	16670	0.99	0.26	0.27	-	-	-
	2012	39846	6935	0.95	0.26	0.26	-	-	-
	2013	35783	6828	0.92	0.29	0.16	-	-	-
	2014	35699	18601	0.92	0.29	0.16	-	-	-
	2015	43606	-		0.29	-	-	-	-

Table 10 continued.

Stock	Year	Target Catch	Obs. Catch	Landings Prop.	Target *F*	Est. *F*	Index	Target C/I	Est. C / I
GOM Haddock	2006	1279	1167	0.92	-	0.226	4.58	0.23	0.25
	2007	1254	1343	0.93	-	0.322	4.40	0.23	0.31
	2008	1229	1162	0.93	-	0.298	3.78	0.22	0.31
	2009	1187	946	0.96	-	0.247	3.15	0.22	0.30
	2010	1265	958	0.98	0.32	0.287	-	-	-
	2011	1206	744	0.98	0.32	0.26	-	-	-
	2012	1013	739	0.90	0.32	0.337	-	-	-
	2013	290	793	0.64	0.35	0.296	-	-	-
	2014	341	1021	0.62	0.35	0.26	-	-	-
	2015	435	-	-	0.35	-	-	-	-
GB Yellowtail	2004	7900	6400	0.87	0.25	1.94	-	-	-
	2005	6000	4100	0.83	0.25	1.39	-	-	-
	2006	3000	2500	0.58	0.25	1.54	-	-	-
	2007	1300	1100	0.65	0.25	1.05	-	-	-
	2008	2500	1700	0.65	0.25	0.57	-	-	-
	2009	2100	1900	0.53	0.11	0.83	-	-	-
	2010	2000	1300	0.57	0.10	0.73	-	-	-
	2011	2700	1100	0.79	0.20	0.60	-	-	-
	2012	1200	600	0.67	0.19	0.32	-	-	-
SNE / MA Yellowtail	2004	707	619	0.79	0.37	1.11	-	-	-
	2005	1982	346	0.70	0.37	0.81	-	-	-
	2006	146	396	0.53	0.26	0.82	-	-	-
	2007	213	502	0.41	0.26	0.66	-	-	-
	2008	312	583	0.33	0.26	0.59	-	-	-
	2009	272	453	0.41	0.17	0.46	-	-	-
	2010	493	291	0.39	0.08	0.30	-	-	-
	2011	687	390	0.63	0.08	0.41	-	-	-
	2012	1002	-	0.61	0.08	0.72	-	-	-
	2013	700	-	0.71	0.21	1.01	-	-	-
	2014	700	-	0.83	0.20	1.64	-	-	-
	2015	700	-	-	0.20	NA	-	-	-

Table 10 continued.

Stock	Year	Target Catch	Obs. Catch	Landings Prop.	Target *F*	Est. *F*	Index	Target C/I	Est. C / I
	2006	650	620	0.86	0.26	1.48	-	-	-
	2007	1078	633	0.78	0.26	1.06	-	-	-
	2008	1406	699	0.78	0.26	1.16	-	-	-
CC / GOM	2009	608	639	0.73	0.09	0.75	-	-	-
Yellowtail	2010	863	633	0.86	0.18	0.49	-	-	-
	2011	1041	758	0.90	0.18	0.65	-	-	-
	2012	1159	1092	0.87	0.18	0.98	-	-	-
	2013	548	676	0.87	0.20	0.82	-	-	-
	2014	548	475	0.89	0.15	0.35	-	-	-
	2015	548	-	-	0.11	-	-	-	-
	2004	3695	2070	0.83	0.23	0.55	-	-	-
	2005	3625	1636	0.82	0.23	0.33	-	-	-
	2006	3666	1402	0.80	0.23	0.28	-	-	-
	2007	4104	1238	0.80	0.23	0.13	-	-	-
	2008	5121	1358	0.81	0.23	0.17	-	-	-
Plaice	2009	3614	1770	0.78	0.14	0.20	-	-	-
	2010	3156	1796	0.78	0.14	0.14	-	-	-
	2011	3444	1568	0.87	0.14	0.11	-	-	-
	2012	3632	1747	0.84	0.14	0.13	-	-	-
	2013	1557	1449	0.90	0.14	0.10	-	-	-
	2014	1515	1328	0.93	0.14	0.08	-	-	-
	2015	1544	-	-	0.14	-	-	-	-
	2004	5174	3247	0.90	0.23	0.94	-	-	-
	2005	6992	2810	0.95	0.23	0.86	-	-	-
	2006	5511	1957	0.96	0.23	0.90	-	-	-
	2007	5075	1175	0.92	0.23	0.57	-	-	-
	2008	4331	1075	0.94	0.23	0.66	-	-	-
Witch	2009	3558	1068	0.90	0.23	0.58	-	-	-
	2010	944	855	0.89	0.15	0.67	-	-	-
	2011	1369	947	0.92	0.15	0.63	-	-	-
	2012	1639	1110	0.94	0.15	0.78	-	-	-
	2013	783	737	0.93	0.17	0.64	-	-	-
	2014	783	605	0.94	0.13	0.43	-	-	-
	2015	783	-	-	0.11	-	-	-	-

Table 10 continued.

Stock	Year	Target Catch	Obs. Catch	Landings Prop.	Target *F*	Est. *F*	Index	Target C/I	Est. C / I
	2006	1424	880	0.78	0.32	0.27	-	-	-
	2007	1604	807	0.78	0.32	0.31	-	-	-
	2008	1782	967	0.82	0.32	0.37	-	-	-
GB	2009	1955	1670	0.83	0.32	0.46	-	-	-
Winter	2010	2052	1297	0.84	0.20	0.37	-	-	-
	2011	2224	1853	0.90	0.20	0.51	-	-	-
	2012	3753	1994	0.91	0.32	0.50	-	-	-
	2013	3750	1687	0.96	0.32	0.53	-	-	-
	2014	3598	1126	0.92	0.32	0.38	-	-	-
	2004	3286	689	0.95	0.43	-	-	-	-
	2005	2634	388	0.93	0.43	-	-	-	-
	2006	-	248	0.95	0.43	-	-	-	-
	2007	-	300	0.94	0.43	-	-	-	-
	2008	-	426	0.96	0.43	-	-	-	-
GOM	2009	-	283	0.94	0.43	-	-	-	-
Winter	2010	238	140	0.94	-	-	-	-	-
	2011	238	173	0.95	-	-	-	-	-
	2012	1078	348	0.97	0.23	-	-	-	-
	2013	1078	218	0.97	0.23	-	-	-	-
	2014	1078	213	0.97	0.23	-	-	-	-
	2004	2860	1942	0.85	0.32	0.43	-	-	-
	2005	3550	1563	0.92	0.32	0.35	-	-	-
	2006	2481	2023	0.92	0.32	0.41	-	-	-
	2007	3016	1867	0.93	0.32	0.36	-	-	-
	2008	3577	1298	0.91	0.32	0.28	-	-	-
SNE / MA	2009	3309	532	0.67	0.23	0.12	-	-	-
Winter	2010	644	363	0.56	0.01	0.07	-	-	-
	2011	897	531	0.40	0.01	0.09	-	-	-
	2012	626	650	0.25	0.07	0.11	-	-	-
	2013	1676	1074	0.80	0.17	0.19	-	-	-
	2014	1676	753	0.91	0.14	0.16	-	-	-
	2015	1676	-	-	0.10	-	-	-	-

Table 10 continued.

Stock	Year	Target Catch	Obs. Catch	Landings Prop.	Target *F*	Est. *F*	Index	Target C/I	Est. C / I
	2004	1632	523	0.76	0.01	0.004	-	-	-
	2005	1725	665	0.85	0.01	0.004	-	-	-
	2006	1946	648	0.77	0.01	0.004	-	-	-
	2007	2075	1160	0.68	0.01	0.006	-	-	-
	2008	2167	1373	0.87	0.01	0.006	-	-	-
Redfish	2009	2210	1667	0.88	0.01	0.007	-	-	-
	2010	7586	1852	0.89	0.03	0.007	-	-	-
	2011	8356	2223	0.90	0.03	0.008	-	-	-
	2012	9224	4146	0.93	0.03	0.012	-	-	-
	2013	10995	3974	0.89	0.03	0.011	-	-	-
	2014	11465	5086	0.90	0.03	0.012	-	-	-
	2015	11974	-		0.03	-	-	-	-
	2004	3839	3722	0.97	-	0.33	5.29	1.03	0.66
	2005	3822	2849	0.97	-	0.31	4.21	1.03	0.63
	2006	2056	1854	0.97	-	0.19	3.95	1.03	0.43
	2007	1676	1622	0.98	-	0.13	5.02	1.03	0.30
	2008	1367	1550	0.89	-	0.12	6.17	1.03	0.22
White	2009	428	1874	0.96	-	0.15	6.35	0.23	0.27
Hake	2010	2832	2015	0.95	0.08	0.12	6.53	-	0.28
	2011	3295	3039	0.98	0.08	0.15	-	-	-
	2012	3638	2888	0.99	0.08	0.14	-	-	-
	2013	3638	2306	0.99	0.08	0.10	-	-	-
	2014	4642	1980	0.98	0.15	0.08	-	-	-
	2015	4713	-	-	0.15	-	-	-	-
	2004	10584	6064	0.93	-	-	1.925	5.88	3.16
	2005	10584	7228	0.96	-	-	2.533	5.88	2.86
	2006	12005	7078	0.95	-	-	0.959	5.88	7.41
	2007	12005	9280	0.96	-	-	0.754	5.88	12.34
	2008	12005	12216	0.90	-	-	-	5.88	-
Pollock	2009	11043	8755	0.92	-	-	-	5.88	-
	2010	3813	7373	0.88	-	-	-	5.88	-
	2011	16900	9738	0.89	0.31	0.191	-	-	-
	2012	15400	8277	0.88	0.31	0.163	-	-	-
	2013	15600	8594	0.79	0.31	0.152	-	-	-
	2014	16000	6071	0.85	0.31	0.076	-	-	-

Table 10 continued.

Stock	Year	Target Catch	Obs. Catch	Landings Prop.	Target *F*	Est. *F*	Index	Target C/I	Est. C / I
	2004	534	328		-	-	0.671	1.11	0.433
	2005	534	968		-	-	0.677	1.11	1.389
	2006	389	683		-	-	0.653	1.11	1.024
	2007	389	1091		-	-	0.242	1.11	2.082
	2008	389	376		-	-	0.447	1.11	0.841
North Windowpane	2009	434	440		-	-	0.633	1.11	0.998
	2010	169	236		-	-	0.295	0.375	0.515
	2011	169	-		-	-	-	0.375	-
	2012	173	-		-	-	-	0.375	-
	2013	151	-		-	-	-	0.33	-
	2014	151	-		-	-	-	0.33	-
	2015	151	-		-	-	-	0.33	-
	2004	285	400		-	-	0.21	0.98	1.87
	2005	273	330		-	-	0.21	0.98	1.6
	2006	173	431		-	-	0.17	0.98	2.53
	2007	166	349		-	-	0.19	0.98	1.82
	2008	159	321		-	-	0.20	0.98	1.58
South Windowpane	2009	98	463		-	-	0.25	0.49	1.86
	2010	237	490		-	-	0.35	1.1025	1.4
	2011	237	-		-	-	-	1.1025	-
	2012	237	-		-	-	-	1.1025	-
	2013	548	-		-	-	-	1.57	-
	2014	548	-		-	-	-	1.57	-
	2015	548	-		-	-	-	1.57	-
	2004	77	296		-	-	1.28	0.03	0.23
	2005	77	205		-	-	0.53	0.03	0.38
	2006	38	188		-	-	0.51	0.03	0.37
	2007	38	169		-	-	0.48	0.03	0.36
	2008	38	127		-	-	0.49	0.03	0.26
Pout	2009	14	168		-	-	0.45	0.01	0.37
	2010	271	127		-	-	0.41	0.57	0.31
	2011	271	-		-	-	-	0.57	-
	2012	256	-		-	-	-	0.57	-
	2013	235	-		-	-	-	0.57	-
	2014	235	-		-	-	-	0.57	-
	2015	235	-		-	-	-	0.57	-

Table 10 continued.

Stock	Year	Target Catch	Obs. Catch	Landings Prop.	Target *F*	Est. *F*	Index	Target C/I	Est. C / I
Halibut	2004	-	39		-	-	-	-	-
	2005	-	51		-	-	-	-	-
	2006	-	45		-	-	-	-	-
	2007	-	82		-	-	-	-	-
	2008	-	88		-	-	-	-	-
	2009	-	107		-	-	-	-	-
	2010	71	52		0.04	0.03	-	-	-
	2011	78	-		0.04	-	-	-	-
	2012	85	-		0.04	-	-	-	-
	2013	99	-		0.04	-	-	-	-
	2014	109	-		0.04	-	-	-	-
	2015	119	-		0.04	-	-	-	-
Wolffish	2004	-	131		-	-	-	-	-
	2005	-	126		-	-	-	-	-
	2006	-	100		-	-	-	-	-
	2007	-	77		-	-	-	-	-
	2008	-	63		-	-	-	-	-
	2009	-	45		-	-	-	-	-
	2010	83	17		-	-	-	-	-
	2011	83	-		-	-	-	-	-
	2012	83	-		-	-	-	-	-
	2013	70	-		0.25	-	-	-	-
	2014	70	-		0.25	-	-	-	-
	2015	70	-		0.25	-	-	-	-

Table 11. The mean relative error (RE) in terminal estimates of biomass and recruitment by stock. GOM winter flounder was omitted due to a large amount of uncertainty in the GARM 2 and all subsequent assessments, preventing the calculation of relative error in historical assessment estimates for this stock.

	RE in Terminal	
Stock	Biomass	Recruitment
GB Cod	0.55	0.62
GOM Cod	1.15	0.79
GB Haddock	0.38	0.48
GOM Haddock	-0.34	0.26
GB Yellowtail	2.54	1.00
SNE/MA Yellowtail	1.00	-0.14
CC/GOM Yellowtail	0.72	0.11
Plaice	0.62	0.14
Witch	1.59	2.52
GB Winter	0.41	1.62
SNE/MA Winter	-0.18	0.12
Redfish	-0.03	0.89
White Hake	0.30	0.25
Pollock	-0.27	-0.19

Table 12.

Equations governing the age-based projections. Recruitment is either based on a Beverton-Holt stock-recruit relationship, or drawn from an empirical cumulative distribution function (see text for more details).

