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Goals and strategies for rebuilding New England groundfish stocks

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Rebuilding depleted fishery resources is a world-wide problem. In the U.S., the Sustainable Fisheries Act requires that management measures should prevent overfishing and achieve B_{MSY} in order to produce optimum yields. However, translating this legal mandate into tangible goals and actions presents several technical challenges. In this paper, we describe our experiences with helping to quantify goals and evaluating strategies to rebuild New England groundfish stocks. Maximum sustainable yields and biomass reference points for chronically overfished stocks are poorly defined unless sufficient data are available from periods of low fishing mortality rates and relatively high stock size. The conundrum of how to set meaningful rebuilding goals given limited information on population dynamics and trophic interactions of a rebuilt stock can generally be addressed through adaptive management. Monitoring the pace of rebuilding relative to changes in life history parameters and recruitment is also important for a successful rebuilding strategy. Periodic re-evaluation of rebuilding targets is also needed to address uncertainties due to density dependence, trophic interactions or environmental factors.

Keywords: depleted fishery resources, reference points, adaptive management, rebuilding goals

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Introduction

Rebuilding depleted fishery resources is a world-wide problem. Overfishing, for example, has severely reduced abundances of many Atlantic cod (*Gadus morhua*) stocks across the North Atlantic ranging from the North Sea to Newfoundland southward to Georges Bank (Hutchings and Reynolds 2004). In the U.S., the Sustainable Fisheries Act (SFA, DOC 1996) requires that management measures should prevent overfishing to achieve optimum yields . However, translating this legal mandate into tangible goals and actions presents several technical challenges. One common problem is the lack of observations of stock dynamics at high biomasses due to persistent overfishing of stocks at low biomasses. Maximum sustainable yields and associated reference points (F_{MSY} and B_{MSY}) are difficult to directly estimate without knowledge of the stock recruitment relationship (see, for example, Mace 1994). However, this relationship is often uncertain due to a lack of contrast in stock-recruitment data. This is especially true for overfished stocks which lack observations of stock dynamics from periods of low fishing mortality rates and relatively high stock sizes that are generally needed to determine F_{MSY} and B_{MSY}. Changes in trophic dynamics, ecosystem structure, essential fish habitat, and oceanographic conditions can also present substantial challenges.

In this paper, we describe our experiences with helping to quantify goals and evaluating strategies to rebuild New England groundfish stocks. We begin by describing recent U.S. legislative mandates that require cessation of overfishing and rebuilding of depleted fishery resources in comparison to the ICES management system. The prevailing U.S. legal requirements for not exceeding a maximum allowable fishing mortality were used by environmental organizations in 1999 to file suit against the National Marine Fisheries Service (NMFS) to eliminate overfishing of New England groundfish. Revised biological reference points were also required to provide the best available scientific information as mandated by law. Amendment 13 (NEFMC 2003) to the groundfish management plan was developed to address the requirement to cease overfishing (U.S. District Court for the District of Columbia 2002). This plan, as implemented on May 1st, 2004, requires substantial reductions in fishing effort along with other measures to reduce overfishing. Case studies of two depleted New England groundfish stocks, Georges Bank haddock (*Melanogrammus aeglefinus*) and Southern New England yellowtail flounder (*Limanda ferruginea*), provide both an historic perspective and show how rebuilding plans have been designed. We conclude by describing how adaptive management can be used to set meaningful rebuilding goals given limited information on population dynamics and trophic interactions of a rebuilt stock. The necessary ingredients and potential impediments for successful stock recovery are also discussed.

Legislative mandates

The U.S. Sustainable Fisheries Act (DOC 1996) states that, "*Conservation and management measures shall prevent overfishing while achieving on a continuing basis, the optimum yield from each fishery for the United States fishing industry*." Overfishing is defined as "*a rate or level of fishing mortality that jeopardizes the capacity of a fishery to produce the maximum sustainable yield on a continuing basis*." If a resource is determined to be overfished, management action must be taken to rebuild the fish stock "*to a level consistent with producing maximum sustainable yield.*" The Act further requires that the rebuilding time period should not exceed ten years, with exceptions for situations where rebuilding within a decade is not biologically feasible. Guidelines to the Act specify that an "overfished" resource is one that has been depleted to a minimum stock size threshold (e.g., 50% of B_{MSY} for many stocks, NMFS 1998). A precise translation of this legal text into biological reference points for fisheries is "*MSY is the management strategy, F_{MSY} is the limit reference point, and B_{MSY} is the rebuilding target*."

In contrast to the U.S. management system, ICES fishery management advice is based on not exceeding "safe biological limits," typically specified as the stock size below which average recruitment is low (B_{lim}), and the target fishing mortality rate that is expected to maintain that stock size in the long-term (ACFM 2003). Despite the divergence in management strategies, both the U.S. and ICES frameworks relate to elements of the Precautionary Approach (FAO 1995), with the U.S. system emphasizing maximum sustainable yield strategies and the ICES system focusing on avoiding undesirable outcomes. A common goal of the two systems is the requirement to rebuild depleted stocks. One general advantage of the ICES system is that the rebuilding target (B_{pa}, a stock size greater than the limit biomass, B_{lim}, accounting for estimation uncertainty) has generally been observed in the series of stock size estimates, and stock dynamics are thus more predictable between B_{lim} and B_{pa}. Alternatively, one disadvantage is that B_{pa} may be too low to realize the full potential productivity of the resource if overfishing has been prevalent throughout the documented exploitation history of the stock. By comparison, many stocks in the northwest Atlantic have been overfished for several decades, and projections for rebuilding to B_{MSY} may involve extrapolation beyond the observed stock assessment data.

As a management strategy, limiting fishing mortality to less than F_{MSY} and rebuilding overfished stocks to B_{MSY} is highly desirable and has been successful for many U.S. fishery resources. However, the strategy imposes technical difficulties for estimating biomass reference points and developing rebuilding plans under required time frames. Experiences with New England groundfish and adaptive rebuilding plans illustrate how legislative mandates were met while considering these technical difficulties.

Management by lawsuit

The legislative mandate to stop overfishing allowed the Conservation Law Foundation (CLF) to sue NMFS in 1991 to cease overfishing on New England groundfish. This lawsuit led to Amendments 5 (NEFMC 1994) and 7 (NEFMC 1996) to the Northeast Multispecies Fishery Management Plan. As a direct result of this lawsuit, the New England Fishery Management Council (NEFMC), which has advisory authority to put forward fishery management measures for approval by NMFS, agreed to three large-scale area closures on Georges Bank and in Southern New England. The three areas closed were: Closed Area I, Closed Area II, and the Nantucket Lightship Closed Area (Figure 1). These areas were closed to all fishing gears that were capable of catching groundfishes, including otter trawls, gillnets, longlines, and dredges. In 1998, year-round closed areas were established in the Western Gulf of Maine and on Cashes

Ledge to reduce fishing mortality on Gulf of Maine cod. Individual vessels were allocated a baseline number of days at sea based on their recorded fishing history. Management measures from Amendments 5 and 7 were effective for some stocks like Georges Bank haddock (see below), but not for others. In particular, Atlantic cod stocks in the Gulf of Maine and Georges Bank continued to experience overfishing through the late-1990s.

The lack of progress in reducing fishing mortality on cod led the CLF and four other environmental organizations to sue NMFS again in 1999. In this lawsuit, the Plaintiffs asserted that NMFS was not in compliance with its legal mandate to cease overfishing (reduce F to or below F_{MSY}) on Atlantic cod and other groundfish stocks. The environmental organizations prevailed in this lawsuit. As a result, the U.S. District Court for the District of Columbia ordered NMFS and the NEFMC to complete Amendment 13 (NEFMC 2003, see below), a comprehensive plan to end overfishing on all New England groundfish stocks.

Revised biological reference points

The historical development of overfishing definitions for New England groundfish reflects changes in national standards as well as advances in technical methodology. Prior to the Sustainable Fisheries Act of 1996, New England groundfish were managed according to various overfishing definitions. Amendment 4 of the Northeast Multispecies Plan (1992) specified an overfishing definition as the fishing mortality rate that would produce 20% of unfished spawning biomass per recruit ($F_{20\%}$, see, for example, Goodyear (1993)) for most groundfish stocks. A national review recommended that minimum biomass thresholds be established and warned that some of the fishing mortality rate overfishing definitions specified in Amendment 4 were greater than F_{MSY} (Rosenberg et al. 1994). The next change occurred in 1996, when Amendment 7 (1996) specified $F_{0.1}$ as an overfishing reference point for all principal groundfish stocks and set spawning stock rebuilding targets for the main stocks. These first estimates of biomass rebuilding targets were specified as minimum spawning biomasses deemed necessary to avoid lower average recruitment (i.e., B_{lim}) rather than biomasses that would be necessary to generate the maximum sustainable yield (i.e., B_{MSY}). Passage of the SFA in 1996 would subsequently require the latter.

In 1997, the New England Fishery Management Council formed an Overfishing Definition Review Panel to recommend biological reference points for consideration as overfishing definitions in conformance with the SFA (Applegate et al. 1998). The Panel reviewed existing reference point estimates, analyzed biomass dynamics, and recommended MSY reference points or proxies for all northeast groundfish stocks. The Panel used three basic methods to derive MSY reference points or their proxies for the groundfish stocks: 1) biomass dynamics models; 2) dynamic pool models (i.e., $F_{MSY} = F_{0.1}$ or $F_{20\%}$, and B_{MSY} is a function of average recruitment); and 3) survey proxies of biomass and exploitation ratios from periods presumed to produce relatively large sustainable yields where estimates of absolute population size were not available. Estimates of B_{MSY} for nearly all stocks were similar to biomass estimates or survey indices observed in the 1960s, due in part to the model configurations employed. For the principal groundfish stocks, estimates of B_{MSY} were substantially greater than the Amendment 7 rebuilding targets. Although MSY reference points for most of these stocks were updated through peer reviews (e.g., the Northeast Stock Assessment Workshop or the Transboundary Resources Assessment Committee) from 1998 to 2000, the methodology for estimation was not revised during this period.

