Northeast Fisheries Science Center Reference Document 02-04

Re-Evaluation of Biological Reference Points for New England Groundfish

by

Working Group on Re-Evaluation
of Biological Reference Points
for New England Groundfish

March 2002

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U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Northeast Region
Northeast Fisheries Science Center
Woods Hole, Massachusetts

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Northeast Fisheries Science Center Reference Documents

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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.

Background

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

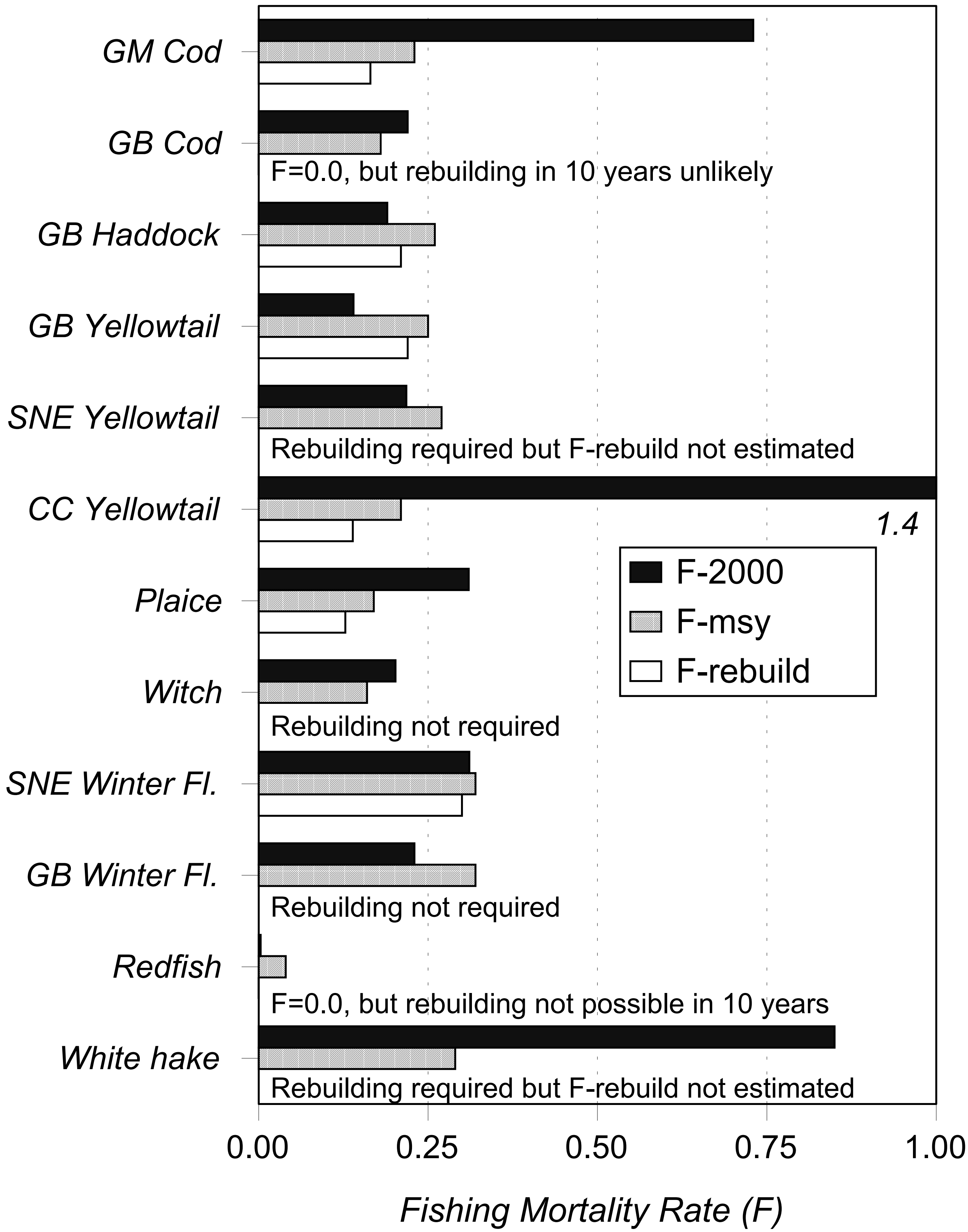


Figure 1. Estimates of F in 2000, Fmsy (or proxy) and corresponding fishing mortality rates needed to reach Bmsy by 2009 with >50% probability (F-rebuild). Data are only for stocks with analytical assessments (e.g., non index-based).

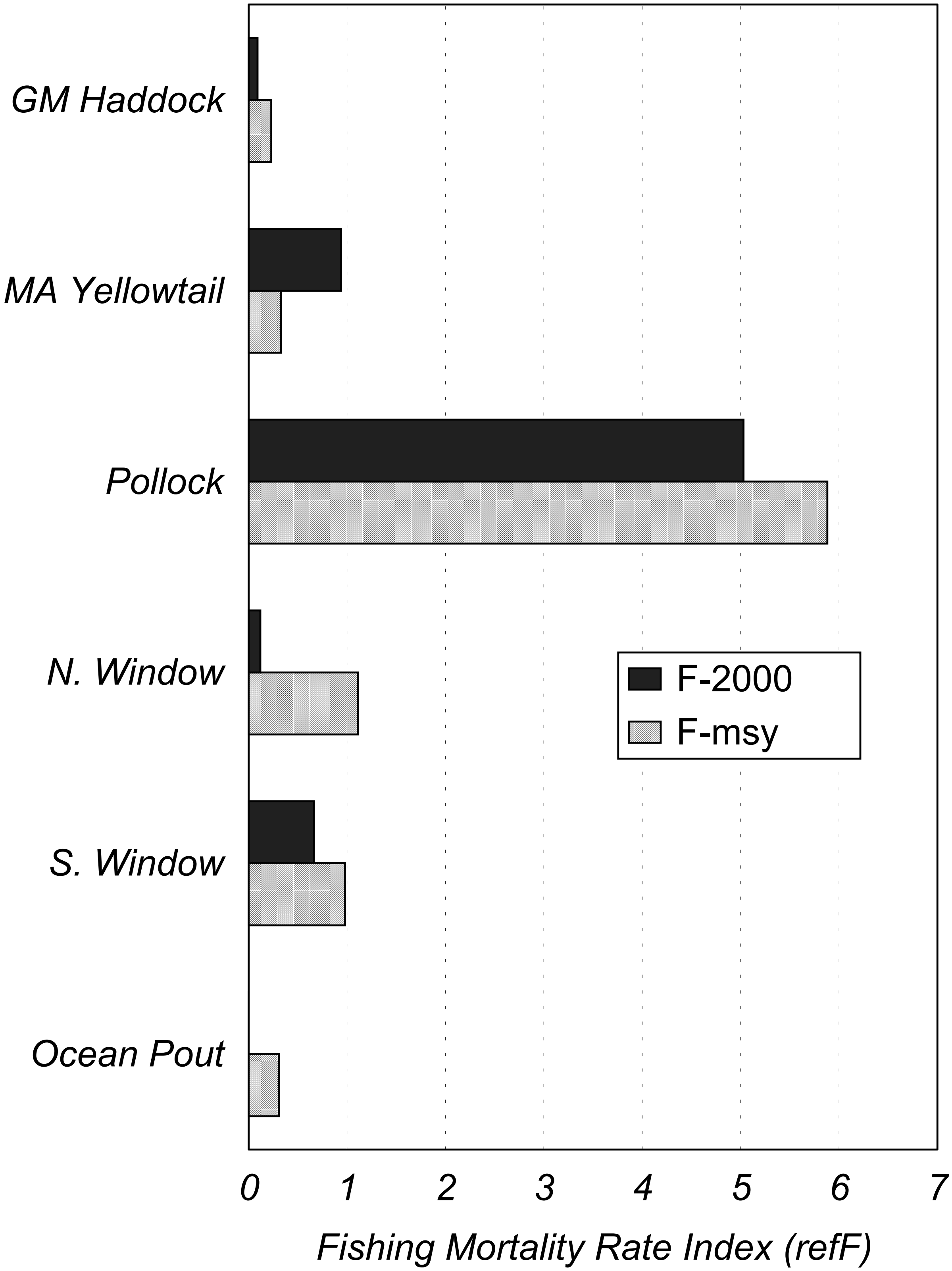


Figure 2. Estimates of fishing mortality rate indices (relF) in 2000 and the Fmsy proxy for six New England groundfish stocks Data are only for stocks with index-based assessments.

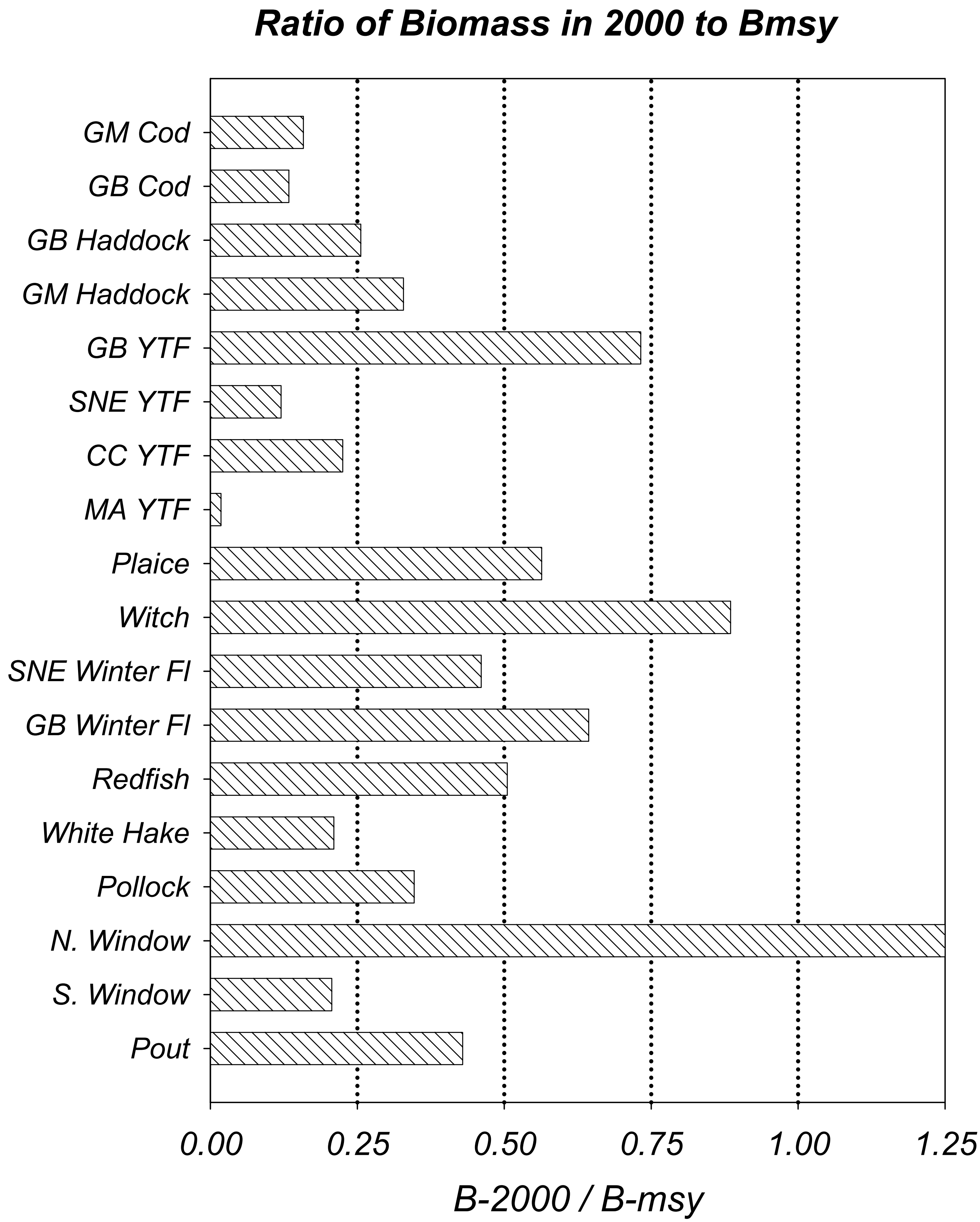


Figure 3. Ratios of the biomasses in 2000 to Bmsy for 18 groundfish stocks.

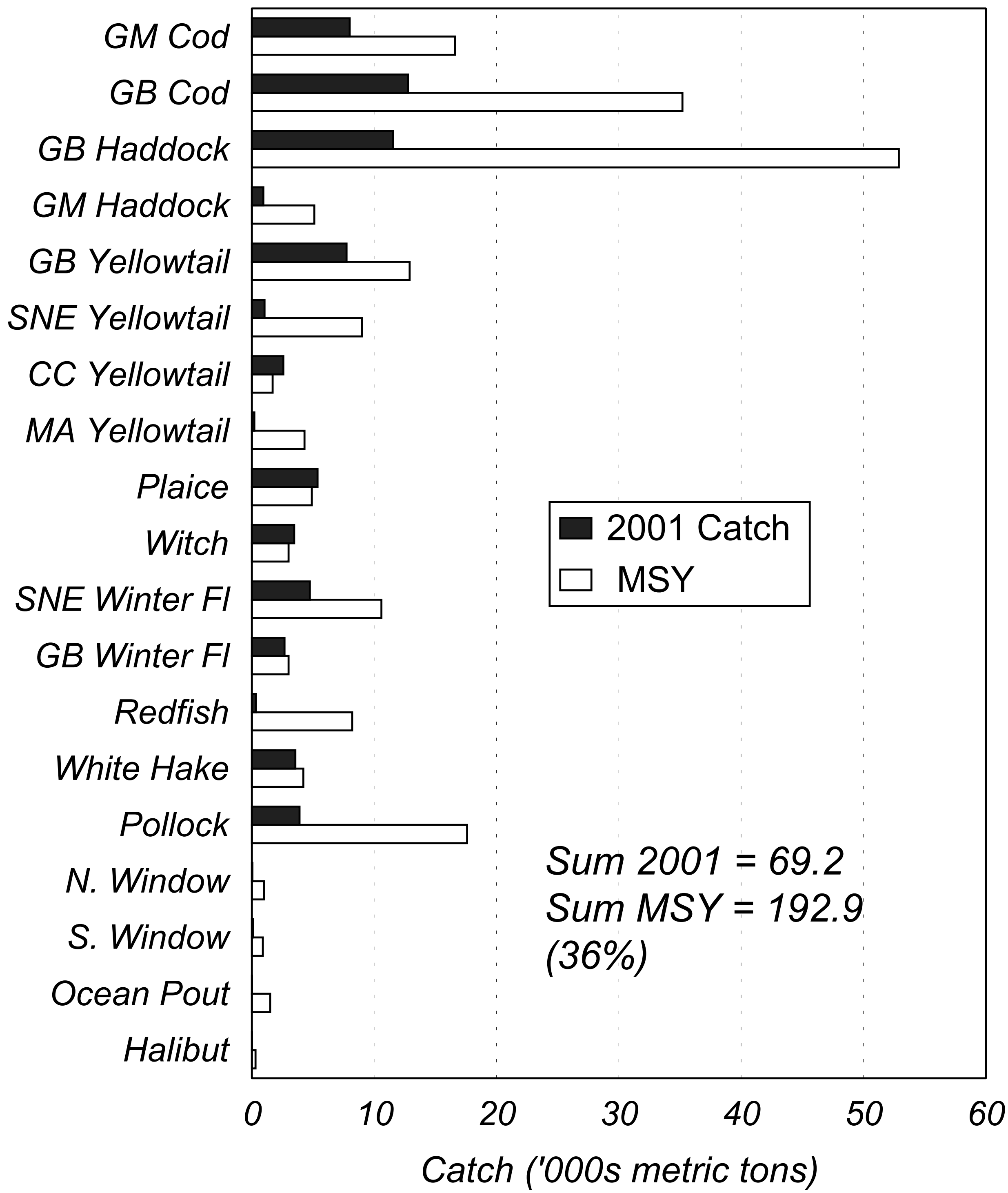


Figure 4. Estimated catches in 2001 and MSY values for 19 New England groundfish stocks.

Every scientific fulfillment raises new questions; it asks to be surpassed and outdated.

-Max Weber (d. 1920), Methodology of the Social Sciences

1.1 Introduction

The *Working Group on Re-Evaluation of Biological Reference Points for New England Groundfish* was created to address the need for a timely re-evaluation of biological reference points for the New England groundfish complex. The 19 stocks comprising the complex (Table 1.4.1) are managed under the New England Fishery Management Council's Northeast Multispecies Fishery Management Plan (the 'groundfish plan'). Under this plan, overfishing definitions including biomass thresholds and limits and fishing mortality thresholds and limits are required and have been previously specified (Applegate et al. 1998; Table 1.4.2). The purpose of this study is 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 specific conditions leading to this re-analysis are detailed in Section 1.5). Full terms of reference assigned to the group are given in section 1.3.

1.2 Working Group Membership

Membership in the working group was determined by two factors: (1) the need to include various species experts with specific information and experience in the stocks being considered, and (2) the desire to bring in independent scientists with no vested interest in the stocks being assessed, but with expertise both in the application of quantitative methods for reference point estimation and knowledge of the provisions of the Sustainable Fisheries Act (DOC 1996) and NMFS' guidelines for reference point development and control laws (DOC 1998; Restrepo et al. 1998). Accordingly, the following team of experts was assembled:

Experts from outside the northeast USA region:

Jim Armstrong
North Carolina Division of Marine Fisheries
Morehead City, North Carolina

Stratis Gavaris
Canadian Department of Fisheries and Oceans
St. Andrews, New Brunswick, Canada

Pamela Mace
National Marine Fisheries Service, Office of Science and Technology
Silver Spring, Maryland

Rick Methot
National Marine Fisheries Service, Northwest Fisheries Science Center
Seattle, Washington

Grant Thompson
National Marine Fisheries Service, Alaska Fisheries Science Center
Seattle Washington

Doug Vaughan, National Marine Fisheries Service
Beaufort, North Carolina

Experts from the NEFSC, Woods Hole, Massachusetts:

Jon Brodziak
Steven Cadrin
Chris Legault
Ralph Mayo
Steven Murawski - Chair
Loretta O'Brien
William Overholtz
Paul Rago
Fredric Serchuk
Michael Sissenwine
Mark Terceiro
Mike Sissenwine
Susan Wigley

Additionally, because the details of current reference points and the Council's interpretation of them and associated control rules was important to the deliberations, Council staff was requested to observe and present appropriate materials:

New England Fishery Management Council Observers:

Tom Nies
Steve Correia (Chair of the NEFMC's Multispecies Monitoring Committee) attended part-time

The full team met from 12-14 February in Woods Hole, Massachusetts to discuss approaches to the task, review preliminary data and analyses, and to develop a strategy for undertaking the required analyses and scheduling an expedited review procedure. Staff of the Northeast Fisheries Science Center (NEFSC) undertook the required data analyses and modeling studies. A draft copy of the final report was sent via regular and electronic format to the external panel members on March 8, 2002. The full panel developed comments which were submitted in writing on 15 March. The panel then met via conference call to discuss comments and agree on the final contents of the report. Because of the considerable number of analyses and large volume of data considered, this report is intended to provide updated reference points and graphical depictions of likely stock performance over the forecast periods. A full accounting of all data, methods and computer output is being developed into an associated technical appendix (currently being completed).

1.3 Terms of Reference

The terms of reference assigned to the working group were:

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

(b) 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,

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

(d) 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),

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

1.4 Description of Current Reference Points

Important management reference points previously developed for the species comprising the New England groundfish complex are detailed in Tables 1.4.1 and 1.4.2. Specifically, these include estimates of Bmsy and Fmsy (or their proxies, depending on availability of data [Table 1.4.1]), and estimates of biomass thresholds for the various stocks. Maximum Sustainable Yield (MSY) has been estimated for all of the stocks in the complex, using a variety of analytical or heuristic methods (e.g., either the results of surplus production models, or catch averages over some specified historical period when the stock was judged to be in a relatively healthy condition). In most cases, for stocks with time series of catch (usually landings) and at least one fishery-independent abundance index, Applegate et al. (1998) undertook production modeling using the ASPIC (non-equilibrium) production modeling framework (Prager 1994; 1995). This method produced estimates of management parameters, their uncertainty, and allowed for projections of stock status assuming a fixed estimated intrinsic rate of population growth (r), and a stochastic version using uncertainty about the model fit. These predictions from ASPIC were used to assess potential re-building times for the various resources. Based on these analyses, the Council adopted 5-year and 10-year rebuilding time tables for resources judged to be in an overfished condition (NEFMC 1998; 2000). The Council also adopted estimates of threshold biomass, many of which, in retrospect, were inconsistent with the National Standard Guidelines because these biomass thresholds were specified below ½ Bmsy (Restrepo et al. 1998).

For a number of the stocks, where the results of surplus production models were judged to be either uninformative or unreliable, a multi-stage process for developing biomass and fishing mortality rate proxies and MSY was undertaken (e.g. Gulf of Maine haddock, Mid-Atlantic yellowtail flounder, etc., Table 1.4.2). 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. Important assumptions of the method are that the catch (e.g. landings) series is a consistent measure of the force of exploitation (e.g., changes in the discarding vs. landings patterns are minimal) and that the age/size groups included in the biomass index are appropriate to those groups represented in the catch. As a practical matter, no adjustment of the research vessel survey indices for pre-recruit size fish were made, but this is generally thought to be a minor effect since *per capita* weight of pre-recruits is substantially less than that of exploited sizes caught in the surveys. 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.

1.5 Background and Need for Reference Point Re-Evaluation

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 overfishing definitions of $F_{30\%MSP}$ for Georges Bank haddock, and $F_{20\%MSP}$ for other stocks. A national review including Amendment 4 overfishing definitions concluded that biomass thresholds were needed, and some of the fishing mortality rate overfishing definitions specified in Amendment 4 were greater than F_{MSY} (e.g., Gulf of Maine cod, Georges Bank cod, Georges Bank haddock, Gulf of Maine haddock, redfish; Rosenberg et al. 1994). Amendment 7 (1996) specified $F_{0.1}$ as an overfishing reference point for all principal groundfish stocks (Gulf of Maine cod, Georges Bank cod, Georges Bank haddock, Georges Bank yellowtail, and southern New England yellowtail), and spawning stock rebuilding targets for Georges Bank cod (70,000 mt), Georges Bank haddock (80,000 mt), Georges Bank yellowtail (10,000 mt), and southern New England yellowtail (10,000 mt). These first estimates of biomass rebuilding targets were specified as minimum spawning biomasses deemed necessary to avoid lower recruitment stanzas (higher probabilities of recruitment failure) rather than biomasses that would be necessary to generate the maximum sustainable yield of these stocks. Passage of the SFA in would subsequently require the latter.

In 1997, The New England Fishery Management Council (NEFMC) 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 nineteen groundfish stocks considered in this report: 1) biomass dynamics models for ten stocks (Gulf of Maine cod, Georges Bank cod, Gulf of Maine haddock, Georges Bank yellowtail, southern New England yellowtail, Cape Cod yellowtail, witch flounder, southern New England winter flounder, Georges Bank winter flounder, and white hake); 2) dynamic pool models for five stocks (i.e., $F_{MSY} = F_{0.1}$ or $F_{20\%}$, and B_{MSY} is a function of average recruitment or a MSY proxy; Georges Bank haddock, American plaice, redfish, Pollock, and halibut); and 3) survey proxies of biomass and exploitation ratios from periods presumed to produce relatively large sustainable yields. Estimates of B_{MSY} for nearly all stocks were similar to biomass estimates or survey indices observed in the 1960s. The fact that Bmsy values were within the range of observed biomasses was due to the tendency of biomass dynamics models to estimate within this range, was an implicit outcome of the choice of observed average recruitments for dynamic pool methods, or explicitly as the chosen period for survey proxies. For the principal groundfish stocks, estimates of B_{MSY} were substantially greater than the Amendment 7 rebuilding targets (e.g., 108,000 mt total biomass of Georges Bank cod; 105,000 mt spawning biomass of Georges Bank haddock; 49,000 mt total biomass of Georges Bank yellowtail, and 51,000 mt total biomass of southern New England yellowtail). Although MSY reference points for most of these stocks were updated through peer reviews (e.g., the Northeast Stock Assessment Workshop [SAW], or the Transboundary Resources Assessment Committee) from 1998 to 2000, the methodology for estimation was not revised.

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 (NEFMC 2000). The Committee concluded that many of the production models for groundfish stocks need to be updated with more comprehensive approaches. In 2001, the Gulf of Maine cod assessment and production modeling in general were externally reviewed by the 33rd SAW (NEFSC 2001c). With respect to production modeling, the workshop 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 was likely better accomplished through techniques that could incorporate recruitment dynamics explicitly.

This Working Group adopted many of the recommendations of SAW33 for completing its terms of reference. Therefore, age-based production models were developed for stocks with time series of age-structured assessment information, and reviewed age-based production models as candidate methods for estimating MSY reference points.

The historical development of overfishing definitions for New England groundfish reflects changes in national standards as well as advances in technical methodology.

In the intervening period since the NEFSC adopted its various biomass and fishing mortality targets and thresholds, a number of technical limitations of the various estimation approaches have emerged. First, for most of the stocks currently assessed with age-based stock assessment models (e.g. VPA, table 1.4.1) the biomass and F reference points were determined in weight-based units using ASPIC. This has 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 (Fmsy) 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 (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 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 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. This problem is described in more detail in the methods development section of NEFSC (2001c). These difficulties in interpreting biomass-weighted reference points using age-based assessments, caused the Northeast Stock Assessment Review Committee (SARC) proposed new reference points to be calculated based on consistent age-based methods. These were recently calculated for Gulf of Maine cod and redfish (NEFSC 2001c).

A second issue related to the current 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 poor selection patterns. Thus, if production models estimate Bmsy 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 too modest a level.

A recent example of this situation is instructive. Atlantic sea scallops were significantly growth overfished for many years, with strong year classes depleted quickly and landings and stock sizes fluctuating significantly over time. Because of the chronic growth overfishing scenario, the Overfishing Definition Review Panel (Applegate et al. 1998) recommended that the biomass targets be set at levels that *should be realized* if the stock were fished consistently with mortality

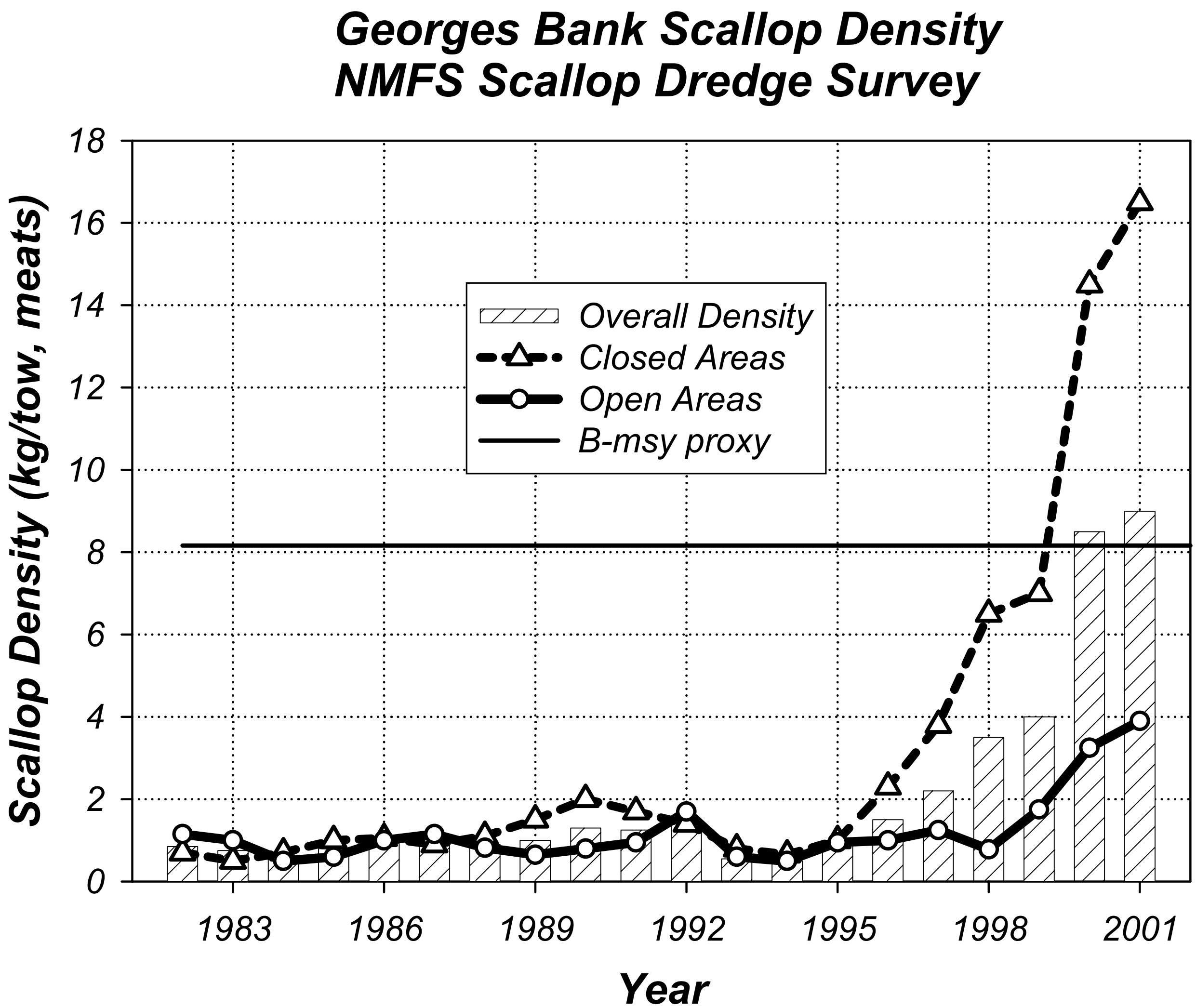


Figure 1.5. Relative sea scallop biomass on Georges Bank, 1982-2001. Data are the average scallop biomass indices (calculated meat weight per dredge tow) for open and closed areas and the USA portion of the Bank as a whole. The B-msy proxy of 8.16 kg/tow is given. The proxy was calculated by multiplying the median recruit index of 99.9 recruit-sized scallops per tow by the expected biomass per recruit of 81.6 g associated with fishing at Fmax. Areas were closed On Georges Bank beginning in late 1994.

set at Fmax. The panel developed a biomass proxy based on the median recruitment (in survey units) observed over the time series of scallop dredge surveys multiplied by the biomass per recruit that would be obtained if the stock were fished at Fmax. The resulting target was more than three times the highest biomass index ever seen in the survey to that time (Applegate et al. 1998, page 148). Owing to significant reductions in harvest rates due to effort cuts and closed areas, combined with strong recruitment, the biomass of Georges Bank scallops has recently surpassed the biomass target developed by the panel (Murawski et al. 2000; Figure 1.5). In this example, the biomass series from the surveys was not considered an informative time series from which to draw inferences about the proper level of Bmsy (e.g., the actual biomass potential of the stock was never observed because of chronic overfishing). Thus, if surplus production modeling methods seek Bmsy by inferring equilibrium conditions occurring within these series, then there is an inherent bias to underestimation of Bmsy and likely overestimation of Fmsy. As noted above, there are significant concerns that biomass targets developed to date for the New England groundfish resource are too low relative to the true production potential of properly fished resources.

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* (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. Similar issues were raised by Crecco (2002) in his memorandum related to the choice of stock-recruitment models for biomass and F reference point estimation, and reviewed by this Working Group. Also, since the first Overfishing Definition Review Panel met, the final guidelines for the SFA were issued by NMFS. The existing overfishing 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 need to be developed.

For the reasons stated above, re-estimation of the basic reference points for groundfish management was considered a priority issue.

1.6 Organization of Data and Analyses to be Undertaken

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 each of the 19 stocks covered in Amendment 9, and a general section related to the conclusions of this work. Numerical data and full computer output from all analyses described herein will be included in a companion technical appendix (section 7); such data are too voluminous to be included in this summary report.

The section on *Estimation and Projection Methodology* describes the multiple approaches used for the various stocks, and is primarily sorted on 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 form were evaluated for the various stocks. Some objective model diagnostics were 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 (s-r) model approaches, and also used for stocks where s-r models could not reliably be fit to data. This approach applied various moments of the observed recruitment series and expected biomass per recruit to estimate the theoretical spawning biomass expectation associated with fishing at various F reference levels. This approach was used as a semi-independent check of s-r model results and as a basis for inferring the bounds of likely biomass had stocks not been growth overfished (e.g., see the scallop example cited in section 1.5). For stocks where the non-parametric approach was used to estimate Bmsy, the default F proxy of F40% msp was chosen as a robust reference point, based on several meta-analyses of spawning potential associated with sustainable fisheries (Clark 1991; Clark 1993). For Acadian redfish, an F proxy of 50% msp was chosen based on specific meta-analyses of similar west coast species (Dorn 2002).

Index-based methods for reference point estimation are 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. Biomass and catch data are used to develop these relationships, and the robustness of the approach is evaluated with some proposed test statistics.

Existing biomass and fishing mortality rate targets for all 19 stocks (a 20th stock, Gulf of Maine winter flounder is not evaluated in either the former review or this update) are re-considered in light of the quantitative approaches. Where appropriate, recommendations on revised management parameters are given. In each species section predictions of stock status, biomass and catch are given for the period from the current year (2002) to 2010 . The probabilities of achieving the proposed revised management targets are evaluated under the revised Fmsy value. 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 is calculated.

In the last section of this report, the information on revised reference points is summarized in light of the various approaches and data. For some 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 potential multispecies interactions, is it feasible to restore all the major components of this resources to Bmsy simultaneously? Some data and analyses and previous studies germane to this question are considered.

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 producing larger year classes (Brodziak et al. 2001). However, there is substantial variability around 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 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.

Table 1.4.1. Common and scientific names, stock definitions, and assessment types and lengths of assessment time series for 19 stocks regulated under the Northeast Multispecies Fisheries Management Plan of the New England Fishery Management Council. Assessment types are: VPA = age-based assessment using catch and survey data, surplus production = age-aggregated analyses using catch and survey data, Index = survey indices and catch data.

Common Name	Scientific Name	Stock Unit	Assessment Type / Period
Atlantic Cod	*Gadus morhua*	Gulf of Maine	VPA - 1982+
		Georges Bank	VPA - 1978+
Haddock	*Melanogrammus aeglefinus*	Gulf of Maine	Index - 1963+
		Georges Bank	VPA - 1931+
Yellowtail Flounder	*Limanda ferrugineus*	Georges Bank	VPA 1973+
		S. New England	VPA 1973+
		Cape Cod	VPA 1985-1998
		Mid-Atlantic	Index 1967+
Winter Flounder	*Pseudopleuronectes americanus*	Georges Bank	Sur Prod. 1964+
		S. New England	VPA 1982-1998
American Plaice	*Hippoglossoides platessoides*	Gulf of Maine-Georges Bank	VPA -1980+
Witch Flounder	*Glyptocephalus cynoglossus*	Gulf of Maine	VPA 1982-1998
Acadian Redfish	*Sebastes fasciatus*	Gulf of Maine	VPA 1963+
White Hake	*Urophycis tenuis*	Gulf of Maine-Georges Bank	Surplus Production 1964+
Pollock	*Pollachius virens*	Gulf of Maine-Georges Bank	VPA 1971-1993
Ocean Pout	*Macrozoarces americanus*	S. New England	Index 1968+
Windowpane Flounder	*Scophthalmus aquosus*	Northern	Index 1963+
		Southern	Index 1963+
Atlantic Halibut	*Hippoglossus hippoglossus*	Gulf of Maine	Index - 1963

Table 1.4.2. Current estimates of biological reference points for stocks managed under the Northeast Multispecies Fishery Management Plan (note that no revision is provided for Gulf of Maine winter flounder)

SPECIES	STOCK	STAT. AREAS	ESTIMATED REFERENCE POINTS				SOURCE OF ESTIMATE
			B_{TARGET} (metric tons)	$B_{THRESHOLD}$ (metric tons)	F_{MSY}	MSY (metric tons)	
COD	GB	520-600	108,000	27,000	0.32	35,000	Amendment 9 to the NEMS
	GOM	510-515	90,300 (total) 78,000 (ssb)	45,150 (total) 39,000 (ssb)	0.23	16,100	SAW - 33
HADDOCK	GB	520-562	105,000[1]	53,000	0.26	NA	Amendment 9 to the NEMS
	GOM	510-515	8.25 kg/tow[2]	2.06 kg/tow[2]	0.29(C/I)[3]	2,400	Amendment 9 to the NEMS
POLLOCK		441-616	102,000[1]	26,000[1]	0.65	40,000	Amendment 9 to the NEMS
REDFISH		500-562	121,000	60,500	0.116	14,000	Amendment 9
WHITE HAKE		Areas 5+	14,700	7,350	0.29	4,200	SAW - 33
YELLOWTAIL FLOUNDER	GB	522,525, 551,552, 561,562	43,500	21,750	0.33 (biomass weighted)	14,100	TRAC 2001
	SNE	526, 537-539	51,000	12,800	0.23	11,700	SAW - 27
	Mid-Atl.	600s	9.15 kg/tow[2]	4.58 kg/tow[2]	0.36(C/I)[3]	3,300	Amendment 9
	Cape Cod	514, 521	6,100	3,050	0.4	2,400	SAW - 28
WINDOWPANE FLOUNDER	Northern	Area 5 except:	0.94 kg/tow[2]	0.47 kg/tow[2]	1.11(C/I)[3]	1,000	Amendment 9
	Southern	526, 530-539, 541, Area 6	0.41 kg/tow[2]	0.10 kg/tow[2]	2.24(C/I)[3]	900	Amendment 9

WINTER FLOUNDER	GB	522, 525, 551-562	2.49 kg/tow[2]	1.24 kg/tow[2]	1.21 (C/I)[3]	3,000	SAW - 34
	GOM	510-515	*No recommendation*			2,000	
	SNE/MA	521, 526, 537-539, 600s	27,810	6,952	0.37	10,220	SAW - 28
AMERICAN PLAICE		Areas 5+	24,200[1]	6,050[1]	0.19	4,400	SAW - 28/SAW - 32
WITCH FLOUNDER		Areas 5+	25,000	10,500	0.106	2,684	SAW - 29
ATLANTIC HALIBUT		Areas 5+	5,400	2,700	0.06	300	Amendment 9
OCEAN POUT		Areas 5+	4.9 kg/tow[2]	2.4 kg/tow[2]	0.31(C/I)[3]	1,500	Amendment 9

[1] Biomass level based on spawning stock biomass (SSB) not total biomass

[2] Reference points expressed in nominal survey units rather than total stock biomass because the model estimate of the catchability coefficient could not be verified. F_{msy} based on relative exploitation index

[3] Relative exploitation index (catch/survey index)

[4] B_{msy} calculated from F_{msy} proxy and estimate of MSY

2.0 Estimation and Projection Methodology

As described in section 1.6, methods for management reference point estimation and predictions of stock status through 2009 have been classed into three categories, depending on the availability of data: age-based reference points; surplus production estimators, and index-based approaches. The theory and specific application of methods associated with the three approaches are summarized below.

2.1 Age-based assessments of reference points

Both a parametric and an 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. Where results differ appreciably, the results of the empirical approach were used as a component in final model selection. Automatic objective application these techniques is often compromised by lack of sufficient observation on stock and recruitment over a suitable 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 very variable data. Subjective judgement, drawn from collective scientific experience, was used to establish the following guidelines for applying both of these approaches. Unless there is convincing evidence to the contrary, the shape of the stock recruit relation will be assumed to be asymptotic. This assumption leads to an adaptive management approach to test the strength of super-compensatory mechanisms at higher stock sizes that should permit gradual accumulation of information at higher biomass, facilitating subsequent refinement of reference points (section 4.4). Making the assumption of increasing recruitment as biomass increases can result in predicting recruitment outside the range of observation and can result in unreasonably large estimates of B_{MSY}. Alternatively, making the assumption that recruitment varies inversely with biomass beyond some point result in a more aggressive harvesting strategy which might not permit learning about the potential productivity of the resource at higher biomass. In the absence of a plausible mechanism for overcompensation (cannibalism, spatial interference between adults and progeny, etc.) an asymptotic relationship is preferred as a basis for reference point estimation and projections.

For stocks that have been consistently growth overfished, if the estimate of Fmsy is substantially greater than Fmax or F40% msp, the basis of this needs to be closely examined for possible model mis-specification.

The specific procedures used for age-based reference point estimation are described below. We emphasize again that reference point estimates will periodically be updated and possibly change substantially as we learn more about stock dynamics at higher biomass. Parametric and non-parametric approaches should be attempted in parallel, if re-enforcing, either approach can be used for projections.

2.1.1 Empirical Non-parametric Approach

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. For this purpose, we developed a consistent format ("4-panel plots", see Figure 3.1.2 for the example of Gulf of Maine cod). The 4-panel plots includes the time series of spawning stock biomass and recruitment (plots a and b) and the scatterplot of stock-recruit data (plot c). A lowess smoother is fit to the s-r data as a visual guide to any trend in the relationship between stock and recruitment. If this trend is flat, then the mean or median recruitment is chosen for biomass calculation, depending on the leverage exerted by outliers (usually very large year classes). In the lower right corner of the 4-panel plot the moments of the recruitment series are multiplied by the BPR at F0.1 and F40% msp to give point estimates of associated spawning biomasses. For example, in Figure 3.1.2 the mean of all recruitment values in the series is 7.67 million fish. If this value is multiplied by 11.412 kg/fish at F40% msp, this results in a spawning biomass of 87,580 metric tons. This value is compared to the results from parametric analyses of model fits. The full bpr/ypr analysis for this stock is given in Table 3.1.2.

Several types of analyses of the recruitment * BPR analysis are 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 will be used.

- The B_{MSY} proxy will be 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, consisted with the recommended adaptive approach to increasing stock biomass.

- Projections to evaluate rebuilding plans incorporate uncertainty in the current population estimate (either bootstrap replicates or suitable variance simulation) and stochasticity in predicted recruitment (see section 2.4.1 below). Recruitment stochasticity is accommodated by either resampling from observed recruitment, r/ssb or their CDFs, (as long as the s-r model used is consistent with that used for estimating reference points).

- 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.

2.1.2 Parametric Model Approach

The parametric model approach uses a fitted parametric stock-recruitment model along with yield and spawning biomass per recruit information to calculate MSY-based references points using a standard algorithm. A key difference between the nonparametric proxy and the parametric approach is that the parametric approach produces a direct estimate of F_{MSY} in contrast to using an assumed proxy value. 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. Descriptions of the stock-recruitment models, estimation of stock-recruitment model parameters, and computation of maximum sustainable yield are given below.

Stock-Recruitment Models

The stock-recruitment models for estimation of MSY-based reference points were chosen to allow for compensatory and overcompensatory stock-recruitment dynamics. This choice provided two competing hypotheses about the possible forms of density-dependence. Both compensatory and overcompensatory models included a deterministic component to describe equilibrium stock-recruitment dynamics. Similarly, the models included an observation error term to account for randomness in the stock-recruitment data.

<u>Deterministic Component</u>

The Beverton-Holt curve (Beverton and Holt 1957) was used to model compensatory stock-recruitment dynamics where recruitment increases with spawning stock to an asymptote at large spawning stock size. This curve has a sound theoretical basis as a model of stock-recruitment dynamics. The Beverton-Holt curve arises naturally when density-dependent effects are critical at some early life history stage (see, for example, Quinn and Deriso 1998) and can also arise as a result of adaptation to balance predation and foraging risk in a variable environment (Walters and Korman 1999). This model was considered to be the null hypothesis in the absence of evidence that it was inconsistent with the observed data.

The modified Beverton-Holt curve (Mace and Doonan1988) was used for parameter estimation:

$$R = \frac{4\mathrm{z}_{\mathrm{MAX}}\mathrm{R}_{\mathrm{MAX}}S}{S_{MAX}(1-z_{MAX})+S(5z_{MAX}-1)}$$

where S_{MAX}= maximum observed level in the stock-recruitment data; R_{MAX} = maximum expected recruitment; and z_{MAX} = steepness of the modified Beverton-Holt curve computed as the ratio of R at 20% of S_{MAX} to R_{MAX}.

A standard form of the Beverton-Holt curve was used for projections:

$$R = \frac{\alpha S}{\beta + S}$$

The parameters of the standard and modified curves were related as:

$$\alpha = \frac{4 z_{MAX} R_{MAX}}{5 z_{MAX} - 1}$$

and

$$\beta = \frac{S_{MAX}(1 - z_{MAX})}{5 z_{MAX} - 1}$$

For the purposes of using the results of Myers et al. (1999) to determine appropriate prior distributions for the steepness parameter, the steepness calculated relative to the unfished spawning stock size, $S_{UNFISHED}$, denoted as z, was related to unfished equilibrium recruitment, $R_{UNFISHED}$, and the parameters of the standard curve via:

$$z = \frac{\dfrac{\alpha S_{UNFISHED} 0.2}{\left(\beta + S_{UNFISHED} 0.2\right)}}{R_{UNFISHED}}$$

For stocks that had short time series of stock-recruitment data and had relatively high NEFSC autumn survey biomass indices during the 1960s, values of S_{MAX} were computed as the product of average spawning biomass times the ratio of average NEFSC autumn survey biomass indices during 1963-1970 to the average biomass indices during 1990 to the most recent year for which stock-recruitment data were available. This computation was done for Gulf of Maine cod (S_{MAX} =77,500 mt), Georges Bank cod (S_{MAX} =104,200 mt), Georges Bank (S_{MAX} =36,200 mt) and Southern New England (S_{MAX} =64,400 mt) yellowtail flounder. For the other three stocks where parametric models were investigated, the maximum spawning biomass value in the stock-recruitment time series was S_{MAX} ; these were Georges Bank haddock (S_{MAX} =199,500 mt), Cape Cod yellowtail flounder (S_{MAX} =5,000 mt), and Southern New England winter flounder (S_{MAX} =14,600 mt). Here it is important to note that S_{MAX} was simply a fixed value for which to estimate the R_{MAX} parameter.

The Ricker curve (Ricker 1954) was used to model overcompensatory stock-recruitment dynamics where recruitment decreases with spawning stock as stock size becomes large. The form of the Ricker model used for parameter estimation was:

$$R = S e^{\alpha + \beta S}$$

where α = the slope at the origin and β = the strength of density-dependence in the relationship.

Stochastic Component

The stochastic component was represented by a multiplicative lognormal or an autoregressive, multiplicative lognormal error structure with a lag of one year. The stochastic component was multiplied by the deterministic component, denoted as $f(S_i)$ for the i^{th} data point, to obtain the stock-recruitment model:

$$R_i = f(S_i)e^{\varepsilon_i}$$

For uncorrelated errors, the ϵ_i were iid Gaussian random variables with zero mean and constant variance σ^2. In this case, the error variance (σ^2) was a parameter to be estimated. For autoregressive lag-1 errors, the ϵ_i were distributed as:

$$\varepsilon_i = \phi\varepsilon_{\text{i-1}} + w_i \text{ , where } |\phi| < 1, \ \text{Var}(\varepsilon) = \sigma^2,$$
$$w_i \sim \text{N}(0, \ \sigma_{\text{w}}^2), \text{ and } \sigma_{\text{w}}^2 = (1-\phi^2)\sigma^2$$

and the autoregressive coefficient and the error variance were additional model parameters to be estimated. The multiplicative lognormal error term was used because this positively-skewed distribution arises naturally when groundfish survival rates during early life history are affected by numerous independent random events represented as multiplicative log-scale effects. In this context, as the number of random events becomes large, the distribution of the mean of the log-scale multiplicative process approaches a normal random variable under the central limit theorem. The autoregressive error term was included to model serial correlation in random environmental variation because this allowed successive recruitments to be correlated when the effects of environmental forcing were strong, e.g., periods of good recruitment followed by periods of poor recruitment, regardless of the deterministic component.

Estimation of Stock-Recruitment Model Parameters

Maximum Likelihood Estimation

Parameter estimates were computed using maximum likelihood estimation conditioned on the stock-recruitment model (see, for example, Brodziak et al. 2001). The support function, or loglikelihood (log*L*), for a total of n stock-recruitment data points (R_i,S_i) with uncorrelated lognormal errors was:

$$\log L(\underline{\theta},\sigma^2) = -\frac{\text{n}}{2}\log(2\pi) - n\log\sigma - \sum_{i=1}^{n}\log R_i - \frac{1}{2\sigma^2}\sum_{i=1}^{n}\left(\log R_i - \log f(S_i)\right)^2$$

For models with autoregressive lag-1 correlated lognormal errors (see, for example Seber and Wild 1989) the loglikelihood was:

$$\log L(\underline{\theta}, \sigma^2, \phi) = -\frac{n}{2}\log(2\pi) - n\log\sigma_w - \sum_{i=1}^{n}\log R_i + \frac{1}{2}\log\left(1-\phi^2\right)$$

$$-\frac{1}{2\sigma_w^2}\sum_{i=2}^{n}\left(\log R_i - \phi\log R_{i-1} - \log f(S_i) + \phi\log f(S_{i-1})\right)^2 - \frac{(1-\phi^2)}{2\sigma_w^2}\left(\log R_1 - \log f(S_1)\right)^2$$

Maximum likelihood estimates (MLEs) of model parameters were computed using these support functions and the time series of stock-recruitment data. The AD Model Builder software package (Otter Research Ltd. 2001) was used to compute the MLEs.

Bayesian Priors on Steepness, Slope at the Origin or Unfished Recruitment

Because it was recognized that there would be limited information on the value of the steepness parameter of the Beverton-Holt curve or the slope at the origin of the Ricker curve, we borrowed from the strength of meta-analyses of numerous fish populations (Myers and Mertz 1998) to help to determine these parameters in a Bayesian statistical estimation framework (Gelman et al.1995; Hilborn and Mangel 1997; Punt and Hilborn 1997). In this context, an informative prior on the steepness or slope at the origin was determined using results of Myers et al.'s (1999) meta-analysis of a large number of stock-recruitment data sets. In a frequentist estimation framework, the use of such a prior would be conceptually equivalent to applying a penalty function to the support function to constrain parameter estimates (e.g., Edwards 1992).

The prior on steepness of the Beverton-Holt curve was based on values of z reported in Table 1 of Myers et al. (1999). The informative prior was assumed to be distributed as a normal random variable. Thus, the negative log of the prior on steepness (P(z)) was:

$$-\log P(z) = 0.5\log(2\pi) + \log(\sigma_z) + \frac{(z-\mu_z)^2}{2\sigma_z^2}$$

The mean of the informative prior was taken to be the median point estimate of steepness (z). The standard error of the informative prior was computed from the upper and lower values of the 60% confidence interval for steepness and the assumption that the steepness was normally distributed. This led to informative priors for the steepness of Atlantic cod, haddock, yellowtail flounder, and winter flounder (Table 2.1.2.1).

Similarly, the prior on the slope at the origin of the Ricker curve was based on values of α=logA and standard errors reported in Table 1 of Myers et al. (1999). As with the steepness parameter, the informative prior was assumed to be distributed as a normal random variable so the negative log of the prior on the slope at the origin (P(α)) was:

$$-\log P(\alpha) = 0.5\log(2\pi) + \log(\sigma_\alpha) + \frac{(z-\mu_\alpha)^2}{2\sigma_\alpha^2}$$

The parameters of the informative priors for the slope at the origin of Atlantic cod, haddock, yellowtail flounder, and winter flounder (Table 2.1.2.1).

Bayesian Prior on Recruitment

It was also recognized that there could be limited information on recruitment at high spawning stock sizes because the assessment time horizons of most stocks were short in comparison to their historic period of exploitation. For example, Georges Bank cod had been fished since the 1700s but the assessment time horizon begins in the late-1970s. As a result, an empirical Bayesian statistical estimation approach (Carlin and Louis 2000) was used to determine informative priors for the distribution of unfished recruitment, $R_{UNFISHED}$. The informative prior for $R_{UNFISHED}$, denoted by $P(R_{UNFISHED})$, was assumed to be normally distributed so that the negative log prior had form:

$$-\log P(R_{UNFISHED}) = 0.5\log(2\pi) + \log(\sigma_R) + \frac{(z-\mu_R)^2}{2\sigma_R^2}$$

The mean and standard error of the informative prior on $R_{UNFISHED}$ was determined using the empirical data on recruitment at high spawning stock size. For stocks that had a pattern of increasing recruitment with increasing spawning stock size, either in the hindcast or observed recruitment data, an appropriate subset of the observed recruitment data was used to determine the mean and standard error of the prior. These stocks were: Georges Bank haddock, Georges Bank cod, Southern New England winter flounder, and Georges Bank and Southern New England yellowtail flounder. For Georges Bank haddock, recruitment values during 1931-1960 were used to determine the prior parameters. For Georges Bank cod, recruitment values for spawning stock sizes in the top quartile of the spawning stock distribution were used to determine the prior parameters. For Southern New England winter flounder, recruitment values for the five highest observed spawning stock sizes were used to determine prior parameters; this was done because the data series was short (n=17). For the Georges Bank and Southern New England yellowtail flounder, recruitment values for spawning stock sizes in the top quartile of the hindcast spawning stock distribution were used to determine the prior parameters.

For stocks that had no discernable trend in recruitment with spawning stock size, the entire set of observed recruitment values were used to compute the mean and standard error of the prior. These stocks were: Gulf of Maine cod and Cape Cod yellowtail flounder.

Bayesian Estimation of Parameter Uncertainty

We used a Bayesian approach to characterize the uncertainty in output parameters of the parametric model to compute MSY-based reference points. This was done to give estimates of precision and Bayesian credibility intervals (confidence intervals) for the key output parameters. The AD Model Builder software package (Otter Research Ltd. 2001) was applied with an informative prior on either steepness, slope at the origin, or unfished recruitment, depending upon model configuration and with an uninformative prior on the remaining model parameters. In this approach, the posterior distribution of model parameters is assumed to be multivariate normal with mode equal to the MLE. The observed Hessian matrix at the MLE is used to estimate the covariance of the posterior distribution and samples from the posterior distribution are calculated using a Markov Chain Monte Carlo (MCMC) algorithm based on the Gibbs sampler (Gelman et al. 1995). The MCMC algorithm was run for 500,000 iterations to obtain representative samples from the posterior distribution with a sampling interval of every 100^{th} value to reduce autocorrelation in the series of samples. Thus, there were 5,000 posterior samples available for inference.

Computation of Maximum Sustainable Yield

Maximum sustainable yield for a fixed equilibrium stock-recruitment curve combined with yield and spawning biomass per recruit information was computed using a standard algorithm (Sissenwine and Shepherd 1987; Clark 1991; Brodziak 2002). In this approach, equilibrium yield is determined for a uniform grid of fishing mortality values. In this case, we used a grid of F ranging from 0 to 2 in 0.005 increments. The first step of the algorithm is to compute yield per recruit (Y/R) and spawning biomass per recruit (S/R) for each value of F. In this case, standard procedures to compute YR and S/R were applied (Gabriel et al. 1989). The second step of the algorithm is to determine the equilibrium spawning biomass based on the spawning biomass per at F and the stock-recruitment parameters over the grid of F values. For the Beverton-Holt model, the equilibrium spawning biomass (S*) is:

$$S^* = \alpha(S/R) - \beta$$

while for the Ricker model, it is:

$$S^* = \frac{-1}{\beta}\left(\log\left(S/R\right) + \alpha\right)$$

The third step of the algorithm is to compute equilibrium recruitment (R*) from equilibrium spawning biomass and the stock-recruitment parameters over the grid of F values. For the Beverton-Holt model, R* is:

$$R^* = \frac{\alpha S^*}{\beta + S^*}$$

while for the Ricker model, R* is:

$$R^* = S^* e^{a+\beta S^*}$$

The fourth step of the algorithm is to compute equilibrium yield (Y*) over the grid of F values as the product of equilibrium recruitment and yield per recruit:

$$Y^* = (R^*)(Y / R)$$

The last step of the algorithm is to determine MSY as the maximum value of Y* over the grid of F values; this also determines the value of B_{MSY} and F_{MSY}.

Use of Median Stock-Recruitment Curve

Applying a logarithmic transformation to either parametric stock recruitment model leads to a nonlinear regression equation:

$$Z = \log(F(S)) + \varepsilon$$

where Z=logR. This provides a way to estimate the parameters of F(S) in a logarithmic scale which is natural approach to rescaling the estimation equation.

In log-scale, any estimate of Z calculated from the parameters of F(S) for a particular value of S is an unbiased estimate of the expected value of Z, E[Z]. In contrast, any estimate of F(S) computed from the parameters of F(S) under inverse transformation to the original measurement scale is a biased estimate of the expected value of F(S). This bias is approximately equal to the exponential function of the population error variance divided by 2 and it applies only to the statistical expectation of F(S). In fact, the estimate of F(S) computed from the parameters of F(S) under inverse transformation to the original measurement scale is equal to the median of the distribution of the estimator of F(S) (see, for example Seber and Wild 1989, pp. 86-87).

For the purposes of evaluating whether MSY-based reference points are achieved, the median value of the distribution of any skewed estimator has been considered preferable to the mean. For example, projections are conducted to determine the fishing mortality that would lead to B_{MSY} being achieved with a 50% probability in a given year. In practice, the achievement of management targets under simulation has been consistently evaluated with respect to the 50% probability or median level for New England groundfish stocks. This implies that, to be consistent with the interpretation of achieving reference points under projection, the median stock-recruitment curve, as estimated under a logarithmic or any other monotonic transformation of the data, may be used as the basis for reference point computations. As a result, the median stock-recruitment curve is used for MSY-based reference point computations, in contrast to the expected value which would be subject to accurate estimation of the population error variance and correct specification of the observation error distribution.

Table 2.1.2.1 Parameters of informative prior distributions for steepness and slope at the origin.

	Steepness		Slope at the origin	
Species	Mean	SE	Mean	SE
Atlantic cod	0.84	0.08	1.37	0.15
Haddock	0.74	0.11	0.72	0.21
Yellowtail flounder	0.75	0.07	0.79	0.34
Winter flounder[1]	0.80	0.09	0.79	0.18

[1] Based on reported values for Pleuronectids

Hierarchical Criteria for Comparing Parametric Stock-Recruitment Model Fits

For each of the candidate stock-recruitment models, an hierarchy of criteria is applied to determine whether the maximum likelihood model fits are consistent with auxiliary information and with respect to model goodness-of-fit measures. These criteria are used as a quality control check to ensure that the individual model outputs make sense.

A priori, it is required that the estimated MLE from the model fit satisfies first- and second-order derivative conditions required for a strict maximum. These are that the gradient of the loglikelihood is identically zero at the MLE and that the Hessian matrix of second derivatives of the negative loglikelihood is positive definite.

In addition to satisfying the derivative conditions, each model must satisfy the following hierarchy of criteria to be considered credible:

1. Parameter estimates must not lie on the boundary of their feasible range of values
2. The estimate of MSY lies within the range of observed landings
3. The estimate of S_{MSY} is not substantially greater than the nonparametric proxy estimate
4. The estimate of F_{MSY} is not substantially greater than the value of F_{MAX}
5. The dominant frequencies for the autoregressive parameter, if applicable, lie within the range of one-half of the length of the stock-recruitment time series
6. The estimate of recruitment at S_{MAX} , the maximum spawning stock size proxy input to the stock-recruitment model, is consistent with the value of recruitment used to compute the nonparametric proxy estimate of S_{MSY}

For the subset of models that satisfy these criteria, Akaike's Information Criterion (AIC) can be used to assign relative probabilities to each model based on loglikelihood values (Brodziak et al. 2001). In this approach, each candidate model is assigned an equal prior probability of being the true state of nature. Model likelihood ratios are then compared using Bayes' Theorem to compute the posterior probability that each model represents the true state of nature. Last, the most likely model is selected as the best parametric model from which to base reference point calculations and stochastic projections. Further details of these calculations are provided below.

A bias-corrected form of the AIC criterion, known as AIC_C (Burnham and Anderson 1998 and references therein), was computed for each candidate model fit to data set D, with K parameters, n data points and, likelihood value $L(D \mid \underline{\Theta})$ at the MLE $\underline{\Theta}$,**:**

$$AIC_C \;=\; -2\log L(D \mid \underline{\Theta}) + 2K + \frac{2K(K+1)}{n-K-1}$$

In theory, the best model has the lowest AIC_C value. However, when AIC_C values were very similar among models, support for a single best model was limited.

Given the AIC_C values, Bayes' theorem was applied to evaluate the relative goodness of fit of each model. The probability that each candidate model was the true state of nature was computed for the available stock-recruitment data. Estimated AIC_C values were used to measure the relative likelihood of each model, with a penalty applied for the number of parameters which differed according to the assumed error structure. In particular, let $\underline{M} = \{M_k\}$ denote the set of models and let M_{MAX} denote the model with the maximum AIC_C value; M_{MAX} is the least likely model in $\underline{M}$. Thus, for a given set of stock-recruitment data D and model M with corresponding AIC_C value of $AIC_C(D|M)$, the likelihood ratio of model M to the least likely model is $\Lambda(D|M,M_{MAX})$ where:

$$\Lambda(D|\,M, M_{MAX}) \;=\frac{\mathrm{L}\left(D \mid \Theta_{\mathrm{M}}\right)}{\mathrm{L}\left(D \mid \Theta_{\mathrm{M_{MAX}}}\right)} \;\propto\; \frac{e^{-AIC_C(D|M)}}{e^{-AIC_C(D|M_{MAX})}}$$

The posterior distribution of relative model credibility was calculated from the likelihood ratio form of Bayes' Theorem using the model likelihood ratios relative to the least likely model and the prior distribution of each model, $\Pr(M_k)$. The posterior probability of model M, denoted by $\Pr(M|D)$, is the product of its likelihood ratio and prior probability divided by a normalizing constant

$$\Pr(M|D) \;=\; \frac{\Lambda(D|\,M, M_{MAX})\Pr(M)}{\sum_{M_k \in \underline{\mathrm{M}}} \Lambda(D|\,M_k, M_{MAX})\Pr(M_k)}$$

In the absence of any prior information on the credibility of candidate models, we assumed equal prior probabilities for each them. Models that did not satisfy first- or second-order derivative conditions at the calculated maximum or that did not satisfy one or more of the hierarchical criteria were assigned a prior probability of zero.

Model Name Decoder

Model names were built iteratively as more analyses were conducted (For example, see table 3.1.1 for Gulf of Maine cod). To decode the model name:

1. Start at the right, the last two letters are either BH (Beverton and Holt) or RK (Ricker), which distinguish the two possible underlying stock recruitment relationships.
2. If there is an A just before either BH or RK this means that an autoregressive error term was assumed in the model.
3. All the remaining models start with a P.
4. If the P is alone except for the letters already examined this means that the model assumed a prior for the steepness parameter in the Beverton and Holt model or the slope parameter in the Ricker model.
5. If the P is followed by R (not part of RK for the Ricker model), then the model assumed a prior for the unfished recruitment from the VPA data.
6. If the P and R are followed by HC, then the model assumed a prior for the unfished recruitment that was derived from hindcast data.
7. If the P is followed by 2, then the model assumed both a prior for unfished recruitment (either from the VPA data, no additional letters, or the hindcast data, HC) and a prior for either the steepness parameter in the Beverton and Holt model or the slope parameter in the Ricker model.

The 24 possible model names (note that all models are not examined for all stocks) are given in the table 2.1.2.2.

Table 2.1.2.2. Definition of model names for fitting stock-recruitment data.

			Priors			
					Unfished R	
Name	Stock Recruitment Relationship	Auto-regressive	Steepness	Slope	VPA	Hindcast
BH	Beverton & Holt					
ABH	Beverton & Holt	Yes				
PBH	Beverton & Holt		Yes			
PABH	Beverton & Holt	Yes	Yes			
PRBH	Beverton & Holt				Yes	
PRABH	Beverton & Holt	Yes			Yes	
P2BH	Beverton & Holt		Yes		Yes	
P2ABH	Beverton & Holt	Yes	Yes		Yes	
PRHCBH	Beverton & Holt					Yes
PRHCABH	Beverton & Holt	Yes				Yes
P2HCBH	Beverton & Holt		Yes			Yes
P2AHCBH	Beverton & Holt	Yes	Yes			Yes
RK	Ricker					
ARK	Ricker	Yes				
PRK	Ricker			Yes		
PARK	Ricker	Yes		Yes		
PRRK	Ricker				Yes	
PRARK	Ricker	Yes			Yes	
P2RK	Ricker			Yes	Yes	
P2ARK	Ricker	Yes		Yes	Yes	
PRHCRK	Ricker					Yes
PRHCARK	Ricker	Yes				Yes
P2HCRK	Ricker			Yes		Yes
P2AHCRK	Ricker	Yes		Yes		Yes

2.2 Surplus Production Assessments

Biomass Dynamics Analyses

A nonequilibrium surplus production model incorporating covariates (ASPIC; Prager 1994, 1995) was applied to each stock using landings (and discards where available) and multiple survey indices of stock biomass. The model assumes logistic population growth, in which the change in stock biomass over time (dB_t/dt) is a quadratic function of biomass (B_t):

$$dB_t/dt = rB_t - (r/K)B^2_t \quad (1)$$

where r is intrinsic rate of population growth, and K is carrying capacity. For a fished stock, the rate of change is also a function of fishing mortality (F):

$$dB_t/dt = (r\text{-}F_t)B_t - (r/K)B_t^2 \quad (2)$$

Biological reference points can be calculated from the production model parameters:

$$\text{MSY} = K\,r / 4 \tag{3}$$
$$B_{MSY} = K / 2 \tag{4}$$
$$F_{MSY} = r / 2 \tag{5}$$

Initial biomass (expressed as a ratio to B_{MSY}: *B1R*), *r*, MSY, and catchability of biomass indices (*q*) were estimated using nonlinear least squares of survey residuals. Biomass indices from research surveys or commercial catch rate contributed as independent biomass indices. Survey residuals were randomly resampled to approximate precision and model bias through bootstrap analysis.

Biomass dynamics models are simpler than age-based models such as VPA with relative advantages (e.g., they require only aggregate catch and biomass indices, and make simple assumptions about population dynamics) and disadvantages (e.g., they may ignore important age-based dynamics; National Research Council 1998a). With reliable observations of catch and biomass indices and a wide range of observed stock conditions, nonequilibrium models of biomass dynamics can provide reliable perspectives on stock status relative to MSY reference points (Hilborn and Walters 1992).

2.3 Index-based Assessments

Application of Index Methods: Catch and Fishery Independent Abundance Surveys

One of the core problems in fisheries science is the estimation of the scaling factor between estimates of relative abundance and true population size. This scaling factor is generally called the catchability coefficient. Assessment models that rely on VPA utilize the record of age-specific catches to approximate the virtual population. The utility of the virtual population as a means of estimating catchability rests on assumptions that the losses due to fishing are both known and large relative to natural mortality. Age structured assessments are data intensive and their scope is restricted to years in which both catch and abundance indices can be aged. In this section we explore the general trends in abundance and fishing mortality deducible from a time series of catch (or landings for some species) and survey indices. For all stocks, only the total catch (mt) and autumn and spring research trawl survey indices (kg/tow) are utilized. We explore the relative fishing mortality rate, defined as the ratio of catch to survey index, and relate it to what we call the replacement ratio. The replacement ratio is introduced 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.

The replacement ratio draws from the ideas underlying the Sissenwine-Shepherd model, delay-difference models, life-history theory, and statistical smoothing. We begin by defining $\mathbf{I}_{j,s,t}$ as the j-th relative abundance index for species-stock unit s at time t and $\mathbf{C}_{s,t}$ as the catch (or landings) of species-stock unit s at time t. The simple relative fishing mortality rate with respect to index type j, stock s and time t is defined as the ratio of $\mathbf{C}_{s,t}$ to $\mathbf{I}_{j,s,t}$. This ratio can be noisy, owing to imprecision of survey estimates, and the variation can be damped by writing the relative F as a ratio of the catch to some average of the underlying indices. Following the recommendation of the previous reference point panel review team, relative F is defined as the ratio of catch in year t to a centered 3-yr average of the survey indices:

$$relF_{j,s,t} = \frac{C_{s,t}}{\left(\frac{I_{j,s,t-1} + I_{j,s,t} + I_{j,s,t+1}}{3}\right)} \qquad (1)$$

Note that under this definition, the estimates of relative F for the first and last years of a time series are based on only 2 years of data.

Noise in the survey indices also affects the ability to relate inter-annual changes in abundance estimates to removal from fishing. The general approach of averaging adjacent years to estimate current stock size underlies statistical smoothing procedures (e.g., LOWESS) as well as formal time series models (e.g., ARIMA methods). One of the difficulties of applying such approaches in the present context, is that the derived parameters, if any, are unrelated to the species' biology or any aspect of the fishery. Moreover, we are interested in a basic questions of whether the current stock is replacing itself and whether the current level of catch is too high or low. Population dynamics models usually come to the rescue and allow approximate answers to these questions. However, if age-structure models cannot be applied, and more importantly, if the recent history of the fishery is uninformative, then most mathematical models will fail. The underlying reasons for model failure may not be immediately obvious from analysis of standard diagnostic measures. Of greater concern is the issue of the model mis-specification, wherein an inappropriate model adequately fits the data but leads to deductions inconsistent with basic biology and the fishery. The proposed replacement ratio is a "data-based" technique relying on fewer assumptions. No technique however, can fully compensate for model mis-specification errors.

If we assume that the survival from eggs to the juvenile stage is largely independent of stock size, then the number of recruits will be proportional to stock size. Locally, (i.e, in the neighborhood of any give stock size) this assumption holds for any stock-recruitment function. Since a population is a weighted sum of recruitment events, the interannual change in total stock size tends to be small relative to the total range of stock sizes (at least in the Northeast USA). Recruitment in any year is likely to be small relative to the biomass of the total population. Thus, the change in total biomass is likely to be small relative to the change in annual recruitment. Although the mathematics are more complicated than this ,the argument is based on the premise that if $Var(x/1) = \sigma^2$ then $Var(\Sigma x/n)\ \sigma^2/n$. Of course, the magnitude of such changes depends on the variation of recruitment and the magnitude of fishing mortality.

Using the linearity assumption defined above, we can employ basic life history theory to write abundance at time t as a function of the biomasses in previous time periods. The number of recruits at time t (**R_t**) is assumed to be proportional to the biomass at time t (**B_t**). More formally,

$$R_t = S_o \; Egg \; B_t \qquad (2)$$

where **Egg** is the number of eggs produced per unit of biomass, and **S_o** is the survival rate between the egg and recruit stages. Survival for recruited age groups at age a and time t (**$S_{a,t}$**) is defined as

$$S_{a,t} = e^{-F_{a,t} - M_{a,t}} \qquad (3)$$

where F and M refer to the instantaneous rates of fishing and natural mortality, respectively. We also need to consider the weight at age a and time t (**$W_{a,t}$**) and the average longevity (A) of the species

Using these standard concepts we now write the biomass at time t as a linear combination of the **A** previous years. Without loss of generality, we can drop the subscripts on the survival terms and assume that average weight at age is invariant with respect to time. Further, set the product **S_o Egg** equal to the coefficient **α**. The biomass at time t can now be written as

$$B_t = R_{t-1}S^1W_1 + R_{t-2}S^2W_2 + R_{t-3}S^3W_3 + .. + .R_{t-(A-1)}S^{A-1}W_{A-1} + R_{t-A}S^AW_A \quad (4)$$

Substituting Eq. (2) into Eq. (4) leads to

$$B_t = \alpha B_{t-1}S^1W_1 + \alpha B_{t-2}S^2W_2 + \alpha B_{t-3}S^3W_3 + .. + .\alpha B_{t-(A-1)}S^{A-1}W_{A-1} + \alpha B_{t-A}S^AW_A \quad (5)$$

If the population is replacing itself, then the left hand side of Eq. (5) will equal the right hand side. The replacement ratio **Ψ_t** can then be defined as

$$\Psi_t = \frac{B_t}{\alpha B_{t-1}S^1W_1 + \alpha B_{t-2}S^2W_2 + \alpha B_{t-3}S^3W_3 + .. + .\alpha B_{t-(A-1)}S^{A-1}W_{A-1} + \alpha B_{t-A}S^AW_A} \quad (6$$

Further simplifications of the replacement ratio can be obtained by letting $\phi_j = \alpha\, S^jW_j$ and noting that **$I_t = q\, B_t$** where **q** is the catchability coefficient.

$$\Psi_t = \frac{q\ I_t}{\sum_{j=1}^{A} \phi_j\ q\ I_{t-j}} \qquad (7)$$

The **q**'s cancel out such that Ψ_t is represented as a ratio of the survey indices to a weighted average of the previous survey values. The survival term S^j is equivalent to the l_x term in the Euler-Lotka equation for population growth (l_x is the probability of surviving to age x). For high levels of fishing mortality the S^j term is decreasing faster than the average weight W_j is increasing. Thus the importance of earlier indices rapidly diminishes. All of the I_t and ϕ_j terms are positive, and at equilibrium, $I_t=I_{t+1}$ and $I_t = \Sigma\ \phi_j\ I_{t-j}$ both hold. Therefore, $\Sigma\ \phi_j = 1$. It would be desirable to express each of the ϕ_j weighting terms as function of the underlying population parameters. As expected, increases in fishing mortality increase the weight to more recent indices, whereas the converse hold for lower fishing mortality rates. As an approximation for this initial analyses, we assumed that all of the $\phi_j = \phi$ which implies that $\phi = 1/\mathbf{A}$.
Given the high rate of fishing mortality observed in Northeast stocks, we further assumed that A=5 was a valid approximation. Note that even moderate levels of fishing mortality imply low ϕ_j values beyond the fifth term. (e.g., F=0.5, M=0.2 imply $S^5 = 0.03$. For the fifth to be important the ratio of the weights between the youngest and oldest ages would have to be greater than $1/S^5$ which, for this example, would exceed 33. As a first approximation, we defined $\phi_j = 1/5$ for all j. Thus Eq. 7 becomes the ratio of the current index to the average of the 5 previous years.

