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Goals and strategies for rebuilding New England groundfish stocks

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ABSTRACT

Rebuilding depleted fishery resources is a worldwide problem. In the U.S., the Magnuson Stevens Fishery Conservation and Management Reauthorization Act (MSRA) of 2007 requires that "Conservation and management measures shall prevent overfishing while achieving, on a continuing basis, the optimum yield from each fishery...". However, translating this legal mandate into tangible goals and actions presents several technical challenges, especially for resources that have been chronically over-exploited. For example, maximum sustainable yields and biomass reference points are poorly estimated for stocks that have been overfished for a long period of time and are poorly defined unless sufficient data are available from periods of low-fishing mortality rates and relatively high-stock sizes. The conundrum of how to set meaningful rebuilding goals given limited information on the population dynamics and trophic interactions of a rebuilt stock can generally be addressed through adaptive management procedures incorporating learning about density-dependent population dynamics. Monitoring changes in life history parameters and recruitment is critical for successful rebuilding strategies realizing the full yield potential of rebuilt stocks while periodic re-evaluation of rebuilding targets is also needed to address uncertainties due to density dependence, trophic interactions or environmental factors. This paper summarizes the development and implementation of goals and strategies to rebuild New England groundfish stocks over the past decade. Management is particularly challenging because the true yield and population size potentials of these interacting stocks is unknown due to chronic overfishing throughout the modern history of the fishery, uncertainty in compensatory/depensatory population dynamics and in the degree of stationarity in environmental control of groundfish recruitment.

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1. Introduction

Rebuilding depleted fishery resources is a worldwide problem. Overfishing and reduced stock productivity, for example, has depleted 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; Shelton et al., 2006). In the U.S., the Sustainable Fisheries Act (DOC, 1996; DOC, 2007) requires that management measures shall prevent overfishing to achieve optimum yields. However, translating this legal mandate into tangible goals and actions presents several technical challenges. Maximum sustainable yield and associated reference points (F_{MSY}, the fishing mortality rate that produces MSY and the associated spawning biomass, B_{MSY}) are difficult to estimate directly without knowledge of the stock recruitment relationship over the full dynamic range of stock biomass (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 correspondingly high-stock biomass generally needed to determine F_{MSY} and B_{MSY} with reasonable precision. 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 quantifying 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. The prevailing U.S. legal requirement that conservation and management measures shall prevent overfishing was used by environmental organizations in 2000 to file suit against the National Marine Fisheries Service (NMFS) to eliminate overfishing of New England groundfish (Table 1). Revised biological reference points were also required to provide the best available scientific information as mandated by law. Amendment 13 to the groundfish

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Table 1
Timeline of important events in the recent history of New England groundfish fishery management and in the development of the Northeast Multispecies Fishery Management Plan (FMP)

Year	Event	Importance
1991	Conservation Law Foundation (CLF) sues NMFS to cease overfishing of cod, haddock, and yellowtail flounder	Settlement required NMFS to develop a management plan to eliminate overfishing
1992	Amendment 4 to the FMP	Established $F_{20\%}$ as the groundfish overfishing definition
1994	Amendment 5 to the FMP	Established a moratorium on groundfish permits, initiated an effort control program for days at sea (DAS), and initiated mandatory reporting of landings (NEFMC, 1994)
1994	Amendment 6 to the FMP	Established large-scale closed areas and trip limit for haddock
1996	Sustainable Fisheries Act (SFA) of 1996	Required overfishing definitions, minimum stock size thresholds, and rebuilding plans for overfished stocks (DOC, 1996)
1996	Amendment 7 to the FMP	Established $F_{0.1}$ as the overfishing definition, set minimum stock size thresholds, reduced DAS allocations, eliminated exemptions to the effort control program (NEFMC, 1996)
1997	NEFMC Overfishing Definition Review Panel formed	Developed recommendations for biological reference points and overfishing definitions to conform with SFA requirements (Applegate et al., 1998)
2000	CLF and four other organizations sued NMFS to cease overfishing of cod, haddock, and yellowtail flounder	Federal District Court of the District of Columbia ruled in 2001 that NMFS was not in compliance with SFA requirements. Court accepted the settlement agreement in 2002 which required the completion of Amendment 13 to eliminate overfishing (U.S. District Court for the District of Columbia, 2002)
2000	NEFMC Groundfish Overfishing Definition Committee formed	Recommended age-based methods be applied to estimate MSY reference points
2002	First Groundfish Assessment Review Meeting (GARM I)	Conducted stock assessments for all groundfish stocks in FMP and established baseline data for re-evaluation of biological reference points (NEFSC, 2002a)
2002	Working Group on Re-Evaluation of Biological Reference Points for New England Groundfish formed	Evaluated alternative approaches for estimating biological reference points. Established MSY-based reference points for use in Amendment 13 and $F_{40\%}$ as an F_{MSY} proxy (NEFSC, 2002b)
2003	Groundfish Peer Review Panel formed	Reviewed the adequacy of revised estimates of biological reference points for use in Amendment 13
2004	Amendment 13 to the FMP	Established comprehensive plan to rebuild groundfish stocks and to satisfy the settlement agreement (NEFMC, 2003)
2005	Second Groundfish Assessment Review Meeting (GARM II)	Conducted stock assessments for all groundfish stocks in the FMP to estimate stock condition when Amendment 13 was implemented on 1 May 2004 (Mayo and Terceiro, 2005)
2008	Third Groundfish Assessment Review Meeting (GARM III)	Will conduct stock assessments for all groundfish stocks in he FMP to monitor rebuilding progress. Will re-evaluate biological reference points if necessary

management plan (NEFMC, 2003) addressed the requirement to cease overfishing (U.S. District Court for the District of Columbia, 2002). This plan required substantial reductions in fishing mortality (effort) along with other measures to reduce overfishing (Table 2). Case studies of two depleted New England groundfish stocks, Georges Bank haddock (*Melanogrammus aeglefinus*) and Southern New England/Mid-Atlantic yellowtail flounder (*Limanda ferruginea*), provide an historic perspective on overfishing and show how rebuilding plans were designed. We conclude by describing how adaptive management can be used to re-evaluate 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.