Eqn.		
1	$N(a,t) = \begin{cases} R(t) & a = a_R \\ N(a-1,t-1)e^{-Z(a-1,t-1)} & a_R < a < a_{max} \\ N(a-1,t-1)e^{-Z(a-1,t-1)} + & a = a_{max} \\ N(a,t-1)e^{-Z(a,t-1)} & \end{cases}$	**Numerical** abundance at **age**
2	$R(t) = \frac{\alpha S(t-a_R)}{\beta S(t-a_R)} e^{\theta_R - 0.5\sigma_R^2}$ $R(t) = ECDF_{all}$ $R(t) = \begin{cases} ECDF_{low} & S < S_{thresh} \\ ECDF_{high} & S \geq S_{thresh} \end{cases}$	Recruitment
3	$S(t) = \sum_a m(a) w_S(a) N(a,t)\, e^{-\phi\, Z(a,t)}$	**Total** spawning biomass
4	$Z(a,t) = M(a,t) + s(a,t)F(t)$	Total mortality
5	$C(a,t) = \frac{s(a,t)F(t)}{Z(a,t)} w_C(a) N(a,t)\left(1 - e^{-Z(a,t)}\right)$ $C(t) = \sum_a C(a,t)$	Catch (at age and total)

Table 13. Comparison of age-based projection inputs based on each assessment (GARM 1 – 3) and the updated values, along with mean interim *F* and future recruitments based on the original inputs and the updated values. Updated recruitments and age-based estimates were averaged from the first projection year to the final year of catch advice from the projection (e.g., 2002 – 2005 for GARM 1), while the mean *F* was calculated using only the interim years before catch advice was calculated for a target F (2002-2003 for GARM 1).

GARM 1

	Mean *F*	Mean *R* (x 10^3)
True	0.78	3425.8
Input	0.46	5236.5

Age	1	2	3	4	5	6	7	8	9	10
Abundance (x 10^3)										
True	3962	2109	3717	3963	672	585	154	31	22	17
Input	1648	1276	2736	2843	654	1029	474	216	43	25
Catch weights (kg)										
True	0.32	1.39	2.2	2.97	3.89	4.79	5.8	7.63	8.8	11.08
Input	0.88	1.51	2.36	3.61	5	6.54	8.25	9.68	11.3	14.64
Selectivity										
True	0.01	0.11	0.51	0.89	0.99	1	1	1	1	1
Input	0	0.15	0.6	1	1	1	1	1	1	1

GARM 2

	Mean *F*	Mean *R* (x 10^3)
True	0.65	4953
Input	0.15	8546.5

Age	1	2	3	4	5	6	7	8	9	10
Abundance (x 10^3)										
True	6959	1018	2417	871	826	609	96	83	22	10
Input	5083	15900	1396	1366	977	1124	691	85	127	51
Catch weights (kg)										
True	0.38	1.33	2.16	3	3.72	4.63	5.87	7.23	8.11	10.15
Input	0.59	1.89	2.4	3.1	4.14	5.11	6.29	8.06	9.41	11.7
Selectivity										
True	0.02	0.1	0.51	0.89	0.99	0.99	1	1	1	1
Input	0	0.06	0.57	0.8	1	1	1	1	1	1

GARM 3

	Mean *F*	Mean *R* (x 10^3)
True	7735	0.29
Input	12300	0.18

Age	1	2	3	4	5	6	7	8	9	10
Abundance (x 10^3)										
True	5327	4746	2476	565	1245	103	145	40	36	35
Input	2834	5075	3633	882	2782	151	216	70	25	21
Catch weights (kg)										
True	0.32	1.22	2.25	2.91	3.63	4.16	4.77	5.81	8.74	13.19
Input	0.43	1.3	2.15	3.01	3.81	4.63	5.86	7.03	8.01	10.21
Selectivity										
True	0	0.1	0.52	0.9	1	1	1	1	1	1
Input	0.01	0.1	0.39	0.74	1	1	1	1	1	1

Table 14. Similar to Table 13, but for GOM cod. Earlier assessments for GOM cod assumed a younger maximum age in the assessment and projection models.

		Mean *F*	Mean *R* (x 10^3)							
	True	0.62	4260							
	Input	0.37	6982							
	Age	1	2	3	4	5	6	7	8	9
	Abundance (x 10^3)									
	True	5199	948	2930	3132	767	397	103	48	30
GARM 1	Input	5901	467	2967	4558	1340	426	279	-	-
	Catch weights (kg)									
	True	0.16	0.66	1.72	2.66	3.81	5.27	7.05	8.94	12.53
	Input	0.47	1.58	2.06	2.73	3.98	5.8	10.77	-	-
	Selectivity									
	True	0.02	0.08	0.33	0.74	0.94	0.99	1	1	1
	Input	0	0.01	0.29	1	1	1	1	-	-
		Mean *F*	Mean *R* (x 10^3)							
	True	0.87	3980							
	Input	0.19	7462							
	Age	1	2	3	4	5	6	7	8	9
	Abundance (x 10^3)									
	True	3767	5002	1186	2088	230	408	298	64	47
GARM 2	Input	6315	15201	1960	3518	165	703	501	-	-
	Catch weights (kg)									
	True	0.16	0.66	1.72	2.66	3.81	5.27	7.05	8.94	12.53
	Input	0.39	1.62	2.41	3.24	3.97	5.53	8.61	-	-
	Selectivity									
	True	0.01	0.04	0.23	0.65	0.92	0.99	1	1	1
	Input	0	0	0.26	1	1	1	1	-	-
		Mean *F*	Mean *R* (x 10^3)							
	True	0.93	2100							
	Input	0.18	5834							
	Age	1	2	3	4	5	6	7	8	9
	Abundance (x 10^3)									
	True	1310	1706	2041	1908	1116	239	144	16	21
GARM 3	Input	6116	2430	13938	3285	3787	181	217	25	110
	Catch weights (kg)									
	True	0.16	0.66	1.72	2.66	3.81	5.27	7.05	8.94	12.53
	Input	0.42	1.86	2.35	3.12	3.93	4.94	6.5	8.13	12.4
	Selectivity									
	True	0.01	0.04	0.23	0.65	0.92	0.99	1	1	1
	Input	0	0	0.16	0.68	0.9	1	0.83	0.73	0.75

Table 15. Similar to Table 13, but for witch flounder.

Witch

GARM 1

	Mean F	Mean R (x 10^3)
True	0.69	7124
Input	0.19	16550

Age	3	4	5	6	7	8	9	10	11
Abundance (x 10^3)									
True	11213	10382	8071	6661	6142	3096	1740	240	510
Input	22294	53585	57899	27995	16036	4570	1463	983	1160
Catch weights (kg)									
True	0.1	0.21	0.28	0.36	0.44	0.54	0.62	0.71	0.88
Input	0.12	0.29	0.34	0.39	0.48	0.56	0.7	0.8	0.96
Selectivity									
True*	0.01	0.06	0.21	0.42	0.74	0.92	0.97	0.93	0.93
Input	0.01	0.1	0.22	0.42	1	1	1	1	1

GARM 2

	Mean F	Mean R (x 10^3)
True	0.92	6380
Input	0.1	4346

Age	3	4	5	6	7	8	9	10	11
Abundance (x 10^3)									
True	3702	4364	5920	5806	3840	1676	736	458	259
Input	2605	3472	8503	12935	19304	16262	8525	2147	2965
Catch weights (kg)									
True	0.11	0.21	0.29	0.37	0.46	0.55	0.64	0.71	0.85
Input	0.09	0.2	0.27	0.35	0.44	0.53	0.61	0.71	0.87
Selectivity									
True*	0.01	0.04	0.11	0.27	0.71	0.84	0.88	0.84	0.84
Input	0.01	0.1	0.2	0.3	0.6	1	1	1	1

GARM 3

	Mean F	Mean R (x 10^3)
True	0.79	5453
Input	0.15	11310

Age	3	4	5	6	7	8	9	10	11
Abundance (x 10^3)									
True	4713	4229	2563	2095	1758	1573	544	309	186
Input	9838	20213	5001	1160	1377	1996	853	1292	399
Catch weights (kg)									
True	0.12	0.2	0.28	0.37	0.46	0.53	0.63	0.66	0.77
Input	0.1	0.21	0.28	0.35	0.45	0.54	0.63	0.7	0.88
Selectivity									
True*	0.01	0.05	0.14	0.3	0.64	0.99	1.01	0.96	0.96
Input	0.01	0.08	0.22	0.43	0.85	1	1	1	1

Table 16. Similar to Table 13, but for SNE/MA winter flounder.

GARM 1		Mean *F*	Mean *R* (x 10^3)					
	True	0.59	11238					
	Input	0.45	18997					
	Age	1	2	3	4	5	6	7
	Abundance (x 10^3)							
	True	7457	11098	6119	3426	2005	1165	849
	Input	5707	15467	6543	2890	2157	1605	1053
	Catch weights (kg)							
	True	0.13	0.38	0.51	0.65	0.81	0.97	1.21
	Input	0.32	0.38	0.46	0.59	0.72	0.92	1.25
	Selectivity							
	True	0.01	0.19	0.7	1	0.97	0.89	0.67
	Input	0.02	0.27	0.75	1	1	1	1
GARM 2		Mean *F*	Mean *R* (x 10^3)					
	True	0.37	10451					
	Input	0.28	19790					
	Age	1	2	3	4	5	6	7
	Abundance (x 10^3)							
	True	14188	11634	3754	1958	1699	578	720
	Input	9728	17507	2559	1642	1765	468	99
	Catch weights (kg)							
	True	0.11	0.36	0.47	0.63	0.81	1.03	1.29
	Input	0.13	0.38	0.52	0.64	0.83	1.03	1.28
	Selectivity							
	True	0.01	0.19	0.7	1	0.97	0.89	0.67
	Input	0.01	0.2	0.79	1	1	1	1
GARM 3		Mean *F*	Mean *R* (x 10^3)					
	True	0.24	10324					
	Input	0.01	24512					
	Age	1	2	3	4	5	6	7
	Abundance (x 10^3)							
	True	13501	5566	4235	4185	2337	552	764
	Input	6381	2720	3737	3524	1732	174	63
	Catch weights (kg)							
	True	0.12	0.34	0.47	0.6	0.76	0.95	1.1
	Input	0.12	0.38	0.5	0.65	0.84	1.03	1.25
	Selectivity							
	True	0.01	0.19	0.7	1	0.97	0.89	0.67
	Input	0.01	0.14	0.59	0.97	1	1	1

Table 17. Similar to Table 13, but for GB yellowtail flounder for GARM 1 and 3. Projection files for GARM 2 were not available for this stock, so we omitted GARM 2 projections from our analysis.

		Mean *F*	Mean *R* (x 10^3)				
	True						
	Input						
	Age	1	2	3	4	5	6
	Abundance (x 10^3)						
	True	15117	17992	10544	4374	1559	1108
GARM 1	Input	20902.64	41855.81	29748.7	20544.96	17568.4	10080.34
	Catch weights (kg)						
	True	0.25	0.309	0.417	0.553	0.714	1.068
	Input	0.181	0.349	0.462	0.578	0.71	0.948
	Selectivity						
	True	0.031	0.446	0.677	1	1	1
	Input	0.006	0.315	0.648	1	1	1
		Mean *F*	Mean *R* (x 10^3)				
	True	0.57	3714				
	Input	0.14	23436				
	Age	1	2	3	4	5	6
	Abundance (x 10^3)						
	True	5424	5041	5295	2153	315	62
GARM 3	Input	18603	13587	30219	5021	1832	523
	Catch weights (kg)						
	True	0.1	0.2	0.37	0.48	0.6	0.85
	Input	0.11	0.31	0.42	0.54	0.72	0.96
	Selectivity						
	True	0.01	0.13	0.6	1	1	1
	Input	0.02	0.22	0.66	1	1	1

Table 18. Similar to Table 13, but for pollock. Input values for pollock were based on SAW 50 (NEFSC 2010).

	Mean *F*	Mean *R* (x 10^3)							
True	0.16	24498							
Input	0.31	20261							

Age	1	2	3	4	5	6	7	8	9
Abundance (x 10^3)									
True	18400	10200	13900	9250	6820	3120	3980	2110	17200
Input	23411	16490	13417	8605	5887	3967	4637	2606	22433
Catch weights (kg)									
True	0.15	0.36	0.8	1.55	2.25	3.09	3.82	4.4	5.35
Input	0.1	0.28	0.72	1.32	2.03	2.92	3.8	4.73	6.39
Selectivity									
True	0	0.03	0.06	0.13	0.3	0.67	1	0.87	0.27
Input	0.01	0.02	0.04	0.08	0.2	0.61	1	0.85	0.26

Table 19. Error in catch estimates (relative to the updated catch at F_{target}) from projections updated with the estimates from the current assessment for each input (N = initial abundance-at-age, $F = F$ in the interim years, R = recruitments, W_c = catch weight-at-age, and s = fishery selectivity-at-age). Base refers to the projections using the original inputs. Values in bold indicate the updated piece of information that had the largest impact on the catch advice for a given stock / assessment period. For example, the mean error in original projected catches for GB cod based on the GARM 1 assessment was 70% above the true catch at F_{target}. When projections were updated with the weight at age in the catch, projected catches were only 24% higher than the estimated catch at F_{target}.

			Relative error in projected catch					
Stock	Assessment Basis	Years	Base	Updated N	Updated F	Updated R	Updated W_c	Updated s
GB Cod	GARM 1	2004-2005	0.70	0.95	0.35	0.48	**0.24**	0.66
	GARM 2	2006-2009	3.00	**0.60**	2.01	2.69	2.60	3.04
	GARM 3	2010-2011	1.03	**0.40**	0.46	0.92	0.91	1.13
GOM Cod	GARM 1	2004-2005	1.12	**0.53**	0.71	1.03	0.85	1.11
	GARM 2	2006-2009	1.95	**0.38**	1.87	1.78	1.60	1.70
	GARM 3	2010-2013	2.40	**0.47**	1.76	2.18	1.97	2.75
Witch	GARM 1	2004-2005	6.96	**0.57**	4.70	6.96	6.31	6.29
	GARM 2	2006-2009	4.36	**0.34**	2.28	4.36	4.26	4.14
	GARM 3	2010	2.24	**0.43**	1.66	2.22	2.20	1.87
SNE/MA Winter	GARM 1	2004-2005	0.55	0.36	0.46	**0.21**	0.61	0.40
	GARM 2	2006-2009	0.42	0.44	0.29	**0.23**	0.34	0.34
	GARM 3	2010-2012	-0.08	0.59	-0.31	-0.10	-0.17	-0.10
GB Yellowtail	GARM 1	2004-2005*	6.10	**1.53**	4.08	5.15	5.68	5.82
	GARM 2	2006-2009*	-	-	-	-	-	-
	GARM 3	2010-2012*	6.89	**0.79**	5.02	5.53	5.55	6.55
Pollock	SAW 50	2011-2014	0.07	-0.04	0.12	0.07	**0.02**	0.12

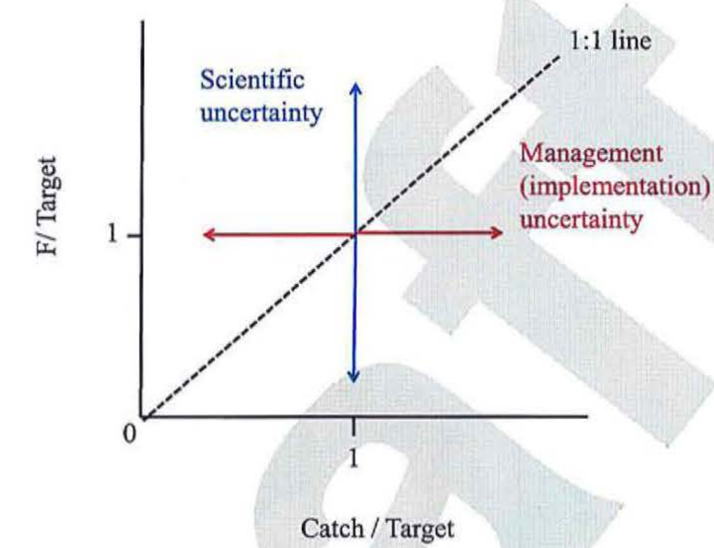


Figure 1. When catches are accurately estimated (i.e., no misreporting), management and scientific uncertainty result in deviations of the realized catch and F from the targets, respectively.