Application of any smoothing technique reflects a choice between signal and noise. A greater degree of smoothing eliminates the noise but may fail to detect true changes in the signal. Given the abrupt changes in fishing mortality that have occurred in some Northeast stocks, we chose to utilize the current year in the numerator of the replacement ratio. Use of the current index in the numerator rather than a running average of say k years, increases the sensitivity of the ratio to detect such changes. The penalty for such sensitivity is that the proportions of false positives and false negative responses increase. This penalty was judged acceptable for two reasons. First, it is desirable to detect abrupt changes in resource condition given the magnitude of recent and proposed management regulations. Second, the current formulation of the replacement ratio has a natural relationship to stock-recruitment hypotheses and the ratio can be investigated as a function of variations in underlying parameters, especially survival. Alternative formulations of the replacement ratio, say with a 2-yr average population size in the numerator can (and will) be developed, but their basic properties have not been investigated.

When fishing mortality rates exceed the capacity of the stock to replace itself the population is expected to decline over time. The expected behavior of Ψ_t under varying fishing mortality and recruitment is complicated, but it will have a stable point = 1 when the fishing mortality rate is in balance with recruitment and growth. Variations in fishing mortality will induce complex patterns, but in general terms, Ψ_t will exceed 1 when relative F is too high, and will be below 1 when F is too low. To account for these general properties and to reduce the influence of wide changes in either $\mathbf{\Psi_t}$ or the relative F, we applied robust regression methods (Goodall 1983) to estimate the relative F corresponding to $\mathbf{\Psi_t}$ =1. The parameters of the regression model

$$\ln(\Psi_t) = a + b \ln(relF_t) \qquad (8)$$

were estimated by minimizing the median absolute deviations. Median Absolute Deviation estimators are known as MAD estimators in the statistical literature (eg.Mosteller and Tukey 1977). Residuals were downweighted using a bisquare distribution in which the sum of the MAD standardized residuals was set to 6. This roughly corresponds to a rejection point of about plus or minus two standard deviations from the mean. (Goodall 1983).

The relative F at which $\mathbf{\Psi_t}$ = 1 was estimated from Eq. 8. as

$$relF_{threshold} = e^{-a/b} \qquad (9)$$

where the estimates of **a** and **b** from Eq. 8 were substituted into Eq. 9. This derived quantity may be appropriately labeled as a threshold since values in excess of it are expected to lead to declining populations. Alternatively, populations are expect to increase when $\mathbf{relF_t < relF_{threshold}}$

Employing the general standard that managers should attempt to rebuild fish stocks within 10 years, we estimated the relative fishing mortality rate at which the expected value of $\mathbf{\Psi_t}$ = 1.1 as a measure of $\mathbf{relF_{target}}$. Applying a little algebra to the Eq. 8 leads to the following estimator of $\mathbf{relF_{target}}$:

$$relF_{target} = e^{\frac{0.09531 - a}{b}} \qquad (10)$$

The asymptotic standard errors of $\mathbf{relF_{threshold}}$ and $\mathbf{relF_{target}}$ were derived from the Hessian matrix of the regression model.

The usual tests of statistical significance do not apply for the model described in Eq. 8. The relation between $\mathbf{\Psi_t}$ and $\mathbf{relF_t}$ is of the general form of Y/X vs X where X and Y are random variables. The expected correlation between Y/X and X is less than zero and is the basis for the oft stated criticism of spurious correlation. To test for spurious correlation we developed a sampling distribution of the correlation statistic using a randomization test. The randomization test is based on the null hypothesis that the catch and survey time series represent a random ordering of observations with no underlying association. The randomization test was developed as follows:

1. Create a random time series of length **T** of $\mathbf{C}_{r,t}$ from the set $\{\mathbf{C}_t\}$ and $\mathbf{I}_{r,t}$ from the set $\{\mathbf{I}_t\}$ by sampling with replacement.

2. Compute a random time series of relative F ($\mathbf{relF}_{r,t}$) and replacement ratios ($\boldsymbol{\Psi}_{r,t}$)
3. Compute the r-th correlation coefficient, say ρ_r between ln($\mathbf{relF}_{r,t}$) and ln($\boldsymbol{\Psi}_{r,t}$).
4. Repeat steps 1 to 3 1000 times.
5. Compare the observed correlation coefficient $\mathbf{r}_{obs}$ with the sorted set of ρ_r
6. The approximate significance level of the observed correlation coefficient $\mathbf{r}_{obs}$ is the fraction of values of ρ_r less than $\mathbf{r}_{obs}$

It should be emphasized that relF is not necessarily an adequate proxy for Fmsy, since this parameter only estimates the average mortality rate at which the stock was capable of replacing itself. Thus, while relF defined as average replacement fishing mortality is a necessary condition for an Fmsy proxy, it is not sufficient, since the stock could theoretically be brought to the stable point under an infinite array of biomass states.

Even with an estimate of relF derived from the above procedure, externally-derived estimates of Bmsy or MSY are necessary in order to develop consistent estimates of all the management reference points: MSY, Bmsy and Fmsy or their proxies. For index-based assessments these terms are related by

$$MSY/I_{Bmsy} = relF$$

where I_{Bmsy} is the survey index associated with Bmsy. Knowledge of any two of these terms allows for estimation of the third. For some index stocks (e.g. Gulf of Maine haddock) an external estrimate of MSY was considered, based on average catches over a stable period. For others, the Ibmsy proxy was considered more reliable and MSY derived from the above equation.

Six-Panel Plots of Catch, Relative F, and Replacement Ratios

The relationships among the catches, abundance indices, relative F, replacement ratios and time are summarized in a series of six-panel plots for each stock (19) and survey type (fall, spring). The panels are aligned to facilitate interpretation of the stock dynamics and to allow for a standard approach for comparison among stocks. The top four panels illustrate the interelationships among ln($\mathbf{relF}_t$), ln($\boldsymbol{\Psi}_{,t}$), $\mathbf{I}_t$, and time **t**. The variables share axes such that the temporal and phase plane interactions are easily followed. The bottom two panels illustrate the temporal patterns between catch $\mathbf{C}_t$ and ln($\mathbf{relF}_t$). Two of the panels warrant special consideration. The upper left panel plots ln($\boldsymbol{\Psi}_t$) vs ln($\mathbf{relF}_t$). The strength of the linear association can be inferred from the shape of the confidence ellipse (or principle component) surrounding the points. When the association is strong the ellipse will be long and narrow; when the association is weak the ellipse will approach a circle. The diagonal line represents the robust regression estimate and the dashed horizontal line represents the replacement ratio of 1.0. The intersection of the diagonal line with the replacement line represents the estimate of

$\mathbf{relF}_{\mathbf{threshold}}$. The intersection of the regression line with a horizontal line at a replacement ratio of 1.1 (not shown) represents the estimate of $\mathbf{relF}_{\mathbf{target}}$

The middle left panel represents the phase plane relationship between the log of the survey, $\mathbf{ln(I_t)}$ and the ln($\mathbf{relF}_{,t}$). Each point is labeled with the survey year and the points are connected to illustrate the temporal sequence. If the population declines with increases in fishing mortality and increases when the fishing mortality is reduced, the population should move up and down a linear isocline. In many species it is interesting to note that the return path for biomass, when F is reduced, tends to deviate sharply from the decline path. This general result may suggest that the rebuilding of stocks will be less predictable than the path of decline. In particular, the influence of truncated age structures on reproduction may be important and certainly, the presence of strong year classes will have a substantial, yet unpredictable influence on stock rebuilding.

Guide to 6 panel plots

The six panel plot developed for the "index" species attempts to show the interelationships among survey estimates of abundance, landings, functions of landings and relative abundance, and time. The two functions of landings and relative abundance considered are the replacement ratio (Eq. 6, section 2.3) and relative F (Eq. 9, section 2.3). The concept of using multiple panels to relate multiple variables over time has been advocated for use in fisheries science (e.g . Clark 1976, Hilborn and Walters 1992) and other fields (e.g. Cleveland 1993). The 6-panel plots attempt to show the logical connections among variables and to estimate underlying biological rates. The example for GOM Haddock (Figure 2.3) will be discussed in detail here.

The first aspect to note about the plots are the shared axes in the top four plots (A,B, C, D) and F. Panels B , D and F show the time series for the replacement ratio, the fall survey index, and the relative F, respectively. The horizontal line in A and B is the replacement ratio =1 line. The relationship between the replacement ratio and relative F in panel A is the key to understanding the influence of fishing mortality on stock size. Panel A is a phase plane that describes the relationship between two variables ordered by time. The degee of association between these variables is characterized by a Gaussian bivariate ellipsoid with a nominal probability level of p=0.6827 equivalent to $\pm$ 1 SD about the mean of the x and y variables. The primary and secondary axes of the ellipse are the first and second principal components, respectively. When the degree of association between relative F and replacement ratio decreases, the ellipse becomes more circle-like. The implication is that either the survey is too imprecise to detect changes induced by historical levels of fishing removals, or that the levels of fishing effort have been too low to effect changes in relative abundance. These alternatives can often be distinguished by consideration of the sampling gear and its interaction with the behavior of the species. Similarly incompleteness of the catch record, particularly for species in which the magnitude of discard mortality has varied widely, is another critical factor in the interpretation of the confidence ellipse.

The assumption that the relative F and replacement ratio have a joint bivariate normal distribution in the log –log scale may not hold for all (or any) species. In particular, the

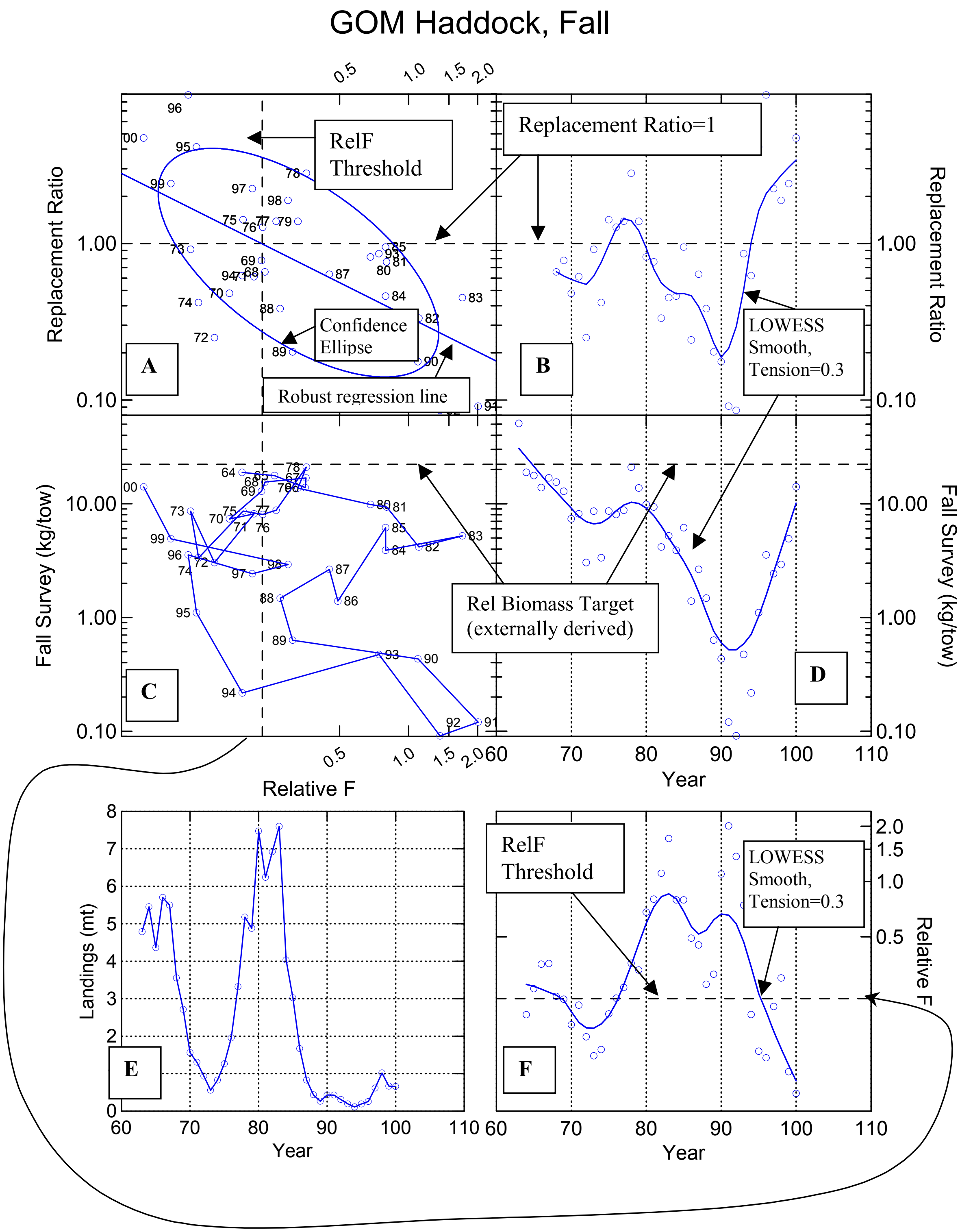


Figure 2.3. Annotated six-panel plot depicting trends in relative biomass, landings, relative fishing mortality rate (landings/index) and replacement ratios for Gulf of Maine haddock. Horizontal dashed (---) lines represent replacement ratios = 1 in (A) and (B), threshold relF in (F) and target relative biomass in (C) and (D). Vertical dashed lines in (A) and (C) represent the derived relF thresholds. Smooth lines in (B), (D), and (F) are Lowess smooths (tension=0.3). The confidence ellipse in (A) has a nominal probability level of 0.68. The regression line in (A) represents a robust regression using bisquare downweighting of residuals. See text for additional details.

replacement ratio model is designed to be sensitive to contemporary changes, so that by definition it will be highly variable. Large changes that are subsequently validated by future observations imply true changes in population status. When the converse is true, it is proper to conclude that the change was an artifact of sampling variation. The degree to which high residuals influence the pattern is tested using the robust regression method of Tukey (Mosteller and Tukey 1977) that downweights large residuals using a bisquare distribution (see Goodall 1983 for details). Thus the regression line in panel A will not be aligned with the primary axis of the ellipse when high residuals distort the confidence ellipse. The expected value of correlation between the replacement rate and relative F is negative. The empirically derived estimate of the sampling distribution for the correlation coefficient , via the randomization test, provides a way of judging the significance of the robust regression line.

The predicted value of relative F at which the replacement ratio is 1 is defined by Eq. 8 and denoted by the vertical line in Panel A and B. The precision of that point depends largely upon where it lies within the confidence ellipse. If the confidence ellipse is nearly centered about the intersection point, then the precision of the relative F threshold will be high. This also indicates that over time, a wide range of F and replacement ratios greater than one have been observed. In contrast, when the intersection point lies in the upper right portion of ellipse, the precision will be low. This is, of course, is a common property of linear regression in which the prediction interval for Y increases with the square of the distance between the independent variable X and its mean. Thus a high degree of correlation between relative F and the replacement ratio does not necessarily ensure high precision in the threshold if relatively few observations have replacement ratios greater than one. Panel A demonstrates, in a slightly different way, the implications of the “one-way trip” described in Hilborn and Walters (1992)

Panel C depicts the phase plane for relative biomass (ie. The index) and the relative F. At equilibrium, the population should move up and down a linear isocline. The degree of departure from linearity reflects both sampling variation as well as true variations induced by recruitment pulses and its transient influence on total biomass. Thus the trace of points can give useful insights into parametric model selection of population dynamics under exploitation .

The simple data of catch and survey are generally not sufficient to estimate simultaneously both the threshold F and biomass targets. This property characterizes the common property of indeterminancy of r and K in standard surplus production models. For the GOM haddock example, the relative biomass target is defined external to the model (Panel C and D).

To facilitate the detection of temporal patterns, Lowess smoothing is applied in panels B, D, and F. A relatively low tension =0.3 (i.e., 30% of the span of data are used for the estimate of each smoothed Y value) is used to allow for more sensitive flexing of the smoothed line. As noted earlier, the heightened sensitivity is desirable for this particular application in fisheries management. In a sense, the Lowess smoothing counterbalances the sensitivity built into the definitions of replacement ratio and relative F, by damping the rates of change and allowing for detection of general trends.

The final point to note is that the 6 panel plot may allow one to develop a reasonable picture of the population dynamics in relation to exploitation. With the exception of a brief period in the late 70's the replacement rate for GOM haddock was below one and continued its downward trend until 1990 (Panel A). This was accompanied by a continuously decreasing population size (Panel D). The reduction in landings from nearly 8000 mt in 1984 to less than 500 mt by 1989 (Panel E) greatly reduced the relative F (Panel F) below the threshold level and subsequently led to the replacement ratio exceeding one. The inter-relationships among Panels B, D, and F resemble the kinetics of simple chemical reactions and conceptually one should look for counteracting trends among indices and the influence of the trends in catch and relative survey abundance.

2.4 Projection Methodologies

One principle of conducting stock projections is that the basis for such projections (e.g., stock-recruit model, or emporical approach, production analysis or index method) should be consistent with the approach taken for reference point estimation (see the problems as noted in section 1.5 when this is not the case). Our analyses used consistent projections methodologies in all cases.

2.4.1 Age-Based Projections

Age-based projections are conducted using standard methodology and software (Brodziak et al. 1998; Brodziak and Rago 2002). In this approach, standard statistical techniques of bootstrapping and Monte Carlo simulation are used to project performance measures such as landings, discards, spawning biomass, and recruitment under alternative management policies. The key idea is to propagate variability in estimates of initial stock size forward in stochastic projections of future possibilities based on the same dynamical model and data used in the stock assessment model. Bootstrap replicates of current population size from an age-structured assessment model are combined with a stochastic stock-recruitment relationship to simulate population trajectories through the projection horizon. As a consequence, uncertainties in both initial population abundance and future recruitment are directly incorporated into management advice. The implications of management decisions can be quantified and compared using empirically-derived sampling distributions of catch, landings, discards, spawning biomass, recruitment, and, in the case of management under fixed catch quotas, fishing mortality. Estimates of the probability of exceeding biological reference points or achieving management targets are also quantified.

2.4.2 Surplus Production Projections

Stochastic projection was performed using bootstrap distributions of stock biomass in 2001, and estimated biomass dynamics parameters from ASPIC (Prager 1995). Projections assumed observed catch in 2001 (adjusted upward from January-November data), and the resulting fishing mortality in 2001 was assumed to continue in 2002 (expressed as a ratio to F in the terminal year, 2000). Projections were run through 2010. Results were described using bias corrected confidence intervals of projected biomass and catch.

2.4.3 Projections from Index-Based Methods

Catch Estimation and Projections

The estimates of $\mathbf{relF_{threshold}}$ and $\mathbf{relF_{target}}$ from Eq. 9 and 10 respectively, can be used to project the expected catches during any forecast period. Under the theory, multiplication of the current abundance index It by $\mathbf{relF_{threshold}}$ leads to an estimate of Ct. If the estimate of $\mathbf{relF_{threshold}}$ is unbiased then the population is expected to remain constant. This leads to the rather uninteresting forecast of constant catches over any time horizon. Conversely, when the population is fished at $\mathbf{relF_{target}}$, the population is expected to grow by an average of 10% per year and the catches will grow at a similar rate. For short time periods and low initial population sizes, this approximation is likely to hold. Results of this approach, summarized in Table 4.1.2, suggest a reasonable degree of coherence with rebuilding schedules and catch projections derived from more complicated age-structured models. Thus, the catch projection estimates for the species without more complicated models may be used for planning and management purposes.

2.5 Mean Generation Times

The calculation of mean generation times for the various stocks is relevant to rebuilding times and rates in as much as life history is a determinant of maximum rebuilding potential and the ability of stocks to recover to Bmsy over a defined time interval (Restrepo et al. 1998). In the context of stocks determined to be unable to meet Bmsy targets in a 10 year time frame once a re-building program has been initiated, the National Standard Guidelines state that the actual rebuilding time plus one mean generation time may be specified as the maximum rebuilding period. The formula of Goodyear (1995) was modified for application to the New England groundfish stocks for which adequate estimates of natural mortality (M) mean weights at age in the stock, and proportion mature at age are available. Generation time, G is the weighted mean age of spawners in a population not subjected to fishing:

$$G = \sum_{a=1}^{A} aE_aN_a \Big/ \sum_{a=1}^{A} E_aN_a$$

N_a is the number at any age in the population, E_a is the weighting factor calculated as the proportion mature at age multiplied by the mean weight at age in the stock, and a is age. For the New England groundfish species, basic data inputs to the calculation are given in the appropriate yield and spawning stock biomass per recruit tables (e.g., Table 3.1.2 for Gulf of Maine cod). The number of ages was determined by applying M to the population numbers at age until there was an insignificant number of fish remaining from the initial assumed cohort size (for redfish we assumed 200 ages, for all others 50 years). Results of the mean generation time calculations are given in Table 2.5. Owing to its low natural mortality rate and delayed maturity, Acadian redfish had the longest mean generation time (30.6 years) while the Georges Bank and Southern New England yellowtail flounder stocks had the lowest G values, under 9 years.

Table 2.5. 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

3.0 Reference Point Re-Estimation and Stock Projections through 2009

3.1 Gulf of Maine cod

Catch and Survey Indices

Atlantic cod (*Gadus morhua*) in the Gulf of Maine region have been commercially exploited since the 17th century, and reliable landings statistics are available since 1893. Historically, the Gulf of Maine fishery can be separated into four periods: (1) an early era from 1893-1915 in which record-high landings (> 17,000 mt) in 1895 and 1906 were followed by about 10 years of sharply-reduced catches; (2) a later period from 1916-1940 in which annual landings were relatively stable, fluctuating between 5,000 and 11,500 mt, and averaging 8,300 mt per year; (3) a period from 1941-1963 when landings sharply increased (1945: 14,500 mt) and then rapidly decreased, reaching a record-low of 2,600 mt in 1957; and (4) the most recent period from 1964 onward during which Gulf of Maine landings have generally increased but have declined steadily since the early 1990s. Commercial landings doubled between 1964 and 1968, doubled again between 1968 and 1977, and averaged 12,200 mt per year during 1976-1985 (Figure 3.1.1). Gulf of Maine cod landings subsequently increased, reaching 17,800 mt in 1991, the highest level since the early 1900s.

Commercial landings declined sharply in 1992, and have since decreased steadily to 1,636 mt in 1999 before increasing to 3,730 mt in 2000. The sharp decline in landings between 1998 and 1999 and the subsequent increase in 2000 likely reflects the imposition of very low trip limits during 1999 and the subsequent relaxation of these limits in early 2000. The extent of discarding increased sharply in 1999 and remained relatively high in 2000. Landings of Gulf of Maine cod from the recreational sector have also been significant, averaging about 20% of the total (commercial and recreational) landings since 1982.

Fishery-independent spring and autumn bottom trawl surveys conducted by the NEFSC have documented a steady decline in total stock biomass since the 1960s; the largest decreases occurred during the 1980s (Figure 3.1.1). Although the most recent indices suggest a slight increase, overall, the Gulf of Maine cod stock biomass remains low relative to the 1960s and 1970s.

Stock Assessment

The most recent assessment of the Gulf of Maine cod stock was completed in 2001 (Mayo *et al.* 2002a), and the results were reviewed at the 33rd Northeast Regional Stock Assessment Workshop in June, 2001 (NEFSC 2001c). At that time fully recruited fishing mortality in 2000 was estimated to be 0.73. Spawning stock biomass had increased slightly from 9,900 mt in 1998 to 13,100 mt in 2000, still well below the maximum of 24,200 mt observed during the 1982-2000 VPA period. Except for the 1998 year class, recruitment had been relatively poor since the appearance of the 1992 year class. Plots of spawning stock biomass (SSB) and recruitment estimates obtained from the 2001 assessment are provided in Figure 3.1.2. Over the range of spawning stock observed during the VPA period (1982-2000), there appears to be no appreciable trend in recruitment with respect to SSB.

Fishing mortality (fully recruited) and biomass reference points were estimated from a yield and spawning biomass per recruit analysis combined with a stock-recruitment analysis employing a parametric Beverton-Holt model. The following reference points were estimated: $F_{0.1} = 0.15$, $F_{msy} = 0.23$, $F_{max} = 0.27$, $B_{msy} = 90{,}300$ mt, and $SSB_{msy} = 78{,}000$ mt.

Yield and SSB per Recruit Analysis

The yield and spawning stock biomass analysis conducted during the course of the 2001 assessment was revised slightly during the present analysis to achieve consistency with the likely age distribution of fish within the plus group by adjusting the age 11+ mean weight at age to account for the F likely to rebuild spawning biomass. Partial recruitment and maturation at age were the same as those employed in the 2001 assessment. Estimates of $F_{0.1}$ and F_{max} presented in Table 3.1.2 are virtually identical to those given in the 2001 assessment. The yield and spawning stock biomass per recruit estimated over a range of fishing mortality rates were employed in the estimation of MSY-based reference points as described in the following section.

MSY-based Reference Point Estimation

<u>Empirical Nonparametric Approach</u>

The stock-recruitment data derived from the 2001 VPA do not suggest any appreciable trend in recruitment with respect to spawning stock biomass, the average recruitment from the entire series is used to represent the expected recruitment at Bmsy (Figure 3.1.2). If the estimate of F40% is taken as a proxy for Fmsy, the fishing mortality threshold is 0.166. This fishing mortality rate produces 11.412 kg of spawning stock biomass per recruit and 1.7913 kg of yield per recruit. The resulting mean of 7.67 million fish results in an SSB_{msy} estimate of 87,580 mt when multiplied by the SSB per recruit, and an MSY estimate of 13,739 mt when multiplied by the yield per recruit.

Although this estimate of SSB_{msy} is well above the range of SSB observed during the VPA period, a series of hindcast spawning biomass and recruitment estimates based on autumn NEFSC surveys (Figure 3.1.3) suggests the existence of SSB levels during the1960s which were well above the maximum estimate from the VPA.

<u>Parametric Model Approach</u>

Maximum likelihood fits of the 10 parametric stock-recruitment models to the Gulf of Maine cod data from 1982-2000 are listed below (Table 3.1.1). The model acronyms are:
BH = Beverton-Holt, ABH = Beverton-Holt with autoregressive errors, PBH = Beverton-Holt with steepness prior, PABH = Beverton-Holt with steepness prior and autoregressive errors, PRBH = Beverton-Holt with recruitment prior, PRABH = Beverton-Holt with recruitment prior and autoregressive errors, RK = Ricker, ARK = Ricker with autoregressive errors, PRK = Ricker

with slope at the origin prior, PARK = Ricker with slope at the origin prior and autoregressive errors. The six hierarchical criteria are applied to each of the models to determine the set of candidate models.

The first criterion is not satisfied by the PRK and PARK models because the estimate of F_{MSY} lies on the boundary of its feasible range. The second criterion is not satisfied by the PBH model which has a point estimate of MSY=21.300 mt. This eliminates the PBH as a candidate. The third criterion is satisfied by the remaining models. The fourth criterion is not satisfied by the RK and ARK models, where the F_{MSY} estimates of 0.60 greatly exceed the value of F_{MAX} =0.27 for Gulf of Maine cod. The fifth criterion is not satisfied by the remaining autoregressive models which have dominant frequencies greater than ½ of the length of the rather short stock-recruitment time series for Gulf of Maine cod (Figure 3.1.4). Finally, the sixth criterion is considered to be satisfied by the remaining 2 models: BH and PRBH.

Given the two candidate models (BH and PRBH), the AIC criterion assigns a slightly greater probability to the PRBH model. The odds ratio of BH being true to PRBH is roughly 1.1:1. There is limited basis for choosing between these two parametric models, although their point estimates of $S_{MSY,}$ F_{MSY}, and MSY differ. The two model differ only in the inclusion of a prior on recruitment in the PRBH model. However, given the limited range of the stock and recruitment data for Gulf of Maine cod, this may not be the most appropriate choice. As well, the steepness estimated by the BH model (0.91) was within $\pm$1 standard error of the average for the cod group while the steepness estimated by the PRBH model (0.95) was outside of $\pm$1 standard error and very close to the boundary (1.0). Therefore, the Beverton-Holt model without priors was considered to best fit the data for this stock.

The results of using the BH model as the best fit parametric model are shown below (Table 3.1.1 and Figures 3.1.5, 3.1.6 and 3.1.7). The standardized residual plot of the fit of the BH model to the stock-recruitment data shows that the standardized residuals generally lie within ± two standard deviations of zero (Figure 3.1.5), with the exception of the 1988 data point. MSY-based reference points derived from the BH model are: F_{msy} = 0.225 and SSB_{msy} = 82,830 mt.

In the equilibrium yield plot (Figure 3.1.6), the yield surface is relatively flat in the neighborhood of the point estimate of F_{MSY} = 0.225. The point estimates of SSB_{MSY} (82.8 kt) and MSY (16.6 kt) appear consistent with the nonparametric proxy estimate of SSB_{MSY} and previous estimates of F_{MSY} and SSB_{msy} from SAW 33. The stock-recruitment plot (Figure 3.1.7) shows that recruitment values near SSB_{MSY} are roughly 9 million fish which is slightly larger than the long-term average of the observed recruitment series but is consistent with the 75th percentile of the observed recruitment series (9.5 million fish).

Parameter uncertainty plots show histograms of 5000 MCMC sample estimates of MSY, S_{MSY}, and F_{MSY} drawn from the posterior distribution of the MLE based on an uninformative prior. Both MSY and S_{MSY} had distributions with high positive skewness. For MSY, the 80 percent credibility interval was (14.1, 34.6) with a median of 19.3 kt (Figure 3.1.8). For S_{MSY}, the 80 percent credibility interval was (66.3, 193.6) with a median of 99.1 kt (Figure 3.1.8). For F_{MSY}, the 80 percent credibility interval was (0.195, 0.240) with a median of 0.215 (Figure 3.1.8).

Overall, the point estimates of MSY and S_{MSY} were lower than the medians of the MCMC samples.

Reference Point Advice

Reference points derived from the Beverton-Holt model are: F_{msy} = 0.225, MSY = 16,600 mt and SSB_{msy} = 82,830 mt. The estimate of MSY represents total catch, including commercial and recreational landings, and commercial discards.

The revised SSBmsy estimate for Gulf of Maine cod (82,800 mt) is slightly higher than the value estimated during SAW 33 (78,000 mt) (NEFSC 2001c). The change is a result of a slight increase in the stock mean weights at age applied to the yield per recruit calculations in the age structured production model resulting in higher biomass per recruit ratios. The increase in the mean weights at age is due a change in the time period used in the averaging from long term (1982-1998) in the SAW 33 to a more recent period (1996-1998) in the present analysis.

Projections

Stochastic age-based projections (Brodziak and Rago MS 2002) were performed over a 10-year time horizon beginning in 2001 to evaluate relative trajectories of stock biomass and catch under various fishing mortality scenarios. Recruitment was derived from the Beverton-Holt spawning stock-recruitment relationship employed in the age structured production model. Stock and catch mean weights at age, the maturity at age schedule, and the partial recruitment at age vector are the same as those employed in the yield and SSB per recruit analyses presented above. The 2001 survivors derived from 600 bootstrap iterations of the final VPA formulation were employed as the initial population vector. The projection was performed at two fishing mortality rates: F_{msy} (0.225) and F calculated to rebuild spawning biomass to SSB_{msy} by 2009. Fully recruited fishing mortality in 2001 was derived from iterative calculations based on the estimated total 2001 catch (7,994 mt), including commercial landings and discards and recreational landings. Fishing mortality in 2002 was fixed at the Amendment 7 target (F_{max} = 0.26), the present management target.

The medium-term projections (Figures 3.1.9, 3.1.10, and 3.1.11) suggest that fishing at F_{msy} (0.225) between 2003 and 2009 will result in only a 22% probability of rebuilding spawning biomass to SSB_{msy} (82, 830 mt) by 2009 (Figure 3.1.9). To achieve a 50% probability of rebuilding spawning biomass to SSB_{msy} by 2009, F must be reduced to 0.165 during 2003-2009 (Figures 3.1.9 and 3.1.10). The total annual catch, including commercial landings and discard and recreational landings, is expected to increase from 3,850 mt in 2003 to 11,530 mt in 2009 (Figure 3.1.11).

Table 3.1.1. Stock-recruitment model comparisons for Gulf of Maine cod - age 11+ formulation.

Gulf of Maine Cod 11-Age Class Model Comparison										
SMAX =	77500									
	Prior	Prior	Prior	Prior	Prior	Prior	Prior	Prior	Prior	Prior
	0.5000	0	0	0	0.5000	0	0	0	0	0
	BH	**ABH**	**PBH**	**PABH**	**PRBH**	**PRABH**	RK	ARK	PRK	PARK
Posterior Probability	**0.52**	0.00	**0.00**	0.00	**0.48**	0.00	0.00	0.00	0.00	0.00
Odds Ratio for Most Likely Model	1.00				1.06					
Normalized Likelihood	0.52	0.00	0.00	0.00	0.48	0.00	0.00	0.00	0.00	0.00
Model AIC Ratio	1.06449				1					
	BH	**ABH**	**PBH**	**PABH**	**PRBH**	**PRABH**	**RK**	**ARK**	**PRK**	**PARK**
Number_of_data_points	18	18	18	18	18	18	18	18	18	18
Number_of_parameters	3	4	3	4	3	4	3	4	3	4
Negative_loglikelihood	172.151	171.265	170.666	169.886	180.249	179.296	172.104	171.195	186.623	177.639
Bias-corrected_AIC	352.016	353.607	352.171	353.933	352.141	353.609	351.922	353.467	373.269	363.252
Diagnostic Comments	**Most Likely Model**	Power spectrum dominant frequency exceeds 1/2 time series length	MSY outside range of observed landings	Power spectrum dominant frequency exceeds 1/2 time series length		Power spectrum dominant frequency exceeds 1/2 time series length	FMSY substantially exceeds FMAX	FMSY substantially exceeds FMAX	FMSY at boundary of feasible range	FMSY at boundary of feasible range
Parameter Point Estimates										
***********************										
MSY	16636.6	14090.3	21293.5	20252.6	13931.9	13787.8	10912.8	10829.7	18113.3	13385.9
FMSY	0.225	0.24	0.21	0.21	0.24	0.245	0.595	0.595	2	2
SMSY	82829.7	66237.8	112815	107300	65493.6	63648.3	25607.3	25412.1	23494.3	17362.5
alpha	9854.36	7998.51	13240.5	12522	7910.29	7780.58	0.0107473	0.00556144	0.904107	1.03259
expected_alpha	11313.5	9176.81	15219.2	14371.3	9090.31	8928.95	0.0123317	0.00637066	1.23523	1.14695
beta	7516.1	3275.83	15537.3	14087.2	3253.36	2809.65	-5.34E-05	-5.36E-05	-6.26E-05	-9.21E-05
RMAX	8983.15	7674.13	11029.3	10596	7591.6	7508.37	1252.84	1226.64	1494.91	172.625
expected_RMAX	10313.3	8804.65	12677.6	12160.8	8724.08	8616.56	1437.54	1405.12	2042.4	191.743
Prior_mean			0.84	0.84	7674	7674			1.37	1.37
Prior_se			0.08	0.08	1226	1226			0.15	0.15
Z_Myers	0.91	0.95	0.86	0.87	0.95	0.95				
sigma	0.52552	0.524261	0.528	0.525	0.527	0.525	0.524	0.521	0.790	0.458
phi		0.31		0.28		0.31		0.30		0.38
sigmaw		0.499		0.50		0.50		0.50		0.42
last log-residual R		-0.088		0.024		-0.094		-0.086		-0.684
expected lognormal error term	1.148	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.37	1.11

Table 3.1.2. Yield and biomass per recruit for Gulf of Maine cod.

The NEFC Yield and Stock Size per Recruit Program - PDBYPRC
PC Ver.2.0 [Method of Thompson and Bell (1934)] 9-Aug-2001

Run Date: 21- 2-2002; Time: 10:44:58.63
GULF OF MAINE COD (5Y) - 2001 UPDATED AVE WTS, FPAT AND MAT VECTORS

Proportion of F before spawning: .1667
Proportion of M before spawning: .1667
Natural Mortality is Constant at: .200
Initial age is: 1; Last age is: 11
Last age is a PLUS group;
Original age-specific PRs, Mats, and Mean Wts from file:
==> yrcodgma.dat

Age-specific Input data for Yield per Recruit Analysis

Age	Fish Mort Pattern	Nat Mort Pattern	Proportion Mature	Average Weights Catch	Average Weights Stock
1	.0000	1.0000	.0400	.468	.264
2	.0134	1.0000	.3800	1.582	.860
3	.2867	1.0000	.8900	2.064	1.811
4	.9899	1.0000	.9900	2.726	2.336
5	1.0000	1.0000	1.0000	3.982	3.314
6	1.0000	1.0000	1.0000	5.804	4.659
7	1.0000	1.0000	1.0000	9.569	7.916
8	1.0000	1.0000	1.0000	12.507	10.889
9	1.0000	1.0000	1.0000	16.015	14.253
10	1.0000	1.0000	1.0000	18.709	16.199
11+	1.0000	1.0000	1.0000	19.198	17.472

Summary of Yield per Recruit Analysis for:
GULF OF MAINE COD (5Y) - 2001 UPDATED AVE WTS, FPAT AND MAT VECTORS

Slope of the Yield/Recruit Curve at F=0.00: --> 29.4040
F level at slope=1/10 of the above slope (F0.1): -----> .151
Yield/Recruit corresponding to F0.1: -----> 1.7547
F level to produce Maximum Yield/Recruit (Fmax): -----> .258
Yield/Recruit corresponding to Fmax: -----> 1.8744
F level at 40 % of Max Spawning Potential (F40): -----> .166
SSB/Recruit corresponding to F40: --------> 11.4116

1

Listing of Yield per Recruit Results for:
GULF OF MAINE COD (5Y) - 2001 UPDATED AVE WTS, FPAT AND MAT VECTORS

	FMORT	TOTCTHN	TOTCTHW	TOTSTKN	TOTSTKW	SPNSTKN	SPNSTKW	% MSP
	.000	.00000	.00000	5.5167	30.3366	3.8396	28.5329	100.00
	.050	.11707	1.03050	4.9337	22.1467	3.2550	20.4493	71.67
	.100	.19537	1.52129	4.5446	17.0849	2.8642	15.4734	54.23
	.150	.25150	1.75096	4.2662	13.7410	2.5841	12.1992	42.75
F0.1	.151	.25271	1.75465	4.2602	13.6723	2.5781	12.1320	42.52
F40%	.166	.26582	1.79128	4.1953	12.9345	2.5127	11.4116	39.99
	.200	.29377	1.84734	4.0571	11.4231	2.3734	9.9383	34.83
	.250	.32681	1.87408	3.8941	9.7562	2.2088	8.3179	29.15
Fmax	.258	.33155	1.87438	3.8708	9.5287	2.1852	8.0972	28.38
	.300	.35338	1.86457	3.7634	8.5212	2.0765	7.1212	24.96
	.350	.37523	1.83693	3.6562	7.5835	1.9677	6.2151	21.78
	.400	.39356	1.80113	3.5666	6.8563	1.8766	5.5141	19.33
	.450	.40917	1.76268	3.4906	6.2820	1.7990	4.9615	17.39
	.500	.42264	1.72460	3.4252	5.8209	1.7321	4.5185	15.84
	.550	.43440	1.68842	3.3683	5.4454	1.6737	4.1580	14.57
	.600	.44477	1.65490	3.3184	5.1354	1.6223	3.8607	13.53
	.650	.45399	1.62429	3.2741	4.8766	1.5766	3.6124	12.66
	.700	.46225	1.59660	3.2345	4.6580	1.5356	3.4026	11.93
	.750	.46971	1.57170	3.1990	4.4715	1.4987	3.2235	11.30
	.800	.47648	1.54936	3.1668	4.3110	1.4651	3.0692	10.76
	.850	.48266	1.52937	3.1376	4.1716	1.4345	2.9350	10.29
	.900	.48833	1.51148	3.1109	4.0496	1.4065	2.8173	9.87
	.950	.49355	1.49547	3.0863	3.9420	1.3806	2.7133	9.51
	1.000	.49839	1.48112	3.0637	3.8464	1.3567	2.6207	9.18

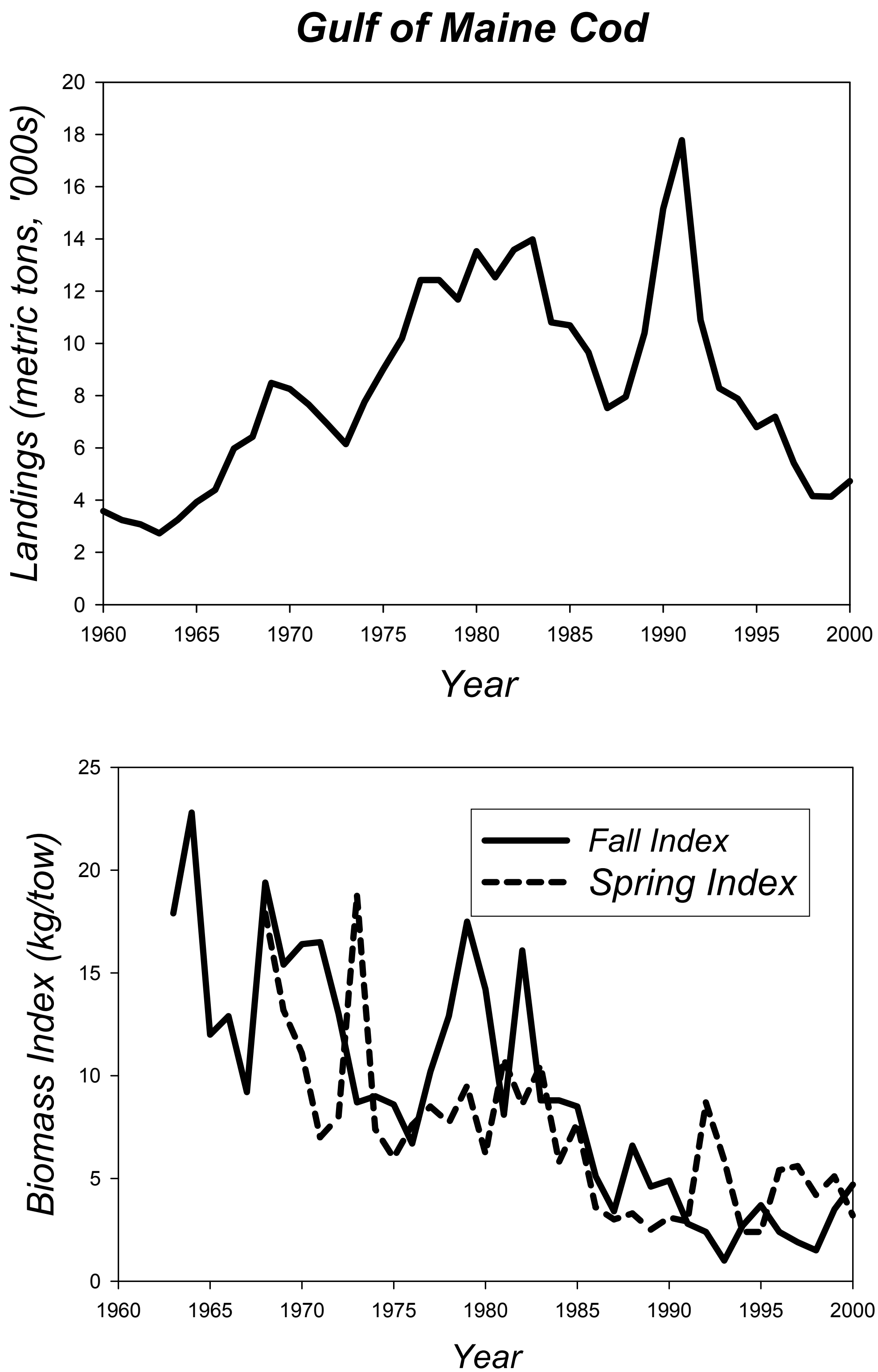
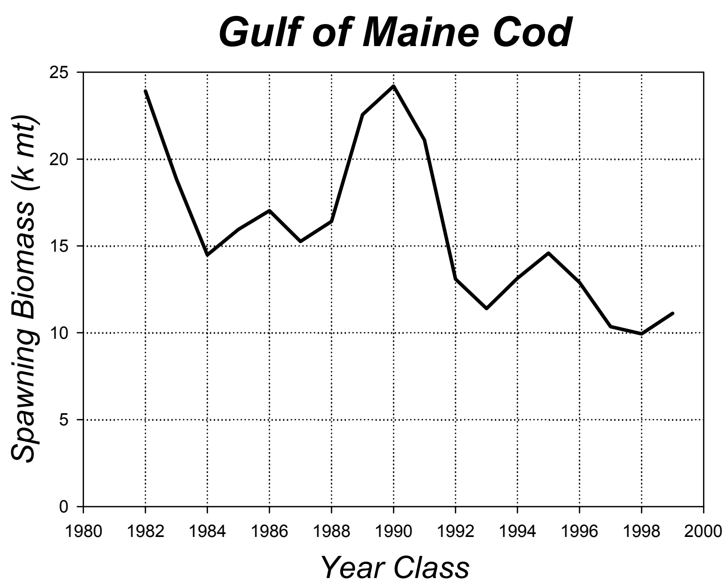
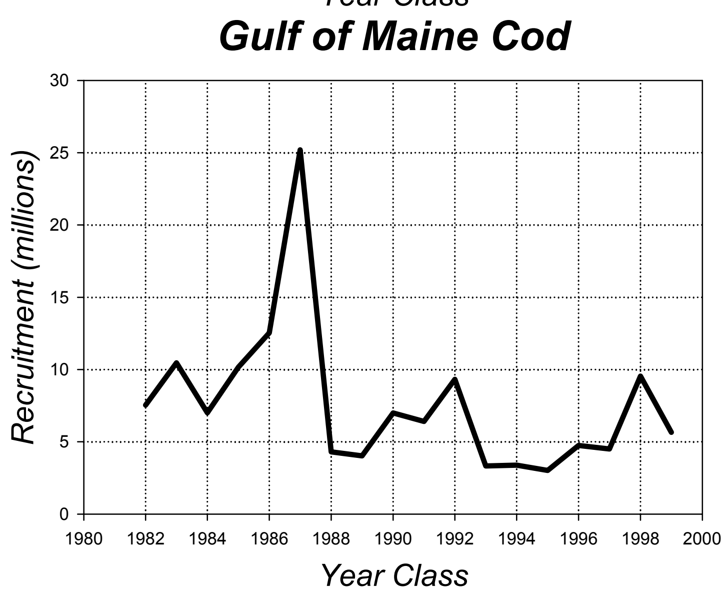


Figure 3.1.1. Landings and research vessel survey abundance indices for Gulf of Maine cod.

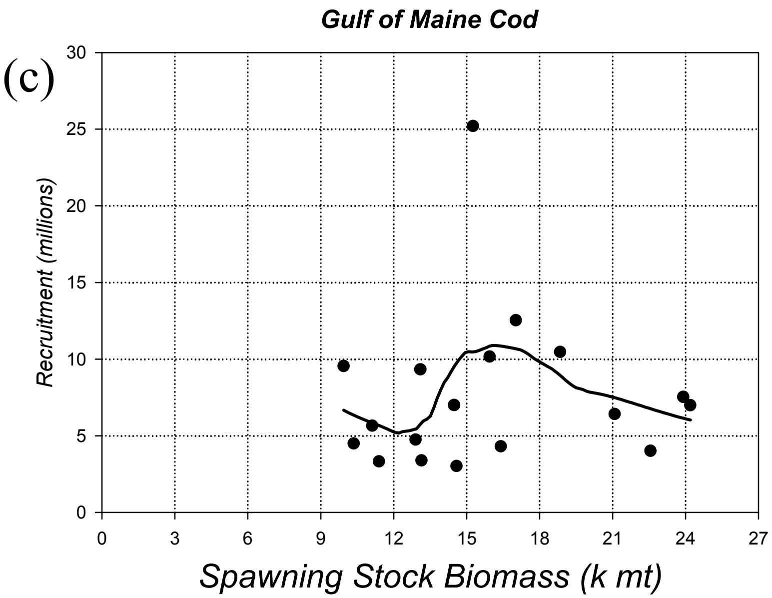
(a)



(b)



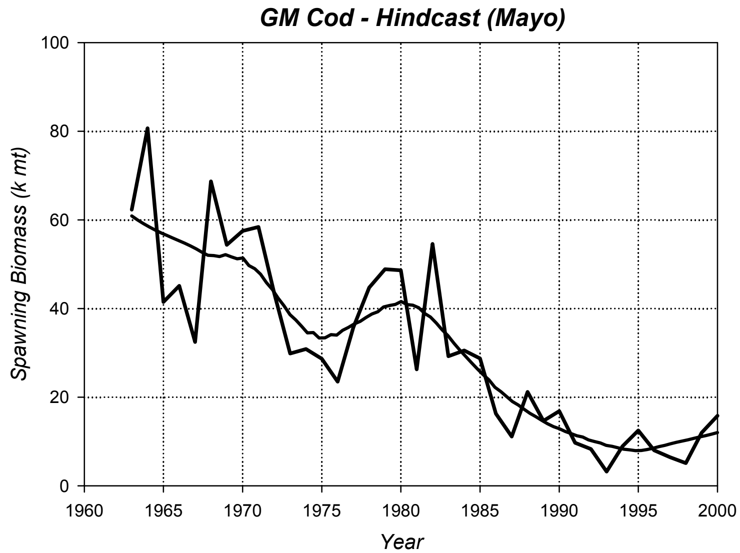
(c)



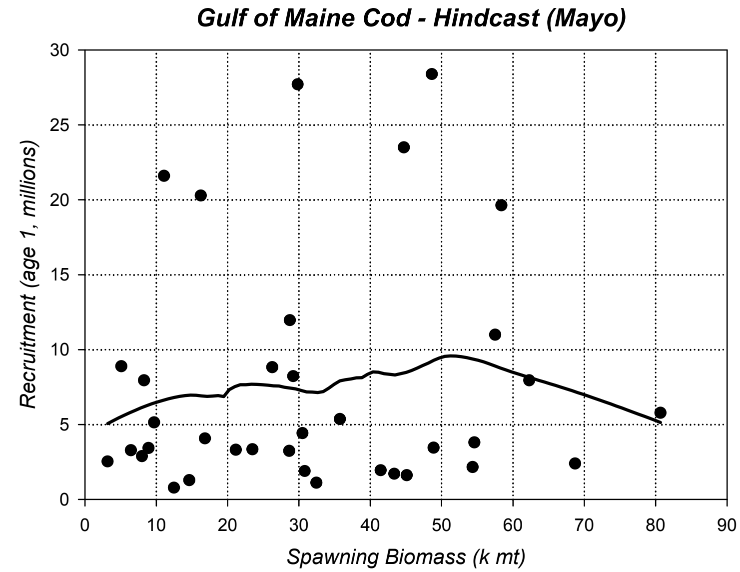
		F0.1	F40% MSP
F reference point		0.151	0.166
ssb per recruit at F		12.132	11.412
	Recruitment (millions)	SS Biomass at F0.1	SS Biomass at F40%
n	18	18	18
mean	7.67	93.10	87.58
min	3.02	36.64	34.46
max	25.20	305.70	287.55
10th %'tile	3.37	40.86	38.43
25th %'tile	4.35	52.79	49.65
50th %'tile	6.70	81.30	76.47
75th %'tile	9.49	115.18	108.34
90th %'tile	11.09	134.50	126.51
Std Dev	5.20	63.10	59.35
CV	0.68	0.68	0.68
For Top 5 values of SSB			
Mean	7.09	85.96	80.86
Median	6.99	84.83	79.79

Figure 3.1.2. Spawning stock (a), recruitment (age 1 millions, b), and scatterplot (c) for Gulf of Maine cod. Data are the calculated spawning stock biomasses for various recruitment scenarios multiplied by the expected SSB per recruit for F0.1 and F40% MSP, assuming recent patterns of growth, maturity and partial recruitment at age (Table 3.1.2). Smoother in the stock-recruitment plot is lowess with tension = 0.5.

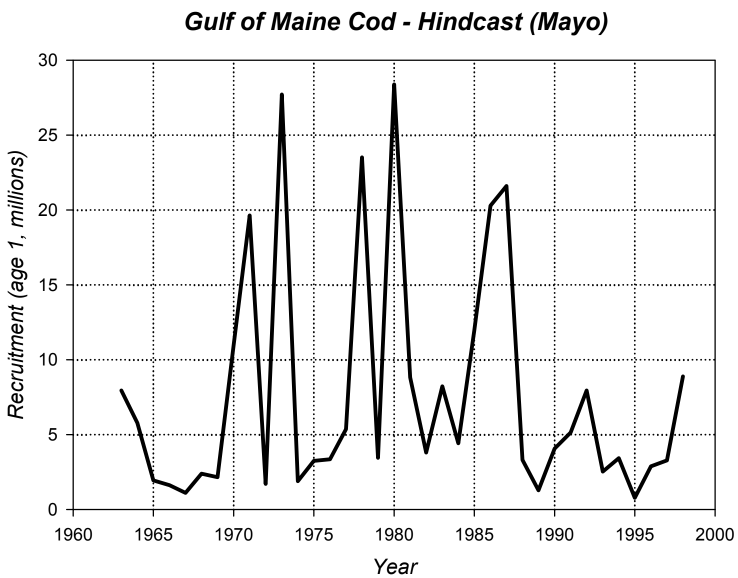
(a)



(c)



(b)



		F0.1	F40% MSP
F reference point		0.151	0.166
ssb per recruit at F		12.132	11.412
	Recruitment (millions)	SS Biomass at F0.1	SS Biomass at F40%
n	36	36	36
mean	7.63	92.62	87.12
min	0.78	9.43	8.87
max	28.38	344.34	323.91
10th %'tile	1.66	20.17	18.97
25th %'tile	2.50	30.28	28.48
50th %'tile	3.93	47.73	44.90
75th %'tile	8.84	107.26	100.90
90th %'tile	20.94	254.04	238.96
Std Dev	7.84	95.16	89.51
CV	1.03	1.03	1.03
For Top Quartile of SSB			
Mean	9.39	113.97	107.20
Median	5.78	70.14	65.98

Figure 3.1.3. Spawning stock (a), recruitment (age 1 millions, b), and scatterplot (c) for Gulf of Maine cod. Data are hindcast back to 1963 and are the calculated spawning stock biomasses for various recruitment scenarios multiplied by the expected SSB per recruit for F0.1 and F40% MSP, assuming recent patterns of growth, maturity and partial recruitment at age (Table 3.1.2). Smoother in the stock-recruitment plot is lowess with tension = 0.5, for the spawning biomass plot, the lowess smoother tension = 0.3.

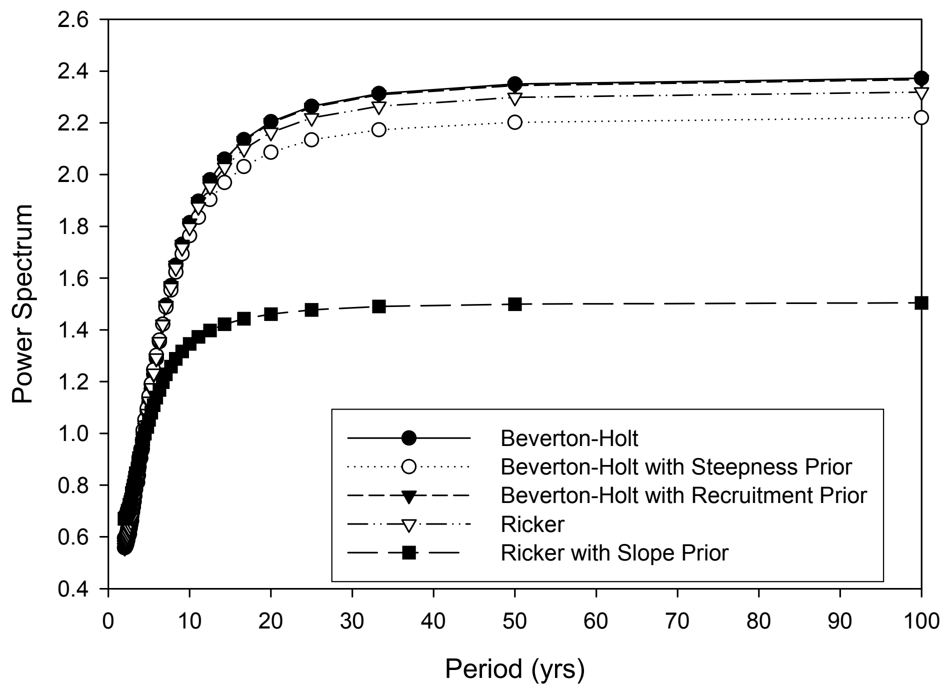


Figure 3.1.4. Gulf of Maine cod 11+ periodicity of environmental forcing for Autoregressive stock-recruitment models.

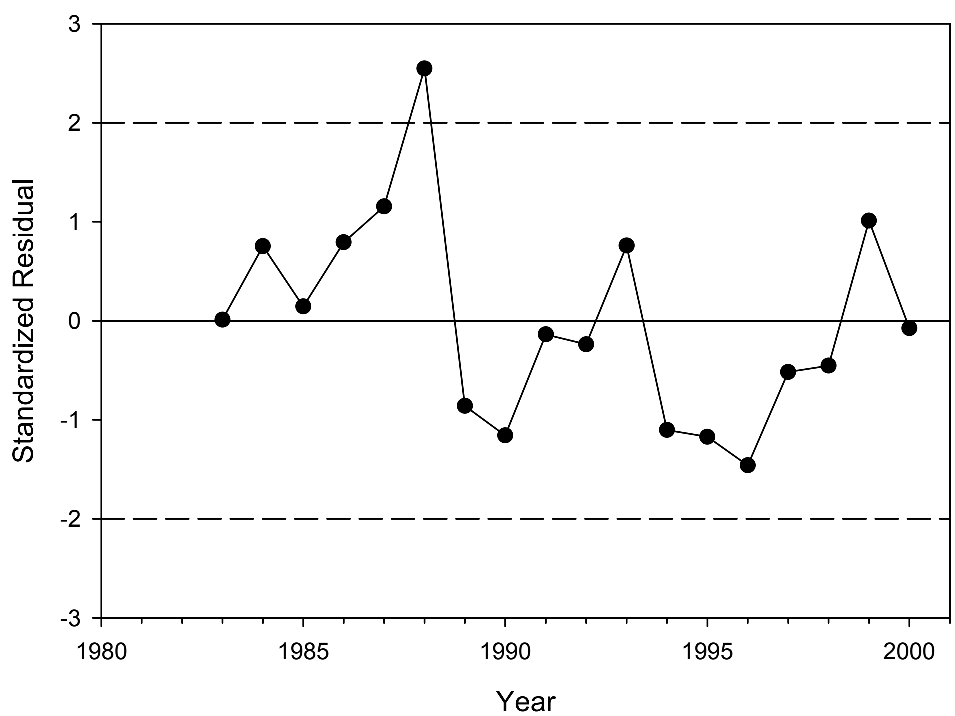


Figure 3.1.5. Gulf of Maine cod 11+ standardized residuals for the most likely stock-recruitment model

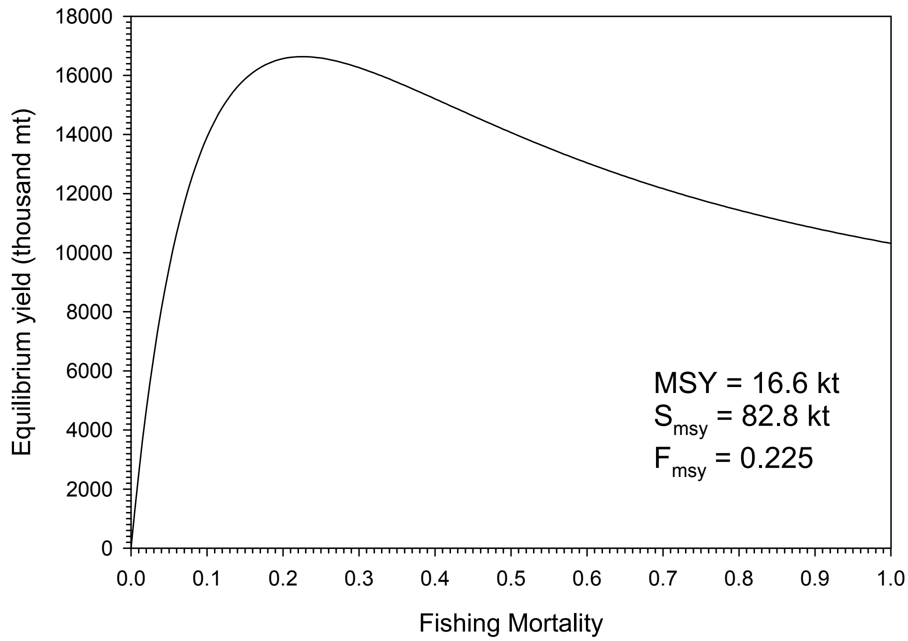


Figure 3.1.6. Gulf of Maine cod 11+ equilibrium yield vs. F for the most-likely Stock-recruitment model.

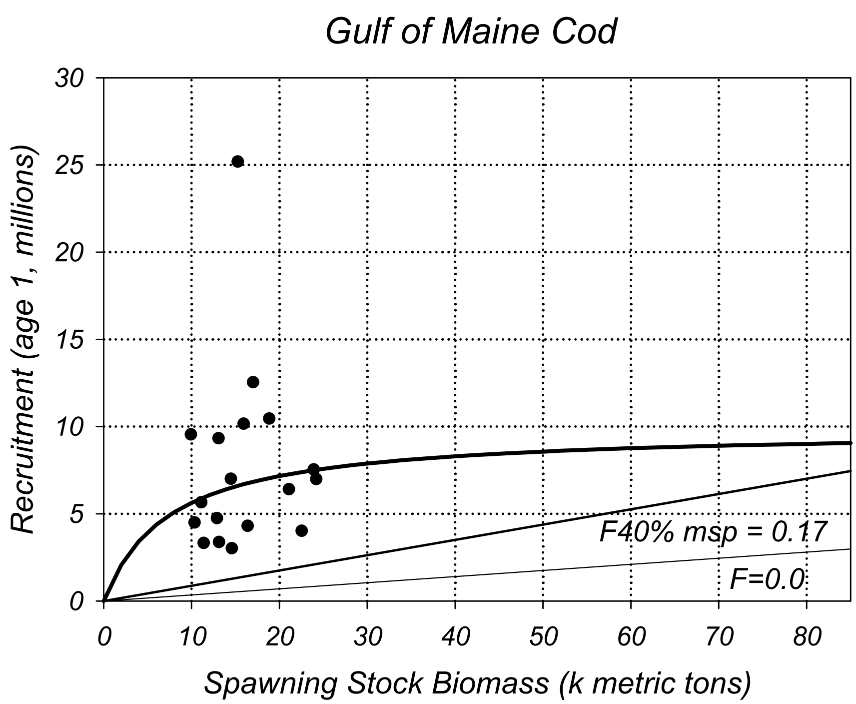
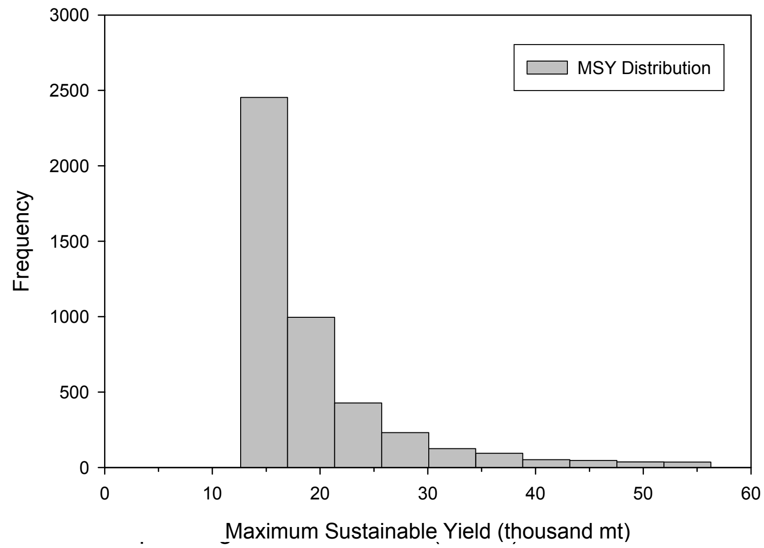
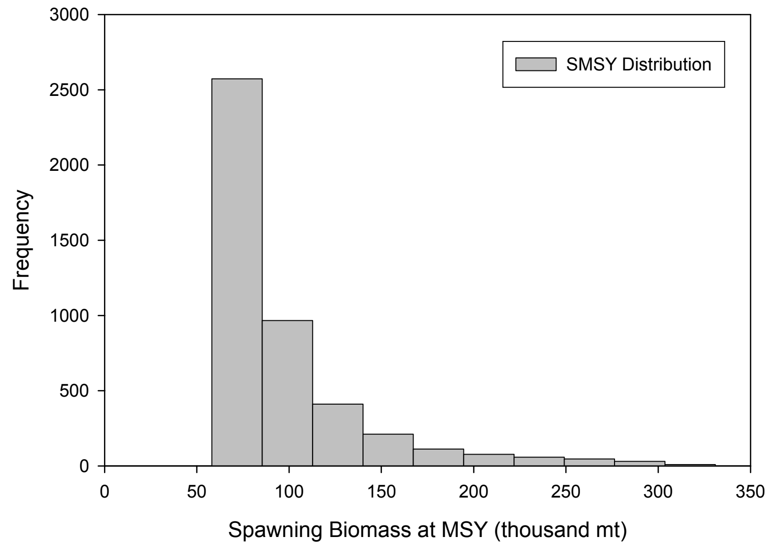


Figure 3.1.7. Stock recruitment relationship for best fit parametric model for Gulf of Maine cod. Stock-recruitment data points are overplotted, along with the predicted S-R line and replacement lines for F=100% msp=0.00 and F40%msp = 0.17.





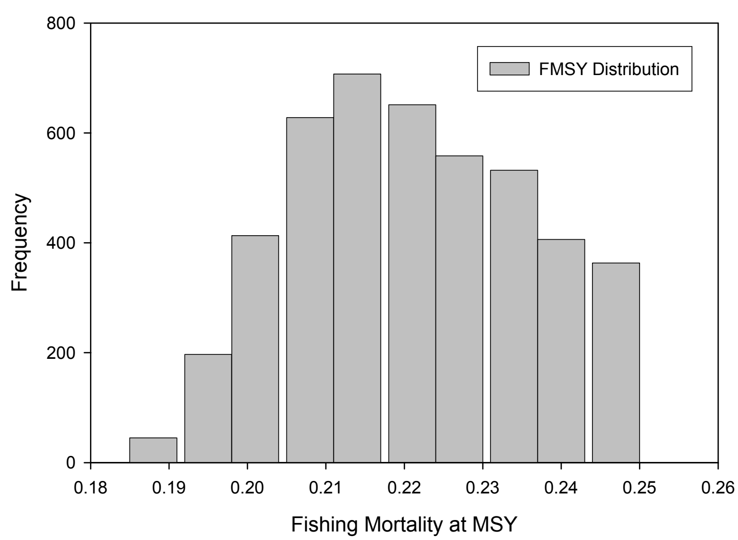


Figure 3.1.8. Gulf of Maine cod 11+ posterior distribution of MSY, BMSY and FMSY for most likely model fit.

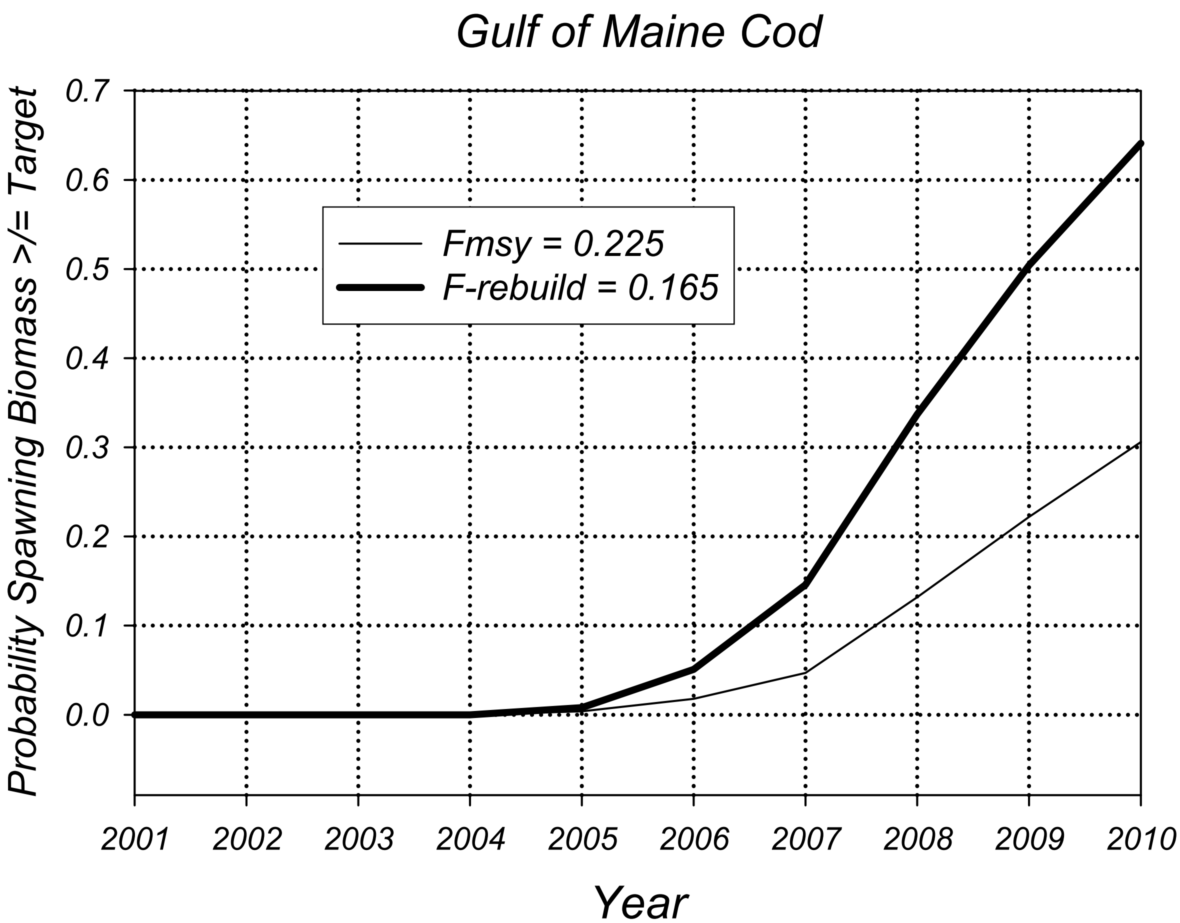


Figure 3.1.9. Probability that Gulf of Maine cod spawning biomass will exceed Bmsy (82,800 mt) annually under two fishing mortality scenarios: Fmsy and F required to rebuild the stock to Bmsy by 2009.

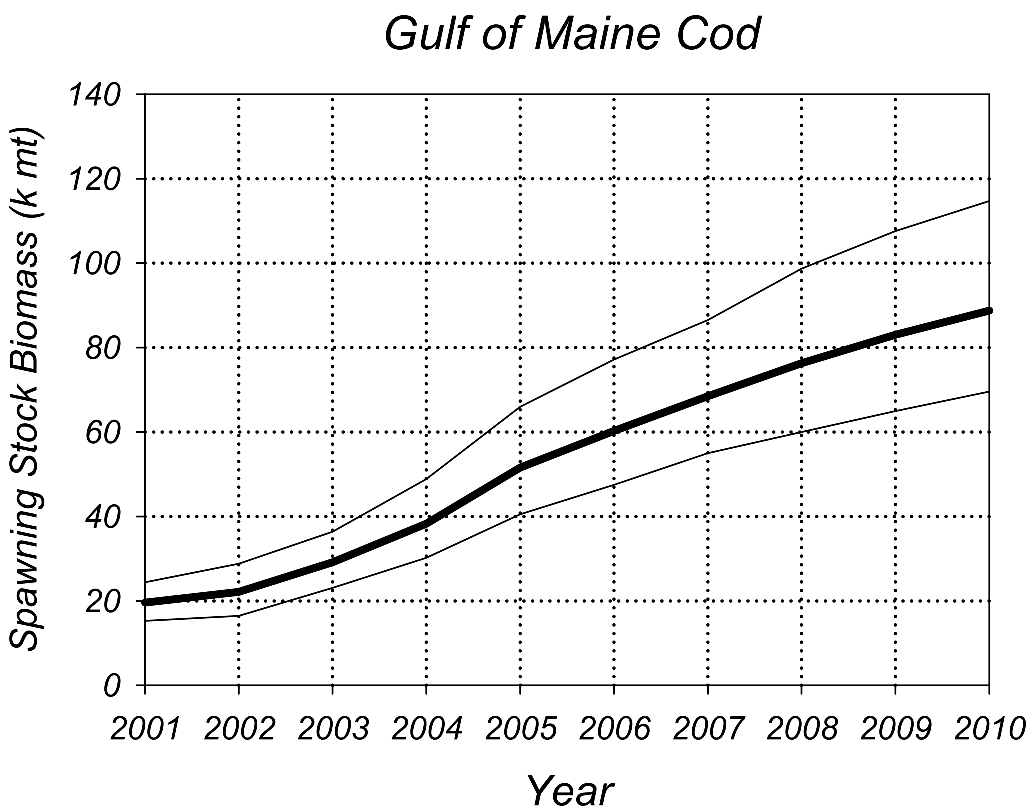


Figure 3.1.10. Median and 80% confidence interval of predicted spawning biomass for Gulf of Maine cod under F-rebuild fishing mortality rates.