2. Legislative mandates

The U.S. Sustainable Fisheries Act (DOC, 1996; revised as the Magnuson Stevens Fishery Conservation and Management Reauthorization Act (MSRA) DOC, 2007) states that, "Conservation and management measures shall prevent overfishing while achieving on a continuing basis, the optimum yield from each fishery for the

Table 2
Estimates of B_{MSY} (thousand mt) and F_{MSY} for 10 New England groundfish stocks with age-structured assessments along with the fishing mortality projected to rebuild ($F_{REBUILD}$) the stock with a probability of 0.50 by 2014, the ratio of estimated fishing mortality in 2004 to F_{MSY} and that estimated spawning biomass in 2004 to B_{MSY} at the start of Amendment 13 from Mayo and Terceiro (2005), and the ratio of the median projected spawning biomass in 2008 to B_{MSY} under the rebuilding plan (NEFMC, 2003) if applicable

Groundfish stock	B_{MSY}	F_{MSY}	$F_{REBUILD}$	F_{2004}/F_{MSY}	B_{2004}/B_{MSY}	B_{2008}/B_{MSY}
Georges Bank cod	216.8	0.18	0.18[a]	1.33	0.10	0.23
Georges Bank haddock	250.3	0.26	0.24	0.92	0.47	0.86
Georges Bank yellowtail flounder[b]	58.8	0.25	0.23	7.00	0.14	0.42
Southern New England–Mid-Atlantic yellowtail flounder	69.5	0.26	0.17	3.81	0.01	0.65
Cape Cod–Gulf of Maine yellowtail flounder[c]	12.6	0.17	0.07	4.41	0.09	0.60
Gulf of Maine cod	82.8	0.23	0.22	2.52	0.25	0.64
Witch flounder[d]	19.9	0.16	–	1.25	1.06	–
American plaice	28.6	0.17	0.15	0.88	0.49	0.79
Gulf of Maine winter flounder[d]	4.1	0.43	–	0.30	0.84	–
Southern New England–Mid-Atlantic winter flounder	30.1	0.32	0.23	1.19	0.13	0.48
Acadian redfish[e]	236.7	0.04	0.01	0.06	0.74	0.65

[a] The ending year of the rebuilding plan is 2026.
[b] The results are reported for the "major change VPA" scenario (Mayo and Terceiro, 2005).
[c] The ending year of the rebuilding plan is 2023.
[d] No rebuilding plan is required.
[e] The ending year of the rebuilding plan is 2051.

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 overfished (defined at the stock biomass below the limit at which MSY can be produced, on a continuing basis), 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 10 years, but includes an exception 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 below a minimum stock size threshold (e.g., 50% of B_{MSY} for many stocks, NMFS, 1998). A translation of this legal text into biological reference points for fisheries is "MSY is the overall goal, F_{MSY} is the overfishing threshold, and B_{MSY} is the rebuilding target." However, adopting these goals imposes technical requirements for estimating biomass reference points and developing rebuilding plans within required time frames. Experiences with New England groundfish and adaptive rebuilding plans illustrate how legislative mandates were met while considering these technical challenges.

3. Management by lawsuit

The legislative mandate to stop overfishing allowed the environmental Non-Governmental Organization (E-NGO) the Conservation Law Foundation (CLF) to sue NMFS in 1991 to cease overfishing on New England groundfish (Table 1). This lawsuit led to Amendment 5 (NEFMC, 1994) and Amendment 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 (Table 1, Fig. 1). These areas were closed to all fishing gears that were capable of catching groundfishes, including otter trawls, gillnets, longlines, and dredges. Year-round closed areas were established in the Western Gulf of Maine in 1998 and on Cashes Ledge in 2002 to reduce fishing mortality on Gulf of Maine cod and other species. Individual vessels were allocated a baseline number of fishing days at sea based on their recorded fishing history. Management measures from Amendments 5 and 7 were effective for some stocks such as Georges Bank haddock (see below), but not for others. In particular, stock assessments indicated that Atlantic cod stocks in the Gulf of Maine and Georges Bank continued to experience overfishing through the late-1990s (NEFSC, 2002a).

The lack of progress in reducing fishing mortality on cod led the CLF and four other E-NGOs to sue NMFS again in 2000 (Table 1). This lawsuit asserted that NMFS was not in compliance with its legal mandate to cease overfishing on Atlantic cod and other groundfish stocks. The E-NGOs 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.

4. 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 (Table 1). Prior to the Sustainable Fisheries Act of 1996, New England groundfish were managed

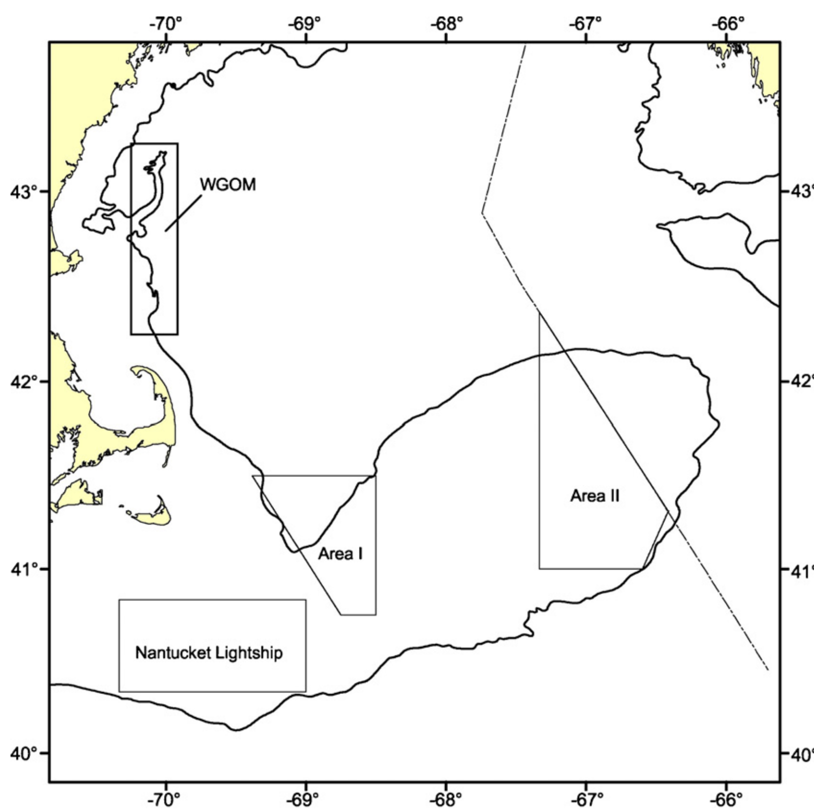

Fig. 1. Four areas that were closed year-round to all fishing gears capable of catching groundfish in the northwest Atlantic: Closed Area I, Closed Area II, the Nantucket Lightship Closed Area, and the Western Gulf of Maine Closed Area (WGOM).