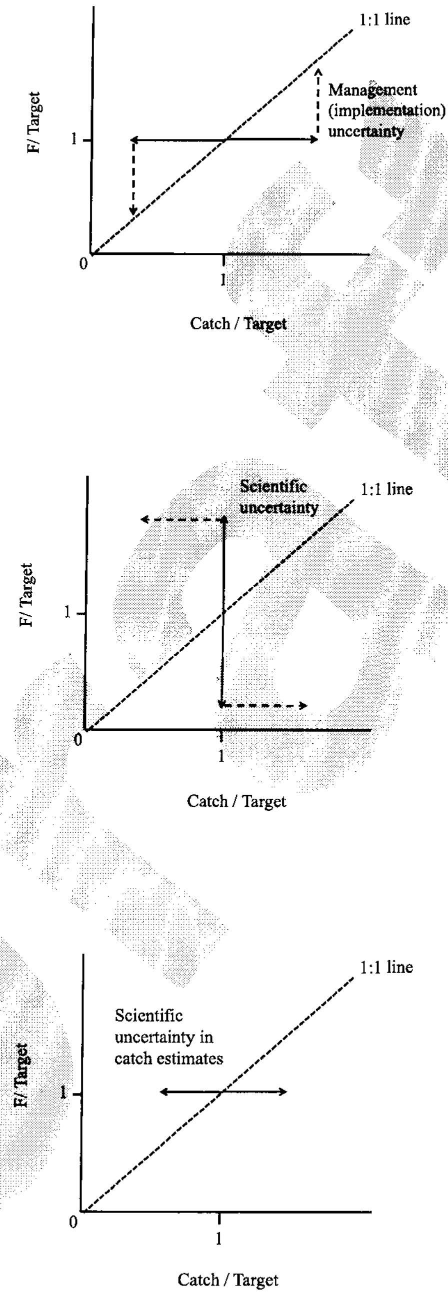


Figure 2. In cases of low scientific uncertainty (top), catches above or below the target should result in a similar change in the realized *F* relative to the target. When scientific uncertainty is high (middle), the fishery may have difficulty in achieving the target catch, resulting in implementation uncertainty. Misreporting of catches is another form of scientific uncertainty (bottom) that can result in deviations away from the 1:1 line.

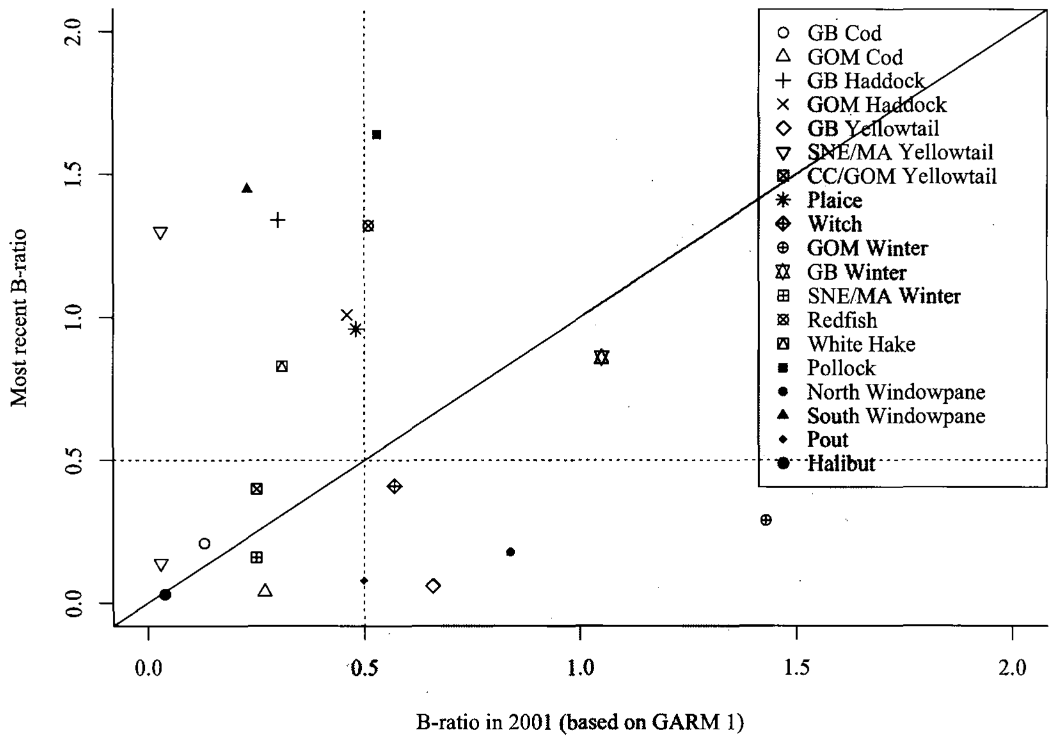
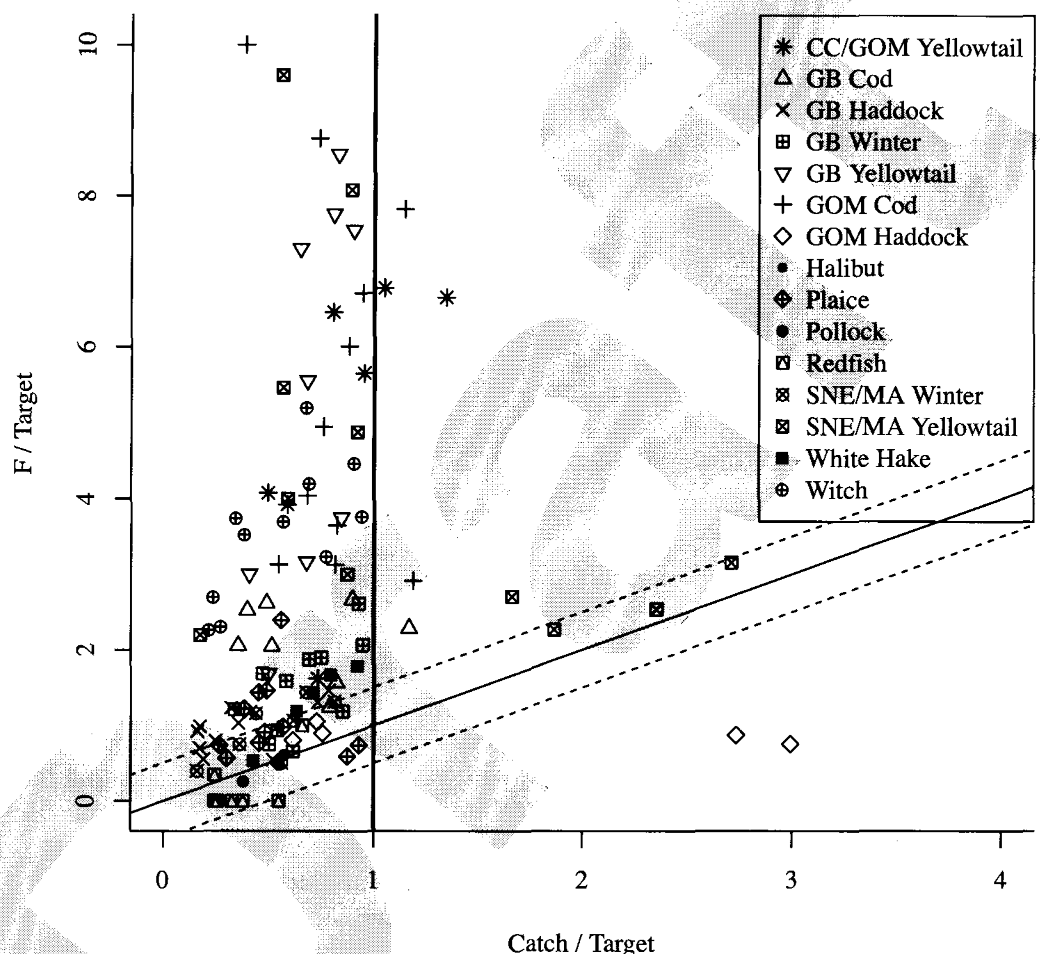


Figure 3. Current estimate of relative abundance (*B*-ratio = biomass or proxy / target) from the most recent assessment compared to the terminal estimate of relative abundance in 2001 from the GARM 1 assessment (NEFSC 2002). Dotted lines represent the overfished thresholds. The solid line is the 1:1, with values above the line indicating the stock status (the *B*-ratio) has improved since 2001 and values below indicating status has worsened. Black delineates stocks where both the 2001 and current estimates are biomass-based, blue delineates stocks where both estimates are index-based, and red delineates stocks where the 2001 estimate is index-based and the current estimate is biomass-based. Two points are shown for SNE/MA yellowtail flounder accounting for the multiple estimates of SSB_{MSY} from the most recent assessment (NEFSC 2012).



Figures 4. Annual estimates by stock of the ratio of observed F / F_{target} as a function of the observed catch / target catch. The solid vertical red line at 1 separates the plot space to highlight when catches were above or below the target. The solid black line is the 1:1 line, with values above or below the line indicating the achieved F is disproportionately high or low, respectively, for a given catch ratio. Dashed lines represent +/- 0.5 from the 1:1 line.

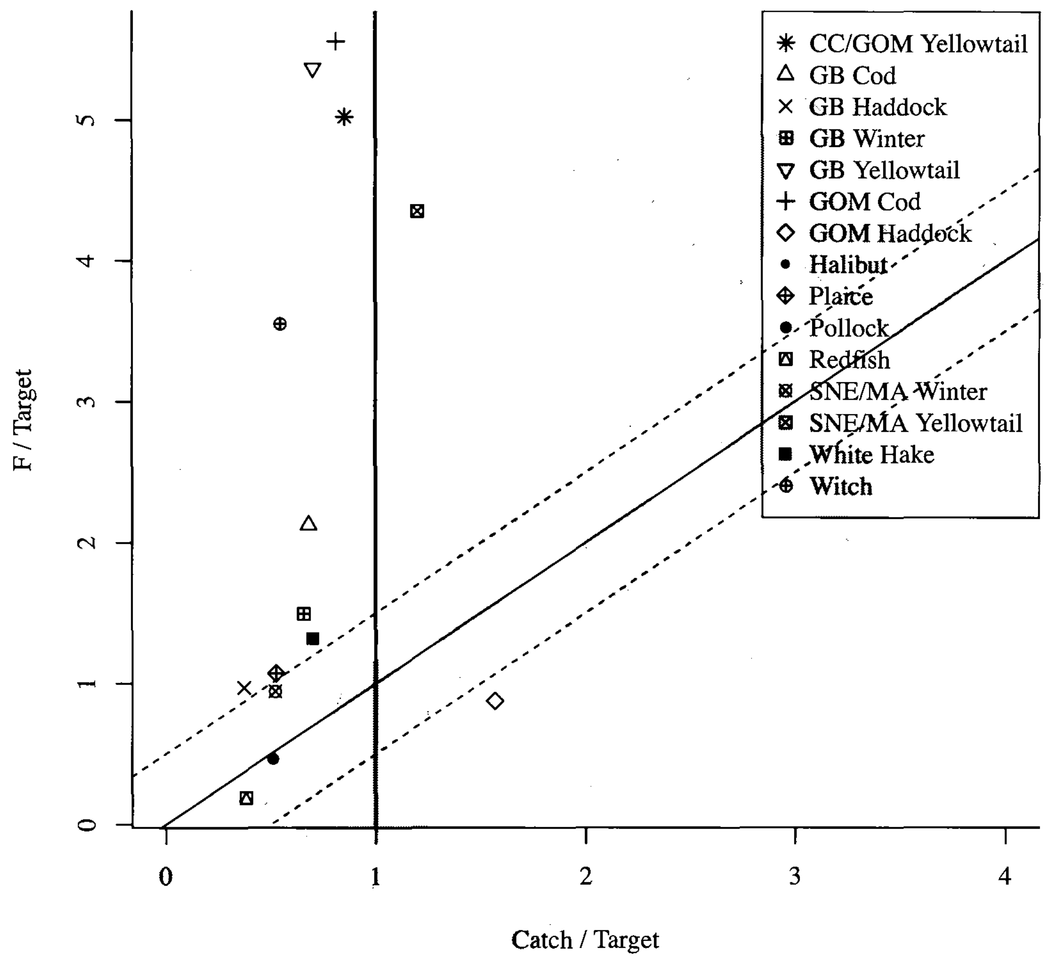


Figure 5. Average estimates by stock of the ratio of observed F / F_{target} as a function of the observed catch / target catch. The solid vertical red line at 1 separates the plot space to highlight when catches were above or below the target. The solid black line is the 1:1 line, with values above or below the line indicating the achieved F is disproportionately high or low, respectively, for a given catch ratio. Dashed lines represent +/- 0.5 from the 1:1 line.

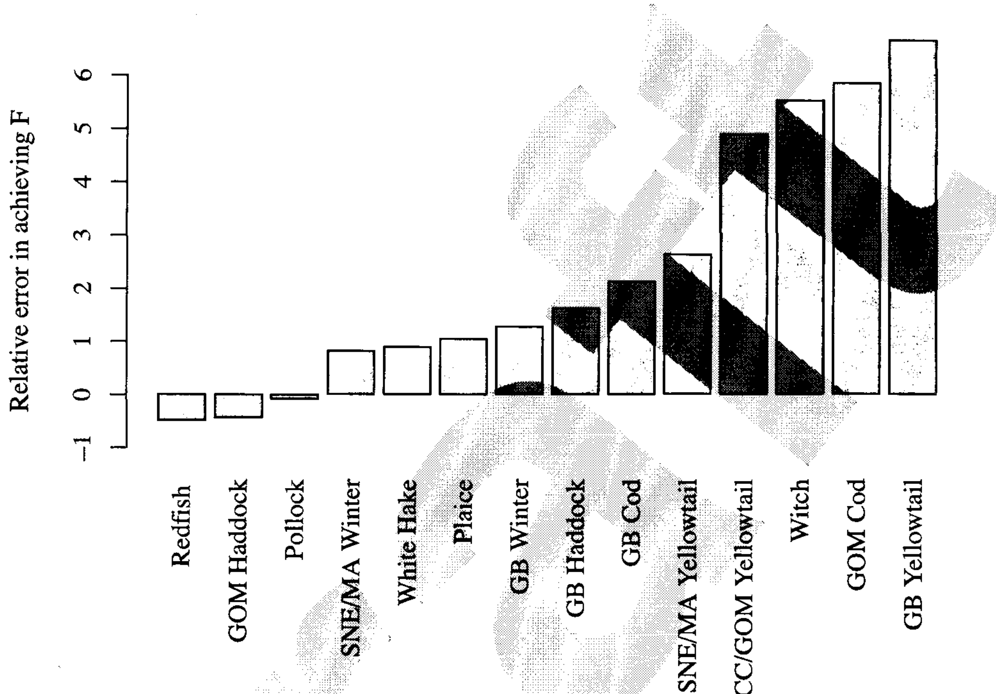


Figure 6. The relative error in achieving the target fishing mortality rate for a stock (F_{error}; equation 1). Values close to 0 indicate low scientific uncertainty in catch advice.