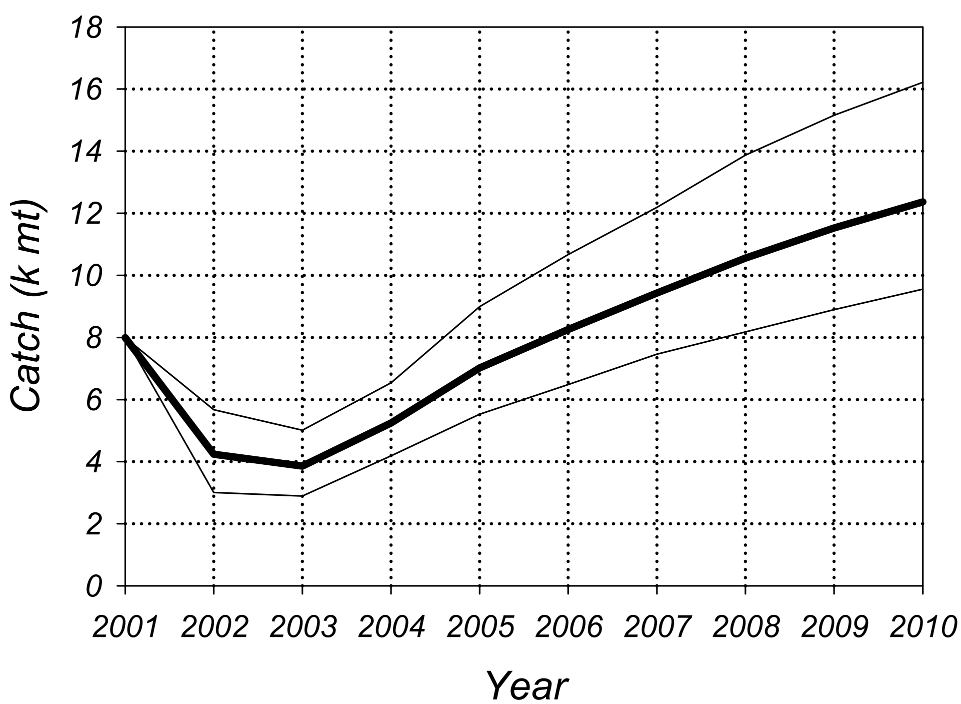


Figure 3.1.11. Median and 80% confidence interval of predicted catch for Gulf of Maine cod under F-rebuild fishing mortality rates.

3.2 Georges Bank cod

Catch and Survey Indices

Atlantic cod on Georges Bank have been exploited since 1758 (Serchuk and Wigley 1992) and landings data are available since the late 1800s (Fig. 3.2.1). Record high landings occurred in 1966 (53,100 mt) and 1982 (57,200) and then landings subsequently declined, except for a peak in 1990 (42,500 mt). In 1995, landings reached a record low (7,900 mt) and have remained relatively constant since that time. Both spring and autumn bottom trawl survey indices also indicate a declining trend in biomass starting in the early 1970s and the stock has remained at a relatively stable but low biomass during the 1990s. Although strict management regulations implemented in 1994 reduced the fishing mortality on Georges Bank cod for both the US and Canada, the stock does not appear to be responding positively.

Stock Assessment

The most current assessment of Georges Bank cod (O'Brien and Munroe 2001) was peer reviewed by the Transboundary Resources Assessment Committee (TRAC) in 2001 (NEFSC 2001d). The assessment included US and Canadian commercial landings catch at age (10+) data from 1978-2000. US recreational landings and discard estimates were reported but not included in the total catch at age. The NMFS and Department of Fisheries and Oceans (DFO) spring bottom trawl survey data for ages 1-8 and NMFS autumn bottom trawl survey data for ages 1-6 were used to calibrate the Virtual Population Analysis (VPA). Estimates of both spawning stock biomass and recruitment at age 1 indicate a declining trend over the time series (Fig. 3.2.2a, Fig. 3.3.2b). The most recent estimates of recruitment are subject to change in subsequent assessments as more catch is taken from each of the cohorts.

Yield and SSB per Recruit Analysis

A yield and spawning stock biomass (SSB) per recruit analyses conducted using recent assessment data (O'Brien and Munroe 2001) resulted in changes in the previously estimated biological reference points (Table 3.2.2). Input data for catch weights (ages 1-10+) and stock weights (ages 1-9) were derived from the long term average weight during 1978-2000 (O'Brien and Munroe 2001). Stock mean weights for ages 10+ were derived from an expanded age structure out to age 18 (oldest age observed in survey) at F = F 40% = 0.167 and M= 0.2. The mean weights for ages 10 to 18 were estimated from the length- weight equation (O'Brien and Munroe 2001) : ln Weight (kg, live) = -11.7231 + 3.0521 ln Length (cm). The mean length at ages 10-18 were derived from the linear regression of length vs ln(age) using the 1978-1997 commercial length sample data. The partial recruitment (PR) is based on a normalized geometric mean of 1996-1999 fishing mortality and the maturity ogive is from the most recent assessment.

The newly estimated YPR biological reference points for $F_{0.1}$=0.169 , F_{max} = 0.331 and $F_{40\%}$ = 0.167 are slightly lower than those reported in O'Brien and Munroe (2001).

MSY-based Reference Point Estimation

Empirical Nonparametric Approach

The stock-recruit relationship for Georges Bank cod indicates a general increasing trend of recruitment of age 1 fish with increased spawning stock biomass (Figure 3.2.2c). The recruitment expected at B_{msy} can be considered to be the mean or median recruitment associated with the upper quartile of SSB. Using $F_{40\%} = 0.167$ as a proxy for F_{MSY}, the SSB/R at $F_{40\%} = 10.769$, and the mean recruitment of 23.25 million fish results in a SSB_{msy} of 250,000 mt. Similarly, multiplying the yield per recruit of 1.6714 by mean recruitment results in a MSY estimate of 38,900 mt.

The estimate of MSY is within the range of observed landings, although SSB is higher than the maximum (93,000 mt) observed in the VPA time series. Hindcasting of autumn research survey indices suggest that higher levels of SSB, ranging from 72,000 mt to 233,000 mt, occurred during the 1970s (Brodziak *et al.* 2001).

Parametric Model Approach

Maximum likelihood fits of the 10 parametric stock-recruitment models to the Georges Bank cod data from 1978-2000 are listed below (Table 3.2.1). The model acronyms (BH= Beverton-Holt, etc.) are described in Section 2.1.2 and Table 2.1.2. The six hierarchical criteria described in Section 2.1.2 are applied to each of the models to determine the set of candidate models.

The first criterion is not satisfied by the PRK and PARK models because the estimate of F_{MSY} lies on the boundary of its feasible range. The second criterion is satisfied by all remaining models except models BH and ABH, where the point estimate of MSY exceed 1000 kt. This eliminates the BH and ABH models from being candidates. The third criterion is not satisfied by the PBH and PABH models because the point estimate of S_{MSY} is substantially greater than the nonparametric proxy. The fourth criterion is not satisfied by the RK and ARK models, where the F_{MSY} estimates of 0.67 and 0.67 greatly exceed the value of F_{MAX} =0.33 for Georges Bank cod. The fifth criterion is satisfied by the remaining autoregressive model PRABH. Last, the sixth criterion is considered be satisfied by the remaining 2 models: PRBH and PRABH.

Given the two candidate models (PRBH and PRABH), the AIC criterion assigns the greatest probability to the PRBH model. The odds ratio of PRBH being true to PRABH being true is over 4:1. Thus, there is clear basis for choosing between these two parametric models, even though both give virtually identical point estimates of $S_{MSY,}$ F_{MSY}, and MSY.

The results of using the PRBH model as the best fit parametric model are shown below (Table 3.2.1 and Figures 3.2.3-3.2.6). The standardized residual plot of the fit of the PRBH model to the stock-recruitment data shows that the standardized residuals generally lie within ± two standard deviations of zero (Figure 3.2.4), with the exception of the 1985 and 2000 data points.

In the equilibrium yield plot (Figure 3.2.5), the yield surface is relatively flat in the neighborhood of the point estimate of F_{MSY} = 0.175. The point estimates of S_{MSY} (217 kt) and MSY (35 kt) appear consistent with the nonparametric proxy estimate of S_{MSY} and previous estimates of MSY. The stock-recruitment plot (Figure 3.2.6) shows that recruitment values near S_{MSY} are roughly 23 million fish which is consistent with the long-term average of the observed recruitment series when spawning biomass was high, lying within its upper quartile of values.

Parameter uncertainty plots show histograms of 5000 MCMC sample estimates of MSY, S_{MSY}, and F_{MSY} drawn from the posterior distribution of the MLE based on an uninformative prior. For MSY, the 80 percent credibility interval was (29.4, 38.0) with a median of 33.6 kt (Figure 3.2.7, upper panel). For S_{MSY}, the 80 percent credibility interval was (169.6, 234.1) with a median of 201.7 kt (Figure 3.2.7, middle panel). For F_{MSY}, the 80 percent credibility interval was (0.165, 0.200) with a median of 0.18 (Figure 3.2.7, lower panel). Overall, the point estimates of MSY and S_{MSY} were slightly larger than the medians of the MCMC samples.

Reference Points

Reference points derived from the Beverton-Holt stock recruit relationship with an assumed prior for the unfished recruitment from the VPA data are : F_{MSY} = 0.175, MSY = 35,200 mt and SSB_{MSY} = 217,000 mt. The MSY includes commercial landings only and does not include recreational landings or discards.

Projections

Stochastic age-based projections (Brodziak and Rago 2002) were performed to forecast the probability of attaining SSB_{MSY} within 10 years under an F_{MSY} (0.175) and an $F_{rebuilding}$ (0.0) strategy. Recruitment was derived from the Beverton-Holt stock recruit relationship using parameter values from the PRBH model (Table 3.2.1). Stock and catch mean weight, maturity at age, and partial recruitment input data are the same as described above for the yield and SSB per recruit analysis. The 2001 starting year population vector was derived from 1000 bootstrap iterations of the final VPA formulation (O'Brien and Munroe 2001). Fishing mortality in 2001 was derived based on estimated landings of 12,765 mt (US:10,631 mt + CAN:2,134 mt) and F in 2002 was set equivalent to the Amendment 7 target ($F_{0.1}$=0.169), the current management target.

The projections (Figures 3.2.8-3.2.10) indicate that there is only a 0.2% probability of reaching SSB_{MSY} (217,000 mt) by 2009 under an F_{MSY} strategy. A 50% probability of achieving SSB_{MSY} by 2009 is not possible under any F strategy (Figure 3.2.8). Under a rebuilding F=0.0, there is only a 34% probability of achieving SSB_{MSY} by 2009 (Figure 3.2.8-3.2.9). The landings would decline to zero in 2003 under F rebuilding (Figure 3.2.10).

Table 3.2.1. Stock-recruitment model comparisons for Georges Bank cod.

Georges Bank Cod Model Comparison										
SMAX =	104.2									
	Prior	Prior	Prior	Prior	Prior	Prior	Prior	Prior	Prior	Prior
	0	0	0	0	0.5000	0.5000	0	0	0	0
	BH	ABH	PBH	PABH	**PRBH**	**PRABH**	RK	ARK	PRK	PARK
Posterior Probability	0.00	0.00	0.00	0.00	**0.82**	**0.18**	0.00	0.00	0.00	0.00
Odds Ratio for Most Likely Model					1.00	4.41				
Normalized Likelihood	0.00	0.00	0.00	0.00	0.82	0.18	0.00	0.00	0.00	0.00
Model AIC Ratio					4.40835	1				
	BH	**ABH**	**PBH**	**PABH**	**PRBH**	**PRABH**	**RK**	**ARK**	**PRK**	**PARK**
Number_of_data_points	23	23	23	23	23	23	23	23	23	23
Number_of_parameters	3	4	3	4	3	4	3	4	3	4
Negative_loglikelihood	74.3004	74.1295	75.1716	75.163	78.3868	78.382	83.8389	80.4065	92.8811	81.6877
Bias-corrected_AIC	155.864	158.481	158.403	161.161	159.003	161.97	174.941	171.035	193.927	175.53
Diagnostic Comments										
Parameter Point Estimates	MSY and SMSY are outside credible range	MSY and SMSY are outside credible range	SMSY is substantially greater than nonparametric proxy	SMSY is substantially greater than nonparametric proxy	**Most Likely Model**		Estimate of FMSY is substantially greater than FMAX	Estimate of FMSY is substantially greater than FMAX	FMSY at boundary of feasible range	FMSY at boundary of feasible range
************************										
MSY	20436.3	38550.8	45.8844	47.614	35.236	35.1229	28.1625	27.9784	39.4505	50.5792
FMSY	0.135	0.14	0.175	0.175	0.175	0.175	0.67	0.67	2	2
SMSY	161234	293660	282.291	292.932	216.78	216.083	54.8568	54.4983	39.1762	50.2274
alpha	20193.6	37973.7	36.4922	38.1719	28.2855	28.2016	0.000046	4.54183E-05	1.37	1.34697
expected_alpha	23621.4	44444.3	43.475	45.4171	33.8542	33.7593	0.0000659	0.000067713	0.15	5.30705
beta	88263.2	165045	97.6222	104.468	77.6945	77.5179	-2.20E-02	-2.21E-02	1.21594	-0.033924
RMAX	23.8117	23.9592	18.8408	19.0615	16.2036	16.1713	10.5563	10.3985	2.7619	11.6858
expected_RMAX	27.8536	28.0418	22.446	22.6794	19.3937	19.3581	15.121	15.5029	-0.04015	46.0419
Prior_mean			0.84	0.84	23.248	23.248			5.35846	1.37
Prior_se			0.08	0.08	4.38	4.38			12.1712	0.15
Z_Myers	0.61	0.61	0.72	0.71	0.71	0.71				
sigma	0.560	0.561	0.592	0.590	0.600	0.600	0.848	0.894	1.281	1.656
phi		-0.14		-0.04		0.02		0.59		0.88
sigmaw		0.56		0.59		0.60		0.72		0.78
last log-residual R		-1.361		-1.579		-1.502		-2.189		-3.194
expected lognormal error term	1.170	1.17	1.19	1.19	1.20	1.20	1.43	1.49	2.27	3.94

Table 3.2.2. Yield and biomass per recruit of Georges Bank cod.

```
   The NEFC Yield and Stock Size per Recruit Program - PDBYPRC
    PC Ver.1.2 [Method of Thompson and Bell (1934)] 1-Jan-1992
              ------------------------------------
              Run Date: 21- 2-2002;  Time: 14:26:43.51
 Cod Georges Bank 2002 -10+ from 18+ mean wt, 78-2000 weights,96-99 P

 Proportion of F before spawning:  .1667
 Proportion of M before spawning:  .1667
 Natural Mortality is Constant at:  .200
 Initial age is:  1; Last age is: 10
 Last age is a PLUS group;
 Original age-specific PRs, Mats, and Mean Wts from file: ==> GBYPR102.DAT
```

Age-specific Input data for Yield per Recruit Analysis

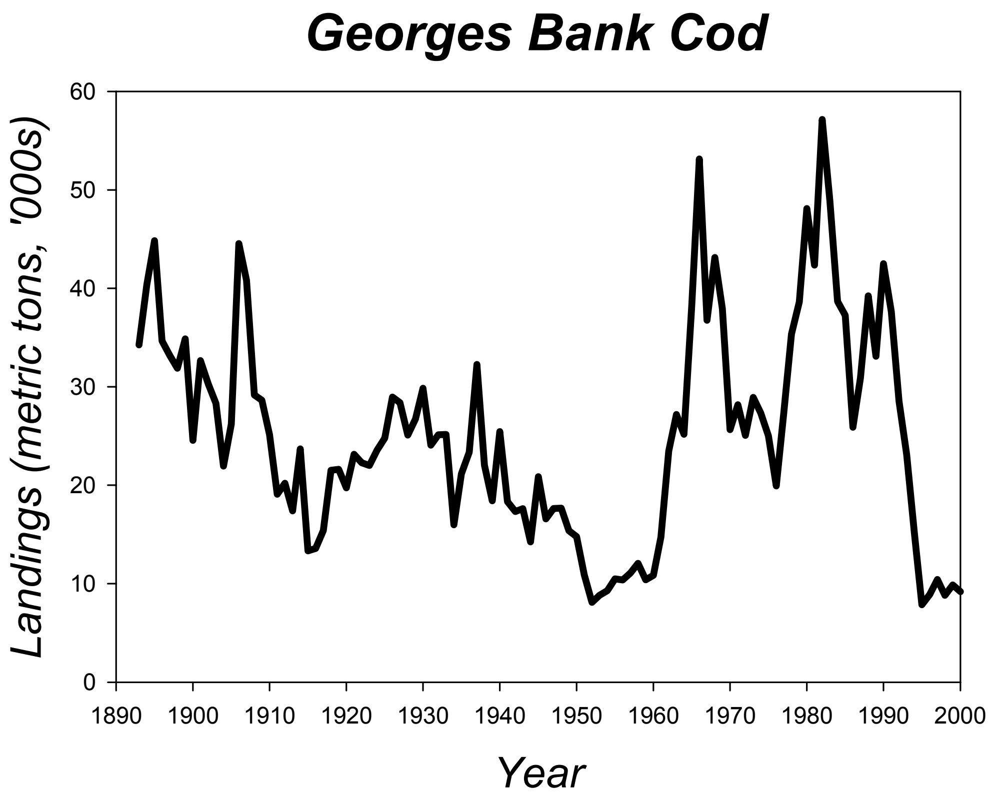
Age	Fish Mort Pattern	Nat Mort Pattern	Proportion Mature	Average Weights Catch	Average Weights Stock
1	.0001	1.0000	.1300	.888	.682
2	.1900	1.0000	.5700	1.514	1.146
3	.6600	1.0000	.9200	2.361	1.882
4	1.0000	1.0000	1.0000	3.634	2.926
5	1.0000	1.0000	1.0000	5.024	4.245
6	1.0000	1.0000	1.0000	6.588	5.716
7	1.0000	1.0000	1.0000	8.334	7.387
8	1.0000	1.0000	1.0000	9.742	8.963
9	1.0000	1.0000	1.0000	11.366	10.489
10+	1.0000	1.0000	1.0000	14.736	15.231

```
 Summary of Yield per Recruit Analysis for:
 Cod Georges Bank 2002 -10+ from 18+ mean wt, 78-2000 weights,96-99 PR

  Slope of the Yield/Recruit Curve at F=0.00: -->   25.9200
    F level at slope=1/10 of the above slope (F0.1): ----->    .169
      Yield/Recruit corresponding to F0.1: ----->    1.6768
    F level to produce Maximum Yield/Recruit (Fmax): ----->    .331
      Yield/Recruit corresponding to Fmax: ----->    1.8234
    F level at 40 % of Max Spawning Potential (F40): ----->    .167
      SSB/Recruit corresponding to F40: -------->   10.7691
```

Listing of Yield per Recruit Results for:
Cod Georges Bank 2002 -10+ from 18+ mean wt, 78-2000 weights,96-99 PR

	FMORT	TOTCTHN	TOTCTHW	TOTSTKN	TOTSTKW	SPNSTKN	SPNSTKW	% MSP
	.000	.00000	.00000	5.5167	28.9398	4.1019	26.9291	100.00
	.050	.13176	.92201	4.8605	21.2025	3.4448	19.2924	71.64
	.100	.22012	1.38404	4.4213	16.4507	3.0046	14.6204	54.29
	.150	.28367	1.62149	4.1061	13.3248	2.6884	11.5583	42.92
F0.1	.169	.30318	1.67679	4.0095	12.4235	2.5914	10.6776	39.65
F40%	.167	.30112	1.67136	4.0197	12.5172	2.6016	10.7691	39.99
	.200	.33169	1.74194	3.8684	11.1619	2.4498	9.4469	35.08
	.250	.36936	1.79889	3.6825	9.6051	2.2629	7.9321	29.46
	.300	.39976	1.82056	3.5327	8.4480	2.1123	6.8094	25.29
Fmax	.331	.41593	1.82339	3.4532	7.8716	2.0324	6.2514	23.21
	.350	.42489	1.82243	3.4093	7.5643	1.9881	5.9543	22.11
	.400	.44604	1.81326	3.3057	6.8737	1.8837	5.2876	19.64
	.450	.46412	1.79810	3.2173	6.3229	1.7946	4.7570	17.66
	.500	.47980	1.77992	3.1409	5.8757	1.7175	4.3270	16.07
	.550	.49355	1.76043	3.0741	5.5069	1.6501	3.9729	14.75
	.600	.50572	1.74066	3.0152	5.1984	1.5905	3.6773	13.66
	.650	.51659	1.72119	2.9627	4.9371	1.5374	3.4272	12.73
	.700	.52637	1.70234	2.9155	4.7133	1.4896	3.2132	11.93
	.750	.53524	1.68430	2.8729	4.5197	1.4465	3.0283	11.25
	.800	.54332	1.66712	2.8342	4.3506	1.4072	2.8670	10.65
	.850	.55073	1.65084	2.7988	4.2017	1.3713	2.7251	10.12
	.900	.55755	1.63544	2.7663	4.0696	1.3383	2.5993	9.65
	.950	.56386	1.62088	2.7363	3.9517	1.3078	2.4871	9.24
	1.000	.56972	1.60712	2.7086	3.8457	1.2796	2.3863	8.86



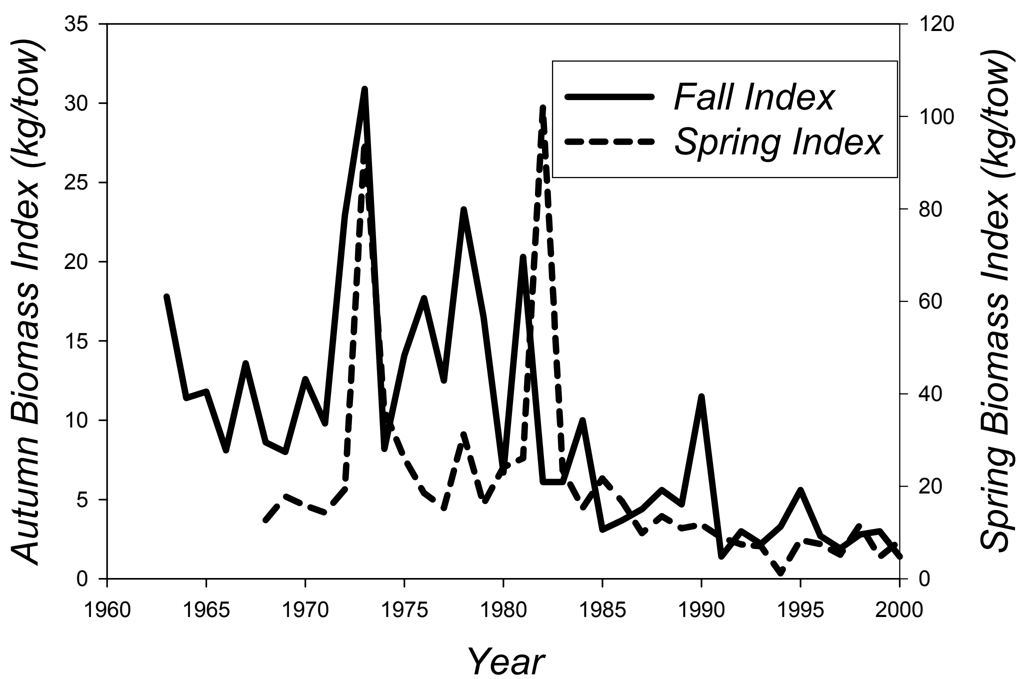
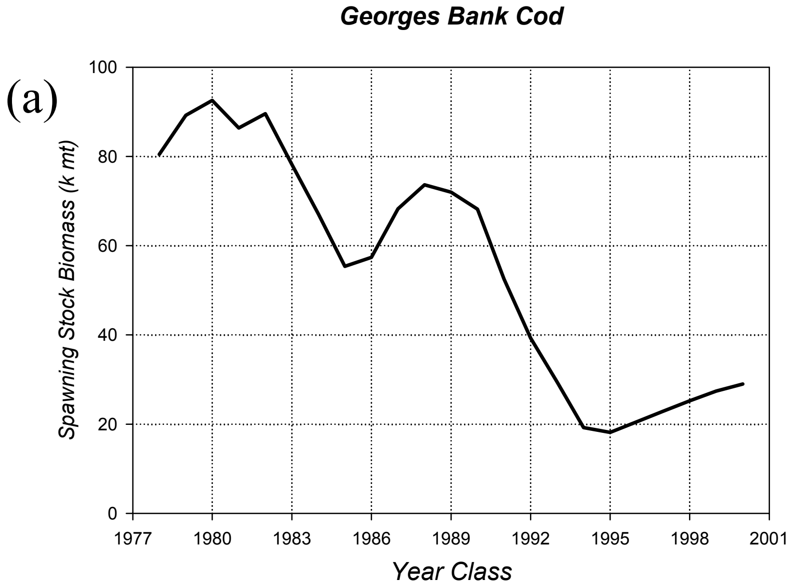
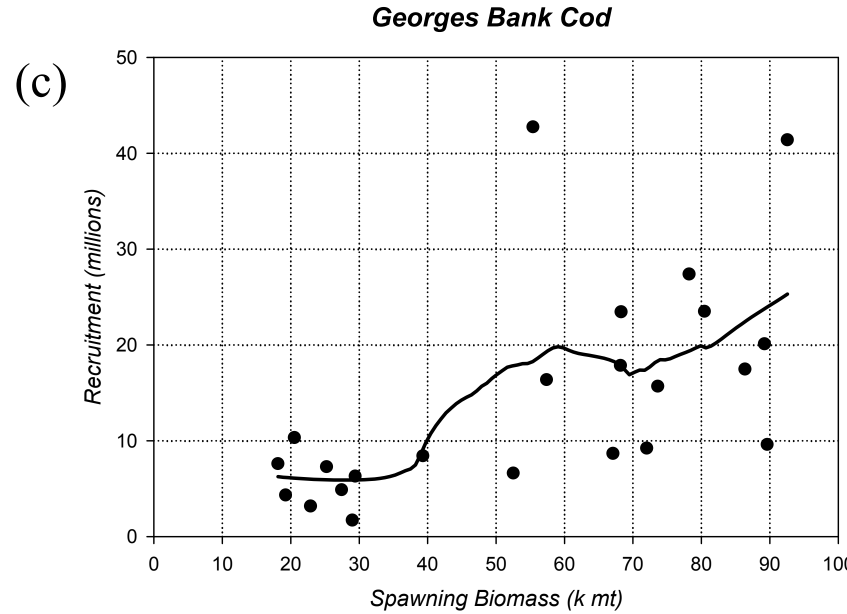
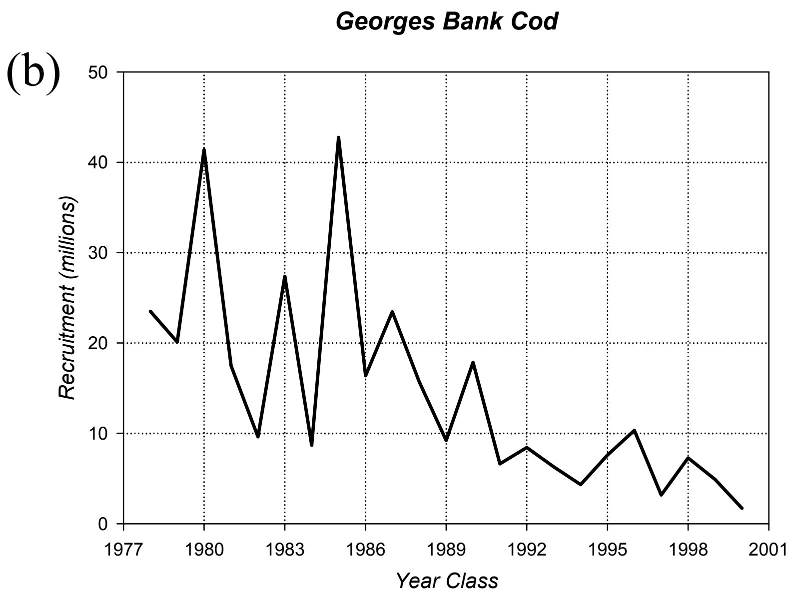


Figure 3.2.1. Landings and research vessel survey abundance indices for Georges Bank cod.







		F0.1	F40% MSP
F reference point		0.169	0.167
ssb per recruit at F		10.6776	10.7691
	Recruitment (millions)	SS Biomass at F0.1	SS Biomass at F40%
n	23	23	23
mean	14.53	155.16	156.49
min	1.71	18.26	18.42
max	42.75	456.48	460.39
10th %'tile	4.44	47.45	47.86
25th %'tile	6.96	74.33	74.97
50th %'tile	9.62	102.67	103.54
75th %'tile	18.99	202.74	204.48
90th %'tile	26.61	284.18	286.61
Std Dev	11.20	119.62	120.65
CV	0.77	0.77	0.77
For Top Quartile of SSB			
Mean	23.25	248.23	250.36
Median	21.81	232.88	234.88

Figure 3.2.2. Spawning stock (a), recruitment (age 1 millions, b), and scatterplot (c) for Georges Bank cod. Data are the calculated spawning stock biomasses for various recruitment scenarios multiplied by the expected SSB per recruit for F0.1 and F40% MSP, assuming recent patterns of growth, maturity and partial recruitment at age (Table 3.2.2). Smoother in the stock-recruitment plot is lowess with tension = 0.5.

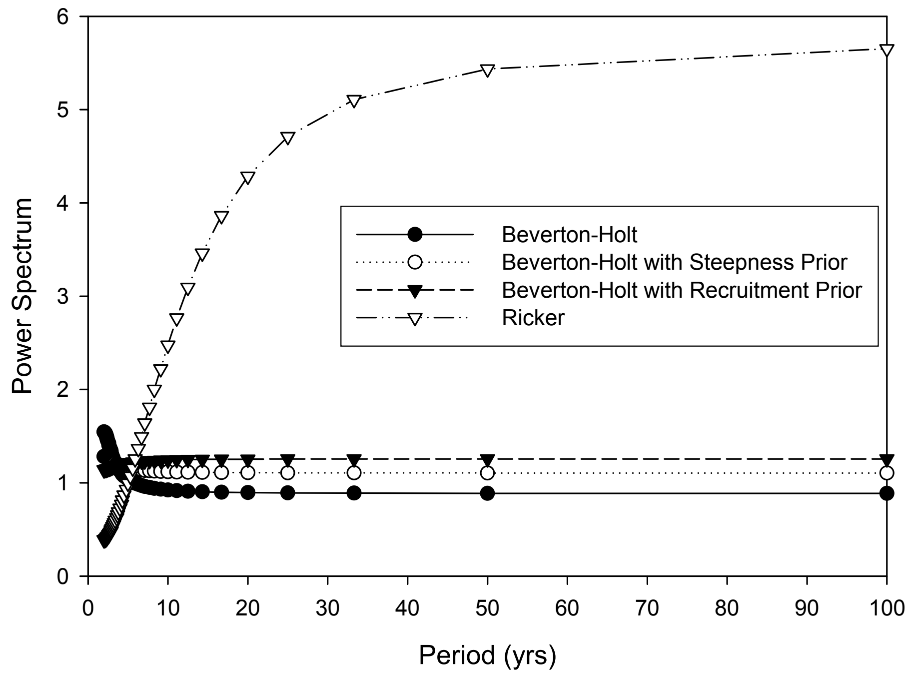


Figure 3.2.3. Georges Bank cod periodicity of environmental forcing for autoregressive stock-recruitment models

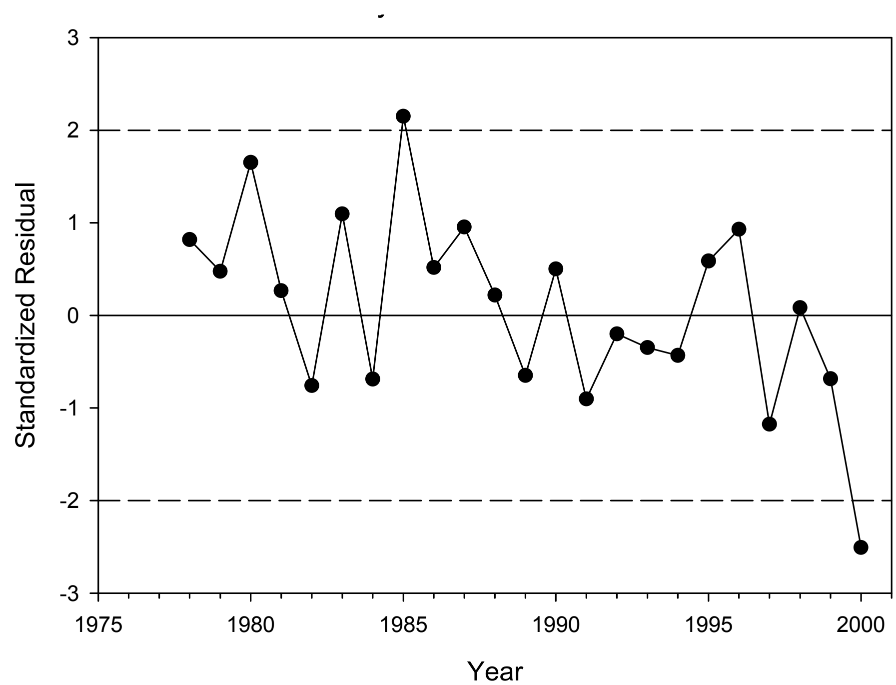


Figure 3.2.4. Georges Bank cod standardized residuals for the most likely stock-recruitment model

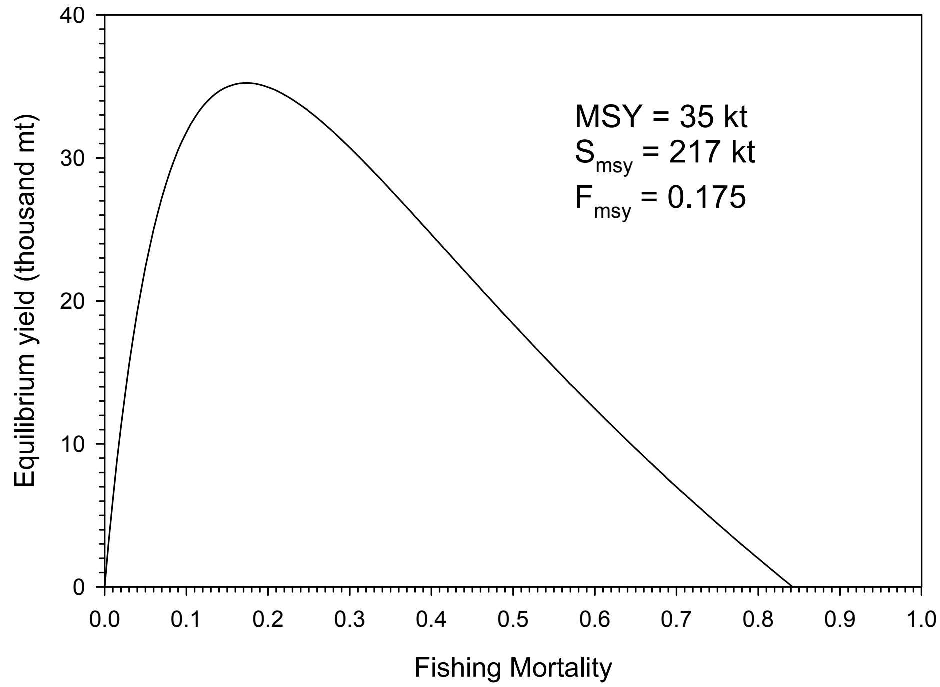


Figure 3.2.5. Georges Bank cod equilibrium yield vs. F for the most likely stock-recruitment model.

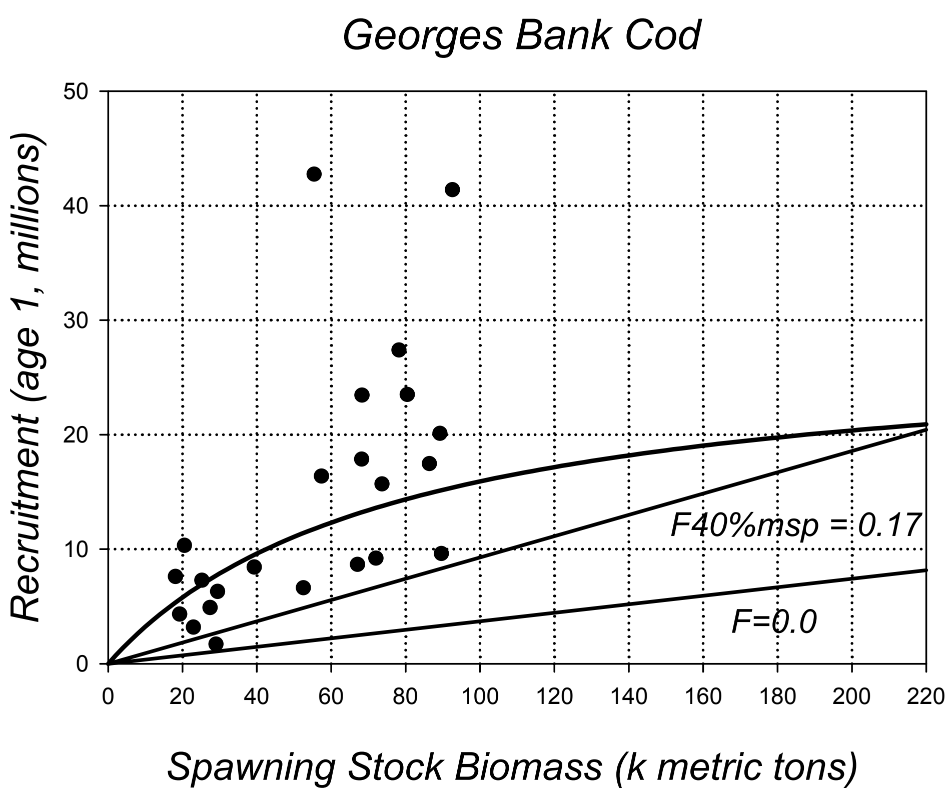


Figure 3.2.6. Stock recruitment relationship for best fit parametric model Georges Bank cod. Stock-recruitment data points are overplotted, along with the predicted S-R line and replacement lines for F=100% msp=0.00 and F40%msp = 0.17.

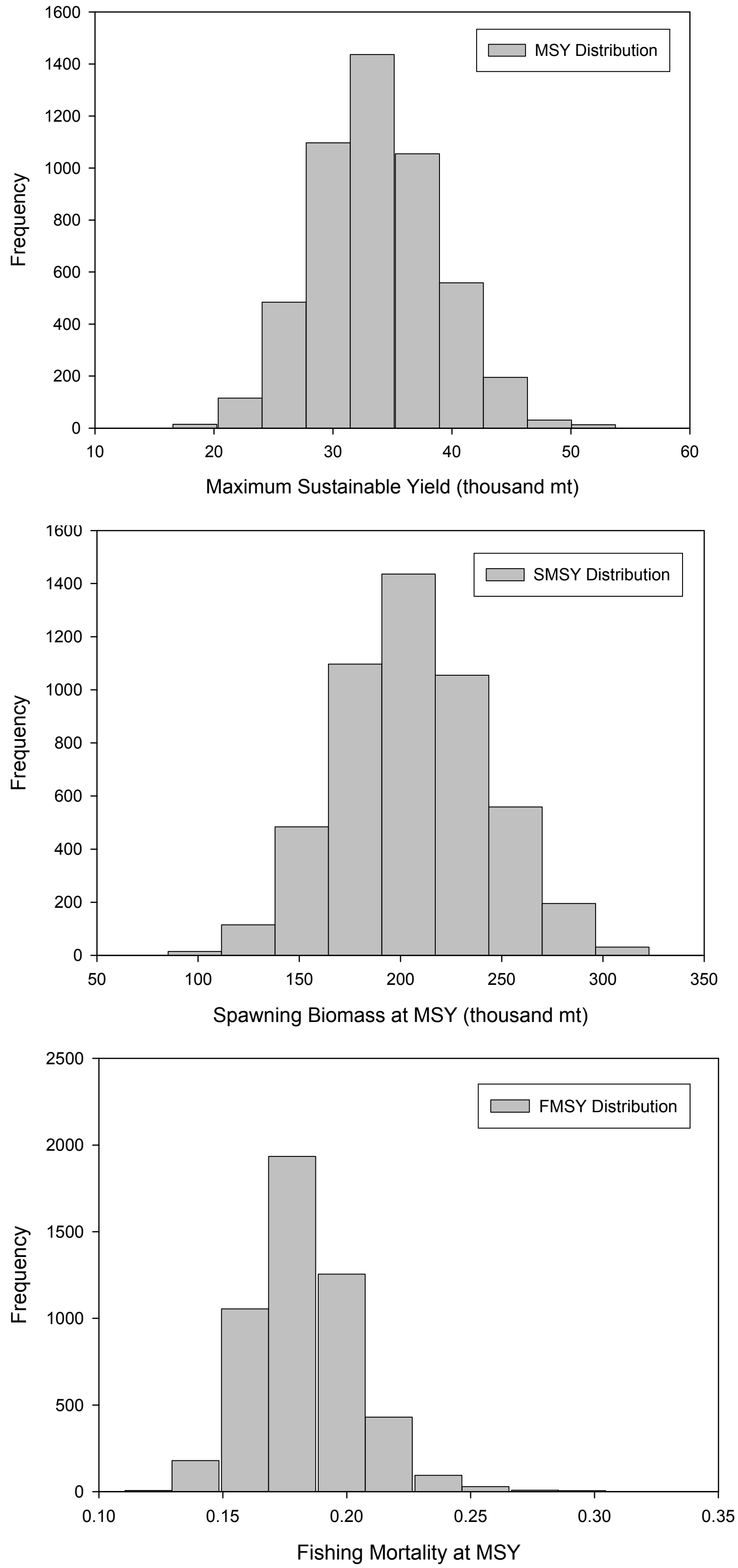


Figure 3.2.7. Georges Bank cod posterior distribution of MSY, BMSY and FMSY for most likely model fit.

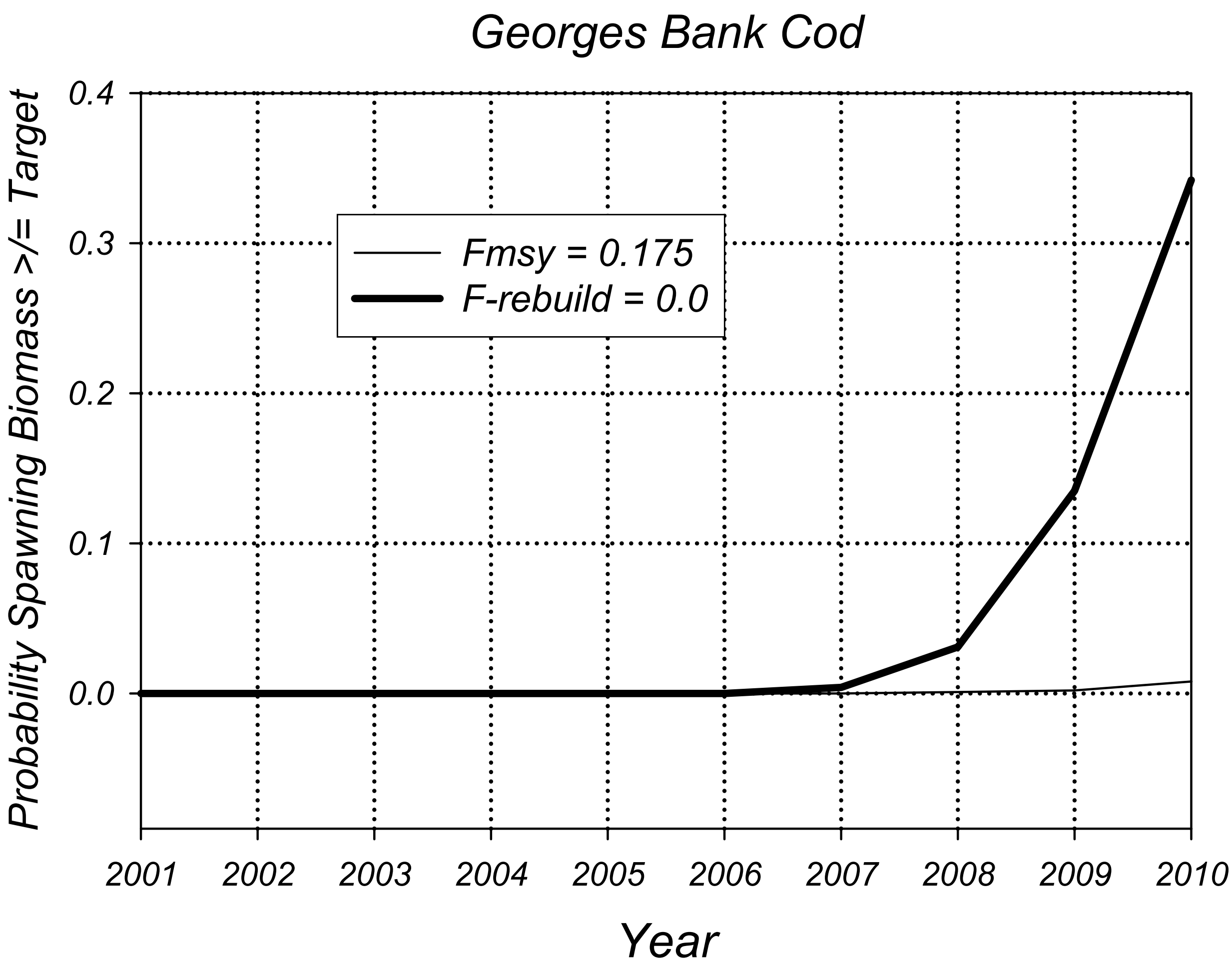


Figure 3.2.8. Probability that Georges Bank cod spawning biomass will exceed Bmsy (216,800 mt) annually under two fishing mortality scenarios: Fmsy and F required to rebuild the stock to Bmsy by 2009.

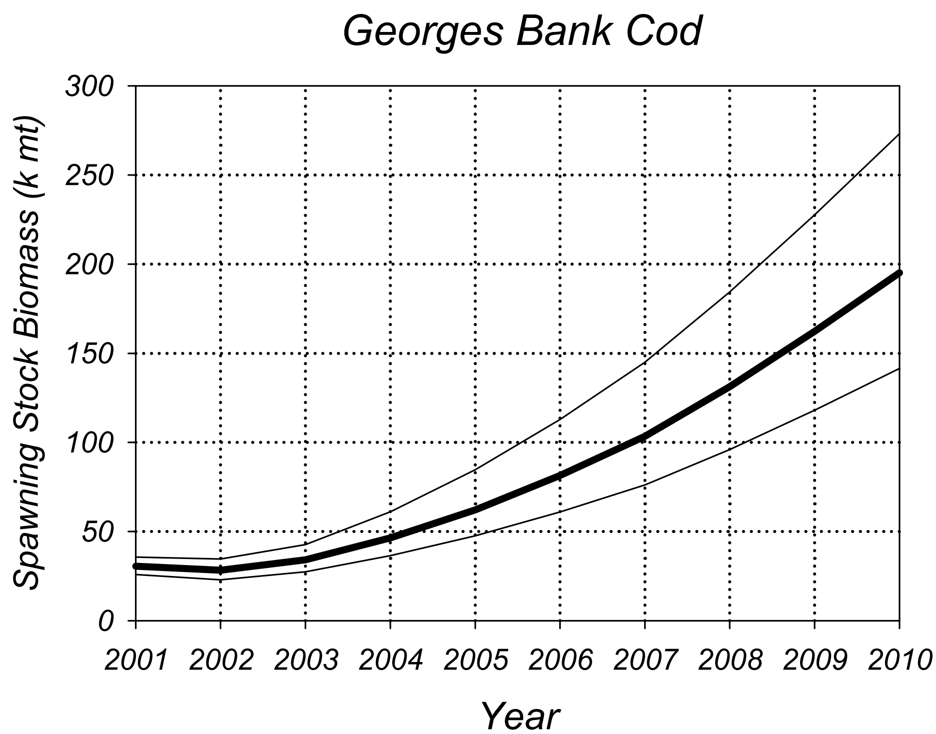


Figure 3.2.9. Median and 80% confidence interval of predicted spawning biomass for Georges Bank cod under F-rebuild fishing mortality rates.

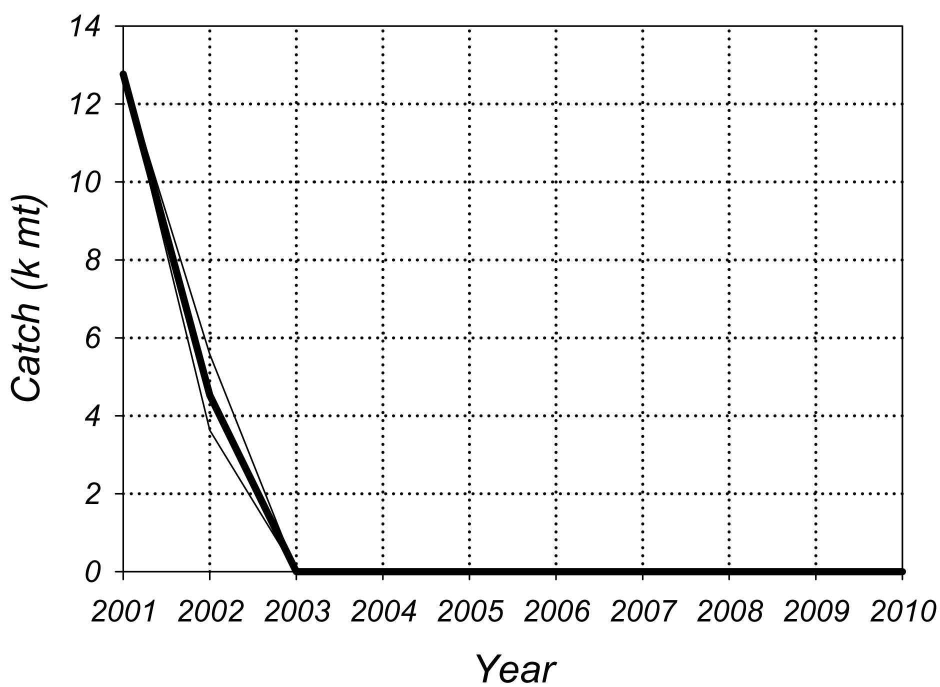


Figure 3.2.10. Median and 80% confidence interval of predicted catch for Georges Bank cod under F-rebuild fishing mortality rates.

3.3 Georges Bank haddock

Catch and Survey Indices

The Georges Bank haddock (*Melanogrammus aeglefinus*) stock has been commercially exploited since the 19th century with reliable landings statistics available beginning in 1904 (Clark *et al.* 1982). The fishery for Georges Bank haddock can be separated into six periods (Figure 3.3.1): (1) the stable early period from 1904-1923 when annual landings averaged 17,400 mt; (2) the rapid fishery expansion during 1924-1930 when landings averaged 73,200 mt; (3) the thirty-year period of relative stability during 1931-1960 when landings averaged 46,300 mt; (4) the rapid fishery expansion by foreign distant water fleets during 1961-1968 when landings averaged 73,000 mt; (5) the fishery decline during 1969-1984 when landings averaged 13,400 mt; and (6) the recent period of fishery depletion from 1985-2000 when annual landings have averaged only 5,500 mt. Landings have increased moderately in recent years as stock biomass has begun to rebuild under restrictive management measures for the Georges Bank region. In 2000, the fishery yield (8,800 mt) was roughly four times larger than the lowest recorded landings observed in 1995.

Fishery-independent research survey data provide relative abundance indices for the Georges Bank haddock stock from the 1960s to the present (Figure 3.3.1). These indices show the long-term decline in stock biomass that has occurred since the 1960s. The NEFSC fall survey index series averaged 53.3 kg/tow during 1963-1968, declined to14.5 kg/tow during 1969-1984, and declined further to 6.3 kg/tow during 1985-2000. Similarly, the NEFSC spring survey index series averaged 19.3 kg/tow during 1968-1984 and then declined by more than ½ to an average of 8.2 kg/tow during 1985-2000. Survey indices have increased in recent years as stock biomass has begun to rebuild. In 2000, the fall survey index was 15.4 kg/tow while the spring index was 17.9 kg/tow.

Stock Assessment

The most recent assessment of the Georges Bank haddock stock was conducted in 2001, and the results were reviewed at the 4th meeting of the Transboundary Resource Assessment Committee in April 2001 (NEFSC 2001d). At that time, fully recruited fishing mortality in 2000 was estimated to be 0.19. Spawning stock biomass had continued to increase from the low (< 15,000 mt) of the early 1990s to 64,100 mt in 2000. Recruitment has improved in recent years, as the 1996 and 1998 year classes are among the strongest since the 1978 year class appeared.

The time series of spawning stock biomass (SSB) and recruitment for the Georges Bank haddock stock extends from the 1930s to present. Plots of the SSB and recruitment obtained from the most recent assessment are provided in Figure 3.3.2. There appears to be a significant positive relationship between SSB and the likelihood of obtaining good recruitment.

Yield and Spawning Biomass Per Recruit

A revised yield and spawning biomass analysis for Georges Bank haddock was conducted to ensure that the distribution of fish within the plus-group was consistent with what would be expected in a rebuilt stock. This was accomplished by recomputing the 9+ mean weight to match with the equilibrium survivorship under an F likely to rebuild spawning biomass ($F_{40\%}$=0.26). Fishery selectivity, growth, and fraction mature at age were the same as used in the most recent management projections and MSY-reference point calculations described below. The resulting estimates of $F_{40\%}$ and $F_{0.1}$ were equal to 0.26 (Table 3.3.2); these values are similar to the estimates in the most recent assessment.

A sensitivity analysis was conducted to evaluate whether the use of growth and maturity patterns from 1931 would have changed the calculated reference points based on historic data (Clark et al. 1982). The results of the sensitivity analysis (Table 3.3.3) indicated that spawning biomass per recruit values based on the historic data were very similar to those using the current data. Similarly, reference points were robust to the use of historic growth and maturity data with estimates of $F_{40\%}$ =0.28 and $F_{0.1}$=0.25. Yield per recruit values using the historic data were lower, however, primarily due to the lower weights at age observed in the 1930s.

MSY-Based Reference Point Estimation

Empirical Nonparametric Approach

The Georges Bank haddock stock has a much greater chance of producing high recruitment when spawning biomass is above its observed median value (Brodziak et al. 2001). Furthermore, average recruitment strength is roughly 5 times larger when spawning biomass is above its median than when it falls below its median. Based on these observations, average recruitment from the entire time series of stock-recruitment data is not representative of the expected recruitment at B_{MSY} because of the severe depletion of spawning biomass since the 1970s. Two cases for determining the expected recruitment at B_{MSY} are considered.

In the first case, mean recruitment from the distribution of spawning biomass values >/= 75,000 mt is used to represent the expected recruitment at B_{MSY}; this value is 68.87 million age-1 recruits (the 1963 year class is excluded from the mean because it is considered a significant outlier; Figure 3.3.2). The mean is considered the appropriate measure of central tendency of the recruitment distribution at the upper stanza of spawning biomass (> 75,000 mt). If the F_{MSY} proxy is $F_{40\%}$=0.263, then the expected spawning biomass per recruit is 3.6341 kg of spawning biomass per recruit and the expected yield per recruit is 0.7686 kg of yield per recruit (Table 3.3.2). Multiplying the expected spawning biomass per recruit times the expected recruitment at B_{MSY} produces an B_{MSY} proxy of 250,300 mt of spawning biomass. Multiplying the expected yield per recruit times the expected recruitment at B_{MSY} produces an MSY proxy of 52,900 mt of yield.

In the second case, average recruitment from the 1931-1960 time period is used to represent the expected recruitment at B_{MSY}; this value is 75.230 million age-1 recruits (Figure 3.3.2). The mean is considered to be the appropriate measure of central tendency of the recruitment distribution during 1931-1960 because of the relative stability of both the stock size and the fishery yield during this period. If the F_{MSY} proxy is $F_{40\%}$=0.277 using the 1931 growth and maturity patterns, then the expected spawning biomass per recruit is 3.0590 kg of spawning biomass per recruit and the expected yield per recruit is 0.5986 kg of yield per recruit (Table 3.3.3). Multiplying the expected spawning biomass per recruit times the expected recruitment at B_{MSY} produces an B_{MSY} proxy of 230,000 mt of spawning biomass. Multiplying the expected yield per recruit times the expected recruitment at B_{MSY} produces an MSY proxy of 45,000 mt of yield. Thus, the calculation of Bmsy in the 230-250,000 mt range is robust to the substantial variation in life history parameters that has occurred for this stock in the past 70 years.

Parametric Model Approach

Maximum likelihood fits of the 10 parametric stock-recruitment models to the Georges Bank haddock data from 1931-2000 are listed below (Table 3.3.1). The model acronyms are:
BH = Beverton-Holt, ABH = Beverton-Holt with autoregressive errors, PBH = Beverton-Holt with steepness prior, PABH = Beverton-Holt with steepness prior and autoregressive errors, PRBH = Beverton-Holt with recruitment prior, PRABH = Beverton-Holt with recruitment prior and autoregressive errors, RK = Ricker, ARK = Ricker with autoregressive errors, PRK = Ricker with slope at the origin prior, PARK = Ricker with slope at the origin prior and autoregressive errors. The six hierarchical criteria are applied to each of the models to determine the set of candidate models.

The first criterion is satisfied by all models because none of the parameter estimates lie on the boundary of their feasible range. The second criterion is satisfied by all models except models BH and ABH, where the point estimate of MSY exceed 200 kt. This eliminates the BH and ABH models from being candidates. The third criterion is satisfied by all remaining models. The fourth criterion is satisfied for all remaining models because F_{MAX} exceeds 1.0 for Georges Bank haddock. The fifth criterion is not satisfied by the remaining autoregressive models, PABH, PRABH, ARK, and PARK, because the dominant period of environmental forcing is outside of the range of 1/2 of the length of the stock recruitment time series (Figure 3.3.4). The fact that the autoregressive parameters (ϕ) exceed ½ for the autoregressive models indicates that there must be a multidecadal environmental forcing term operating on the stock-recruitment process for Georges Bank haddock if these models represent the true state of nature. While the existence of multidecadal environmental forcing is not outside the realm of possibility, it is not a testable hypothesis within the available data. Furthermore, the detection of low-frequency oscillations is confounded by the appearance of two stock-recruitment stanzas for the stock: 1931-1960 and 1961-2000. Early in the second stanza, the stock virtually collapsed after intensive harvest by distant water fleets in the 1960s. Thus, the serial correlation in the stock-recruitment time series is coincident and confounded with the significant decreasing trends in both recruitment and spawning biomass data. As a result, the possible effects of strong serial correlation and density-dependence are not separable without a longer (100+ year) time series (see, for example, Manly 1997). Last, the sixth criterion is considered be satisfied by the remaining 4 models: PBH, PRBH, RK, and PRK. In this case, the R_{MAX} values may be lower than expected under the RK and PRK models but they do not appear to be anomalously low.

Given the four candidate models (PBH, PRBH, RK, and PRK), the AIC criterion assigns the greatest likelihood to the PRBH model, followed closely by the PBH model. In particular, the odds ratio of PRBH being true to PBH being true is 1.3:1 (Table 3.3.1). Thus, there is limited basis for choosing between these two parametric models, although both models give very similar point estimates of B_{MSY}, F_{MSY}, and MSY. The other two models, RK and PRK, are much less likely than the PRBH model. In particular, the odds ratio of PRBH being true to RK being true is over 50:1 while the odds ratio of PRBH being true to PRK being true is over 500:1. This indicates that overcompensatory stock-recruitment dynamics are very unlikely in this stock given the available data.

The results of using the PRBH model as the best fit parametric model are shown below (Table 3.3.1 and Figures 3.3.5, 3.3.6, and 3.3.7). The standardized residual plot of the fit of the PRBH model to the stock-recruitment data shows that the standardized residuals generally lie within ± two standard deviations of zero (Figure 3.3.5), with the exception of the time period immediately following the exceptional 1962-63 year classes and coincident with the highest catches by distant water fleets in the 1960s. The early part of the residual plot shows that residuals were consistently positive. This feature may represent the fact that the stock-recruitment time series likely underestimates the actual recruitment values during the 1931-early 1950s period when there was no mesh size regulation and discarding of undersized haddock was commonplace (Herrington 1932; Herrington 1935; Premetz et al. 1954). If recruitment estimates during the 1931-early 1950s period were increased upwards to account for discards, the model fit would change and likely produce a higher steepness. The latter part of the residual plot shows that residuals were generally negative during the 1980s. This feature may represent the fact that the magnitude and seasonal extent of spawning output was severely reduced after the spawning stock was depleted in the 1970s. In this context, accurately modeling the stock-recruitment dynamics during this time period may require a non-stationary model.

The equilibrium yield plot (Figure 3.3.6) shows that the yield surface is relatively flat from F=0.16 to F=0.22 in the neighborhood of the point estimate of $F_{MSY} = 0.18$. The point estimates of B_{MSY} =243,000 mt and MSY =36,700 mt are consistent with the observed values of maximum observed spawning stock size (200,000 mt) and long-term average yield (32,300 mt during 1904-2000), although the MSY value may seem low relative to the observed yields during 1931-1960. Again, the effect of not including discards of undersized haddock during the time period of unregulated mesh size, 1931 to the early-1950s, likely leads to a downward bias in the estimates of recruitment from this period and this reduces the apparent stock productivity. Regardless, the stock-recruitment plot (Figure 3.3.7) shows that recruitment values near B_{MSY} are roughly 54 million fish which is consistent with the long-term average (56 million) of the observed recruitment series during 1931-2000 excluding the exceptional 1962 and 1963 year classes.

Parameter uncertainty plots show histograms of 5000 MCMC sample estimates of MSY, B_{MSY}, and F_{MSY} drawn from the posterior distribution of the MLE based on an uninformative prior (Figure 3.3.8). For MSY, the 80 percent credibility interval was (33,100 mt, 41,500 mt) with a median of 37,300 mt. For B_{MSY}, the 80 percent credibility interval was (213,700 mt, 253,000 mt) with a median of 233,500 mt. For F_{MSY}, the 80 percent credibility interval was (0.165, 0.225) with a median of 0.19. Overall, the point estimates of MSY, B_{MSY}, and F_{MSY} were similar to the medians of the MCMC samples.

Reference Point Advice

Based on the conformance of the nonparametric proxy and parametric analyses, the following management parameters (based on the non-parametric approach) were selected by the Working Group as being most appropriate: Bmsy = 250,300 mt, Fmsy = 0.263, MSY=52,900 mt. The median recruitment, stock-recruitment scatterplot, and replacement lines under F=0 and F=0.263 are given in Figure 3.5.9. The non-parametric approach was selected because the best fit parametric model had a nonstationary residual pattern (Figure 3.3.5) which suggested that further research w needed to apply this approach.

Projections

Stochastic age-based projections were performed over a 10-year time horizon for 2001-2010 to compute likely trajectories of spawning biomass and catch under two fishing mortality scenarios: (i) $F = F_{MSY}$ and (ii) F calculated to rebuild the stock to B_{MSY}=250,300 mt in 2009. Recruitment was modeled by resampling from the CDF of the recruitments from SSBs > 75,000 mt, excepting the 1963 year class.

Projections used values of spawning stock weights at age, catch weights at age, maturity fraction at age, fishery selectivity at age, and natural mortality that were equal to those used in the spawning biomass and yield per recruit analyses of the current fishery (Table 3.3.2). A total of 1,000 bootstrap realizations of the initial population size at age vector at the beginning of 2001 were used for the projections. A total of 50 simulations were conducted for each initial population vector giving a total of 50,000 simulated population trajectories. Fully-recruited fishing mortality in 2001 was based on preliminary estimates of total catch in 2001 (11,553.6 mt with USA catch=4841.6 mt and Canadian catch=6712.0 mt); this gave a median F_{2001}=0.19. The fully-recruited fishing mortality in 2002 was taken to be the Amendment 7 fishing mortality target for Georges Bank haddock of $F_{0.1}$=0.26. Fishing mortality rates in 2003-2009 were set according to the two scenarios: (i) $F = F_{MSY}$ and (ii) F calculated to rebuild the stock to B_{MSY}=250,300 mt in 2009.

The medium term projections under fishing mortality scenario (i) (Figure 3.3.10) show that fishing at F_{MSY} during 2003-2009 would give a 35% probability of achieving B_{MSY} in 2009.

The medium term projections under fishing mortality scenario (ii) (Figure 3.3.10) show that the F calculated to rebuild the stock to B_{MSY} in 2009 with at least a 50% probability would be $F_{REBUILD}$=0.21. Projections results show that fishing at $F_{REBUILD}$ during 2003-2009 would give a 53% probability of achieving B_{MSY} in 2009. Projected median spawning biomass would increase from 80,500 mt in 2001 to 254,000 mt in 2009 (Figure 3.3.11). Projected median catches would increase from 11,500 mt in 2001 to roughly 43,600 mt in 2009 (Figure 3.3.12).

Table 3.3.1. Stock-recruitment model comparisons for Georges Bank haddock

Georges Bank Haddock Model Comparison										
SMAX =	199.5									
	Prior	Prior	Prior	Prior	Prior	Prior	Prior	Prior	Prior	Prior
	0	0	0.25	0	0.25	0	0.25	0	0.25	0
	BH	ABH	**PBH**	PABH	**PRBH**	PRABH	**RK**	ARK	**PRK**	PARK
Posterior Probability	0.00	0.00	**0.43**	0.00	**0.56**	0.00	**0.01**	0.00	**0.00**	0.00
Odds Ratio for Most Likely Model			1.31		**1.00**		50.70		588.75	
Normalized Likelihood	0.00	0.00	0.43	0.00	0.56	0.00	0.01	0.00	0.00	0.00
Model AIC Ratio			450.1136		588.74903		11.6115466		1	
	BH	**ABH**	**PBH**	**PABH**	**PRBH**	**PRABH**	**RK**	**ARK**	**PRK**	**PARK**
Number_of_data_points	70	70	70	70	70	70	70	70	70	70
Number_of_parameters	3	4	3	4	3	4	3	4	3	4
Negative_loglikelihood	337.963	328.003	338.497	327.477	341.129	330.825	342.401	329.758	346.749	331.503
Bias-corrected_AIC	682.29	664.622	683.851	665.937	683.314	664.965	691.166	668.131	696.07	672.205
Diagnostic Comments	MSY and SMSY are outside credible range	Power spectrum dominant frequency exceeds 1/2 time series length		Power spectrum dominant frequency exceeds 1/2 time series length	**Most Likely Model**	Power spectrum dominant frequency exceeds 1/2 time series length		Power spectrum dominant frequency exceeds 1/2 time series length		Power spectrum dominant frequency exceeds 1/2 time series length
Parameter Point Estimates										
************************										
MSY	250.308	1990.13	40.8311	28.0879	36.7247	37.1899	35.0312	39.1603	36.9555	47.2048
FMSY	0.145	0.145	0.21	0.29	0.18	0.19	0.53	0.53	0.71	1.04
SMSY	2020.56	16065	235.313	122.094	243.145	234.469	93.4673	104.484	79.4513	78.0314
alpha	824.447	6676.98	94.6193	50.7077	96.3656	95.0454	4.54054E-05	4.54149E-05	0.246943	0.54437
expected_alpha	1961.96	15797.2	229.613	127.855	232.272	227.714	0.000121489	0.00012059	0.709649	1.73527
beta	2068.06	17047.7	154.847	51.8471	187.557	178.74	-9.12E-03	-8.16E-03	-0.011437	-0.012309
RMAX	72.5348	77.2331	53.2713	40.2478	49.6695	50.131	32.3677	39.2096	26.08	29.5075
expected_RMAX	172.613	182.728	129.274	101.481	119.719	120.106	86.6045	104.113	74.947	94.0604
Prior_mean			0.74	0.74	75.229	75.229			0.72	0.72
Prior_se			0.11	0.11	5.646	5.646			0.21	0.21
Z_Myers	0.48	0.47	0.58	0.69	0.54	0.55				
sigma	1.317	1.312	1.332	1.360	1.326	1.322	1.403	1.398	1.453	1.523
phi		0.50		0.53		0.50		0.55		0.61
sigmaw		1.14		1.15		1.14		1.17		1.20
last log-residual R		0.899		0.747		0.878		0.445		0.149
expected lognormal error term	2.38	2.37	2.43	2.52	2.41	2.40	2.68	2.66	2.87	3.19

Table 3.3.2. Yield and biomass per recruit for Georges Bank haddock, using current growth and maturity.