The NEFMC formed the Groundfish Overfishing Definition Committee in 2000 to address concerns about MSY reference points, including the reliability of biomass dynamics models for deriving overfishing definitions. The Committee concluded that many of the production models for groundfish stocks need to be updated with more comprehensive approaches. With respect to production modeling, the Committee concluded that age-based production models should be applied to many groundfish stocks, because age-based information is available for many, stocks may be far from equilibrium, and that predictions from age-based models for the purposes of estimating rebuilding schedules were likely better accomplished through techniques that could incorporate recruitment dynamics explicitly. For most of the stocks assessed with age-based stock assessment models (e.g. VPA) the biomass and fishing mortality (F) reference points were determined in weight-based units using the surplus production model ASPIC (Prager 1994). This created some difficulties and confusion regarding the interpretation of annual status of resources, and in projecting stock performance under mandated recovery plans. For example, the fishing mortality rate reference points (F_{MSY}) estimated in ASPIC are biomass weighted, meaning that they assume the full force of mortality over all age groups included in the tuning indices and catches. This is as opposed to a typical age-based assessment that estimates the partial recruitment (selectivity) at age and monitors the fishing mortality rate averaged over just the age groups determined to be fully-represented in the catch. When large but partially recruited year classes enter the fishery, the biomass-weighted fishing mortality rate may change in relation to the dominance of these partially selected fish, which cannot be determined independently in the assessment method. Thus, assessment scientists have had to convert fully-recruited fishing mortality into biomass-weighted fishing mortality rates in order to provide advice on the annual fishing mortality rates in relation to F_{MSY}. This problem is described in more detail in the methods development section of NEFSC (2002).

A second issue related to the previous reference points is the tendency of surplus production methods to estimate MSY and Bmsy within the observed ranges of the data, irrespective of the exploitation histories of the various resources. Many of the fishery resources of the Northeast region have been heavily exploited and overfished (both growth- and in some cases recruitment-overfished), for decades. For example, Georges Bank haddock were overfished with significant discards of young fish beginning in the 1910s (Herrington 1932; Clark et al. 1982). Landings data representing the 70 year documented exploitation history probably do not represent the true production potential of this and other resources, because of the high fishing mortality rates and undesirable retention of small haddock (e.g., mesh sizes have steadily increased in the past two decades to reduce discards). Thus, if production models estimate B_{MSY} as some average or quantile of the biomass time series, this estimate may under-represent the real biomass potential of a well-managed stock, thereby setting the target biomasses and the expectations of managers at perhaps too modest a level.

Several other issues also prompted interest in re-estimation of the reference points for these and other resources. The National Research Council's reports on *Improving Stock Assessments* (National Research Council 1998a) and its *Review of Northeast Fishery Stock Assessments* (National Research Council 1998b) both emphasized that when estimating management parameters, a wide array of candidate models and approaches should be evaluated, so as to improve understanding of the processes involved and to allow for corroboration of approaches.

The Working Group on Re-Evaluation of Biological Reference Points for New England Groundfish was created in 2002 to address the need for a re-evaluation of biological reference points for the New England groundfish complex (NEFSC 2002). This Working Group adopted many of the above recommendations for completing its terms of reference. Therefore, age-based production models were developed for stocks with time series of age-structured assessment information. These were reviewed by the Working Group as candidate methods for estimating MSY reference points. The Working Group agreed that the approach used to estimate current population abundance and fishing mortality rates should be similar to that used to estimate biological reference points. A range of models was then evaluated for setting the new biological reference points.

Both parametric and empirical non-parametric approaches to age-based production analyses were employed to derive F_{MSY} and B_{MSY} or their proxies, and to conduct projections for evaluating rebuilding plans if required. The two approaches were applied to each stock (where appropriate) so as to be potentially complementary and supportive and because using both should build confidence in the results. Rote, objective application of these techniques is often compromised by lack of sufficient observation on stock and recruitment over a range of biomass to provide suitable contrast. Thus it is often necessary to extrapolate beyond the range of observation and to infer the shape of the stock recruit relationship, within the range of observation, from limited and highly variable data.

Basic life history and fishery information often allow better estimation of a target fishing mortality rate than B_{MSY}, which requires estimation of recruitment (R) at high spawning stock biomass (SSB). The use of $F_{40\%}$ as a proxy for F_{MSY} is likely to maintain adequate spawning potential for most primary New England groundfish based on the results of Clark (1993) and Mace (1994). This choice represents a more conservative spawning potential ratio than recommended by Clark (1991), and is consistent with the analyses of Thompson (1993) who suggested that fishing mortality rates be set no greater than $F_{30\%}$ and with the review of spawning-per-recruit requirements by Mace and Sissenwine (1993), who found that, on average, stocks require threshold spawning potential ratio values of at least 31% for sustainability. Overall, these results suggest that an F_{MSY} proxy of $F_{35\%}$ may be too high to sustain stocks in the long term. Based on the results of Dorn (2002), $F_{40\%}$ appears to be too aggressive a harvest rate for long-lived West Coast *Sebastes* spp., and therefore the use of $F_{50\%}$ as a proxy for F_{MSY} is considered to be appropriate for Acadian redfish (*Sebastes fasciatus*). For stocks that have been consistently growth overfished, if the estimate of F_{MSY} is substantially greater than F_{MAX} or $F_{40\%}$, the basis of this estimate needs to be closely examined for possible model mis-specification.

The general approach of the empirical non-parametric method is to evaluate various statistical moments of the observed series of recruitment data and to apply the estimated biomass per recruit associated with common F reference points to derive the implied spawning stocks and equilibrium yields. Hindcasting recruitment for years prior to the beginning of the age structured assessment was accomplished using survey information and estimated catchabilities. These hindcast recruitments were often larger than the recruitment estimates from the assessment due to the decline in stock abundance from overfishing. The expected value of the recruitment series (E[R]) was multiplied by the biomass per recruit (BPR) at $F_{0.1}$ and $F_{40\%}$ to give point estimates of the associated spawning biomasses. Several types E[R] times BPR analyses were undertaken, depending on the shape of the relationship between stock and recruitment. For cases where recruitment appears to be impaired at lower biomass, the average recruitment at a higher biomass stanza is evaluated as the proxy for recruitment at MSY, otherwise the average recruitment over all observations was used. The B_{MSY} proxy is calculated from the spawning biomass per recruit at $F_{40\%}$ and the proxy for recruitment at MSY. This assumes that compensatory mechanisms such as impaired growth or maturity schedules or reduced recruit survival are negligible over the range of expected biomass considered. All of these parameters can be monitored, consistent with the recommended adaptive approach to increasing stock biomass.

The parametric model approach uses a fitted stock-recruitment relationship along with yield and spawning biomass per recruit information to calculate MSY-based references points using a standard algorithm (NEFSC 2002). A key difference between the nonparametric proxy and the parametric approach is that the latter approach produces a direct estimate of F_{MSY} in contrast to using an assumed proxy value (e.g., $F_{40\%}$). A key similarity between the nonparametric proxy and the parametric approach is that both use yield and spawning biomass per recruit analyses to determine MSY and B_{MSY} values. Both Beverton-Holt and Ricker type stock-recruitment relationships were considered. Autoregressive and independent error structures were allowed. Priors were used for steepness or slope at the origin of the stock-recruitment relationship as well as for asymptotic recruitment. All combinations of models were fit to the stock-recruitment observations and the best fitting model selected based on Akaike's Information Criterion.

Projections to evaluate rebuilding plans incorporate uncertainty in the current population estimate (either bootstrap replicates or suitable variance simulation) and stochasticity in predicted recruitment. Recruitment stochasticity is accommodated by either resampling from observed recruitment, recruits per SSB or their cumulative distribution functions. The stock-recruitment model used in projecting rebuilding times was consistent with that used for estimating reference points. However, short-term projections sometimes used a different stock-recruitment model to reflect recent recruitment observations.

Application of the non-parametric and parametric approaches to the 19 groundfish stocks resulted in some significant changes in biological reference points, particularly with respect to the biomass targets. For example, the Georges Bank haddock B_{MSY} estimate increased from 105,000 mt to 250,300 mt, while the F_{MSY} remained at 0.26. The Working Group recognized that setting biomass targets to levels not seen in decades, or in fact outside of the maximum levels estimated in modern fishery monitoring systems, is a difficult proposition for managers, fishermen and the public. In cases where the Working Group recommended such targets, they are based on observed recruitment histories and biomass per recruit that should be realized if fisheries are managed to their F targets. Yield and biomass per recruit models are simple and robust and relatively high confidence can be placed in their results. Improving biomasses should result in higher and more stable recruitments and larger fishery catches, in the long-term. In several examples where reference biomasses have been set at high levels relative to recent history, fishery yields and catch rates have increased steadily and significantly when fishing mortality rates were reduced to appropriate levels (e.g. sea scallop (*Placopecten magellanicus*) and summer flounder (*Paralichthys dentatus*)). An adaptive approach to understanding the limits of groundfish stock productivity at higher biomasses was also recommended.

Developing a plan to rebuild New England groundfish: Amendment 13

In December 2001, the U.S. District Court for the District of Columbia ruled that NMFS was not in compliance with SFA requirements to institute fishery management plans to cease overfishing on New England groundfish stocks. Given the differences in some of the estimated reference points as a result of the Working Group recommendations, there was ongoing debate over the scientific basis of the rebuilding targets and time frames. The increases in B_{MSY} targets for Georges Bank cod, haddock, yellowtail flounder, Gulf of Maine cod, and Southern New England yellowtail flounder were at the heart of the controversy. Changes in fishing mortality reference points were not generally controversial. Instead, the issue was what biomasses would exist if the stocks were fished at $F_{MSY.}$ During the 1980s, the NEFMC considered the “target” overfishing rate of $F_{20\%}$ to be sufficient for maintaining stock productivity. Many groundfish stocks were fished in excess of $F_{20\%}$ and it was considered reasonable that a reduction in F to $F_{20\%}$ would improve stock condition. In contrast, the revised biological reference points were based on an $F_{40\%}$ proxy for FMSY. The adoption of $F_{40\%}$ as an F_{MSY} proxy along with the use of the empirical non-parametric method to estimate B_{MSY} (see Revised biological reference points) substantially increased the biomass targets for Georges Bank haddock and yellowtail flounder and for Southern New England yellowtail flounder (see Case study below). The industry charged that scientists were “*moving the goal posts*” for stock rebuilding. This generated uncertainty in the management process and ongoing debate.

As the Court ordered deadline for completion of Amendment 13 approached, there were numerous proposals to alter the process. One proposal was to use the highest 3-year average biomasses of groundfish stocks projected from survey data as an alternative set of rebuilding targets. While these calculations showed that the projected biomasses would be comparable to the targets put forward by the Working Group (NEFSC 2002), there was a logical inconsistency in this approach. In particular, the biomass targets needed to be consistent with the fishing mortality target to produce MSY. The survey-based values were not logically linked to the $F_{40\%}$ limit and as a result, were rejected as having no scientific standing. An independent panel of stock assessment experts, the Groundfish Peer Review Panel, addressed the question of whether the best estimates of reference points were adequate. The Panel concluded that they were, insofar as the $F_{40\%}$ target was judged to be adequate and the B_{MSY} targets were recognized to be uncertain.