according to various overfishing definitions. In 1991, Amendment 4 of the Northeast Multispecies Plan specified an overfishing definition as the fishing mortality rate that would produce 20% of unfished spawning biomass per recruit ($F_{20\%}$, see, for example, Gabriel et al., 1989 and Goodyear, 1993) for most groundfish stocks. A national review panel recommended that minimum biomass thresholds be established and warned that some of the overfishing definitions specified in Amendment 4 were greater than F_{MSY} (Rosenberg et al., 1994). The next change occurred in 1996, when Amendment 7 (NEFMC, 1996) specified $F_{0.1}$ (Gulland and Boerema, 1973) as an overfishing reference point for most principal groundfish stocks and set minimum stock size thresholds for the main stocks (Table 1) below which estimated recruitment was lower than when spawning biomass was above the threshold. As a result, these initial thresholds were systematically lower than the biomasses needed to produce maximum sustainable yield (i.e., B_{MSY}). Passage of the Sustainable Fisheries Act (SFA) in 1996 would subsequently require thresholds equal to or above B_{MSY}.

The New England Fishery Management Council formed an Overfishing Definition Review Panel in 1997 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 (e.g., surplus production) models; (2) dynamic pool models (i.e., use a proxy for F_{MSY} with $F_{MSY} = F_{0.1}$ or $F_{20\%}$, and calculate B_{MSY} as the product of average recruitment and biomass per recruit at the F_{MSY} proxy); (3) survey proxies of biomass and exploitation ratios from periods presumed to produce relatively large sustainable yields when 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, prior to intensive distant water fleet fishing on the groundfish stocks (Boreman et al., 1997), and when systematic bottom trawls were initiated (Grosslein, 1969). For the principal groundfish stocks, estimates of B_{MSY} from biomass dynamics models were substantially greater than the Amendment 7 rebuilding targets (Fig. 2).

One concern with the use of surplus production methods to estimate MSY and B_{MSY} was that many of the groundfish stocks had experienced long-term declines in abundance (e.g., one-way trips) and lacked contrast or full cycles in their exploitation history. In particular, most New England groundfish stocks have been heavily exploited and overfished for decades. As a result, the exploitation histories of most stocks included many observations of stock dynamics at high-fishing effort but relatively few, if any, observations at high biomass and low effort or at low biomass and low effort. The lack of observations at low effort can lead to estimation problems and unreliable estimates of reference points (see, for example, Hilborn, 1979). In 2000, the NEFMC formed the Groundfish Overfishing Definition Committee to address concerns about the use of biomass dynamics models for deriving overfishing definitions and rebuilding targets for New England groundfish. This Committee concluded that age-based production models should be applied for estimating rebuilding schedules and rebuilding targets because these models were likely to provide more reliable estimates and a better approximation of recruitment dynamics.

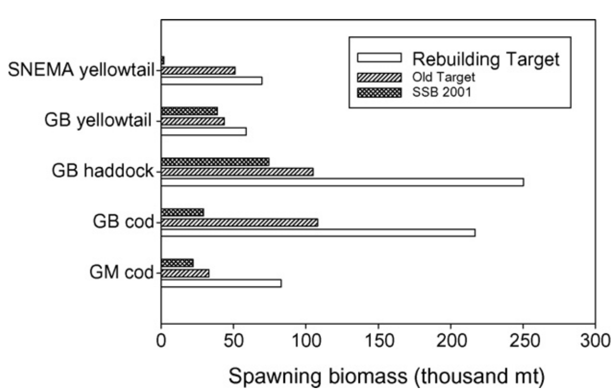

Fig. 2. Estimates of spawning biomass in 2001 (NEFSC, 2002a) along with the new (NEFSC, 2002b; Cadrin, 2003) and old (NEFMC, 1996) rebuilding targets for five primary New England groundfish stocks: SNEMA yellowtail, Southern New England–Mid-Atlantic yellowtail flounder; GB yellowtail, Georges Bank yellowtail flounder; GB haddock, Georges Bank haddock; GB cod, Georges Bank cod; GM cod, Gulf of Maine cod.

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, 2002b). The Working Group developed age-based estimates of MSY reference points for stocks with time series of age-structured assessment information. 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. Both of these approaches are summarized below (see, for example, Sissenwine and Shepherd, 1987; NEFSC, 2002b). 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 (i.e., NRC, 1998). Effective application of these techniques can be compromised by a lack of sufficient observations on stock and recruitment over a range of biomass to provide suitable contrast. In this case, it may be 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} (Williams and Shertzer, 2003; Kell et al., 2005), which requires estimation of recruitment (R) at high-spawning biomass (SB). The Working Group recommended $F_{40\%}$ as a proxy for F_{MSY} for most New England groundfish because it was judged to be likely to maintain adequate spawning potential based on the results of Clark (1993), Thompson (1993), Mace and Sissenwine (1993), and Mace (1994). Furthermore, based on the results of Dorn (2002), $F_{50\%}$ appears to be an appropriate target harvest rate for many long-lived West Coast *Sebastes* spp., and therefore the Working Group recommended $F_{50\%}$ as a proxy for F_{MSY} of Acadian redfish (*Sebastes fasciatus*).

The empirical non-parametric method estimated B_{MSY} as the product of an estimate of the expected average or median value of recruitment times the estimated spawning biomass per recruit associated with potential proxies for F_{MSY}. For several stocks, recruitment estimates prior to the assessment time period were hindcast using research survey catch at age and estimated catchabilities. These hindcast recruitments were often larger than the recruitment estimates from the assessment time periods. The expected value of the recruitment series ($E[R]$) was multiplied by the biomass per recruit at the F_{MSY} proxy (BPR_{MSY}) to compute point estimates of B_{MSY} as $B_{MSY} = E[R] \cdot BPR_{MSY}$. Two types of $E[R]$ times BPR analyses were undertaken, depending on the relationship between stock and recruitment. For cases where recruitment appears to be reduced at lower spawning biomasses, the average recruitment for a higher biomass stanza was evaluated as the proxy for the expected recruitment at MSY; otherwise the average recruitment over all observations was used. This empirical approach for estimating B_{MSY} assumes that compensatory mechanisms such as changes in growth or maturity schedules or reduced early life history survival are negligible over the range of expected biomass considered.