The NEFC Yield and Stock Size per Recruit Program - PDBYPRC
PC Ver.2.0 [Method of Thompson and Bell (1934)] 1-Jan-1999

Run Date: 21- 2-2002; Time: 09:17:28.80
Gb Haddock using recent weight at age and maturity

Proportion of F before spawning: 0.2500
Proportion of M before spawning: 0.2500
Natural Mortality is Constant at: 0.200
Initial age is: 1; Last age is: 9
Last age is a PLUS group;
Original age-specific PRs, Mats, and Mean Wts from file:
==> C:\groundfish\ypr\gbhad_new_ypr.dat

Age-specific Input data for Yield per Recruit Analysis

Age	Fish Mort Pattern	Nat Mort Pattern	Proportion Mature	Average Weights Catch	Average Weights Stock
1	0.0030	1.0000	0.0400	0.545	0.388
2	0.0880	1.0000	0.4900	1.060	0.732
3	0.4710	1.0000	0.9500	1.533	1.277
4	0.9200	1.0000	1.0000	1.874	1.704
5	1.0000	1.0000	1.0000	2.247	2.039
6	1.0000	1.0000	1.0000	2.498	2.350
7	1.0000	1.0000	1.0000	2.970	2.749
8	1.0000	1.0000	1.0000	3.180	3.204
9	1.0000	1.0000	1.0000	3.678	3.678

Summary of Yield per Recruit Analysis:

Slope of the Yield/Recruit Curve at F=0.00: --> 8.3488
F level at slope=1/10 of the above slope (F0.1): -----> 0.263
Yield/Recruit corresponding to F0.1: -----> 0.7683
F level to produce Maximum Yield/Recruit (Fmax): -----> 1.312
Yield/Recruit corresponding to Fmax: -----> 0.9211
F level at 40 % of Max Spawning Potential (F40): -----> 0.263
SSB/Recruit corresponding to F40: --------> 3.6341

1
Listing of Yield per Recruit Results for:

	FMORT	TOTCTHN	TOTCTHW	TOTSTKN	TOTSTKW	SPNSTKN	SPNSTKW	% MSP
	0.00	0.00000	0.00000	5.5167	10.2738	3.9054	9.0870	100.00
	0.10	0.20503	0.50516	4.4964	6.9291	2.8811	5.7783	63.59
	0.20	0.30918	0.70302	3.9803	5.3582	2.3612	4.2323	46.58
F0.1	0.26	0.35212	0.76827	3.7682	4.7516	2.1470	3.6374	40.03
F40%	0.26	0.35237	0.76861	3.7670	4.7481	2.1457	3.6341	39.99
	0.30	0.37288	0.79587	3.6660	4.4694	2.0435	3.3611	36.99
	0.40	0.41630	0.84475	3.4529	3.9066	1.8272	2.8109	30.93
	0.50	0.44807	0.87270	3.2978	3.5214	1.6691	2.4349	26.80
	0.60	0.47253	0.88973	3.1790	3.2422	1.5475	2.1625	23.80
	0.70	0.49208	0.90061	3.0846	3.0307	1.4505	1.9560	21.53
	0.80	0.50816	0.90782	3.0073	2.8646	1.3709	1.7939	19.74
	0.90	0.52171	0.91271	2.9425	2.7304	1.3039	1.6628	18.30
	1.00	0.53332	0.91607	2.8872	2.6194	1.2465	1.5544	17.11
	1.10	0.54345	0.91838	2.8393	2.5258	1.1966	1.4629	16.10
	1.20	0.55238	0.91994	2.7971	2.4455	1.1527	1.3844	15.23
	1.30	0.56035	0.92097	2.7596	2.3757	1.1135	1.3161	14.48
Fmax	1.31	0.56126	0.92106	2.7554	2.3678	1.1091	1.3084	14.40
	1.40	0.56752	0.92160	2.7260	2.3143	1.0784	1.2561	13.82
	1.50	0.57404	0.92192	2.6956	2.2597	1.0465	1.2028	13.24
	1.60	0.58000	0.92201	2.6679	2.2107	1.0175	1.1550	12.71
	1.70	0.58547	0.92192	2.6425	2.1665	0.9908	1.1118	12.24
	1.80	0.59054	0.92169	2.6190	2.1262	0.9662	1.0726	11.80
	1.90	0.59525	0.92135	2.5973	2.0893	0.9434	1.0367	11.41
	2.00	0.59964	0.92092	2.5770	2.0554	0.9221	1.0038	11.05

Table 3.3.3. Yield and biomass per recruit of Georges Bank haddock using 1931 growth and maturity patterns.

```
____________________________________________________________________
   The NEFC Yield and Stock Size per Recruit Program - PDBYPRC
    PC Ver.2.0 [Method of Thompson and Bell (1934)] 1-Jan-1999
            ----------------------------------------
            Run Date: 19- 2-2002;  Time: 14:33:20.07
 Gb Haddock using 1931 weight at age and maturity
 ____________________________________________________________________
 Proportion of F before spawning: 0.2500
 Proportion of M before spawning: 0.2500
 Natural Mortality is Constant at: 0.200
 Initial age is:  1; Last age is:  9
 Last age is a PLUS group;
 Original age-specific PRs, Mats, and Mean Wts from file:
 ==> C:\groundfish\ypr\gbhad_old_ypr.dat
------------------------------------------------------------
 Age-specific Input data for Yield per Recruit Analysis
------------------------------------------------------------
  Age | Fish Mort  Nat Mort | Proportion | Average Weights
      |  Pattern    Pattern |   Mature   |  Catch   Stock
------------------------------------------------------------
   1  |  0.0030     1.0000  |   0.0000   |  0.750   0.750
   2  |  0.0880     1.0000  |   0.5000   |  0.780   0.780
   3  |  0.4710     1.0000  |   1.0000   |  1.180   1.180
   4  |  0.9200     1.0000  |   1.0000   |  1.370   1.370
   5  |  1.0000     1.0000  |   1.0000   |  1.650   1.650
   6  |  1.0000     1.0000  |   1.0000   |  2.010   2.010
   7  |  1.0000     1.0000  |   1.0000   |  2.310   2.310
   8  |  1.0000     1.0000  |   1.0000   |  2.540   2.540
   9  |  1.0000     1.0000  |   1.0000   |  3.030   3.030

------------------------------------------------------------
 Summary of Yield per Recruit Analysis:
 ____________________________________________________________________
  Slope of the Yield/Recruit Curve at F=0.00: -->    6.6163
    F level at slope=1/10 of the above slope (F0.1): ----->          0.246
      Yield/Recruit corresponding to F0.1: ----->    0.5795
    F level to produce Maximum Yield/Recruit (Fmax): ----->          2.313
      Yield/Recruit corresponding to Fmax: ----->    0.6949
    F level at 40 % of Max Spawning Potential (F40): ----->  0.277
      SSB/Recruit corresponding to F40: -------->    3.0590
 ____________________________________________________________________
1
 Listing of Yield per Recruit Results for:
 ----------------------------------------------------------------------------
      FMORT   TOTCTHN  TOTCTHW  TOTSTKN  TOTSTKW  SPNSTKN  SPNSTKW    % MSP
 ----------------------------------------------------------------------------
       0.00   0.00000  0.00000   5.5167   9.1092   3.9070   7.6478   100.00
       0.10   0.20503  0.39463   4.4964   6.3547   2.8820   4.9214    64.35
       0.20   0.30918  0.54308   3.9803   5.0604   2.3615   3.6462    47.68
 F0.1  0.25   0.34162  0.57951   3.8200   4.6804   2.1993   3.2728    42.79
 F40%  0.28   0.36076  0.59856   3.7257   4.4627   2.1037   3.0590    40.00
       0.30   0.37288  0.60964   3.6660   4.3277   2.0431   2.9265    38.27
       0.40   0.41630  0.64304   3.4529   3.8633   1.8262   2.4712    32.31
       0.50   0.44807  0.66132   3.2978   3.5453   1.6675   2.1594    28.23
       0.60   0.47253  0.67205   3.1790   3.3146   1.5453   1.9330    25.28
       0.70   0.49208  0.67877   3.0846   3.1398   1.4477   1.7611    23.03
       0.80   0.50816  0.68321   3.0073   3.0025   1.3674   1.6258    21.26
       0.90   0.52171  0.68628   2.9425   2.8916   1.2999   1.5161    19.82
       1.00   0.53332  0.68848   2.8872   2.7998   1.2420   1.4252    18.64
       1.10   0.54345  0.69012   2.8393   2.7224   1.1915   1.3482    17.63
       1.20   0.55238  0.69136   2.7971   2.6560   1.1470   1.2820    16.76
       1.30   0.56035  0.69232   2.7596   2.5983   1.1074   1.2243    16.01
       1.40   0.56752  0.69306   2.7260   2.5475   1.0717   1.1733    15.34
       1.50   0.57404  0.69364   2.6956   2.5023   1.0393   1.1279    14.75
       1.60   0.58000  0.69408   2.6679   2.4617   1.0098   1.0871    14.21
       1.70   0.58547  0.69442   2.6425   2.4250   0.9826   1.0501    13.73
       1.80   0.59054  0.69466   2.6190   2.3916   0.9575   1.0163    13.29
       1.90   0.59525  0.69482   2.5973   2.3609   0.9343   0.9853    12.88
       2.00   0.59964  0.69492   2.5770   2.3327   0.9126   0.9567    12.51
 ----------------------------------------------------------------------------
```

Georges Bank Haddock

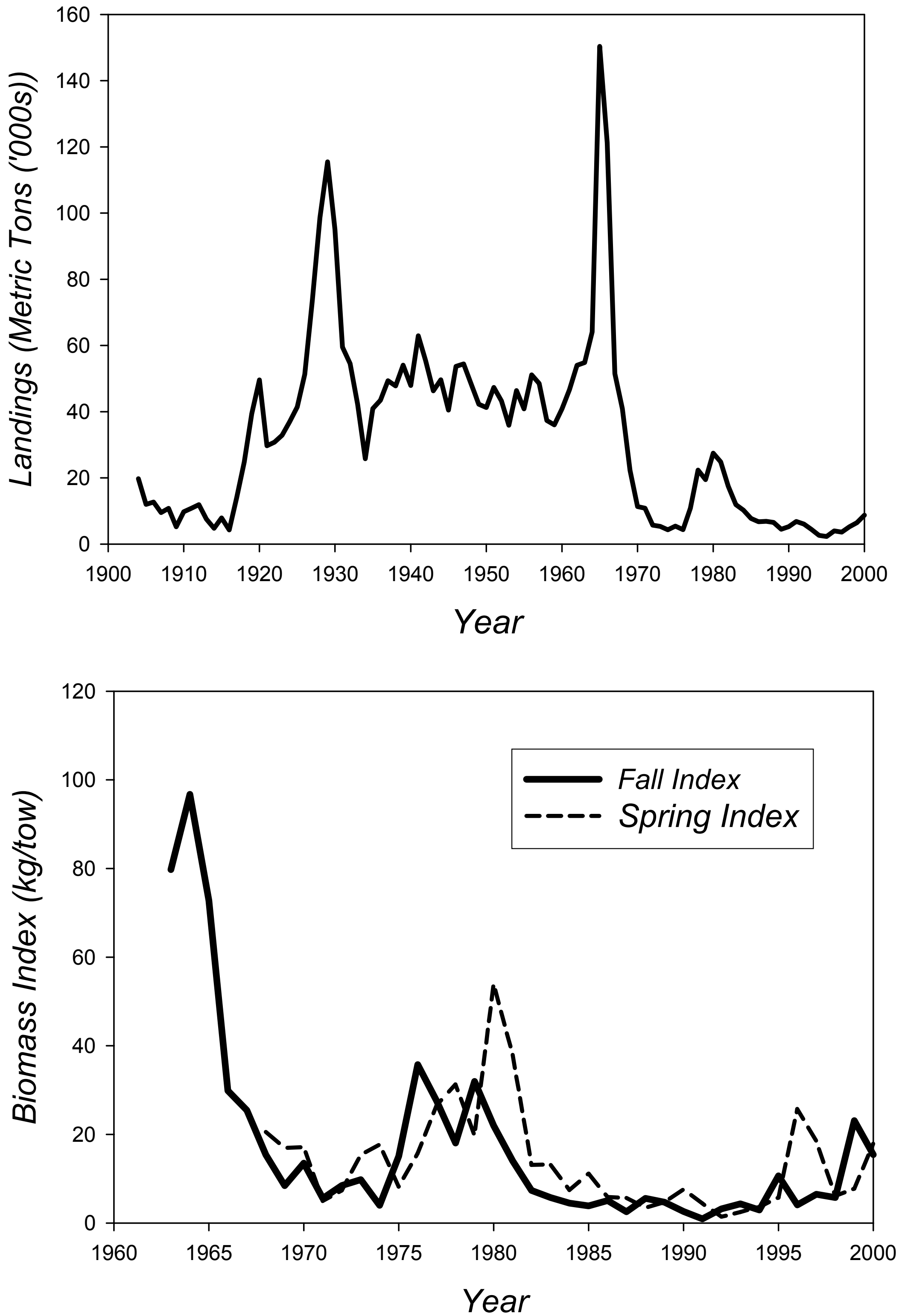
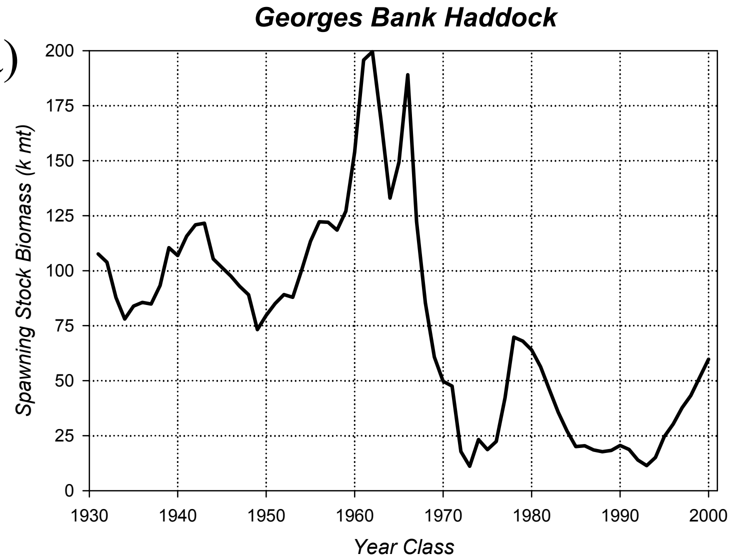
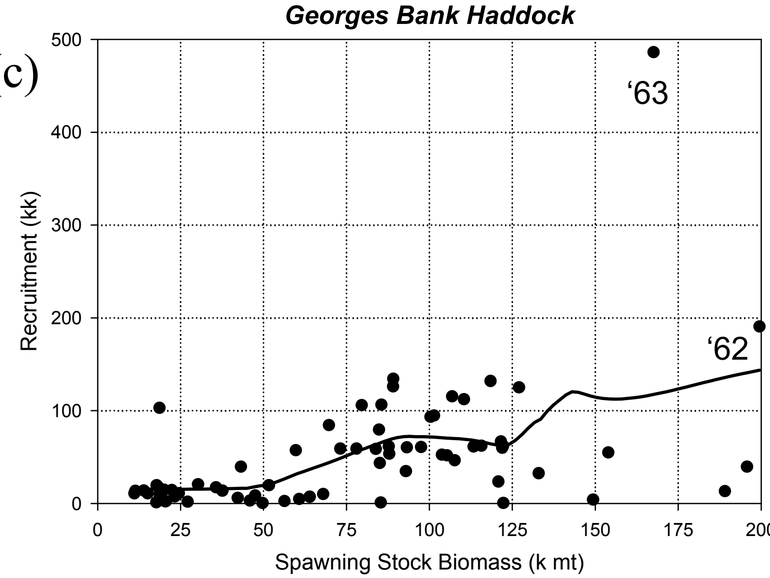


Figure 3.3.1. Landings and research vessel survey abundance indices for Georges Bank haddock.

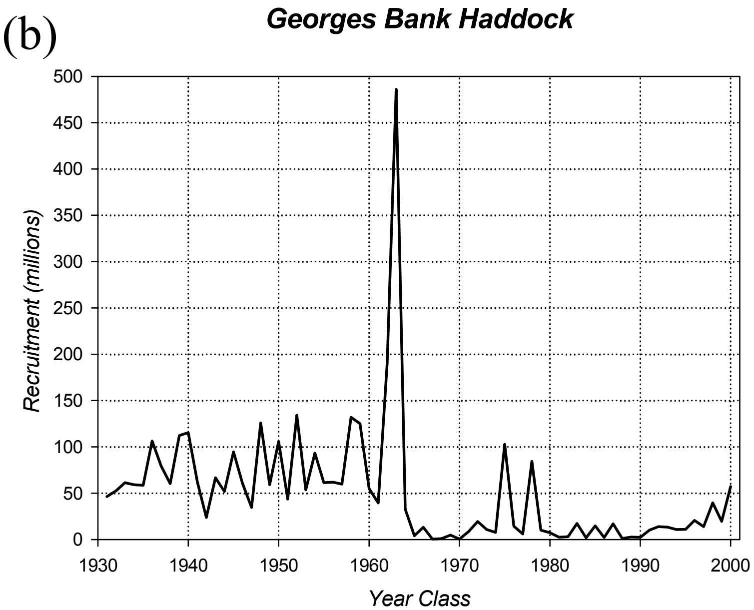
(a)



(c)



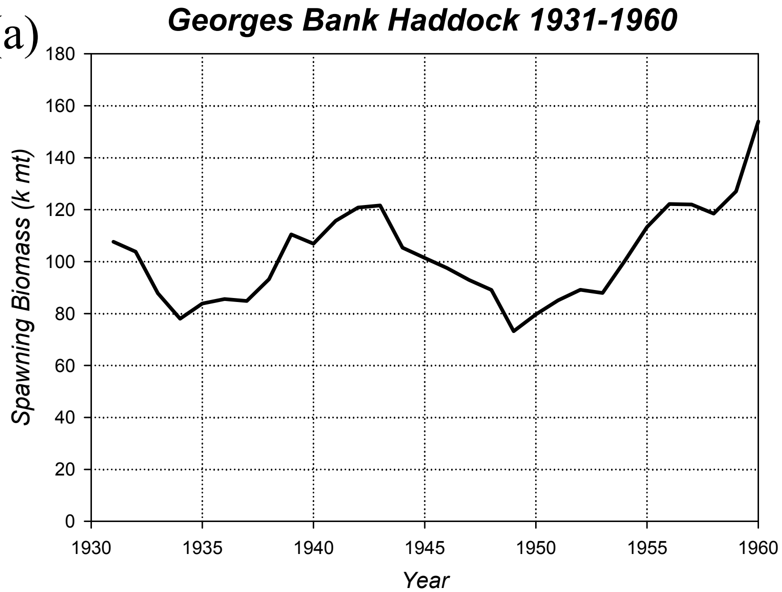
(b)



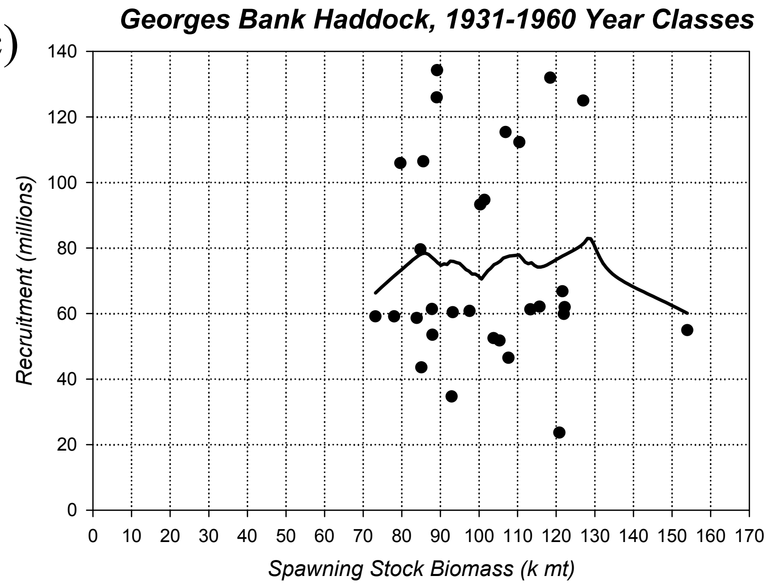
		F0.1	F40% MSP
F reference point		0.263	0.263
ssb per recruit at F		3.6374	3.6341
	Recruitment (millions)	SS Biomass at F0.1	SS Biomass at F40%
n	70	70	70
mean	51.09	185.83	185.66
min	0.42	1.53	1.53
max	486.22	1768.56	1766.95
10th %'tile	2.49	9.07	9.06
25th %'tile	10.30	37.47	37.43
50th %'tile	37.08	134.86	134.74
75th %'tile	61.80	224.78	224.58
90th %'tile	112.58	409.51	409.14
Std Dev	67.73	246.38	246.15
CV	1.33	1.33	1.33
For SSB >/= 75 kmt - w/o '63 YC			
Mean	68.87	250.49	250.27
Median	60.57	220.30	220.10
Mean w/'63 YC	80.15	291.52	291.26

Figure 3.3.2. Spawning stock (a), recruitment (age 1 millions, b), and scatterplot (c) for Georges Bank haddock. Data are the calculated spawning stock biomasses for various recruitment scenarios multiplied by the expected SSB per recruit for F0.1 and F40% MSP, assuming recent patterns of growth, maturity and partial recruitment at age (Table 3.3.2). Smoother in the stock-recruitment plot is lowess with tension = 0.5.

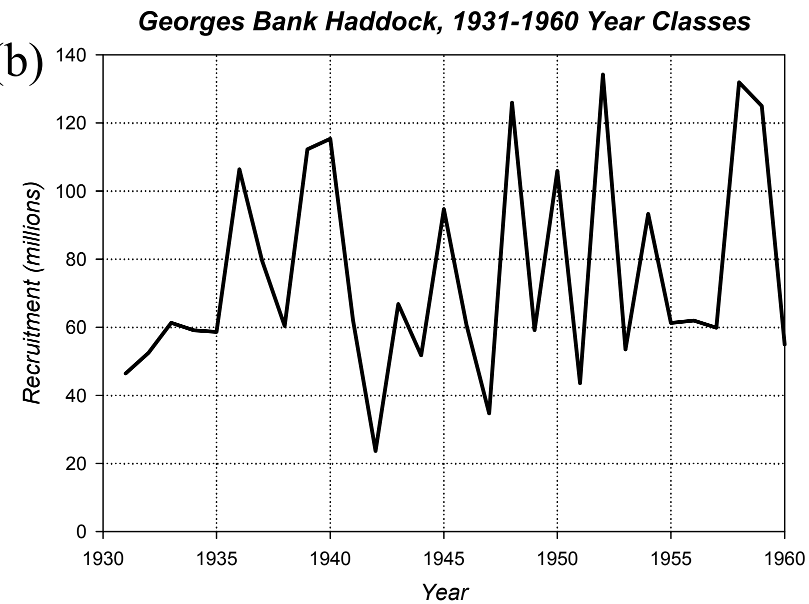
(a)



(c)



(b)



		F0.1	F40% MSP
F reference point		0.246	0.277
ssb per recruit at F		3.27	3.06
1931-1960 Year Classes	Recruitment (millions)	SS Biomass at F0.1	SS Biomass at F40%
n	30	30	30
mean	75.23	246.00	230.20
min	23.64	77.29	72.33
max	134.23	438.93	410.74
10th %'tile	46.16	150.93	141.24
25th %'tile	55.85	182.64	170.91
50th %'tile	61.30	200.43	187.56
75th %'tile	103.12	337.20	315.54
90th %'tile	125.09	409.03	382.76
Std Dev	30.92	101.12	94.62
CV	0.41	0.41	0.41
For Top Quartile of SSB			
Mean	73.27	239.61	224.22
Median	62.02	202.81	189.79

Figure 3.3.3. Spawning stock (a), recruitment (age 1 millions, b), and scatterplot (c) for Georges Bank haddock, 1931-1960. Data are the calculated spawning stock biomasses for various recruitment scenarios multiplied by the expected SSB per recruit for F0.1 and F40% MSP, assuming early patterns of growth and maturity at age (Table 3.3.3). Smoother in the stock-recruitment plot is lowess with tension = 0.5.

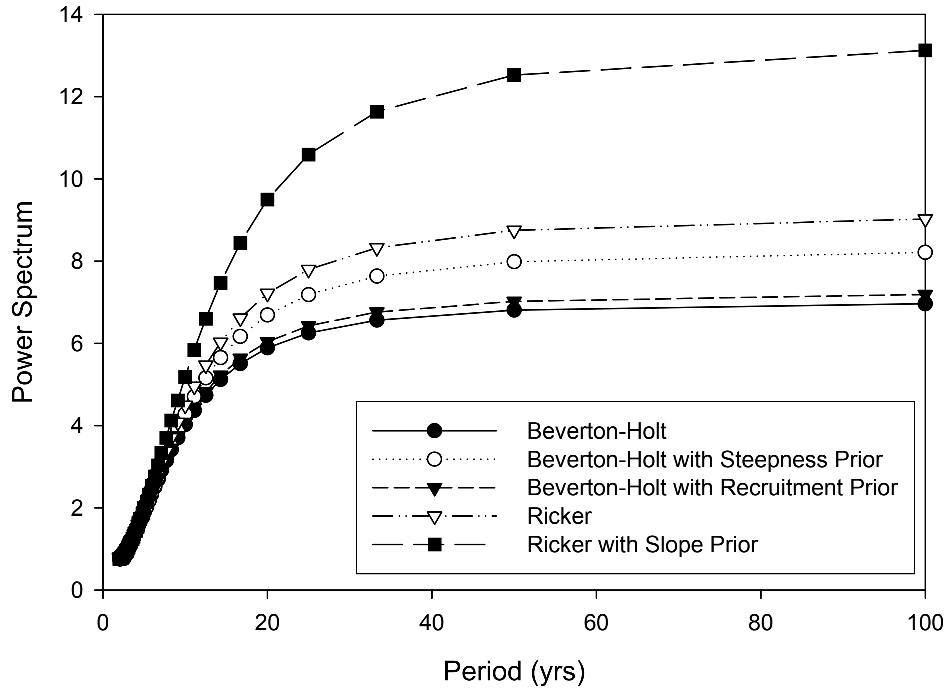


Figure 3.3.4. Georges Bank haddock periodicity of environmental forcing for autoregressive stock-recruitment models

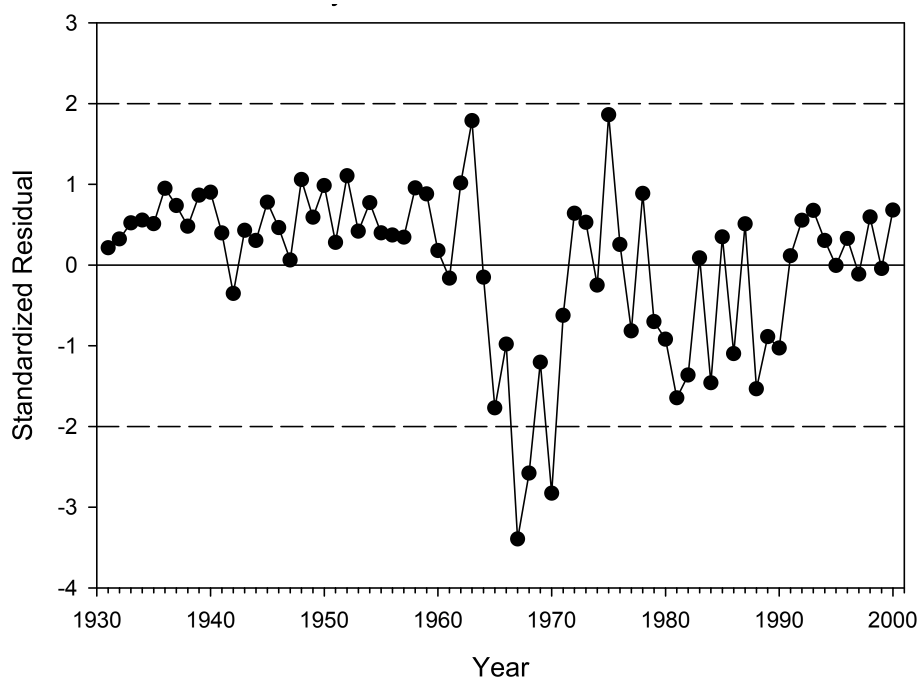


Figure 3.3.5. Georges Bank haddock standardized residuals for the most likely stock-recruitment model

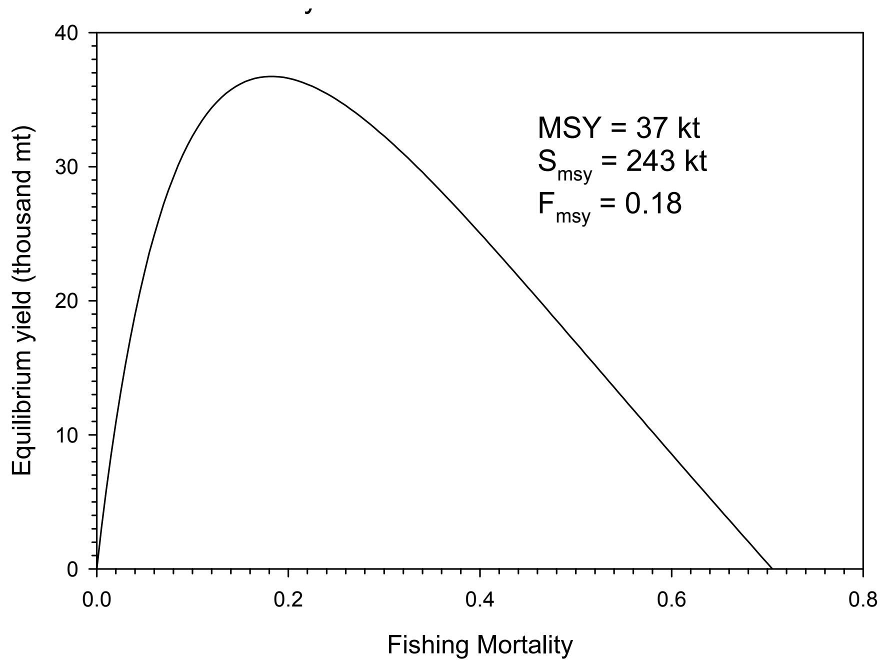


Figure 3.3.6. Georges Bank haddock equilibrium yield vs. F for the most likely stock-recruitment model

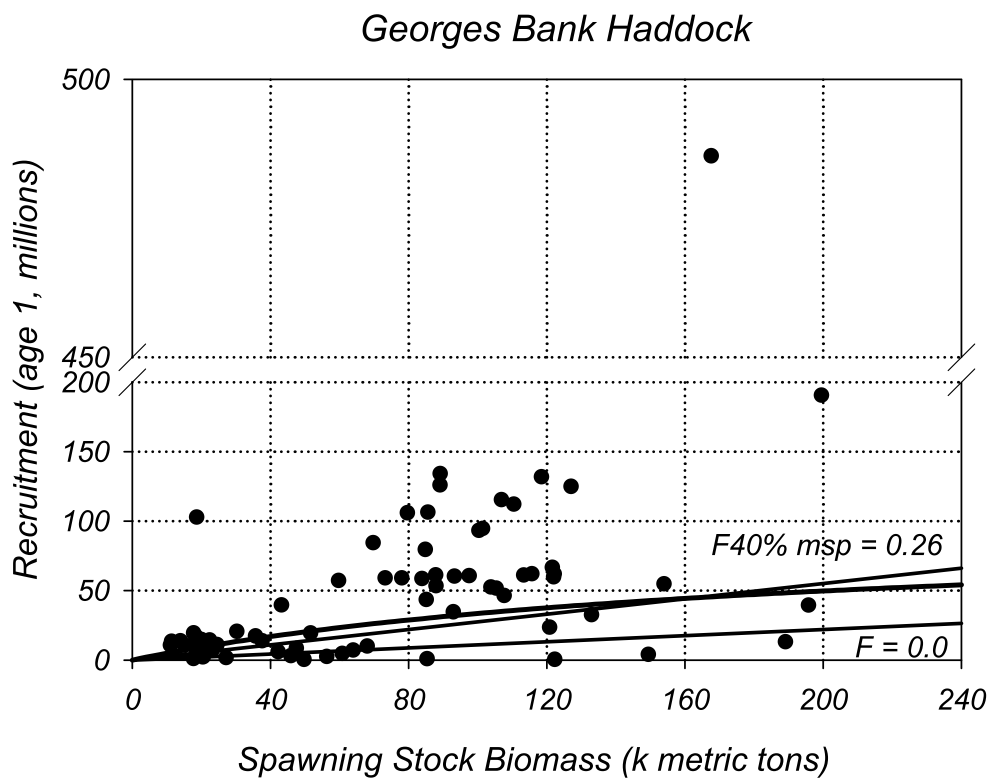


Figure 3.3.7. Stock recruitment relationship for best fit parametric model Georges Bank haddock. Stock-recruitment data points are overplotted, along with the predicted S-R line and replacement lines for F=100% msp=0.00 and F40%msp = 0.26.

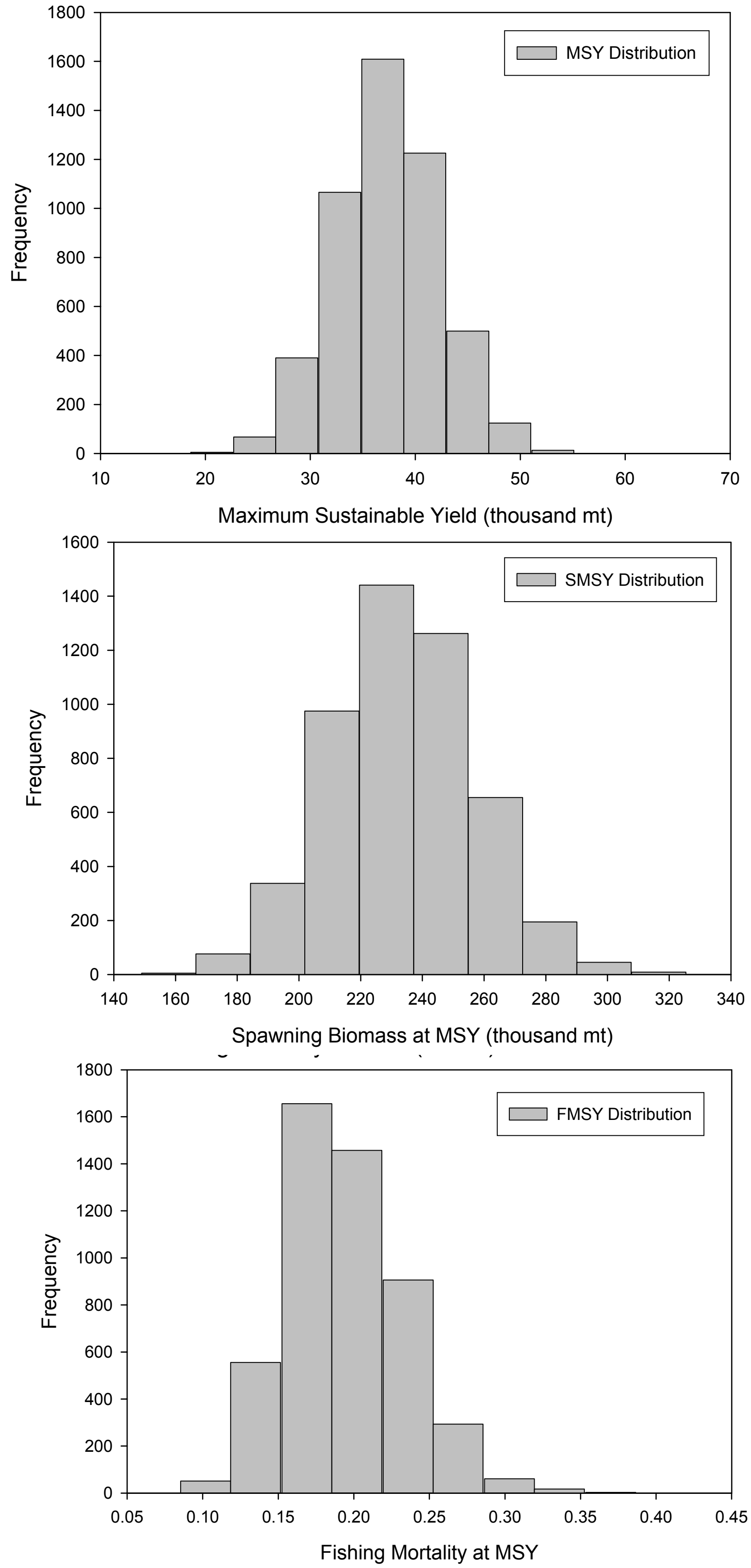


Figure 3.3.8. Georges Bank haddock posterior distribution of MSY, BMSY and FMSY for most likely model fit.

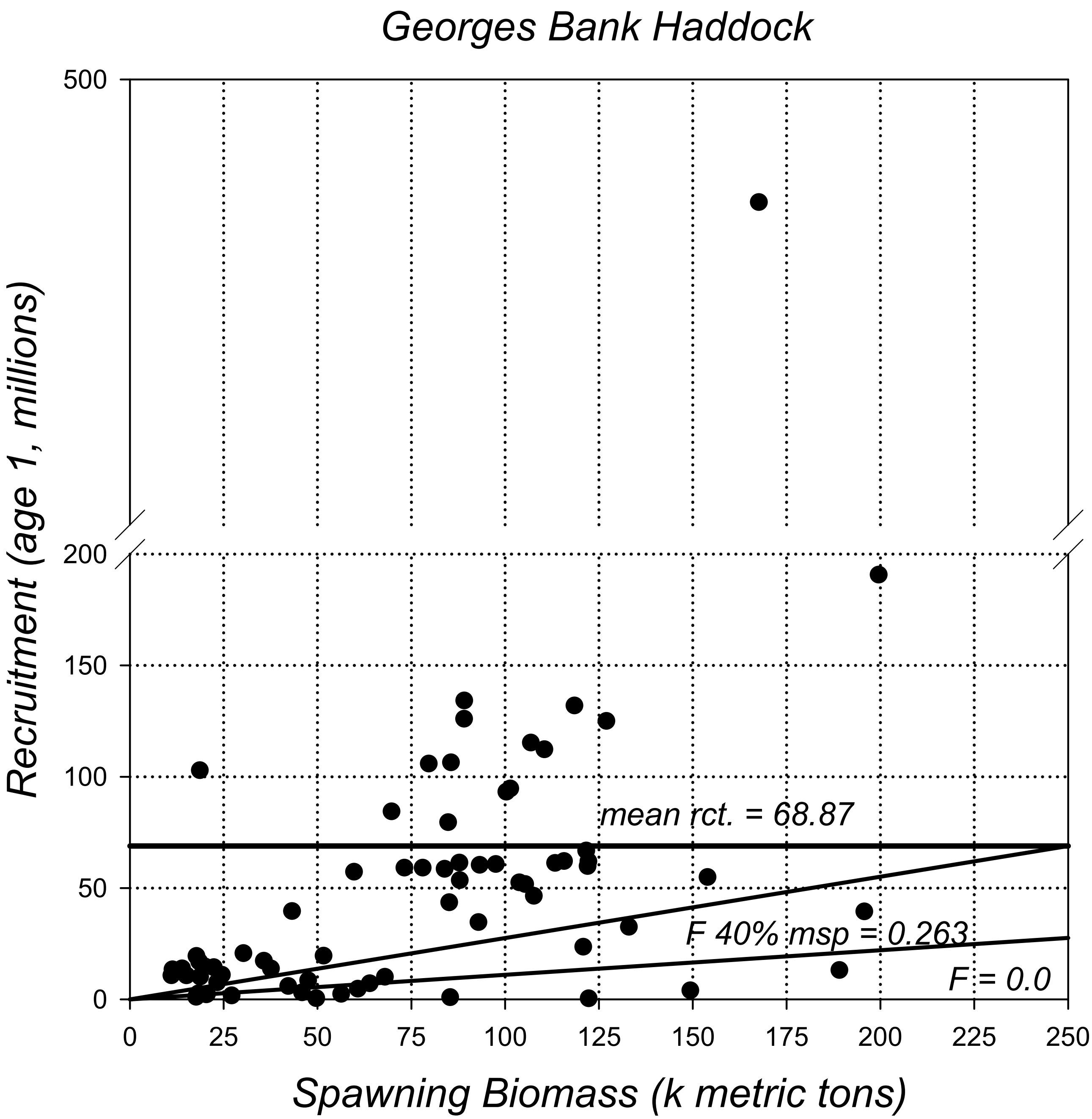


Figure 3.3.9. Stock and recruitment data for Georges Bank haddock. For the empirical non-parametric approach the mean recruitment above 75,000 mt of spawning stock biomass is plotted (excluding the 1963 year class), along with replacement lines for F=0.0 and F 40% msp = 0.263.

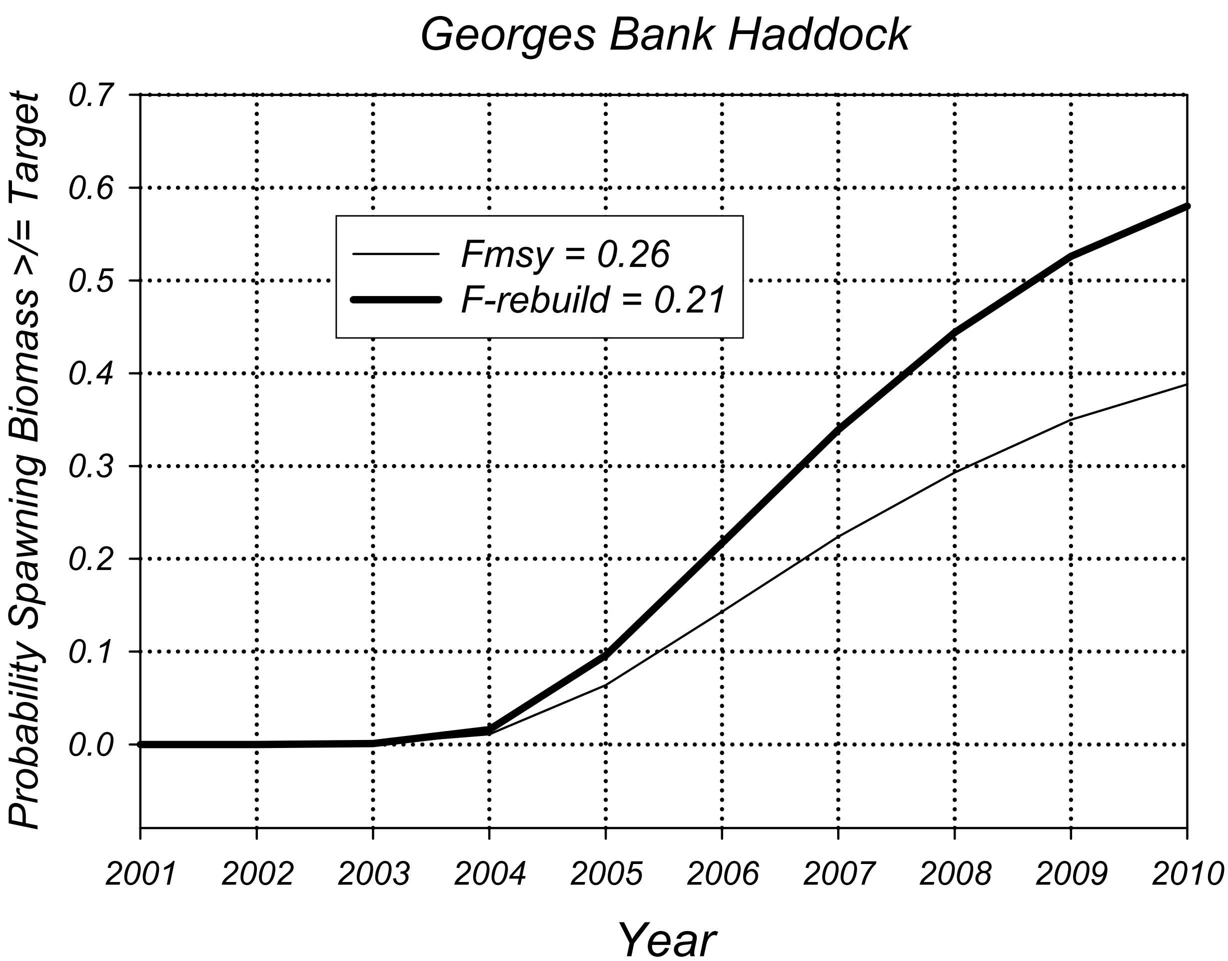


Figure 3.3.10. Probability that Georges Bank haddock spawning biomass will exceed Bmsy (250,300 mt) annually under two fishing mortality scenarios: Fmsy and F required to rebuild the stock to Bmsy by 2009.

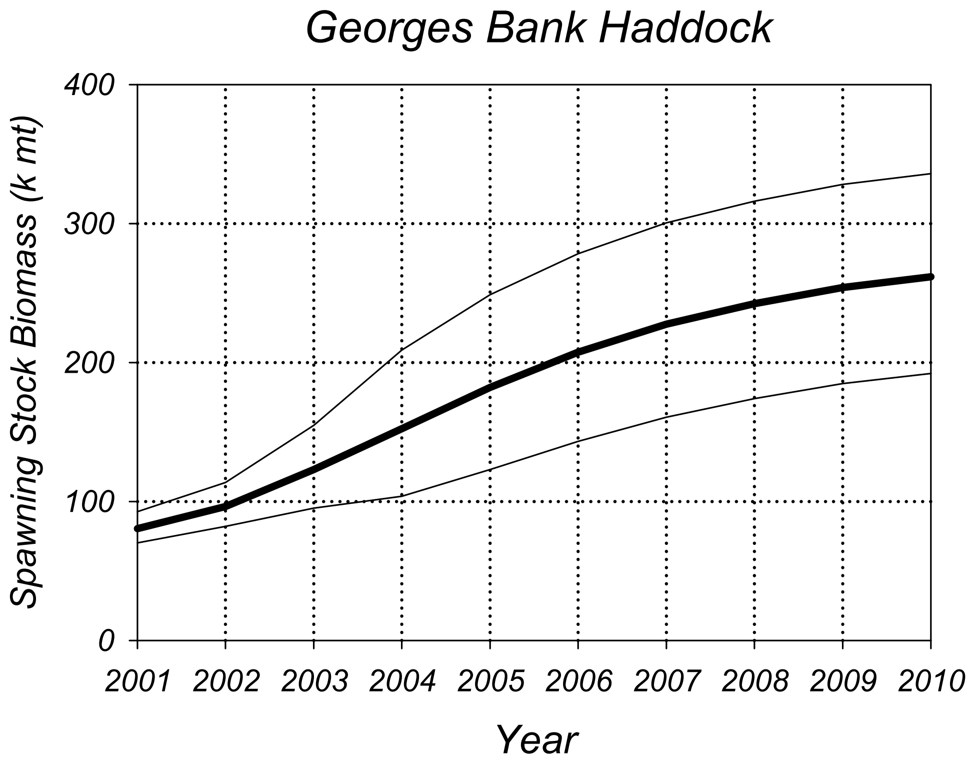


Figure 3.3.11. Median and 80% confidence interval of predicted spawning biomass for Georges Bank haddock under F-rebuild fishing mortality rates.

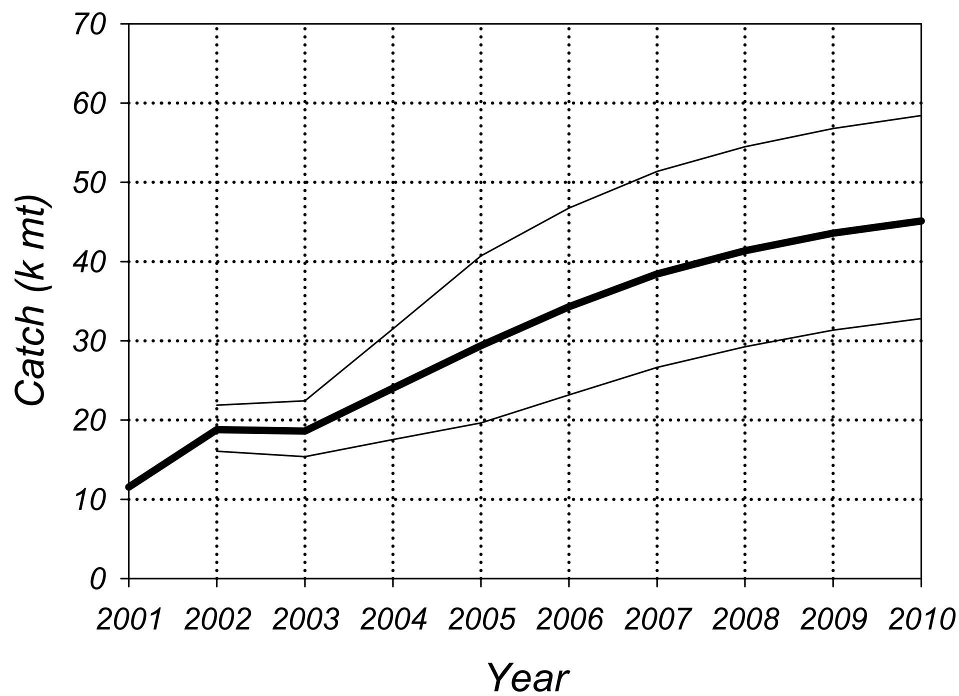


Figure 3.3.12. Median and 80% confidence interval of predicted catch for Georges Bank haddock under F-rebuild fishing mortality rates.

3.4 Gulf of Maine haddock

Catch and Survey Indices

Between 1960 and 2000, landings of Gulf of Maine haddock have generally ranged between 2,000 and 6,000 mt per year with occasional periods of higher or lower catches (Figure 3.4.1). Following recruitment of the 1975 and 1978 year classes, landings of haddock in the Gulf of Maine ranged between 6,000 and 8,000 mt from 1980 to 1984. Landings declined steadily between1982 and the mid 1990s, reaching an historic low of 112 mt in 1994. Haddock landings have increased steadily since 1994 reaching 1,000 mt in 1998 but declined thereafter to about 600-700 mt in 1999 and 2000.

Survey biomass indices (stratified mean weight/tow) are available from the NEFSC spring (1968 to 2000) and autumn (1963 to 2000) surveys. Spring survey biomass indices declined from high levels during the late 1970s to record low levels by 1990 (Figure 3.4.1). During the1990s, spring survey indices remained at chronic low levels, with the exception of 1997, 1999, and 2000. The 2000 biomass index was the highest observed since 1985.

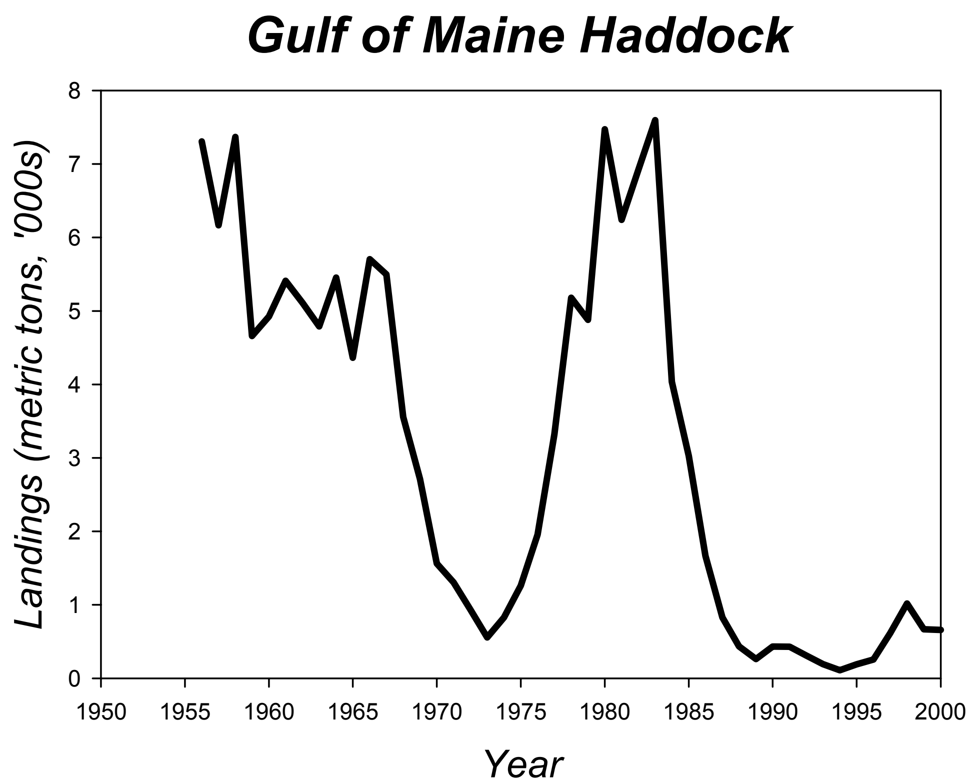
NEFSC autumn survey biomass indices declined from very high levels in the mid -1960s to low levels in the early 1970s. The indices increased during the late 1970s and early 1980s following recruitment of the 1975 and 1978 year classes, and subsequently declined to historic low levels in 1991. Biomass indices increased gradually during the mid 1990s and more rapidly beginning in 1996. The 1999 autumn survey biomass index was the highest observed since1985, and the 2000 biomass index is approaching levels observed during the mid 1960s.

Stock Assessment

The Gulf of Maine haddock stock was last assessed in 2000, and the results were reviewed at the 32nd Northeast Regional Stock Assessment Workshop in 2000 (NEFSC 2001b). At that time, exploitation ratios (catch/survey biomass) had declined and were among the lowest on record. Total survey biomass indices had begun to increase from the very low levels of the early 1990s, and survey indices at age reflected an increase in recruitment and some broadening of the age structure. The survey indices for younger ages indicated improved recruitment, especially for the1998 year class.

Relative Exploitation Rate Analyses

The replacement level of relative F is estimated to be 0.23 (Table 4.1.1). By either fixing the biomass index associated with MSY or MSY itself, the other quantity can be calculated from MSY/I = relF. During the period 1959-1966 landings of Gulf of Maine haddock averaged 5,100 mt and were stable (Clark et al. 1982). If this value is fixed as MSY, then the recommended Bmsy proxy is 5.1/0.23 = 22.17 kg/tow. This value is within the observed survey series (Figure 3.4.1) and is similar in relative increase to that proposed for the Georges bank haddock stock. These two stocks are believed to be closely linked (Figure 3.4.3), so the proposed increases in their reference points (different scales but approximately similar proportional increases in proposed BMSY) seem warranted.



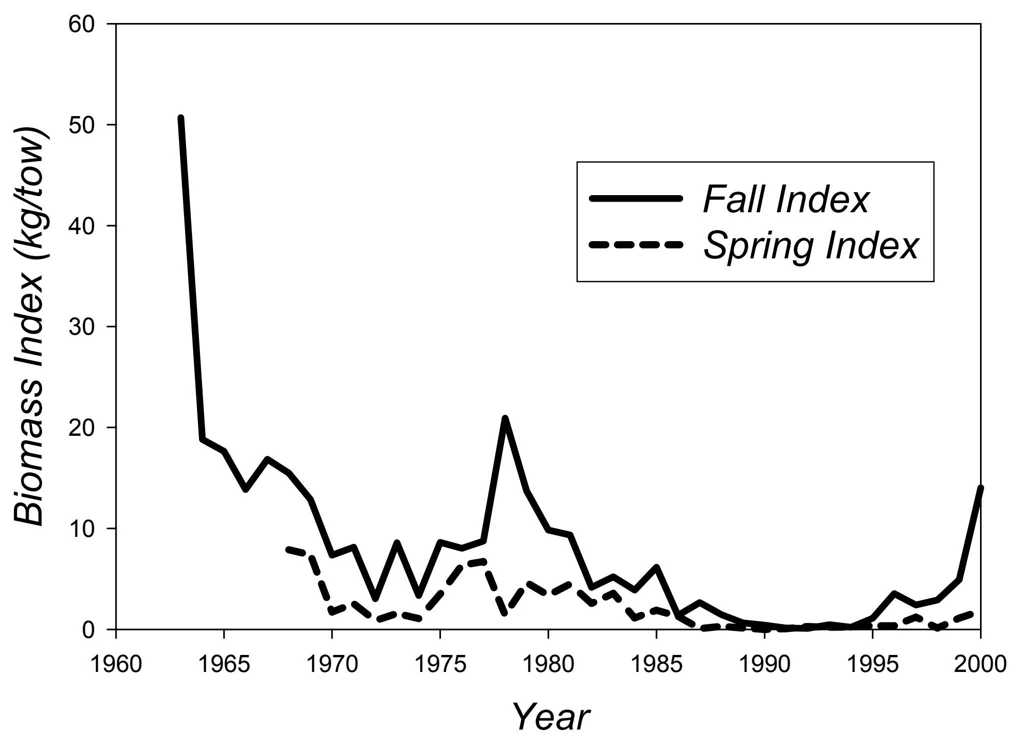


Figure 3.4.1. Landings and research vessel survey abundance indices for Gulf of Maine haddock.

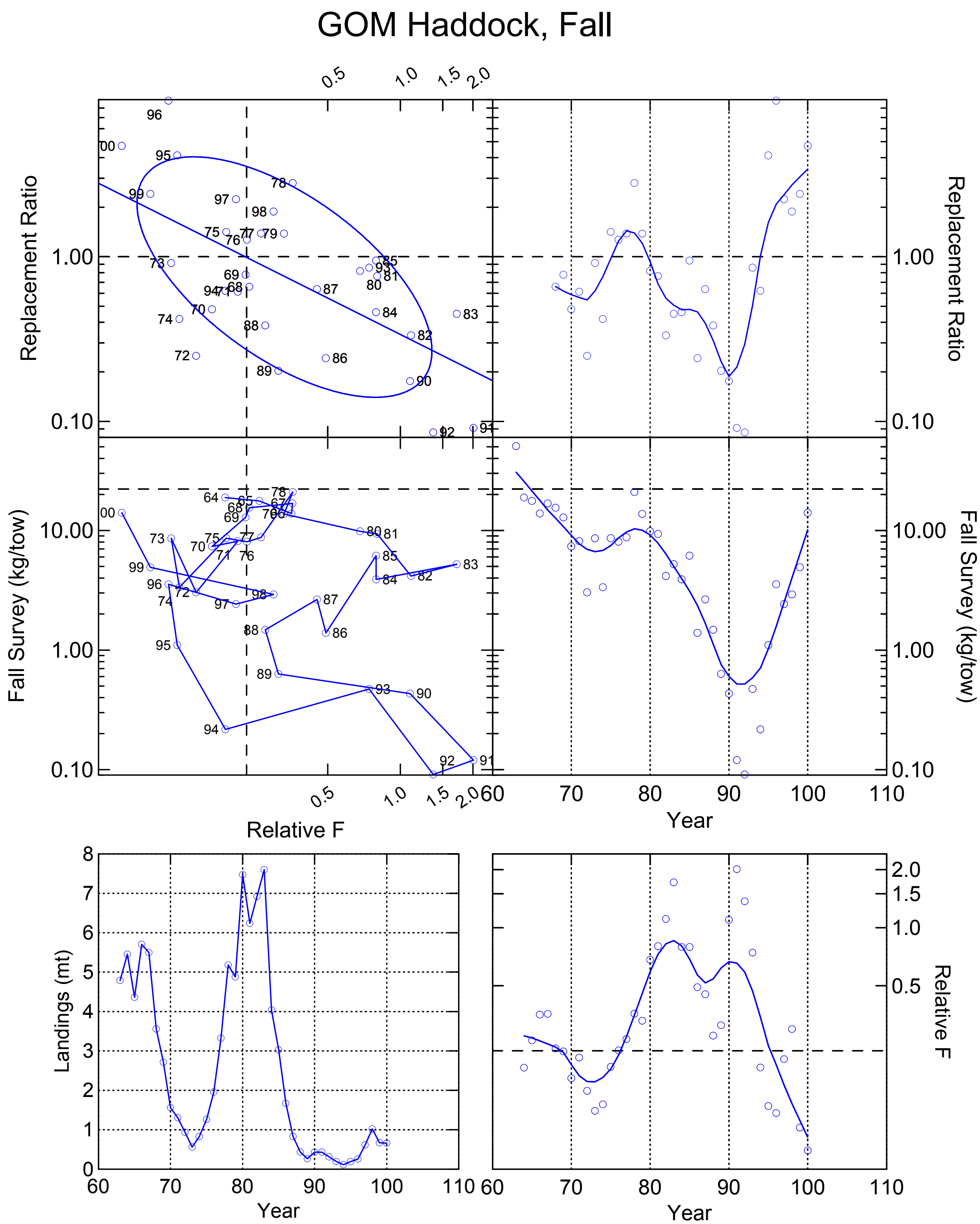


Figure 3.4.2. Trends in relative biomass, landings, fishing rate mortality rate indices (landings/ survey index) and replacement ratios for Gulf of Maine haddock - fall. Dashed lines indicate proposed biomass and fishing mortality rate proxies of Bmsy and Fmsy.

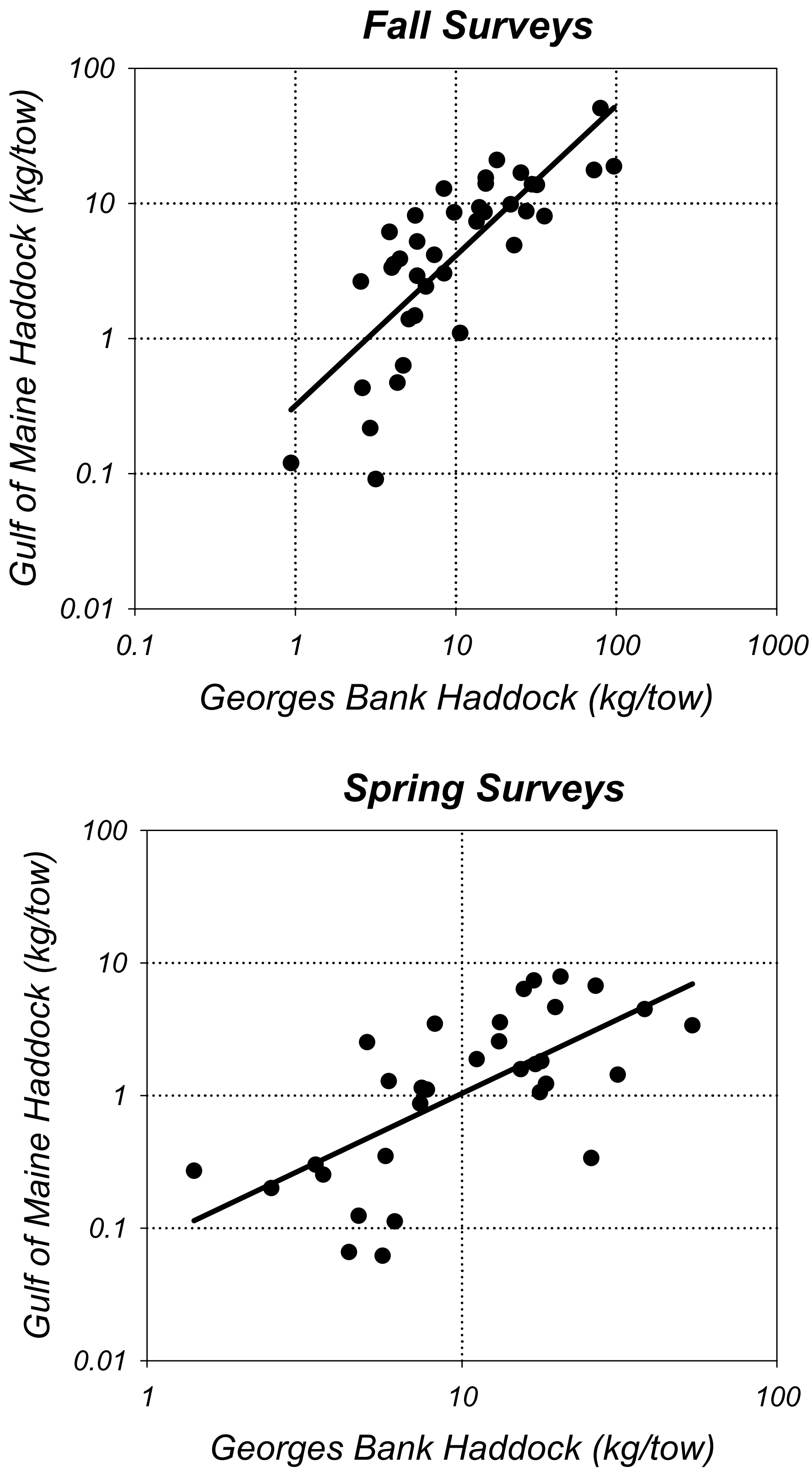


Figure 3.4.3. Relationships between survey abundance indices for Gulf of Maine and Georges Bank haddock in fall and spring surveys. Data are annual weight per tow indices (kg).

3.5 Georges Bank yellowtail

Catch and Survey Indices

Exploitation of Georges Bank yellowtail flounder began in the mid 1930s with catches peaking in the 1960s and early 1970s followed by a decline in the 1980s and early 1990s and an increasing trend over the most recent four years (Figure 3.5.1). Both research survey abundance indices for Georges Bank yellowtail flounder show an overall decline and rebuilding pattern from the 1960s to present (Figure 3.5.1). It is thought that the large catches of the 1960s and 1970s reduced the population abundance so much that the reduced catches in the 1980s were still associated with high fishing mortality rates. Fishing mortality was not reduced until the mid 1990s when strict management regulations were implemented by both the US and Canada. The stock demonstrated a rapid rebuilding and has still appears to be increasing according to the most recent stock assessment.

Stock Assessment

The most recent assessment for Georges Bank yellowtail flounder was reviewed by the Transboundary Resource Assessment Committee (TRAC) in 2001 (Stone et al. 2001). The stock was analyzed with virtual population analysis (VPA), with supporting analysis provided by surplus production modeling. The VPA assessment used data for years 1973 through 2000 and ages 1 through 6+ and was felt to be representative of stock dynamics for the time period. Plots of stock and recruitment estimates from the VPA are provided in Figure 3.5.2. Recruitment has increased with increasing spawning stock size overall, with the most recent year class estimate occurring near the mean of top quartile of spawning stock size. However, the most recent year class is the most poorly estimated in the VPA and may increase or decrease as more catch is taken from the cohort.

Yield and Spawning Stock Biomass per Recruit

The fishing mortality reference points F(0.1) and F40%MSP given in Figure 3.5.2 were calculated for this exercise using ages 1 through 6+ in order to be consistent with the projections described below, and thus may differ slightly from previously reported values (see Table 3.5.2). From the yield per recruit analysis, F(0.1)=0.265 and Fmax=0.8 (both are fully recruited Fs). From the spawning stock biomass per recruit analysis, F40%MSP=0.248 (fully recruited F) with an associated spawning stock biomass per recruit of 1.0925 kg.

Empirical Nonparametric Approach

If F40%MSP is assumed to be an adequate proxy for Fmsy, then the fishing mortality threshold is 0.248. This fishing mortality rate produces 1.093 kg of spawning stock biomass per recruit and 0.2398 kg of yield per recruit (including discards). The strong correlation between the VPA and hindcast stock and recruitment data led to use of hindcast recruitment from the period 1963-1972 in addition to the VPA recruitment data. With this combined dataset, there appears to be two levels of recruitment split at 5,000 mt of spawning biomass. Thus, the arithmetic average of recruitment for spawning biomasses greater than 5,000 mt was used as a proxy for recruitment at maximum sustainable yield; this recruitment is 53.8 million fish. Multiplying this recruitment level by the per recruit biomasses associated with F40%MSP results in a Bmsy proxy of 58,800 mt and an MSY proxy of 12,900 mt assuming that all fish caught are landed.

Parametric Model Approach

Maximum likelihood fits of the 14 parametric stock-recruitment models to the Georges Bank yellowtail flounder data from 1973-1999 are listed below (Table 3.5.1, see Table 2.2.1 for model acronyms). The six hierarchical criteria are applied to each of the models to determine the set of candidate models.

The priors for the Beverton and Holt steepness parameter and Ricker slope parameter from Myers et al (1999) were thought to be insufficient for the yellowtail stocks as the only data sets used to develop the prior were Georges Bank and Southern New England yellowtail stocks. Thus, models PBH, PABH, P2BH, P2ABH, PRK, and PARK are not considered. Criteria 1-4 and 6 are satisfied by all remaining models. The fifth criteria is not satisfied by any of the remaining autoregressive error models. Models BH, PRBH, RK and PRK provided nearly equal statistical fits to the stock-recruitment data. These four models have maximum recruitment levels below 45 million fish, which is within the 90th percentile of the observed recruitment levels. However, examination of hindcast stock and recruitment showed a strong match between the VPA and hindcast values in the years of overlap, with the hindcast stock and recruitment in the year classes prior to the VPA at higher levels on average than the VPA (Figure 3.5.3). This observation led to the creation of a seventh criteria: expected recruitment at high stock sizes is consistent with hindcast recruitment. The recruitment for year classes 1963-1972 was used to generate the prior for unfished recruitment for the PRHCBH and PRHCABH models. Application of the seventh criteria left the PRHCBH model as the only candidate parametric model for Georges Bank yellowtail flounder.

The results of using the PRHCBH model as the best fit parametric model are shown below (Figures 3.5.4-3.5.7). The standardized residual plot of the fit of the PRHCBH model to the stock-recruitment data shows that the standardized residuals generally lie within ± two standard deviations of zero (Figure 3.5.4), with the exception of the 1982 year class.

In the equilibrium yield plot (Figure 3.5.5), the yield surface is relatively flat in the neighborhood of the point estimate of Fmsy=0.32. This estimate of Fmsy is greater than the calculated values for F(0.1) (0.265) and F40%MSP (0.248), which are traditional proxies for Fmsy. This difference is most likely due to the high growth rate, strong resiliency, and current partial recruitment pattern for this stock. For comparison, Fmsy generates approximately 34% of maximum spawning potential. The point estimates of Smsy (63,200 mt) and MSY (17,600 mt) appear consistent with the nonparametric proxy estimate of Smsy, once the hindcast stock and recruitment data are considered, and previous estimates of MSY. The stock-recruitment plot (Figure 3.5.6) shows that expected recruitment values near Smsy are around 68 million fish, which is within the maximum observed range from the VPA data and below the average of the 1963-1972 hindcast recruitments.

Parameter uncertainty plots show histograms of 5000 MCMC sample estimates of MSY, Smsy, and Fmsy drawn from the posterior distribution of the MLE (Figure 3.5.7). For MSY, the 80 percent credibility interval was (16,400, 18,900) with a median of 17,600 mt. For Smsy, the 80 percent credibility level was (57,900, 67,700) with a median of 62,700 mt. For Fmsy, the 80 percent credibility level was (0.285, 0.365) with a median of 0.325. Overall, the point estimates of MSY, Smsy, and Fmsy were nearly identical to the medians of the MCMC samples.

Reference Points

Based on the conformance of the recruitment-biomass per recruit analyses and the parametric stock-recruitment relationship, the following management parameters are considered most appropriate: Bmsy=58,800 mt, Fmsy=0.248 (fully recruited F), and MSY=12,900 mt (including discards). This level of yield is expected by building the stock size through reduced fishing mortality, relative to historical levels that were above 1.0, increased survivorship of young fish relative to the historical use of much smaller mesh size when peak catches were taken, and an expectation that on average recruitment will stay within the range predicted by the most recent stock assessment The median recruitment, stock-recruitment scatterplot, and replacement lines under F=0 and F=0.248 are given in Figure 3.5.8.

Projections

Given that the empirical approach was assumed to provide the most appropriate fit for the stock and recruitment data, projections were conducted assuming two empirical cumulative distribution functions: one for spawning biomasses below 5,000 mt and one for spawning biomasses above 5,000 mt. Since the last year in the VPA was 2000, catch for 2001 was estimated using the US landings from Jan-Nov (7,062 mt), the proportion of US landings in Jan-Nov in 2000 by gear type, the average US discard:landings ratio for 1995-2000 (9.6%), and an estimate of Canadian catch in 2001 (2,890 mt). The 2001 catch estimate is 7,740 mt. For 2002, the fishery was assumed to achieve the target rate of F(0.1), which was calculated as 0.265 (fully recruited F) for these projections. For years 2003 through 2009, the fishery was assumed to fish at a rate of F40%MSP (0.248 fully recruited F). Under these assumptions, there is a 40.4% chance that the spawning biomass in 2009 will be at least as large as Bmsy (Figure 3.5.9). Thus, a rebuilding fishing mortality rate must be calculated. A fishing mortality rate of 0.22 (fully recruited F) gives a 51.4% probability that the spawning biomass in 2009 will be at least as large as Bmsy (Figure 3.5.9). Based on these projections, the median fishing mortality rate in 2001 was 0.185 which can be increased 19% to the Frebuild level of 0.22 and still achieve the rebuilding goal of Bmsy. Under these conditions, the median spawning stock biomass in 2009 will be 59,300 mt with an 80% confidence interval of 42,900 mt to 78,000 mt (Figure 3.5.10). The associated median catch will be 11,600 mt with an 80% confidence interval of 8,500 mt to 15,200 mt (Figure 3.5.11)

Table 3.5.1. Summary of parametric fits for Georges Bank yellowtail flounder.

Georges Bank Yellowtail Flounder

	Prior	Prior	Prior	Prior	Prior	Prior	Prior	Prior	Prior	Prior	Prior	Prior	Prior	Prior
	0	0	0	0	0	0	0	0	0	0	0	0	1	0
	BH	ABH	PBH	PABH	PRBH	PRABH	P2BH	P2ABH	RK	ARK	PRK	PARK	**PRHCBH**	PRHCABH
Posterior Probability	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**1.00**	0.00
Odds Ratio for Most Likely Model													**1.00**	
Normalized Likelihood	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
Model AIC Ratio	0	0	0	0	0	0	0	0	0	0	0	0	1	0

	BH	**ABH**	**PBH**	**PABH**	**PRBH**	**PRABH**	**P2BH**	**P2ABH**	**RK**	**ARK**	**PRK**	**PARK**	**PRHCBH**	**PRHCABH**
Number_of_data_points	27	27	27	27	27	27	27	27	27	27	27	27	27	27
Number_of_parameters	3	4	3	4	3	4	3	4	3	4	3	4	3	4
Fit_negloglikelihood	108.162	105.653	108.249	105.994	108.309	105.669	108.413	105.962	108.388	106.105	108.910	106.94	108.788	106.937
Penalty_steepness	0	0	-1.61707	-1.497	0	0	-1.31856	-1.36112	0	0	0	0	0	0
Penalty_slope	0	0	0	0	0	0	0	0	0	0	1.24421	1.05932	0	0
Penalty_unfished_R	0	0	0	0	2.34124	2.32852	2.38292	2.33588	0	0	0	0	2.14173	2.14266
Negative_loglikelihood	108.162	105.653	106.632	104.497	110.650	107.997	109.478	106.937	108.388	106.105	110.155	108	110.930	109.08
Bias-corrected_AIC	223.368	221.124	223.542	221.806	223.661	221.156	223.870	221.743	223.820	222.028	224.864	223.699	224.619	223.693
Diagnostic Comments	predicted R at high S below mean from hindcast	auto-correlation implies long period forcing	insufficient information for steepness prior	insufficient information for steepness prior	predicted R at high S below mean from hindcast	auto-correlation implies long period forcing	insufficient information for steepness prior	insufficient information for steepness prior	predicted R at high S below mean from hindcast	auto-correlation implies long period forcing	insufficient information for slope prior	insufficient information for slope prior	**model selected**	auto-correlation implies long period forcing
Parameter Point Estimates														
********************************														
MSY	10.10	7.86	11.44	9.69	8.39	8.39	8.34	8.12	9.94	9.14	11.57	9.40	17.55	17.72
FMSY	0.370	0.440	0.345	0.360	0.400	0.425	0.375	0.370	0.640	0.710	0.525	0.505	0.320	0.325
SMSY	31.82	21.18	38.41	31.29	24.63	23.33	25.95	25.58	19.22	16.16	26.63	22.39	63.15	62.86
alpha	47.4957	33.7564	55.9377	46.3317	37.8815	36.6725	38.9316	38.1003	1.56768	1.67495	1.35976	1.32092	90.0315	89.6324
expected_alpha	58.4841	41.7738	68.972	56.9967	46.7517	45.2635	48.1262	47.0907	1.93716	2.07107	1.69432	1.65452	111.96	111.34
beta	7.62838	3.41912	10.4767	7.96709	5.06115	4.1212	6.06283	6.06457	-0.049435	-0.060086	-0.033962	-0.040039	19.84	18.8743
steepness	0.810	0.870827	0.785	0.798832	0.836	0.858682	0.814	0.81096	N/A	N/A	N/A	N/A	0.756	0.764303
R_at_input_SMAX	39.23	30.8432	43.38	37.9741	33.23	32.9243	33.35	32.6333	29.00	21.9529	41.24	31.8355	58.16	58.9148
expected_R_at_input_SMAX	48.30	38.1687	53.49	46.7153	41.02	40.6371	41.22	40.3336	35.83	27.1447	51.39	39.8755	72.32	73.1829
unfished_S	122.10	88.7816	142.31	118.581	98.41	96.0444	100.27	98.0008	52.04	44.5986	69.62	58.0868	226.07	225.944
unfished_R	44.70	32.5046	52.10	43.4148	36.03	35.1637	36.71	35.8799	19.05	16.3284	25.49	21.2667	82.77	82.7222
sigma	0.645162	0.652836	0.647244	0.643688	0.648672	0.648802	0.651184	0.650928	0.650579	0.65159	0.663288	0.67109	0.660282	0.658588
phi	N/A	0.442203	N/A	0.386796	N/A	0.429107	N/A	0.413701	N/A	0.404685	N/A	0.401559	N/A	0.357835
sigmaw	N/A	0.585539	N/A	0.593586	N/A	0.586033	N/A	0.592613	N/A	0.595851	N/A	0.614607	N/A	0.61498
last_residual_R	N/A	3.24529	N/A	-3.39503	N/A	1.24743	N/A	1.69255	N/A	9.01503	N/A	0.566479	N/A	-22.8067
last_logresidual_R	N/A	0.101033	N/A	-0.095793	N/A	0.0376375	N/A	0.0514181	N/A	0.310536	N/A	0.0169164	N/A	-0.516012
expected_lognormal_error_	1.23136	1.23751	1.23301	1.23019	1.23416	1.23426	1.23617	1.23597	1.23569	1.2365	1.24605	1.25255	1.24357	1.24218
prior_mean_steepness	N/A	N/A	0.75	0.75	N/A	N/A	0.75	0.75	N/A	N/A	N/A	N/A	N/A	N/A
prior_se_steepness	N/A	N/A	0.07	0.07	N/A	N/A	0.07	0.07	N/A	N/A	N/A	N/A	N/A	N/A
prior_mean_slope	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.79	0.79	N/A	N/A
prior_se_slope	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.34	0.34	N/A	N/A
prior_mean_unfished_R	N/A	N/A	N/A	N/A	35.35	35.35	35.35	35.35	N/A	N/A	N/A	N/A	82.98	82.98
prior_se_unfished_R	N/A	N/A	N/A	N/A	4.09	4.09	4.09	4.09	N/A	N/A	N/A	N/A	3.39	3.39

Table 3.5.2. Yield and biomass per recruit of Georges Bank yellowtail flounder.

