Executive Summary

The *Working Group on Re-Evaluation of Biological Reference Points for New England Groundfish* was created to address the need for a timely re-analysis of the biological bases used for managing the New England groundfish complex. The 19 evaluated stocks comprising the complex are managed under the New England Fishery Management Council's (NEFMC) Northeast Multispecies Fishery Management Plan. Under this plan, overfishing definitions, including biomass thresholds and targets and fishing mortality thresholds and targets, are required and have been previously specified. The purpose of this study was to review the scientific adequacy of the existing overfishing reference points (biomass producing maximum sustainable yield, or Bmsy, and the fishing mortality rate associated with maximum sustainable yield, or Fmsy). It is appropriate to conduct this review now because there are significant new data and methodological improvements available to researchers with which to undertake such re-analyses.

The terms of reference assigned to the Working Group were:

- assemble appropriate demographic, abundance, and fishery catch data with which to re-estimate biomass and fishing mortality rate reference points for 19 New England groundfish stocks covered in Amendment 9 of the Northeast Multispecies FMP,

- agree on appropriate projection methodology (estimates of vital rates and associated stochastic projection methods) with which to estimate maximum long-term yield and associated biomass and fishing mortality rate for the various stocks,

- revise estimates of Bmsy and Fmsy (or proxies), as appropriate,

- project stock status through 2009 relative to long-term biomass targets, and calculate fishing mortality rates necessary to achieve biomass targets by 2009 (if possible),

- comment on methods to estimate target fishing mortality rates for rebuilt stocks that will maximize yield while providing long-term average biomass at Bmsy.

The Working Group included six population dynamics-stock assessment experts from outside the Northeast region of the USA, and was supported by 12 staff members of the Northeast Fisheries Science Center. A NEFMC staff person participated as an observer to interact with the Working Group, provide background material, and participate in review of the final report. The full committee met from 12-14 February in Woods Hole, Massachusetts, and subsequently interacted via e-mail and conference calls. A draft of the final report was circulated to the full Working Group on 8 March, and the Committee met via conference call on 15 March to finalize selection of reference points and to review its draft report.

<u>Background</u>
In the intervening period since the Council adopted its various biomass and fishing mortality

targets and thresholds, a number of limitations of the various estimation approaches used previously to estimate Bmsy and Fmsy have emerged. First, for most of the stocks currently assessed with age-based stock assessment models the biomass and F reference points were determined in weight-based units by using biomass dynamics approaches. This approach has since created some difficulties and confusion regarding the interpretation of annual status of resources, and in making projections of stock performance under mandated recovery plans. For example, the fishing mortality rate reference points (Fmsy) estimated with production model approaches are biomass weighted, meaning that they assume the full force of mortality occurs for all age groups included in the tuning indices and catches. A typical age-based assessment, however, estimates the partial recruitment (selection) 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 assessment methods based on production models. 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 Fmsy. Changes in the biomass weighting have resulted in a “moving target” for managers owing to the effects of year class variations, and having little to do with the underlying fishing mortality on fully selected age groups. These difficulties in interpreting biomass-weighted reference points using age-based assessments, caused the Northeast Stock Assessment Review Committee (SARC) to propose new reference points to be calculated based on methods consistent with the assessment technique used to monitor the stock, and to apply age-based methods wherever possible.

A second issue related to the application of the current reference points is the characteristic of surplus production methods to estimate MSY and Bmsy within the observed ranges of the data, irrespective of the exploitation histories of the resource. Many of the fishery resources of the Northeast region have been heavily exploited and overfished (both growth-overfished 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. Landings data representing the 70-year documented exploitation history probably do not represent the true production potential of this and other fishery resources, because of the high fishing mortality rates and poor selection patterns. Thus, if production models estimate Bmsy as some value within 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 too modest a level.

Several other issues have 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* and its *Review of Northeast Fishery Stock Assessments* 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. Also, since the first Overfishing Definition Review Panel met, the final guidelines for the SFA were issued by NMFS. The existing definitions need to be re-considered in light of the revised guidelines and the practical experience that has been gained in their use. There are significant new data on stock status, particularly related to recovering stocks and the conditions associated with those recoveries (e.g., Georges Bank haddock and yellowtail flounder, and to a lesser degree other species in the groundfish complex) that may shed light on the estimation of proper management targets and thresholds. Given these changes in stock status, and the requirement to rebuild stocks to Bmsy by 2009, new projections of the fishing mortality rates required to meet these targets are needed by managers. Last, the methods used to define management reference points for index-level species do not include a method to project stock status and rebuilding. There is a need for methodological development in this area, and approaches to this problem must be developed. For the reasons stated above, re-estimation of the basic reference points for groundfish management was considered a priority issue.

<u>Organization of the Report</u>

This report is organized into three sections: descriptions of models and quantitative approaches to reference point estimation and prediction methods, analysis of the reference points for the 19 stocks covered in Amendment 9, and a general section related to the conclusions and implications of this work. Numerical data and full computer output from all analyses described herein are included in a companion technical appendix; such data are too voluminous to be included in this summary report.