Another question arose over the time frame of 10 years required by law to rebuild groundfish stocks to their target biomasses. Several stocks were projected to be incapable of rebuilding in a 10-year time frame. As a result, a little-used provision in the National Standard Guidelines came into play. Stocks that are projected to have a less than 50% probability of rebuilding within 10 years at a fishing mortality of 0 receive an extended rebuilding time frame. This extended time frame was equal to the number of years needed to rebuild with 50% probability at F=0 plus one mean generation time. This provision was invoked for three severely depleted stocks: Georges Bank cod, Cape Cod/Gulf of Maine yellowtail flounder and Acadian redfish (*Sebastes fasciatus*). Further debate ensued over the time frame for stock rebuilding. Did the rebuilding time frame start when the lawsuit was filed, implying the time frame was 1999-2009, or would the clock start when Amendment 13 was implemented in 2004? This debate was settled in favor of a 2004 start for rebuilding plans so that stocks were to be rebuilt by 2014, except for the three severely depleted stocks.

In late-autumn of 2003, the final draft of Amendment 13 was almost complete. At this point in time two last minute changes were made to the proposed Amendment based on an industry-sponsored initiative. In the first, a different interpretation of what an MSY control rule meant was put forward. The prevailing interpretation of an MSY control rule, as described in the NMFS National Standard Guidelines, suggested that fishing mortality could not exceed F_{MSY}, the overfishing limit, at any time. An alternative interpretation of an MSY control rule was that such a rule was a specific plan to achieve MSY in a fixed time frame. Under the alternative interpretation, F_{MSY} could be exceeded in the initial part of a rebuilding time frame as long as B_{MSY} was achieved by the end of the time frame. Using this alternative interpretation, the NEFMC developed phased fishing mortality reduction strategies for several stocks, including Southern New England yellowtail flounder. For this stock, roughly a 60% reduction in fishing effort would have been needed to immediately reduce F to F_{MSY}.

After over two and a half years of development, implementation of Amendment 13 began on May 1st, 2004. Some of the major components of the final plan were: continuation of closed areas, albeit with special access programs, reductions in DAS, creation of a special access program for Georges Bank yellowtail flounder, trawl mesh size increases, other limitations for gill net and hook and line gears, opportunities to lease or permanently transfer DAS between vessels with similar characteristics, implementation of a formal quota sharing agreement between Canada and the U.S. to share the harvest of transboundary resources, in-season monitoring of the catch of transboundary stocks, and total allowable catch quotas for each transboundary stock, including Georges Bank haddock.

Case study: Georges Bank haddock

Georges Bank haddock had been overfished for decades prior to mid-1990s (Brodziak and Link 2002). The stock had experienced long-term declines in spawning biomass and recruitment (Brodziak et al. 2001) and was considered by some to have been near collapse in the early 1990s. It was around this time that the lawsuit by CLF to cease overfishing forced the NEFMC to take actions to recover Georges Bank haddock and other groundfish stocks.

Fishery management measures since 1994 have decreased fishing mortality (Figure 2). These measures included large year-round closed areas, restrictions on fishing effort, increases in trawl mesh size, and other measures (Fogarty and Murawski 1998). Fishing mortality (F) on Georges Bank haddock averaged F=0.39 per year during 1980-1993. This was about 50% higher than the current overfishing limit (F_{MSY}=0.26) for this stock. Since 1994, annual fishing mortality has averaged about F=0.17, about 30% below F_{MSY}.

Stock response to reductions in fishing mortality during the 1990s was dramatic (Figure 2). Under persistent overfishing in the 1980s, Georges Bank haddock spawning biomass declined from over 63,000 mt in 1980 to only 11,000 mt in 1993. Since 1994, spawning biomass has increased substantially as fishing mortality decreased. By 2003, spawning biomass was projected to be about 120,000 mt, the highest abundance of adult spawners since 1967 and over a 10-fold increase since 1993. This represented a substantial improvement the reproductive capacity of this stock. Nonetheless, the Georges Bank haddock stock is still considered to be overfished since its spawning biomass is less than half of its rebuilding target.

Georges Bank haddock recruitment had a similar positive response to reduced fishing mortality (Figure 2). Recruitment averaged only 7 million age-1 recruits per year during 1980-1993. Since 1994, however, average recruitment has increased 3-fold to about 24 million fish. Further, the prospects for continued high recruitment appear to be positive. When Georges Bank haddock spawning stock biomass exceeds its 1931-1998 median value of about 82,000 mt, the odds of above-average recruitment increase over 20-fold (Brodziak et al. 2001). Similarly, the expected magnitude of recruitment increases over 3-fold when SSB exceeds this threshold. Recent survey data suggest that the 2003 year class may be exceptionally abundant.

Recruits per spawner data for Georges Bank haddock shows that survival ratios were relatively low from the late-1960s to early-1990s in comparison to historic ratios during the 1930s-1960s (Figure 2). The impact of the large-scale area closures, reductions in fishing effort, and trawl mesh size increases during the 1990s likely had a positive effect on recruits per spawning stock biomass (R/SSB). During 1980-93, R/SSB averaged about 0.4 recruits per kg. Since 1994, average R/SSB has increased by roughly 50% to almost 0.6 recruits per kg. Further increases in R/SSB may occur since, at least historically, the expected value of R/SSB was higher. The recent increases in average R/SSB indicate that survival ratios are nearing the historical average during 1931-60 of about 0.76 recruits per kg. If the recent increase in productivity can be sustained, it is possible that historic yields on the order of 50,000 mt per year may be achieved.

The formal rebuilding plan for Georges Bank haddock adopted in Amendment 13 calls for fishing at the overfishing limit F_{MSY}=0.26 during 2004-2008 (Figure 3). In 2009, the fishing mortality would be reduced marginally to $F_{REBUILD}$=0.245, the value of F projected to produce a 50% chance that spawning biomass meets or exceeds B_{MSY}=250,000 mt in 2014. This rebuilding strategy is subject to change in 2008 if observed progress towards rebuilding spawning biomass or reducing fishing mortality is not on the projected rebuilding trajectory. This is the adaptive management component of the Amendment 13 groundfish rebuilding plan described below.

Case study: Southern New England-Mid Atlantic yellowtail flounder

Fishing mortality of southern New England-Mid Atlantic yellowtail flounder has been greater than F_{MSY} since the 1940s (Royce et al. 1959, Lux 1969). Stock assessments of yellowtail flounder in the southern New England area indicated increasing fishing mortality and declining stock size in the late 1960s (Brown and Hennemuth 1971). Fishing mortality continued to increase in the 1970s and 1980s (Figure 4), and despite strong recruitment from two dominant year classes in the 1980s, the stock was depleted to record low biomass in the early 1990s (Cadrin 2003).

In December 1994, a large area was closed to fishing year-round, fishing effort was limited, and minimum mesh sizes were increased in the southern New England area. However, re-examination of yellowtail flounder stock structure off New England indicated that the southern New England resource should be assessed and managed together with the Mid Atlantic resource as a single stock (Cadrin 2003). Although landings from the Mid Atlantic Bight were historically much less than those from the southern New England fishing grounds, as a result of recent fishing restrictions in southern New England, Mid Atlantic landings were more than twice those from southern New England in 1997. The inclusion of Mid Atlantic landings, fishery samples and survey data with southern New England data provided a different perspective on current stock status. The estimate of fishing mortality in 2001 from the southern New England-Mid Atlantic yellowtail assessment (F_{2001}=0.91; Cadrin 2003) was nearly double the estimate for southern New England alone (F_{2001}=0.46; Cadrin 2002).

In contrast to the rebuilding illustrated by Georges Bank haddock, southern New England-Mid Atlantic yellowtail has not responded as well to management actions, primarily because fishing mortality was not effectively reduced. No strong year classes have been apparent since the late-1980s. Spawning biomass gradually increased from the record low of 600 mt in 1994 to 2,100 mt in 2000, but then decreased to 1,900 mt in 2001 (Figure 4). Recruitment has been low since the 1990s. The reproductive rate (recruits per spawning biomass) was relatively high in the 1970s and low in the 1980s, with the exception of 1987, when an extremely large cohort was produced from very little spawning biomass (Figure 4). Since 1987, reproductive rates were low to moderate. Experiences from other yellowtail resources on Georges Bank (Legault and Stone 2004) and the Grand Bank (Walsh et al. 2002) suggest that yellowtail flounder are both resilient and productive, because the populations quickly responded to decreased fishing mortality with greater spawning biomass and stronger recruitment.

A technical difficulty of developing a rebuilding plan for southern New England-Mid Atlantic yellowtail is what to expect for future recruitment, in the short-term and eventually at high biomass. The stock-recruit relationship is greatly influenced by the strong 1987 year class, which was produced by low spawning biomass. Based on the difficulty modeling the stock-recruit relationship and the relatively reliable information on life history and fishery selectivity, the rebuilding target (a proxy for B_{MSY}) was derived as the product of 40% maximum spawner-per-recruit and average long-term recruitment, 1963-2000. Stochastic projections for evaluating rebuilding plans used the distribution of all observed year classes to project future recruitment, but long-term recruitment levels may not be produced in the short-term, and projections may be overly optimistic.

The rebuilding plan for southern New England-Mid Atlantic yellowtail involves phased reductions in fishing mortality, from status-quo fishing mortality to the mortality that will allow rebuilding within ten years (Figure 5). This "back-loaded" rebuilding plan includes excessive harvest rates (i.e., greater than F_{MSY}) in the short term, followed by very low fishing mortality rates (e.g., 65% of F_{MSY}) in the medium-term. The plan may be risky with respect to achieving the rebuilding goals if strong recruitment does not occur and stock size decreases in the short-term.

Adaptive management

We proposed an adaptive management strategy for Amendment 13 to attain the biomasses producing maximum sustainable yield (B_{MSY}) for New England groundfish stocks. This strategy was consistent with applicable U.S. SFA guidelines to eliminate overfishing and rebuild depleted stocks. The adaptive strategy had eight primary elements.