The NEFC Yield and Stock Size per Recruit Program - PDBYPRC
PC Ver.2.0 [Method of Thompson and Bell (1934)] 1-Jan-1999

Run Date: 19- 2-2002; Time: 11:52:02.03
GEORGES BANK YELLOWTAIL FLOUNDER - 2002

Proportion of F before spawning: 0.4167
Proportion of M before spawning: 0.4167
Natural Mortality is Constant at: 0.200
Initial age is: 1; Last age is: 6
Last age is a PLUS group;
Original age-specific PRs, Mats, and Mean Wts from file:
==> C:\groundfish\ypr\gbyt_ypr.dat

Age-specific Input data for Yield per Recruit Analysis

Age	Fish Mort Pattern	Nat Mort Pattern	Proportion Mature	Average Weights Catch	Average Weights Stock
1	0.0060	1.0000	0.0000	0.181	0.181
2	0.3150	1.0000	0.5200	0.349	0.349
3	0.6480	1.0000	0.8600	0.462	0.462
4	1.0000	1.0000	0.9800	0.578	0.578
5	1.0000	1.0000	1.0000	0.710	0.710
6	1.0000	1.0000	1.0000	0.948	0.948

Summary of Yield per Recruit Analysis:

Slope of the Yield/Recruit Curve at F=0.00: -->	2.5847	
F level at slope=1/10 of the above slope (F0.1): ----->		0.265
Yield/Recruit corresponding to F0.1: ----->	0.2444	
F level to produce Maximum Yield/Recruit (Fmax): ----->		0.800
Yield/Recruit corresponding to Fmax: ----->	0.2802	
F level at 40 % of Max Spawning Potential (F40): ----->		0.248
SSB/Recruit corresponding to F40: -------->	1.0925	

1
Listing of Yield per Recruit Results for:

	FMORT	TOTCTHN	TOTCTHW	TOTSTKN	TOTSTKW	SPNSTKN	SPNSTKW	% MSP
	0.00	0.00000	0.00000	5.5167	3.3366	3.6975	2.7314	100.00
	0.10	0.22655	0.15910	4.3893	2.3163	2.5736	1.7285	63.28
	0.20	0.34186	0.22291	3.8178	1.8175	2.0055	1.2441	45.55
F0.1	0.26	0.39118	0.24444	3.5742	1.6120	1.7642	1.0468	38.33
F40%	0.25	0.37959	0.23976	3.6314	1.6597	1.8208	1.0925	40.00
	0.30	0.41255	0.25241	3.4690	1.5251	1.6602	0.9639	35.29
	0.40	0.46084	0.26697	3.2318	1.3346	1.4266	0.7838	28.69
	0.50	0.49627	0.27431	3.0588	1.2012	1.2570	0.6593	24.14
	0.60	0.52359	0.27795	2.9259	1.1030	1.1276	0.5689	20.83
	0.70	0.54548	0.27963	2.8200	1.0278	1.0252	0.5004	18.32
	0.80	0.56351	0.28025	2.7332	0.9684	0.9418	0.4469	16.36
Fmax	0.80	0.56356	0.28025	2.7330	0.9682	0.9416	0.4468	16.36
	0.90	0.57871	0.28028	2.6604	0.9202	0.8723	0.4041	14.79
	1.00	0.59177	0.28001	2.5981	0.8802	0.8134	0.3690	13.51
	1.10	0.60314	0.27958	2.5441	0.8465	0.7626	0.3397	12.44
	1.20	0.61318	0.27907	2.4966	0.8177	0.7183	0.3148	11.53
	1.30	0.62214	0.27853	2.4544	0.7927	0.6793	0.2935	10.75
	1.40	0.63020	0.27799	2.4166	0.7707	0.6445	0.2749	10.07
	1.50	0.63750	0.27747	2.3825	0.7513	0.6134	0.2587	9.47
	1.60	0.64417	0.27696	2.3515	0.7339	0.5853	0.2442	8.94
	1.70	0.65030	0.27647	2.3231	0.7182	0.5597	0.2314	8.47
	1.80	0.65595	0.27601	2.2970	0.7040	0.5364	0.2198	8.05
	1.90	0.66119	0.27557	2.2729	0.6911	0.5150	0.2093	7.66
	2.00	0.66607	0.27515	2.2506	0.6792	0.4952	0.1998	7.32

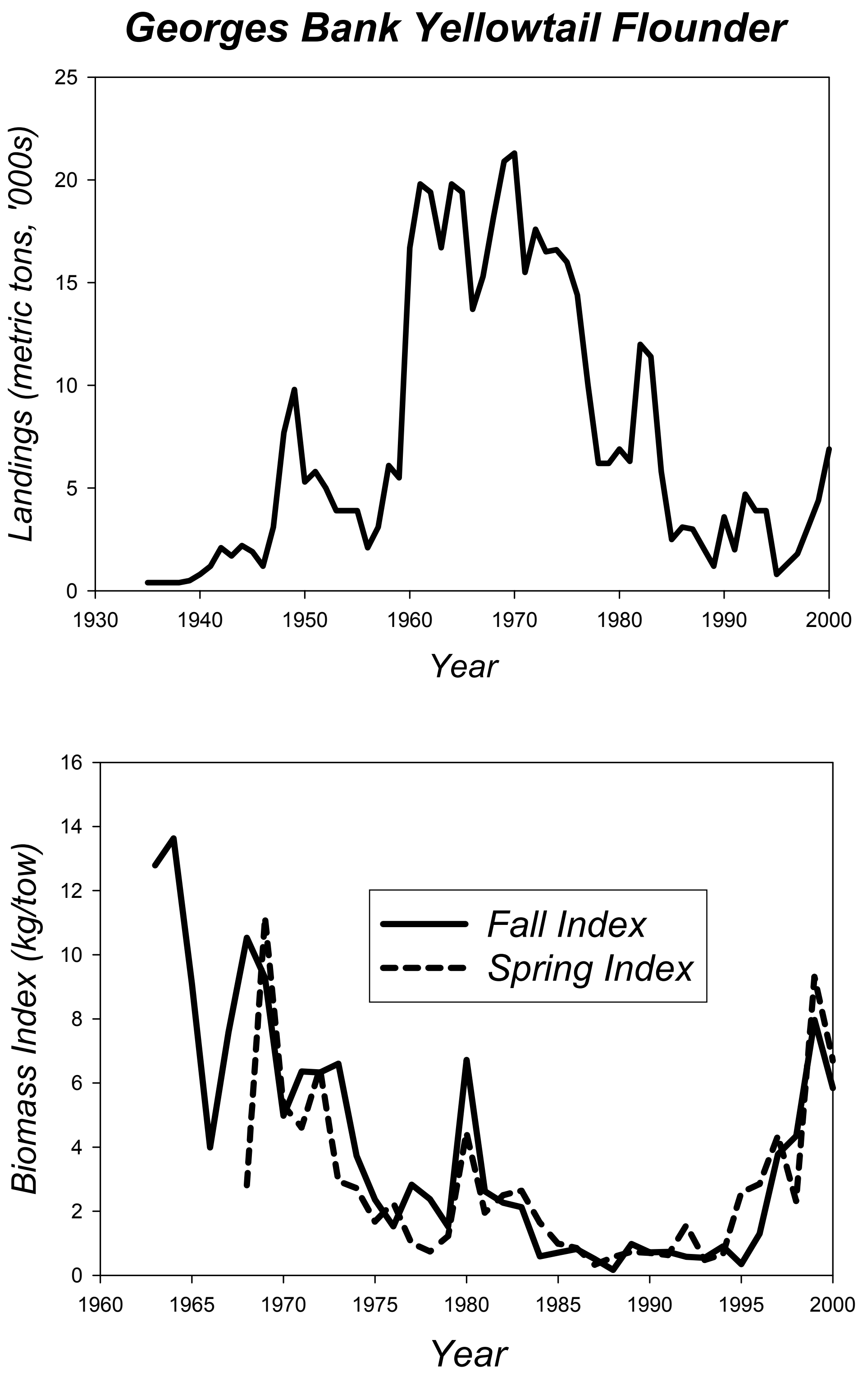
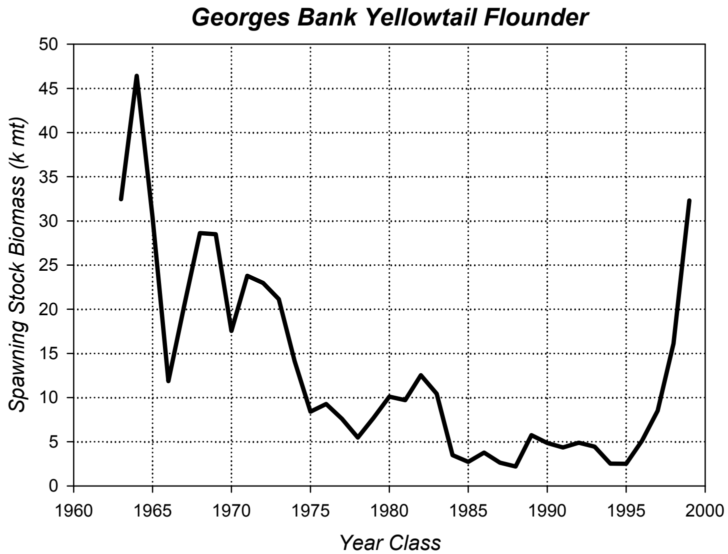
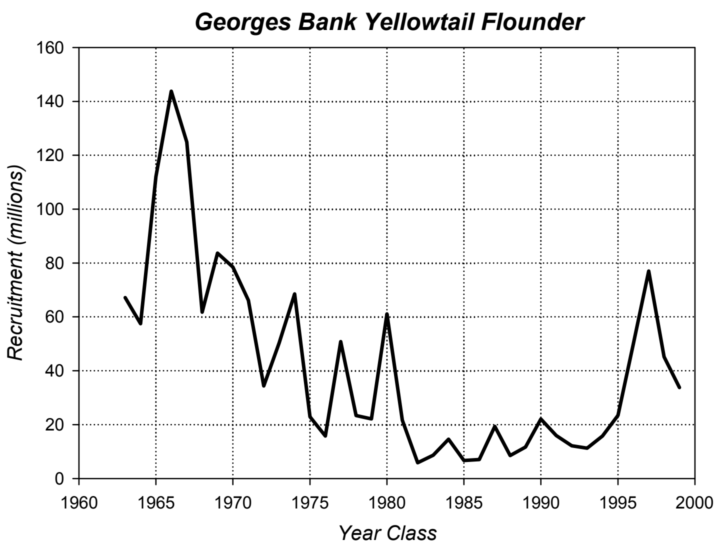


Figure 3.5.1. Landings and research vessel survey abundance indices for Georges Bank yellowtail flounder.

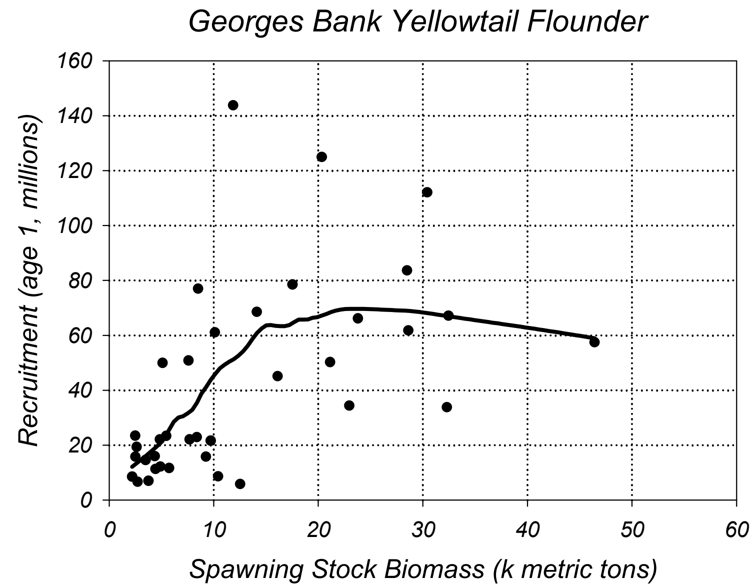
(a)



(b)



(c)



		F0.1	F40%MSP
F reference point		0.265	0.248
ssb per recruit at F		1.047	1.093
	Recruitment (millions)	SS Biomass at F0.1	SS Biomass at F40%
n	37	37	37
mean	42.03	44.00	45.94
min	5.82	6.09	6.36
max	143.75	150.51	157.12
10th %'tile	8.58	8.99	9.38
25th %'tile	15.76	16.50	17.23
50th %'tile	23.44	24.54	25.62
75th %'tile	61.77	64.67	67.51
90th %'tile	80.56	84.35	88.05
Std Dev	34.97	36.62	38.23
CV	0.83	0.87	0.91
For Top Quartile of SSB			
Mean	69.15	72.40	75.58
Median	63.96	66.97	69.91
For SSB>5,000 mt			
Mean	53.78	56.30	58.78
Median	67.93	71.12	74.25

Figure 3.5.2. Spawning stock (a), recruitment (age 1 millions, b), and scatterplot (c) for Georges Bank yellowtail flounder. Data are the calculated spawning stock biomasses for various recruitment scenarios multiplied by the expected SSB per recruit for F0.1 and F40% MSP, assuming recent patterns of growth, maturity and partial recruitment at age (Table 3.5.2). Smoother in the stock-recruitment plot is lowess with tension = 0.5. Year classes from 1963-1972 are hindcast from VPA-fall survey correlations (Figure 3.5.3).

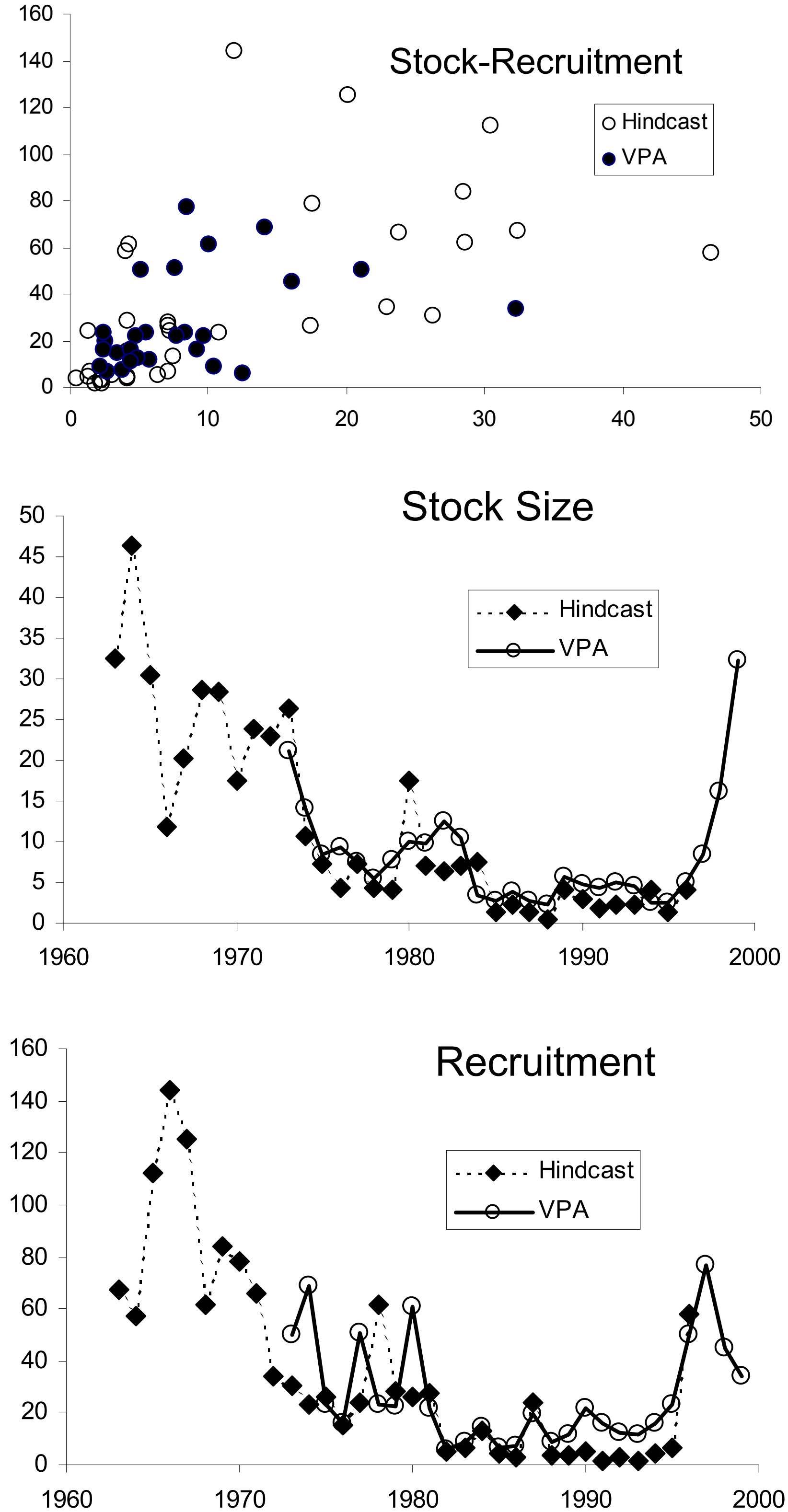


Figure 3.5.3. Comparison of stock and recruitment data from virtual population analysis (VPA) and hindcast for Georges Bank yellowtail flounder.

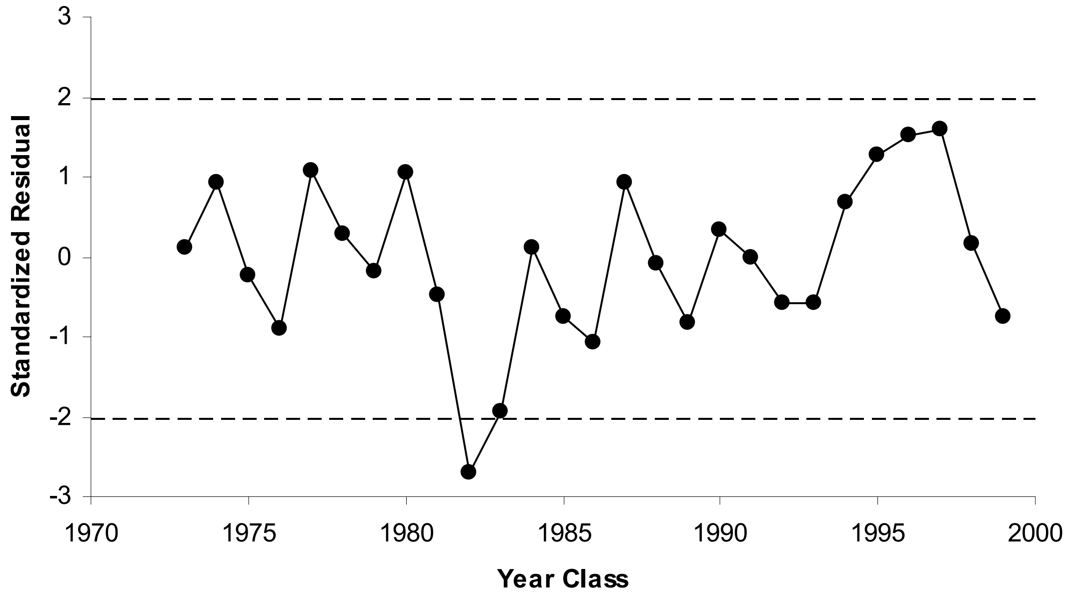


Figure 3.5.4. Standardized residuals from best fit parametric model (PRHCBH) for Georges Bank yellowtail flounder.

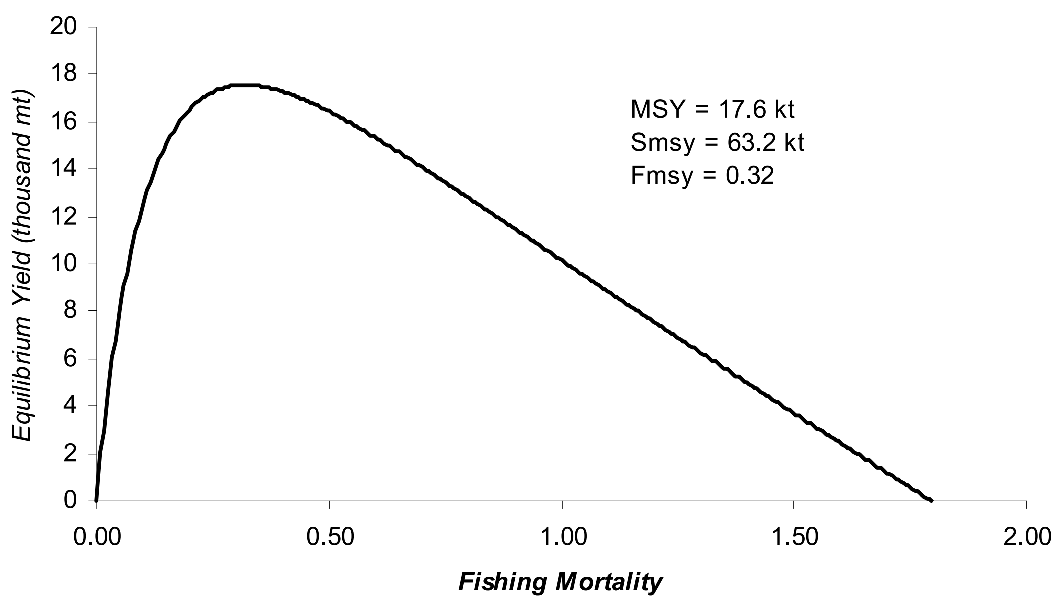


Figure 3.5.5. Equilibrium yield from best fit parametric model (PRHCBH) for Georges Bank yellowtail flounder

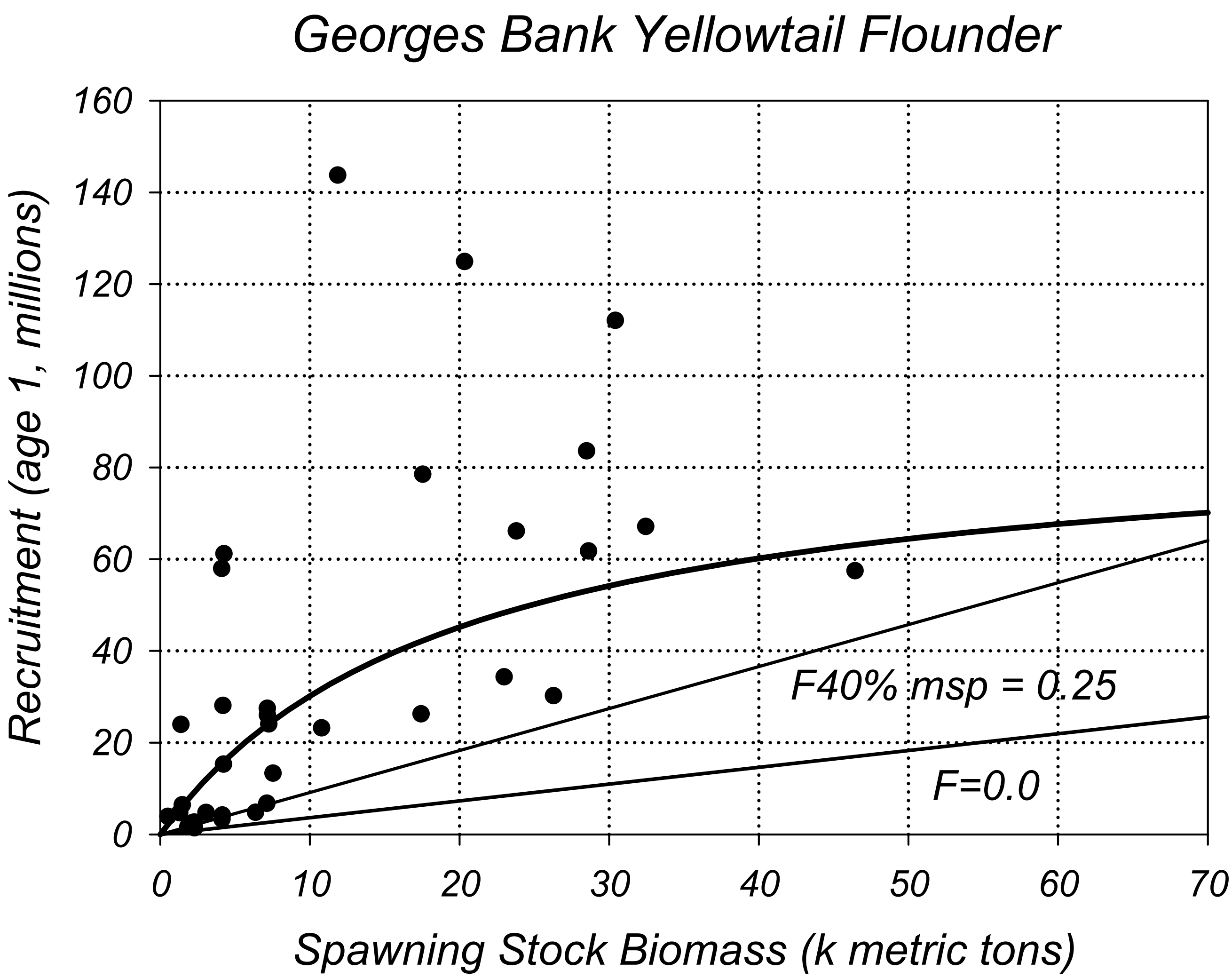


Figure 3.5.6. Stock recruitment relationship for best fit parametric model (PRHCBH) for Georges Bank yellowtail flounder. Hindcast stock-recruitment data points are overplotted, along with the predicted S-R line and replacement lines for F=100% msp=0.00 and F40%msp = 0.25.

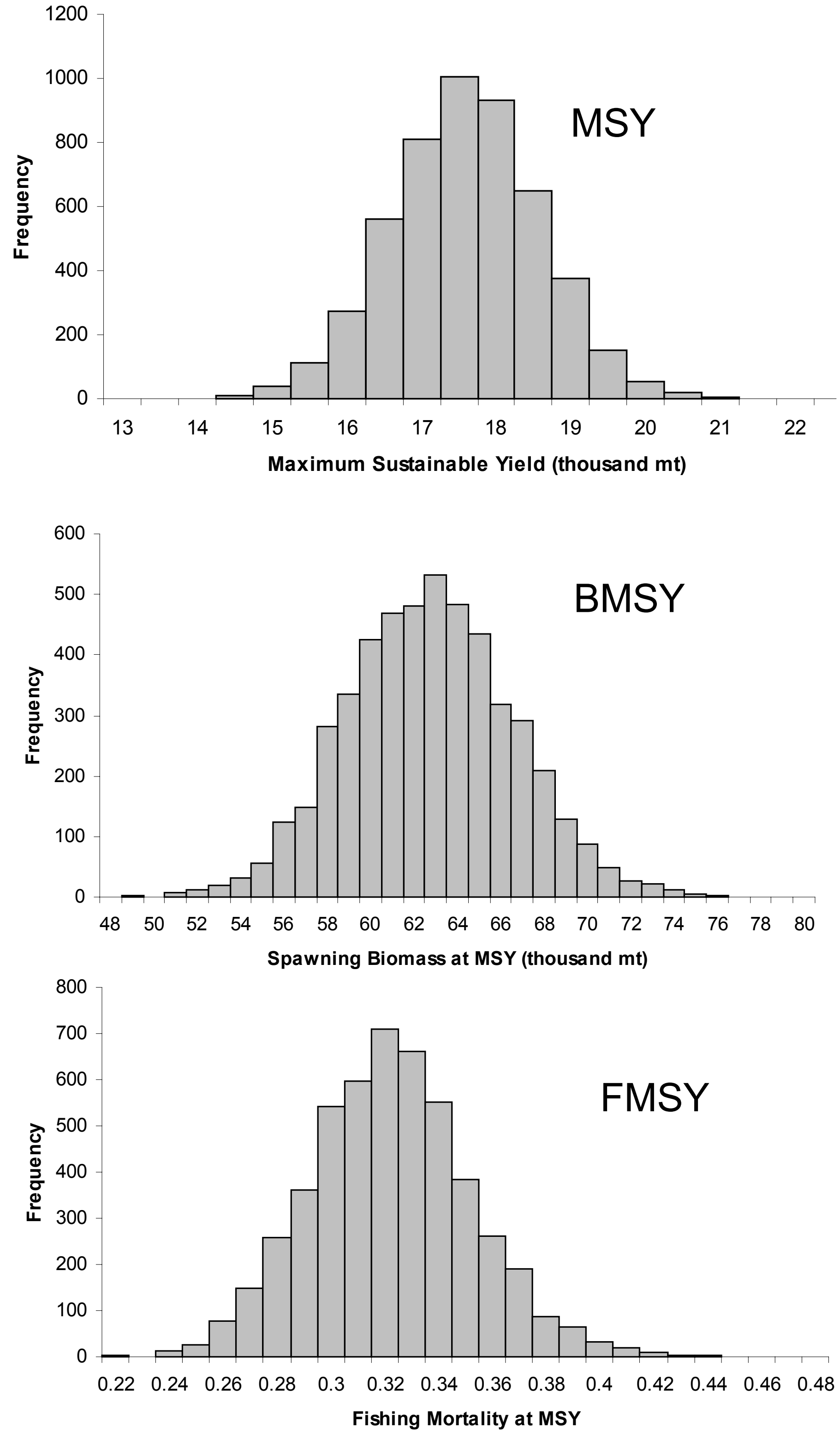


Figure 3.5.7. Histograms of uncertainty in MSY, BMST and FMSY from 5000 MCMC evaluations of best fit parametric model (PRHCBH) for Georges Bank yellowtail flounder.

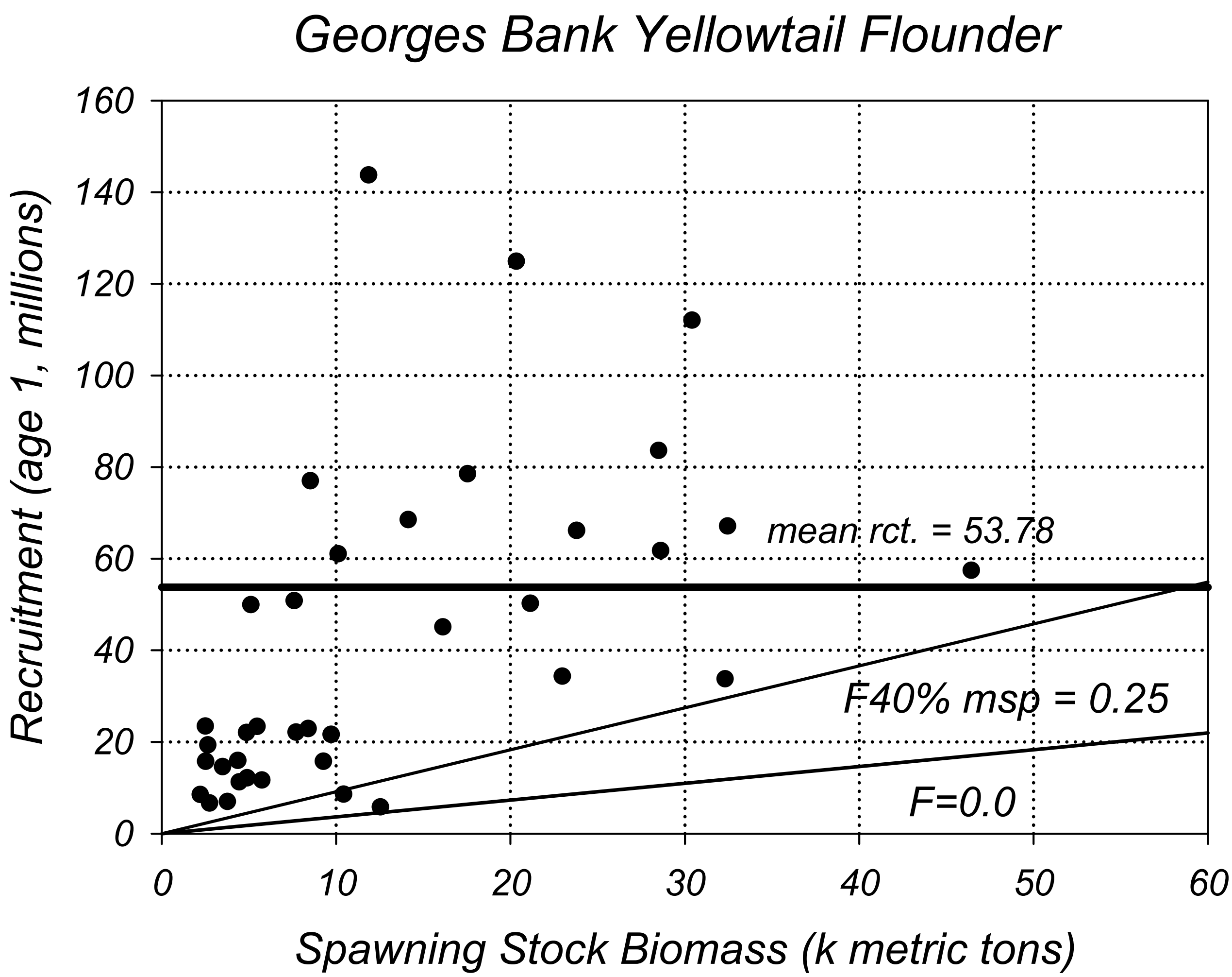


Figure 3.5.8. Stock and recruitment data for Georges Bank yellowtail. For the empirical non-parametric approach the mean recruitment above 5,000 mt of spawning stock biomass is plotted, along with replacement lines for F=0.0 and F 40% msp = 0.248.

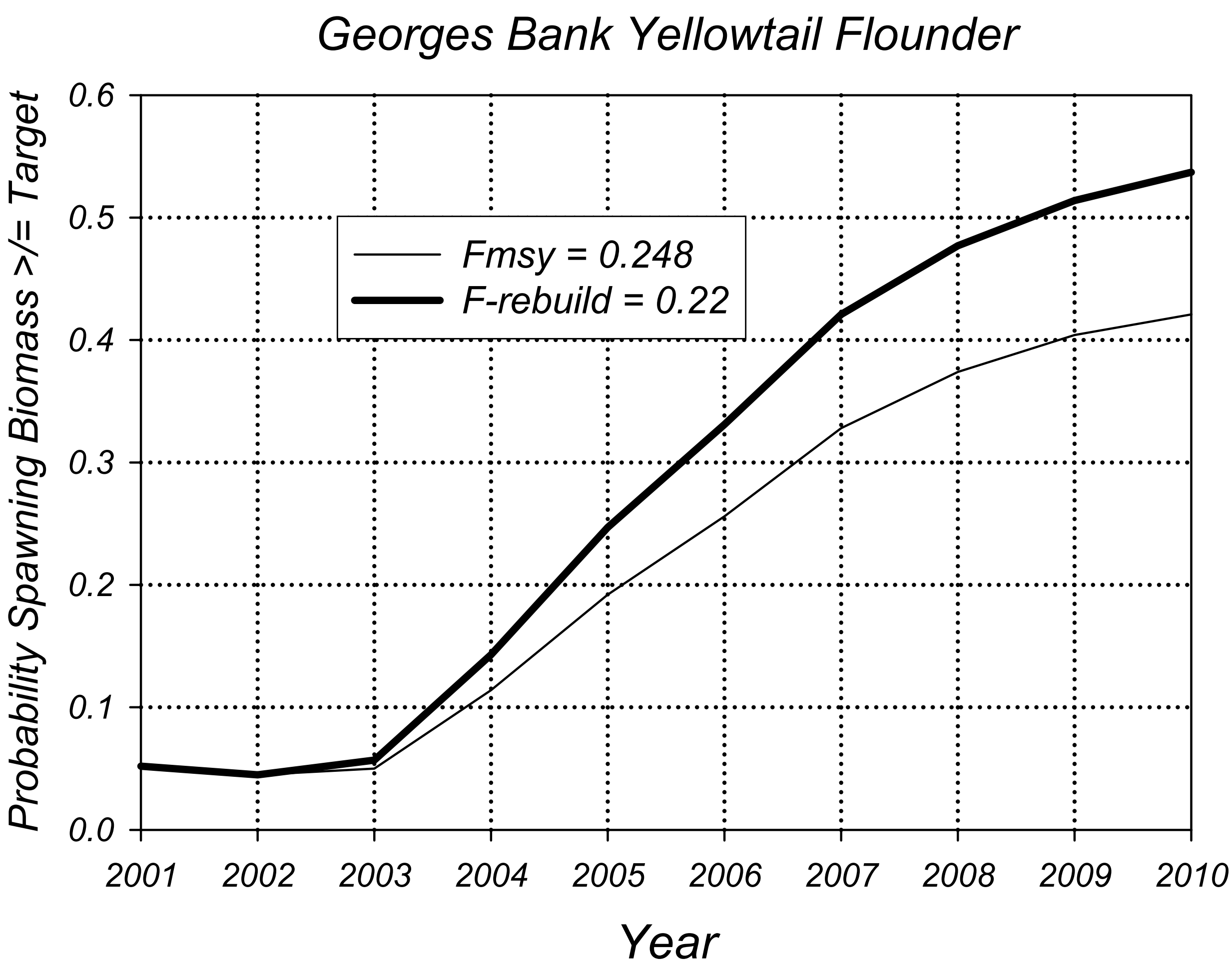


Figure 3.5.9. Probability that Georges Bank yellowtail spawning biomass will exceed Bmsy (58,800 mt) annually under two fishing mortality scenarios: Fmsy and F required to rebuild the stock to Bmsy by 2009.

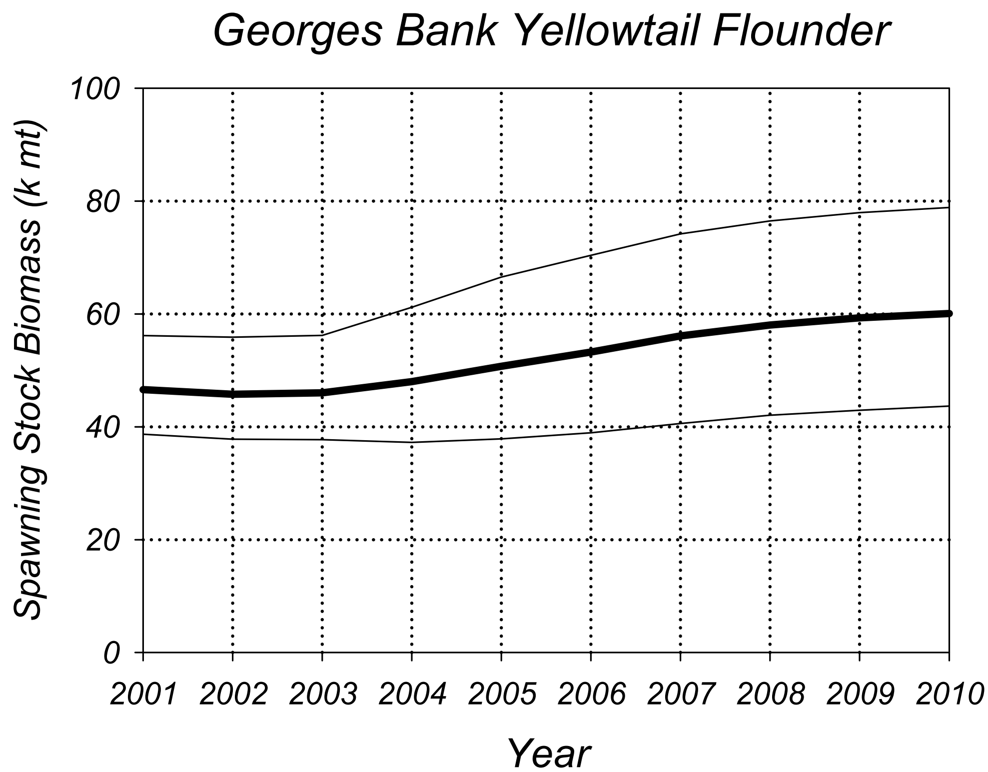


Figure 3.5.10. Median and 80% confidence interval of predicted spawning biomass for Georges Bank yellowtail flounder under F-msy fishing mortality rates.

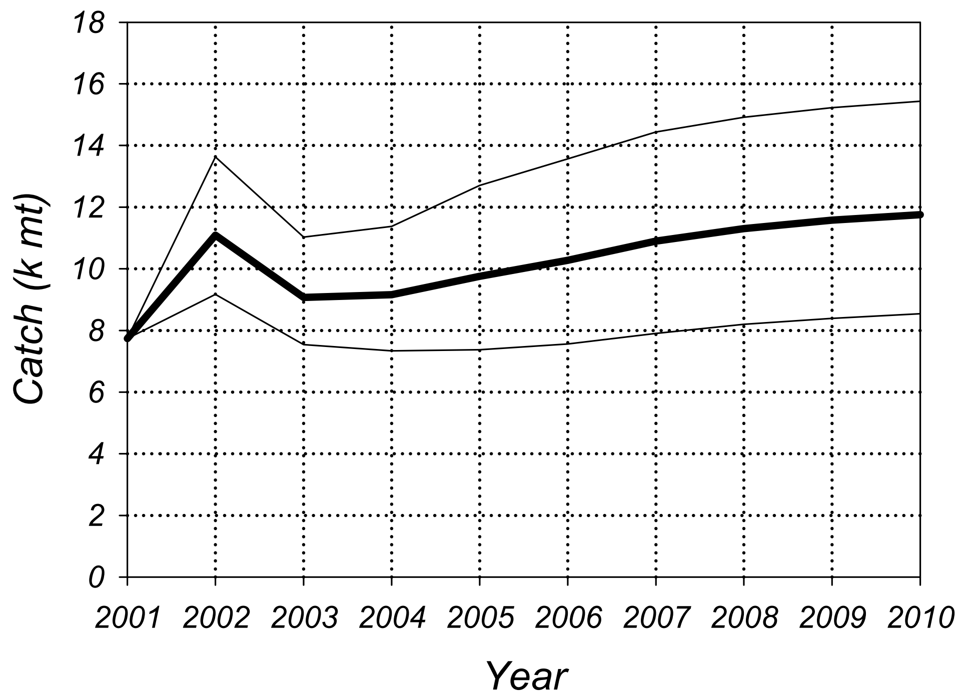


Figure 3.5.11. Median and 80% confidence interval of predicted catch for Georges Bank yellowtail flounder under F-msy fishing mortality rates.

3.6 Southern New England yellowtail flounder

Catch and Survey Indices

Exploitation of Southern New England yellowtail flounder began in the mid 1930s with catches peaking in the 1960s followed by a decline in the 1970s and 1980s and have remained low since 1993 (Figure 3.6.1, Lux 1969b). Both research survey abundance indices for Southern New England yellowtail flounder show a rapid decline in the early 1970s followed by low levels except for two peaks due to large year classes 1980 and 1987 (Figure 3.6.1). It is thought that the large catches of the 1960s reduced the population abundance so much that the reduced catches in the 1980s were still associated with high fishing mortality rates. The stock appears to be increasing at a slow rate according to the most recent stock assessment.

Stock Assessment

The most recent VPA assessment for Southern New England yellowtail flounder was reviewed as part of the 2000 assessment of 11 Northeast groundfish stocks conducted by Northern Demersal Working Group (NEFSC 2000). The stock was analyzed with virtual population analysis (VPA), with supporting analysis provided by surplus production modeling. The VPA assessment used data for years 1973 through 1998 and ages 1 through 7+ and was felt to be representative of stock dynamics for the time period. Plots of stock and recruitment estimates from the VPA are provided in Figure 3.6.2. Recruitment has increased somewhat with increasing spawning stock size overall, however the recruitment series is dominated by two large events, the 1980 and 1987 year classes.

Yield and Spawning Stock Biomass per Recruit

The fishing mortality reference points F(0.1) and F40%MSP given in Figure 3.6.2 were calculated for this exercise using ages 1 through 7+ in order to be consistent with the projections described below, and thus may differ slightly from previously reported values (Table 3.6.2). From the yield per recruit analysis, F(0.1)=0.242 and Fmax=1.5 (both are fully recruited Fs). From the spawning stock biomass per recruit analysis, F40%MSP=0.269 (fully recruited F) with an associated spawning stock biomass per recruit of 1.1095 kg.

Empirical Nonparametric Approach

If F40%MSP is assumed to be an adequate proxy for Fmsy, then the fishing mortality threshold is 0.269. This fishing mortality rate produces 1.1095 kg of spawning stock biomass per recruit and 0.2215 kg of yield per recruit (including discards). The strong correlation between the VPA and hindcast stock and recruitment data led to use of hindcast recruitment from the period 1963-1972 in addition to the VPA recruitment data. With this combined dataset, there did not appear to be a relationship between spawning stock size and recruitment. Thus, the mean of the entire time series is assumed to be representative of recruitment levels expected at maximum sustainable yield; this recruitment level is 40.7 million fish. Multiplying this recruitment level by the per recruit biomasses associated with F40%MSP results in a Bmsy proxy of 45,200 mt and an MSY proxy of 9,000 mt assuming that all fish caught are landed.

Parametric Model Approach

Maximum likelihood fits of the 24 parametric stock-recruitment models to the Southern New England yellowtail flounder data from 1973-1999 are listed below (Table 3.6.1, see Table 2.1.2 for model acronyms). The six hierarchical criteria are applied to each of the models to determine the set of candidate models.

The priors for the Beverton and Holt steepness parameter and Ricker slope parameter from Myers et al (1999) were thought to be insufficient for the yellowtail stocks as the only data sets used to develop the prior were Georges Bank and Southern New England yellowtail stocks. Thus, models PBH, PABH, P2BH, P2ABH, P2HCBH, P2HCABH, PRK, PARK, P2RK, P2ARK, P2HCRK, and P2HCARK are not considered. Of the remaining models, the first criterion is not satisfied for models ABH and PRABH, due to steepness being estimated at its boundary condition of 1.0. The fifth criteria is not satisfied by any of the remaining autoregressive error models. Models RK and PRRK are also not considered due to estimated Smsy values below historical catches of 20,00 mt. Models BH and PRBH have maximum recruitment levels below the mean of the VPA recruitment data (26 million fish) and well below the mean of the hindcast 1963-1972 recruitment data (77 million fish; Figure 3.6.4), so are not considered.

Given the two candidate models (PRHCBH and PRHCRK), the AIC criterion assigns the greatest probability to the PRHCBH model. The odds ratio of PRHCBH being true to PRHCRK being true is over 4:1. Thus, there is a clear basis for choosing between these two parametric models for Southern New England yellowtail flounder.

The results of using the PRHCBH model as the best fit parametric model are shown below (Figures 3.6.5-3.6.8). The standardized residual plot of the fit of the PRHCBH model to the stock-recruitment data shows that the standardized residuals generally lie within ± two standard deviations of zero (Figure 3.6.4), with the exception of the 1987 year class.

In the equilibrium yield plot (Figure 3.6.6), the yield surface is relatively flat in the neighborhood of the point estimate of Fmsy=0.320. This estimate of Fmsy is greater than the calculated values for F(0.1) (0.242) and F40%MSP (0.269), which are traditional proxies for Fmsy. This difference is most likely due to the high growth rate, strong resiliency, and current partial recruitment pattern for this stock. For comparison, Fmsy generates approximately 36% of maximum spawning potential. The point estimates of Smsy (64,200 mt) and MSY (14,800 mt) appear consistent with the nonparametric proxy estimate of Smsy, once the hindcast stock and recruitment data are considered, and previous estimates of MSY. The stock-recruitment plot (Figure 3.6.7) shows that expected recruitment values near Smsy are around 65 million fish, which is within the maximum observed range from the VPA data and below the average of the 1963-1972 hindcast recruitments.

Parameter uncertainty plots show histograms of 5000 MCMC sample estimates of MSY, Smsy, and Fmsy drawn from the posterior distribution of the MLE (Figure 3.6.8). For MSY, the 80 percent credibility interval was (12,900, 16,400) with a median of 14,700 mt. For Smsy, the 80 percent credibility level was (55,900, 71,000) with a median of 63,300 mt. For Fmsy, the 80 percent credibility level was (0.260, 0.400) with a median of 0.330. Overall, the point estimates of MSY, Smsy and Fmsy were nearly identical to the medians of the MCMC samples.

Reference Points

Based on the conformance of the recruitment-biomass per recruit analyses and the parametric stock-recruitment relationship, the following management parameters are considered most appropriate: Bmsy=45,200 mt, Fmsy=0.269 (fully recruited F), and MSY=9,000 mt (including discards). This level of yield is expected by building the stock size through reduced fishing mortality, relative to historical levels that were above 1.0, increased survivorship of young fish relative to the historical use of much smaller mesh size when peak catches were taken, and an expectation that on average recruitment will stay within the range predicted by the most recent stock assessment. The median recruitment, stock-recruitment scatterplot, and replacement lines under F=0 and F=0.269 are given in Figure 3.5.9.

Projections

No projections were considered to truly represent the potential rebuilding rate of this stock due to the recent history of low recruitment during the past ten years. The largest recruitment in this period was 16.4 million fish, which under no fishing would only produce 45,500 mt of spawning biomass in equilibrium. Thus, until recruitment increases from this recent history, rebuilding is not expected to occur.

Table 3.6.1. Summary of parametric fits for Southern New England yellowtail flounder.

Southern New England Yellowtail Flounder

	Prior	Prior	Prior	Prior	Prior	Prior	Prior	Prior	Prior	Prior	Prior	Prior
	0	0	0	0	0	0	0	0	1	0	0	0
	BH	ABH	PBH	PABH	PRBH	PRABH	P2BH	P2ABH	**PRHCBH**	PRHCABH	P2HCBH	P2HCABH
Posterior Probability	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.80**	0.00	0.00	0.00
Odds Ratio for Most									**1.00**			
Normalized Likelihood	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.803	0.000	0.000	0.000
Model AIC Ratio	0	0	0	0	0	0	0	0	4.077565	0	0	0
	BH	**ABH**	**PBH**	**PABH**	**PRBH**	**PRABH**	**P2BH**	**P2ABH**	**PRHCBH**	**PRHCABH**	**P2HCBH**	**P2HCABH**
Number_of_data_points	25	25	25	25	25	25	25	25	25	25	25	25
Number_of_parameters	3	4	3	4	3	4	3	4	3	4	3	4
Fit_negloglikelihood	102.372	96.679	102.653	98.2818	102.605	96.8514	103.002	98.2964	104.158	100.641	104.158	100.737
Penalty_steepness	0	0	-1.51557	-1.3962	0	0	-1.33299	-1.39452	0	0	-1.73985	-1.70931
Penalty_slope	0	0	0	0	0	0	0	0	0	0	0	0
Penalty_unfished_R	0	0	0	0	2.07324	2.04498	2.12351	2.02848	2.57088	2.57576	2.57064	2.57106
Negative_loglikelihood	102.372	96.679	101.137	96.8856	104.678	98.8964	103.793	98.9303	106.729	103.217	104.989	101.599
Bias-corrected_AIC	211.887	203.359	212.448	206.564	212.353	203.703	213.147	206.593	215.458	211.283	215.460	211.474
Diagnostic Comments	predicted R at high S below mean from VPA	steepness at boundry of 1	insufficient information for steepness prior	insufficient information for steepness prior	predicted R at high S below mean from VPA	steepness near boundry of 1	insufficient information for steepness prior	insufficient information for steepness prior	**model selected**	auto-correlation implies long period forcing	insufficient information for steepness prior	insufficient information for steepness prior
Parameter Point Estimates *******************************												
MSY	5.116	2.975	5.778	3.089	4.002	4.079	3.849	3.530	14.767	15.838	14.742	14.987
FMSY	0.415	0.740	0.360	0.370	0.445	0.700	0.375	0.370	0.320	0.385	0.320	0.335
SMSY	18.21	7.11	22.91	11.99	13.53	10.10	14.79	13.70	64.20	59.64	64.09	62.84
alpha	24.9821	12.1636	30.4655	16.0301	18.9398	16.8273	19.8265	18.3126	83.1063	80.454	83.1844	82.5691
expected_alpha	46.685	25.5137	57.7461	31.5299	35.8123	35.5559	38.2677	35.1647	170.955	171.921	171.122	169.108
beta	2.99261	0.0016858	5.38337	2.64026	1.84024	0.0936947	3.15866	3.01346	18.8216	11.9751	19.0081	17.352
steepness	0.853	1.000	0.797	0.808	0.877	0.992	0.813	0.808	0.754	0.823	0.752	0.767
R_at_input_SMAX	23.87	12.16	28.12	15.40	18.41	16.80	18.90	17.49	64.31	67.84	64.23	65.04
expected_R_at_input_SMAX	44.61	25.51	53.29	30.29	34.82	35.50	36.48	33.59	132.29	144.97	132.12	133.22
unfished_S	66.30	33.74	79.12	41.82	50.70	46.58	51.84	47.78	211.70	211.19	211.73	211.68
unfished_R	23.90	12.16	28.52	15.08	18.28	16.79	18.69	17.23	76.32	76.14	76.33	76.31
sigma	1.11827	1.21718	1.13089	1.16316	1.12874	1.22319	1.14681	1.14232	1.20107	1.23235	1.20109	1.19742
phi	N/A	0.691706	N/A	0.587218	N/A	0.690169	N/A	0.564674	N/A	0.541224	N/A	0.49319
sigmaw	N/A	0.879023	N/A	0.941494	N/A	0.885163	N/A	0.942776	N/A	1.03626	N/A	1.04166
last_residual_R	N/A	-4.51754	N/A	1.36882	N/A	-8.3114	N/A	1.04412	N/A	-2.33657	N/A	0.290101
last_logresidual_R	N/A	-0.464844	N/A	0.197604	N/A	-0.736558	N/A	0.147077	N/A	-0.267026	N/A	0.0387421
expected_lognormal_error_	1.86874	2.09754	1.89546	1.96692	1.89085	2.11299	1.93013	1.92024	2.05706	2.13688	2.05713	2.04808
prior_mean_steepness	N/A	N/A	0.75	0.75	N/A	N/A	0.75	0.75	N/A	N/A	0.75	0.75
prior_se_steepness	N/A	N/A	0.07	0.07	N/A	N/A	0.07	0.07	N/A	N/A	0.07	0.07
prior_mean_slope	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
prior_se_slope	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
prior_mean_unfished_R	N/A	N/A	N/A	N/A	17.36	17.36	17.36	17.36	76.94	76.94	76.94	76.94
prior_se_unfished_R	N/A	N/A	N/A	N/A	3.03	3.03	3.03	3.03	5.18	5.18	5.18	5.18

Table 3.6.1. (continued) Summary of parametric fits for Southern New England yellowtail flounder.

Southern New England Yellowtail Flounder

	Prior	Prior	Prior	Prior	Prior	Prior	Prior	Prior	Prior	Prior	Prior	Prior
	0	0	0	0	0	0	0	0	1	0	0	0
	RK	ARK	PRK	PARK	PRRK	PRARK	P2RK	P2ARK	**PRHCRK**	PRHCARK	P2HCRK	P2HCARK
Posterior Probability	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.20**	0.00	0.00	0.00
Odds Ratio for Most Likely Model									**4.08**			
Normalized Likelihood	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.197	0.000	0.000	0.000
Model AIC Ratio	0	0	0	0	0	0	0	0	1	0	0	0

	RK	**ARK**	**PRK**	**PARK**	**PRRK**	**PRARK**	**P2RK**	**P2ARK**	**PRHCRK**	**PRHCARK**	**P2HCRK**	**P2HCARK**
Number_of_data_points	25	25	25	25	25	25	25	25	25	25	25	25
Number_of_parameters	3	4	3	4	3	4	3	4	3	4	3	4
Fit_negloglikelihood	101.207	97.191	102.737	98.8742	102.685	99.1561	103.539	100.24	105.563	102.301	105.713	102.452
Penalty_steepness	0	0	0	0	0	0	0	0	0	0	0	0
Penalty_slope	0	0	1.2304	0.190776	0	0	0.736879	0.248412	0	0	0.0853812	-0.072571
Penalty_unfished_R	0	0	0	0	2.24219	2.3225	2.05584	2.10177	2.56489	2.56491	2.56434	2.56443
Negative_loglikelihood	101.207	97.191	103.967	99.065	104.927	101.479	106.332	102.59	108.128	104.865	108.363	104.943
Bias-corrected_AIC	209.558	204.382	212.617	207.748	212.513	208.312	214.222	210.479	218.269	214.601	218.569	214.903
Diagnostic Comments	Smsy less than historical catch	auto-correlation implies long period forcing	insufficient information for slope prior	insufficient information for slope prior	Smsy less than historical catch	auto-correlation implies long period forcing	insufficient information for slope prior	insufficient information for slope prior		auto-correlation implies long period forcing	insufficient information for slope prior	insufficient information for slope prior
Parameter Point Estimates *******************************												
MSY	5.167	4.936	4.702	2.240	7.171	7.569	6.305	5.575	27.731	27.686	25.236	23.624
FMSY	1.390	1.590	0.595	0.440	0.785	0.935	0.525	0.450	0.485	0.485	0.420	0.380
SMSY	8.50	7.53	12.96	7.63	16.52	15.67	18.94	18.69	88.09	87.94	89.01	89.85
alpha	1.94408	2.01712	1.35695	1.07473	1.58107	1.70706	1.24533	1.09724	1.17225	1.16978	1.02812	0.932069
expected_alpha	3.4364	3.53262	2.58319	2.53485	3.00184	3.22082	2.47408	2.23624	2.6275	2.60716	2.327	2.12669
beta	-	-0.135617	-0.074083	-0.114385	-0.060997	-0.065405	-4.91E-02	-0.047144	-1.03E-02	-0.010295	-9.62E-03	-0.009171
steepness	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
R_at_input_SMAX	0.19	0.08	2.12	0.12	6.16	5.26	9.48	9.27	107.09	106.90	96.90	90.61
expected_R_at_input_SMAX	0.34	0.14	4.03	0.28	11.69	9.92	18.83	18.88	240.02	238.26	219.32	206.75
unfished_S	24.57	22.40	32.09	18.32	42.65	41.70	46.15	44.91	212.73	212.73	212.92	212.89
unfished_R	8.86	8.07	11.57	6.60	15.37	15.03	16.64	16.19	76.69	76.69	76.76	76.75
sigma	1.06737	1.05865	1.13471	1.31001	1.13236	1.12682	1.17172	1.19332	1.27052	1.26606	1.27816	1.28446
phi	N/A	0.521656	N/A	0.680215	N/A	0.49713	N/A	0.518425	N/A	0.482133	N/A	0.495733
sigmaw	N/A	0.903193	N/A	0.960255	N/A	0.977718	N/A	1.02043	N/A	1.10919	N/A	1.11552
last_residual_R	N/A	-2.48565	N/A	3.54602	N/A	-0.725116	N/A	2.94852	N/A	2.27151	N/A	3.39797
last_logresidual_R	N/A	-0.281867	N/A	0.62456	N/A	-0.090741	N/A	0.488144	N/A	0.353184	N/A	0.588985
expected_lognormal_error_	1.76762	1.75132	1.90368	2.35859	1.89861	1.88677	1.98668	2.03807	2.24142	2.22877	2.26334	2.28169
prior_mean_steepness	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
prior_se_steepness	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
prior_mean_slope	N/A	N/A	0.79	0.79	N/A	N/A	0.79	0.79	N/A	N/A	0.79	0.79
prior_se_slope	N/A	N/A	0.34	0.34	N/A	N/A	0.34	0.34	N/A	N/A	0.34	0.34
prior_mean_unfished_R	N/A	N/A	N/A	N/A	17.36	17.36	17.36	17.36	76.94	76.94	76.94	76.94
prior_se_unfished_R	N/A	N/A	N/A	N/A	3.03	3.03	3.03	3.03	5.18	5.18	5.18	5.18

Table 3.6.2. Yields and biomass per recruit of Southern New England yellowtail flounder

The NEFC Yield and Stock Size per Recruit Program - PDBYPRC
PC Ver.2.0 [Method of Thompson and Bell (1934)] 1-Jan-1999

Run Date: 27- 2-2002; Time: 11:03:34.61
SNE YELLOWTAIL FLOUNDER - 2002

Proportion of F before spawning: 0.4167
Proportion of M before spawning: 0.4167
Natural Mortality is Constant at: 0.200
Initial age is: 1; Last age is: 7
Last age is a PLUS group;
Original age-specific PRs, Mats, and Mean Wts from file:
==> C:\groundfish\ypr\snyt_ypr.dat

Age-specific Input data for Yield per Recruit Analysis

Age	Fish Mort Pattern	Nat Mort Pattern	Proportion Mature	Average Weights Catch	Average Weights Stock
1	0.0100	1.0000	0.1300	0.130	0.130
2	0.1200	1.0000	0.7400	0.318	0.318
3	0.5300	1.0000	0.9800	0.398	0.398
4	1.0000	1.0000	1.0000	0.473	0.473
5	1.0000	1.0000	1.0000	0.636	0.636
6	1.0000	1.0000	1.0000	0.785	0.785
7	1.0000	1.0000	1.0000	1.029	1.029

Summary of Yield per Recruit Analysis:

Slope of the Yield/Recruit Curve at F=0.00: --> 2.4632
F level at slope=1/10 of the above slope (F0.1): -----> 0.242
Yield/Recruit corresponding to F0.1: -----> 0.2155
F level to produce Maximum Yield/Recruit (Fmax): -----> 1.500
Yield/Recruit corresponding to Fmax: -----> 0.2423
F level at 40 % of Max Spawning Potential (F40): -----> 0.269
SSB/Recruit corresponding to F40: --------> 1.1095

1
Listing of Yield per Recruit Results for:

	FMORT	TOTCTHN	TOTCTHW	TOTSTKN	TOTSTKW	SPNSTKN	SPNSTKW	% MSP
	0.00	0.00000	0.00000	5.5167	3.2011	4.0669	2.7739	100.00
	0.10	0.21199	0.14794	4.4618	2.1891	3.0065	1.7792	64.14
	0.20	0.31949	0.20335	3.9290	1.7041	2.4686	1.3074	47.13
F0.1	0.24	0.35009	0.21547	3.7779	1.5721	2.3154	1.1799	42.54
F40%	0.27	0.36742	0.22148	3.6925	1.4990	2.2287	1.1095	40.00
	0.30	0.38515	0.22695	3.6052	1.4255	2.1400	1.0389	37.45
	0.40	0.42984	0.23748	3.3860	1.2476	1.9163	0.8688	31.32
	0.50	0.46250	0.24215	3.2265	1.1254	1.7529	0.7527	27.14
	0.60	0.48763	0.24405	3.1046	1.0370	1.6273	0.6690	24.12
	0.70	0.50770	0.24464	3.0077	0.9702	1.5270	0.6060	21.85
	0.80	0.52421	0.24461	2.9284	0.9182	1.4445	0.5569	20.08
	0.90	0.53811	0.24433	2.8619	0.8764	1.3752	0.5176	18.66
	1.00	0.55004	0.24394	2.8051	0.8421	1.3158	0.4853	17.50
	1.10	0.56045	0.24355	2.7558	0.8135	1.2641	0.4582	16.52
	1.20	0.56964	0.24319	2.7124	0.7890	1.2185	0.4351	15.69
	1.30	0.57784	0.24286	2.6738	0.7679	1.1779	0.4152	14.97
	1.40	0.58524	0.24258	2.6391	0.7494	1.1414	0.3976	14.34
	1.50	0.59197	0.24234	2.6076	0.7331	1.1082	0.3821	13.78
Fmax	1.50	0.59200	0.24234	2.6075	0.7330	1.1081	0.3821	13.77
	1.60	0.59813	0.24214	2.5789	0.7184	1.0780	0.3683	13.28
	1.70	0.60380	0.24197	2.5525	0.7052	1.0502	0.3557	12.82
	1.80	0.60906	0.24182	2.5281	0.6933	1.0245	0.3444	12.41
	1.90	0.61395	0.24170	2.5054	0.6823	1.0007	0.3340	12.04
	2.00	0.61853	0.24159	2.4842	0.6722	0.9785	0.3244	11.69

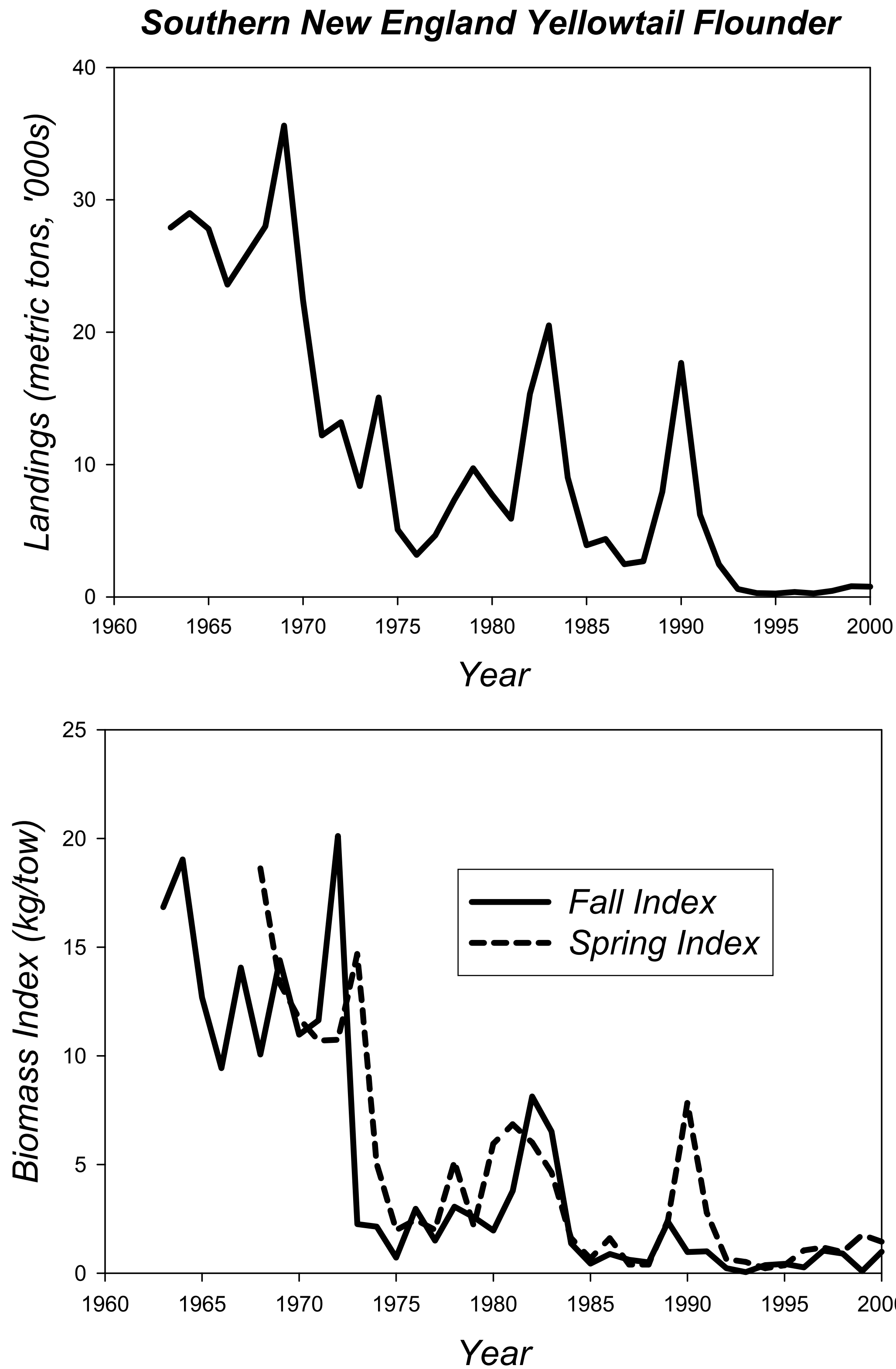
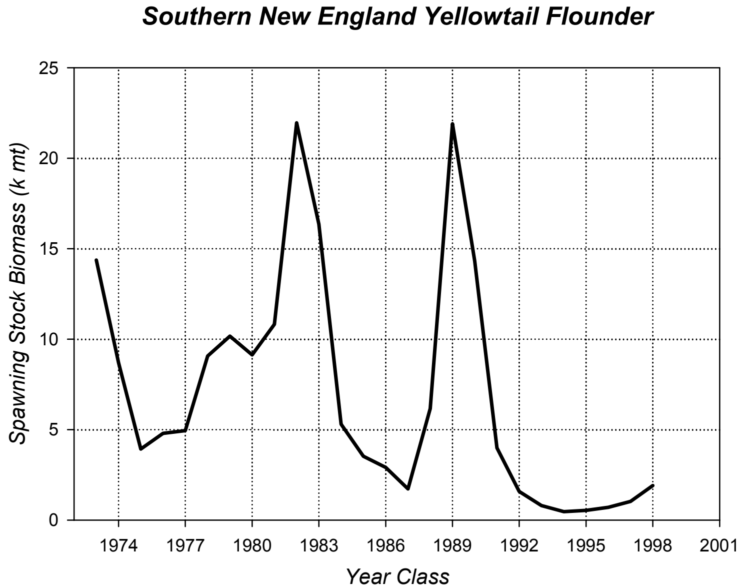
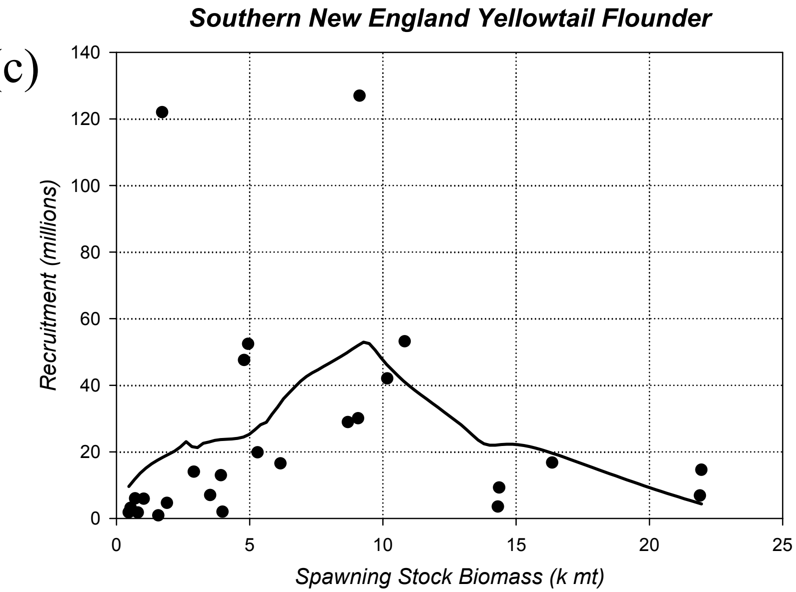


Figure 3.6.1. Landings and research vessel survey abundance indices for Southern New England yellowtail flounder.