The parametric method used a fitted stock–recruitment relationship along with yield- and spawning biomass-per-recruit estimates to calculate MSY-based references points using a standard algorithm (Sissenwine and Shepherd, 1987; NEFSC, 2002b). 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., $F_{40\%}$ or $F_{50\%}$). 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 (see, for example, Brodziak and Legault, 2005). A total of 24 candidate parametric models were considered for each stock (NEFSC, 2002b). These included models with either Beverton-Holt or Ricker stock–recruitment dynamics. Autoregressive and independent error structures were allowed. For some models, priors were assumed for steepness or the slope at the origin of the stock–recruitment relationship based on the results of Myers et al. (1999). Similarly, priors for unfished recruitment were assumed for some models based on the empirical distribution of recruitment estimates at high-spawning biomass. All combinations of models were fit to the stock–recruitment observations and the best fitting model was selected using a hierarchy of goodness-of-fit criteria which included Akaike's Information Criterion (NEFSC, 2002b, see pp. 22–24).

Application of the non-parametric and parametric approaches resulted in some appreciable 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 to 250,300 mt, while the F_{MSY} remained at 0.26 year^{-1}. The Working Group recognized that setting biomass targets to levels not seen in decades, or in some cases, higher than the maximum level estimated in the assessment time horizon (≈200,000 mt for haddock), would be a difficult proposition for managers, fishermen and the public to accept. In cases where the Working Group recommended such targets, they were based on estimated recruitment histories and biomass-per-recruit values that should be realized if fisheries were managed to achieve their fishing mortality targets and biomass dynamics were stationary. For many groundfish stocks, higher spawning biomasses would be expected to produce higher and more stable recruitments (e.g., Brodziak et al., 2001) and lead to larger fishery catches, in the long-term. In two notable examples where target biomasses have been set at high levels relative to recent history (e.g., sea scallop, *Placopecten magellanicus*: Hart and Rago, 2006; summer flounder, *Paralichthys dentatus*: Terceiro, 2006), fishery yields and catch rates have increased steadily and substantially when fishing mortality rates were reduced.

The Working Group also considered stochastic medium-term projections to evaluate rebuilding plans and incorporated uncertainty in the current population estimate (via bootstrap replicates or other variance estimator) and variability in predicted recruitment (i.e., Brodziak et al., 1998). Using the parametric method, recruitment variability was generated by randomly sampling from the estimated error distribution of the fitted stock–recruitment model. Similarly, using the non-parametric method, recruitment variability was generated by resampling from either the observed recruitments, recruits-per-spawner or their empirical cumulative distribution functions. For each stock, the stock–recruitment model used to assess rebuilding times was the same as that used for estimating reference points. Thus, the Working Group provided recommendations on both the rebuilding targets and the projection model for developing rebuilding plans.

5. Developing a plan to rebuild New England groundfish

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 (Table 1). 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 the principal groundfish stocks, Southern New England–Mid-Atlantic yellowtail flounder, Georges Bank yellowtail flounder, Georges Bank haddock, Georges Bank cod, and Gulf of Maine cod (Fig. 2), were at the heart of the controversy, primarily because achieving the higher biomass targets would require greater reductions in fishing effort. In contrast, the moderate changes in fishing mortality reference points were not 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 F_{MSY}. 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 NMFS was "moving the goal posts" for stock rebuilding which generated uncertainty in the management process and ongoing debate (Greene, 2002).

As the Court-ordered deadline for completion of Amendment 13 approached, there were numerous proposals to alter the process for completing the fishery management plan and establish rebuilding goals, given uncertainty and skepticism about some of the biomass targets. One proposal was to use the highest 3-year average biomasses of groundfish stocks projected from bottom trawl survey data collected since 1963 as an alternative proxy for rebuilding targets. While these calculations showed that these projected biomasses would be comparable to the targets put forward by the Working Group (NEFSC, 2002b), there was a logical inconsistency in this approach because the biomass targets needed to be consistent with the fishing mortality target to produce MSY, especially as a basis for stock projections. The survey-based values were not logically linked to $F_{40\%}$ and as a result, were rejected. An independent panel of stock assessment experts, the Groundfish Peer Review Panel, addressed the question of whether the best estimates of reference points recommended by the Working Group were adequate for use in Amendment 13. The Panel concluded that they were, because, despite uncertainty in the B_{MSY} targets, biomasses would be expected to eventually increase to B_{MSY} if the F_{MSY} proxies were successfully implemented.

Another issue arose over the rebuilding time frame of 10 years required by law to increase groundfish stocks to their target biomasses. Several stocks were projected to be incapable (in median terms) of rebuilding in a 10-year time frame even if fishing mortality was zero. As a result, an alternative provision for interpreting the National Standard Guidelines came into play. Stocks that are projected to have a less than 50% probability of rebuilding within 10 years at zero fishing mortality are allowed to have an extended rebuilding time frame equal to the number of years needed to rebuild with 50% probability at zero fishing mortality 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. 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 time frame 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, one last minute change was made to the proposed Amendment based on an industry-sponsored initiative. In this case, the amendment was changed to allow for a different interpretation of what constituted an MSY control rule. The prevailing interpretation of an MSY control rule, as described in the NMFS National Standard Guidelines, suggested that estimated fishing mortality could not exceed F_{MSY}, the overfishing limit, at any time. The change defined an MSY control rule as any specific plan to achieve MSY in a fixed time frame. Thus, F_{MSY} could be exceeded during the initial part of a rebuilding time frame as long as B_{MSY} was achieved by the end of the time frame. Based on this change, the amendment included phased fishing mortality reduction strategies were developed for several stocks, including Southern New England–Mid-Atlantic yellowtail flounder. For this stock, roughly a 60% reduction in fishing effort would have been needed to immediately reduce fishing mortality to F_{MSY}. Subsequently, the MSRA established that overfishing (defined as when F_{MSY} was exceeded) would have to end by 2010 for all stocks (DOC, 2007).

After more than 4 years of development, implementation of Amendment 13 began on 1 May 2004. Some of the major components of the final plan were: continuation of year-round and "rolling" closed areas, albeit with special access programs, reductions in days at sea (DAS), creation of a special access program to some closed areas when fishing 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 catches for each transboundary stock, including Georges Bank haddock and cod in addition to yellowtail flounder.