Methods:

The section on *Estimation and Projection Methodology* describes the multiple approaches used by the Working Group to re-estimate reference points and to make medium-term (10-year) projections of biomass and catch for the various stocks. The approaches are sorted according to the three types of data generally available for the stocks considered. For stocks with full age-based model estimates of stock, recruitment, and biomass per recruit, multiple approaches to describing the relationship between stock and recruitment are evaluated. In this regard, nearly two dozen potential stock-recruitment functional forms were evaluated for the various stocks. A series of objective model diagnostics was developed and applied to all candidate models for the purposes of model comparison.

A model-free (empirical non-parametric) approach was developed for comparison with parametric stock-recruitment model approaches, and also used for stocks where stock-recruitment models could not reliably be fit to data. This approach multiplied various statistical moments (e.g., mean, median, quartiles) of the observed recruitment series by the expected biomass per recruit (from standard yield and spawning biomass per recruit calculations) to estimate the theoretical spawning biomasses associated with fishing at various reference fishing mortality rate levels. This approach was used as a quasi-independent check of stock-recruitment model results and as a basis for inferring the likely biomass had stocks not been growth overfished (i.e., with the observed recruitment and fishing at Fmsy proxies, what should the spawning biomasses for various year classes have been?). For stocks where the non-parametric approach was used to estimate Bmsy, a proxy for Fmsy was chosen to be F40% msp (the fishing mortality rate producing 40% of the maximum spawning potential when F=0.0), based on several published studies of spawning potential requirements associated with sustainable fisheries. For

Acadian redfish, a fishing mortality rate proxy of F50% msp was chosen based on published reviews of similar west coast species. The value of F40%msp was found to be similar to F0.1 for most New England groundfish stocks.

The parametric stock-recruitment model approach was selected for estimation of management reference points for three stocks (Gulf of Maine and Georges Bank cod and Southern New England winter flounder). For the remaining seven stocks with sufficient age based data, the empirical non-parametric approach was used (Georges Bank haddock, Georges Bank yellowtail flounder, Southern New England yellowtail flounder, Cape Cod yellowtail flounder, American plaice, witch flounder, and Acadian redfish).

Owing to limitations in basic catch-at-age data, biomass dynamics model approaches were retained for two stocks (Georges Bank winter flounder and white hake). The Working Group evaluated recent re-assessments of management parameters for these two stocks and recommended no change.

For a number of the stocks, where age-based data are not available and the results of surplus production models were judged to be either uninformative or unreliable, the NEFMC has adopted proxy reference points based on fishery catches (landings) and research vessel survey abundance indices. The biomass proxy was selected as an average or quantile of the research vessel survey indices over some period when the stock was determined to be capable of producing relatively high and stable catches (i.e., the MSY proxy). This was set as Bmsy, and either 1/4 or ½ of this value was chosen as the biomass threshold. For fishing mortality rate proxies, a simple quotient of the annual landings L_t divided by the annual research vessel biomass index value (I_t) was proposed as a relative fishing mortality rate: $relF_t = L_t / I_t$. Taken as a time series, this index should be sensitive to changes in landings with respect to underlying biomass, and vice-versa, thereby indexing fishing mortality. Proxies of Fmsy based on relF were developed by examining the time series of relF in relation to landings to approximate periods when the stock was relatively large, landings were stable, and relF was moderate (in the context of the particular time series). The actual reference points were specified as the running average of relF (usually for three years) owing to the noise inherent in these un-smoothed metrics derived from annual research vessel indices. No methods for forecasting or prediction were previously proposed to account for the effects of regulation on the stocks managed under biomass and relF proxies. A further limitation of the approach, as currently used, is that there were no objective methods applied to select F proxies that were consistent with underlying biomass goals, or to assure that the Fs would result in stock stability or rebuilding.

The Working Group developed and tested several new methods to estimate proxy reference points when only landings and overall survey abundance data are available. The concept of replacement ratio was used here as an analytical tool for examining the historical behavior of a population and any potential influence of removals due to fishing activities. To test these concepts and to facilitate comparisons, the analyses were applied to both the aged and un-aged stocks. Index-based methods for reference point estimation were considered in light of the specific goal of identifying the limit relative fishing mortality rate (relF) that is associated with stock replacement, in the long term. The replacement ratio method was applied to revise estimates of F proxies for six stocks: Gulf of Maine haddock, Mid-Atlantic yellowtail flounder, pollock, northern and southern windowpane, and ocean pout. In some cases, biomass proxies and MSY values were also updated for these stocks.

The Working Group also estimated the mean generation time for all New England groundfish stocks for which adequate estimates of natural mortality, stock weights at age, and the proportion of females mature at age are available. These calculations provide the mean age of breeding animals in the population weighted by fecundity at age (or its proxy). The mean generation time can be used in setting the maximum rebuilding time allowed if the stock is not capable of being rebuilt in 10 years under a no-fishing scenario.