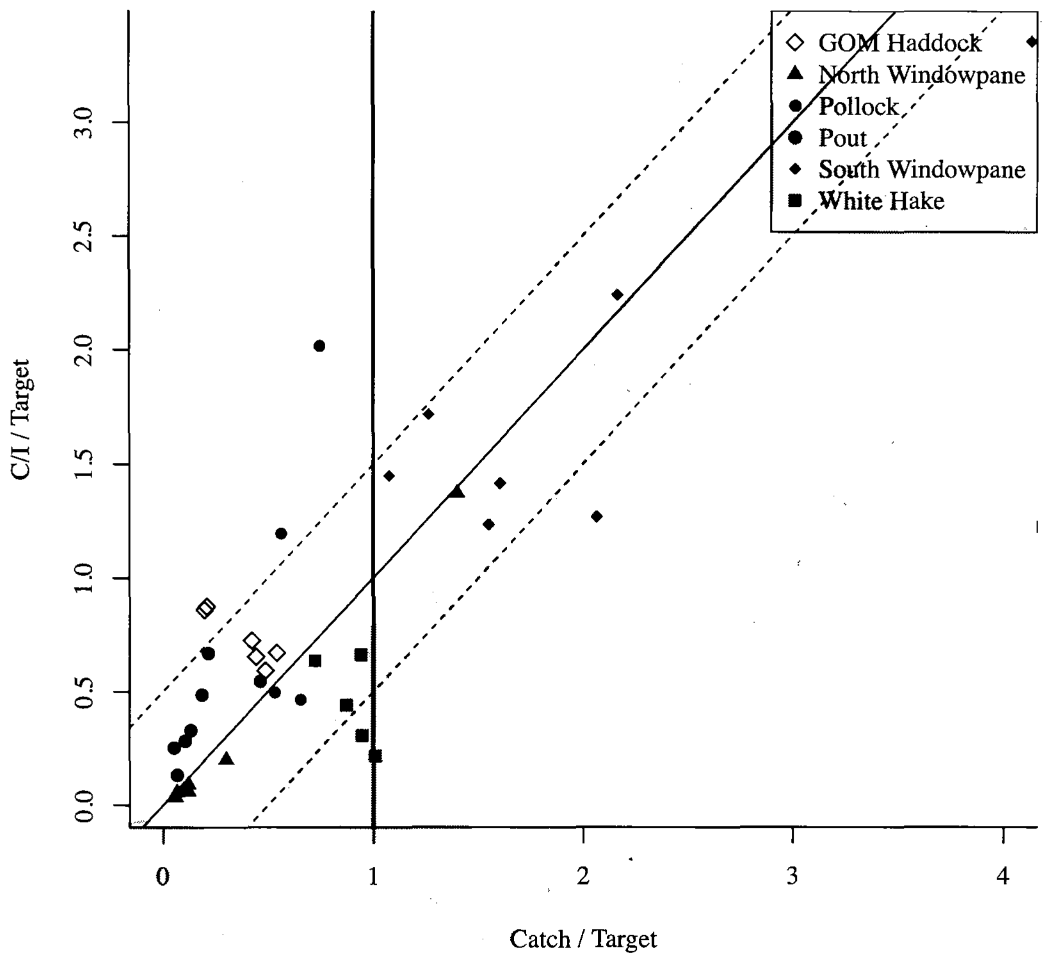


Figure 7. For index-based assessments, the catch per index (*C/I*) is used as a proxy for the fishing mortality rate, so the ratio of the observed *C/I* to the target *C/I* is analogous to the F / F_{target} in Figures 4 and 5. Here, *C/I* ratio is shown as a function the observed catch / target catch for all years in which index-based assessments were used to set catch advice. In some years the target "catch" was specified for landings only and not discards. In such cases the observed "catch" and C/I were based on landings estimates. The solid vertical red line at 1 separates the plot space to highlight when catches were above or below the target. The solid black line is the 1:1 line, with values above or below the line indicating the achieved *F* is disproportionately high or low, respectively, for a given catch ratio. Dashed lines represent +/- 0.5 from the 1:1 line.

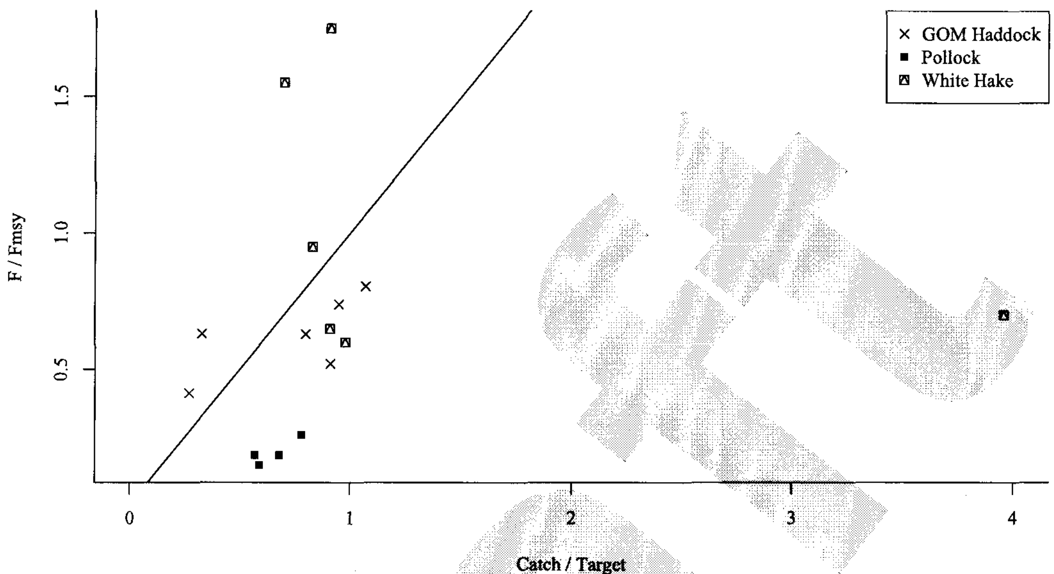


Figure 8. Three stocks were assessed formerly using index-based methods and currently using age-structured assessments, allowing for an evaluation of the effectiveness of catch advice from index-based approaches. Because a target F was not specified for these stocks, we are evaluating the effectiveness of the catch advice by looking at F / F_{MSY} as a function of the observed catch / target catch for stocks where the target catch was set using an index-based approach.

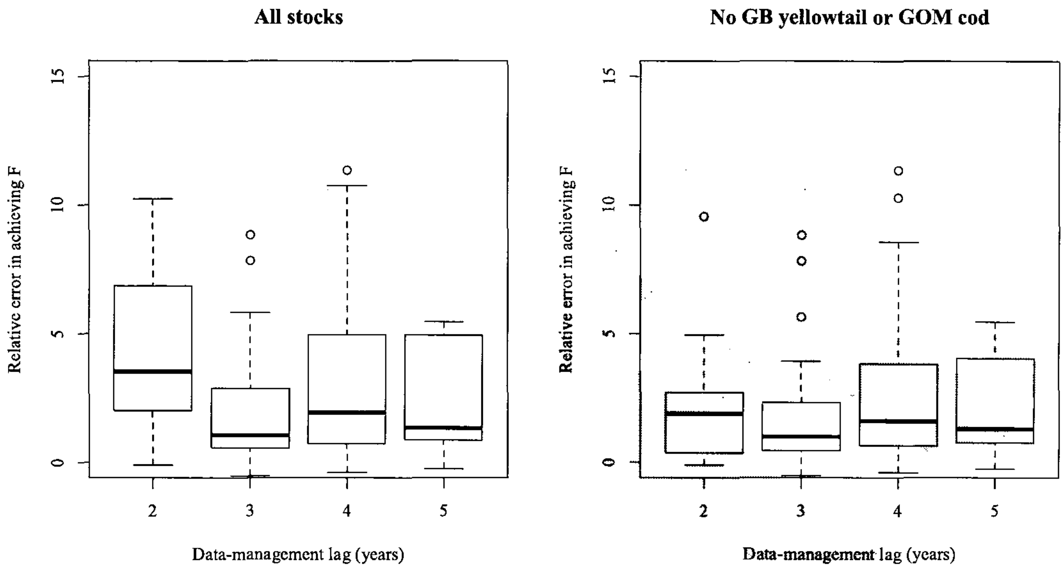


Figure 9. The relative error in achieving the target F (F_{error}; equation 1) as a function of the number of years of data-management lag (DML) for all stocks (left) and omitting GB yellowtail and GOM cod (right).

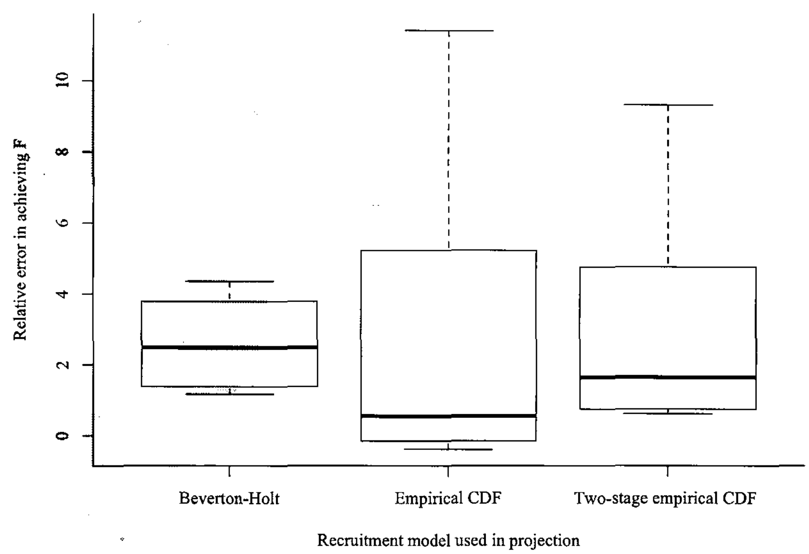


Figure 10. The relative error in achieving the target F (F_{error}; equation 1) as a function of the recruitment model used in the projections to calculate the target catch.

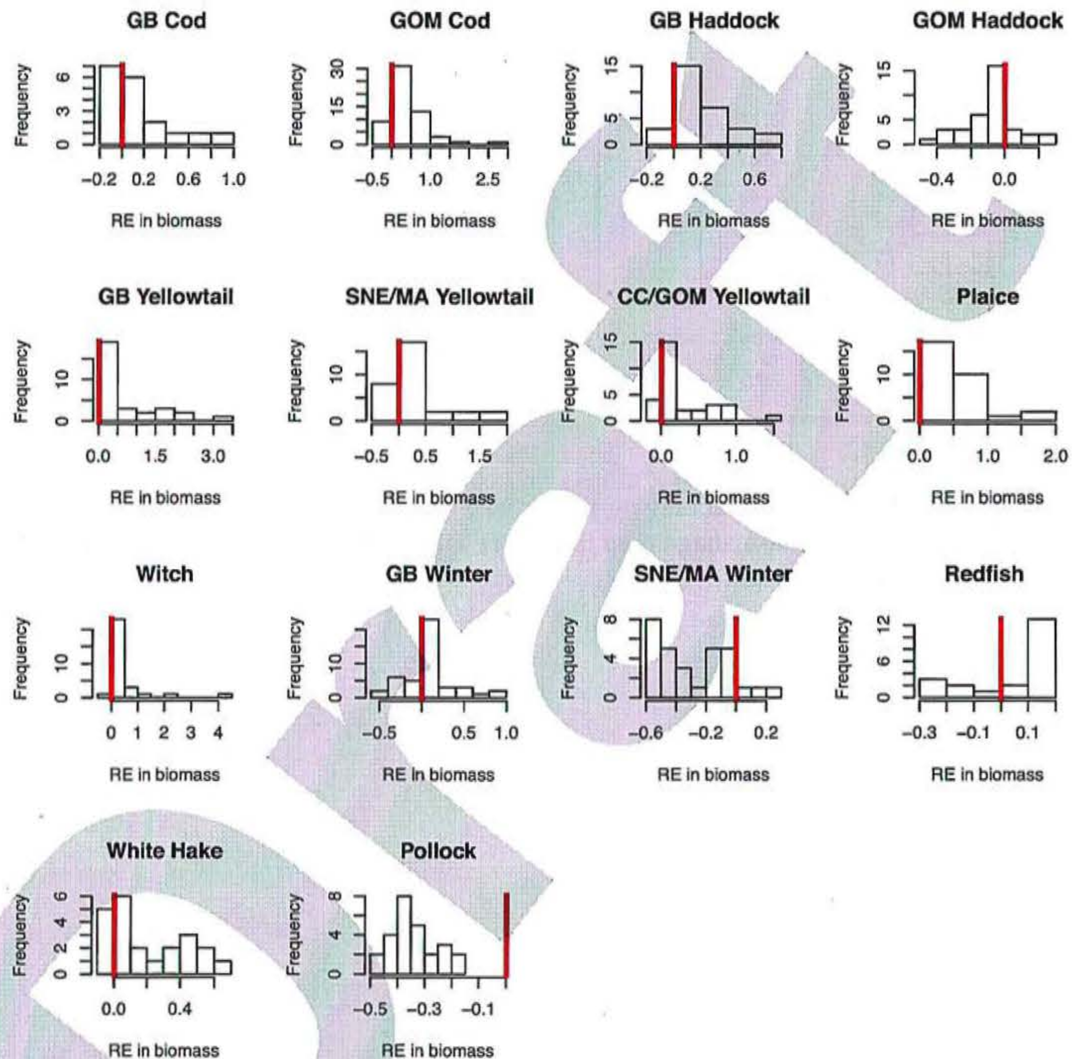


Figure 11. Estimates of relative error in assessment estimates of biomass from 1999 onward using the most recent assessment estimates as the reference. Positive values indicate historical assessment estimates were higher than the updated values. The red line at 0 is shown for reference.