6. Case study of a recovering stock: Georges Bank haddock

Georges Bank haddock had been overfished for decades prior to mid-1990s (Brodziak and Link, 2002). The stock had experienced appreciable long-term declines in spawning biomass and recruitment (Brodziak et al., 2001, 2006), 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 (Fig. 3(a)). 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 on Georges Bank haddock averaged 0.35 $year^{-1}$ during 1980–1993 which was 36% higher than the current overfishing limit for this stock (F_{MSY} = 0.26 $year^{-1}$). Since 1994, annual fishing mortality has averaged about 0.17 $year^{-1}$, or roughly 30% below F_{MSY}.

Stock response to reductions in fishing mortality during the 1990s was dramatic (Fig. 3(b)). Under persistent overfishing in the 1980s, Georges Bank haddock spawning biomass declined from over 67,400 mt in 1980 to only 14,600 mt in 1993. Since 1994, the spawning biomass has increased substantially following the decrease in fishing mortality. The spawning biomass had increased to over 115,000 mt by 2003–2004, the highest abundance of adult spawners since 1966 and roughly an eightfold increase since 1993.

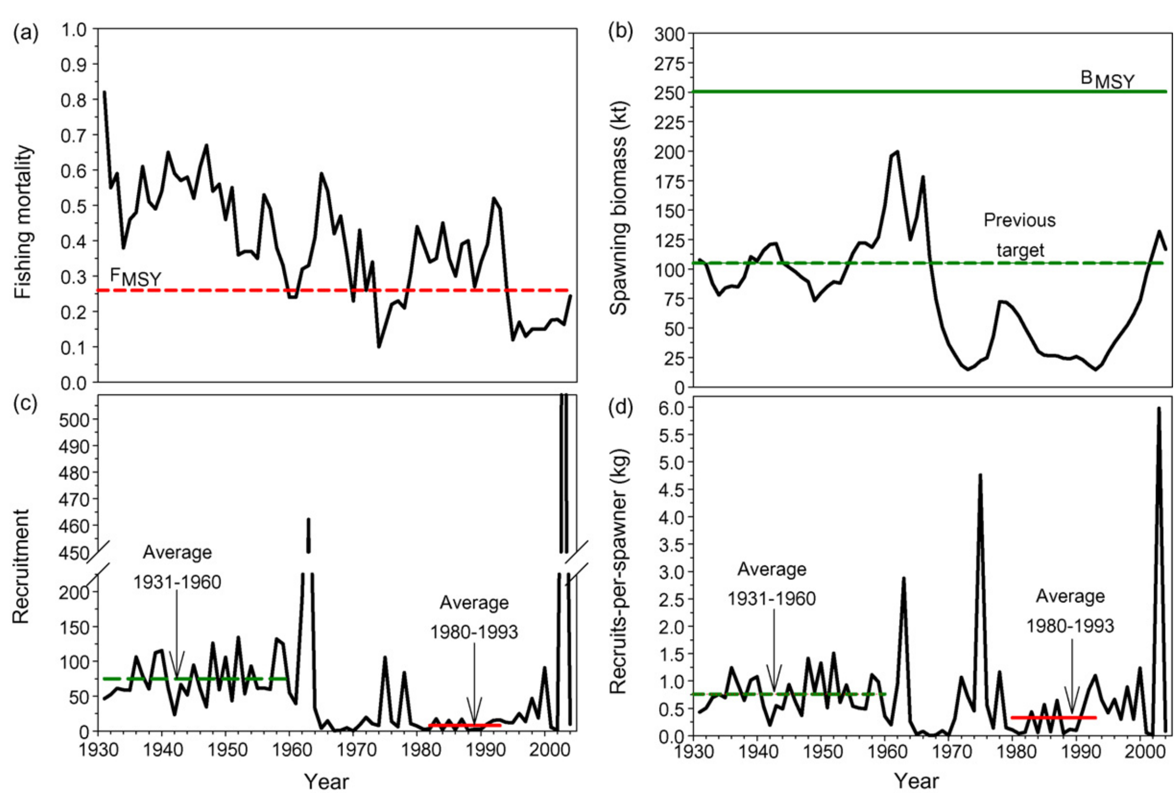

Fig. 3. Estimates of fishing mortality (a), spawning biomass (b), recruitment (c), and recruits-per-spawner (d) for Georges Bank haddock during 1931–2004 (Brodziak et al., 2006).

This represented a substantial improvement in the reproductive capacity of this stock. Nonetheless, the Georges Bank haddock stock was still considered to be overfished in 2004 since its spawning biomass was less than half of its rebuilding target.

Georges Bank haddock recruitment had a similar positive response to reduced fishing mortality (Fig. 3(c)). Recruitment averaged only 8 million age-1 recruits per year during 1980–1993 compared to an annual average of 75 million during 1931–1960. Recruitment increased threefold to an average of about 24 million fish during 1994–2003. The prospects for continued high recruitment appear to be good because the spawning biomass is above an apparent productivity threshold of 75–85,000 mt. In fact, when Georges Bank haddock spawning biomass exceeds its 1931–1998 median value of about 82,000 mt, the odds of realizing above-average recruitment increase over 20-fold (Brodziak et al., 2001). Similarly, the expected magnitude of recruitment increases over threefold when spawning biomass exceeds this threshold. Furthermore, recent assessment data indicate that the 2003 year class may be exceptionally abundant with an estimated size of about 789 million recruits (Brodziak et al., 2006).

Recruits-per-spawner data show that survival ratios were relatively low from the late-1960s to early-1990s in comparison to those during the 1930s to 1960s (Fig. 3(d)). 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-spawner. Recruits-per-spawner averaged about 0.33 kg^{-1} during 1980–1993 and had increased by 50% to average 0.51 kg^{-1} during 1994–2002. Further increases in recruits-per-spawner may occur since, at least historically, the expected value of recruits-per-spawner was higher. The recent trends in average recruits-per-spawner suggest that survival ratios may increase to the historical (1931–1960) average of 0.76 kg^{-1}. If the recent increase in productivity can be sustained, it is possible that historical yields on the order of 46,000 mt per year may be achieved.

The formal rebuilding plan for Georges Bank haddock adopted in Amendment 13 specifies that fishing mortality should be set to the overfishing limit F_{MSY} = 0.26 $year^{-1}$ during 2004–2008 (NEFMC, 2003). In general, the median of the distribution of spawning biomass from stochastic projections incorporating uncertainty in the initial stock size estimates and recruitment (Brodziak et al., 1998) was used to measure progress towards rebuilding. In 2009, the fishing mortality would be reduced to $F_{REBUILD}$ = 0.245 $year^{-1}$, which was projected to correspond to a 50% chance that spawning biomass meets or exceeds B_{MSY} = 250,300 mt in 2014. This rebuilding strategy is subject to change if the estimated spawning biomass in 2008 is not close to the projected median spawning biomass in 2008 or if average fishing mortality during 2004–2008 is not close to F_{MSY}. The strategy of fishing at F_{MSY} and then adjusting fishing mortality as needed to achieve the rebuilding target is the adaptive management component of the Amendment 13 groundfish rebuilding plan described below.