Updated Reference Points and Projections:
Existing biomass and fishing mortality rate targets for all 19 stocks are re-considered in light of the various quantitative approaches used by the Working Group. Where appropriate, recommendations for revised management parameters are given, along with the method upon which the estimation is based, and the units of biomass and fishing mortality in which the reference points are expressed (Table 1). Predictions of stock status, biomass, and catch are given for the period from 2002 to 2010 . This required estimating the catches in 2001, fishing mortality rates in 2001 and survivors at the beginning of 2002. The NEFSC standard population forecasting suite (AGEPRO) was used for all age-based forecasts. Two scenarios of fishing mortalities in 2002-2010 were evaluated. First, the revised Fmsy value was simulated. If there is not at least a 50% chance that the stock will recover to the Bmsy value by 2009, the maximum F level allowing a 50% chance of recovery was calculated by iteratively changing the fishing mortality rate until the maximum F that results in at least a 50% probability of Bmsy in 2009 was found. Forecast results include the annual probabilities of achieving Bmsy under both fishing mortality scenarios, and the median and 80% confidence intervals of annual spawning stock biomasses and catches for the Fmsy or F-rebuild scenario - whichever applies. Forecasts were provided for all age-based stocks except Southern New England yellowtail flounder. For that stock, the last 10 years of recruitment have been poor, but rapid stock rebuilding from depleted conditions has been observed in the past. In this case, the Working Group felt that conditional advice (under the assumptions of continued poor recruitment or larger year classes consistent with the stock's history) better described the uncertainty in stock prognosis than a single set of stochastic projections.

Projections for one of the stocks assessed with biomass dynamics models (Georges Bank winter flounder) were determined by using standard methods. No biomass dynamics projections were made for white hake owing to the unreliability of such medium term projections when stocks are declining or increasing rapidly (especially under the influence of strong or weak year classes).

Projections using the replacement ratio method were made for all 19 of the stocks for the purposes of evaluating the utility of the method. Although these projection results are included in the report, their use for management purposes is cautioned, owing to the developmental nature of their application.

The Working Group recommendations for revised biomass and fishing mortality rate reference points are summarized in Table 1. For most stocks, revised F reference points are similar to those previously recommended (in many cases the comparisons between current and proposed reference points are confounded by differences in the measurement scale - biomass weighted or fully-recruited ages). Similarly, the biomasses associated with MSY are comparable for most stocks - the exceptions being Georges Bank cod and haddock, Gulf of Maine haddock, and Acadian redfish - where recommended Bmsy values represent substantial increases over current values. In the case of Georges Bank cod and the two haddock stocks, historical growth overfishing substantially diminished the biomass potential of year classes. Thus, the observed pattern of spawning biomasses was not consistent with basic yield and spawning biomass per recruit calculations and the observed patterns of recruitment. For redfish, the revised analysis considered historical recruitment patterns that must have occurred to support biomasses that accumulated prior to the initiation of intensive fishing in the 1930s.

Calculations of maximum fishing mortality rates associated with stock rebuilding by 2009 are given in Table 2 and Figure 1. In several cases (witch flounder, and Georges Bank winter flounder) fishing at the proposed Fmsy would allow the stock to rebuild - no further reductions are required. For most others, the F-rebuild is only slightly below the Fmsy level (Gulf of Maine cod, Georges Bank haddock, plaice, Georges Bank yellowtail, SNE winter flounder). For two of the stocks the proposed biomass targets cannot be achieved in 2009 with >50% probability, even if F=0.0 beginning in 2003 - Georges Bank cod and Acadian redfish. In the case of redfish, basic life history constraints limit the rapidity with which rebuilding can occur (Table 3). For Georges Bank cod, the recent run of below average year classes means that it is unlikely that the stock can rapidly rebuild.

For most index-based stocks, current fishing mortality rates are below the threshold levels, the exception being Mid-Atlantic yellowtail flounder (Figure 2).

Current biomass levels as a ratio of proposed Bmsy values are presented in Figure 3. Estimated catches in 2001 are compared to proposed MSY values in Figure 4. The summed catches of all 19 stocks in 2001 was 69,200 mt - 36% of the MSY potential of the complex when the stocks are rebuilt (192,900 mt).

Conclusions and Implications:

<u>Ecosystem Implications for Stock Recovery</u>

For several of the species considered herein, proposed Bmsy values are larger than those previously estimated (although in most cases the existing and proposed biomass targets cannot be directly compared due to the differences in measurement scales [e.g., total vs. spawning stock biomass]). This naturally leads to the question: considering the potential for multispecies interactions (e.g., predation and competition), is it feasible to restore all the major fishery resources of this resource to Bmsy simultaneously? Some data and analyses and previous studies germane to this question are considered in the report. The 40-year time series of research vessel survey data are used to examine the abundance trends of each stock inhabiting an area with the combined survey catches of all other stocks in that area (Gulf of Maine, Georges Bank, Southern New England). In general, current biomasses of each stock are substantially below the series maximum both for the individual species and the aggregate. These analyses imply that most stocks historically were capable of attaining much higher biomasses in the face of higher overall groundfish biomasses. In most cases it is clear that the stocks themselves have coexisted at much higher biomasses in the past.