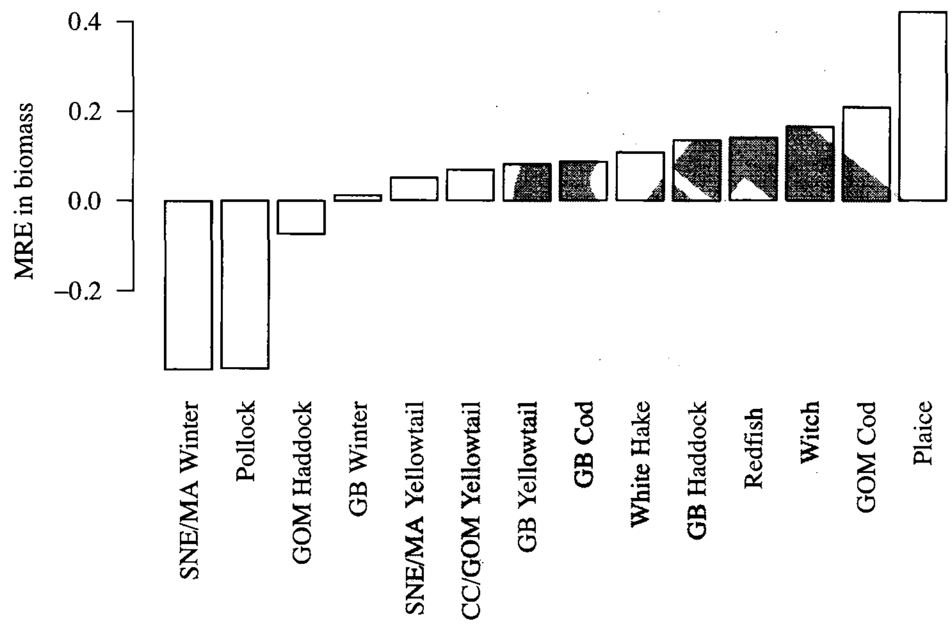


Figure 12. Median relative error (MRE) in biomass estimates from 1999 onward for stocks with two or more stock assessments that estimated biomass. Biomass estimates from the most recent assessment were used as the reference to calculate the relative error (equation 2).

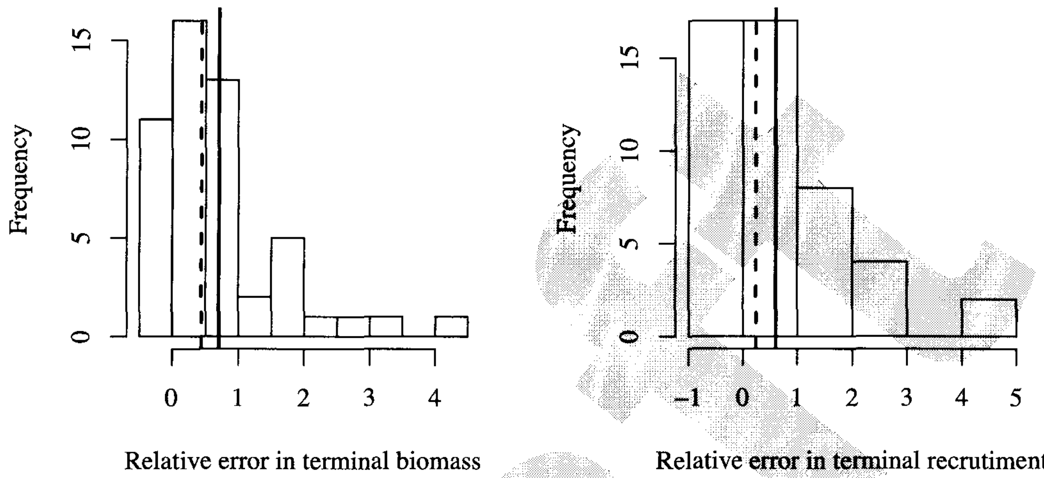


Figure 13. Histogram of the relative error in terminal biomass (left) and recruitment (right) aggregated across stocks and across assessments. The dashed and solid vertical lines represent the median and mean values, respectively. For biomass the median relative error is 0.37 and the mean is 0.66. For recruitment the median relative error is 0.24 and the mean is 0.6.

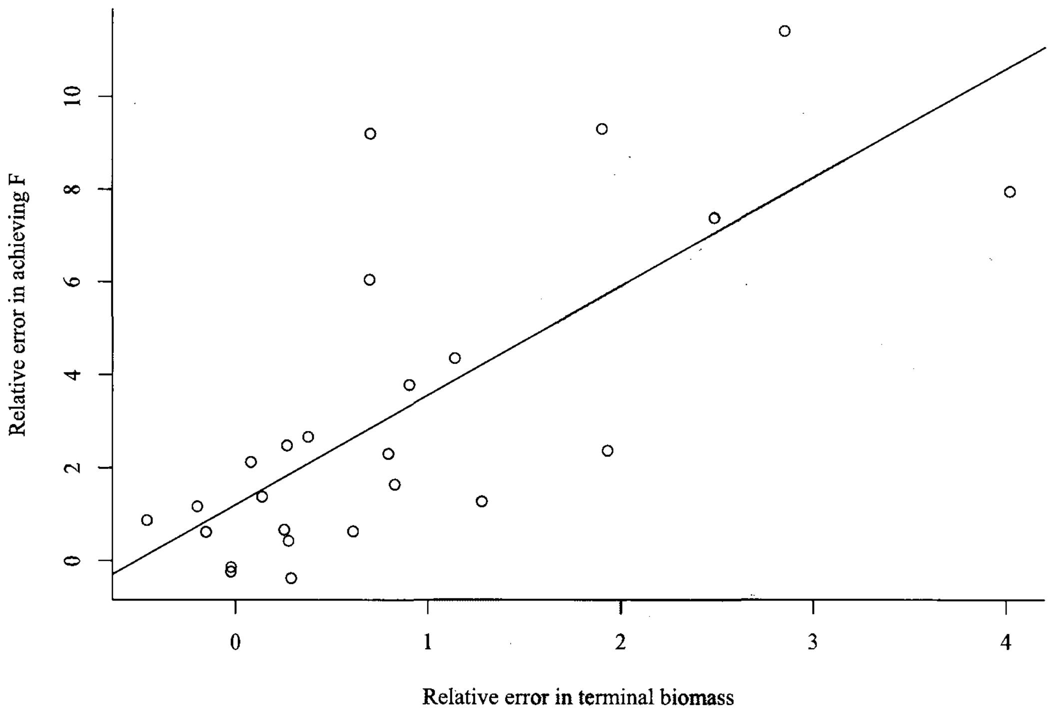


Figure 14. Mean relative error in achieving F (F_{error}; equation 1) as a function of the relative error in terminal biomass. Each point represent a terminal year from a biomass-based assessment for a given stock. The line represents the best linear fit ($y = 2.35x + 1.2$; $R^2 = 0.55$; $p<0.001$).

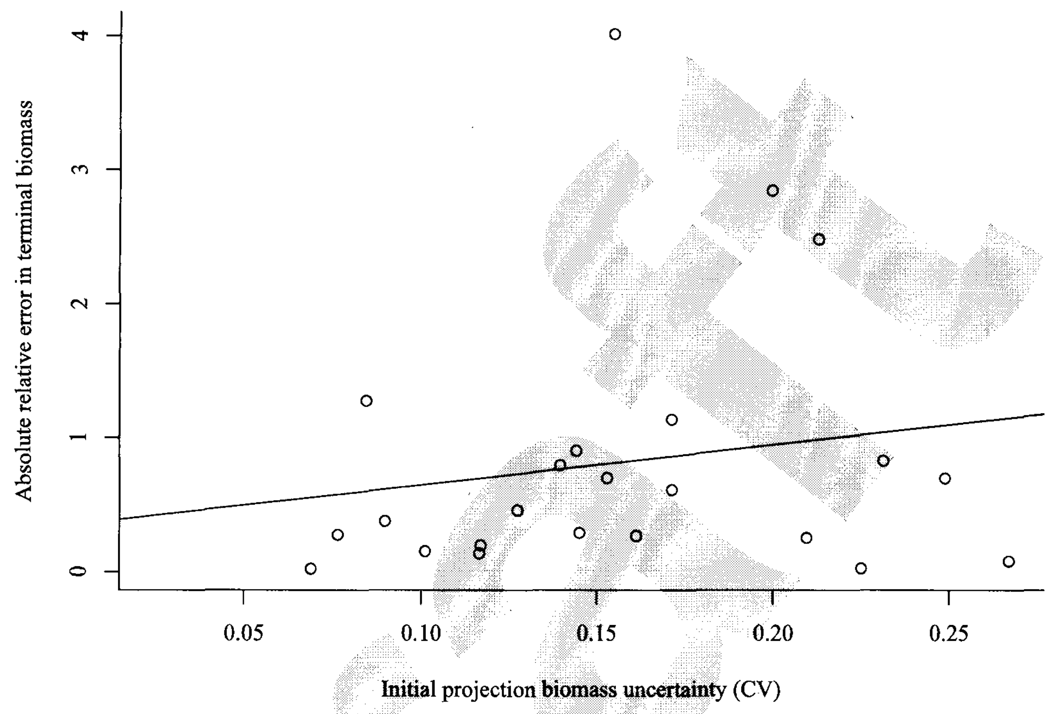


Figure 15. Absolute value of the relative error in terminal biomass from each assessment for a stock as a function of the uncertainty (CV) in the biomass in the first year of the projection model based on that assessment. We used the absolute value here because the CV is always positive, and wanted to determine if a high CV from an assessment reflected a greater chance of error (both positive and negative) in the assessment estimates. The line represents the best fitting linear model, ($y = 3x + 0.346$; $R^2 = 0.03$; $p = 0.43$).

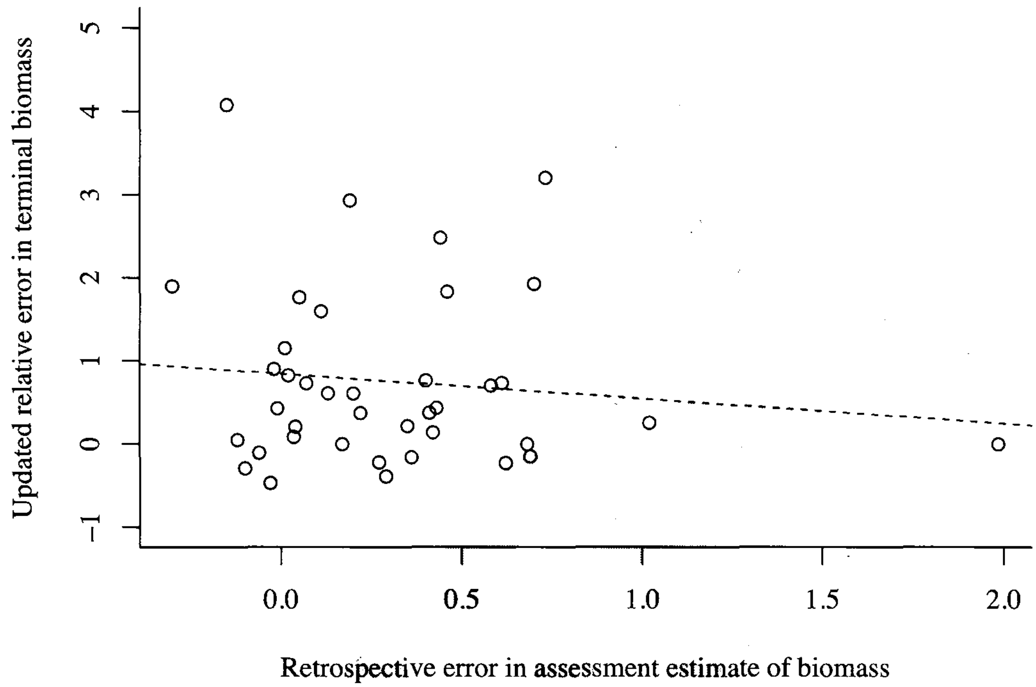


Figure 16. The relative error in terminal biomass estimates (calculated using the updated and historical assessment estimates) as a function of the estimated retrospective error (Mohn's ρ) from the stock assessment used to inform the catch advice. For example, the GARM 3 ρ for GOM cod was 0.19 (NEFSC 2008), while the estimated terminal biomass in 2007 was three times higher than the updated estimate for 2007 (NEFSC 2015). The line represents the best linear fit ($y = -0.3x + 0.84$; $R^2 = 0.01$; $p = 0.49$)

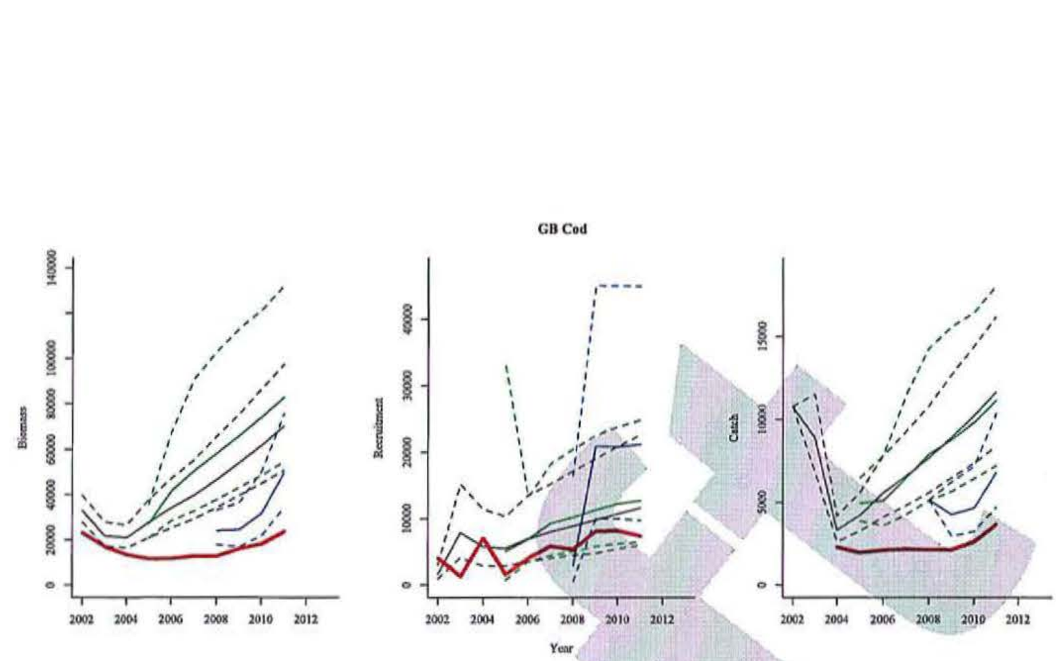


Figure 17. Projected spawning biomass (left), recruitment, and total catch for Georges Bank cod. Thin solid and dashed lines represent the median and 95% confidence intervals for each projection based on output from the GARM 1 (black), GARM 2 (green) and GARM 3 (blue) assessments. The thick solid red line represents the updated values from NEFSC (2013) for biomass and recruitment. The updated target catch was calculated using F_{target} each year and the updated biomass, fishery selectivity and catch weights.