7. Case study of a depleted stock: Southern New England–Mid-Atlantic yellowtail flounder

In contrast to 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. Historical assessments conducted on the Southern New England component of the Southern New England–Mid-Atlantic yellowtail flounder stock indicated that fishing mortality was greater than F_{MSY} during the 1940s to 1960s (Royce et al., 1959; Lux, 1969; Brown and Hennemuth, 1971). Estimates of fishing mortality for the entire Southern New England–Mid-Atlantic yellowtail stock increased in the 1970s and 1980s (Fig. 4(a)), and the stock was depleted to record low biomass

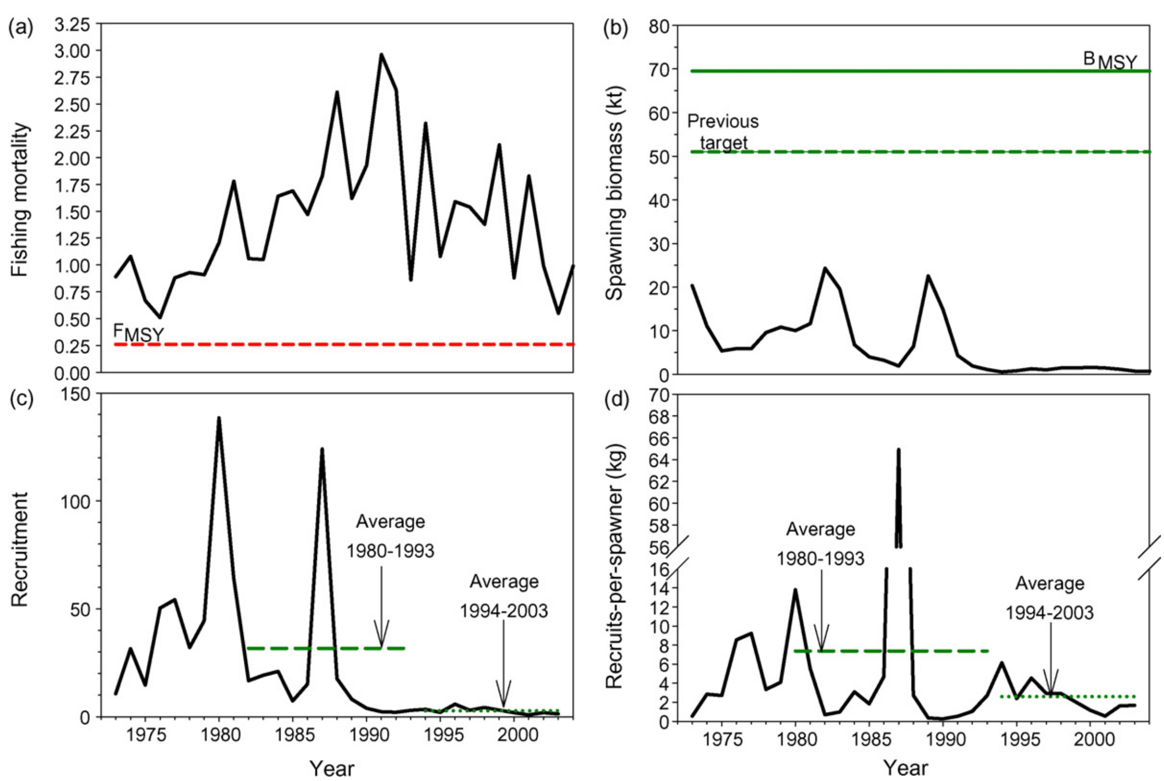

Fig. 4. Estimates of fishing mortality (a), spawning biomass (b), recruitment (c), and recruits-per-spawner (d) for Southern New England–Mid-Atlantic yellowtail flounder during 1973–2004 (Cadrin and Legault, 2005).

by the early-1990s (Fig. 4(b)), despite strong recruitment from 2-year classes in the 1980s (Fig. 4(c): Cadrin, 2003; Cadrin and Legault, 2005). According to the most recent stock assessment (Cadrin and Legault, 2005), no strong year classes have occurred since the late-1980s, although subsequent survey data indicates a moderate increase in recruitment (Cadrin and Brown, 2006). Spawning biomass gradually increased from the record low of 553 mt in 1994 to 1604 mt in 2000, but then decreased to 694 mt in 2004 (Fig. 4(b)). Yellowtail survival ratios were 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 (Fig. 4(d)). Survival ratios have been low to moderate since 1987 (Fig. 4(d)). Experiences from other yellowtail resources on Georges Bank (Legault and Stone, 2004) and the Grand Banks (Walsh et al., 2002) suggest that yellowtail flounder are both resilient and productive, because those stocks responded quickly to decreased fishing mortality with greater spawning biomass and stronger recruitment.

A technical difficulty associated with developing a rebuilding plan for Southern New England–Mid-Atlantic yellowtail is what to expect for future recruitments, in the short-term and eventually at higher 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 (1963–2000) recruitment. 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 10 years (NEFMC, 2003). This “back-loaded” rebuilding plan includes target fishing mortality rates that are greater than F_{MSY} in the short-term, followed by low-fishing mortality rates (e.g., 65% of F_{MSY}) in the medium-term. Specifically, the target fishing mortality rates for the phased rebuilding plan are: $F_{2004} = F_{2005} = 0.37\,\text{year}^{-1}$, $F_{2006} = F_{2007} = F_{2008} = 0.26\,\text{year}^{-1}$, and $F_{2009–14} = 0.17\,\text{year}^{-1}$ (NEFMC, 2003). 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.