A broader question to pose relative to the recovery of flatfish and groundfish stocks is: can all the components of the ecosystem (flatfish, groundfish, pelagics, and spiny dogfish) coexist simultaneously at high biomass? Based on summarized results of feeding habit studies and trends in abundance and exploitation of major trophic components of the fish in the ecosystem, there do not appear to be trophic limitations to the recovery of groundfish biomasses to the targets recommended herein.

Strategic Goals vs. Tactics for Depleted Stock Recovery

The primary task at hand is the re-estimation of *long-term* biomass and fishing mortality rates for this complex of species. The critical component of all of these analyses is the course of future recruitment to the stocks. In the Northeast region there is clear evidence that larger spawning stocks associated with stock rebuilding give higher odds of obtaining larger year classes. However, there is substantial variability in the relationship between parental stock size and subsequent recruitment, and the functional form of that relationship is elusive (hence the nearly two dozen candidate forms of stock-recruitment models evaluated herein). We have purposely not considered management tactics in light of short-term recruitment prospects, and specifically approaches to managing depleted stocks for which recent recruitment has been well below average. It is possible that these stocks cannot meet long term targets without recruitment that will rarely occur even if fishing is stopped. These issues are simply beyond the scope of the current study.

Working Group Advises an Adaptive Approach to Biomass Management

For several important stocks, revised biomass reference points are higher than the current estimates of Bmsy – in some cases substantially so. The new estimates rely on recruitment distributions near the long term mean or recruitments correlated with increases in projected spawning stock biomasses. For many of the stocks the proposed biomass reference points are in *terra incognita* - chronic growth overfishing has limited stock biomasses to well below their estimated potential. Given the lack of experience in observing these populations at high biomass, we can only model the expected behavior of the system under varying assumptions. The NEFMC is advised that an adaptive approach to biomass management is a prudent tactic to explore the implications of higher biomasses and to find the point of diminishing returns to yields as a function of increased stock density. Given the histories of most of these stocks, there is likely substantial biomass growth, and commensurate increases in catch, before these points are reached. Continued monitoring of vital population rates - including growth, sexual maturity at age, feeding habits to reveal predation and competition among populations, and distribution patterns in relation to abundance - will indicate when biomass production becomes limited by density-dependent factors. Under these conditions the form of the stock-recruitment relationships will become more apparent, as will be the MSY potential for each of the stocks and the system as a whole.

Table 1. Summary of current and recommended biomass and fishing mortality rate reference points for New England groundfish stocks. The units for biomass (total or spawning stock) and fishing mortality reference points are provided as footnotes.

Stock	Biomass target (Bmsy)		MSY (metric tons)		Fishing Mortality Threshold (Fmsy)		Basis for Reference Points
	Current	Recommended	Current	Recommended	Current	Recommended	
Gulf of Maine Cod	78,000[1]	82,800[1]	16,100	16,600	0.23[3]	0.23[3]	Parametric S-R
Georges Bank Cod	108,000[2]	216,800[1]	35,000	35,200	0.32[4]	0.18[3]	Parametric S-R
Georges Bank Haddock	105,000[1]	250,300[1]	N/A	52,900	0.26[3]	0.26[3] (F40%)	Empirical Non-parametric
Gulf of Maine Haddock	8.25 kg/tow	22.17 kg/tow	2,400	5,100	0.29 (C/I)	0.23 (C/I)	Catch-Survey Proxy
Georges Bank Yellowtail Flounder	43,500[2]	58,800[1]	14,100	12,900	0.33[4]	0.25[3] (F40%)	Empirical Non-parametric
Southern New England Yellowtail Flounder	51,000[2]	45,200[1]	11,700	9,000	0.23[4]	0.27[3] (F40%)	Empirical Non-parametric
Cape Cod Yellowtail Flounder	6,100[2]	8,400[1]	2,400	1,700	0.40[4]	0.21[3] (F40%)	Empirical Non-Parametric (mean)
Mid-Atlantic Yellowtail Flounder	11.69 kg/tow	12.91 kg/tow	3,300	4,300	0.36 (C/I)	0.33 (C/I)	Catch-Survey Proxy
American Plaice	24,200[1]	28,600[1]	4,400	4,900	0.19[3]	0.17[3] (F40%)	Empirical Non-parametric (mean)
Witch Flounder	25,000[2]	19,900[1]	2,684	3,000	0.106[4]	0.16[3] (F40%)	Empirical Non-Parametric (mean)