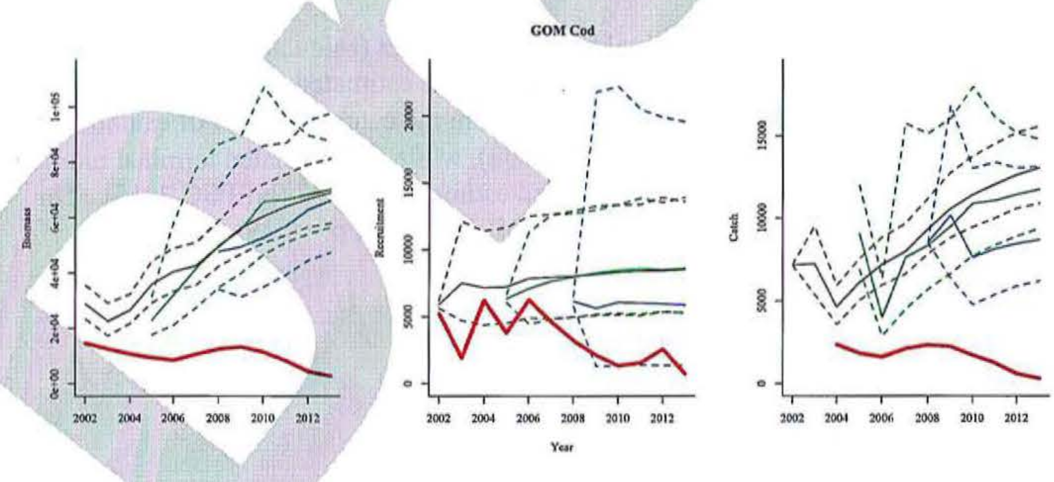


Figure 18. Projected spawning biomass (left), recruitment, and total catch for Georges Bank cod. Thin solid and dashed lines represent the median and 95% confidence intervals for each projection based on output from the GARM 1 (black), GARM 2 (green) and GARM 3 (blue) assessments. The thick solid red line represents the updated values for biomass and recruitment from Palmer (2014). The updated target catch was calculated using F_{target} each year and the updated biomass, fishery selectivity and catch weights.

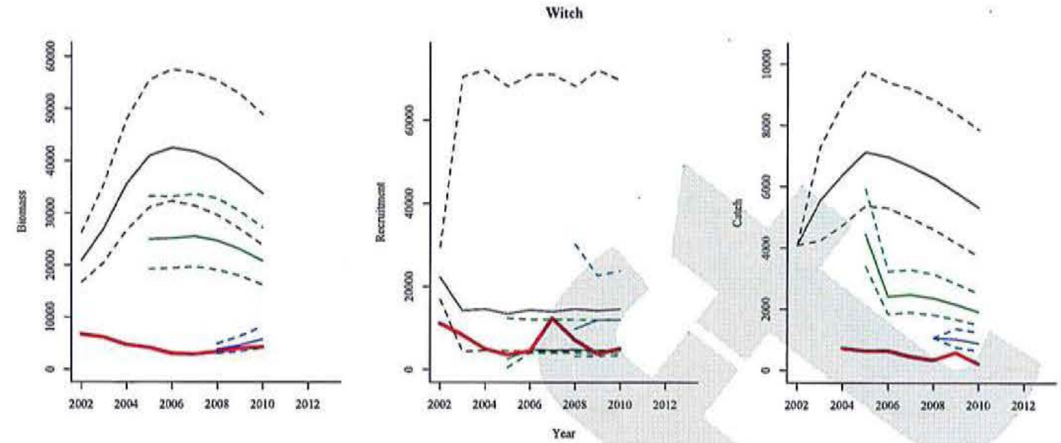


Figure 19. Projected spawning biomass (left), recruitment, and total catch for witch flounder. Thin solid and dashed lines represent the median and 95% confidence intervals for each projection based on output from the GARM 1 (black), GARM 2 (green) and GARM 3 (blue) assessments. The thick solid red line represents the updated values for biomass and recruitment from NEFSC (2012). The updated target catch was calculated using F_{target} each year and the updated biomass, fishery selectivity and catch weights.

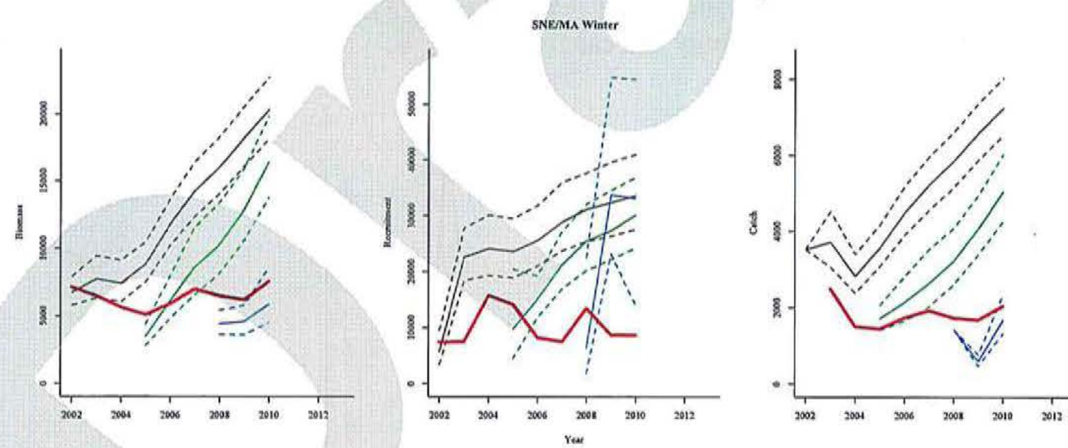


Figure 20. Projected spawning biomass (left), recruitment, and total catch for SNE/MA winter flounder. Thin solid and dashed lines represent the median and 95% confidence intervals for each projection based on output from the GARM 1 (black), GARM 2 (green) and GARM 3 (blue) assessments. The thick solid red line represents the updated values for biomass and recruitment from NEFSC (2011). The updated target catch was calculated using F_{target} each year and the updated biomass, fishery selectivity and catch weights.

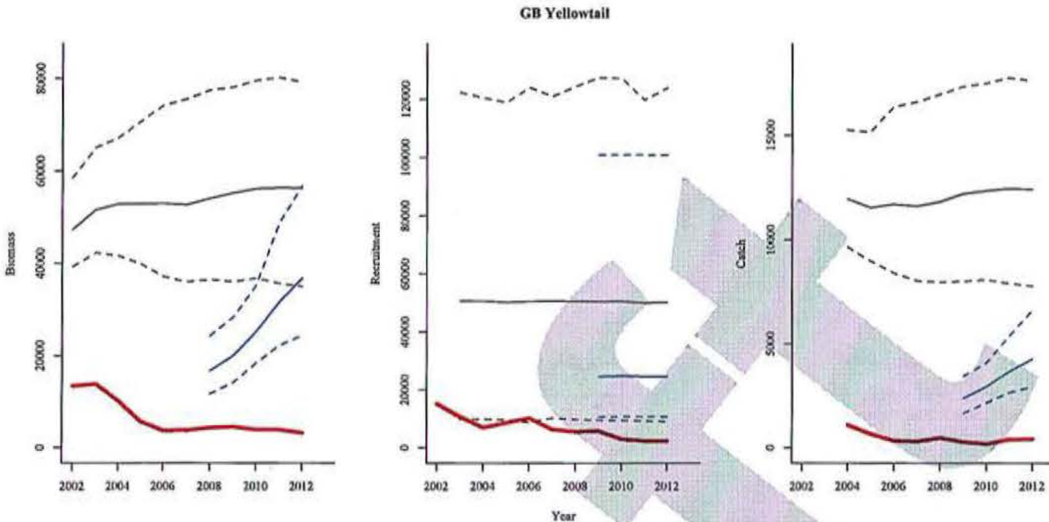


Figure 21. Projected spawning biomass (left), recruitment, and total catch for GB yellowtail flounder. Thin solid and dashed lines represent the median and 95% confidence intervals for each projection based on output from the GARM 1 (black) and GARM 3 (blue) assessments. Projection files were not available from the GARM 2 assessment and therefore projections were not done using GARM 2 estimates. The thick solid red line represents the updated values for biomass and recruitment from Legault et al. (2013). The updated target catch was calculated using F_{target} each year and the updated biomass, fishery selectivity and catch weights.

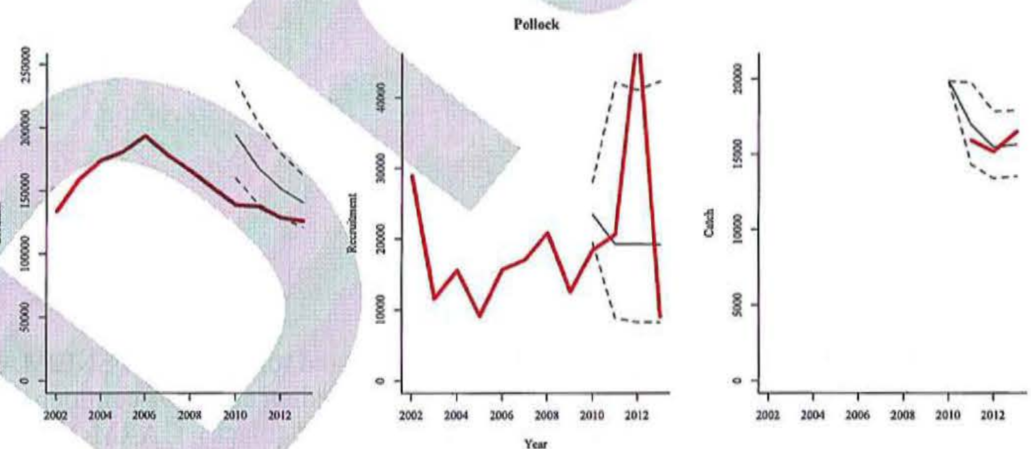


Figure 22. Projected spawning biomass (left), recruitment, and total catch for pollock. Thin solid and dashed lines represent the median and 95% confidence intervals for each projection based on output from the SAW 50 (black) assessments. The thick solid red line represents the updated values for biomass and recruitment. The updated target catch was calculated using F_{target} each year and the updated biomass, fishery selectivity and catch weights.

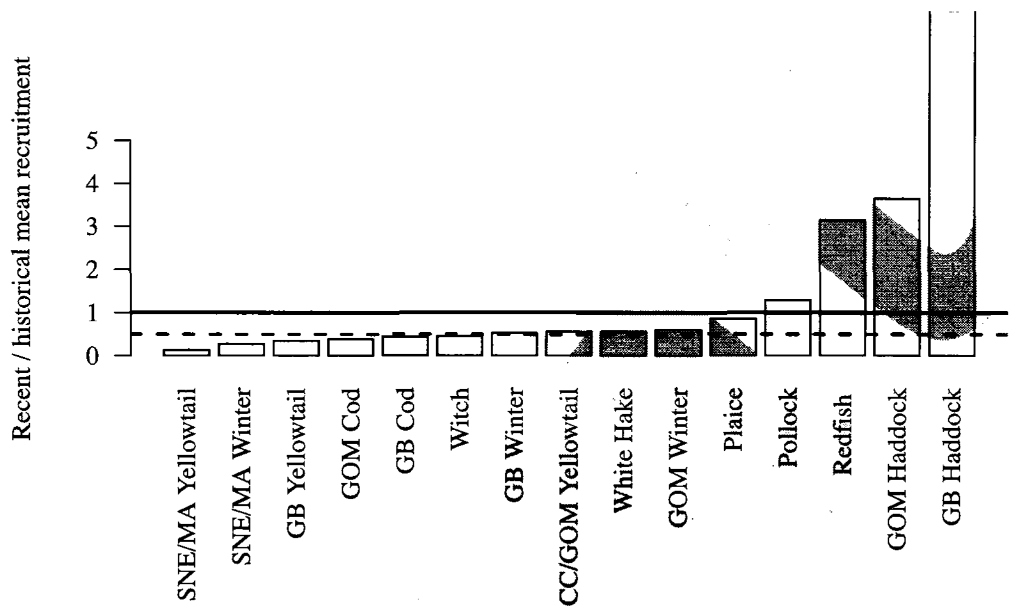


Figure 23. Ratio of the mean recent recruitment (2004 onward) to the mean historical recruitment (prior to 2004). Recruitment estimates are based on the most recent assessment for each stock. The solid and dashed lines represent values of 1 and 0.5, respectively. The ratio for GB haddock is > 20 due to a very large (and uncertain) estimate of terminal recruitment from the most recent.

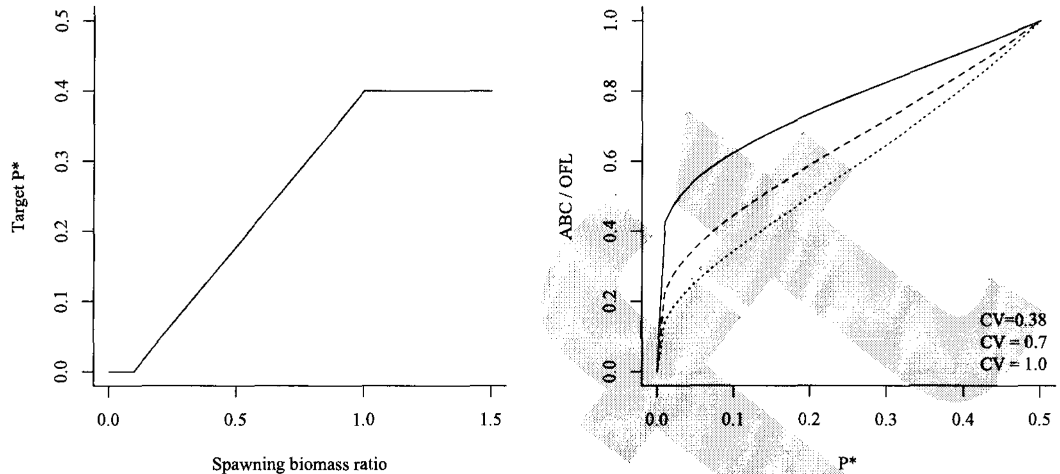


Figure 24. Left : Threshold-based P* control rule, where the target P* declines linearly as the estimated spawning biomass falls below the S_{MSY} level. Right: Buffer size (ABC / OFL) as a function of the target P* and the assumed CV of the distribution for the OFL.

Appendix A.

The New England ABC control rule specific in Amendment 16. The text below is verbatim from the Federal Register (2010):

> The mortality reductions used to design management measures implemented by this final rule are listed in Table 3. These mortality reductions were determined based upon the ABC control rule specified by the Council's Scientific and Statistical Committee (SSC) and the F necessary to rebuild overfished stocks within the rebuilding period ($F_{rebuild}$). The ABC control rule proposed by the SSC and established through this action replaces the MSY control rule that was added to the FMP by Amendment 13. The ABC control rule specifies that the ABC for each stock would be determined as the catch at 75 percent of F_{MSY}, and that, if the catch at 75 percent of F_{MSY} would not achieve the mandated rebuilding requirements, ABC would be based upon $F_{rebuild}$. For stocks that cannot be rebuilt within existing rebuilding periods, the ABC would be based upon incidental bycatch, including a reduction in the existing bycatch rate. Finally, for stocks with unknown status, ABC would be determined on a case-by case basis by the SSC. Table 3 lists the percentage change in F necessary to achieve the target F (either $F_{rebuild}$ or the catch at 75 percent of F_{MSY}), as appropriate, from F estimated for FY 2008. Mortality reductions for several stocks are not available because the assessments for these stocks did not produce reliable estimates of F that could be used in projection models to estimate $F_{rebuild}$.

Appendix B.