First, for a number of stocks, estimates of B_{MSY} were beyond the observed range of stock biomasses, due to the effects of chronic overfishing. Although the current estimates of B_{MSY} were based on demonstrated recruitment and current growth and fishery selection parameters, uncertainty remained in the direction of these critical population rates under stock rebuilding, and thus in the ability of the stocks to attain the calculated B_{MSY} values. The calculated B_{MSY} values might be too high, or too low, depending on how dynamic rates of recruitment, growth and natural mortality were as the stock complex is rebuilt (e.g. density-dependence).

Second, by definition, fishing a stock at or below F_{MSY} would eventually result in the attainment of B_{MSY}, with the stock thereafter fluctuating at or around that value, depending on rates of recruitment and fishing mortality. By allowing the stock to equilibrate when fished at these rates, more information regarding the actual biomasses associated with F_{MSY} would follow.
Third, based on the results of the Working Group on *Re-Estimation of Biological Reference Points for New England Groundfish* (NEFSC 2002), and the *Peer Review of Groundfish Science* (February 2003), there was general consensus that estimates and proxies for F_{MSY} (Table 1) were robust to uncertainty in B_{MSY} and are appropriate thresholds for management. Therefore, attaining fishing mortalities at or below these rates was the cornerstone of this proposal.

Fourth, the extension of the stock rebuilding time frames (e.g., to 10 years) allowed for fishing plans that were consistent with an overall strategy of initially fishing the stocks at or below F_{MSY}, and adjusting either the fishing rates or the biomass reference points, consistent with the pace of rebuilding relative to the nominal targets. When the 2004-2014 time frame was chosen for all stocks (e.g., a 2004-2014 rebuilding period), the strategy of fishing at or below F_{MSY} for a significant portion of the rebuilding period became more viable as a strategy, thereby minimizing the influence (and reliance) on a particular value of B_{MSY}.

Fifth, an adaptive fishing mortality schedule and strategy to rebuild New England groundfish (Table 1, Figures 6 and 7) was specified. The fishing mortality schedule had three parts. In the first part, fishing mortality rates for all stocks are maintained at F_{MSY} for the first 5 years of the plan. In 2009-2014, the fishing mortality rates would be adjusted to those required to meet B_{MSY} targets initially estimated for the stocks (Table 2) with a 50% probability in 2014 (e.g. an F-rebuild to be applied during 2009-2014, unless adjusted at a later date, as specified below). This strategy was expected, on average, to result in the attainment of B_{MSY} by 2014 with a 50% probability, all things being equal (e.g. recruitment growth, natural mortality). In the second part, the median rebuilding trajectory in biomass (Figure 6) and fishing mortality (Figure 7) from stochastic population projections was the expected path to stock recovery. This path determined a series of "way-points" upon which the pace of stock rebuilding could be judged. The median of the distribution of projected values of SSB_{2007} was used as an interim biomass target along the path to stock rebuilding and provided an appropriate benchmark to evaluate the efficacy of the rebuilding program. The third part of the schedule was a formal review to assess progress towards rebuilding the stocks. Based on the findings of that review, one of three determinations can be made: (I) the stocks were "on track" to rebuilding (that is, the inter-quartile range (range between the 25th and 75th percentiles of biomass in 2007) of the estimated stock biomass intersected the *projected* 2007 biomass, consistent with the proposed rebuilding trajectory, (ii) the stock was above the projected strategy, or (iii) the stock was below the proposed rebuilding trajectory.

Sixth, depending on the actual stock biomass in 2007, matrices of nine possible management and scientific actions were prescribed (Figures 8 and 9). One of the critical elements to be assessed was whether the management program had been successful in achieving F_{MSY} or below for individual stocks. This was important since the condition of the stock and the specific management actions were dependent on the causal factors contributing to the observed stock biomasses. For example, if the stock size in 2007 was judged to be significantly below the projected path, the critical question was why did this happen? If fishing mortality rates were consistently and significantly above F_{MSY}, the question to be assessed was if F_{MSYs} *were* attained, would the stock condition intersect the rebuilding path? Alternatively, was there evidence in population dynamics data (recruitment, growth, natural mortality) that showed no significant improvement in the stock could have occurred, due to these stock conditions, even though the stock was overfished. The management and science responses in these cases were different.

Seventh, potential factors associated with all nine cases for stock biomass and fishing mortality rate conditions during 2007 were described (Figure 8). These factors would be examined in detail in developing appropriate adaptive management advice pertaining to the second half of the rebuilding period (e.g. 2009-2014).

Last, default management and scientific review actions were also proposed as a key element of the adaptive approach (Figure 9). These outcomes were conditional on the status of the stock biomass relative to the interim (2007) waypoints, and the 2002-2007 average fishing mortality rate relative to F_{MSY}. The nine possible cases were:

Case 1: $F_{2002\text{-}2007} > F_{MSY}$ and $B_{2007} > B_{waypoint}$
In this situation the fishing mortality rates for 2002-2007 exceeded the F_{MSY} values, but the stock was judged to be above the median rebuilding path (way point). This condition could arise due to exceptional recruitment or other biological factors that offset the continued overfishing of the stock. In this case, the management action would be to reduce F to F_{MSY}. More analysis would be required to see if the fishing mortality on the stock should be reduced further to the rebuild value originally projected for the stock (Table 1). It was also possible that F_{MSY} or B_{MSY} may have originally been set too low. In this event, re-consideration of the evidence would be recommended before fishing rates were reduced (e.g. for 2009-2014).

Case 2: $F_{2002\text{-}2007} > F_{MSY}$ and $B_{2007} = B_{waypoint}$
In this case, F exceeded F_{MSY} but the stock was on the rebuilding trajectory. The default management advice would be to reduce F to the F rebuild value. Or, if it could be demonstrated to be appropriate, to the F_{MSY} value, which ever was higher. In this situation, stock conditions were apparently offsetting the continued overfishing. This would most likely be due to greater than expected recruitment. While there might be some justification to revise B_{MSY} and F_{MSY} values, they were not likely to be different from those currently in place. The exception could be F_{MSY}, which might need to be re-evaluated if the partial recruitment pattern (gear selectivity-at-age) changed due to additional fishing gear restrictions.

Case 3: $F_{2002\text{-}2007} > F_{MSY}$ and $B_{2007} < B_{waypoint}$
The condition of excessive fishing mortality and biomass below the projected rebuilding path would require, at a minimum, reduction of F to the original F rebuild value. In this case, it would be useful to evaluate whether the stock would have been on the rebuilding path had overfishing not been occurring. This could be accomplished by simulating the combined impacts of the observed recruitment stream and the F_{MSY} values. If the stock would have been near the path had the stock not been overfished, the managers might consider the feasibility of additional F reductions (below the original $F_{REBUILD}$ values) to allow the stock to regain the rebuilding path.

Case 4: $F_{2002\text{-}2007} = F_{MSY}$ and $B_{2007} > B_{waypoint}$
If the fishing mortality rate was held at F_{MSY} for 2002-2007 and the stock was above the rebuilding path, the managers should consider suspending the default reduction in F to Frebuild. Simulations could determine if stock rebuilding to B_{MSY} would be impeded by such a strategy. This scenario would likely occur if one or more exceptional year classes were produced during 2002-2007. In this event, revisions in B_{MSY} (upward) might be warranted (although this would not apply to the 2014 rebuilding program).

Case 5: $F_{2002\text{-}2007} = F_{MSY}$ and $B_{2007} = B_{waypoint}$
In this event, F targets were achieved and stock rebuilding was on track. The prescriptive advice would be to reduce F to $F_{REBUILD}$. Updated estimates of $F_{REBUILD}$ might be appropriate if the stock could be fished at a higher rate (than the original $F_{REBUILD}$) and still attain the target.

Case 6: $F_{2002\text{-}2007} = F_{MSY}$ and $B_{2007} < B_{waypoint}$
If fishing mortality rate targets were met and the stock biomass was below the rebuilding trajectory, the nominal management advice would be to reduce F to the original $F_{REBUILD}$ value. Specific conditions in the stock should be re-evaluated to determine why stock biomass had not responded. Three potential causal factors were (1) continued below-average recruitment due to poor environmental conditions (e.g., regime change), (2) multispecies effects such as increased predation on juveniles or (3) competition with other species for food, resulting in reduced growth rates, or other population dynamics factors. In this event, scientists should re-consider biomass and fishing mortality rate targets in light of prevailing hypotheses for poor rebuilding progress.

Case 7: $F_{2002\text{-}2007} < F_{MSY}$ and $B_{2007} > B_{waypoint}$
If fishing mortality was below F_{MSY} and the stock biomass exceeded the rebuilding waypoint, then the appropriate management advice would be to maintain F at or below F_{MSY}. In this event, it was unlikely that F needed to be reduced to F rebuild to meet the 2014 time frame for rebuilt stocks. Revision (upwards) of biomass and especially F targets should be considered, but if biomass targets were revised upwards, they would not apply to the 2014 end point of the original rebuilding program (a policy choice).

Case 8: $F_{2002\text{-}2007} < F_{MSY}$ and $B_{2007} = B_{waypoint}$
If the fishing mortality rate was below the F_{MSY} value but above Frebuild, and the stock was on track, then a re-evaluation of the need to reduce F to $F_{REBUILD}$ should be undertaken. If the stock could be rebuilt to the original B_{MSY} fishing at the average F during 2002-2007 then this rate should be maintained.

Case 9: $F_{2002\text{-}2007} <$ Fmsy and $B_{2007} < B_{waypoint}$
In this event, there were significant problems with the near-term productivity of the stock likely unrelated to current fishing effects (although there could be ongoing depensatory effects due to historical stock depletion). The lack of recovery of stock biomass might be due to continued below-average recruitment (e.g., due to environmentally-caused regime change) or other single- or multispecies influences on growth, natural mortality, and maturity. As a result, scientists should re-consider biomass and fishing mortality rate targets in light of prevailing hypotheses for poor stock performance.

Discussion

During the late-1990s, a new U.S. legislative mandate to rebuild fish stocks to B_{MSY} augmented the previous goal of achieving optimum yield and not overfishing. At present, the overall goal of U.S. marine fisheries management is to achieve a target biological state in which stock biomass is at or above B_{MSY}, fishing mortality is at or below F_{MSY}, and yield is at or below MSY. The biomass, fishing mortality, and yield components of the target state are interrelated. In particular, if an estimate of one of the three changes, then the other two would also be expected to change. Maintaining consistency between B_{MSY}, F_{MSY}, and MSY estimates is necessary for providing the best available estimates of rebuilding targets for depleted fish stocks.