Stock	Biomass target (Bmsy)		MSY (metric tons)		Fishing Mortality Threshold (Fmsy)		Basis for Reference Points
	Current	**Recommended**	**Current**	**Recommended**	**Current**	**Recommended**	
Southern New England Winter Flounder	27,810[2]	30,100[1]	10,220	10,600	0.37[4]	0.32[3]	Parametric S-R
Georges Bank Winter Flounder	2.49 kg/tow	9,400[2]	3,000	3,000	1.21 (C/I)	0.32[4]	Surplus Production
Acadian Redfish	121,000[2]	236,700[1]	14,000	8,200	0.116[4]	0.04[3] (F50%)	Empirical Non-Parametric (mean upper Q)
White Hake	14,700[5]	14,700[5]	4,200	4,200	0.29[4]	0.29[4]	Surplus Production
Pollock	102,000[1,6]	3.0 kg/tow	40,000[6]	17,600[7]	0.65[1]	5.88 (C/I)	Catch-Survey proxy
N. Windowpane	0.94 kg/tow	0.94 kg/tow	1,000	1,000	1.11 (C/I)	1.11 (C/I)	Catch-Survey proxy
S. Windowpane	0.41 kg/tow	0.92 kg/tow	900	900	2.24 (C/I)	0.98 (C/I)	Catch-Survey Proxy
Ocean Pout	4.9 kg/tow	4.9 kg/tow	1,500	1,500	0.31 (C/I)	0.31 (C/I)	Catch-Survey Proxy
Atlantic Halibut	5,400[2]	5,400[2]	300	300	0.06[3]	0.06[3]	Catch-YPR prox

1/ unit is spawning stock biomass, metric tons
2/ unit is total biomass, metric tons
3 / unit is fully-recruited F
4 / unit is biomass-weighted F
5/ unit is total stock biomass >/= 60 cm
6/ applies to NAFO Divisions 4VWX and Subareas 5&6
7/ applies to NAFO subareas 5&6 only

Table 2. Summary of estimated maximum fishing mortality rates required to rebuild stocks to Bmsy by 2009 with probability >/= 50%. Estimated fishing mortality rates in 2000 are also given.

Species/Stock	F-rebuild	Fishing Mortality Rate in 2000
Gulf of Maine Cod	0.17	0.73
Georges Bank Cod	0.0[1]	0.22
Georges Bank Haddock	0.21	0.19
Georges Bank Yellowtail Flounder	0.22	0.14
Southern New England Yellowtail Flounder	N/A	0.22
Cape Cod Yellowtail Flounder	0.14	1.39
American Plaice	0.13	0.31
Southern New England Winter Flounder	0.30	0.31
Acadian Redfish	0.00[2]	0.003
White Hake	N/A	0.85

1/ based on projections the probability of Georges Bank cod biomass reaching the target in 2009 is <50% even if F=0.0
2/ redfish will not rebuild by 2009 even if F=0.0, owing to its life history

Table 3. Calculated mean generation times for Northeast groundfish stocks

Species	Stock	Mean Generation Time (Years)
Atlantic cod	Gulf of Maine	10.8
	Georges Bank	10.3
Haddock	Georges Bank (current)	8.9
	Georges Bank (1931)	8.8
Yellowtail Flounder	Georges Bank	8.1
	Southern New England	8.3
	Cape Cod	8.8
American plaice	Georges Bank-Gulf of Maine	11.1
Witch Flounder	Georges Bank-Gulf of Maine	12.0
Winter Flounder	Southern New England	8.9
Acadian Redfish	Georges Bank-Gulf of Maine	30.6