8. An adaptive management strategy

Amendment 13 includes the characteristics of a passive-adaptive management strategy (Walters, 1986) to attain the biomasses producing maximum sustainable yield for New England groundfish stocks. This strategy was consistent with applicable U.S. SFA guidelines and aimed to eliminate overfishing and rebuild the following stocks: Gulf of Maine cod, Gulf of Maine and Georges Bank haddock, Acadian redfish, Southern New England–Mid-Atlantic winter flounder (*Pseudopleuronectes americanus*), Southern windowpane flounder (*Scophthalmus aquosus*), and ocean pout (*Zoarces americanus*). In contrast, phased rebuilding plans were developed for the following stocks: Georges Bank cod, American plaice (*Hippoglossoides platessoides*), Cape Cod–Gulf of Maine and Southern New England–Mid-Atlantic yellowtail flounder, and white hake (*Urophycis tenuis*). Rebuilding plans were not required for the witch flounder (*Glyptocephalus cynoglossus*) and Gulf of Maine winter flounder stocks. The adaptive strategy had six primary elements and assumptions.

First, for a number of stocks, estimates of B_{MSY} were beyond the observed range of stock biomasses due to persistent overfishing and commensurate low recruitments. Although the current estimates of B_{MSY} were based on the best estimates of average recruitment, current somatic growth and fishery selection parameters, uncertainty remained regarding how these critical population rates may change during stock rebuilding, and 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 rates of recruitment, growth and natural mortality change as the stock complex is rebuilt.

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 B_{MSY}, 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, and the Peer Review of Groundfish Science (February 2003), there was general consensus that estimates and proxies for F_{MSY} (Table 2) were robust to uncertainty in B_{MSY} and were appropriate thresholds for management. Therefore, attaining fishing mortalities at or below these rates was the cornerstone of the management strategy.

Fourth, the extension of the rebuilding period (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 then adjusting either the fishing rates or the biomass reference points in 2009, consistent with the pace of rebuilding relative to the nominal targets. This approach avoids frequent adjustments to biomass reference points which can be influenced by noisy data (e.g., Punt and Ralston, 2007). When the 2004–2014 rebuilding period was chosen for all stocks, the strategy of fishing at or below F_{MSY} for a substantial 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 rate schedule was specified for each New England groundfish stock with an adaptive rebuilding plan (NEFMC, 2003; Figs. 5 and 6). The fishing mortality schedule

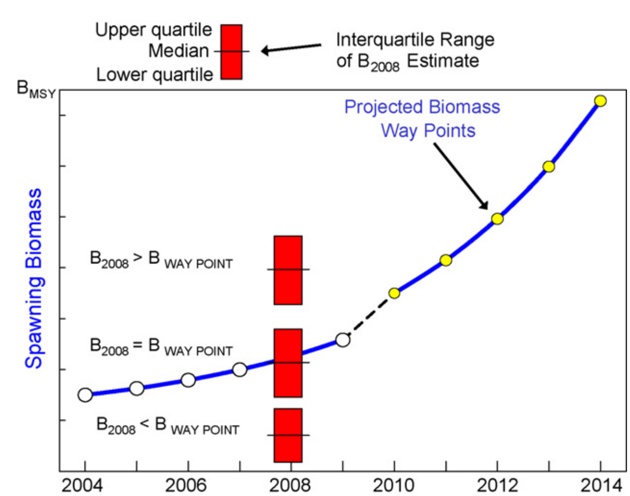

Fig. 5. Comparison of the projected median spawning biomass rebuilding trajectory (open circle, $B_{WAY POINT}$) and the interquartile range of spawning biomass in 2008 (B_{2008}) as estimated from a stock assessment conducted in 2008 to categorize whether stock rebuilding is progressing faster than expected (top boxplot, $B_{2008} > B_{WAY POINT}$), is on track (middle boxplot, $B_{2008} = B_{WAY POINT}$), or is progressing slower than expected (bottom boxplot, $B_{2008} < B_{WAY POINT}$).

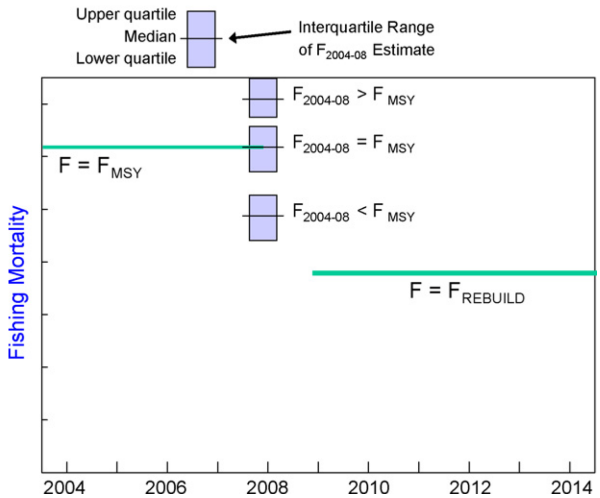

Fig. 6. Comparison of the projected median fishing mortality rebuilding trajectory (solid line, $F = F_{MSY}$) and the interquartile range of average fishing mortality during 2004–2008 ($F_{2004–08}$) as estimated from a stock assessment conducted in 2008 to categorize whether the fishing mortality rate during the stock rebuilding plan is higher than expected (top boxplot, $F_{2004–08} > F_{MSY}$), is on track (middle boxplot, $F_{2004–08} = F_{MSY}$), or is lower than expected (bottom boxplot, $F_{2004–08} < F_{MSY}$).

had three parts. In the first part, fishing mortality rates for all stocks were assessed at the beginning of Amendment 13 (Table 1). Fishing mortality rates for the first 5 years of the plan were to be maintained at F_{MSY}. The fishing mortality rates during in 2009–2014 would then be set 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, maturity at age). In the second part, the median rebuilding trajectory in spawning biomass (Fig. 5) from stochastic age-structured 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 spawning biomass in 2008 ($B_{WAY POINT}$) 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. For this review, estimates of spawning biomass in 2008 (B_{2008}) and its interquartile range (Fig. 5, boxplot) from stock assessments conducted in 2008 (Table 1) would be used to judge the progress towards the interim stock rebuilding targets. Based on the findings of that review, one of three determinations would be made: (i) stock rebuilding is on track, that is, the interim spawning biomass target lies within the inter-quartile range of the estimate of spawning biomass in 2008 (Fig. 5, middle boxplot), consistent with the projected rebuilding trajectory; (ii) stock rebuilding is progressing faster than expected (Fig. 5, top boxplot); or (iii) stock rebuilding is progressing slower than expected (Fig. 5, bottom boxplot). Similarly, estimates of average fishing mortality during 2004–2008 ($F_{2004–08}$) and its interquartile range (Fig. 6, boxplot) from the stock assessment conducted in 2008 would be used to judge whether the fishing mortality rate during the stock rebuilding plan is on track (Fig. 6, middle boxplot), higher than expected (Fig. 6, top boxplot), or lower than expected (Fig. 6, bottom boxplot).