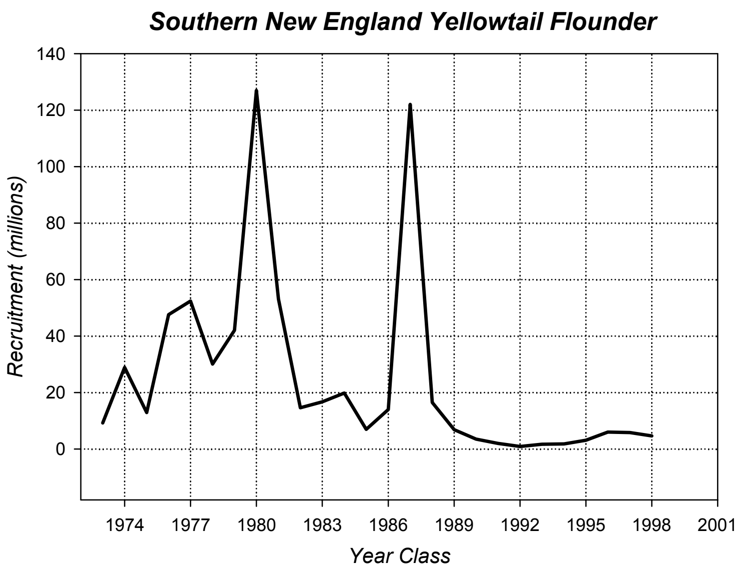
(a)



(c)



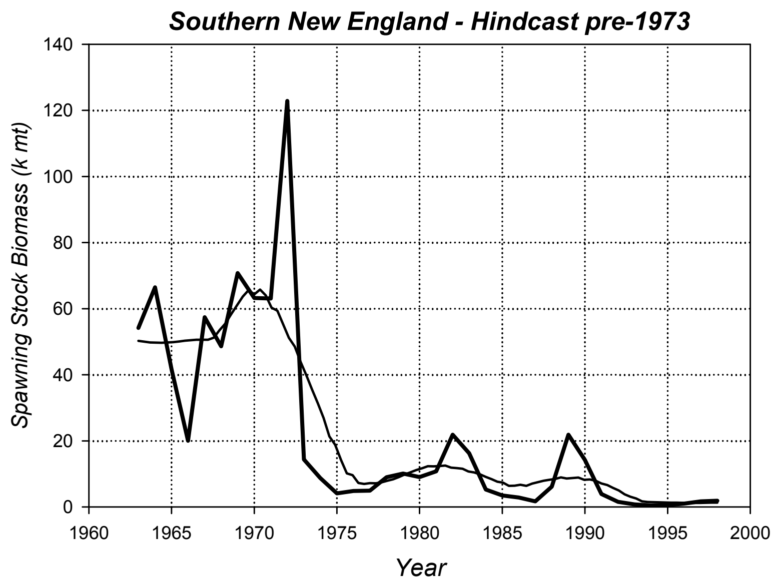
(b)



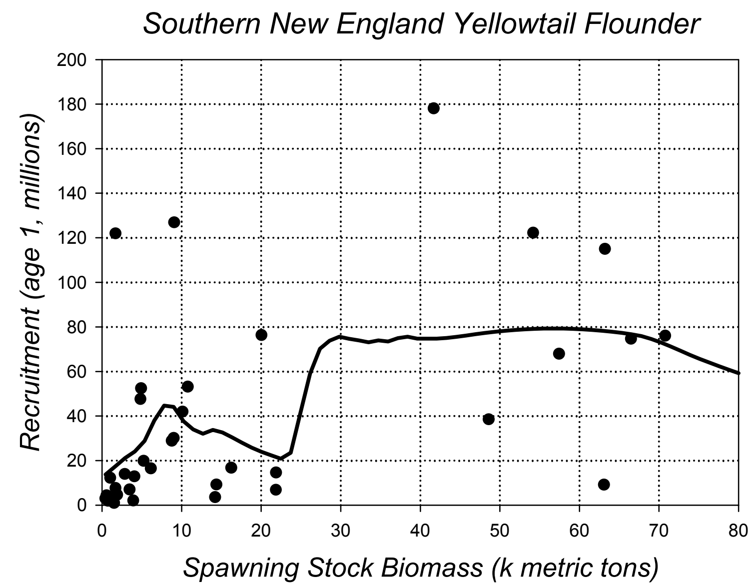
		F0.1	F40% MSP
F reference point		0.242	0.269
ssb per recruit at F		1.1799	1.1095
	Recruitment (millions)	SS Biomass at F0.1	SS Biomass at F40%
n	26	26	26
mean	25.01	29.51	27.75
min	0.88	1.04	0.98
max	126.93	149.77	140.83
10th %'tile	1.89	2.23	2.10
25th %'tile	4.94	5.83	5.49
50th %'tile	13.46	15.89	14.94
75th %'tile	29.78	35.14	33.05
90th %'tile	52.78	62.28	58.56
Std Dev	33.41	39.42	37.07
CV	1.34	1.34	1.34
For Top Quartile of SSB			
Mean	20.88	24.63	23.16
Median	14.61	17.24	16.21

Figure 3.6.2. Spawning stock (a), recruitment (age 1 millions, b), and scatterplot (c) for Southern New England yellowtail flounder. Data are the calculated spawning stock biomasses for various recruitment scenarios multiplied by the expected SSB per recruit for F0.1 and F40% MSP, assuming recent patterns of growth, maturity and partial recruitment at age (Table 3.6.2). Smoother in the stock-recruitment plot is lowess with tension = 0.5.

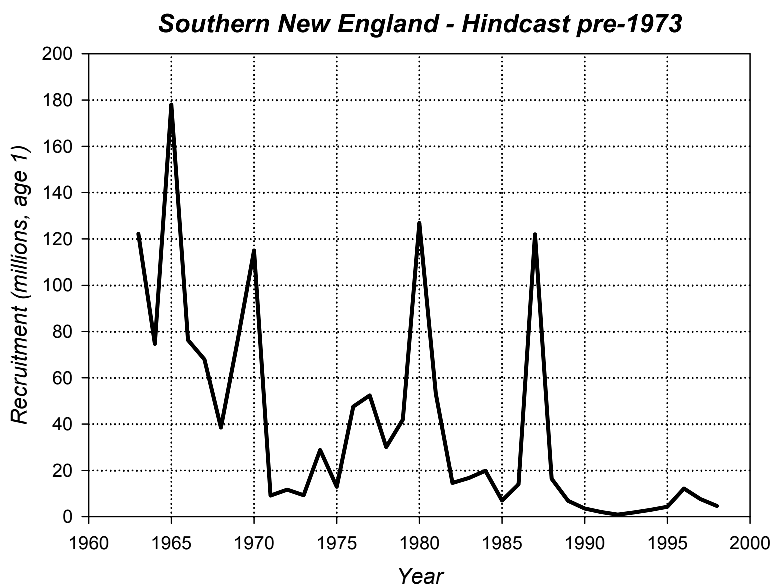
(a)



(c)



(b)



		F0.1	F40%MSP
F reference point		0.242	0.269
ssb per recruit at F		1.1799	1.1095
	Recruitment (millions)	SS Biomass at F0.1	SS Biomass at F40%
n	35	35	35
mean	40.72	48.05	45.18
min	0.91	1.07	1.01
max	178.05	210.08	197.55
10th %'tile	3.21	3.78	3.56
25th %'tile	8.36	9.86	9.28
50th %'tile	16.73	19.74	18.56
75th %'tile	60.53	71.42	67.16
90th %'tile	119.20	140.64	132.25
Std Dev	45.24	53.38	50.19
CV	1.11	1.31	1.23
For Top Quartile of SSB			
Mean	77.01	90.87	85.45
Median	74.66	88.09	82.84
For Hindcast Recruitment			
Mean	76.94	90.78	85.37

Figure 3.6.3. Spawning stock (a), recruitment (age 1 millions, b), and scatterplot (c) for Southern New England yellowtail flounder using hindcasts data prior to 1973. Data are the calculated spawning stock biomasses for various recruitment scenarios multiplied by the expected SSB per recruit for F0.1 and F40% MSP, assuming recent patterns of growth, maturity and partial recruitment at age (Table 3.6.2). Smoother in the stock- recruitment plot is lowess with tension = 0.5. Smoother for the spawning stock biomass plot (a) is 0.3.

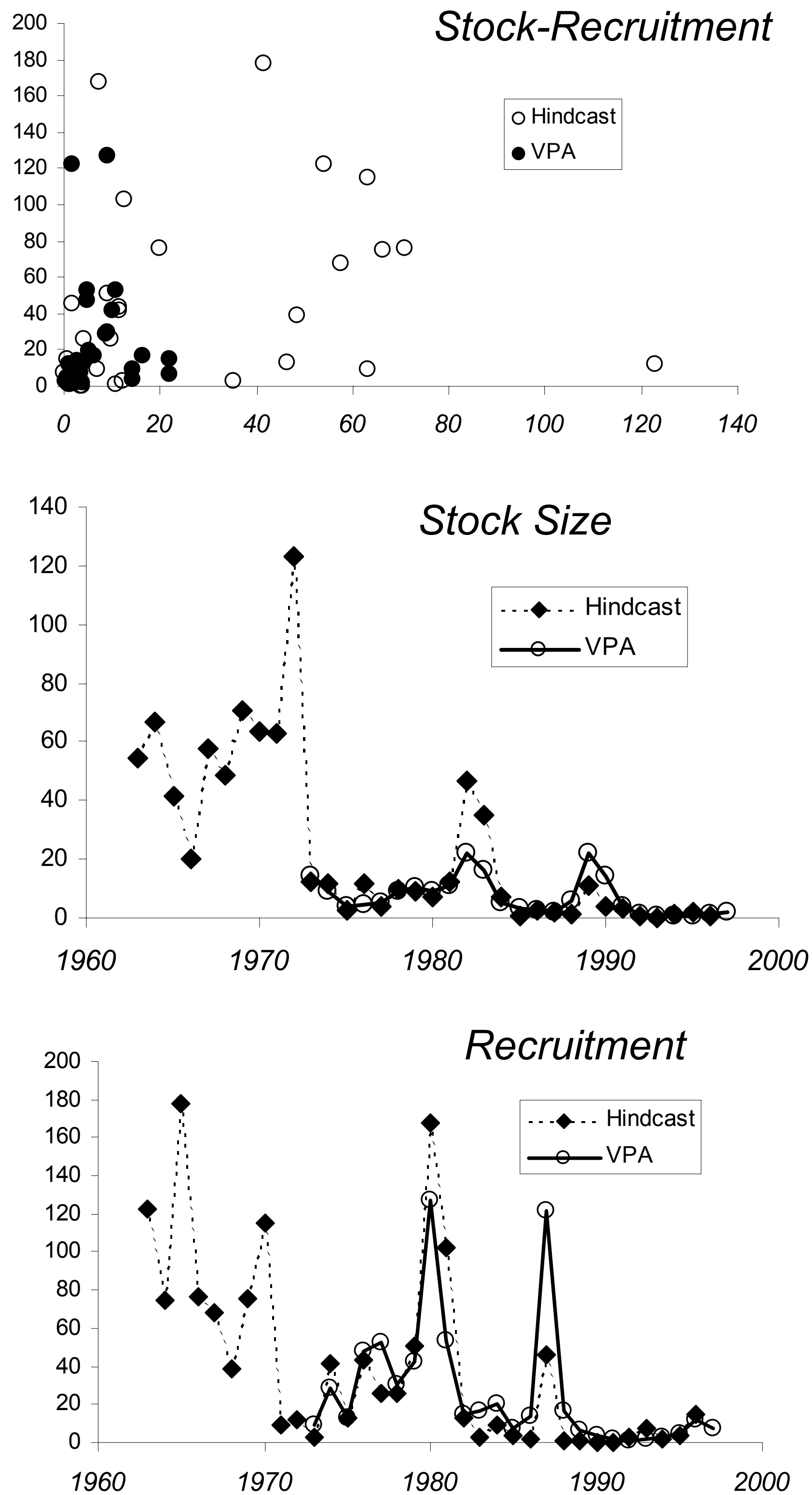


Figure 3.6.4. Comparison of stock and recruitment data from virtual population analysis (VPA) and hindcast for Southern New England yellowtail flounder.

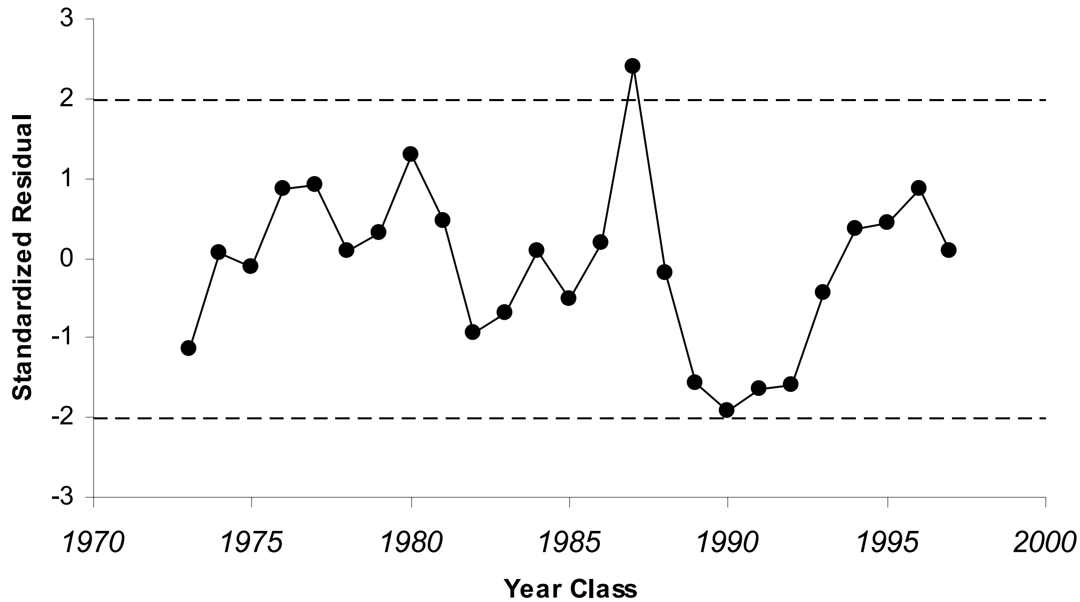


Figure 3.6.5. Standardized residuals from best fit parametric model for Southern New England yellowtail flounder

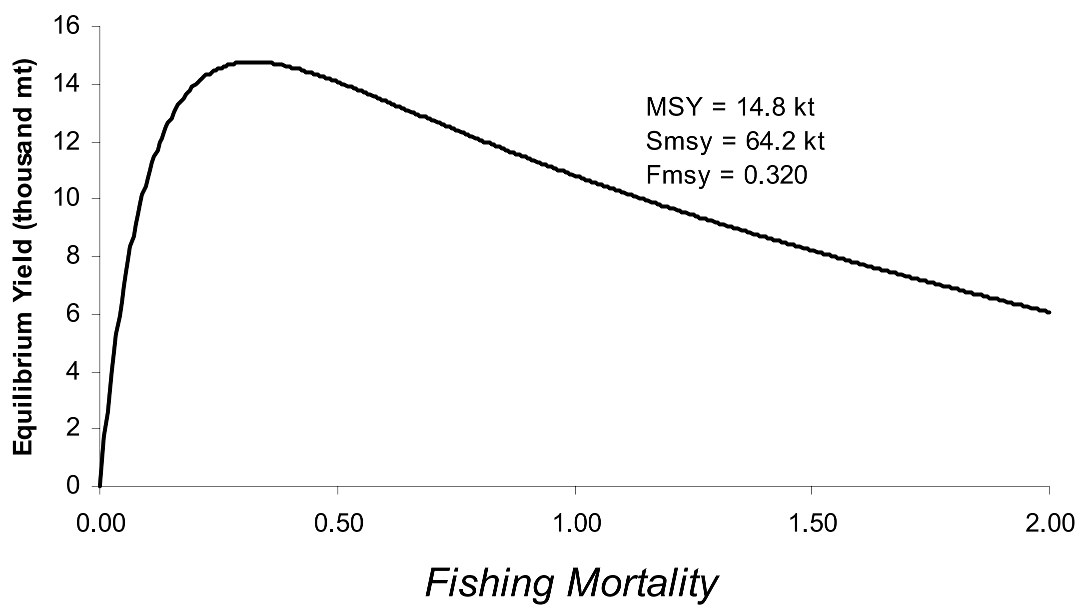


Figure 3.6.6. Equilibrium yield from best fit parametric model for Southern New England yellowtail flounder.

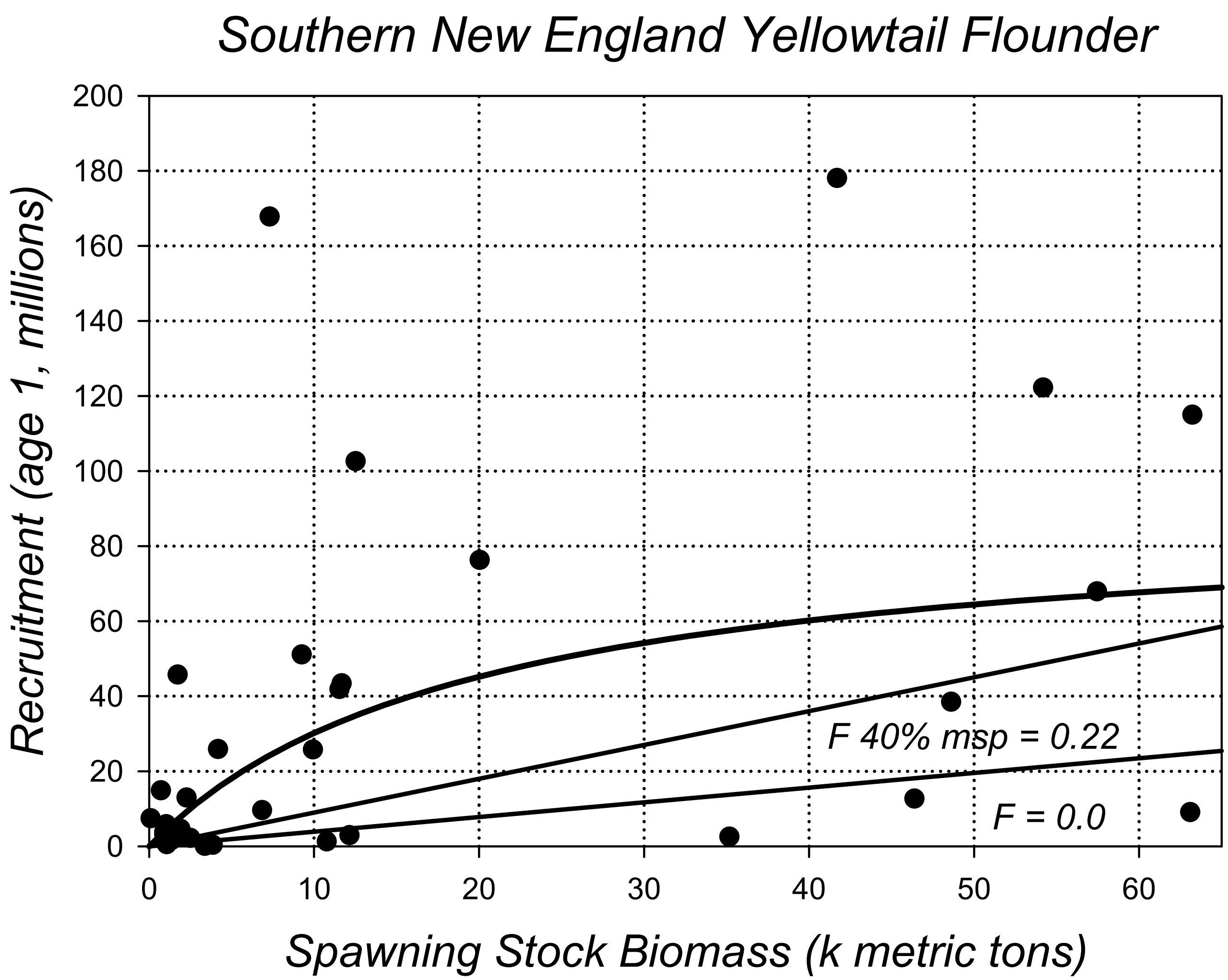


Figure 3.6.7. Stock recruitment relationship for best fit parametric model for Southern New England yellowtail flounder. Hindcast stock-recruitment data points are overplotted, along with the predicted S-R line and replacement lines for F=100% msp=0.0 and F40% msp=0.22.

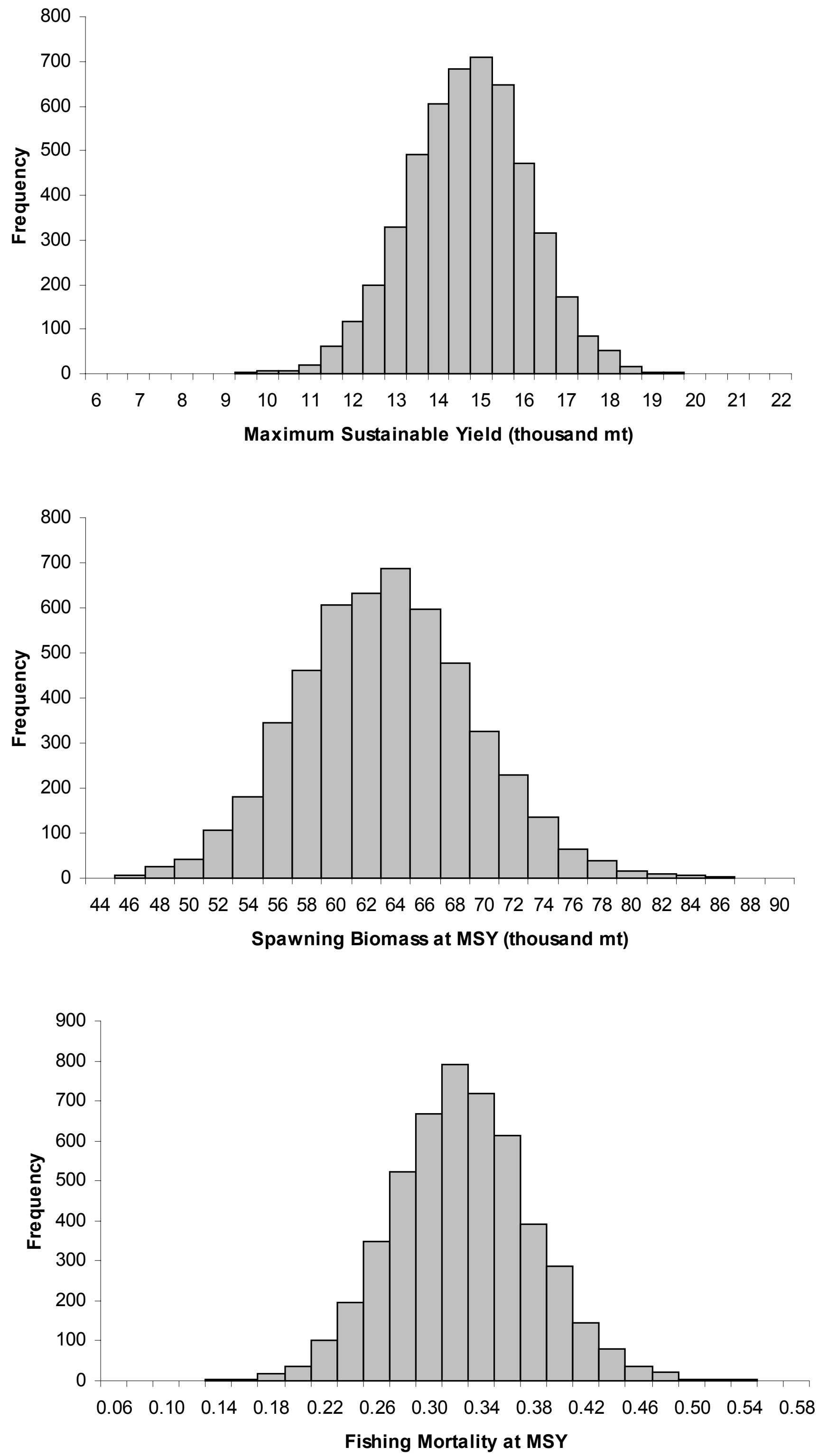


Figure 3.6.8. Histograms of uncertainty in MSY, Bmsy, and Fmsy from 5000 MCMC evaluations of best fit parametric stock-recruitment model for Southern New England yellowtail flounder.

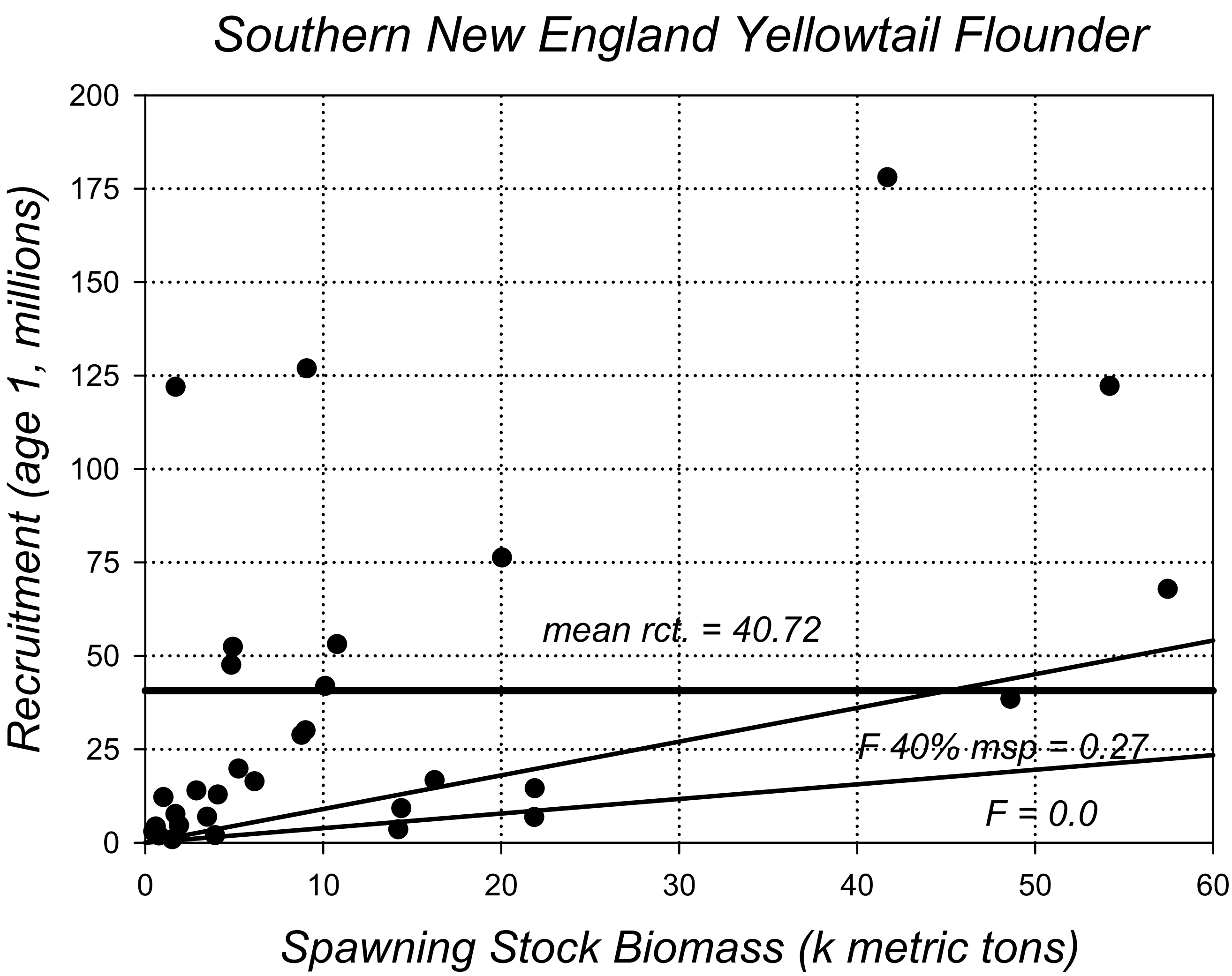


Figure 3.6.9. Stock and recruitment data for Southern New England yellowtail. For the empirical non-parametric approach the mean recruitment for all spawning stock biomss is plotted, along with replacement lines for F=0.0 and F 40% msp = 0.269.

3.7 Cape Cod yellowtail flounder

Catch and Survey Indices

Catches of Cape Cod yellowtail flounder peaked in the late 1970s followed by a decline in the 1980s and have remained low (Figure 3.7.1). All four research survey abundance indices for Cape Cod yellowtail flounder show an overall decline and rebuilding pattern from the early 1980s to present (Figure 3.7.1). The increasing stock size in recent years is difficult to explain considering the high exploitation rates thought to be occurring based on the most recent stock assessment.

Stock Assessment

The most recent assessment for Cape Cod yellowtail flounder was reviewed as part of the 2001 review of 19 Northeast groundfish stocks conducted by Northeast Fisheries Science Center staff (Northern Demersal and Southern Demersal Working Groups 2001). The stock was analyzed with virtual population analysis (VPA). The VPA assessment used data for years 1985 through 1999 and ages 1 through 6+ and was felt to be representative of stock dynamics for the time period. Plots of stock and recruitment estimates from the VPA are provided in Figure 3.7.2. Recruitment has been nearly independent of spawning stock size overall, however the recruitment series is dominated by a single large events, the 1987 year class.

Yield and Spawning Stock Biomass per Recruit

The fishing mortality reference points F(0.1) and F40%MSP given in Figure 3.7.2 were calculated for this exercise using ages 1 through 6+ in order to be consistent with the projections described below, and thus may differ slightly from previously reported values (Table 3.7.2). From the yield per recruit analysis, F(0.1)=0.231 and Fmax=0.528 (both are fully recruited Fs). From the spawning stock biomass per recruit analysis, F40%MSP=0.214 (fully recruited F) with an associated spawning stock biomass per recruit of 1.0680 kg.

Empirical Nonparametric Approach

If F40%MSP is assumed to be an adequate proxy for Fmsy, then the fishing mortality threshold is 0.214. This fishing mortality rate produces 1.068 kg of spawning stock biomass per recruit and 0.2165 kg of yield per recruit (including discards). Since the VPA estimates of recruitment does not increase with increasing spawning stock size, the mean of all recruitments is assumed to be representative of recruitment levels expected at maximum sustainable yield (MSY). Thus, recruitment of 7.85 million fish results in an estimate of 8,400 mt of spawning stock biomass (Bmsy proxy) and 1,700 mt of yield (MSY proxy) assuming that all fish caught are landed.

Parametric Model Approach

Maximum likelihood fits of the 12 parametric stock-recruitment models to the Cape Cod yellowtail flounder data from 1985-1998 are listed below (Table 3.7.1, see Table 2.1.2 for model acronyms). Note that the historical stock and recruitment data did not match well with the VPA data (Figure 3.7.3), and so no parametric models using hindcast recruitment priors were considered. The six hierarchical criteria are applied to each of the models to determine the set of candidate models.

The priors for the Beverton and Holt steepness parameter and Ricker slope parameter from Myers et al. (1999) were thought to be insufficient for the yellowtail stocks as the only data sets used to develop the prior were Georges Bank and Southern New England yellowtail stocks. Thus, models PBH, PABH, P2BH, P2ABH, PRK, and PARK are not considered. Of the remaining models, the first criterion is not satisfied for models PRBH and PRABH due to steepness being estimated at its boundary condition of 1.0. The fourth criterion is not satisfied for models RK and ARK as the estimates of Fmsy are twice as large as the estimate of FMAX (0.528). The fifth criteria is not satisfied by model ABH given the short time period of data (14 years). The only remaining model, BH, estimates Smsy at nearly half the nonparametric proxy of 8,400 mt and thus is not considered. Thus, no parametric model fits were considered to be appropriate for Cape Cod yellowtail flounder (see Figure 3.7.4 for plots of parametric fits).

Reference Points

Based on the rejection of all parametric model fits, the following management parameters are considered most appropriate: Bmsy proxy=8,400 mt, Fmsy proxy=0.214 (fully recruited F), and MSY=1,700 mt (including discards). This level of yield is expected by building the stock size through reduced fishing mortality, relative to historical levels that were above 2.0, increased survivorship of young fish relative to the historical use of much smaller mesh size when peak catches were taken, and an expectation that on average recruitment will stay within the range predicted by the most recent stock assessment.

Projections

Given that all the parametric model fits were rejected, projections were conducted by resampling observed recruitments using a cumulative distribution function to allow predicted recruitment values between those observed to occur. Since the last year in the VPA was 1999, catch for 2000 and 2001 were estimated using the 2000 US landings, 2000 US landings from Jan-Nov (7,062 mt), 2001 US landings in Jan-Nov in 2000 by gear type, and the average US discard:landings ratio for 1995-1999 (15.6%). The 2000 catch estimate is 2,354 mt and the 2001 catch estimate is 2,571 mt. For 2002, the fishery was assumed to fish at the median rate projected for 2001 (2.047 fully recruited F). For the first projection, for years 2003 through 2009, the fishery was assumed to fish at a rate of F40%MSP (0.214 fully recruited F). Under these assumptions, there is a 13.3% chance that the spawning biomass in 2009 will be at least as large as the Bmsy proxy (Figure 3.7.5). Thus, a rebuilding F must be calculated. The constant fishing mortality rate for years 2003 through 2009 was found that produced a 50% probability the spawning biomass in 2009 will be at least as large as the Bmsy proxy. This constant F was found to be 0.139 (fully recruited F) which generated a 50.3% probability of achieving the spawning biomass goal (Figure 3.7.5). Based on these projections, the median fishing mortality rate in 2001 was 2.047 which must be decreased 93% to the rebuilding F level of 0.139. Under the rebuilding F, the median spawning stock biomass in 2009 will be 6,900 mt with an 80% confidence interval of 6,100 mt to 8,600 mt (Figure 3.7.6). The associated median catch will be 1,400 mt with an 80% confidence interval of 1,200 mt to 1,700 mt (Figure 3.7.7).

Table 3.7.1. Summary of parametric fits for Cape Cod yellowtail flounder.

Cape Cod Yellowtail Flounder

	Prior	Prior	Prior	Prior	Prior	Prior	Prior	Prior	Prior	Prior	Prior	Prior
	0	0	0	0	0	0	0	0	0	0	0	0
	BH	ABH	PBH	PABH	PRBH	PRABH	P2BH	P2ABH	RK	ARK	PRK	PARK
Posterior Probability												
Odds Ratio for Most Likely Model Normalized Likelihood												
Model AIC Ratio	0	0	0	0	0	0	0	0	0	0	0	0

	BH	**ABH**	**PBH**	**PABH**	**PRBH**	**PRABH**	**P2BH**	**P2ABH**	**RK**	**ARK**	**PRK**	**PARK**
Number_of_data_points	14	14	14	14	14	14	14	14	14	14	14	14
Number_of_parameters	3	4	3	4	3	4	3	4	3	4	3	4
Fit_negloglikelihood	32.6521	32.3295	33.8297	33.1961	32.8685	32.8563	33.2378	35.5944	33.1894	32.4656	37.9647	36.3346
Penalty_steepness	0	0	0.727911	-0.334412	0	0	3.74079	-1.62222	0	0	0	0
Penalty_slope	0	0	0	0	0	0	0	0	0	0	4.59894	-0.120112
Penalty_unfished_R	0	0	0	0	-0.180217	-0.179228	-0.08469	-0.189339	0	0	0	0
Negative_loglikelihood	32.6521	32.3295	34.5576	32.8617	32.6883	32.6771	36.8939	33.7828	33.1894	32.4656	42.5636	36.2145
Bias-corrected_AIC	73.7043	77.1034	76.0593	78.8367	74.1371	78.157	74.8756	83.6332	74.7788	77.3757	84.3294	85.1136
Diagnostic Comments	Smsy well below non-parametric proxy	auto-correlation implies long period forcing	insufficient information for steepness prior	insufficient information for steepness prior	steepness at boundry of 1	steepness at boundry of 1	insufficient information for steepness prior	insufficient information for steepness prior	Fmsy>> Fmax	Fmsy>> Fmax	insufficient information for slope prior	insufficient information for slope prior
Parameter Point Estimates *******************************												
MSY	2.008	2.475	3.206	4.591	1.742	1.741	1.735	1.388	1.839	2.043	55891.000	0.525
FMSY	0.470	0.415	0.375	0.340	0.525	0.525	0.485	0.280	1.465	1.180	0.600	0.270
SMSY	4.627	6.425	9.173	14.438	3.611	3.608	3.878	5.267	1.415	1.947	101965.00	2.062
alpha	8.45769	10.91	14.7462	22.2218	7.09551	7.0997	7.23484	7.58127	2.80473	2.58121	1.83892	0.885876
expected_alpha	8.96835	11.5946	15.8054	24.1227	7.53779	7.54235	7.71103	11.1742	2.98802	2.75584	2.08424	2.64375
beta	0.149475	0.477534	1.02708	2.26831	4.27E-06	0.0050366	0.0897127	1.39428	-0.759707	-0.555828	-1.01E-05	-0.380285
steepness	0.974	0.938	0.906	0.867	1.000	0.999	0.982	0.784	N/A	N/A	N/A	N/A
R_at_input_SMAX	8.21	9.96	12.23	15.29	7.10	7.09	7.11	5.93	1.85	4.10	31.45	1.81
expected_R_at_input_SMAX	8.71	10.58	13.11	16.59	7.54	7.53	7.58	8.74	1.97	4.38	35.64	5.40
unfished_S	22.44	28.66	38.35	57.07	18.95	18.95	19.23	18.85	4.98	6.41	278224.00	4.91
unfished_R	8.40	10.73	14.36	21.37	7.10	7.10	7.20	7.06	1.87	2.40	104187.00	1.84
sigma	0.342422	0.348875	0.372469	0.405171	0.347756	0.347797	0.35705	0.880825	0.355818	0.36184	0.500452	1.47877
phi	N/A	0.293138	N/A	0.493203	N/A	0.0461746	N/A	0.89135	N/A	0.370318	N/A	0.961539
sigmaw	N/A	0.333549	N/A	0.352464	N/A	0.347426	N/A	0.399291	N/A	0.336115	N/A	0.406172
last_residual_R	N/A	-0.260495	N/A	-0.761572	N/A	0.89756	N/A	4.08344	N/A	-0.60565	N/A	5.9353
last_logresidual_R	N/A	-0.03215	N/A	-0.091228	N/A	0.119431	N/A	0.717765	N/A	-0.073216	N/A	1.36424
expected_lognormal_error_	1.06038	1.06275	1.07183	1.08554	1.06233	1.06235	1.06582	1.47392	1.06535	1.06765	1.1334	2.98434
prior_mean_steepness	N/A	N/A	0.75	0.75	N/A	N/A	0.75	0.75	N/A	N/A	N/A	N/A
prior_se_steepness	N/A	N/A	0.07	0.07	N/A	N/A	0.07	0.07	N/A	N/A	N/A	N/A
prior_mean_slope	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.79	0.79
prior_se_slope	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.34	0.34
prior_mean_unfished_R	N/A	N/A	N/A	N/A	7.05	7.05	7.05	7.05	N/A	N/A	N/A	N/A
prior_se_unfished_R	N/A	N/A	N/A	N/A	0.33	0.33	0.33	0.33	N/A	N/A	N/A	N/A

Table 3.7.2. Yield and biomass per recruit of Cape Cod yellowtail flounder.

```
   The NEFC Yield and Stock Size per Recruit Program - PDBYPRC
    PC Ver.2.0 [Method of Thompson and Bell (1934)] 1-Jan-1999
            ---------------------------------------
            Run Date: 19- 2-2002;  Time: 13:41:13.00
 CAPE COD YELLOWTAIL FLOUNDER - 2002
 _____________________________________________________________________
 Proportion of F before spawning: 0.4167
 Proportion of M before spawning: 0.4167
 Natural Mortality is Constant at: 0.200
 Initial age is:  1; Last age is:  6
 Last age is a PLUS group;
 Original age-specific PRs, Mats, and Mean Wts from file:
 ==> C:\groundfish\ypr\ccyt_ypr.dat
------------------------------------------------------------
 Age-specific Input data for Yield per Recruit Analysis
------------------------------------------------------------
```

Age	Fish Mort Pattern	Nat Mort Pattern	Proportion Mature	Average Weights Catch	Average Weights Stock
1	0.0200	1.0000	0.0000	0.048	0.048
2	0.1100	1.0000	0.0800	0.263	0.263
3	0.6500	1.0000	0.8100	0.382	0.382
4	1.0000	1.0000	1.0000	0.493	0.493
5	1.0000	1.0000	1.0000	0.588	0.588
6	1.0000	1.0000	1.0000	1.056	1.056

```
------------------------------------------------------------
 Summary of Yield per Recruit Analysis:
 _____________________________________________________________________
  Slope of the Yield/Recruit Curve at F=0.00: -->     2.6001
    F level at slope=1/10 of the above slope (F0.1): ----->          0.231
      Yield/Recruit corresponding to F0.1: ----->     0.2214
    F level to produce Maximum Yield/Recruit (Fmax): ----->          0.528
      Yield/Recruit corresponding to Fmax: ----->     0.2455
    F level at 40 % of Max Spawning Potential (F40): ----->   0.214
      SSB/Recruit corresponding to F40: -------->     1.0680
 _____________________________________________________________________
1
 Listing of Yield per Recruit Results for:
```

	FMORT	TOTCTHN	TOTCTHW	TOTSTKN	TOTSTKW	SPNSTKN	SPNSTKW	% MSP
	0.00	0.00000	0.00000	5.5167	3.1973	3.3453	2.6704	100.00
	0.10	0.21691	0.15544	4.4373	2.1221	2.2682	1.6168	60.54
	0.20	0.32679	0.21209	3.8928	1.6043	1.7261	1.1164	41.81
F0.1	0.23	0.35074	0.22136	3.7745	1.4958	1.6086	1.0126	37.92
F40%	0.21	0.33789	0.21655	3.8380	1.5538	1.6716	1.0680	39.99
	0.30	0.39382	0.23458	3.5623	1.3061	1.3982	0.8325	31.17
	0.40	0.43937	0.24309	3.3389	1.1156	1.1776	0.6537	24.48
	0.50	0.47261	0.24545	3.1768	0.9850	1.0185	0.5330	19.96
Fmax	0.53	0.48035	0.24553	3.1392	0.9559	0.9817	0.5062	18.96
	0.60	0.49812	0.24506	3.0531	0.8909	0.8979	0.4471	16.74
	0.70	0.51847	0.24351	2.9551	0.8204	0.8030	0.3835	14.36
	0.80	0.53517	0.24153	2.8750	0.7657	0.7263	0.3348	12.54
	0.90	0.54921	0.23949	2.8081	0.7223	0.6628	0.2966	11.11
	1.00	0.56123	0.23753	2.7511	0.6870	0.6093	0.2658	9.95
	1.10	0.57170	0.23573	2.7018	0.6577	0.5636	0.2406	9.01
	1.20	0.58092	0.23410	2.6585	0.6330	0.5239	0.2195	8.22
	1.30	0.58915	0.23262	2.6201	0.6118	0.4891	0.2016	7.55
	1.40	0.59655	0.23128	2.5856	0.5934	0.4584	0.1863	6.97
	1.50	0.60327	0.23007	2.5545	0.5773	0.4310	0.1729	6.48
	1.60	0.60941	0.22895	2.5261	0.5630	0.4064	0.1612	6.04
	1.70	0.61507	0.22792	2.5001	0.5501	0.3842	0.1509	5.65
	1.80	0.62030	0.22696	2.4761	0.5385	0.3641	0.1417	5.31
	1.90	0.62516	0.22605	2.4539	0.5280	0.3456	0.1334	4.99
	2.00	0.62970	0.22520	2.4332	0.5184	0.3288	0.1259	4.71

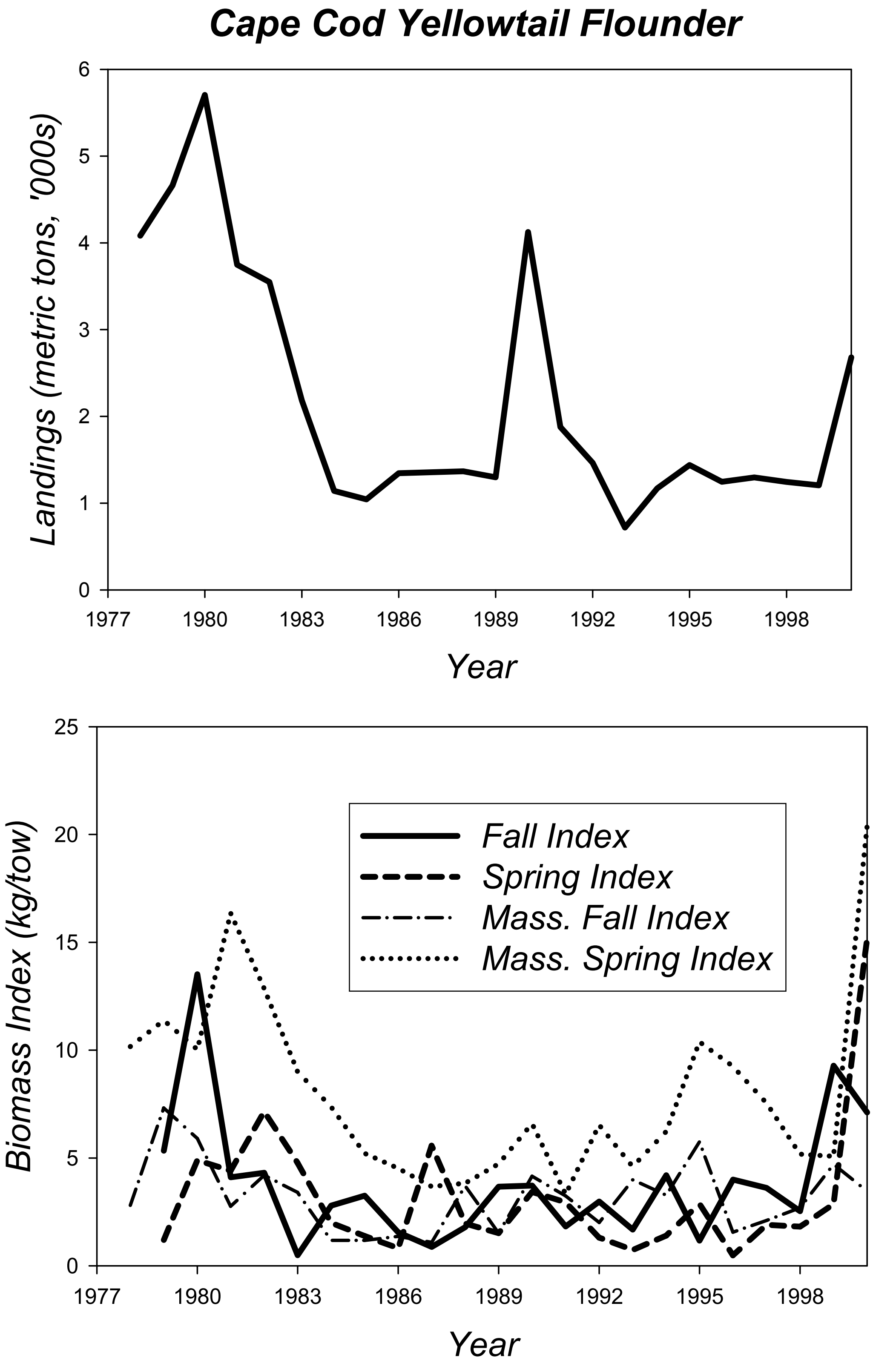
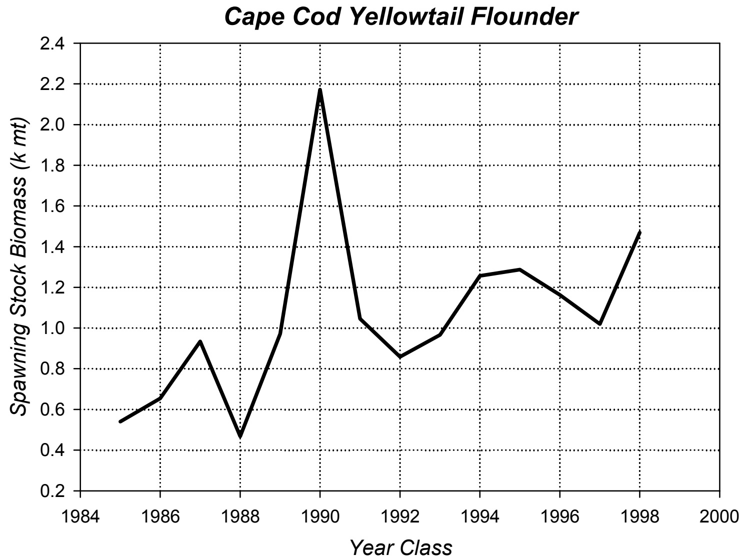
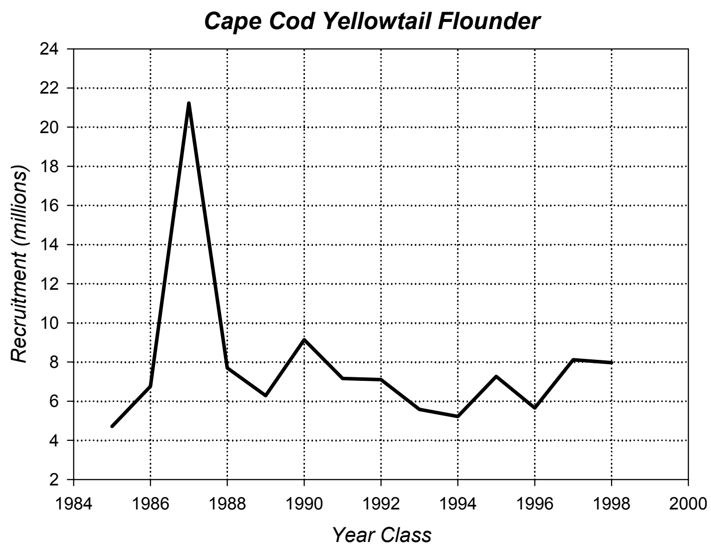


Figure 3.7.1. Landings and research vessel survey abundance indices for Cape Cod yellowtail flounder.

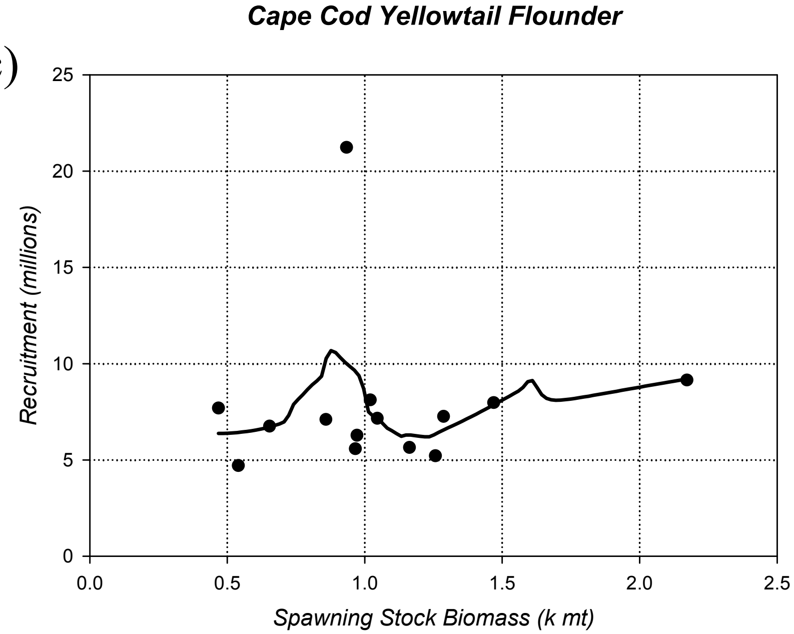
(a)



(b)



(c)



		F0.1	F40% MSP
F reference point		0.231	0.214
ssb per recruit at F		1.013	1.068
	Recruitment (millions)	SS Biomass at F0.1	SS Biomass at F40%
n	14	14	14
mean	7.85	7.95	8.38
min	4.71	4.77	5.03
max	21.23	21.50	22.67
10th %'tile	5.33	5.39	5.69
25th %'tile	5.81	5.88	6.20
50th %'tile	7.13	7.22	7.61
75th %'tile	7.90	8.00	8.44
90th %'tile	8.84	8.95	9.44
Std Dev	4.04	4.09	4.32
CV	0.52	0.52	0.52

Figure 3.7.2. Spawning stock (a), recruitment (age 1 millions, b), and scatterplot (c) for Cape Cod yellowtail flounder. Data are the calculated spawning stock biomasses for various recruitment scenarios multiplied by the expected SSB per recruit for F0.1 and F40% MSP, assuming recent patterns of growth, maturity and partial recruitment at age (Table 3.7.2). Smoother in the stock-recruitment plot is lowess with tension = 0.5.

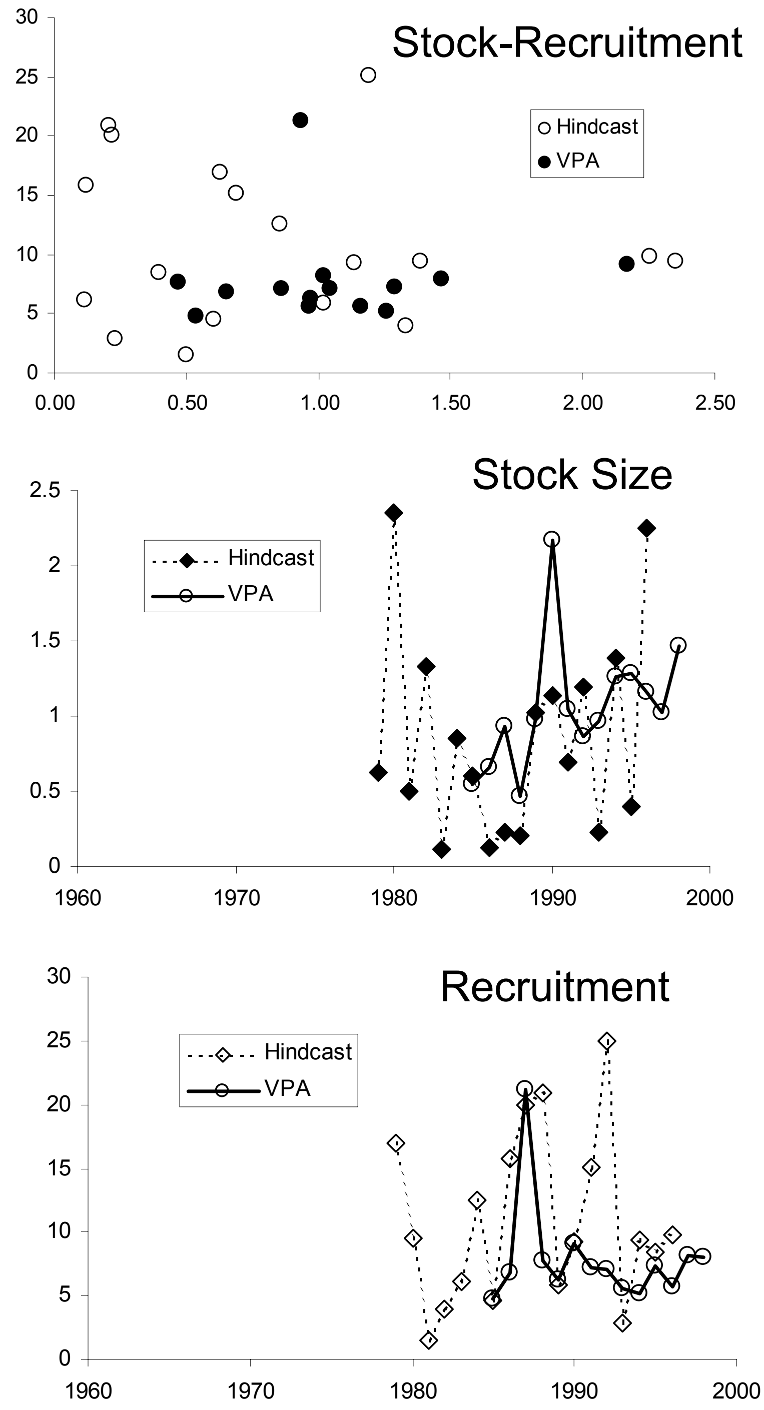


Figure 3.7.3. Comparison of stock and recruitment data from virtual population analysis (VPA) and hindcast for Cape Cod yellowtail flounder.

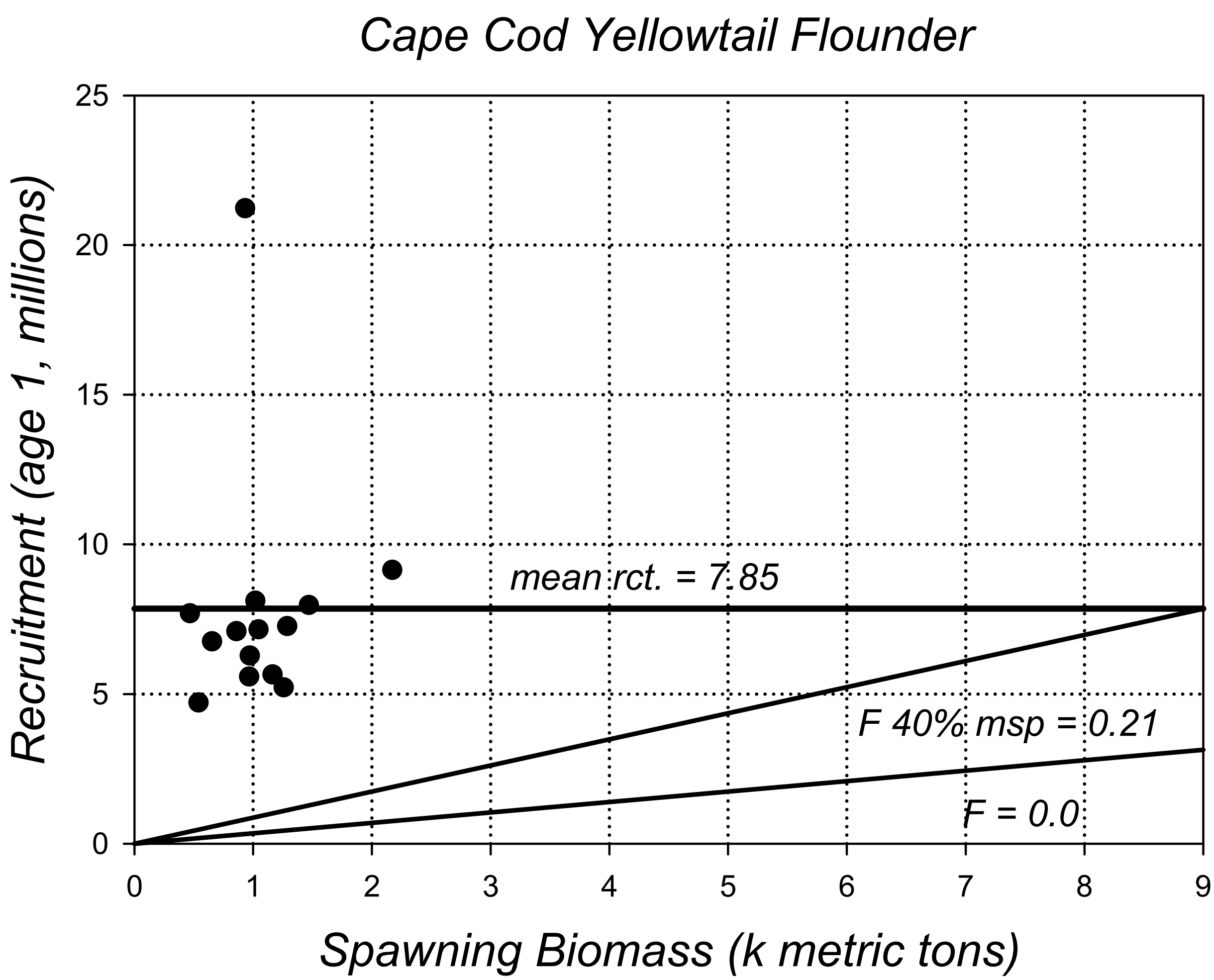


Figure 3.7.4. Stock and recruitment data for Cape Cod yellowtail flounder. For the empirical non-parametric approach the mean recruitment is plotted along with the replacement lines for F=0.0 and F 40% msp = 0.21.

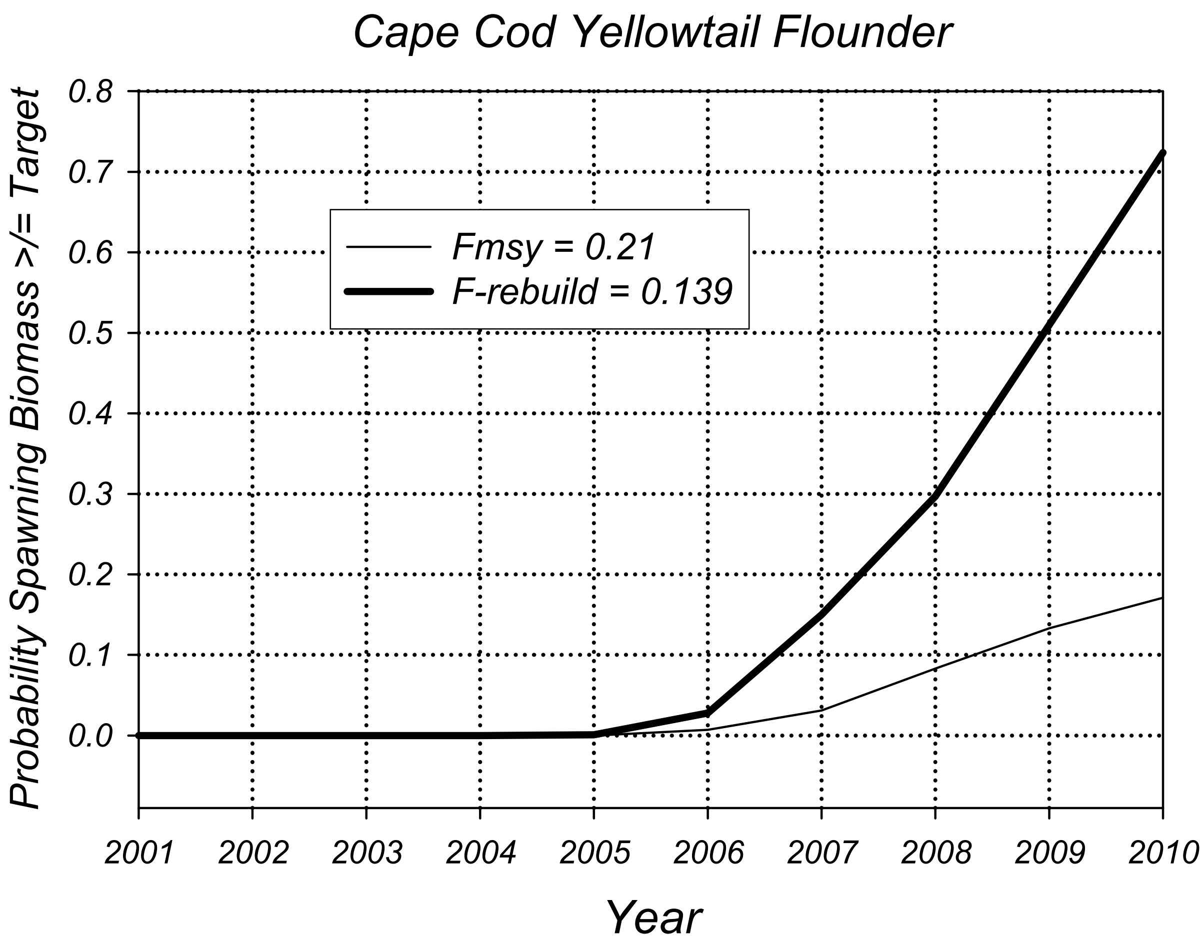


Figure 3.7.5. Probability that Cape Cod yellowtail spawning biomass will exceed Bmsy (8,400 mt) annually under two fishing mortality scenarios: Fmsy and F required to rebuild the stock to Bmsy by 2009.

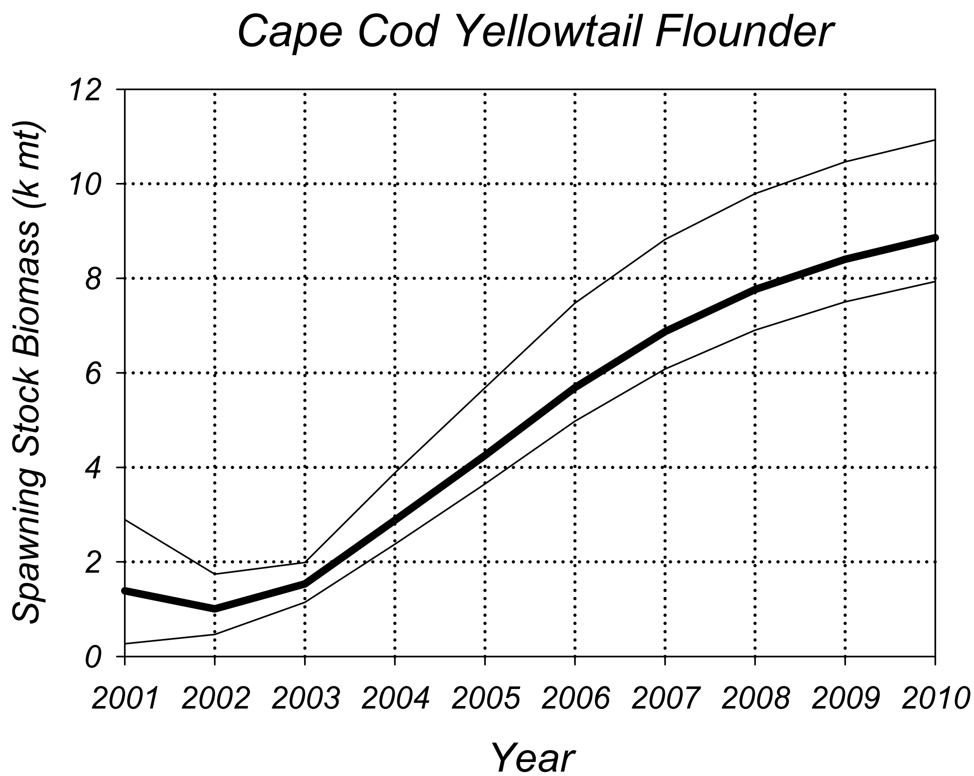


Figure 3.7.6. Median and 80% confidence interval of predicted spawning biomass for Cape Cod yellowtail under F-rebuild fishing mortality rates.

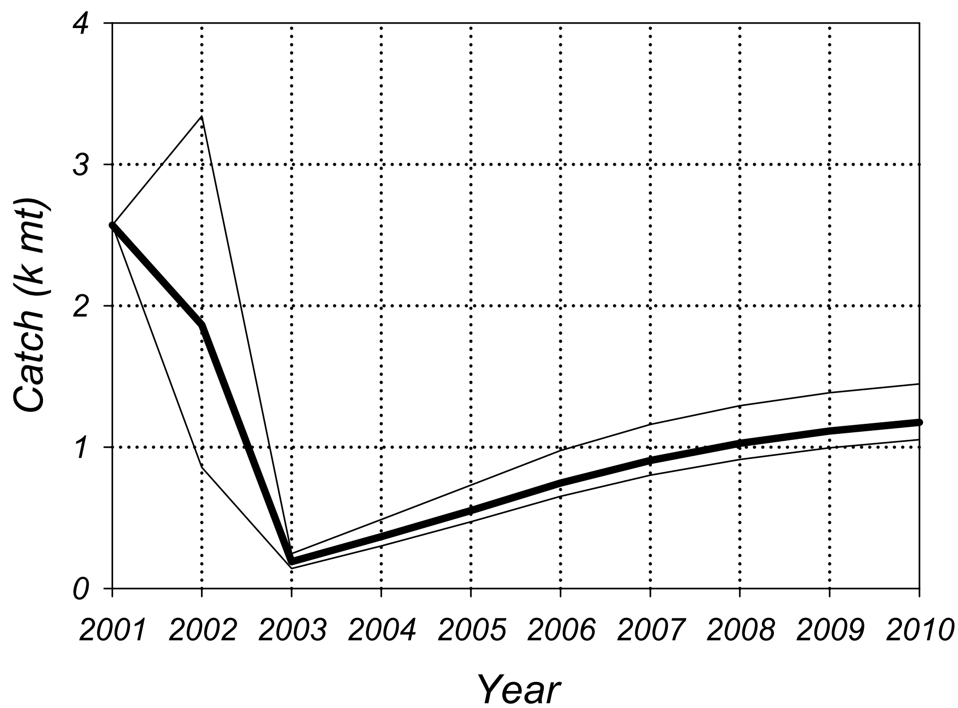


Figure 3.7.7. Median and 80% confidence interval of predicted catch for Cape Cod yellowtail under F-rebuild fishing mortality rates.

3.8 Mid Atlantic Yellowtail Flounder

Catch and Survey Indices

A fishery for yellowtail flounder in the Mid-Atlantic Bight developed in the 1940s, and expanded in the 1960s. Landings ranged from 3,000 to 9,000 mt between 1967 and 1973, but subsequently declined to less than 1,000 mt after 1975 and have not exceeded 500 mt since 1985 (Figure 3.8.1). The fishery for yellowtail in the Mid-Atlantic area occurs in proximity to the western boundary of the Southern New England yellowtail stock.

Survey catches indicate relatively high biomass in the 1960s and early 1970s, followed by a sharp decrease in the mid 1970s (Figure 3.8.1). Survey indices have been less than 10% of historical levels since the late 1980s.

Stock Assessment

The Mid-Atlantic yellowtail flounder stock has never been assessed through the SAW/SARC process. The state of this stock was most recently evaluated in 2000 via index assessment (NEFSC 2001a). At that time, it was noted that the average fall biomass index for the last three years (1997-1999 average=0.26 kg/tow) was about 2% of the current B_{MSY} proxy (1963-1972 median=11.69 kg/tow) and well below the biomass threshold ($B_{MSY}/2$=5.85 kg/tow).

Survey observations from 1963-1966 are not directly comparable to subsequent observations, because strata south of New Jersey were not sampled prior to 1967. However, the median survey biomass index for 1967-1972 (12.91 kg/tow) is similar to the median for 1963-1972. Therefore, a revised B_{MSY} proxy of 12.91 kg/tow indicates essentially the same stock status as the current proxy.

The recent average exploitation index (landings/fall survey biomass index = 2.01) was 618% of the F_{MSY} proxy (0.28), derived as the MSY proxy (1964-1969 average annual landings, 3300 mt) divided by the current B_{MSY} proxy.

Relative Exploitation Rate Analyses

The replacement ratio analysis for Mid-Atlantic Bight yellowtail suggests that the stock can replace itself at an exploitation index of 0.33 (with a CV of 48% and marginally significant correlation of replacement ratio and exploitation index, P=0.108; Figure 3.8.2; Table 4.1.1). Using the revised biomass proxy, which is based on consistent survey data (median biomass index for 1967-1972 = 12.91 kg/tow), the MSY proxy is 4,300 mt ($F_{MSY} \cdot B_{MSY} = 0.33 \cdot 12.91$; Table 4.2).

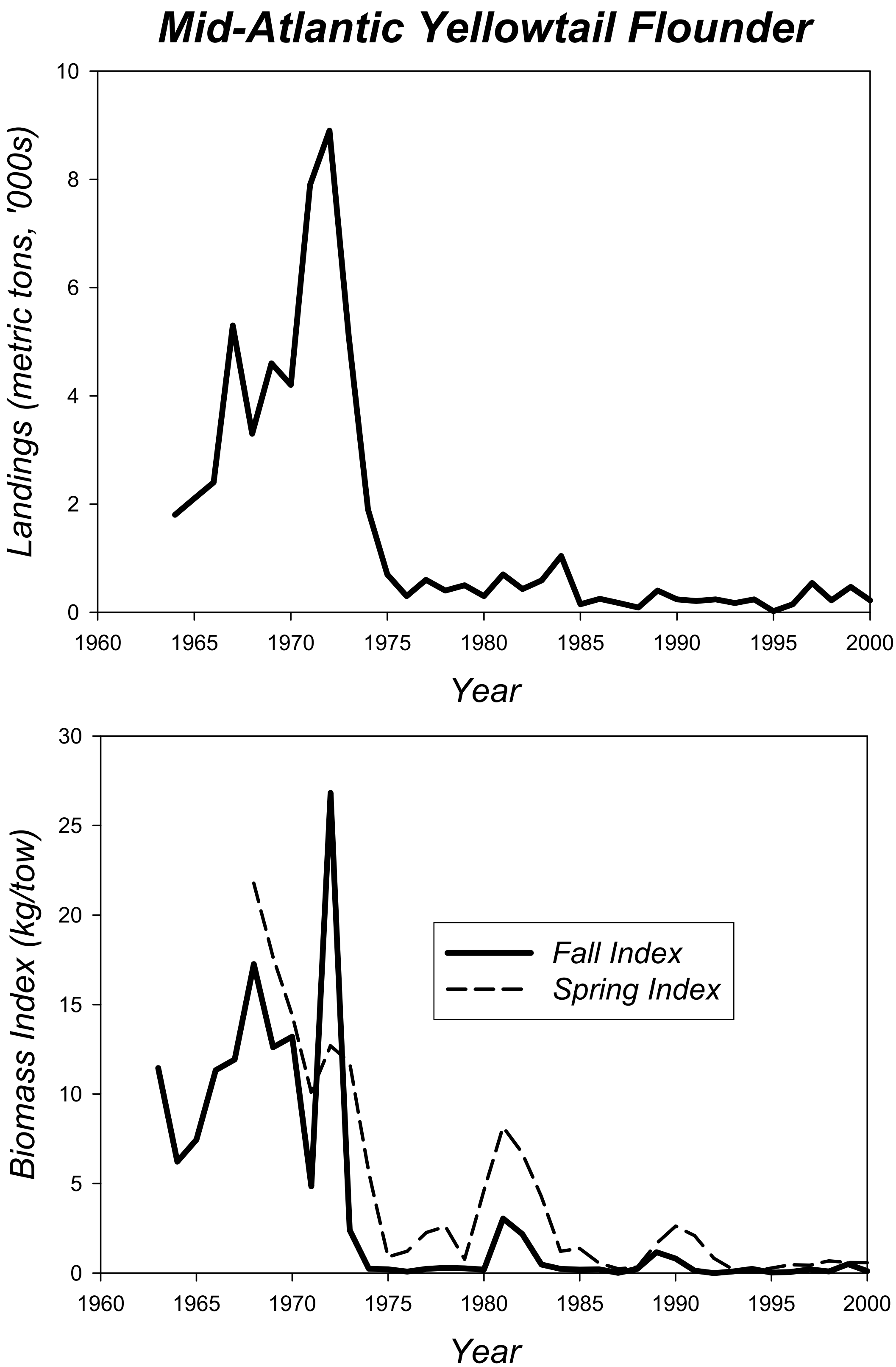


Figure 3.8.1. Landings and research vessel survey abundance indices for Mid-Atlantic yellowtail flounder.