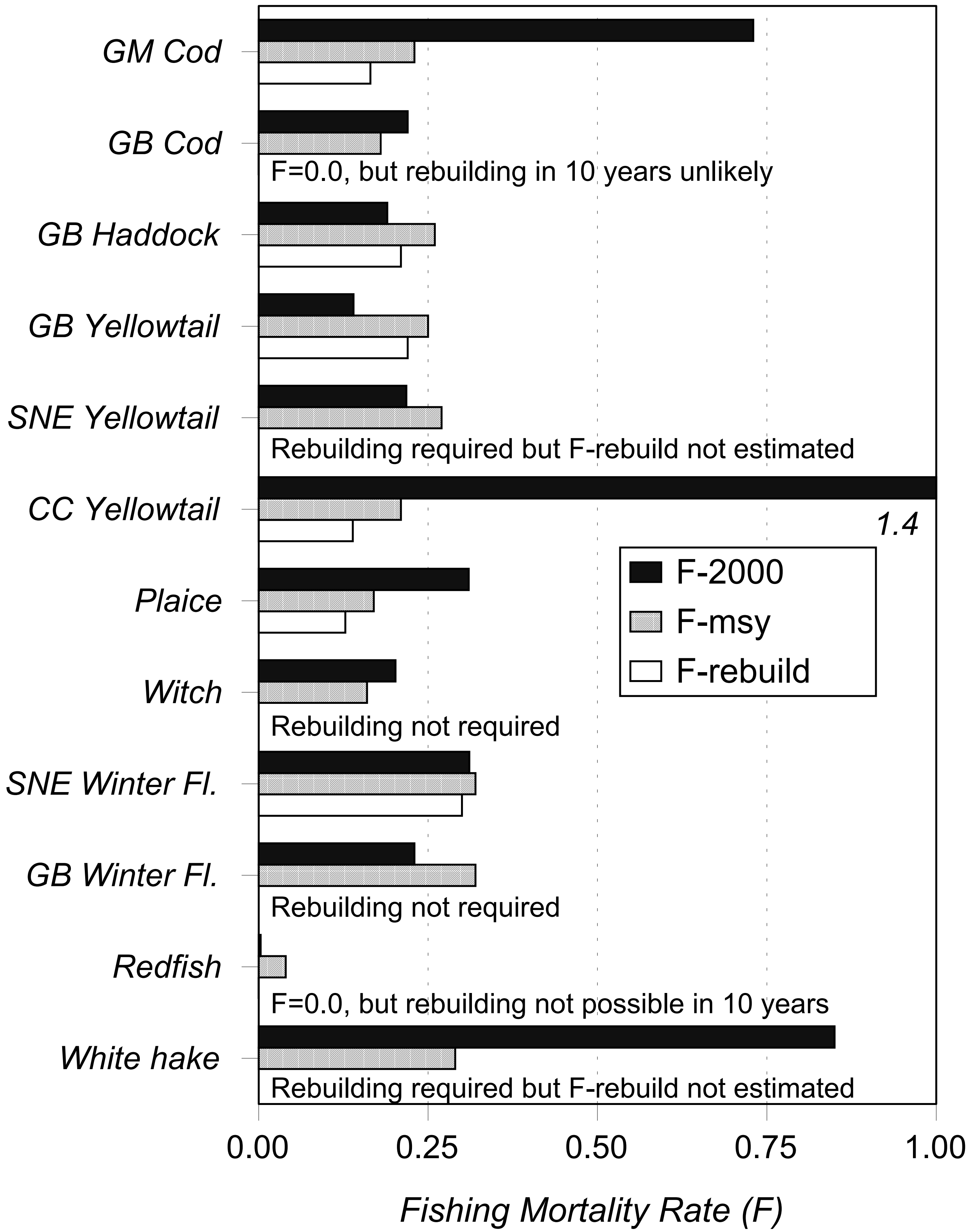

Figure 1. Estimates of F in 2000, Fmsy (or proxy) and corresponding fishing mortality rates needed to reach Bmsy by 2009 with >50% probability (F-rebuild). Data are only for stocks with analytical assessments (e.g., non index-based).