Sixth, depending on the estimated spawning biomass in 2008 and average fishing mortality in 2004–2008, a 3×3 array of 9 possible causal factors and hypotheses along with advice on adaptive management actions was prescribed (Table 3). 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 upon the causal factors contributing to the observed stock biomasses. For example, if the stock abundance in 2008 was judged to be below the projected path, the critical question was why did this happen? If fishing mortality rates were consistently above F_{MSY}, the question to be assessed was if F_{MSY} values 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 improvement in the stock could have occurred, due to these stock conditions, even though the stock was experiencing fishing mortality in excess of F_{MSY}. The management and science responses in these cases would be different. Potential factors associated with all nine cases for stock biomass and fishing mortality rate conditions during 2004–2008 were described (Table 3). These factors would be examined in detail to develop appropriate adaptive management advice pertaining to the second half of the rebuilding period (i.e., 2009–2014).

Table 3
Potential causal factors to explain stock rebuilding status with respect to spawning biomass in 2008 (B_{2008}) and average fishing mortality during 2004–2008 ($F_{2004–08}$) and advice on adaptive management actions corresponding to nine cases of measuring stock rebuilding progress with respect to B_{2008} and $F_{2004–08}$

	$B_{2008} > B_{WAY POINT}$ (stronger recruitment or higher growth rates or lower natural mortality than projected)	$B_{2008} = B_{WAY POINT}$ (recruitment, growth, and natural mortality consistent with projections)	$B_{2008} < B_{WAY POINT}$ (weaker recruitment or lower growth rates or higher natural mortality than projected)
$F_{2004–08} > F_{MSY}$ (effort controls ineffective)	Identify cause of high biomass; re-estimate B_{MSY} and F_{MSY} as appropriate; reduce effort to achieve F_{MSY}	Re-estimate B_{MSY} and F_{MSY} as appropriate; reset $F_{REBUILD}$ if necessary; reduce effort to achieve $F_{REBUILD}$	Identify cause of low biomass; re-estimate B_{MSY} and F_{MSY} as appropriate; reset $F_{REBUILD}$ if necessary; consider extending rebuilding period; reduce effort to achieve $F_{REBUILD}$
$F_{2004–08} = F_{MSY}$ (effort controls effective)	Identify cause of high biomass; re-estimate B_{MSY} and F_{MSY} as appropriate; reset $F_{REBUILD}$ if necessary; maintain effort to keep fishing mortality less than or equal to F_{MSY}	Re-estimate B_{MSY} and F_{MSY} as appropriate; reset $F_{REBUILD}$ if necessary; reduce effort to achieve $F_{REBUILD}$	Identify cause of low biomass; re-estimate B_{MSY} and F_{MSY} as appropriate; reset $F_{REBUILD}$ if necessary; consider extending rebuilding period; reduce effort to achieve $F_{REBUILD}$
$F_{2004–08} < F_{MSY}$ (effort controls more effective than expected)	Identify cause of high biomass; re-estimate B_{MSY} and F_{MSY} as appropriate; reset $F_{REBUILD}$ if necessary; maintain effort to keep fishing mortality less than or equal to F_{MSY}	Re-estimate B_{MSY} and F_{MSY} as appropriate; reset $F_{REBUILD}$ if necessary; maintain effort if $F_{2004–08}$ will rebuild stock to B_{MSY}, otherwise reduce effort to achieve $F_{REBUILD}$	Identify cause of low biomass; re-estimate B_{MSY} and F_{MSY} as appropriate; reset $F_{REBUILD}$ if necessary; consider extending rebuilding period; reduce effort to achieve $F_{REBUILD}$

9. 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, one 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 average 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 over consistent time frames for depleted fish stocks. The general approach here is that fishing effort should be appropriately managed so that robust estimates of MSY and B_{MSY} are emergent properties of the management system.

For many groundfish stocks in the New England region, achieving rebuilding goals will require further reductions 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 guarantee that B_{MSY} targets are achieved. 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 population per capita 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 or through other measures is important, but will not be sufficient to recover migratory stocks or ones that are experiencing high rates of predation at low-population size. Overall, expectations of single-stock productivity may need to be revised as multispecies resources rebuild simultaneously to account for increased biological interactions.

A management strategy that sets fishing mortality to equal F_{MSY} should lead to stock recovery if the necessary biological and environmental conditions 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} under present conditions for some stocks 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–Mid-Atlantic 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. Furthermore, it is highly desirable to use management strategy evaluation to discern the likely outcomes of alternative rebuilding plans (see other papers in this issue).

Given the complexity of biological, social, and environmental interrelationships in marine ecosystems and modest abilities 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. 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 (e.g., since 1931) in 2003. On the other hand, some surprises may be negative. For example, it seems possible that the Southern New England–Mid-Atlantic yellowtail flounder may be currently experiencing depensatory dynamics or that changing oceanographic conditions (e.g., Mountain, 2004) 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 to or below F_{MSY} has been accomplished for this stock, it will be unknown whether depensation, unfavorable environmental conditions or overfishing are the dominant factors impeding stock recovery. This emphasizes the need for an adaptive management approach for rebuilding overfished stocks that discerns the relative impacts of fishing, compensatory/depensatory stock dynamics, and the role of variability and stationarity of environmental forcing on recruitment.

Another reason for adaptive management is that the stock assessment itself may change as additional years of data become available. In some cases, including additional years of data creates a retrospective pattern in the assessment whereby estimates of stock abundance and fishing mortality rates in a given year change in a consistent direction (Mohn, 1999). These changes can be either positive or negative, and are due to a basic conflict in the data, typically assumed to be due to misreported catch, changes in natural mortality, or changes in survey catchabilities. The consequence of a retrospective pattern for management is that catch limits will be found later to have been set too high or too low to achieve a given fishing mortality rate and stock rebuilding will occur slower or faster than expected. This further emphasizes the adaptive approach to rebuilding plans to appropriately deal with changes to estimated stock abundance due to retrospective patterns. While retrospective patterns have not been observed in the Georges Bank haddock assessment, they were present in the late-1990s for the Southern New England yellowtail flounder assessment, but have since gone away (i.e., the tendency to underestimate fishing mortality in the terminal year ended in 2001) as fishery-dependent sampling has increased substantially (Cadrin and Legault, 2005).

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. Nonstationarity in the processes that influence biomass dynamics presents a fundamental challenge 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.

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