For many groundfish stocks in the New England region, achieving rebuilding goals will require a reduction in fishing mortality over the next decade to produce greater benefits in the future. However, while reducing fishing mortality is a necessary precondition for stock recovery, it may not be sufficient to assure B_{MSY}. In a broader perspective, three elements of the fishery and ecosystem must be compatible with stock recovery: biological, social, and environmental. Along the biological dimension, stock dynamics need to be compensatory at low stock sizes. That is, the intrinsic growth rate must increase as stock size decreases. Along the social dimension, there needs to be an effective fishery governance system that mandates stock rebuilding and provides for equitable allocation of benefits. In particular, fishery management institutions need to have the authority to curtail overfishing to comply with the law. Along the environmental dimension, physical oceanographic conditions and trophic dynamics of the ecological community need to provide positive opportunities for juvenile and adult survival and reproduction. This includes maintaining adequate habitat quality along with ecological community structure and function. In particular, maintaining the quality of essential fish habitat through implementation of marine protected areas is important but will not be sufficient to recover migratory stocks or ones that are experiencing high rates of predation at low population size. Taken alone, none of these elements would necessarily guarantee stock recovery. However, taken together, they should be sufficient.

A management strategy that sets fishing mortality at F_{MSY} should lead to stock recovery if the necessary biological, social, and environmental elements are present. This strategy provides a default open loop harvest control rule that would eventually lead to stock recovery. However, when several stocks are jointly harvested in multispecies fisheries, it may be necessary to set fishing mortality below F_{MSY} for some stocks in order to recover all stocks. Although it is important to have a fishery governance system that mandates stock rebuilding, some flexibility in making changes to fishing effort may be necessary to prevent disruption of viable fisheries. In this context, the use of a phased fishing mortality reduction strategy for Southern New England yellowtail flounder provides an example where immediately reducing fishing effort to produce F_{MSY} was not economically or politically feasible. In this case, neither the time frame nor the target biomass for stock rebuilding was altered. Instead, the fishing mortality reduction schedule was adjusted to gradually reduce fishing effort and mortality to rebuild this stock by 2014. When developing a rebuilding plan to recover a depleted stock, it is important to emphasize to fishery stakeholders that the time frame for rebuilding, the rebuilding fishing mortality trajectory, and the biomass rebuilding target are inextricably linked. It is not possible to change one of these alone, without affecting the others. This is particularly important when negotiating with industry and environmental organizations to craft a set of mutually-acceptable measures to reduce fishing mortality. In general, having some flexibility in choosing either the time frame or the rebuilding fishing mortality schedule may be helpful. However, it is important not to allow flexibility in both of these since this simply leaves the status quo of overfishing in place.

Given the complexity of biological, social, and environmental interrelationships in marine ecosystems and our modest ability to monitor them, ecological surprises will likely occur. Some surprises will be positive as in the Georges Bank haddock example. Some thought that the Georges Bank haddock stock had totally collapsed in the early-1990s. There was skepticism that this stock would exhibit compensatory dynamics at low stock sizes even if fishing mortality was reduced. In hindsight, this was an ecologically pessimistic view. At present, the Georges Bank haddock stock appears to have crossed a biological threshold in spawning abundance (e.g., Brodziak et al. 2001) and may have produced the largest year class ever observed in 2003. On the other hand, some surprises may be negative. For example, it seems possible that the Southern New England yellowtail flounder may be currently experiencing depensatory dynamics or that changing oceanographic conditions have reduced survival rates or reproductive success in this stock. Either or both of these causal mechanisms may be affecting productivity of the yellowtail stock. However, until the management experiment of actually reducing fishing mortality below F_{MSY} has been tried with this stock, it will be unknown whether depensation or unfavorable environmental conditions are important factors impeding stock recovery. This emphasizes the need for an adaptive management approach for rebuilding overfished stocks.

Monitoring the pace of stock rebuilding relative to changes in life history parameters and recruitment is also important for a successful rebuilding strategy. Periodic re-evaluation of rebuilding targets will be needed to address uncertainties due to density dependence, trophic interactions or environmental factors. These inherent uncertainties present fundamental challenges for the implementation of an ecosystem approach to rebuilding depleted fishery resources. As a consequence, rebuilding plans need to be flexible to adapt to changing circumstances. This underscores the importance of viewing management as an ongoing experiment that requires flexibility. Our example of implementing rebuilding plans for New England groundfish includes a scheduled re-evaluation of B_{MSY} and F_{MSY} reference points in 2008. This re-evaluation may require a mid-course correction, or alternatively, it may verify that rebuilding targets are appropriate and the progress towards stock recovery has been satisfactory.

While the planned re-evaluation of reference points approach may update biological constraints, one of the important socioeconomic factors affecting fishery management was not explicitly addressed: the overcapacity of the New England groundfish fishing fleet (NOAA 2004). Overcapacity is a world-wide problem (see, for example, Bowman et al. 2004). Having a process to reduce excess fishing capacity is an important component of a long-term fishery management strategy. In this context, provisions in Amendment 13 that allow for the leasing or permanent transfer of days at sea between vessels provides an initial mechanism to begin consolidation. Whether this alone will be sufficient to reduce fishing capacity to be consistent with New England groundfish productivity is unknown. What does seem clear based on our experiences, however, is that persistent overcapacity will lead to ongoing political pressure to deviate from rebuilding plans. Implicit in this point is the issue that recreational fishing vessels also contribute to the overcapacity problem since they harvest depleted groundfish stocks, such as Gulf of Maine cod. Regardless of this potential impediment, it is our view that Amendment 13 represents a significant milestone because it demonstrates that New England's fishery governance system is evolving to meet legal mandates while maintaining some viable fisheries. There is a key role for scientists to play in the ongoing debate to develop rebuilding strategies that comply with the law and are consistent with biological, socioeconomic, and environmental constraints.

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Table 1. Age-structured projection results for groundfish based on $F_{2002} = F_{2003,}$ F_{MSY} in 2004-2008, and $F_{REBUILD}$ in 2009-2014. Spawning stock biomass in 2007 (B_{2007}) and its associated 80th percent confidence interval, B_{2002} (in parentheses), and probability that B_{2014} exceeds B_{MSY} are tabulated for 10 Northeast groundfish stocks.

Stock	F_{2002}	F_{MSY} in 2004-2008	$F_{REBUILD}$ in 2009-2014	Lower 80th CI of B_{2007}	B_{2007} (B_{2002})	Upper 80th CI of B_{2007}	Pr (B_{2014} exceeds B_{MSY})
Gulf of Maine cod	0.36	0.23	0.22	35.4	45.0 (23.8)	58.8	0.51
Georges Bank cod	0.45	0.18	0	29.7	42.1 (26.5)	61.7	0.40
Georges Bank haddock	0.20	0.26	0.25	141.1	199.4 (99.6)	264.7	0.51
Georges Bank yellowtail flounder	0.14	0.25	0.23	39.6	53.5 (47.3)	70.3	0.51
Cape Cod/Gulf of Maine yellowtail flounder	0.95	0.17	0.07	5.6	6.8 (2.5)	8.5	0.51
S. New England/MA yellowtail flounder	0.74	0.26	0.17	10.2	38.7 (2.0)	89.6	0.51
American plaice	0.26	0.17	0.15	18.5	21.8 (15.6)	25.9	0.51
S. New England winter flounder	0.45	0.32	0.23	10.1	12.7 (6.0)	16.0	0.51
Witch flounder	0.19	0.16	0.16	33.9	43.5 (18.7)	55.2	0.88
Acadian redfish	<0.01	0.04	0	150.1	153.4 (130.2)	158.9	0.06
Gulf of Maine winter flounder	0.06	0.43	0.43	4.5	5.3 (7.7)	6.2	0.62

Table 2. Current estimates of B_{MSY} or proxies for New England groundfish stocks.

New England Groundfish Stock	Estimate of B_{MSY} (kmt)
Analytical stocks	
Georges Bank haddock	250.3
Georges Bank cod	216.8
Georges Bank yellowtail	58.8
Gulf of Maine cod	82.8
Georges Bank winter flounder	9.4
Witch flounder	19.9
American plaice	28.6
S. New England-MAB yellowtail	69.5
S. New England winter flounder	30.1
Cape Cod-Gulf of Maine yellowtail	12.6
Acadian redfish	236.7
Index stocks	Proxy B_{MSY} (kg/tow)
Gulf of Maine haddock	22.2
White hake	7.7
Pollock	3.0
Northern windowpane flounder	0.9
Southern windowpane flounder	0.9
Ocean pout	4.9
Atlantic halibut	5.4 kmt

Figure 1. Four areas that are closed year-round to all fishing gears capable of catching groundfish in the northwest Atlantic: Closed Area I, Closed Area II, the Nantucket Lightship Closed Area, and the Western Gulf of Maine Closed Area (WGOM).

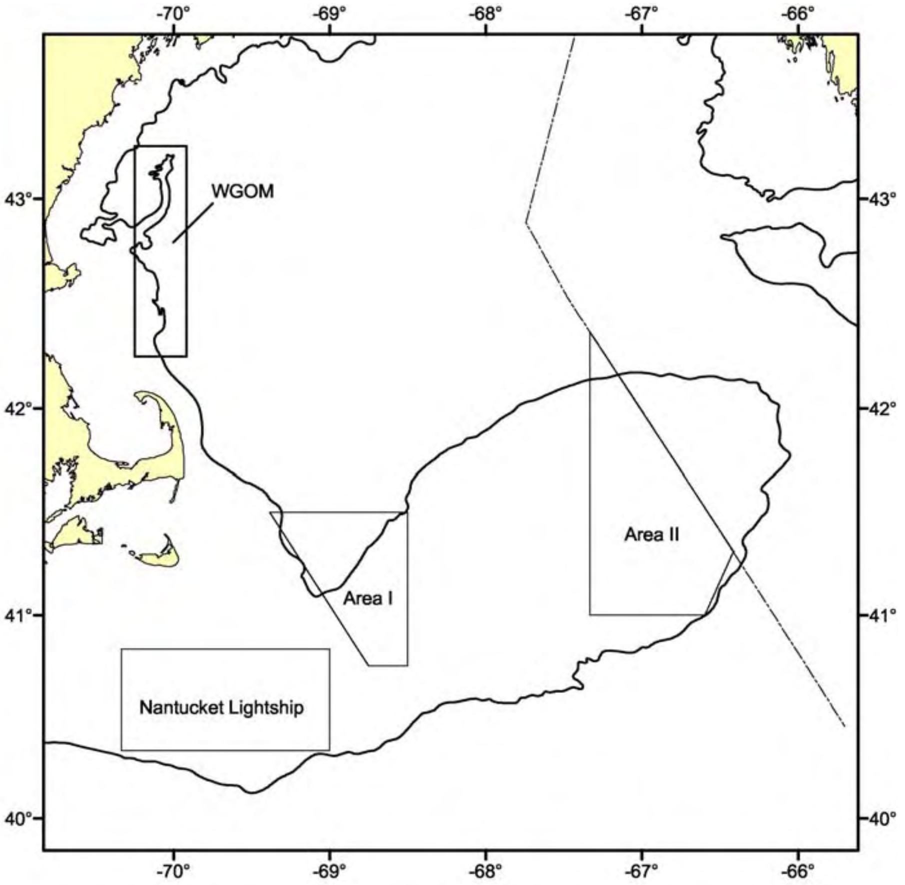


Figure 2. Status of Georges Bank haddock, 1931-2001, from Brodziak et al. (2002).