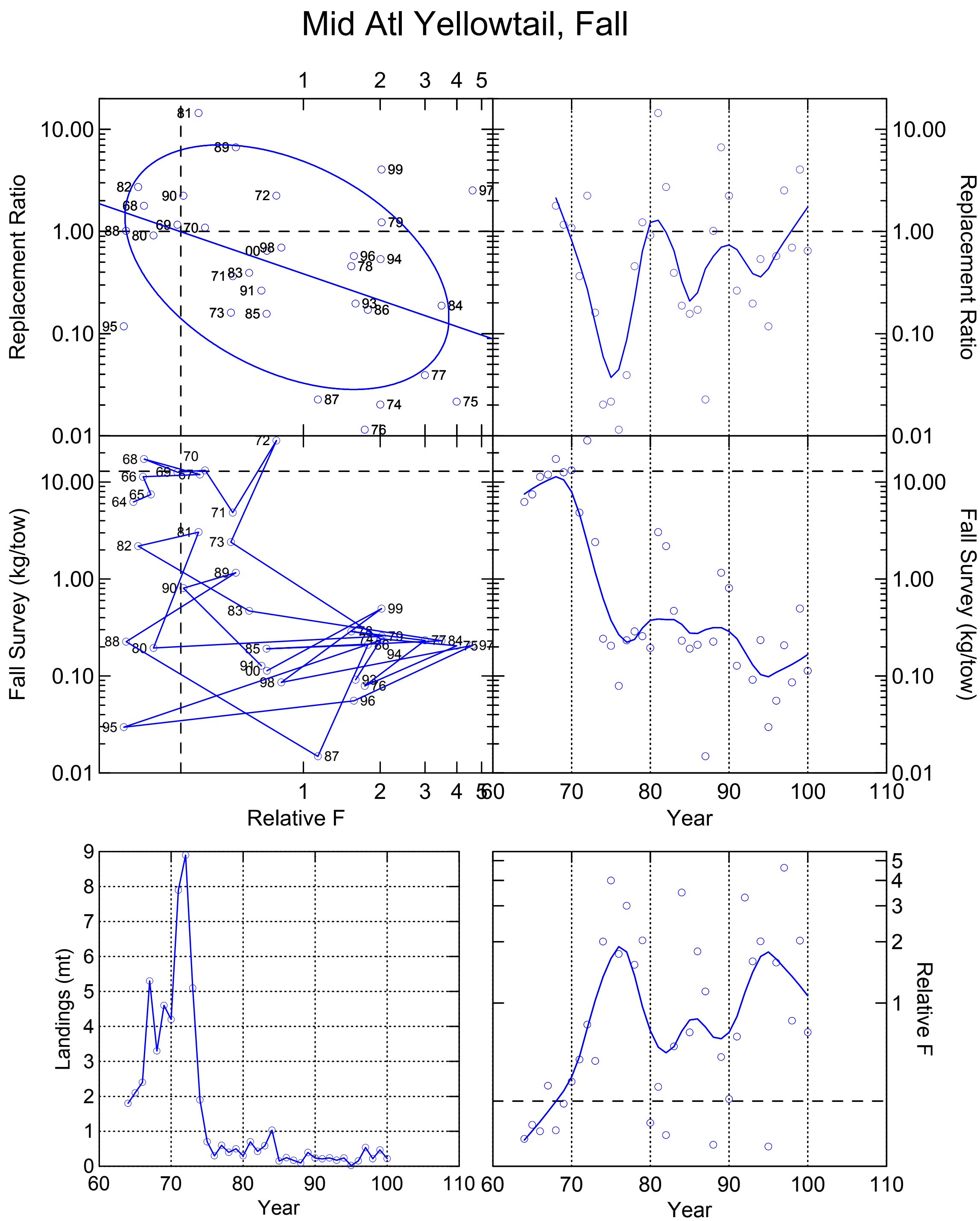


Figure 3.8.2. Trends in relative biomass, landings, fishing rate mortality rate indices (landings/ survey index) and replacement ratios for Mid-Atlantic yellowtail - fall. Dashed lines indicate proposed biomass and fishing mortality rate proxies of Bmsy and Fmsy.

3.9 Gulf of Maine - Georges Bank American Plaice

Catch and Survey Indices

The fishery for American plaice developed in the mid-seventies (Figure 3.9.1) as other popular flounder stocks became less abundant and fisheries were more heavily regulated (Sullivan 1981). Historically, American plaice had either been discarded or used as bait (Lange and Lux 197). Commercial landings increased to a record high in 1980 and then declined to a low in 1989. Landings peaked again in 1992 as the 1987 year class recruited to the fishery and have gradually been declining since 1992 (Figure 3.9.1). Both spring and autumn bottom trawl survey indices indicate relatively higher abundance of American plaice in the early 1960s and during the late 1970s to early 1980s compared to the lower abundance during the 1990s. The stock appears to be slowly increasing since the mid-1980s (Figure 3.9.1).

Stock Assessment

The most current assessment of Gulf of Maine-Georges Bank American plaice (O'Brien and Esteves 2001) was peer reviewed by the 32nd Northeast Regional Stock Assessment Workshop (NEFSC 2001b). The assessment includes US commercial landings and discard catch at age (9+) data from 1980-1999. The NMFS and Massachusetts Division of Marine Fisheries spring and autumn bottom trawl survey age data were used to calibrate the VPA. Estimates of SSB indicate a declining trend during 1980 to 1989 and then a gradual increase since 1989 (Fig 3.9.2a). Recruitment at age 1 has been variable with high recruitment events in 1988, 1993 and 1999 (Fig. 3.3.2b). The most recent estimates of recruitment are subject to change in subsequent assessments as more catch is taken from each of the cohorts.

Yield and SSB per Recruit Analysis

A yield and SSB per recruit analysis conducted using recent assessment data (O'Brien and Esteves 2001) resulted in changes in the previously estimated biological reference points (Table 3.9.1). Input data for catch weight (ages 1-9+) and stock weight (ages 1-8) was derived from the long term average weight during 1980-1999 (O'Brien and Esteves 2001). Stock mean weights for ages 9+ were derived from an expanded age structure to age 24 (oldest age observed in survey) at $F = F_{40\%} = 0.166$ and $M = 0.2$. The mean weights for ages 10 to 24 were estimated from the length-weight equation (Lux 1969a) : log Weight (g) = log(-5.955) + 3.345 log Length (mm). The mean length at ages 10-24 was derived from the von Bertalanffy growth equation: Length (mm) = 675 * (1-exp(-0.15* (age-0.10) for female American plaice (Lux 1970). The partial recruitment (PR) is based on a normalized geometric mean of 1995-1998 fishing mortality and the maturity ogive is derived from pooled 1998-1999 female data (O'Brien and Esteves 2001).

The newly estimated biological reference points for $F_{40\%}=0.166$, $F_{max} = 0.312$ and $F_{0.1} = 0.174$ are slightly lower than those reported in O'Brien and Esteves (2001).

MSY-based Reference Point Estimation

Empirical Nonparametric Approach

The stock-recruit relationship for Gulf of Maine - Georges Bank American plaice indicates a general trend of decreasing recruitment of age 1 fish with increasing spawning stock biomass at SSB less than about 25,000 mt. (Figure 3.9.2c). A review of 1980-1994 hindcasted autumn bottom trawl survey indices indicate a similar stock-recruit relationship as seen in the VPA time series (Brodziak *et al.* 2001). All hindcasted data combined (1963-1994) indicates medium recruitment at high stock sizes similar to those observed in the VPA series. Given this pattern, the recruitment expected at SSB_{msy} can be considered to be the mean recruitment associated with all SSB estimates. Using $F_{40\%}$ = 0.17 as a proxy for F_{MSY}, the SSB/R at $F_{40\%}$ = 0.9985, and the mean recruitment of 28.61 million fish results in a SSB_{msy} of 28,600 mt (Figure 3.9.2 and 3.9.3). Similarly, multiplying the yield per recruit of 0.17143 (Table 3.9.1) by mean recruitment results in a MSY estimate of 4,900 mt.

The estimate of MSY is within the range of observed landings and SSB_{msy} is below the maximum SSB (46,600 mt) observed in the VPA time series.

Parametric Model Approach

The stock recruit relationship for the VPA time series (1980-1999) indicates an atypical negative relationship of decreasing recruitment with increasing SSB (Figure 3.9.3). Autumn survey hindcasted data, as described above, suggests that with a longer VPA time series this negative relationship would not persist. The current VPA time series of stock recruit data was therefore considered insufficient to apply to any parametric stock-recruit model.

Reference Points

Reference points derived from the yield per recruit analysis are : $F_{40\%}$ = 0.166, MSY = 4,900 mt and SSB_{MSY} = 28,600 mt. The MSY includes commercial landings and discards.

Projections

Stochastic age-based projections (Brodziak and Rago 2002) were performed to forecast the probability of attaining SSB_{MSY} within 10 years under an F_{MSY} (0.17) and F rebuilding (0.13) strategy. Recruitment was derived from resampling of predicted recruitment from a cumulative distribution function based on observed VPA age 1 recruitment from 1981-1999. Stock and catch mean weight, maturity at age, and partial recruitment input data are the same as described above for the yield and SSB per recruit analysis. The 2000 starting year population vector was derived from 1000 bootstrap iterations of the final VPA formulation (O'Brien and Esteves 2001).

Fishing mortality in 2000 and 2001 was based on estimated total catch (US + Canada+Discards) of 5,275 mt in 2000 and 5,370 mt in 2001. Fishing mortality in 2002 was set equivalent to the F estimated in 2001 (0.33).

The projections (section 7) indicate that there is only a 15% probability of reaching SSB_{MSY} (28,600 mt) by 2009 under an F_{MSY} strategy (Figure 3.9.4). Under a rebuilding F=0.13, there is a 50% probability of achieving SSB_{MSY} by 2009 (Figure 3.9.4-3.95). The landings are expected to decline in 2003 and subsequently increase at a low rate through 2010 (Figure 3.9.6).

Table 3.9.1. Yield and biomass per recruit of American plaice.

The NEFC Yield and Stock Size per Recruit Program - PDBYPRC
PC Ver.1.2 [Method of Thompson and Bell (1934)] 1-Jan-1992

Run Date: 21- 2-2002; Time: 15:02:52.24
American plaice Gulf of Maine-Georges Bank - 2002

Proportion of F before spawning: .2500
Proportion of M before spawning: .2500
Natural Mortality is Constant at: .200
Initial age is: 1; Last age is: 9
Last age is a PLUS group;
Original age-specific PRs, Mats, and Mean Wts from file:==> AP_LND_2.DAT

Age-specific Input data for Yield per Recruit Analysis

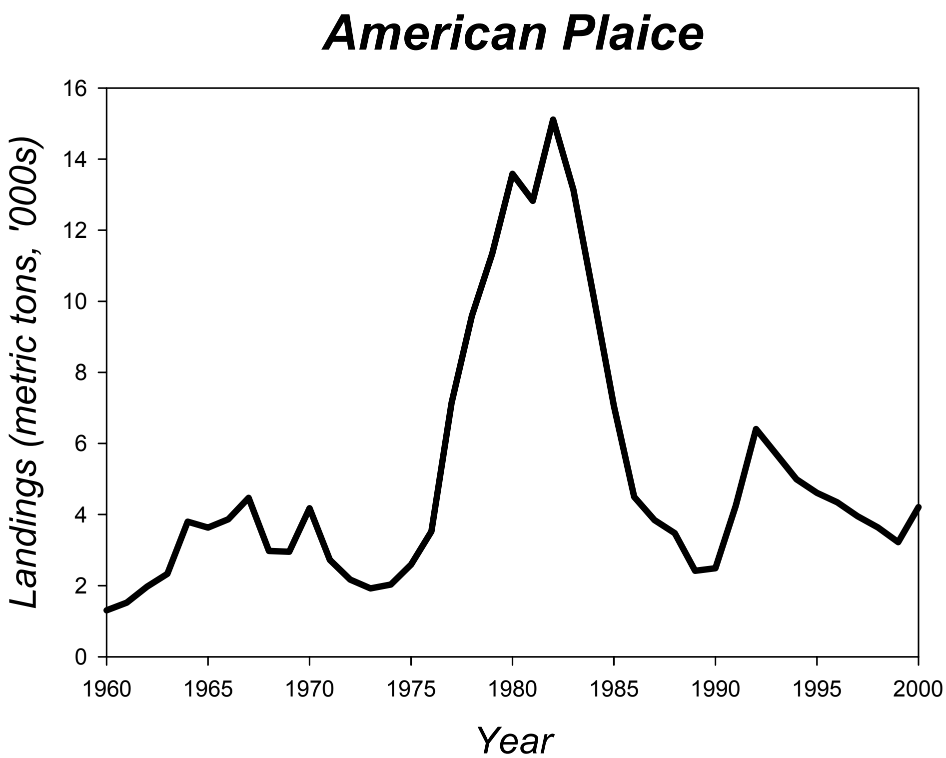
Age	Fish Mort Pattern	Nat Mort Pattern	Proportion Mature	Average Weights Catch	Average Weights Stock
1	.0300	1.0000	.0000	.016	.010
2	.1000	1.0000	.0300	.050	.029
3	.1200	1.0000	.1700	.158	.087
4	.4900	1.0000	.6000	.297	.228
5	1.0000	1.0000	.9200	.439	.360
6	1.0000	1.0000	1.0000	.618	.521
7	1.0000	1.0000	1.0000	.855	.727
8	1.0000	1.0000	1.0000	1.094	.960
9+	1.0000	1.0000	1.0000	1.606	1.565

Summary of Yield per Recruit Analysis for:
American plaice Gulf of Maine-Georges Bank - 2002

Slope of the Yield/Recruit Curve at F=0.00: --> 2.5719
F level at slope=1/10 of the above slope (F0.1): -----> .174
Yield/Recruit corresponding to F0.1: -----> .1735
F level to produce Maximum Yield/Recruit (Fmax): -----> .312
Yield/Recruit corresponding to Fmax: -----> .1869
F level at 40 % of Max Spawning Potential (F40): -----> .166
SSB/Recruit corresponding to F40: --------> .9985

Listing of Yield per Recruit Results for:
American plaice Gulf of Maine-Georges Bank - 2002

	FMORT	TOTCTHN	TOTCTHW	TOTSTKN	TOTSTKW	SPNSTKN	SPNSTKW	% MSP
	.000	.00000	.00000	5.5167	2.7694	2.7687	2.4970	100.00
	.050	.10716	.09294	4.9830	2.0611	2.2447	1.8025	72.19
	.100	.17954	.14100	4.6232	1.6128	1.8944	1.3660	54.71
	.150	.23203	.16624	4.3627	1.3095	1.6433	1.0730	42.97
F0.1	.174	.25222	.17346	4.2627	1.1990	1.5477	.9668	38.72
F40%	.166	.24612	.17143	4.2929	1.2320	1.5765	.9985	39.99
	.200	.27208	.17909	4.1644	1.0943	1.4544	.8667	34.71
	.250	.30381	.18496	4.0076	.9360	1.3068	.7161	28.68
	.300	.32971	.18680	3.8799	.8160	1.1881	.6030	24.15
Fmax	.312	.33506	.18685	3.8535	.7924	1.1639	.5808	23.26
	.350	.35135	.18632	3.7733	.7230	1.0906	.5160	20.66
	.400	.36981	.18451	3.6826	.6493	1.0089	.4477	17.93
	.450	.38579	.18197	3.6042	.5899	.9394	.3932	15.75
	.500	.39983	.17906	3.5355	.5413	.8795	.3489	13.97
	.550	.41231	.17601	3.4746	.5009	.8272	.3126	12.52
	.600	.42350	.17293	3.4199	.4670	.7812	.2823	11.30
	.650	.43364	.16992	3.3705	.4381	.7404	.2568	10.28
	.700	.44290	.16700	3.3255	.4133	.7038	.2350	9.41
	.750	.45140	.16421	3.2842	.3918	.6709	.2164	8.67
	.800	.45927	.16155	3.2460	.3729	.6410	.2003	8.02
	.850	.46657	.15902	3.2106	.3563	.6138	.1862	7.46
	.900	.47340	.15662	3.1775	.3415	.5889	.1738	6.96
	.950	.47980	.15433	3.1465	.3282	.5660	.1628	6.52
	1.000	.48582	.15216	3.1173	.3162	.5449	.1530	6.13



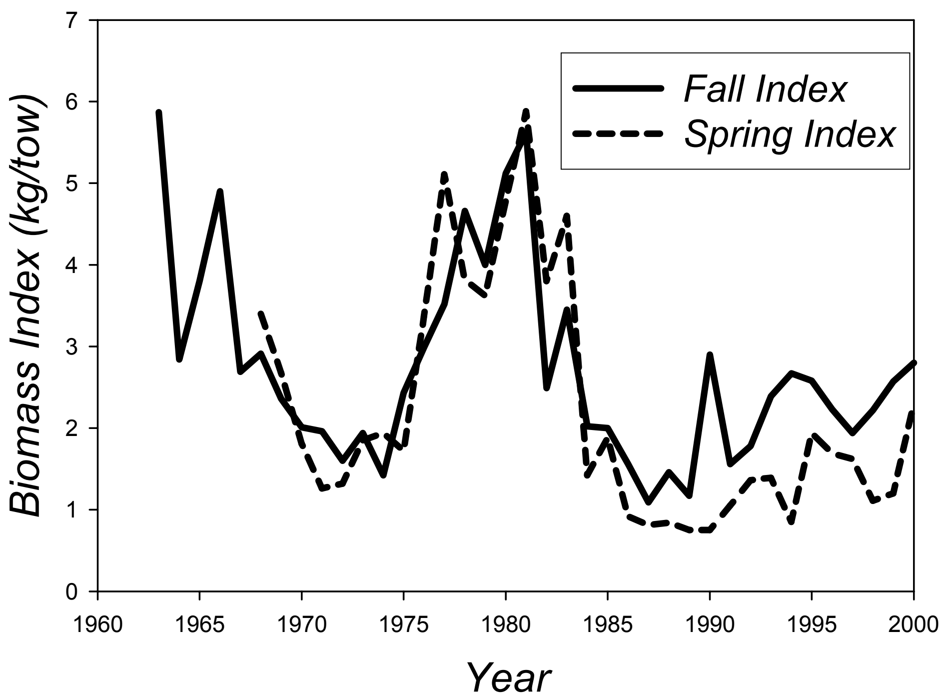
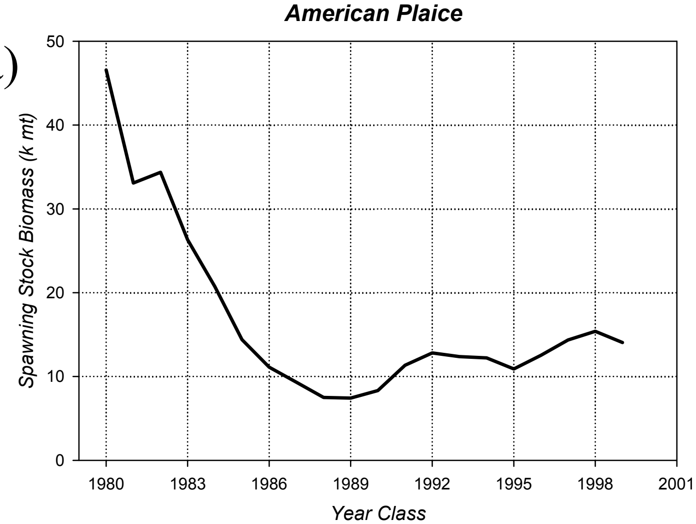
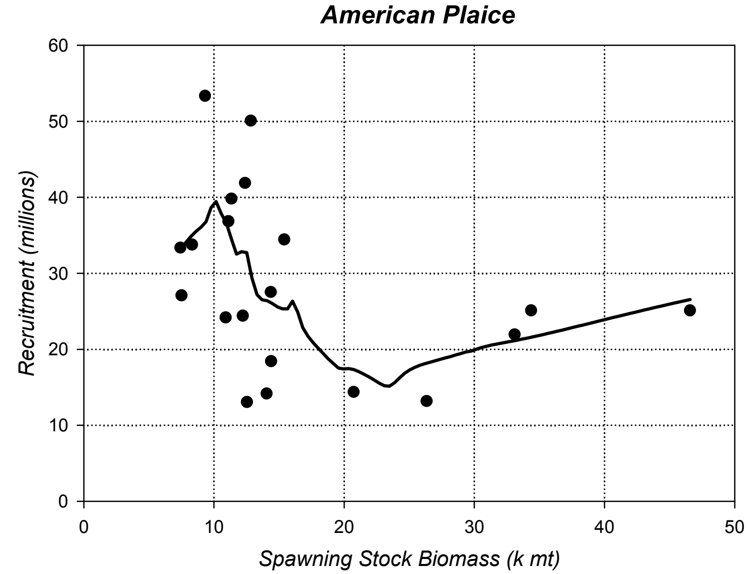


Figure 3.9.1. Landings and research vessel survey abundance indices for American plaice.

(a)



(c)



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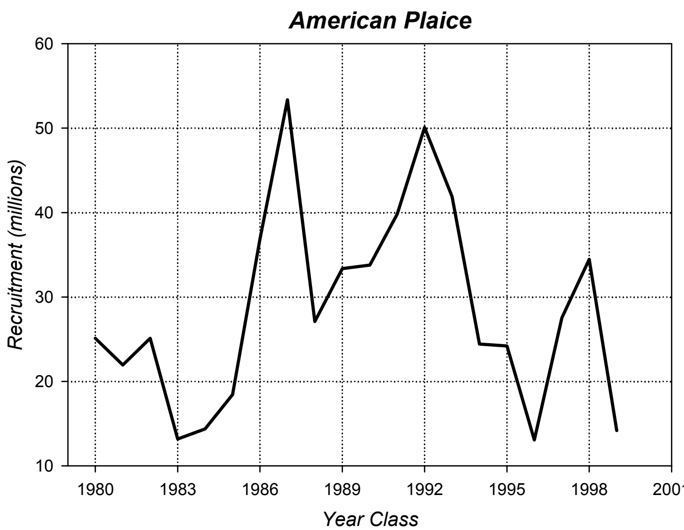


		F0.1	F40% MSP
F reference point		0.174	0.166
ssb per recruit at F		0.9668	0.9985
	Recruitment (millions)	SS Biomass at F0.1	SS Biomass at F40%
n	20	20	20
mean	28.61	27.66	28.57
min	13.06	12.63	13.04
max	53.36	51.58	53.27
10th %'tile	14.09	13.62	14.07
25th %'tile	21.07	20.37	21.04
50th %'tile	26.11	25.24	26.07
75th %'tile	35.05	33.89	35.00
90th %'tile	42.70	41.29	42.64
Std Dev	11.76	11.37	11.75
CV	0.41	0.41	0.41

Figure 3.9.2. Spawning stock (a), recruitment (age 1 millions, b), and scatterplot (c) for American plaice. Data are the calculated spawning stock biomasses for various recruitment scenarios multiplied by the expected SSB per recruit for F0.1 and F40% MSP, assuming recent patterns of growth, maturity and partial recruitment at age (Table 3.9.1). Smoother in the stock-recruitment plot is lowess with tension = 0.5.

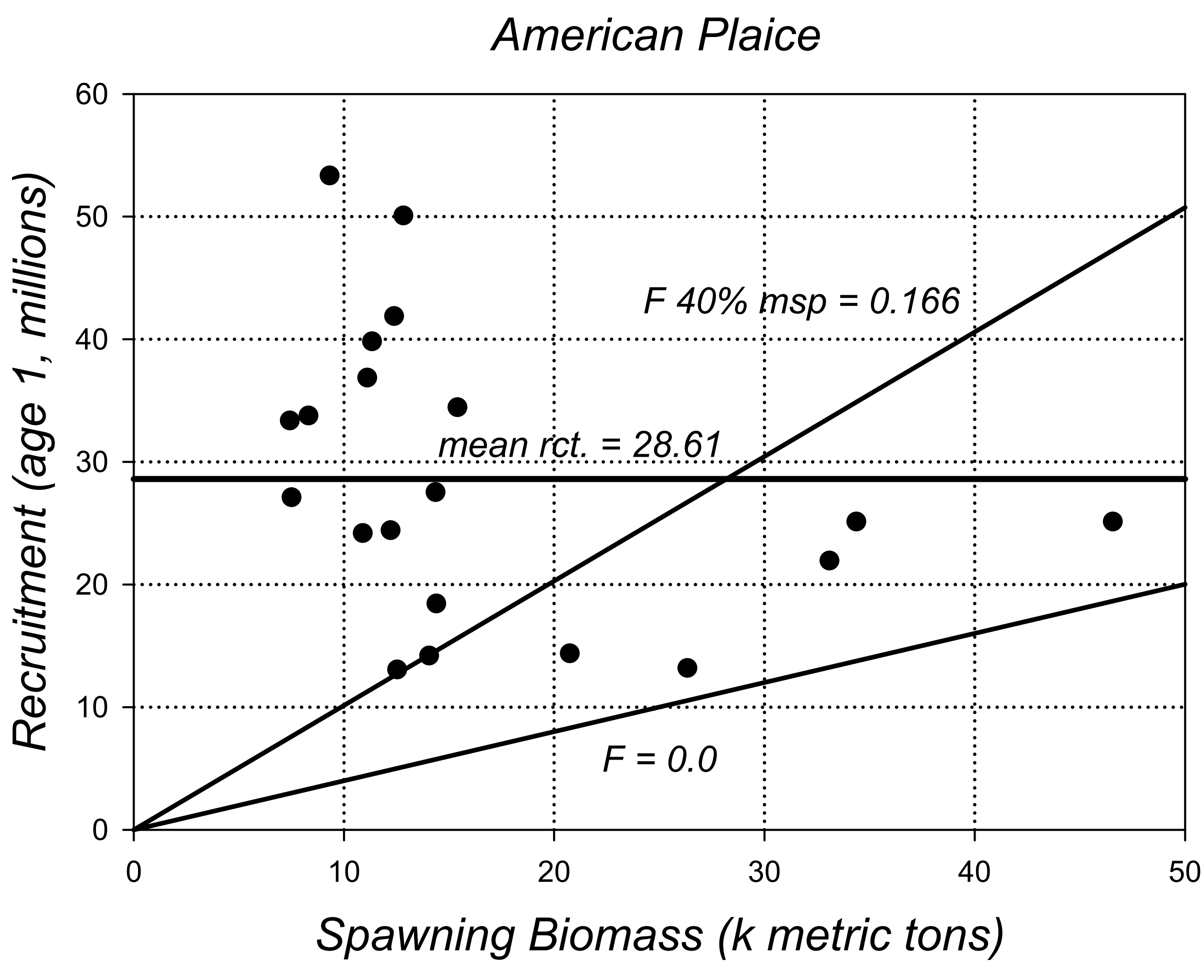


Figure 3.9.3. Stock and recruitment data for American plaice. For the empirical non-parametric approach the mean recruitment is plotted along with the replacement lines for F=0.0 and F 40% msp = 0.17.

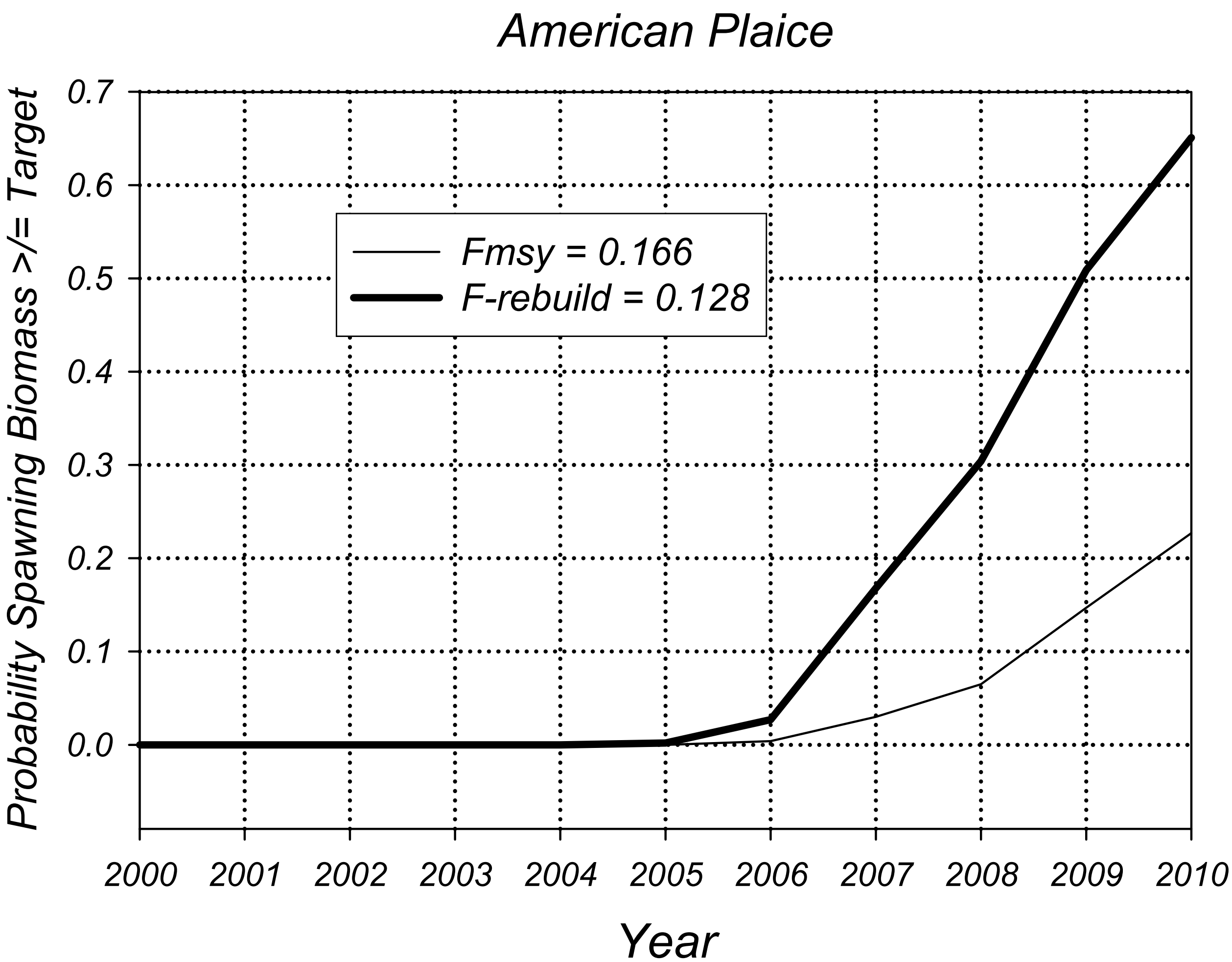


Figure 3.9.4. Probability that American plaice spawning biomass will exceed Bmsy (28,600 mt) annually under two fishing mortality scenarios: Fmsy and F required to rebuild the stock to Bmsy by 2009.

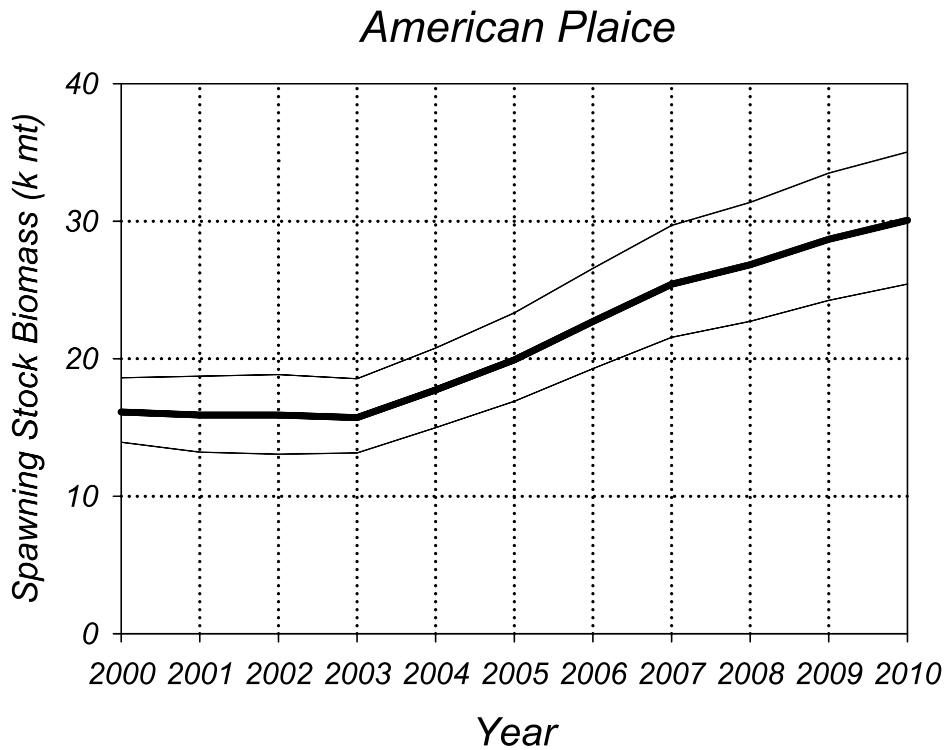


Figure 3.9.5. Median and 80% confidence interval of predicted spawning biomass for American plaice under F-rebuild fishing mortality rates.

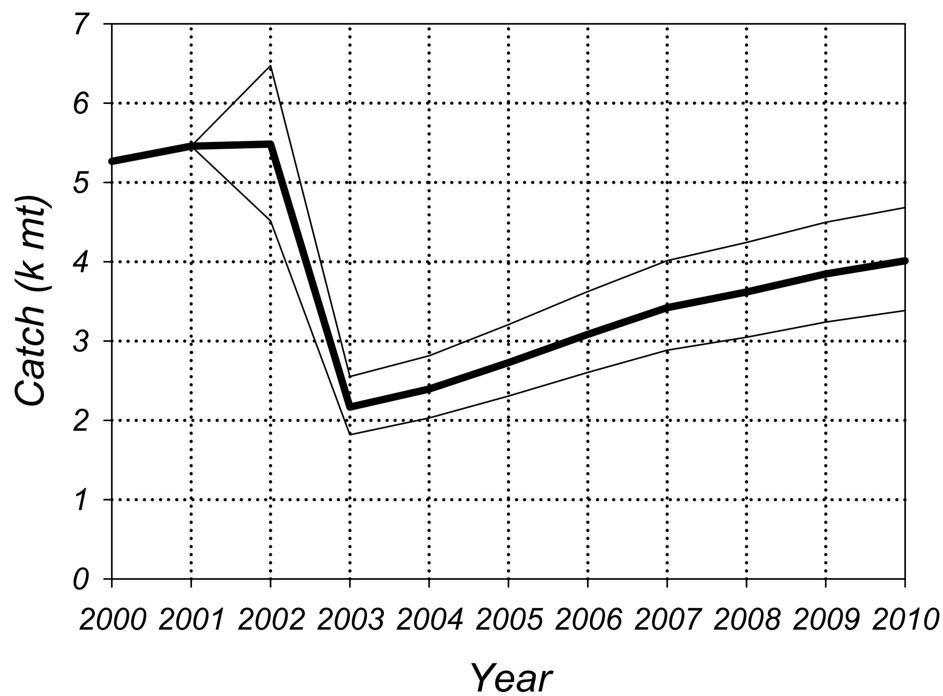


Figure 3.9.6. Median and 80% confidence interval of predicted catch for American plaice under F-rebuild fishing mortality rates.

3.10 Witch Flounder

Catch and Survey Indices

After averaging approximately 1,000 mt since the 1960s, witch flounder landings peaked around 6,000 mt in 1971-72, declined to an annual average of 2,800 mt during 1973-81, and then increased sharply to over 6,000 mt in 1983-85. Landings then declined steadily to 1,500 mt by 1990, the lowest value since 1964. Landings for 1991-2000 averaged 2,200 mt annually (Figure 3.10.1). The NEFSC spring and autumn bottom trawl survey biomass indices fluctuated without trend during the mid-1960 to late 1970s. However, in the 1980s biomass declined to record low levels in the early 1990s; since the mid-1990s, biomass has remained low (Figure 3.10.1).

Stock Assessment

Witch flounder are assessed as a unit stock from the Gulf of Maine southward (NAFO Subareas 5 and 6). An analytical assessment was conducted on this species in 1999 (Wigley et al. 1999) and reviewed at SAW 29 (NEFSC 1999b). The VPA assessment used data from 1982 to 1998 with ages 1 to 11+ which included discards in the catch at age matrix. Estimates of spawning stock biomass and recruitment (age 3) from the VPA are given in Figure 3.10.2. Spawning stock biomass has decreased over the assessment time period while recruitment has increased.

Yield and Spawning Stock Biomass per Recruit Analysis

Yield and spawning stock biomass analysis was revised slightly from the 1999 assessment to fully account for the age distribution of fish within the plus group. This was accomplished by adjusting the age 11+ mean weight at age to account for the F likely to rebuild biomass and using recent catch and stock mean weights derived for the 1994-1998 period. Partial recruitment and maturation at age were consistent with the 1999 assessment. The YPR analysis was performed using ages 3 to 11+ for consistency with the age structure of the stock sizes in the projections. A sensitivity analysis was conducted using maturation at age from 1980-1982, a period of delayed maturation associated with higher biomass levels. The yield and spawning stock biomass results are presented in Table 3.10.1. The yield and spawning stock biomass per recruit analysis indicate that F0.1 = 0.168, F40% = 0.164 and Fmax = 0.358. At F40%, the yield per recruit is 0.2406 kg and the spawning stock biomass per recruit is 1.602 kg. In the sensitivity run, F0.1 and Fmax remained unchanged, F40% decreased to 0.136 and the yield per recruit and spawning stock biomass per recruit decreased to 0.226 kg and 1.439 kg, respectively (Table 3.10.2)

MSY-based Reference Points

<u>Empirical Nonparametric Approach</u>

If F40% msp is assumed to be the proxy for Fmsy, then the fishing mortality threshold is 0.164. The spawning stock biomass per recruit associated with this fishing mortality rate is

1.602 kg and the yield per recruit is 0.2406 kg. Since the VPA stock-recruit data for the 1982-1994 year classes revealed a negative trend, the arithmetic mean of the VPA recruitment (age 3) data was used as a proxy for recruitment at maximum sustainable yield (MSY). The mean recruitment of 12.42 million fish results in an estimate of 19,900 mt of spawning stock biomass (Bmsy proxy) and MSY of 2,990 mt (including landings and discards).

Parametric Model Approach

The spawning stock biomass and age 3 recruitment from the most recent witch flounder assessment revealed an unexplained negative stock-recruit relationship for the 1982-1994 year classes (Figure 3.10.2). This negative relationship persisted regardless of recruitment age (e.g. age 1, age 2 or age 3). To determine if a longer time series of stock-recruit data would provide a different relationship, Brodziak et al. (2001) hindcast stock-recruit data were examined. The survey-derived hindcast data for the 1963-1995 year classes did not provide evidence of a positive relationship. Given the limitations of the survey-derived hindcast data series (no survey age data prior to 1980, and a discrepancy in the magnitude between the hindcast recruitment and the VPA recruitment), the hindcast data were not utilized. Due to the negative trend in the VPA stock-recruit data, parametric modeling was not appropriate, and the Working Group agreed to accept the empirical nonparametric approach.

Reference Points

Based on the yield and spawning stock biomass per recruit analysis, the following management parameters are considered most appropriate: Bmsy = 19,900 mt, Fmsy = F40% = 0.164 (fully recruited F) and MSY = 2,990 mt. This level of yield is expected to rebuild and maintain the stock size given that average recruitment is within the range observed in the most recent assessment (Figure 3.10.3).

Projections

To evaluate the trajectories of spawning stock biomass and catch under the F40% fishing mortality rate, a stochastic age-based projection (Brodziak and Rago MS 2002) was conducted over a twelve year time period beginning in 1999. Since the last year of the VPA was 1998, the projection used estimates of total catch in 1999- 2001. Annual discards for 1999-2001 were estimated by multiplying1999-2001 annual landings by the 1998 discard:landings ratio (0.18). The 2001 landings were estimated by multiplying the 2001 January-November landings by the ratio of 2000 January-November landings to 2000 January-December. The estimated total catch in 1999-2001 was 2,505 mt, 2,878 mt, and 3,459 mt, respectively. The partial recruitment at age, maturity at age and the stock and catch mean weights are the same as used in the yield and spawning stock biomass per recruit analysis given above. Initial stock sizes in 1999 were derived from 1000 bootstrap iterations of the final VPA formulation. To capture the recruitment stochasticity in the rebuilding projections, resampling from the cumulative distribution function based on the VPA age 3 recruitment from the 1982 - 1994 year classes was used (Brodziak and

Rago MS 2002). The F in 2002 was set to the median F in 2001 (0.191). The fishing mortality rate in 2003-2010 was set to Fmsy = F40% = 0.164 as derived in the YPR analysis.

The projection shows that fishing at Fmsy (0.164) between 2003 and 2009 will result in a 76 % probability of rebuilding the spawning biomass to SBBmsy (19,900 mt) by 2009 (Figure 3.10.4). The projected median spawning biomass declines slightly from 28,400 mt in 2003 to 23,100 mt in 2009 (Figure 3.10.5). The projected median catch declines slightly from 4,400 mt in 2003 to 3,500 mt in 2009 (Figure 3.10.6).

Table 3.10.1. Yield and biomass per recruit of witch flounder, using current growth and maturity rates.

```
   The NEFC Yield and Stock Size per Recruit Program - PDBYPRC
    PC Ver.2.0 [Method of Thompson and Bell (1934)] 1-Jan-1999
             ----------------------------------------
             Run Date: 21- 2-2002;  Time: 13:57:11.89
```

Witch flounder

```
Proportion of F before spawning:  .1667
Proportion of M before spawning:  .1667
Natural Mortality is Constant at:  .150
Initial age is:  3; Last age is: 11
Last age is a PLUS group;
Original age-specific PRs, Mats, and Mean Wts from file:
==> wit311s.dat
```

Age-specific Input data for Yield per Recruit Analysis

Age	Fish Mort Pattern	Nat Mort Pattern	Proportion Mature	Average Weights Catch	Average Weights Stock
3	.0130	1.0000	.0000	.067	.042
4	.0730	1.0000	.0800	.179	.114
5	.2330	1.0000	.4500	.264	.221
6	.4730	1.0000	.8500	.399	.333
7	1.0000	1.0000	1.0000	.527	.468
8	1.0000	1.0000	1.0000	.660	.595
9	1.0000	1.0000	1.0000	.868	.766
10	1.0000	1.0000	1.0000	.974	.920
11+	1.0000	1.0000	1.0000	1.248	1.236

Summary of Yield per Recruit Analysis for:

Witch flounder

```
 Slope of the Yield/Recruit Curve at F=0.00: -->    3.8732
   F level at slope=1/10 of the above slope (F0.1): ----->    .168
     Yield/Recruit corresponding to F0.1: ----->     .2420
   F level to produce Maximum Yield/Recruit (Fmax): ----->    .358
     Yield/Recruit corresponding to Fmax: ----->     .2669
   F level at 40 % of Max Spawning Potential (F40): ----->    .164
     SSB/Recruit corresponding to F40: -------->    1.6017
```

Listing of Yield per Recruit Results for:

Witch flounder

	FMORT	TOTCTHN	TOTCTHW	TOTSTKN	TOTSTKW	SPNSTKN	SPNSTKW	% MSP
	.00	.00000	.00000	7.1792	4.3601	4.7636	4.0045	100.00
	.05	.15695	.13425	6.1354	3.1692	3.7230	2.8217	70.46
	.10	.25205	.19992	5.5038	2.4784	3.0947	2.1377	53.38
	.15	.31620	.23412	5.0785	2.0340	2.6726	1.6994	42.44
F0.1	.17	.33462	.24204	4.9565	1.9108	2.5517	1.5782	39.41
F40%	**.16**	**.33102**	**.24057**	**4.9803**	**1.9347**	**2.5753**	**1.6017**	**40.00**
	.20	.36264	.25220	4.7710	1.7281	2.3684	1.3987	34.93
	.25	.39801	.26144	4.5374	1.5069	2.1380	1.1822	29.52
	.30	.42597	.26564	4.3530	1.3409	1.9569	1.0204	25.48
	.35	.44875	.26689	4.2030	1.2126	1.8103	.8958	22.37
Fmax	.36	.45193	.26690	4.1821	1.1953	1.7899	.8790	21.95
	.40	.46774	.26640	4.0783	1.1110	1.6889	.7975	19.92
	.45	.48388	.26491	3.9724	1.0289	1.5864	.7184	17.94
	.50	.49782	.26284	3.8812	.9613	1.4984	.6536	16.32
	.55	.51002	.26046	3.8014	.9048	1.4220	.5997	14.98
	.60	.52084	.25794	3.7309	.8570	1.3549	.5542	13.84
	.65	.53051	.25539	3.6678	.8160	1.2952	.5154	12.87
	.70	.53924	.25287	3.6110	.7804	1.2419	.4819	12.03
	.75	.54717	.25040	3.5595	.7493	1.1937	.4527	11.30
	.80	.55444	.24802	3.5123	.7218	1.1499	.4270	10.66
	.85	.56113	.24573	3.4689	.6973	1.1099	.4043	10.10
	.90	.56733	.24354	3.4287	.6753	1.0732	.3840	9.59
	.95	.57310	.24144	3.3914	.6555	1.0393	.3658	9.13
	1.00	.57848	.23944	3.3566	.6375	1.0079	.3493	8.72

Table 3.10.2. Yield and biomass per recruit of witch flounder using historical maturity rates.

```
 The NEFC Yield and Stock Size per Recruit Program - PDBYPRC
   PC Ver.2.0 [Method of Thompson and Bell (1934)] 1-Jan-1999
            ---------------------------------------
            Run Date: 21- 2-2002;  Time: 13:58:47.68
```

Witch flounder sensitivity run using 1980-1982 maturity ogive

```
Proportion of F before spawning:  .1667
Proportion of M before spawning:  .1667
Natural Mortality is Constant at:  .150
Initial age is:  3; Last age is: 11
Last age is a PLUS group;
Original age-specific PRs, Mats, and Mean Wts from file:
==> wit311sm.dat
```

Age-specific Input data for Yield per Recruit Analysis

Age	Fish Mort Pattern	Nat Mort Pattern	Proportion Mature	Average Weights Catch	Stock
3	.0130	1.0000	.0000	.067	.042
4	.0730	1.0000	.0000	.179	.114
5	.2330	1.0000	.0200	.264	.221
6	.4730	1.0000	.1500	.399	.333
7	1.0000	1.0000	.4900	.527	.468
8	1.0000	1.0000	.8200	.660	.595
9	1.0000	1.0000	.9700	.868	.766
10	1.0000	1.0000	1.0000	.974	.920
11+	1.0000	1.0000	1.0000	1.248	1.236

Summary of Yield per Recruit Analysis for:
Witch flounder sensitivity run using 1980-1982 maturity ogive

```
 Slope of the Yield/Recruit Curve at F=0.00: -->    3.8732
   F level at slope=1/10 of the above slope (F0.1): ----->    .168
     Yield/Recruit corresponding to F0.1: ----->      .2420
   F level to produce Maximum Yield/Recruit (Fmax): ----->    .358
     Yield/Recruit corresponding to Fmax: ----->      .2669
   F level at 40 % of Max Spawning Potential (F40): ----->    .136
     SSB/Recruit corresponding to F40: -------->    1.4388
```

Listing of Yield per Recruit Results for:
Witch flounder sensitivity run using 1980-1982 maturity ogive

	FMORT	TOTCTHN	TOTCTHW	TOTSTKN	TOTSTKW	SPNSTKN	SPNSTKW	% MSP
	.00	.00000	.00000	7.1792	4.3601	3.5826	3.5970	100.00
	.05	.15695	.13425	6.1354	3.1692	2.5748	2.4293	67.54
	.10	.25205	.19992	5.5038	2.4784	1.9775	1.7595	48.92
F40%	**.14**	**.30006**	**.22645**	**5.1854**	**2.1436**	**1.6825**	**1.4388**	**40.00**
	.15	.31620	.23412	5.0785	2.0340	1.5848	1.3345	37.10
F0.1	.17	.33462	.24204	4.9565	1.9108	1.4742	1.2179	33.86
	.20	.36264	.25220	4.7710	1.7281	1.3085	1.0464	29.09
	.25	.39801	.26144	4.5374	1.5069	1.1047	.8417	23.40
	.30	.42597	.26564	4.3530	1.3409	.9489	.6910	19.21
	.35	.44875	.26689	4.2030	1.2126	.8264	.5769	16.04
Fmax	.36	.45193	.26690	4.1821	1.1953	.8097	.5617	15.62
	.40	.46774	.26640	4.0783	1.1110	.7280	.4886	13.58
	.45	.48388	.26491	3.9724	1.0289	.6475	.4189	11.65
	.50	.49782	.26284	3.8812	.9613	.5806	.3630	10.09
	.55	.51002	.26046	3.8014	.9048	.5243	.3176	8.83
	.60	.52084	.25794	3.7309	.8570	.4764	.2801	7.79
	.65	.53051	.25539	3.6678	.8160	.4353	.2490	6.92
	.70	.53924	.25287	3.6110	.7804	.3996	.2227	6.19
	.75	.54717	.25040	3.5595	.7493	.3685	.2005	5.57
	.80	.55444	.24802	3.5123	.7218	.3411	.1815	5.04
	.85	.56113	.24573	3.4689	.6973	.3169	.1651	4.59
	.90	.56733	.24354	3.4287	.6753	.2953	.1508	4.19
	.95	.57310	.24144	3.3914	.6555	.2761	.1384	3.85
	1.00	.57848	.23944	3.3566	.6375	.2587	.1275	3.54

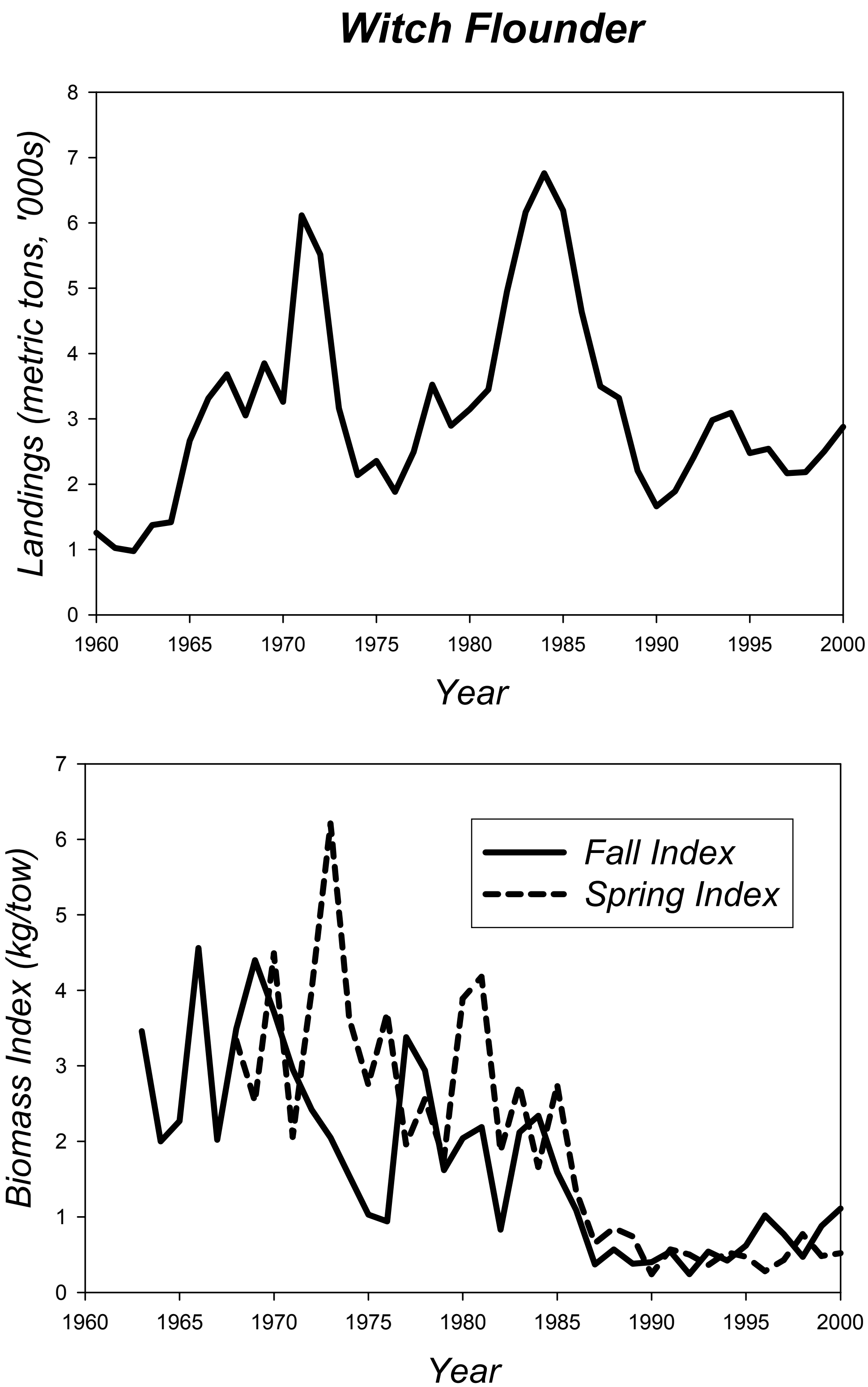
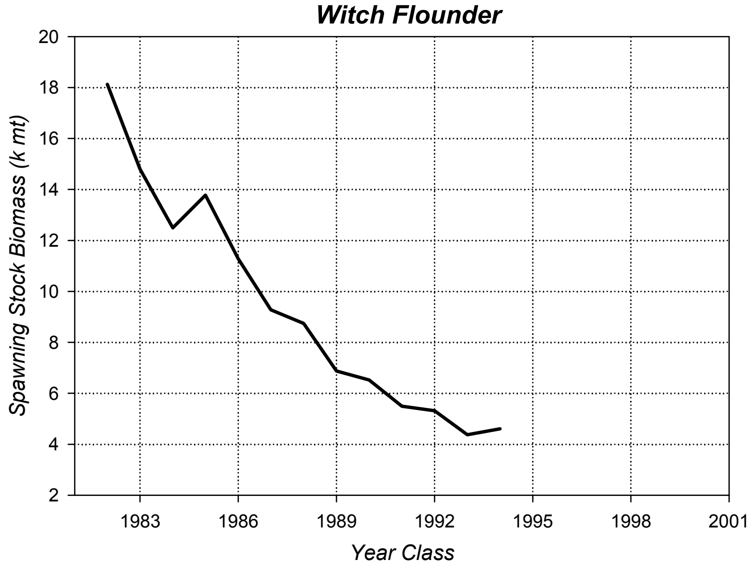
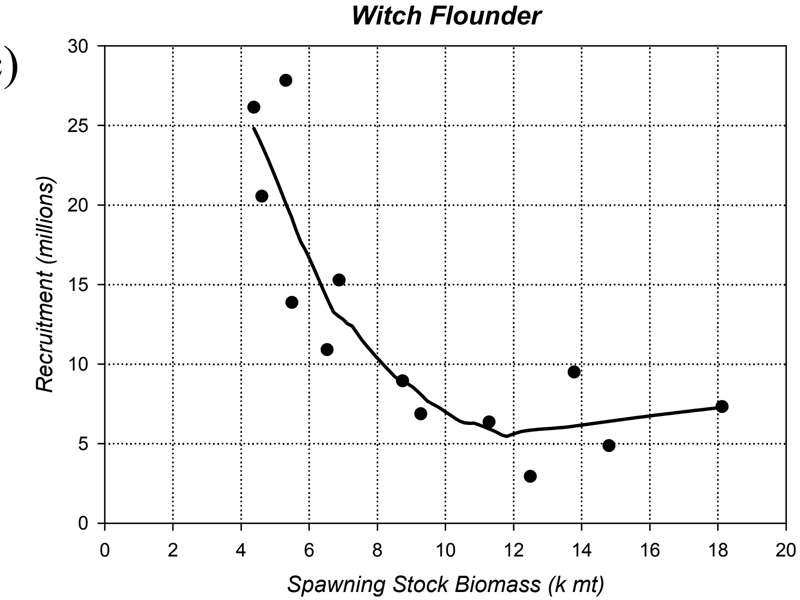


Figure 3.10.1. Landings and research vessel survey abundance indices for Witch flounder.

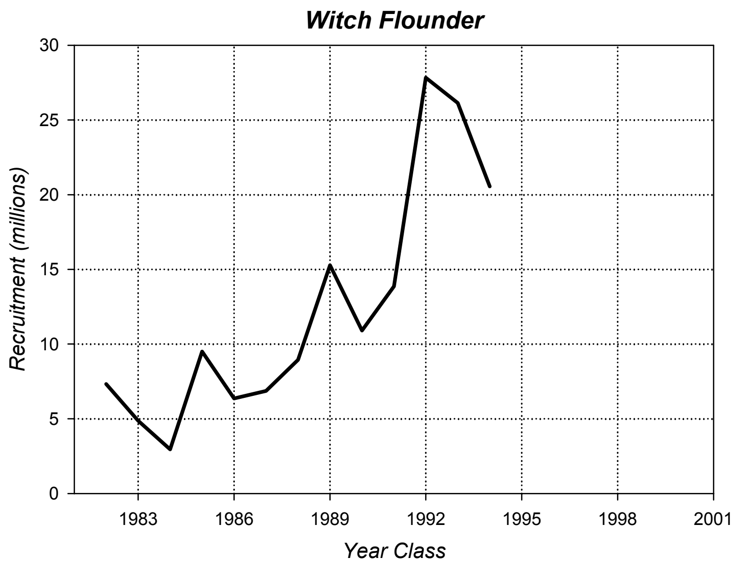
(a)



(c)



(b)



		F0.1	F40% MSP
F reference point		0.168	0.164
ssb per recruit at F		1.578	1.602
	Recruitment (millions)	SS Biomass at F0.1	SS Biomass at F40%
n	13	13	13
mean	12.42	19.60	19.89
min	2.95	4.66	4.73
max	27.83	43.93	44.58
10th %'tile	5.17	8.16	8.28
25th %'tile	6.87	10.84	11.01
50th %'tile	9.50	15.00	15.22
75th %'tile	15.28	24.11	24.47
90th %'tile	25.02	39.49	40.08
Std Dev	7.99	12.60	12.79
CV	0.64	0.64	0.64

Figure 3.10.2. Spawning stock (a), recruitment (age 3 millions, b), and scatterplot (c) for witch flounder. Data are the calculated spawning stock biomasses for various recruitment scenarios multiplied by the expected SSB per recruit for F0.1 and F40% MSP, assuming recent patterns of growth, maturity and partial recruitment at age (Table 3.10.1). Smoother in the stock-recruitment plot is lowess with tension = 0.5.

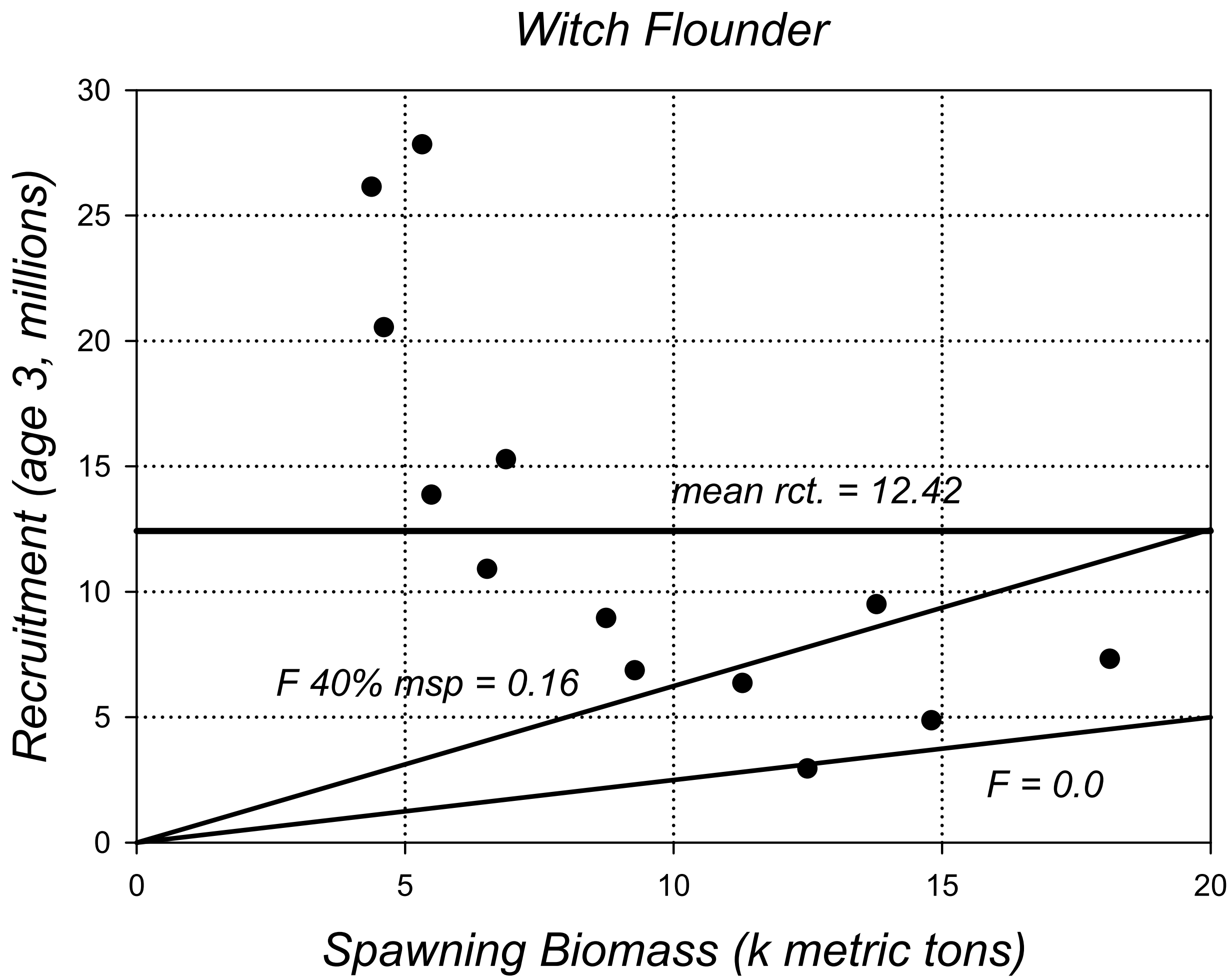


Figure 3.10.3. Stock and recruitment data for witch flounder. For the empirical non-parametric approach the mean recruitment is plotted along with the replacement lines for F=0.0 and F 40% msp = 0.16.

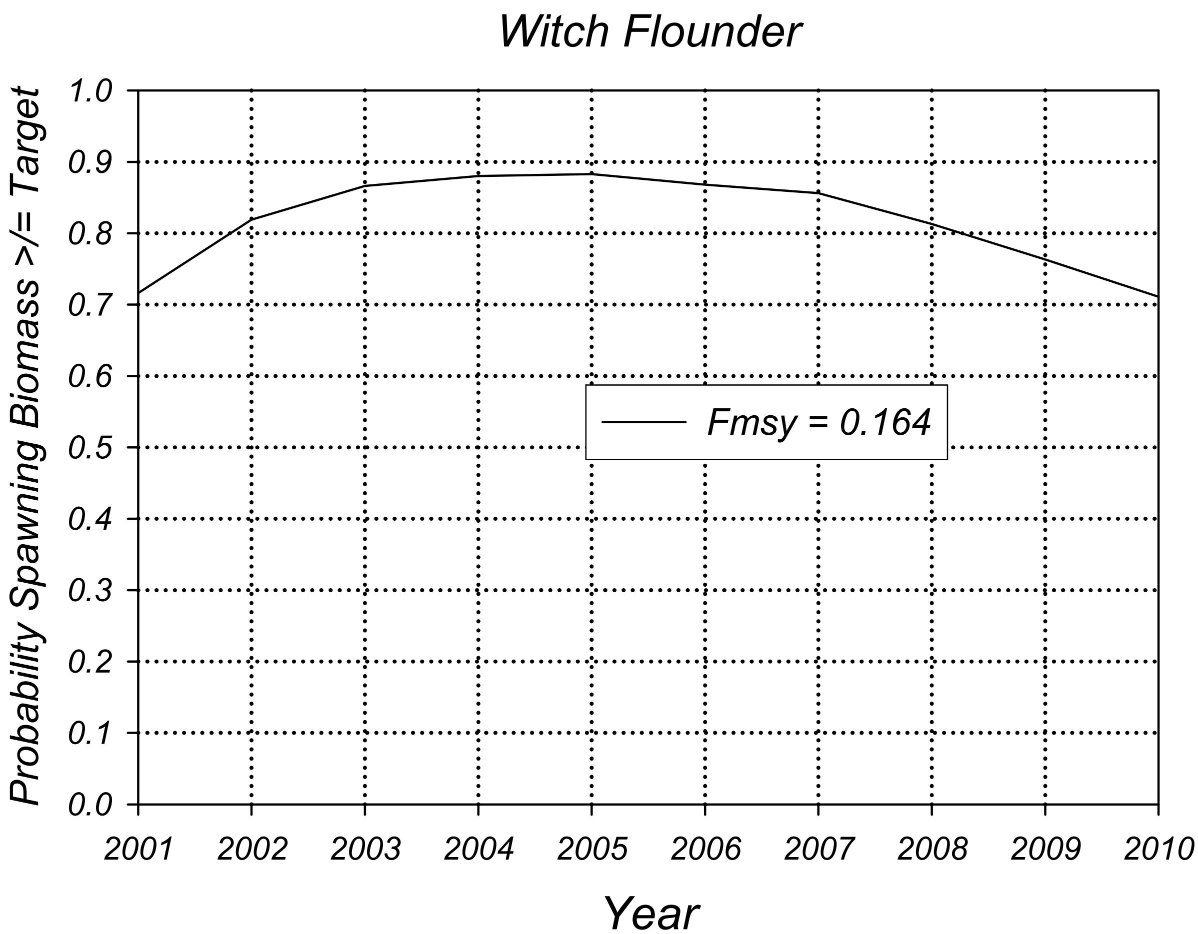


Figure 3.10.4. Probability that witch flounder spawning biomass will exceed Bmsy (19,900 mt) annually under Fmsy.

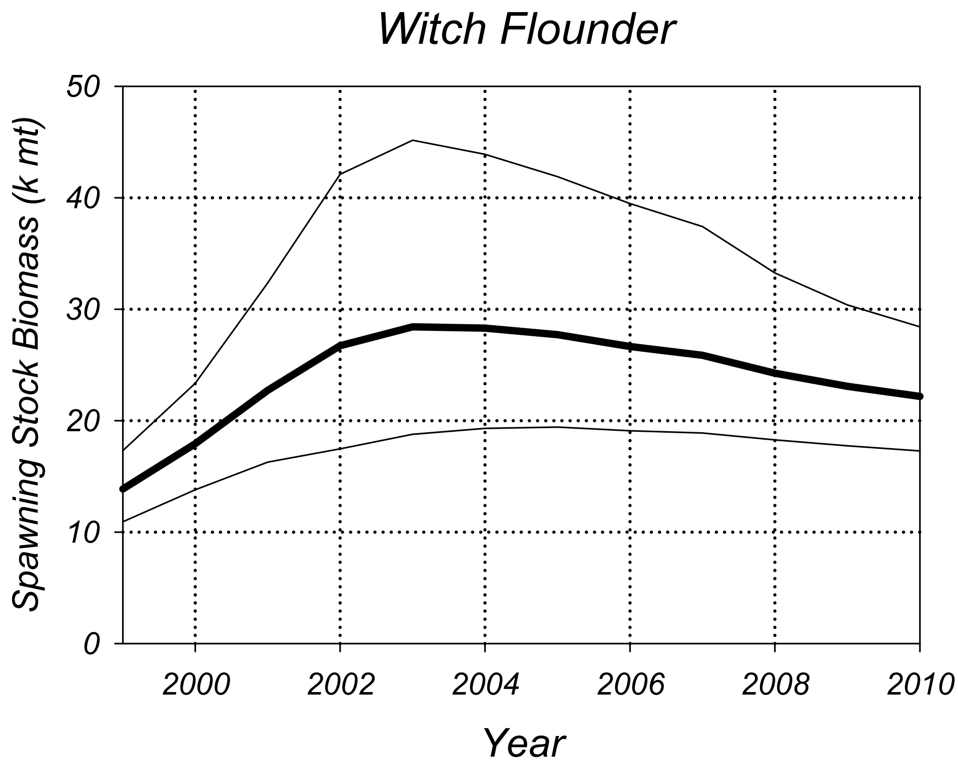


Figure 3.10.5. Median and 80% confidence interval of predicted spawning biomass for witch flounder under F-msy fishing mortality rates.

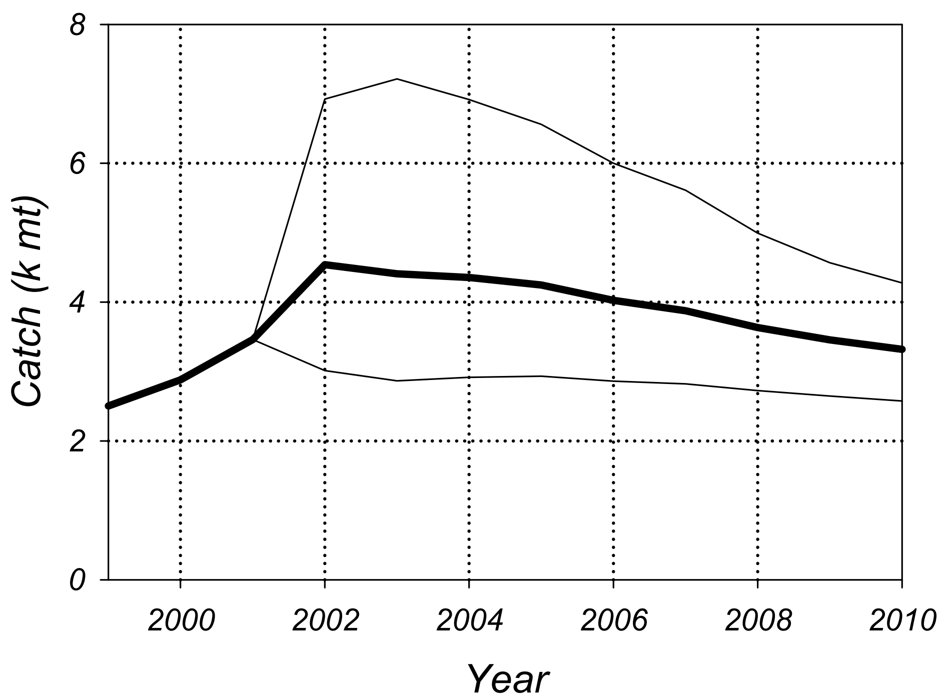


Figure 3.10.6. Median and 80% confidence interval of predicted catch for witch flounder under F-msy fishing mortality rates.

3.11 Southern New England winter flounder

Catch and Survey Indices

After reaching an historical peak of nearly 12,000 metric tons (mt) in 1966, then declining through the 1970s, total U.S. commercial landings again peaked at 11,200 mt in 1981, and then steadily declined to a record low of 2,200 mt in 1994. Commercial landings have increased since 1994 to about 3,900 mt in 2000. Commercial fishery discards are generally about 5-10% of the commercial landings, and were estimated to be about 270 mt in 2000. Recreational landings reached a peak of 5,800 mt in 1984, but declined dramatically thereafter, and were estimated at about 530 mt in 2000. Recreational discards are small in relation to the other components of the catch, and were estimated at only 24 mt in 2000. The total catch of Southern New England winter flounder varied between 12,000 to 16,000 in the early 1980s, declined through the 1980s to about 4,000 mt by 1994, and was about 4,700 mt in 2000 (Figure 3.11.1). NEFSC research survey indices dropped from the beginning of the time series in the 1960s to a low point in the early to mid- 1970s, then rose to a peak by the early 1980s. Following several years of high indices in the early 1980s, NEFSC abundance indices reached near- or record low levels in the late 1980s- early 1990s. NEFSC survey indices have generally increased since 1993, and are currently at about 50% of the peak levels seen in the mid-1960s and early 1980s (Figure 3.11.1). Massachusetts Division of Marine Fisheries (MADMF) research survey indices steadily declined from a peak in 1979 to a low in 1992, and then increased to moderate levels in the late 1990s (Figure 3.11.1).

Stock Assessment

The Southern New England/Mid-Atlantic Bight stock complex of winter flounder was last fully assessed by SAW 28 in 1998, with catches through 1997 (NEFSC 1999a). The assessment is for the entire stock complex, which includes several inshore spawning aggregations that individually may not demonstrate the same trend in abundance as the complex. Fully recruited (ages 4-6) fishing mortality in 1997 was estimated at 0.31, and total stock biomass in 1997 was estimated to be 17,900 mt. Reference points were estimated by a surplus production model in the SAW 28 assessment. Bmsy (total stock biomass) was estimated to be 27,810 mt, and MSY was estimated to be 10,200 mt, Fmsy was estimated to be biomass weighted F = 0.37 (equivalent to fully recruited F of 0.59), and the FMP Amendment 9 ten year rebuilding target biomass weighted fishing mortality was estimated to be $F_{target10}$ = 0.24 (equivalent to fully recruited F of 0.33). Projections for Southern New England winter flounder through 1999 were reviewed as part of the 2001 review of 19 Northeast groundfish stocks conducted by the NEFSC staff (Northern Demersal and Southern Demersal Working Groups 2001). Projections based on 1998 and 1999 total catch indicated that fully recruited F (age 4-6) was still at about 0.30 in 1999, and total stock biomass was estimated to be about 25,300 mt. The fishing mortality reference points F(0.1) and F40% given in Figure 3.11.2 were calculated for this exercise using ages 1 through 7+ in order to be consistent with the projections described below, and thus may differ slightly from previously reported values (see appendix for yield per recruit analysis results).

Empirical Nonparametric approach

If F40% is assumed to be an adequate proxy for Fmsy, then the fishing mortality threshold is 0.206. This fishing mortality rate produces 1.1063 kg of spawning stock biomass per recruit and 0.2462 kg of yield per recruit (including discards; Figure 3.11.2). Since the VPA estimates of recruitment increase with increasing spawning stock size, the mean of the top 5 value of spawning stock biomass is assumed to be representative of recruitment levels expected at maximum sustainable yield (MSY). Thus, recruitment of 42.31 million fish results in an estimate of 46,810 mt of spawning stock biomass (Bmsy proxy) and 10,420 mt of total yield (including discards; Figure 3.11.2).