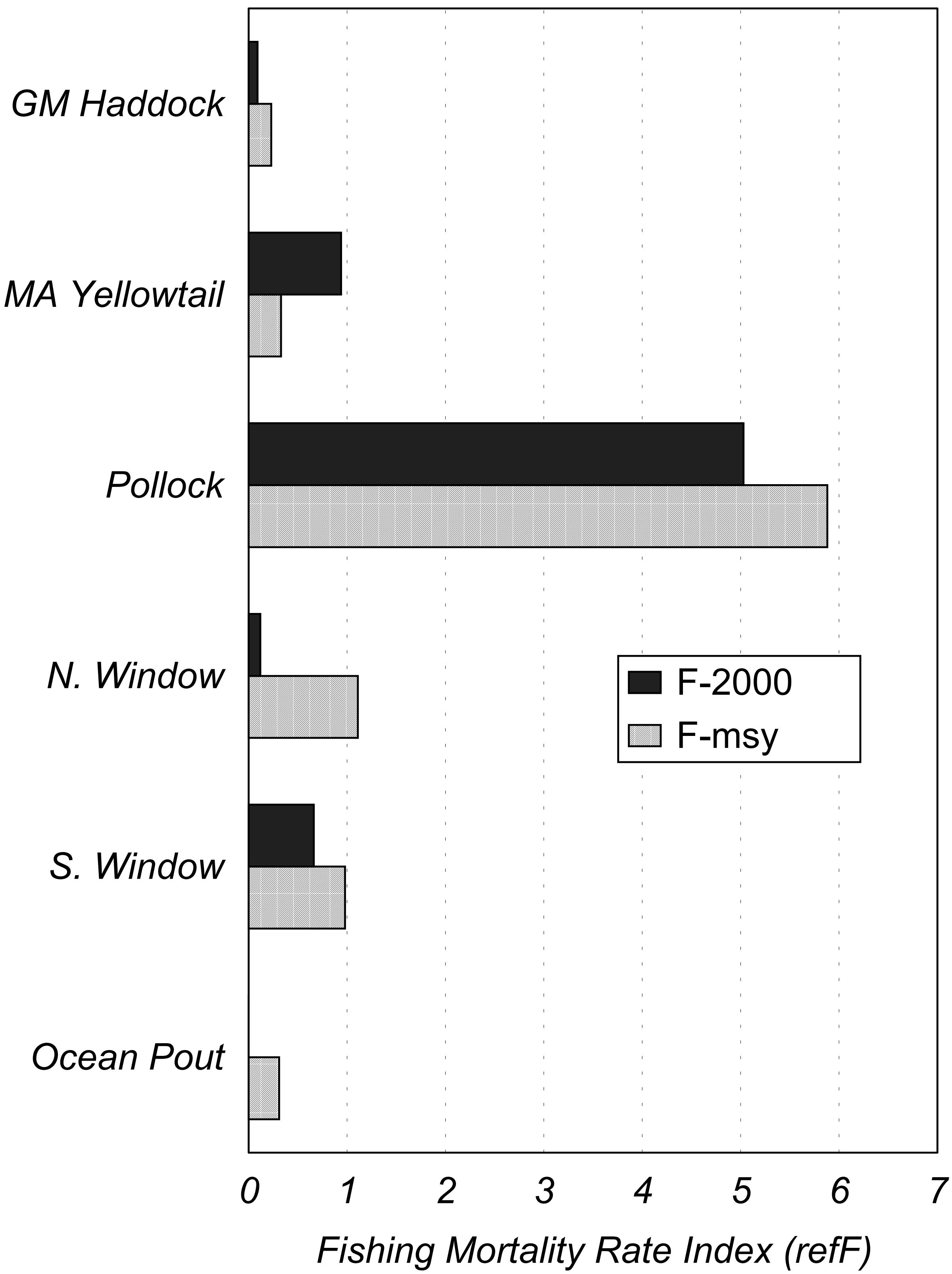

Figure 2. Estimates of fishing mortality rate indices (relF) in 2000 and the Fmsy proxy for six New England groundfish stocks Data are only for stocks with index-based assessments.