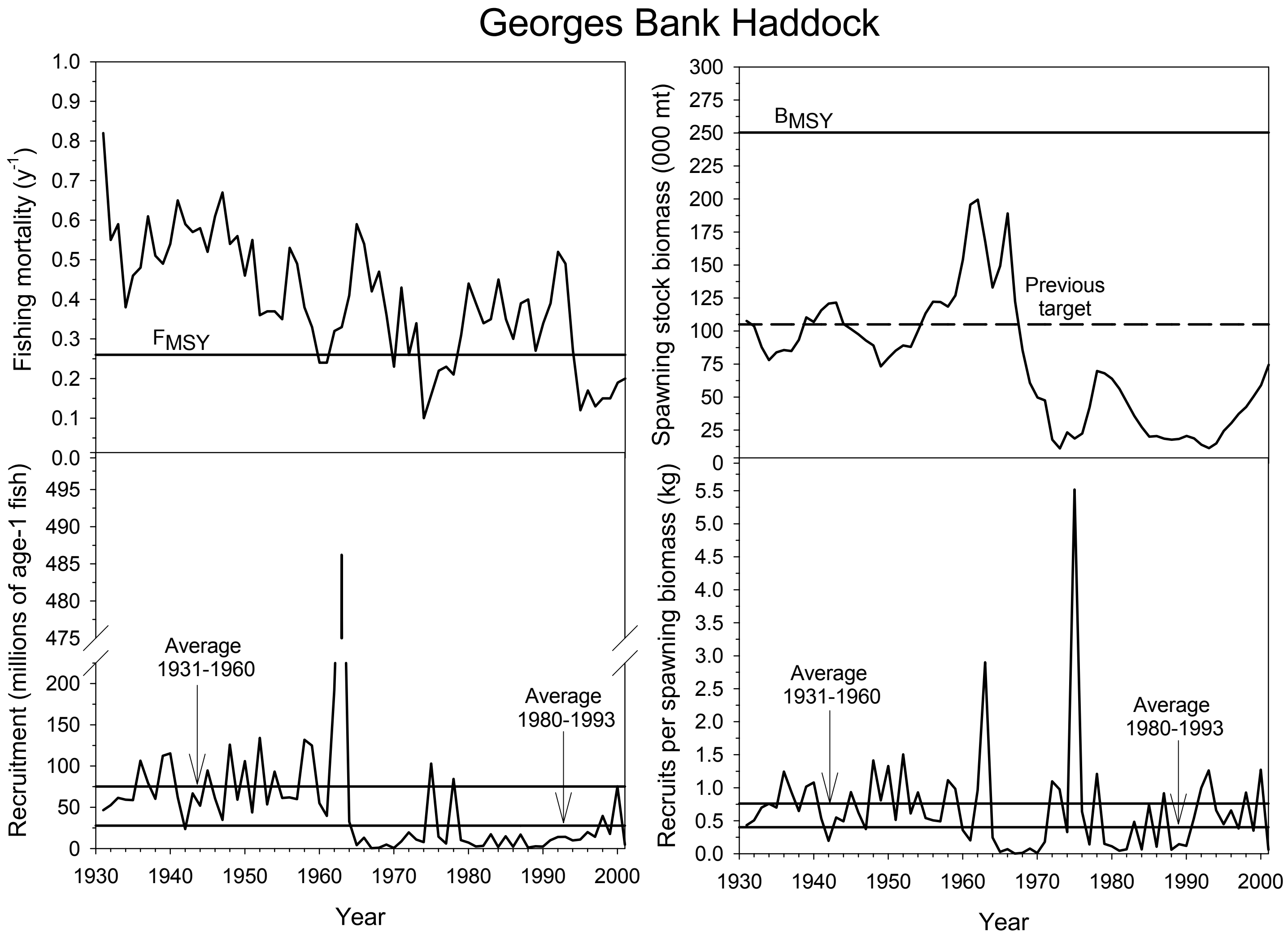


Figure 3. Projected median spawning stock biomass and expected fishing mortality trajectories for Georges Bank haddock during 2004-2014 under an adaptive rebuilding strategy.

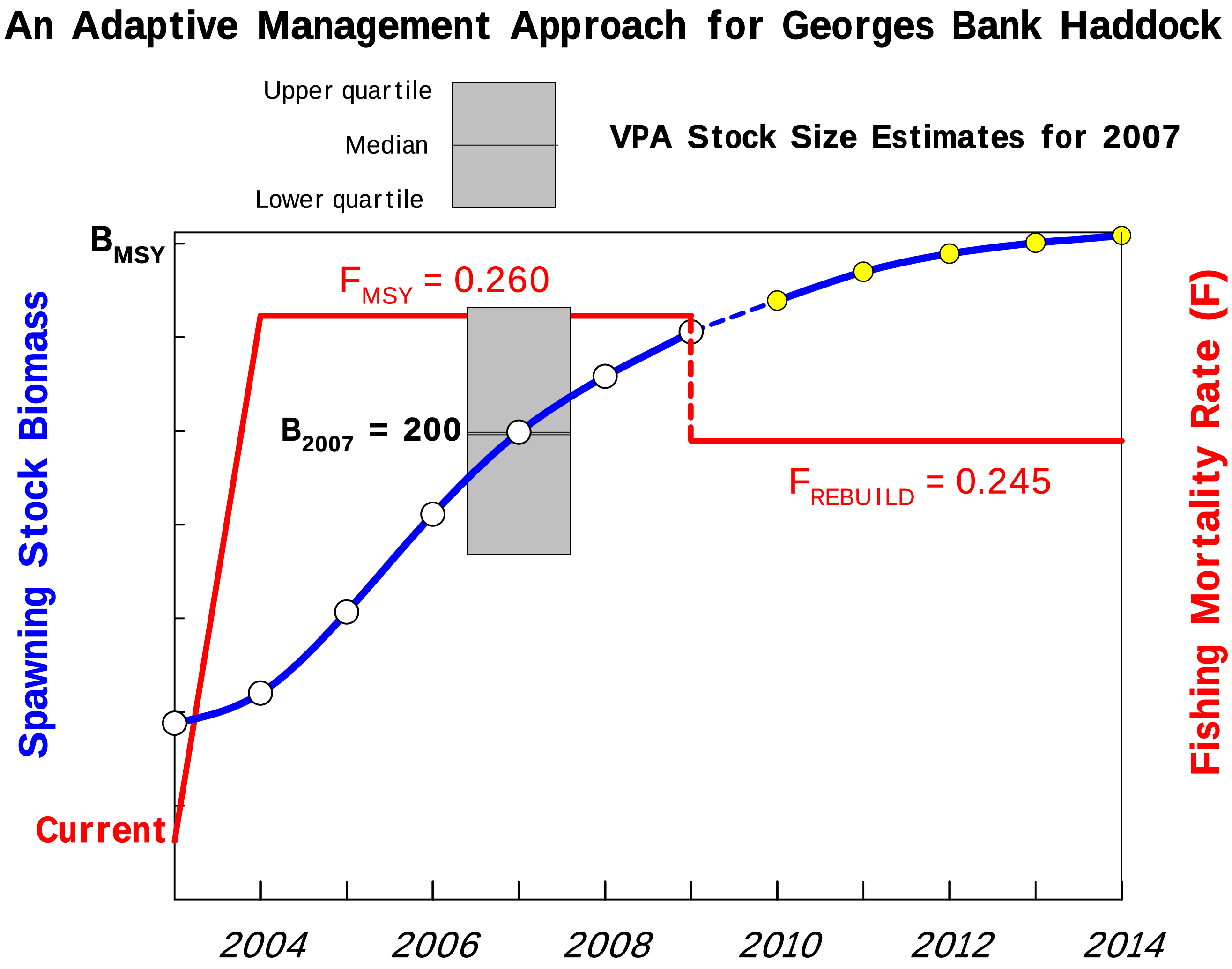


Figure 4. Status of southern New England/Mid-Atlantic yellowtail flounder, 1973-2001, from Cadrin (2003).