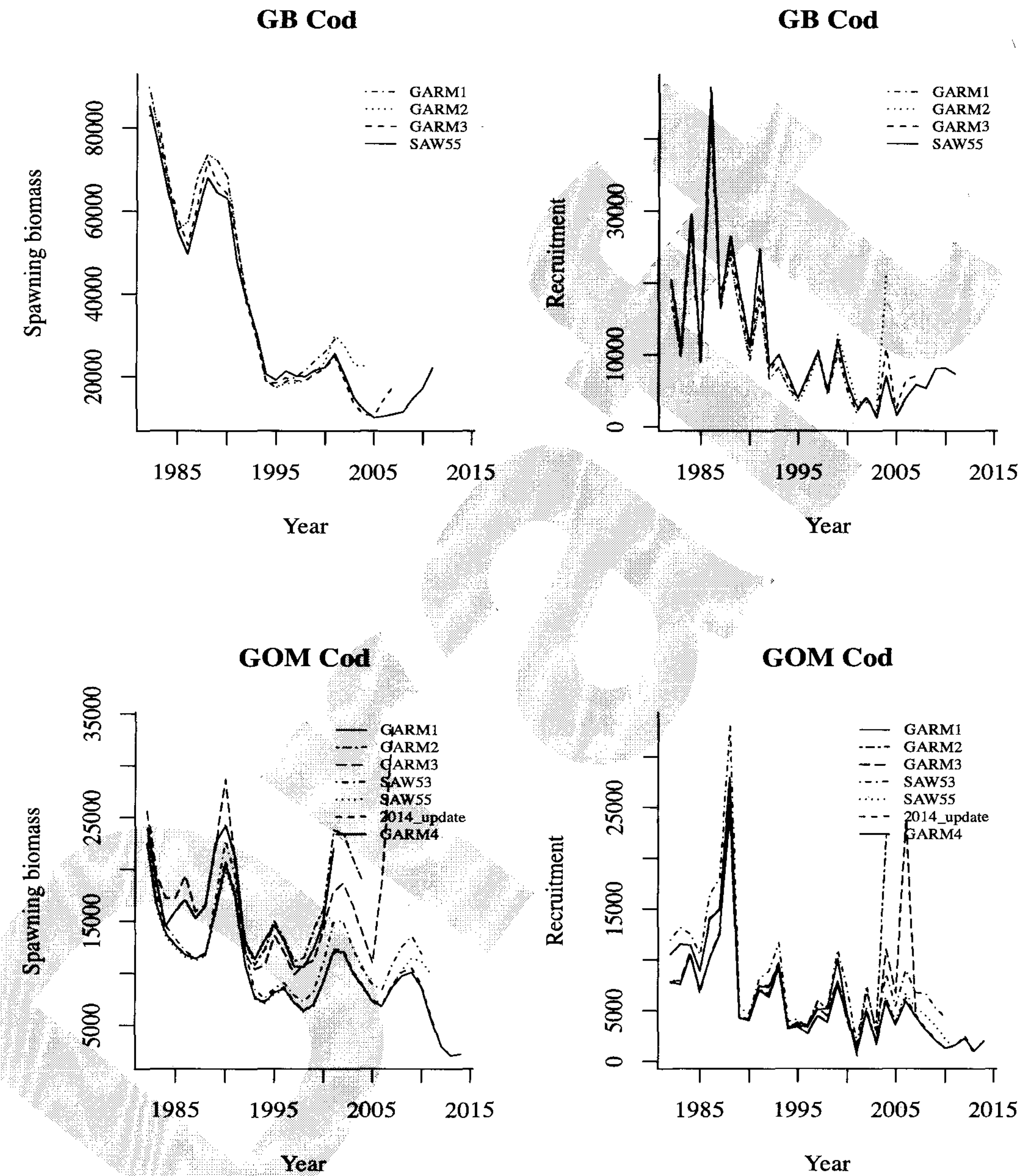


Figure B1. Estimated spawning biomass and recruitment across stock assessments for Georges Bank (GB) and Gulf of Maine (GOM) cod. The lines represent estimates from different assessments (see Table 3 for a complete list of assessments and appropriate citations).

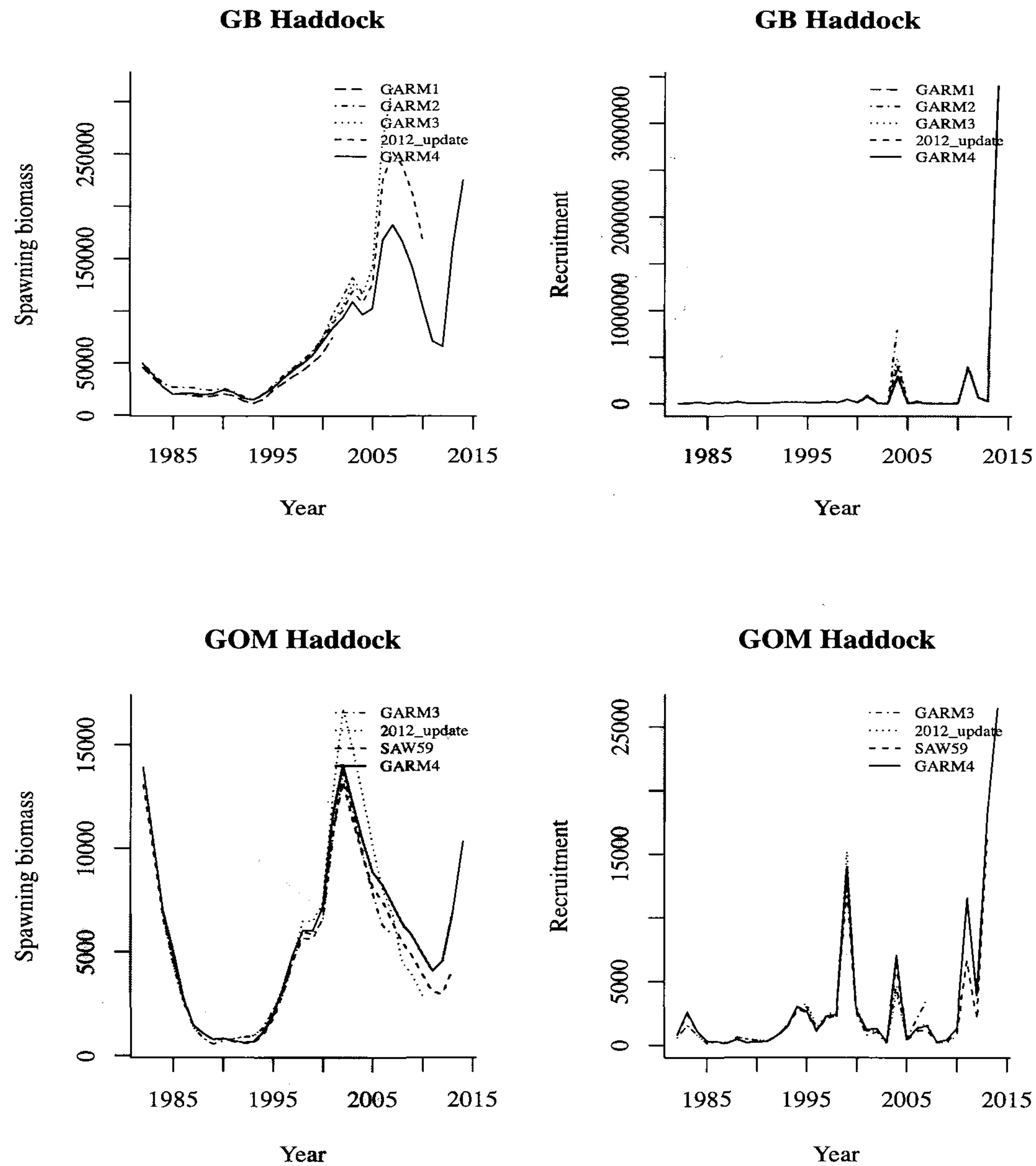


Figure B2. Estimated spawning biomass and recruitment across stock assessments for Georges Bank (GB) and Gulf of Maine (GOM) haddock. The lines represent estimates from different assessments (see Table 3 for a complete list of assessments and appropriate citations).

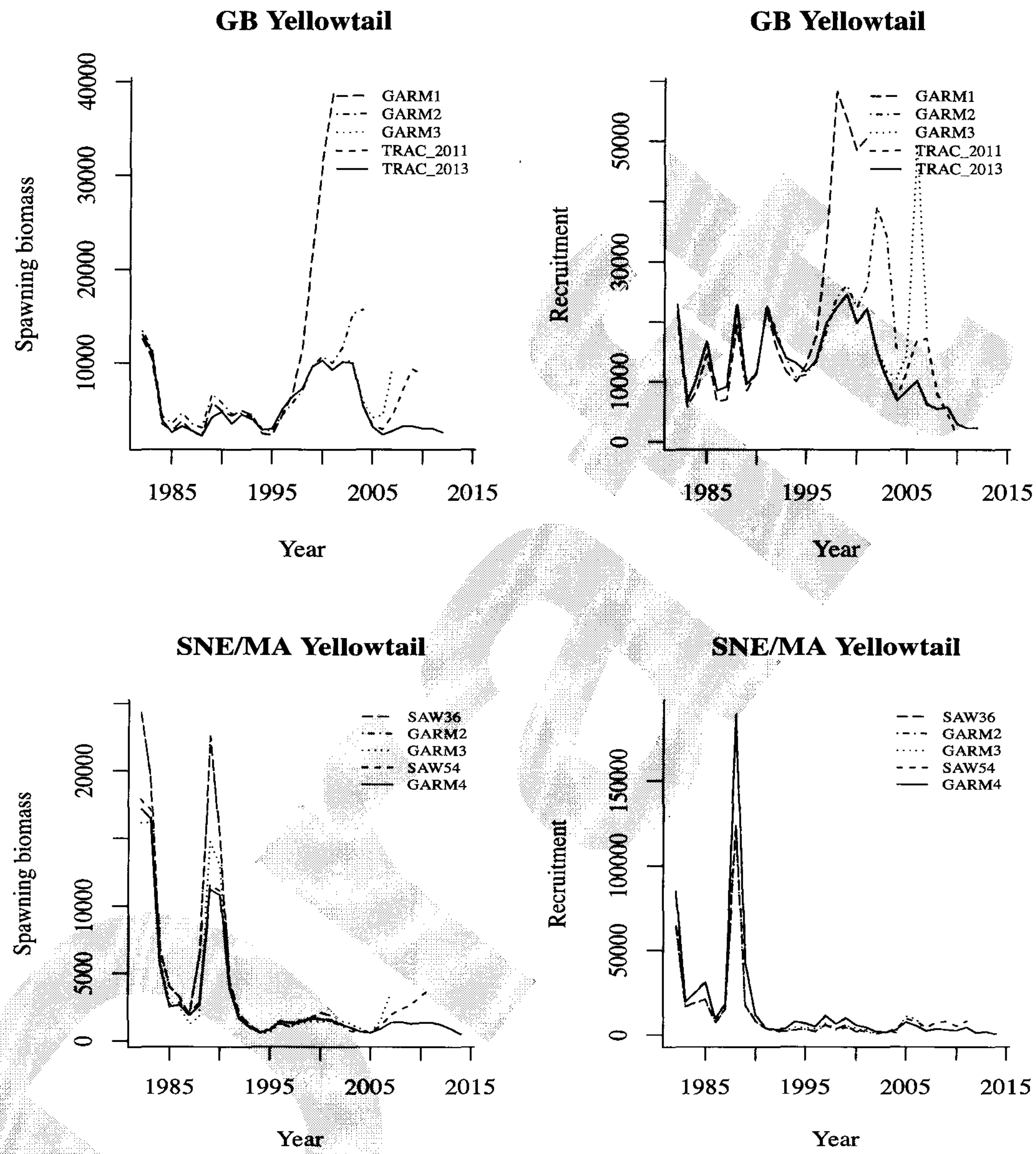


Figure B3. Estimated spawning biomass and recruitment across stock assessments for Georges Bank (GB) and Southern New England / Mid-Atlantic (SNEMA) yellowtail flounder. The lines represent estimates from different assessments (see Table 3 for a complete list of assessments and appropriate citations).

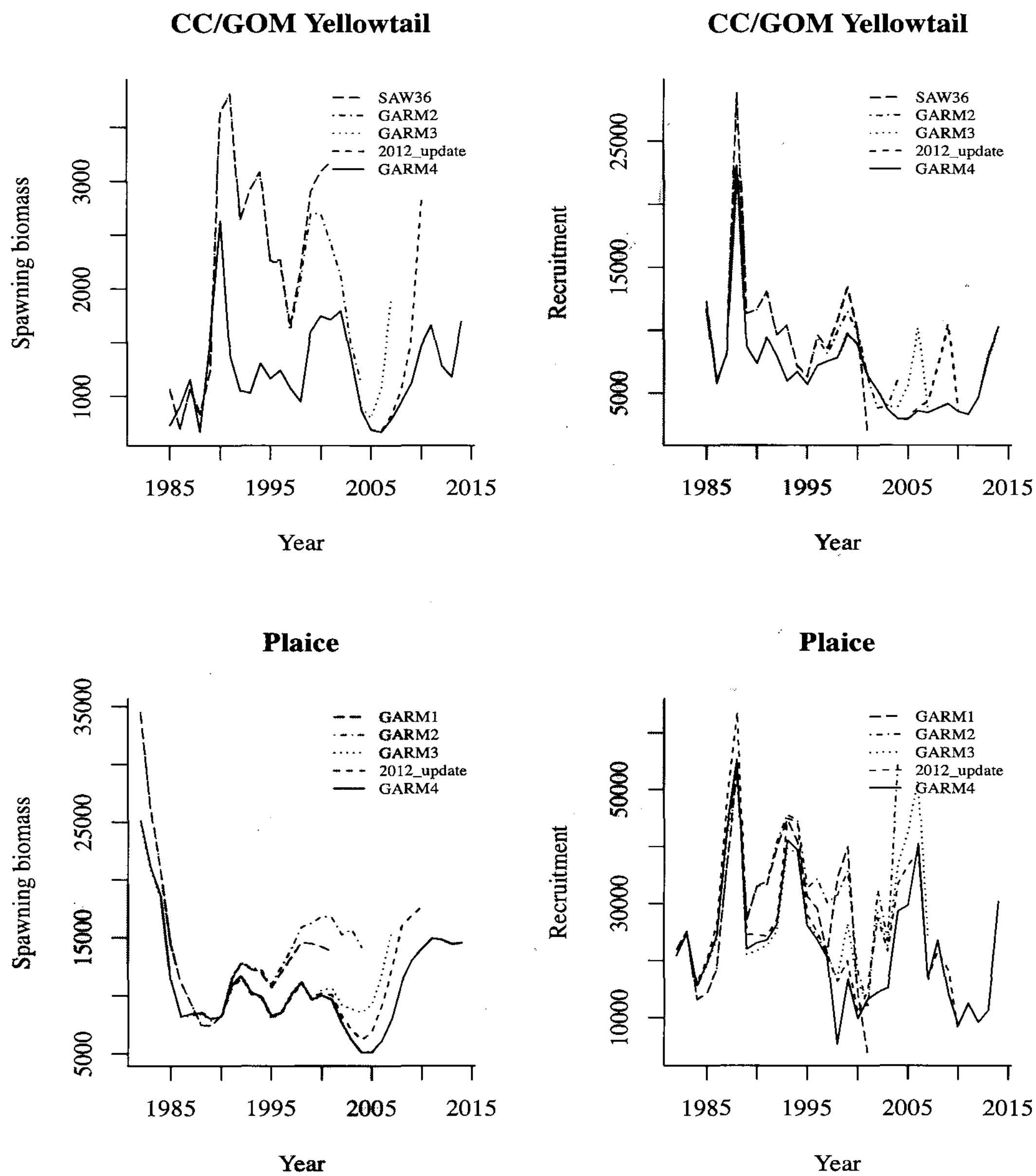


Figure B4. Estimated spawning biomass and recruitment across stock assessments for Caper Cod / Gulf of Maine (CC / GOM) yellowtail flounder and plaice. The lines represent estimates from different assessments (see Table 3 for a complete list of assessments and appropriate citations).