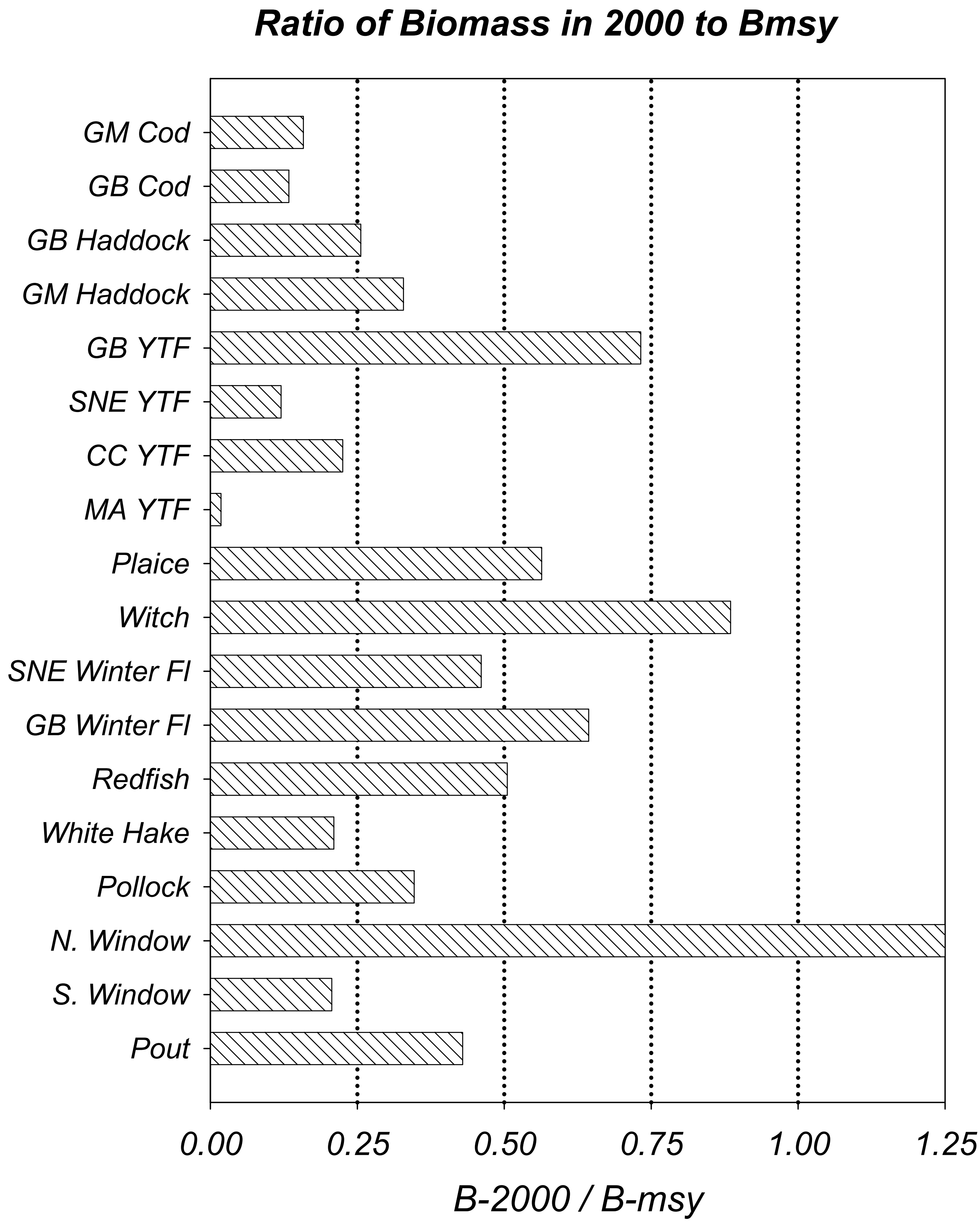

Figure 3. Ratios of the biomasses in 2000 to Bmsy for 18 groundfish stocks.

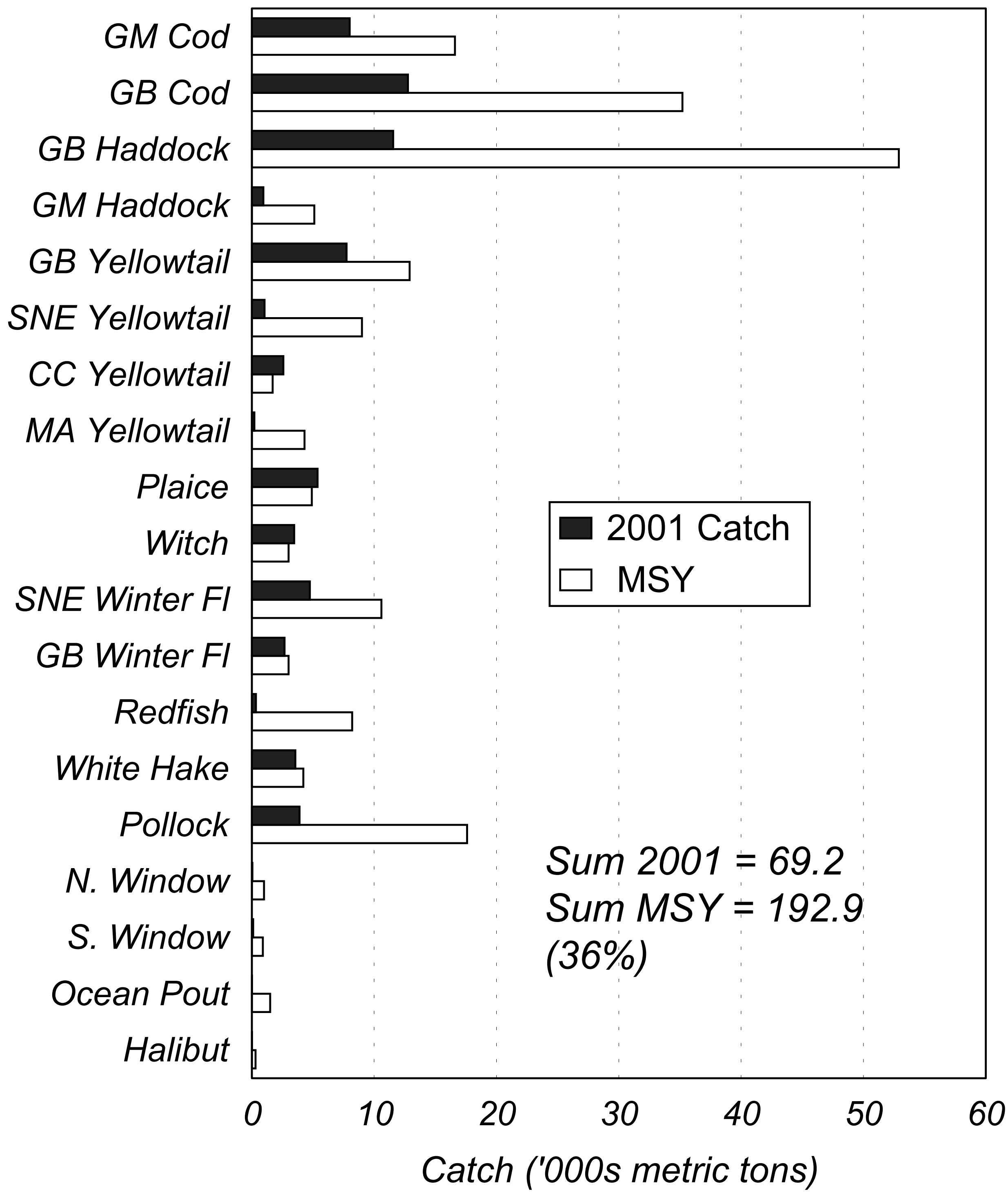

Figure 4. Estimated catches in 2001 and MSY values for 19 New England groundfish stocks.