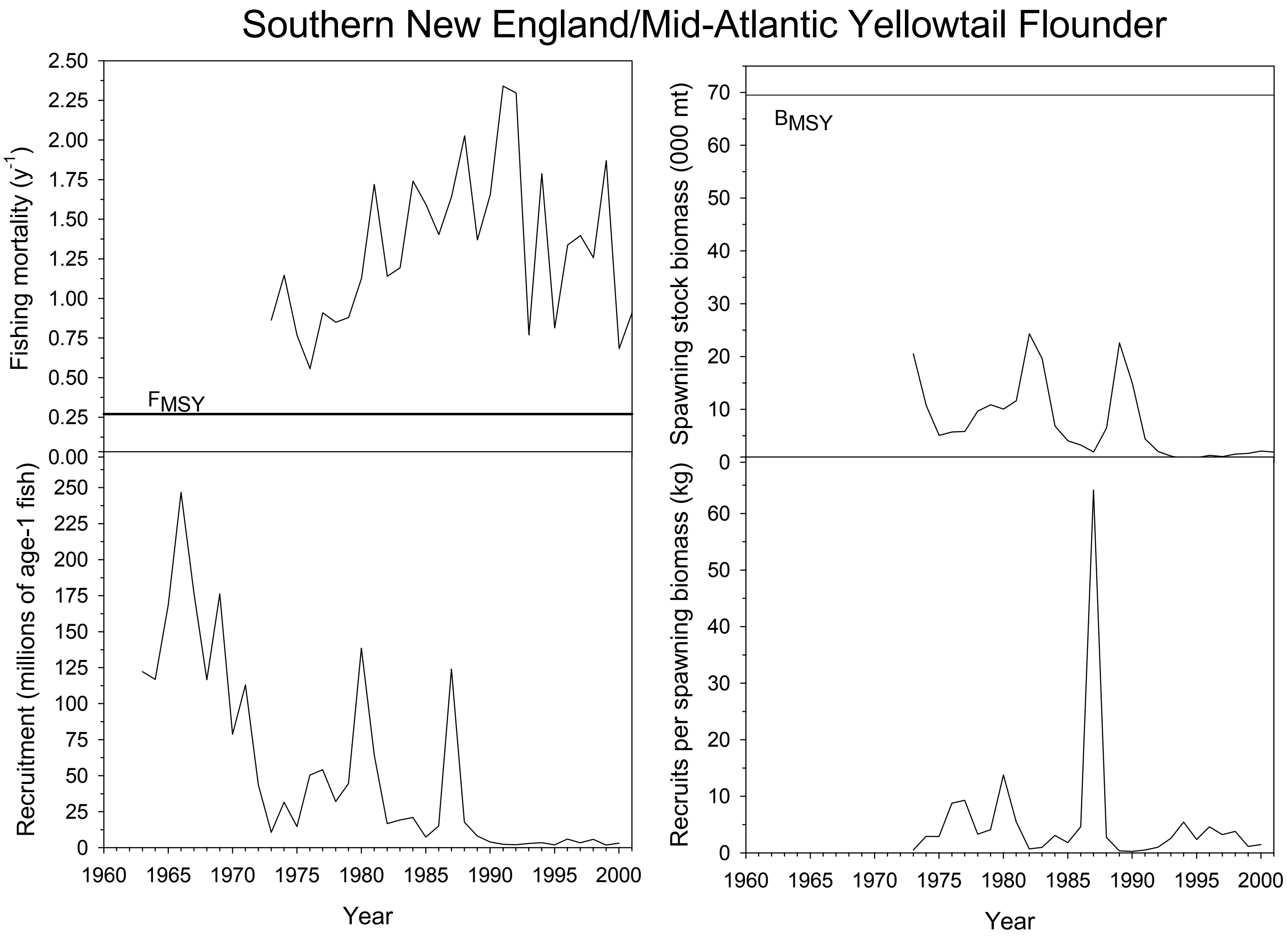


Figure 5. Projected median spawning stock biomass and expected fishing mortality trajectories for Southern New England yellowtail flounder during 2004-2014 under a phased fishing mortality reduction strategy.

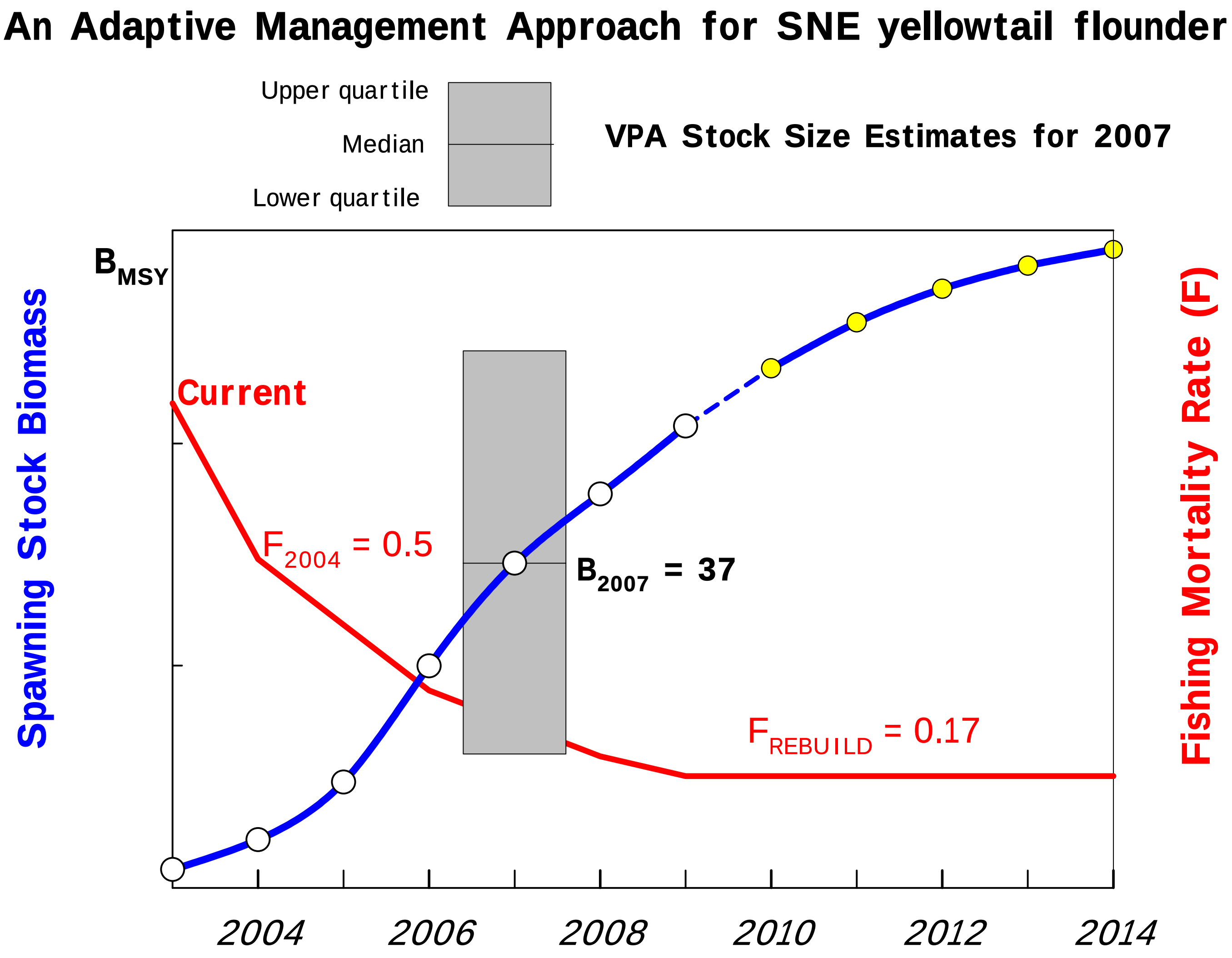


Figure 6. Comparison of projected median and distribution of VPA estimate of spawning biomass in 2007 to categorize whether a stock rebuilding plan is progressing on track.

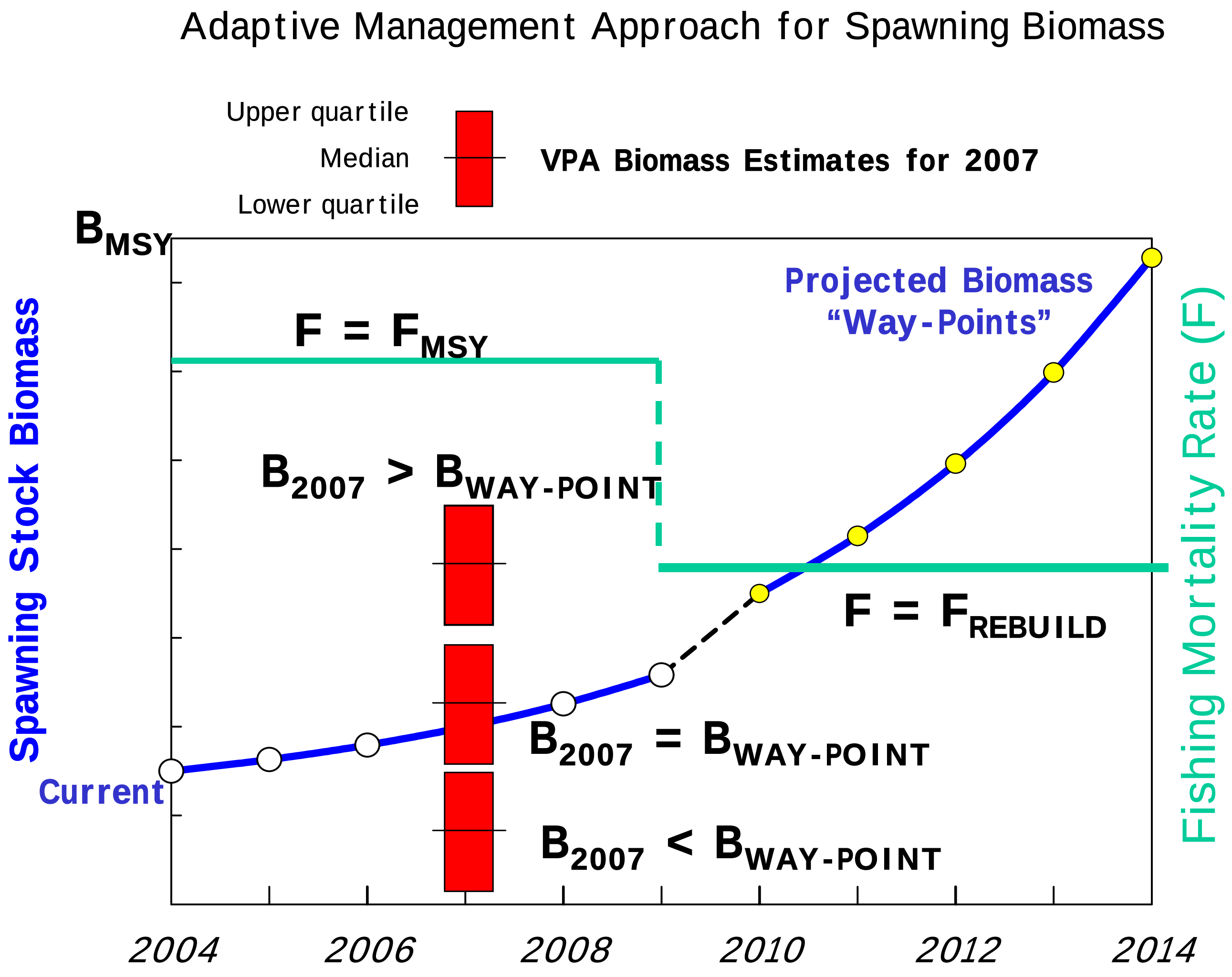


Figure 7. Comparison of projected median and distribution of VPA estimate of fishing mortality in 2007 to categorize whether a stock rebuilding plan is progressing on track.