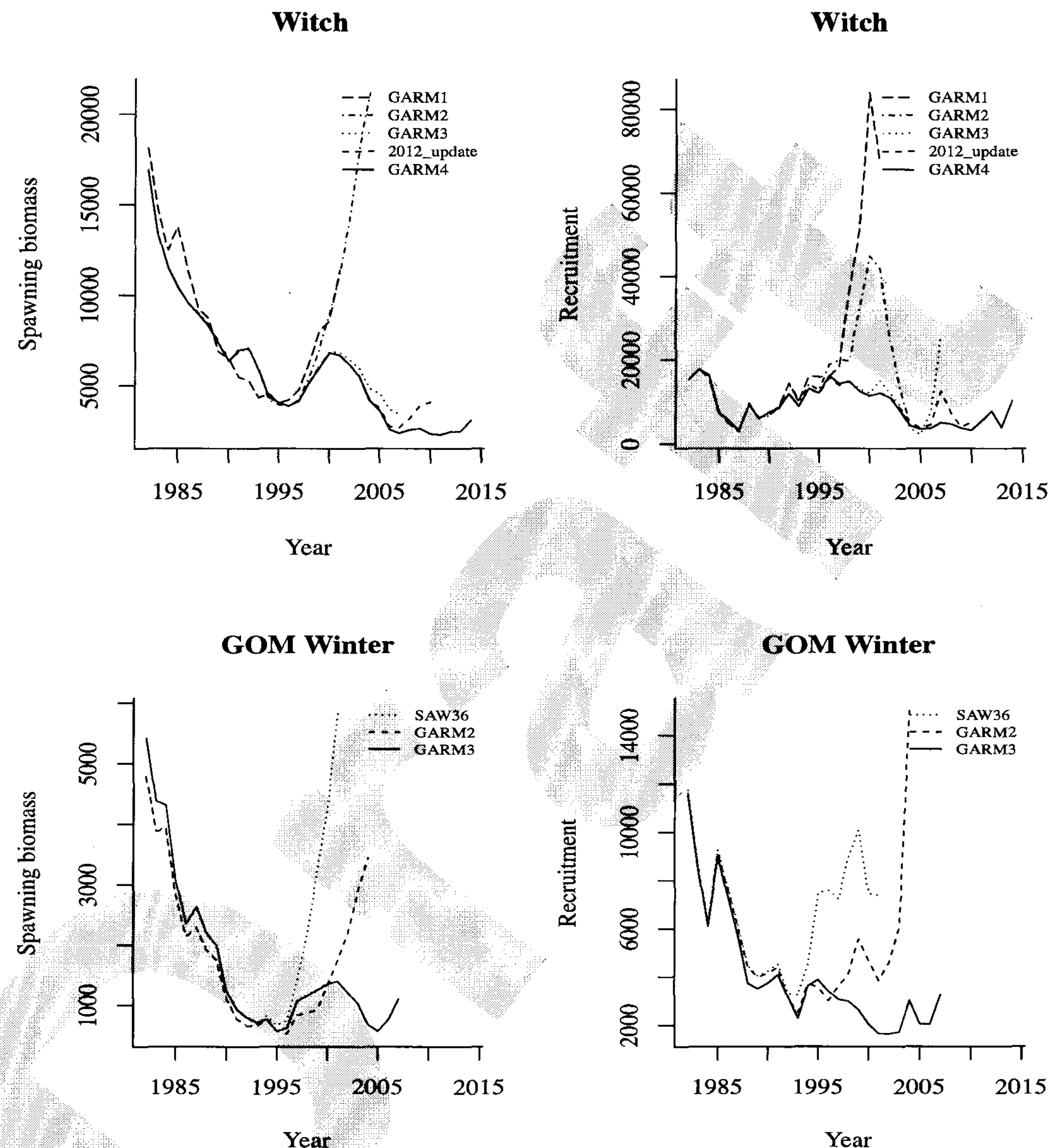


Figure B5. Estimated spawning biomass and recruitment across stock assessments for Gulf of Maine (GOM) winter flounder and with flounder. The lines represent estimates from different assessments (see Table 3 for a complete list of assessments and appropriate citations).

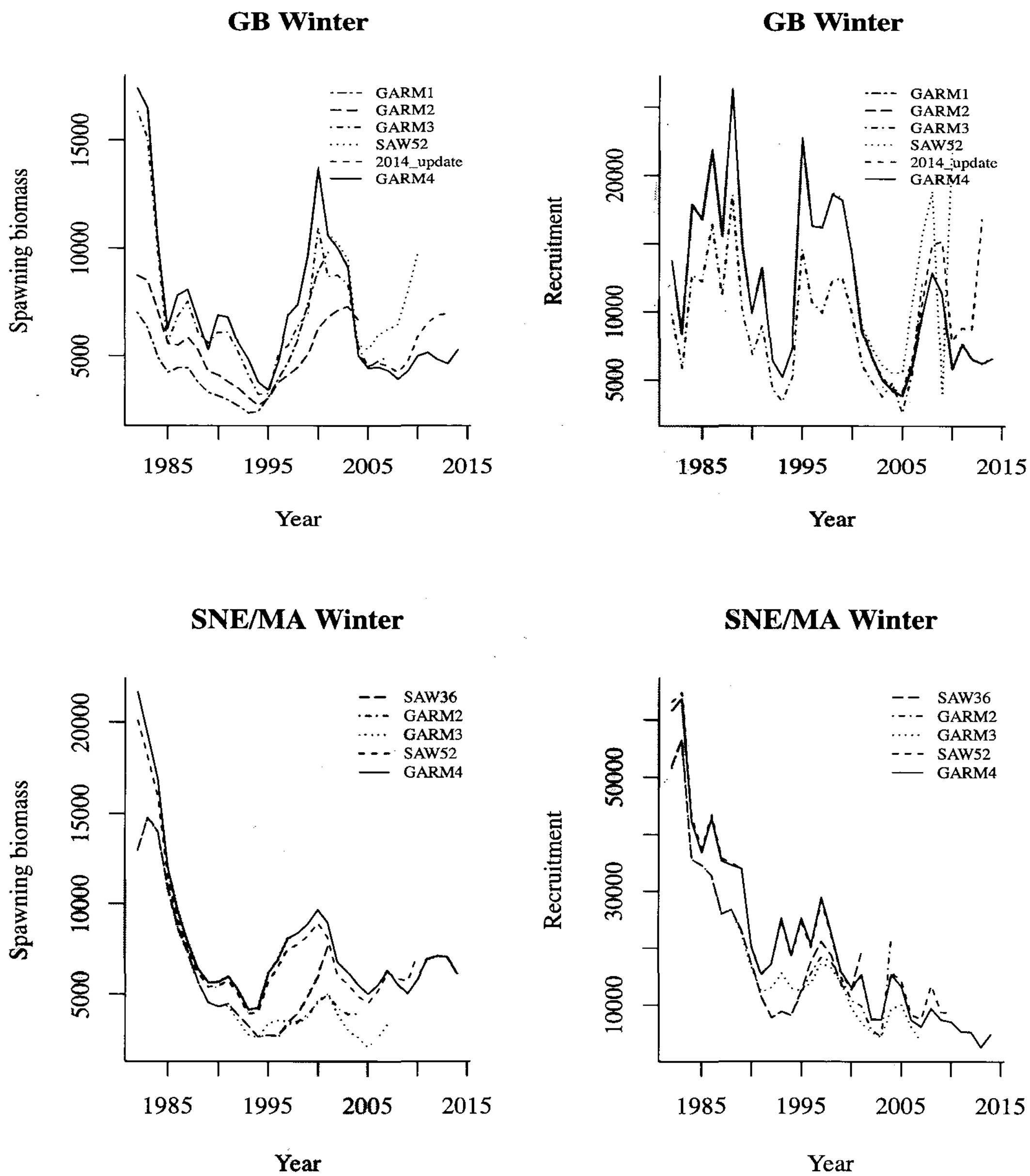


Figure B6. Estimated spawning biomass and recruitment across stock assessments for Georges Bank (GB) and Southern New England / Mid-Atlantic (SNEMA) winter flounder. For GB winter, the first two assessments (GARM 1 and 2) used production models, so the time series of estimates shown here is total biomass for these assessments. The remaining assessments estimates shown for GB winter are spawning biomass. The lines represent estimates from different assessments (see Table 3 for a complete list of assessments and appropriate citations).

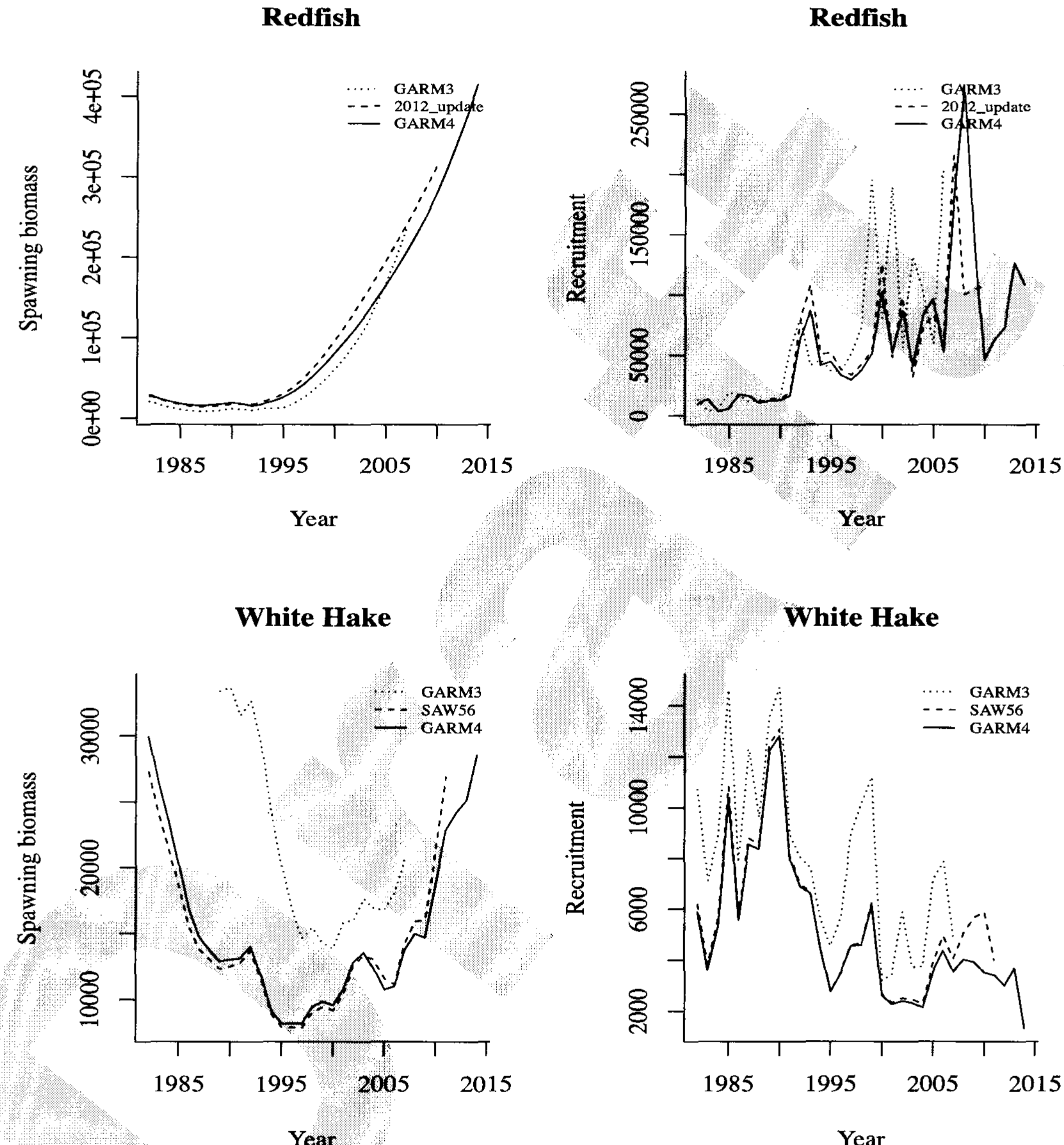
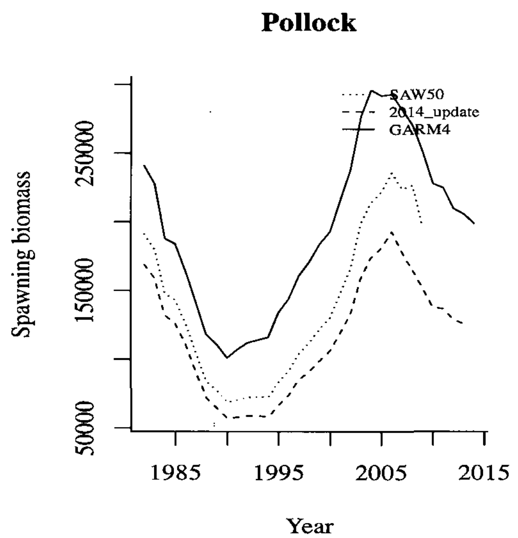


Figure B7. Estimated spawning biomass and recruitment across stock assessments for Acadian redfish and white hake. The lines represent estimates from different assessments (see Table 3 for a complete list of assessments and appropriate citations).



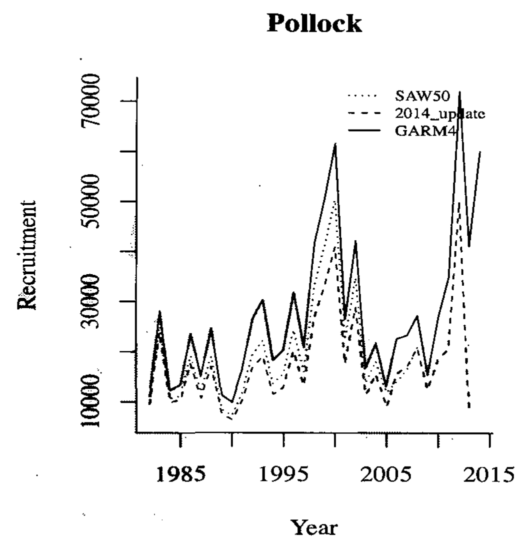


Figure B8. Estimated spawning biomass and recruitment across stock assessments for pollock. The lines represent estimates from different assessments (see Table 3 for a complete list of assessments and appropriate citations).

Table B1. Annual estimates of biomass, recruitment, and fishing mortality rates across stock assessments for New England groundfish conducted since 2002.