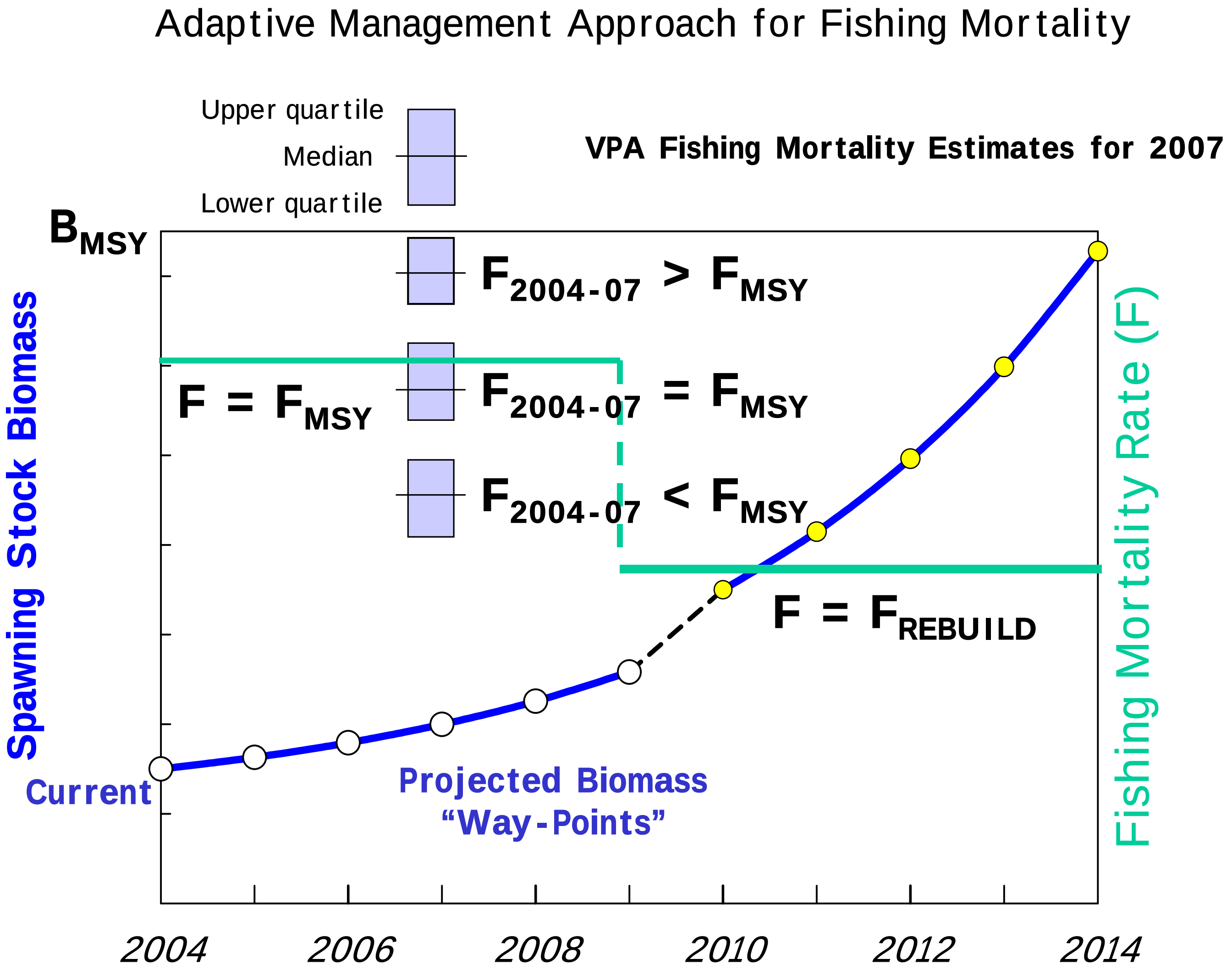
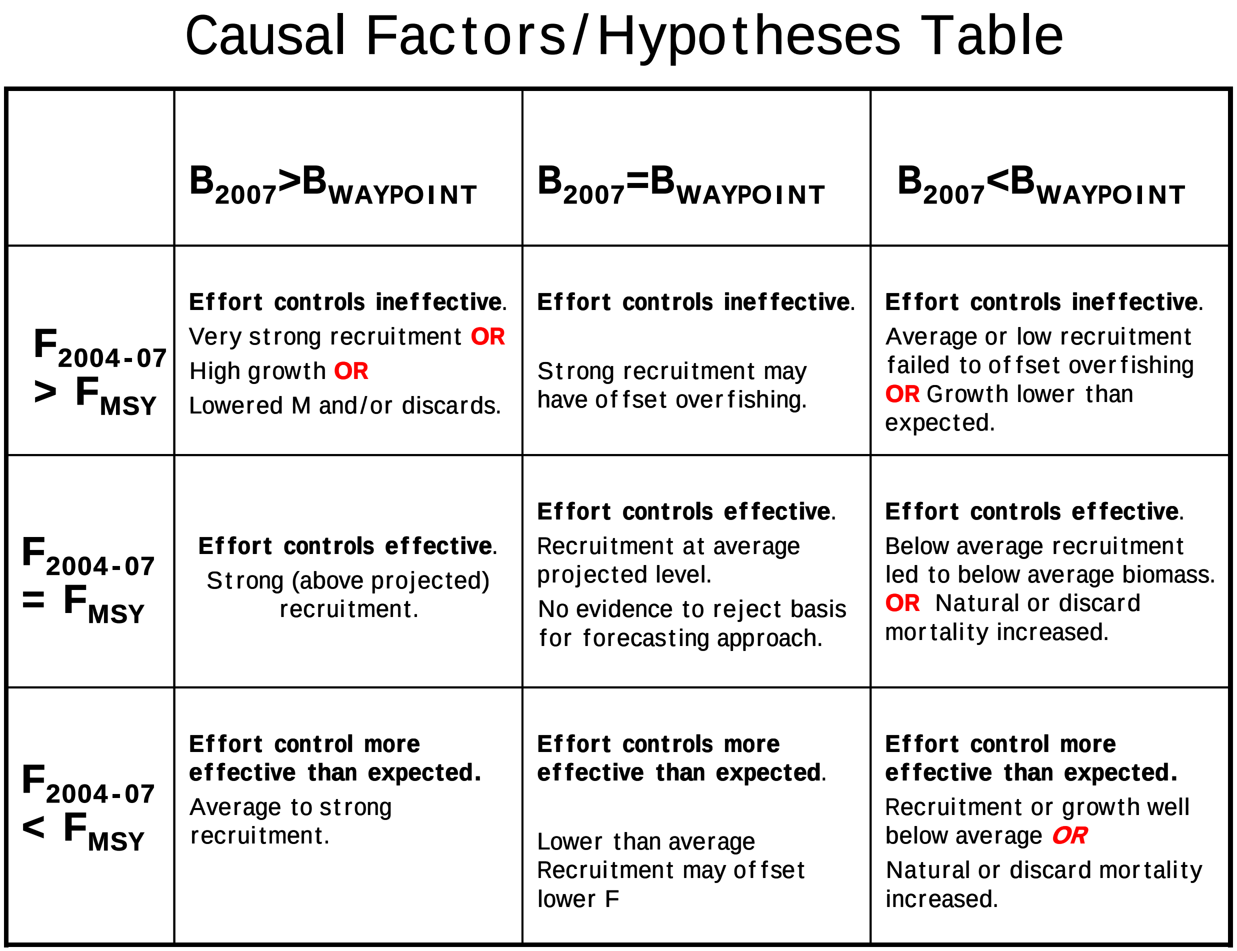


Figure 8. Potential causal factors and hypotheses to explain stock rebuilding status with respect to spawning biomass and average fishing mortality in 2007.



Causal Factors/Hypotheses Table

	$B_{2007}>B_{WAYPOINT}$	$B_{2007}=B_{WAYPOINT}$	$B_{2007}<B_{WAYPOINT}$
$F_{2004-07} > F_{MSY}$	**Effort controls ineffective.** Very strong recruitment **OR** High growth **OR** Lowered M and/or discards.	**Effort controls ineffective.** Strong recruitment may have offset overfishing.	**Effort controls ineffective.** Average or low recruitment failed to offset overfishing **OR** Growth lower than expected.
$F_{2004-07} = F_{MSY}$	**Effort controls effective.** Strong (above projected) recruitment.	**Effort controls effective.** Recruitment at average projected level. No evidence to reject basis for forecasting approach.	**Effort controls effective.** Below average recruitment led to below average biomass. **OR** Natural or discard mortality increased.
$F_{2004-07} < F_{MSY}$	**Effort control more effective than expected.** Average to strong recruitment.	**Effort controls more effective than expected.** Lower than average Recruitment may offset lower F	**Effort control more effective than expected.** Recruitment or growth well below average ***OR*** Natural or discard mortality increased.

Figure 9. Adaptive management actions corresponding to nine cases of measuring stock rebuilding progress in spawning biomass and average fishing mortality in 2007.

Adaptive Management Action Table

	$B_{2007}<B_{WAYPOINT}$	$B_{2007}=B_{WAYPOINT}$	$B_{2007}>B_{WAYPOINT}$
$F_{2004-07} > F_{MSY}$	Reduce F to Fmsy, re-consider Bmsy, Fmsy Reconsideration should come before reduction in F. Identify causes—strong recruitment offset overfishing?	Reduce F to Frebuild Extra measures will be needed since present measures ineffective. Identify causes—strong recruitment offset overfishing?	Reduce F to F rebuild; Consider basis for poor biomass performance Extra measures will be needed since present measures ineffective.
$F_{2004-07} = F_{MSY}$	Maintain F at Fmsy or below Depends on expected biomass trajectory from 2009 to 2014 at Fmsy.	Reduce F to Frebuild Proceed with plan. Consider revising F rebuild if value for 2009-2014 greater than previous value	Reduce F to Frebuild; **and/or** re-estimate Bmsy, Fmsy as appropriate Consider regime changes, multispecies effects, changes in vital rates
$F_{2004-07} < F_{MSY}$	Maintain F </= Fmsy, re-consider Bmsy Reconsider time frame for rebuild. No penalty for early victory. Re-evaluate Fmsy (too low?)	If F_{2007} will rebuild to Bmsy, maintain F	Consider basis, re-estimate Bmsy, Fmsy as appropriate Consider regime changes, multispecies effects, and changes in vital rates