Parametric Model Approach

Maximum likelihood fits of the 10 parametric stock-recruitment models to the Southern New England winter flounder VPA estimates for 1982-1998 are listed below (Table 3.11.1). The model acronyms are: BH = Beverton-Holt, ABH = Beverton-Holt with autoregressive errors, PBH = Beverton-Holt with steepness prior, PABH = Beverton-Holt with steepness prior and autoregressive errors, PRBH = Beverton-Holt with recruitment prior, PRABH = Beverton-Holt with recruitment prior and autoregressive errors, RK = Ricker, ARK = Ricker with autoregressive errors, PRK = Ricker with slope at the origin prior, PARK = Ricker with slope at the origin prior and autoregressive errors. The six hierarchical criteria are applied to each of the models to determine the set of candidate models.

The ABH model does not satisfy criterion 1 because the estimate of steepness is on the boundary of the feasible range. The second criterion is not satisfied by the BH, PBH, RK, and PRK models because their point estimates of MSY are above the maximum observed landings value of 15,800 mt. All remaining models satisfy criterion 3. The remaining models also satisfy the fourth criterion because F_{MAX}=0.89. The remaining autoregressive models PABH, PRABH, ARK, and PARK, do not satisfy criterion 5 because their power spectra imply long-term forcing beyond the length of the stock-recruitment time series (Figure 3.11.3). The last remaining model is the PRBH model which satisifies criteria 3 through 6. Thus, the PRBH model is the only candidate parametric model for Southern New England winter flounder.

The results of using the PRBH model as the best fit parametric model are shown below (Figures 3.11.4-3.11.7). The standardized residual plot of the fit of the PRBH model to the stock-recruitment data shows that the standardized residuals generally lie within ± two standard deviations of zero (Figure 3.11.4), with the exception of the 1992 data point.

In the equilibrium yield plot (Figure 3.11.5), the yield surface is relatively flat in the neighborhood of the point estimate of F_{MSY} = 0.32. The point estimates of S_{MSY} (30,100 mt) and MSY (10,600 mt) appear consistent with the nonparametric proxy estimate of S_{MSY} and previous estimates of MSY. The stock-recruitment plot (Figure 3.11.6) shows that recruitment values near S_{MSY} are roughly 45 million fish which is consistent with the long-term average of the observed recruitment series when spawning biomass was high, during the early 1980s.

Parameter uncertainty plots show histograms of 5000 MCMC sample estimates of MSY, S_{MSY}, and F_{MSY} drawn from the posterior distribution of the MLE based on an uninformative prior. For MSY, the 80 percent credibility interval was (9,500, 11,200) with a median of 10,400 mt (Figure 3.11.7). For S_{MSY}, the 80 percent credibility interval was (25,500, 32,100) with a median of 28,900 mt. For F_{MSY}, the 80 percent credibility interval was (0.305, 0.355) with a median of 0.325. Overall, the point estimates of MSY and S_{MSY} were slightly larger than the medians of the MCMC samples.

Reference Points

Based on the conformance of the recruitment-biomass per recruit analysis and the parametric stock-recruitment relationship, the following management parameters are considered most appropriate: Bmsy = 30,100 mt (spawning stock biomass), Fmsy = 0.32 (fully recruited F), and MSY = 10,600 mt (including commercial and recreational landings and discards). Catch equal to or exceeding this estimate of MSY was removed from the stock during the early 1980s, but at a spawning stock biomass (10,000-15,000 mt) of about 50% of the Bmsy level, and at much higher fully recruited fishing mortality rates (F = 0.45-0.77) than the Fmsy level.

Projections

Given that the Beverton and Holt model with a prior on recruitment (set at the mean of the recruitment (42.31 million) produced by the spawning stock biomass present during the early 1980s (>10,000 mt)) was assumed to be the most appropriate fit for the VPA stock and recruitment data, projections were conducted with this relationship. Since the last year in the VPA was 1997, total catch for 1998-2001 was estimated using 1998-2000 commercial and recreational landings and discard estimates, 2001 commercial landings for January-November raised to an annual total, 2001 commercial discards assumed to be 7% of the 2001 commercial landings, and 2001 preliminary recreational landings and discards estimates. The 2000 total catch estimate is 4,711 mt and the 2001 total catch estimate is 4,746 mt. For 2002, the fishing mortality rate was assumed to be the same as that estimated for 2001, F = 0.251. For years 2003 through 2009, the fishery was assumed to fish at a rate of Fmsy (0.32, fully recruited F). Under these assumptions, there is a 45% chance that the spawning stock biomass will be at least as large as Bmsy by 2009 (see Figures 3.11.8-3.11.10. for projection results). A second projection indicates that fishing mortality would need to be reduced to F = 0.30 during 2003 through 2009 to provide at least a 50% chance that spawning stock biomass will reach Bmsy by 2009.

Table 3.11.1. Stock-recruitment model comparisons for southern New England winter flounder.

Southern New England Winter Flounder Model Comparison										
SMAX =	14.8									
	Prior	Prior	Prior	Prior	Prior	Prior	Prior	Prior	Prior	Prior
	0	0	0	0	1.0000	0.0	0	0	0	0
	BH	ABH	PBH	PABH	**PRBH**	PRABH	RK	ARK	PRK	PARK
Posterior Probability	0.00	0.00	0.00	0.00	**1.00**	0.00	0.00	0.00	0.00	0.00
Odds Ratio for Most Likely Model					1.00					
Normalized Likelihood	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00
Model AIC Ratio					1					
	BH	**ABH**	**PBH**	**PABH**	**PRBH**	**PRABH**	**RK**	**ARK**	**PRK**	**PARK**
Number_of_data_points	17	17	17	17	17	17	17	17	17	17
Number_of_parameters	3	4	3	4	3	4	3	4	3	4
Negative_loglikelihood	57.3304	54.4788	55.9922	53.8859	61.6136	57.7619	57.3451	55.336	59.7565	56.1928
Bias-corrected_AIC	122.507	120.291	122.557	121.841	125.772	121.797	122.536	122.005	124.919	125.295
Diagnostic Comments	MSY exceeds max observed landings & SMSY substantially exceeds proxy	Steepness parameter at boundary of feasible range	MSY exceeds max observed landings & SMSY substantially exceeds proxy	Power spectrum dominant frequency exceeds 1/2 time series length	**Most Likely Model**	Power spectrum dominant frequency exceeds 1/2 time series length	MSY exceeds max observed landings	Power spectrum dominant frequency exceeds 1/2 time series length	MSY and SMSY are outside credible range	Power spectrum dominant frequency exceeds 1/2 time series length
Parameter Point Estimates										
***********************										
MSY	24.8351	7.73735	21.6966	9.71019	10.606	10.4364	17.1342	8.24175	32407.8	1.79024
FMSY	0.265	0.905	0.27	0.345	0.32	0.37	0.44	0.755	0.35	0.26
SMSY	85.9627	7.10725	73.6515	25.4992	30.1439	25.4559	34.7668	9.28666	83823.1	6.32069
alpha	125.526	25.5949	107.923	41.6089	47.5356	43.2341	1.41779	2.06335	1.15144	0.812791
expected_alpha	131.789	29.4582	113.324	44.7586	50.4245	46.8443	1.48866	2.29786	1.21789	2.57165
beta	29.5672	6.641E-06	24.2383	5.30601	7.39754	4.63312	-2.57E-02	-1.06E-01	-1E-05	-0.117795
RMAX	41.8728	25.5948	40.9151	30.6282	31.6939	32.9265	41.7365	24.2483	46.8016	5.83601
expected_RMAX	43.9621	29.4582	42.9627	32.9467	33.6201	35.676	43.8226	27.0042	49.5028	18.465
Prior_mean			0.8	0.8	42.314	42.314			0.79	0.79
Prior_se			0.09	0.09	4.95	4.95			0.18	0.18
Z_Myers	0.75	1.00	0.75	0.84	0.82	0.87				
sigma	0.312	0.530	0.313	0.382	0.344	0.400	0.312	0.464	0.335	1.518
phi		0.88		0.71		0.74		0.82		0.98
sigmaw		0.25		0.27		0.27		0.27		0.28
last log-residual R		-0.419		-0.422		-0.510		-0.479		0.872
expected lognormal error term	1.050	1.15	1.05	1.08	1.06	1.08	1.05	1.11	1.06	3.16

Table 3.11.2. Results of yield and spawning stock biomass per recruit analyses for Southern New England winter flounder.

The NEFC Yield and Stock Size per Recruit Program - PDBYPRC
PC Ver.1.1 [Method of Thompson and Bell (1934)] 1-OCT-1991

Run Date: 21- 2-2002; Time: 11:08:52.02
SNE/MAB WFL: SARC 28 PR, Mean Weights, 7+

Proportion of F before spawning: .2000
Proportion of M before spawning: .2000
Natural Mortality is Constant at: .200
Initial age is: 1; Last age is: 7
Last age is a PLUS group;
Original age-specific PRs, Mats, and Mean Wts from file:
==> YPR28_7.DAT

Age-specific Input data for Yield per Recruit Analysis

Age	Fish Mort Pattern	Nat Mort Pattern	Proportion Mature	Average Weights Stock	Average Weights Catch
1	.0200	1.0000	.0000	.067	.134
2	.2500	1.0000	.0000	.264	.388
3	.6100	1.0000	.5300	.430	.508
4	1.0000	1.0000	.9500	.540	.612
5	1.0000	1.0000	1.0000	.657	.754
6	1.0000	1.0000	1.0000	.817	.941
7+	1.0000	1.0000	1.0000	1.113	1.135

Summary of Yield per Recruit Analysis for:
SNE/MAB WFL: SARC 28 PR, Mean Weights, 7+

Slope of the Yield/Recruit Curve at F=0.00: --> 2.8970
F level at slope=1/10 of the above slope (F0.1): -----> .253
Yield/Recruit corresponding to F0.1: -----> .2626
F level to produce Maximum Yield/Recruit (Fmax): -----> .890
Yield/Recruit corresponding to Fmax: -----> .3023
F level at 40 % of Max Spawning Potential (F40): -----> .206
SSB/Recruit corresponding to F40: --------> 1.1063

1

Listing of Yield per Recruit Results for:
SNE/MAB WFL: SARC 28 PR, Mean Weights, 7+

	FMORT	TOTCTHN	TOTCTHW	TOTSTKN	TOTSTKW	SPNSTKN	SPNSTKW	% MSP
	.000	.00000	.00000	5.5167	3.3129	3.2239	2.7665	100.00
	.050	.13317	.11028	4.8535	2.6281	2.5682	2.0908	75.57
	.100	.22266	.17569	4.4087	2.1821	2.1307	1.6529	59.75
	.150	.28717	.21679	4.0886	1.8711	1.8179	1.3494	48.78
	.200	.33606	.24365	3.8466	1.6435	1.5831	1.1287	40.80
F40%	.206	.34115	.24621	3.8214	1.6203	1.5587	1.1063	39.99
	.250	.37451	.26170	3.6566	1.4708	1.4002	.9624	34.79
F0.1	.253	.37656	.26258	3.6465	1.4618	1.3905	.9537	34.47
	.300	.40565	.27406	3.5032	1.3359	1.2536	.8334	30.13
	.350	.43146	.28266	3.3763	1.2280	1.1336	.7311	26.43
	.400	.45326	.28869	3.2694	1.1401	1.0334	.6483	23.44
	.450	.47197	.29295	3.1778	1.0672	.9485	.5803	20.98
	.500	.48824	.29597	3.0984	1.0059	.8756	.5236	18.93
	.550	.50256	.29811	3.0286	.9537	.8123	.4758	17.20
	.600	.51528	.29961	2.9668	.9088	.7569	.4350	15.72
	.650	.52669	.30065	2.9115	.8697	.7079	.3999	14.45
	.700	.53699	.30136	2.8617	.8354	.6643	.3693	13.35
	.750	.54635	.30182	2.8165	.8050	.6252	.3426	12.38
	.800	.55492	.30210	2.7753	.7780	.5899	.3190	11.53
	.850	.56280	.30225	2.7374	.7537	.5580	.2981	10.78
Fmax	.890	.56870	.30230	2.7091	.7359	.5344	.2829	10.23
	.900	.57008	.30230	2.7024	.7317	.5289	.2794	10.10
	.950	.57684	.30228	2.6701	.7118	.5023	.2627	9.49
	1.000	.58314	.30220	2.6400	.6936	.4779	.2475	8.95

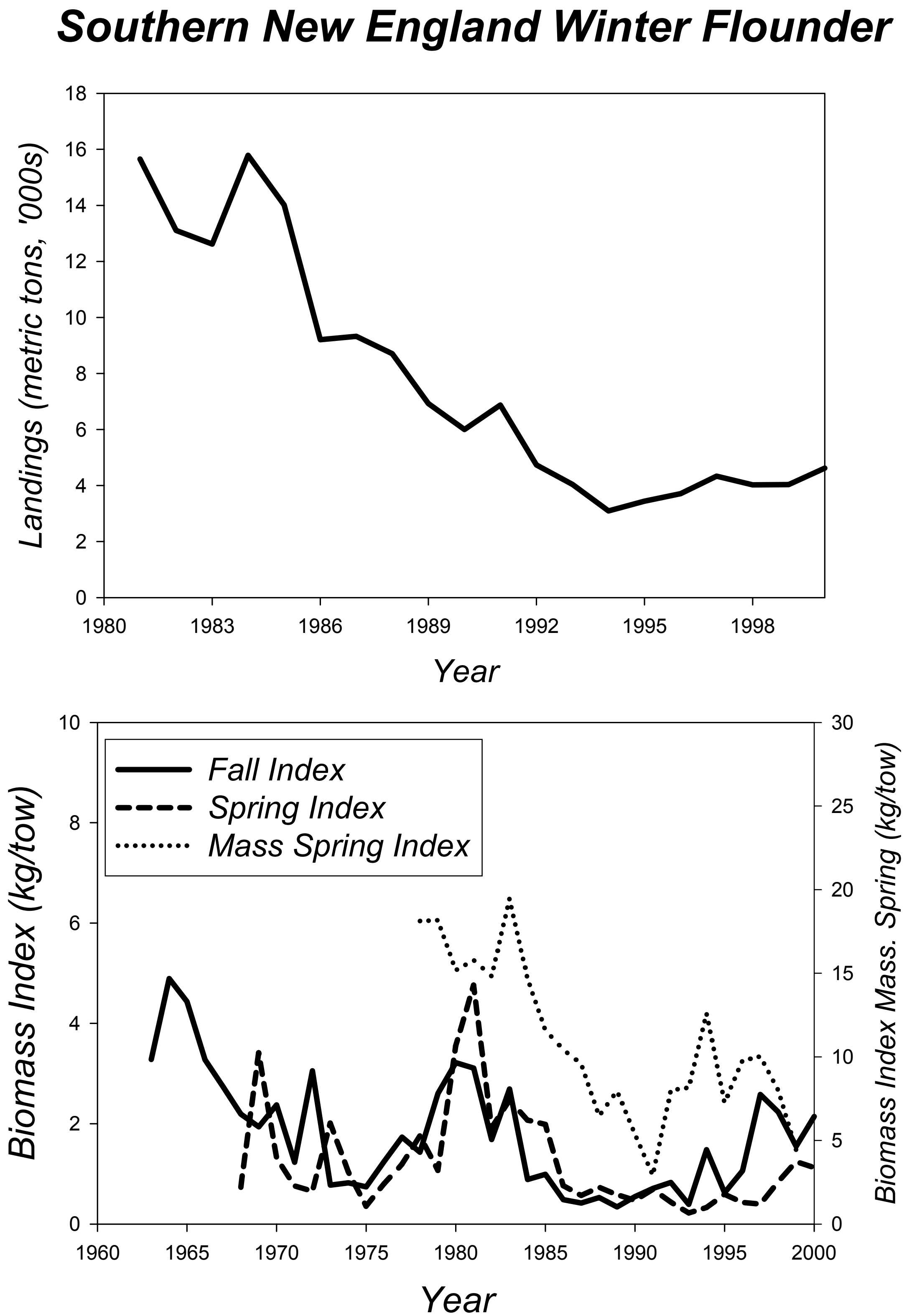
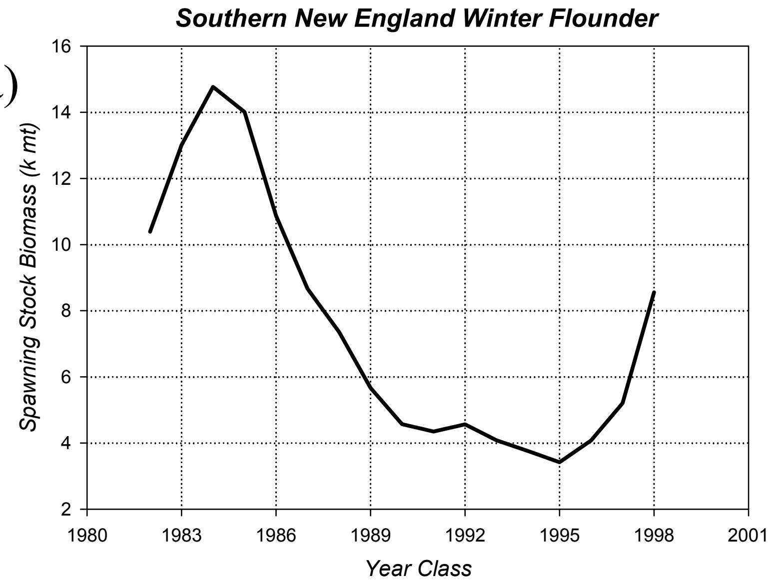
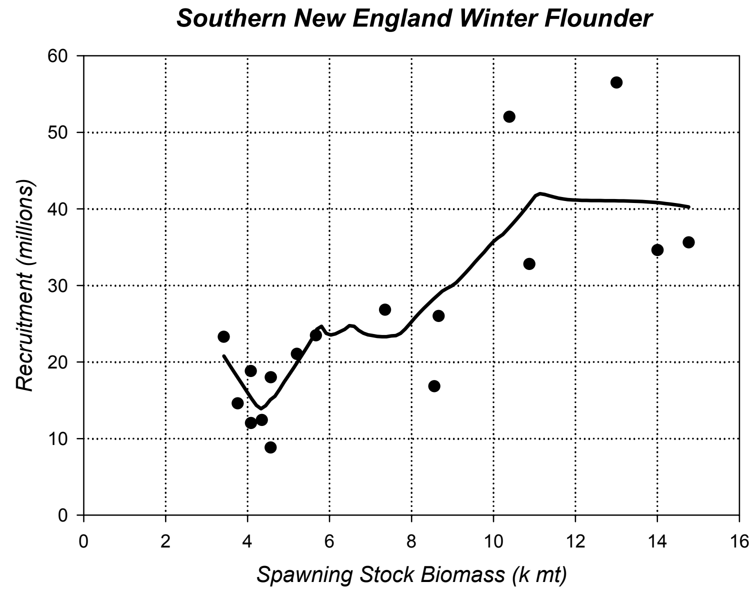


Figure 3.11.1. Landings and research vessel survey abundance indices for Southern New England winter flounder.

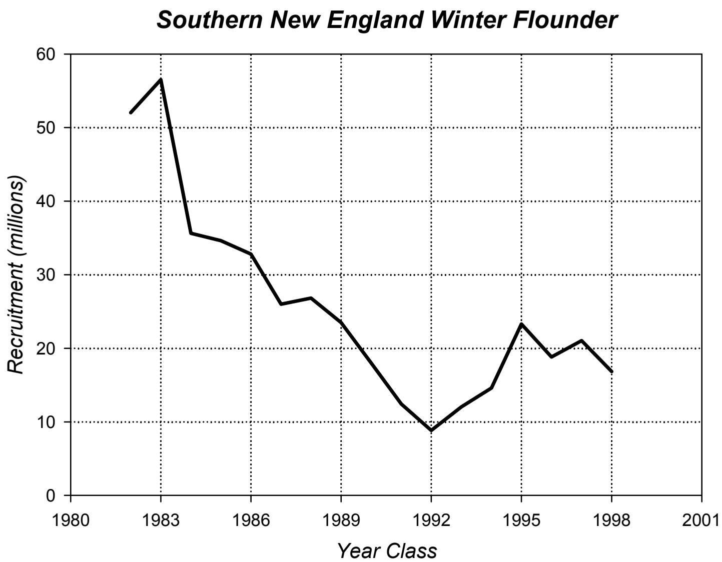
(a)



(c)



(b)



		F0.1	F40% MSP
F reference point		0.253	0.206
ssb per recruit at F		0.9624	1.1063
	Recruitment (millions)	SS Biomass at F0.1	SS Biomass at F40%
n	17	17	17
mean	25.51	24.55	28.23
min	8.83	8.50	9.77
max	56.51	54.38	62.51
10th %'tile	12.26	11.80	13.57
25th %'tile	16.84	16.20	18.63
50th %'tile	23.29	22.41	25.76
75th %'tile	32.81	31.57	36.29
90th %'tile	42.18	40.59	46.66
Std Dev	13.37	12.87	14.79
CV	0.52	0.52	0.52
For Top 5 Values of SSB			
Mean	42.31	40.72	46.81
Median	35.62	34.28	39.40

Figure 3.11.2. Spawning stock (a), recruitment (age 1 millions, b), and scatterplot (c) for Southern New England winter flounder. Data are the calculated spawning stock biomasses for various recruitment scenarios multiplied by the expected SSB per recruit for F0.1 and F40% MSP, assuming recent patterns of growth, maturity and partial recruitment at age (Table 3.11.2). Smoother in the stock-recruitment plot is lowess with tension = 0.5.

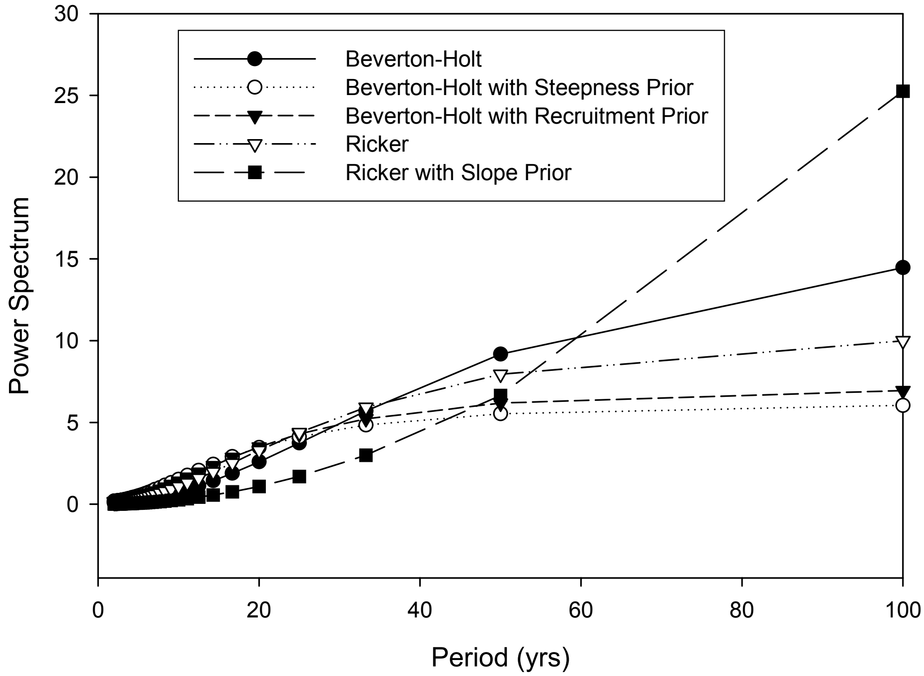


Figure 3.11.3. Southern New England winter flounder periodicity of environmental forcing for autoregressive stock-recruitment models.

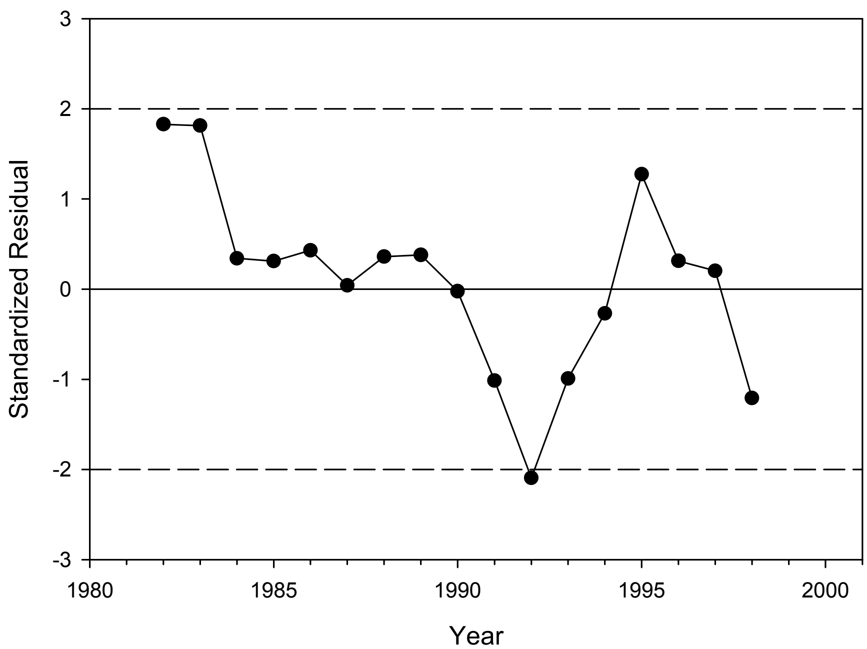


Figure 3.11.4. Southern New England winter flounder standardized residuals for the most likely stock-recruitment model

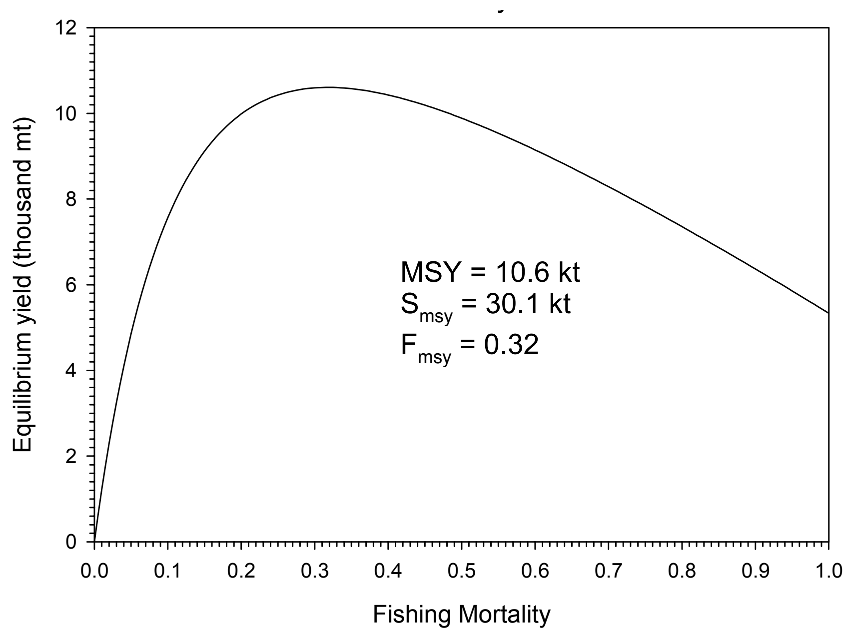


Figure 3.11.5. Southern New England winter flounder equilibrium yield vs. F for the most likely stock-recruitment model.

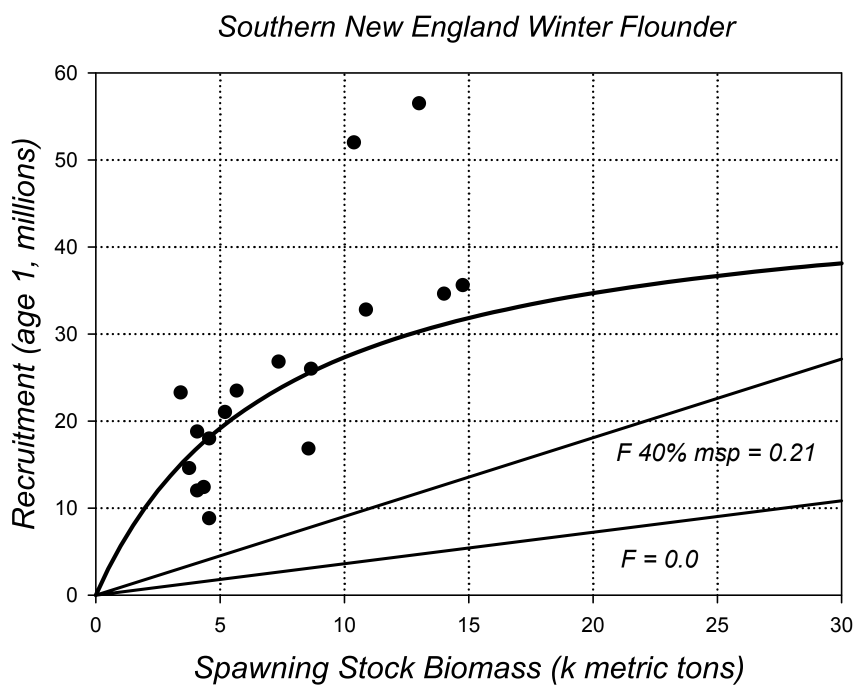


Figure 3.11.6. Stock recruitment relationship for best fit parametric model for Southern New England winter flounder. Stock-recruitment data points are overplotted, along with the predicted S-R line and replacement lines for F=100% msp=0.00 and F40%msp = 0.21.

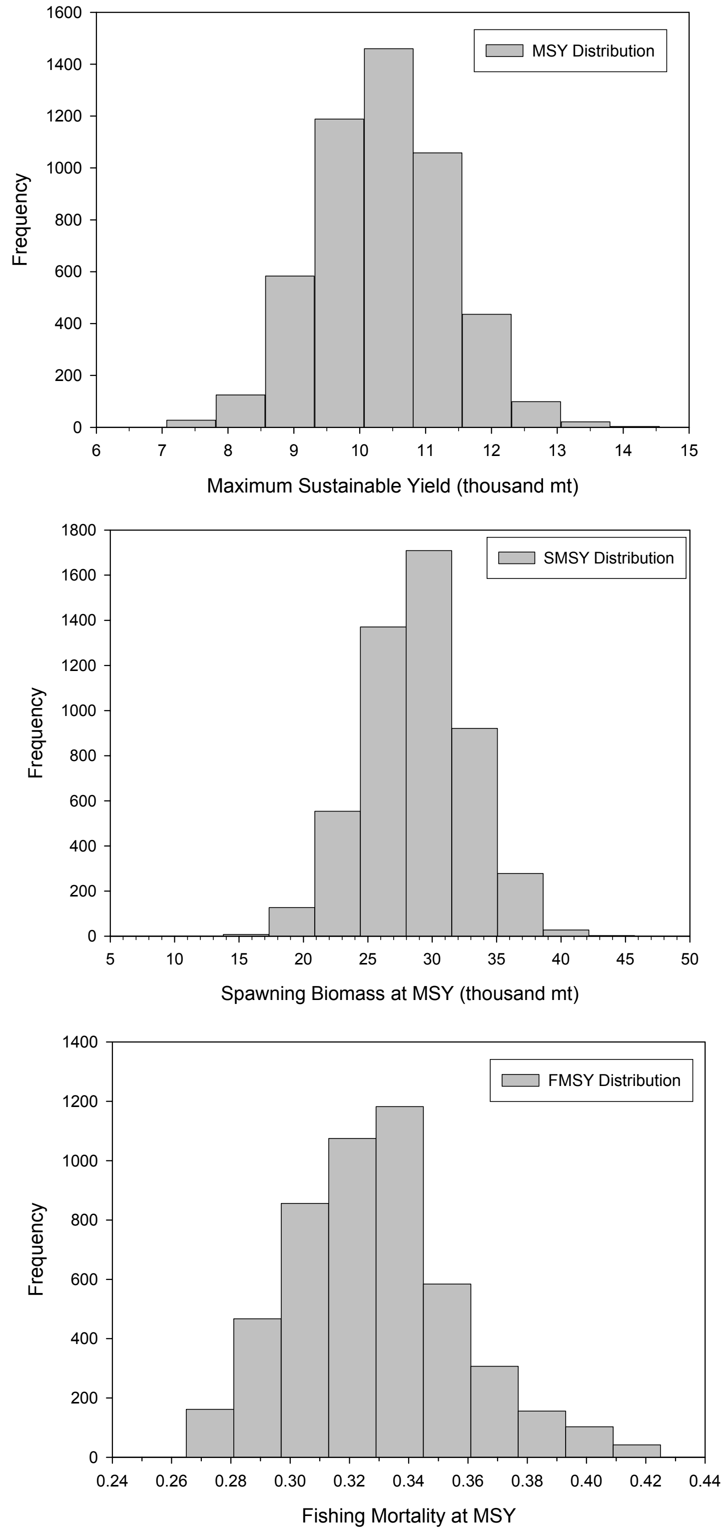


Figure 3.11.7. Histograms of uncertainty in MSY, BMY and FMSY from 5000 MCMC evaluations of best fit parametric model for Southern New England winter flounder.

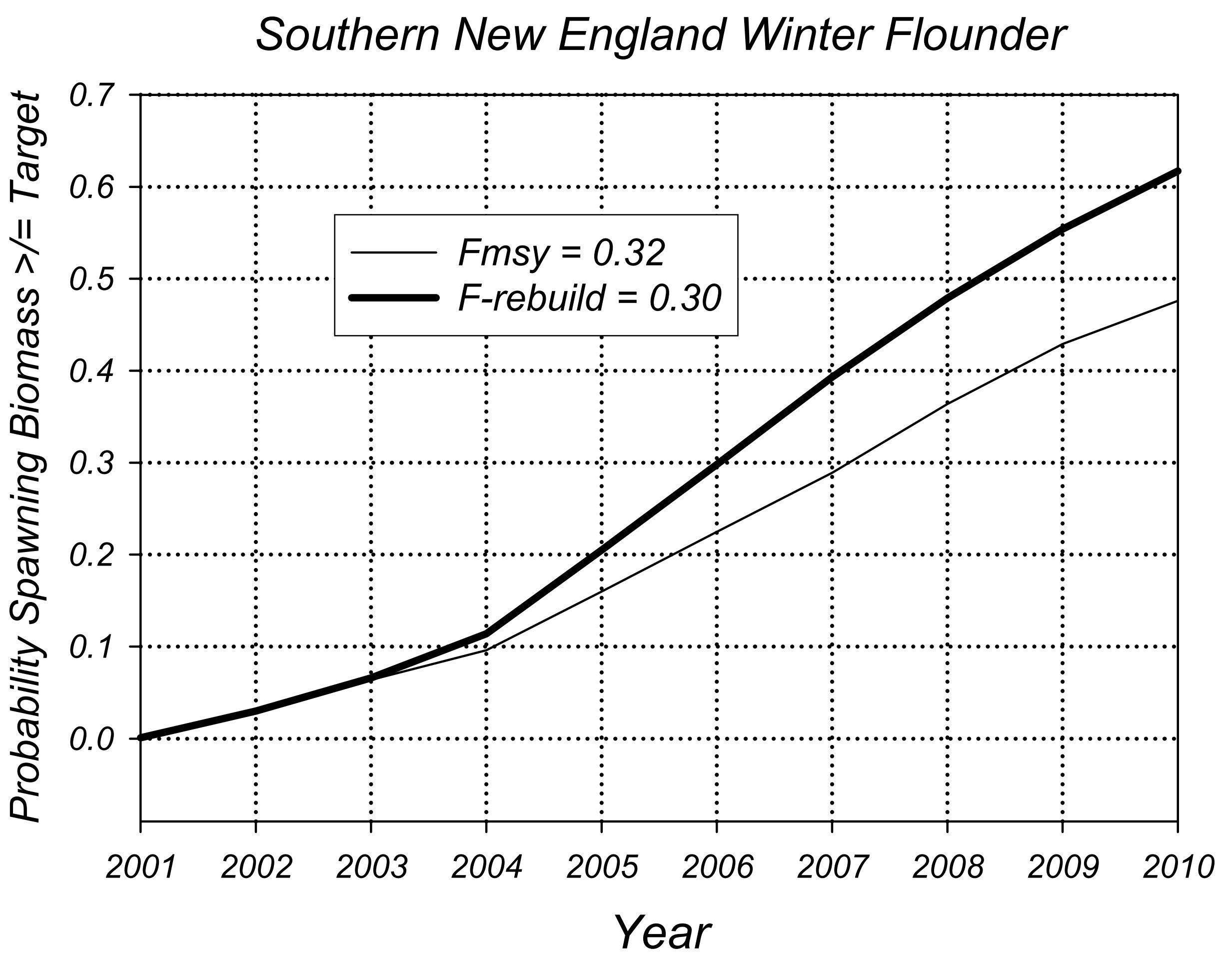


Figure 3.11.8. Probability that Southern New England winter flounder spawning biomass will exceed Bmsy (30,100 mt) annually under two fishing mortality scenarios: Fmsy and F required to rebuild the stock to Bmsy by 2009.

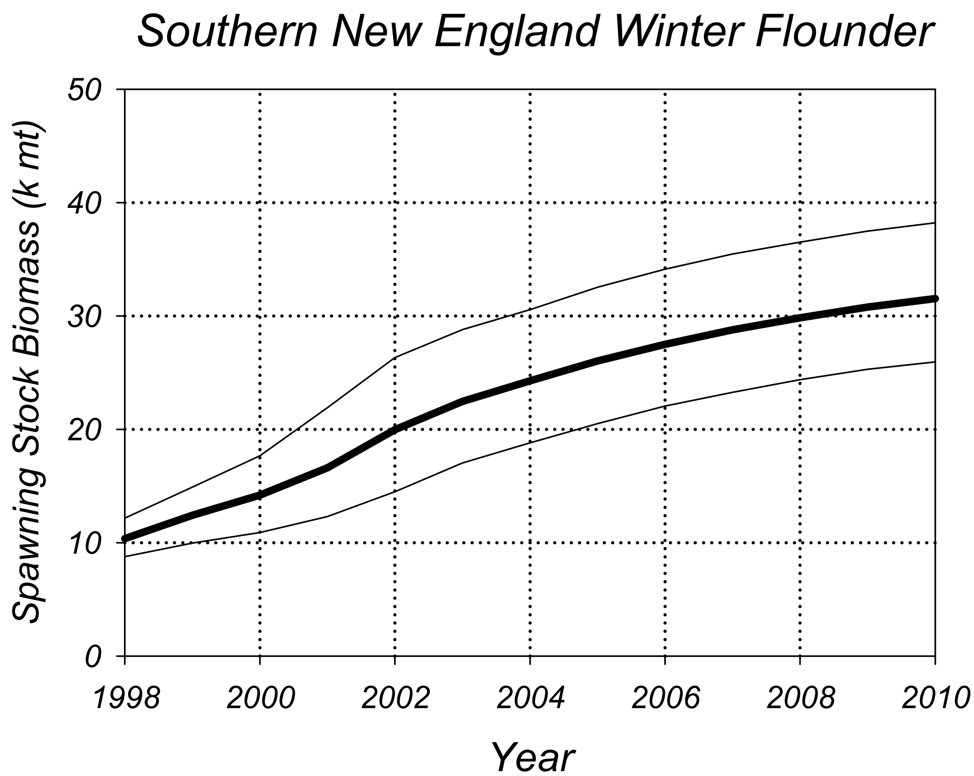


Figure 3.11.9. Median and 80% confidence interval of predicted spawning biomass for Southern New England winter flounder under F-rebuild fishing mortality rates.

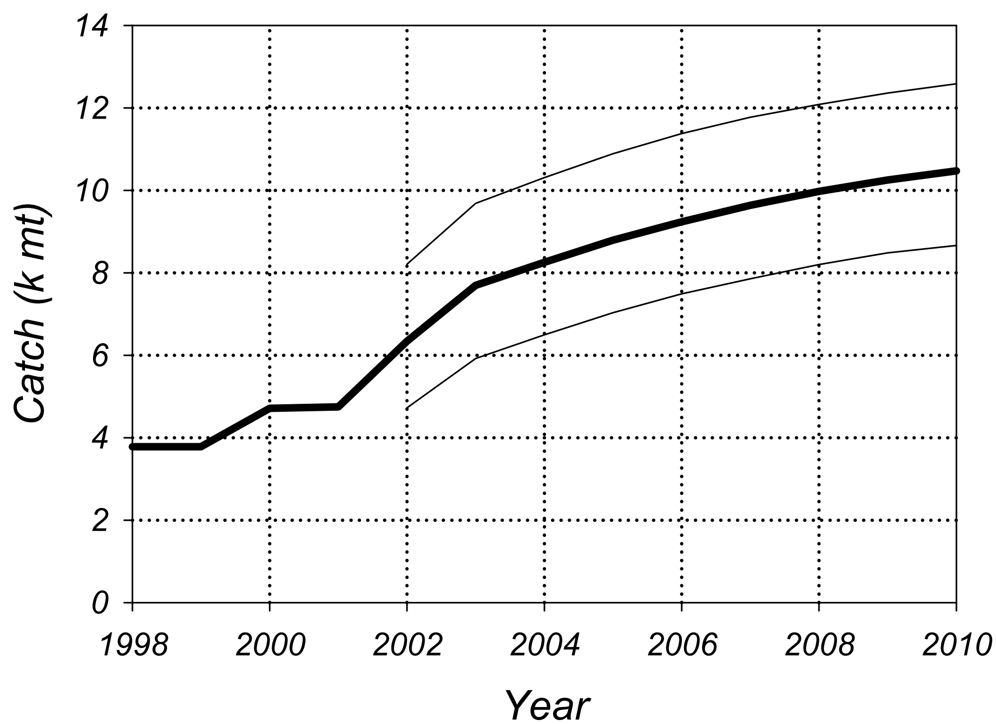


Figure 3.11.10. Median and 80% confidence interval of predicted catch for Southern New England winter under F-rebuild fishing mortality rates.

3.12 Georges Bank Winter Flounder

Catch and Survey Indices

Commercial landings of Georges Bank winter flounder generally increased during the 1960s and early 1970s, ranged between 1,800 and 4,500 mt per year during the 1970s and 1980s, and decreased to less than 2000mt . Since 1989, total landings (U.S. and Canada) have been less than 2000 mt since 1986 (Figure 3.12.1).

Survey biomass indices are relatively variable, but generally suggest intermediate levels of abundance from the early 1960s to early 1980s, a decrease in stock biomass during the 1980s, and an increase in biomass in the 1990s (Figure 3.12.1).

Stock Assessment

The most recent assessment of Georges Bank winter flounder was based on a biomass dynamics model (ASPIC) of catch and survey indices, and the results were reviewed by the 34rd Northeast Regional Stock Assessment Workshop (34th SAW) in November 2001 (NEFSC 2002). Results from the biomass dynamics model indicate that yield has been below the estimated surplus production since 1994 (Figure 3.12.2). Relative estimates of mean biomass (B_t/B_{MSY}) declined sharply during 1977-1994, but then increased to B_{MSY} in 2001.

Reference Points

Results from the biomass dynamics analysis indicate a reasonable fit to the input data. A maximum sustainable yield (MSY) of 3,020 mt was estimated to be produced by a biomass (B_{MSY}) of 9,360 mt at a F_{MSY} of 0.32. Bootstrap analysis indicates that MSY was estimated with relatively high precision (relative interquartile range, IQR = 6%), and B_{MSY} (IQR=29%) and F_{MSY} (IQR=28%) were estimated with moderate precision.

Although current reference points for Georges Bank winter flounder are expressed in survey units (2.49 kg/tow) and an exploitation index proxy for Fmsy (1.21 C/I), estimates of biomass were similar from ASPIC and VPA (NEFSC 2002). Therefore, the working group considers the absolute estimates of B_{MSY}, and F_{MSY} to be more reliable than survey equivalents, because absolute reference points will facilitate determination of stock status through analytical modeling rather than averaging of recent survey observations.

The replacement ratio analysis for Georges Bank winter flounder suggests that the stock can replace itself at an exploitation index of 1.18 (Figure 3.12.6; Table 4.11), which corresponds to an F of 0.31 using the ASPIC estimate of survey catchability (0.2653). Therefore the empirical results generally confirm the F_{MSY} estimate from ASPIC (0.32).

The use of "total biomass" indices in ASPIC, and the resulting currency of MSY reference points (i.e., B_{MSY} in total biomass, and F_{MSY} on total biomass), has presented problems with interpretation, especially during times of strong recruitment, when a large portion of total biomass may not be recruited to the fishery (NEFSC 2001c). Therefore age distributions in the catch and surveys were compared to investigate the proportion of unrecruited fish comprised in the aggregate biomass indices. During the large-mesh regulatory period (1994-2000) age compositions were similar: fishery catch was 3% age-1, 26% age-2 and 71% age-3+, the fall survey was 1% age-1, 22% age-2 and 77% age-3+, and the spring survey was 3% age-1, 24% age-2, and 72% age-3+ (in numbers, differences would be even less in weight). The Working Group concluded that the survey appears to measure the biomass of the exploitable stock. Therefore, survey indices are not expected to be sensitive to biomass of unexploited fish (i.e., prerecruits).

Projections

Stochastic projection was performed using bootstrap distributions of stock biomass in 2001, and biomass dynamics parameters (Prager 1995). Observed catch from January to November 2001 was 1,920mt, which corresponds to a total annual U.S. catch of 2,070mt based on proportion of 2000 landings taken in December, by gear. Canadian catch in 2001 was 590mt, and the total estimate of 2001 catch was 2,670mt. The resulting fishing mortality in 2001 (0.28), was assumed to continue in 2002. For the 2003-2008 fishing years, F_{MSY} (0.32) was projected.

Projected biomass is maintained at B_{MSY} throughout the projected time series with high probability (Figures 3.12.3 and 3.12.4). Projected catch increases to 3,000mt, and is maintained at that level for the projected time series (Figure 3.12.5).

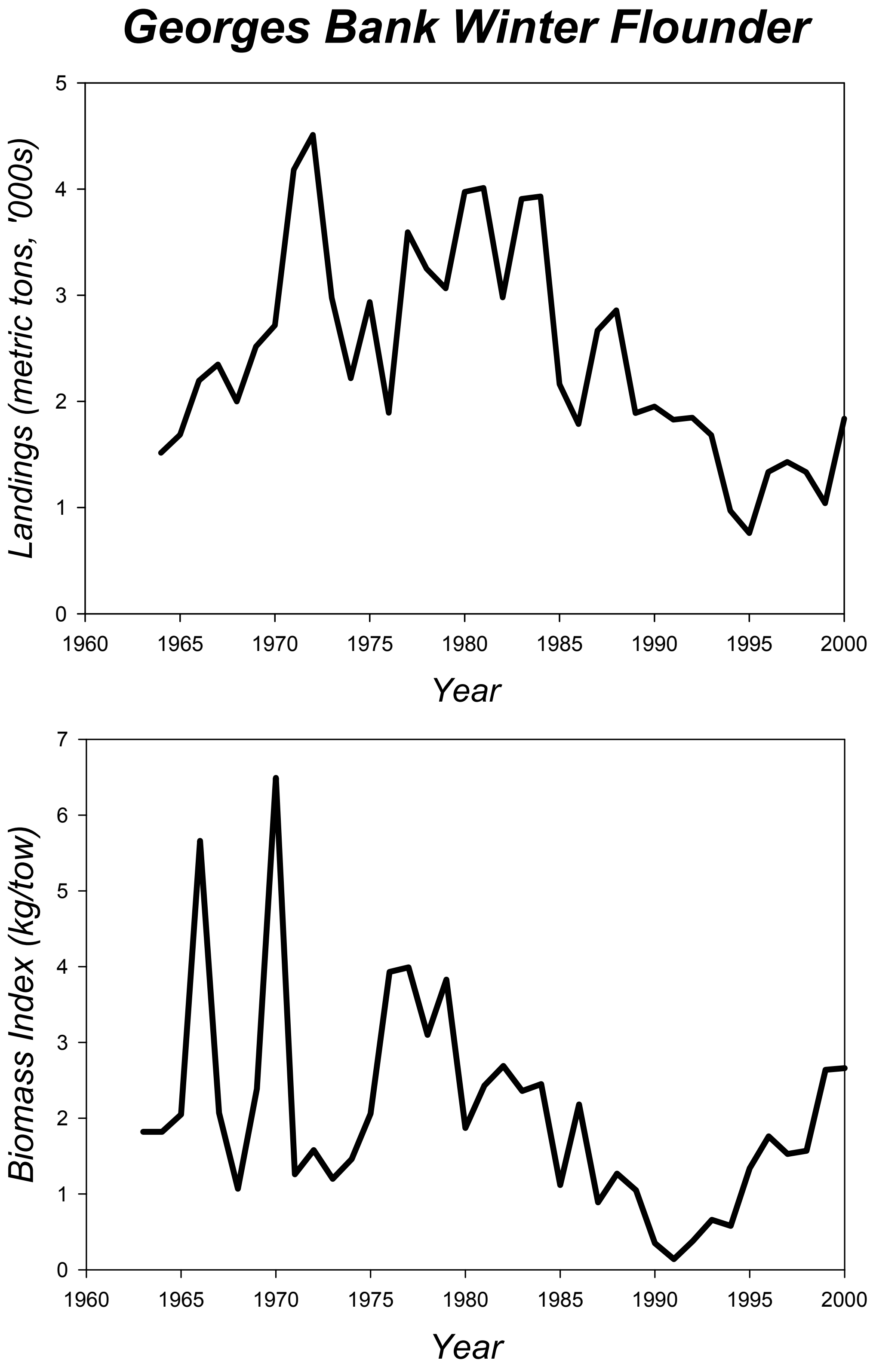


Figure 3.12.1. Landings and research vessel survey abundance indices for Georges Bank winter flounder.

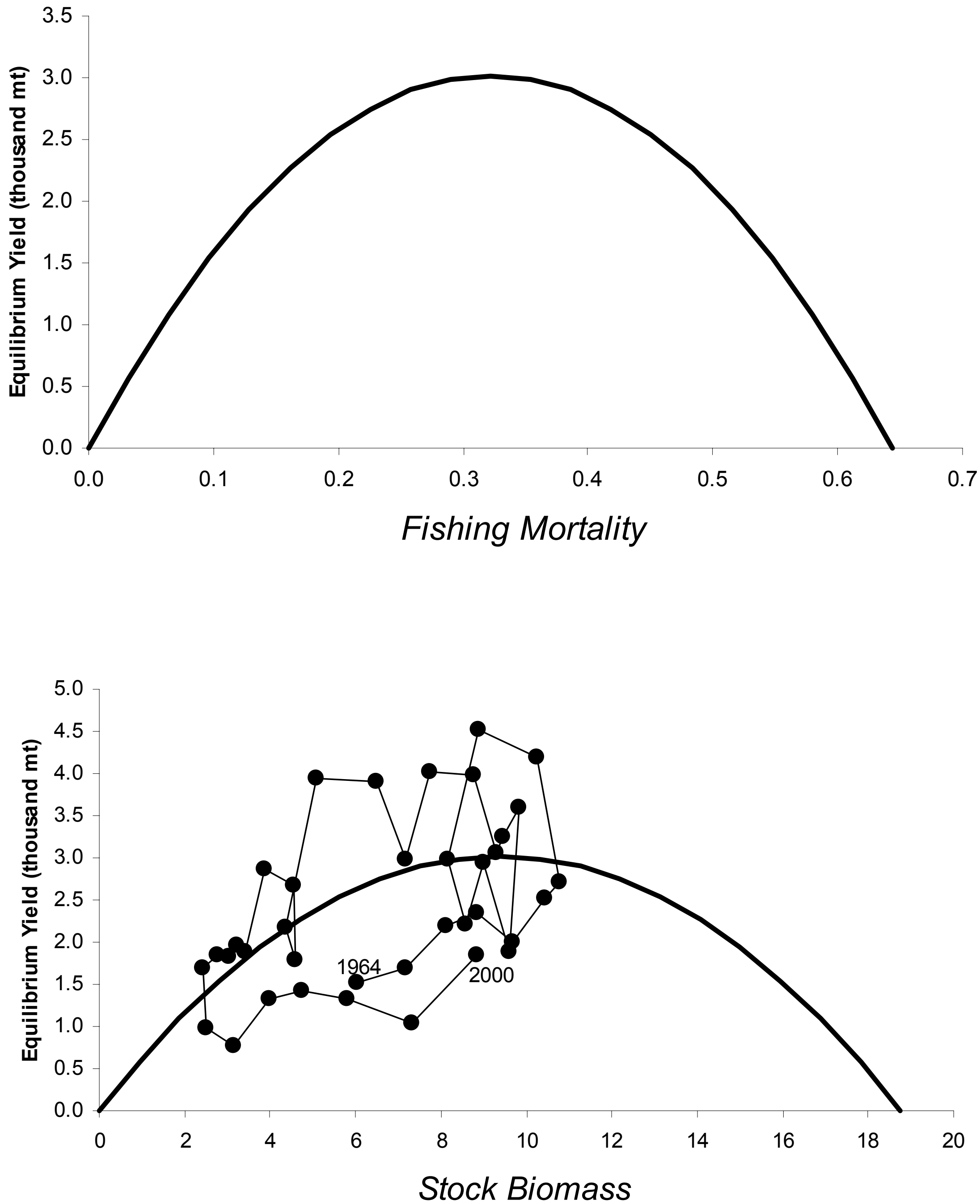


Figure 3.12.2. Results of surplus production analyses (ASPIC) for Georges Bank winter flounder

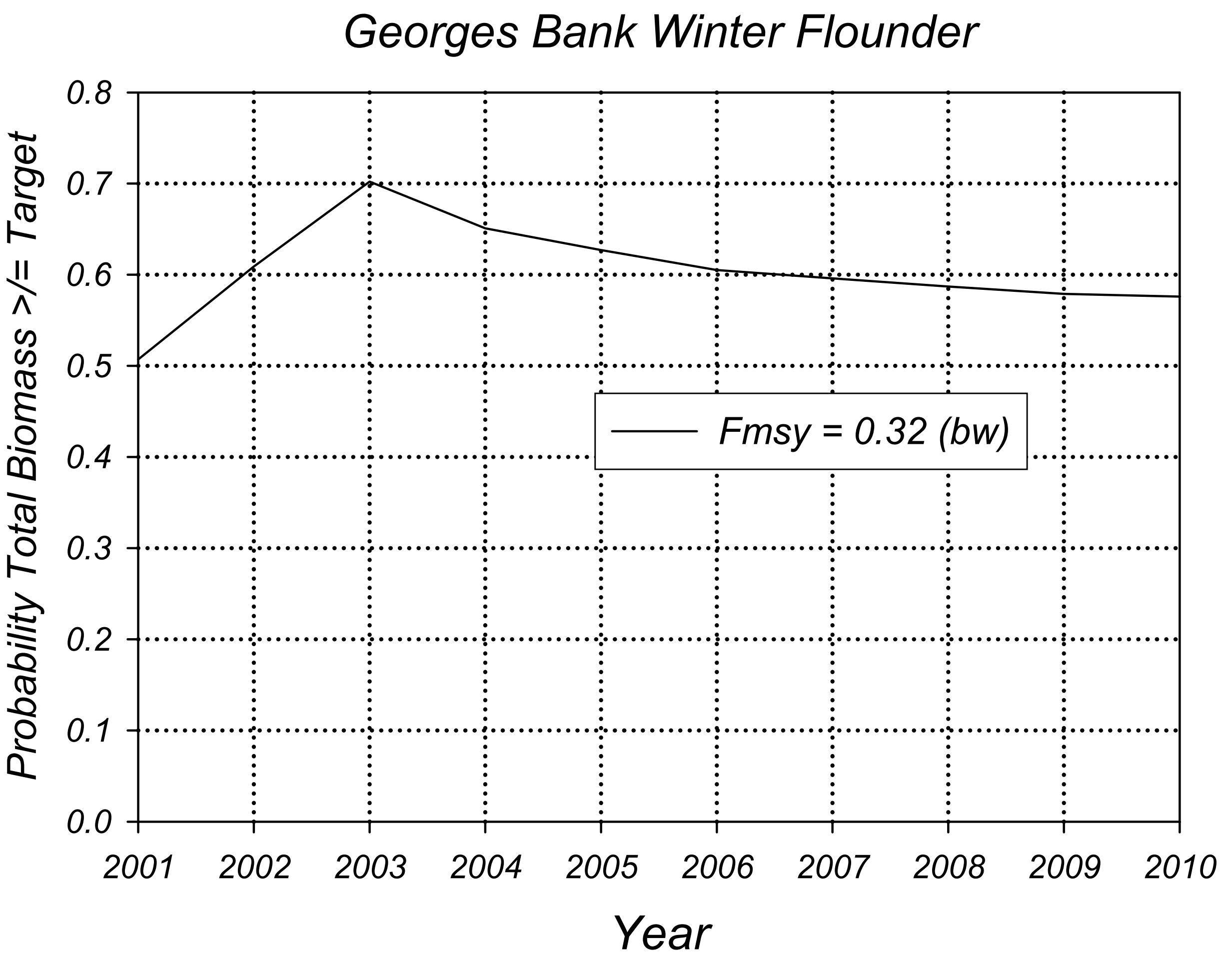


Figure 3.12.3. Probability that Georges Bank flounder total biomass will exceed Bmsy annually under Fmsy. Projections are based on an ASPIC surplus production analysis.

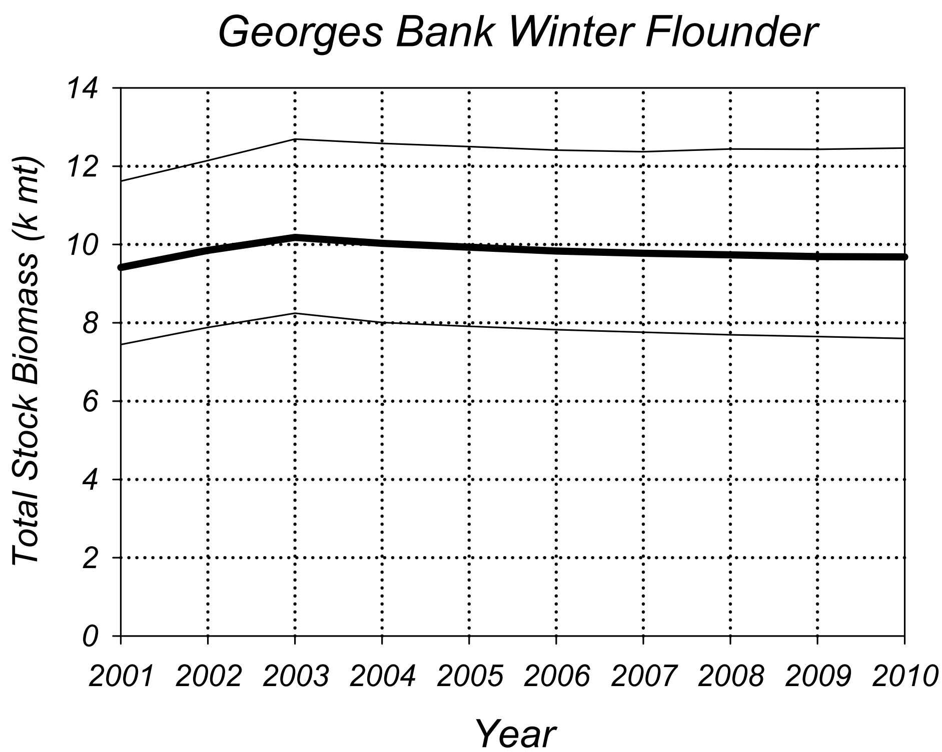


Figure 3.12.4. Median and 80% confidence interval of predicted spawning biomass for Georges Bank winter flounder under F-msy fishing mortality rates.

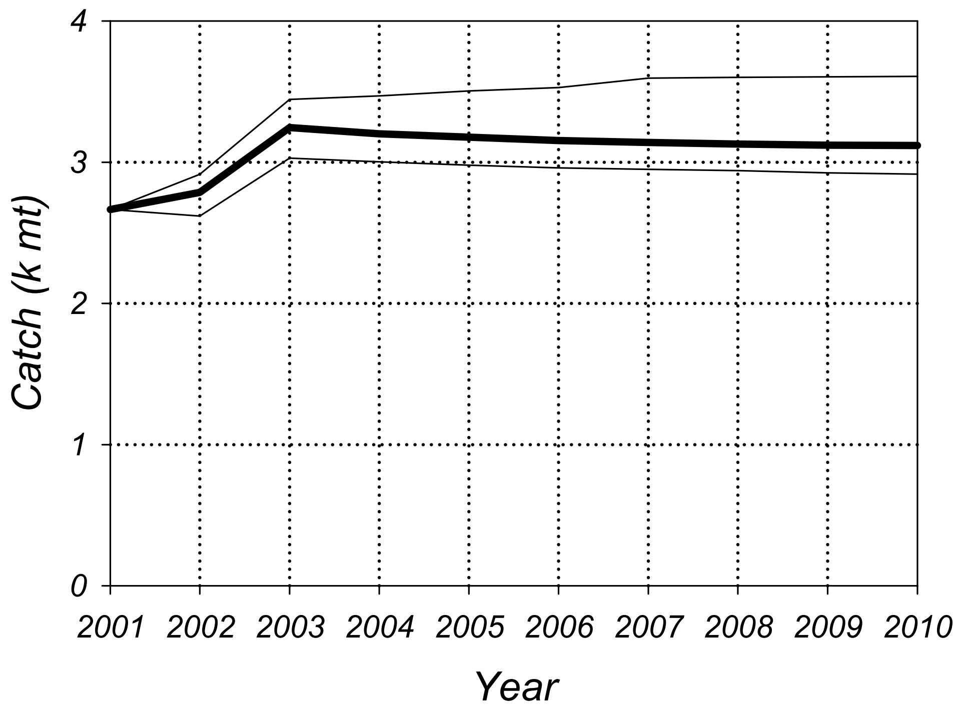


Figure 3.12.5. Median and 80% confidence interval of predicted catch for Georges Bank winter flounder under F-msy fishing mortality rates.

GB Winter Flounder, Fall

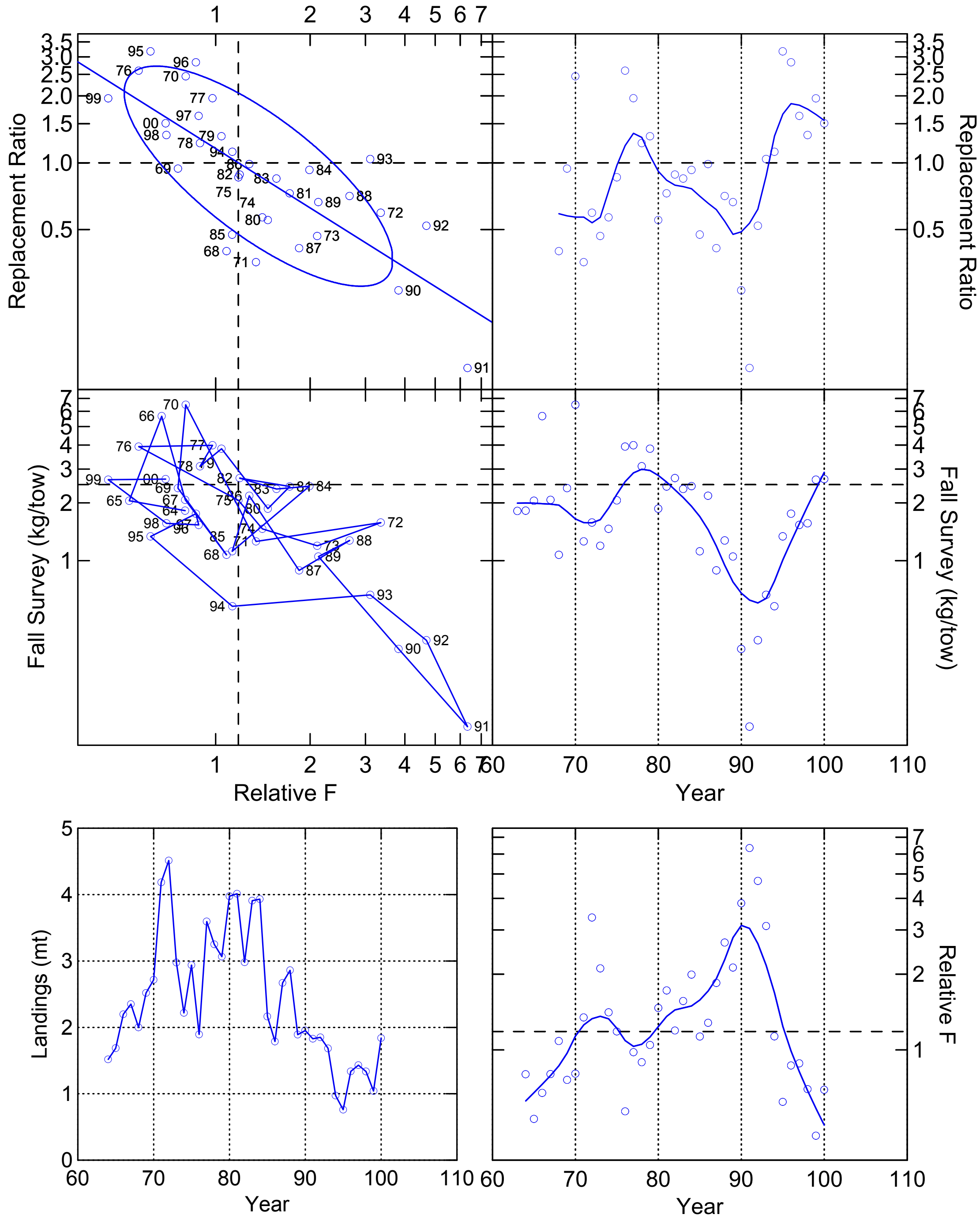


Figure 3.12.6. Trends in relative biomass, landings, fishing rate mortality rate indices (landings/ survey index) and replacement ratios for Georges Bank winter flounder. Dashed lines indicate equivalent biomass and fishing mortality rate proxies of Bmsy and Fmsy.

3.13 Acadian Redfish

Catch and Survey Indices

Redfish, *Sebastes fasciatus* Storer, are assessed as a unit stock in the Gulf of Maine and Georges Bank region (NAFO Subarea 5). The fishery on this stock developed rapidly during the 1930s (Mayo 1980). Landings rose rapidly from less than 100 mt in the early 1930s to over 20,000 mt in 1939, peaking at 56,000 mt in 1942, then declined throughout the 1940s and 1950s (Figure 3.13.1). Redfish have been harvested primarily by domestic vessels, although distant water fleets took considerable quantities for a brief period during the early 1970s. The distant water fleet effort, combined with increased domestic fishing effort, resulted in a brief increase in total catch to about 20,000 mt during the early 1970s. Landings declined throughout the 1980s and have averaged less than 500 mt per year during the 1990s

Relative biomass indices (stratified mean weight per tow) have been calculated from NEFSC spring and autumn surveys based on strata encompassing the Gulf of Maine and portions of the Great South Channel (strata 24, 26-30, 36-40). Trends in total abundance and biomass are similar in both spring and autumn surveys (Figure 3.13.1). Relative biomass of redfish has declined sharply in both survey series, from peak levels in the late 1960s and early 1970s to generally less than 2 kg per tow during the mid-1980s through mid-1990s. Both series suggest a slight increase in biomass between the mid-1980s and 1990s followed by a sharp increase in autumn 1996 and spring 1997.

Stock Assessment

The most recent stock assessment was completed in 2001 (Mayo *et al.* 2002b), and the results were reviewed at the 33rd Northeast Regional Stock Assessment Workshop in June, 2001 (NEFSC 2001c). The assessment was based on several analyses including trends in catch/survey biomass exploitation ratios; a yield and biomass per recruit analysis; an age-structured dynamics model which incorporates information on the age composition of the landings, size and age composition of the population, and trends in relative abundance derived from commercial CPUE and research vessel survey biomass indices; and an age-aggregated biomass dynamics model. Surplus production estimates were derived from the age-structured dynamics model, and information on current biomass and fishing mortality relative to MSY-based reference points were also provided by the biomass dynamics model.

Exploitation ratios (catch/survey biomass) suggested that fishing mortality has been very low since the mid-1980s compared to previous periods. Estimates of fishing mortality derived from the age-structured dynamics model and the age-aggregated biomass model were similar, both indicating that current fishing mortality is low relative to past decades and less than 5% of F_{msy}. Stock biomass has increased since the mid-1990s, and current biomass was estimated to be about 33% of B_{msy} due, in large part, to strong recruitment from the early 1990s. The spawning stock and recruitment estimates derived from the age-structured dynamics model are provided in Figures 3.13.2 and 3.13.3.

Yield and SSB per Recruit Analysis

The yield and spawning stock biomass analysis conducted during the course of the 2001 assessment was revised slightly during the present analysis to provide an estimate of F50% MSP as recommended by the Stock Assessment Review Committee of the 33rd SAW. Partial recruitment, catch and stock mean weights, and maturation at age were the same as those employed in the 2001 assessment. Estimates of $F_{0.1}$ and $F_{50\%}$ are presented in Table 3.1.1. The spawning stock biomass per recruit estimate corresponding to $F_{50\%}$, when combined with information on historical recruitment, provides an estimate of SSB_{msy} as described in the following section.

MSY-based Reference Point Estimation

Empirical Nonparametric Approach

Estimates of recruitment obtained from the age-structured biomass dynamics model reviewed at the 33rd SAW were used to imply the probable recruitment that could be produced by a rebuilt stock. Recruitment estimates derived by the model from the1952-1999 yearclasses served as the basis for evaluating trends and patterns in recruitment. The stock-recruitment data suggest an increase in the frequency of larger year classes (> 50 million fish) at higher biomass levels (Figure 3.13.2). Therefore recruitment estimates corresponding to the upper quartile of the SSB range served as the basis for deriving mean and median recruitment estimates. In accordance with the recommendation of the Stock Assessment Review Committee of the 33rd SAW, the estimate of $F_{50\%}$ (0.04) is taken as a proxy for F_{msy}. This fishing mortality rate produces 4.1073 kg of spawning stock biomass per recruit and 0.1429 kg of yield per recruit. The resulting mean recruitment of 57.63 million fish results in an SSB_{msy} estimate of 236, 700 mt when multiplied by the SSB per recruit, and an MSY estimate of 8,235 mt when multiplied by the yield per recruit.

Reference Point Advice

Reference points derived from the nonparametric approach are: MSY = 8,235 mt and SSB_{msy} = 236,700 mt (Table 4.2). In lieu of an analytically-derived estimate of F_{msy}, the F proxy advised by the 33rd SAW ($F_{50\%}$ = 0.04) is recommended. The estimate of MSY represents total landings..

Projections

Stochastic age-based projections (Brodziak and Rago MS 2002) were performed over a 10-year time horizon beginning in 2001 to evaluate relative trajectories of stock biomass and catch under various fishing mortality scenarios. Recruitment was generated by resampling observed recruitment using a cumulative distribution function which allows predicted recruitment values to occur within the range of those from the 1952 through 1999 yearclasses as estimated by the age structured dynamics model. Stock and catch mean weights at age, the maturity at age schedule, are the same as those employed in the yield and SSB per recruit analyses presented above, and the partial recruitment at age vector was derived from the age structured dynamics model. The 2001 survivors at ages 1 through 26+ age estimated by the age structured dynamics model were employed as the initial population vector. The projection was performed at two fishing mortality rates: $F_{50\%}$ (0.04) and F calculated to rebuild spawning biomass to SSB_{msy} by 2009. Fully recruited fishing mortality in 2001 was derived from iterative calculations based on the estimated total 2001 commercial landings (328 mt). Fishing mortality in 2002 was fixed at the 2001 value.

The medium-term projections (Figures 3.13.4 and 3.13.4 and 3.13.6) suggest that fishing at $F_{50\%}$ (0.04) between 2003 and 2009 will result in less than a 1% probability of rebuilding spawning biomass to SSB_{msy} (236, 700 mt) by 2009 (Figure 3.13.4). Even if F is reduced to 0, there is still less than a 1% probability of rebuilding spawning biomass to SSB_{msy} by 2009 (Figures 3.13.5).

Table 3.13.1. Yield and biomass per recruit of Acadian redfish.

The NEFC Yield and Stock Size per Recruit Program - PDBYPRC
PC Ver.2.0 [Method of Thompson and Bell (1934)] 1-Jan-1999
----Run Date: 27- 6-2001; Time: 15:33:57.67
REDFISH UPDATED AVE WTS & FPAT, MAT VECTOR (MAYO ET AL. 1990)

Proportion of F before spawning: .4000
Proportion of M before spawning: .4000
Natural Mortality is Constant at: .050
Initial age is: 1; Last age is: 26
Last age is a PLUS group;
Original age-specific PRs, Mats, and Mean Wts from file:
==> d:\assess\redf\Yrred.dat

Age-specific Input data for Yield per Recruit Analysis

Age	Fish Mort Pattern	Nat Mort Pattern	Proportion Mature	Average Weights Catch	Average Weights Stock
1	.0138	1.0000	.0100	.010	.002
2	.0312	1.0000	.0200	.020	.012
3	.0697	1.0000	.0500	.059	.033
4	.1507	1.0000	.1500	.099	.064
5	.2999	1.0000	.3600	.145	.103
6	.5084	1.0000	.6400	.178	.148
7	.7291	1.0000	.8500	.201	.196
8	.9289	1.0000	.9500	.250	.246
9	1.0000	1.0000	.9800	.272	.295
10	1.0000	1.0000	.9900	.310	.343
11	1.0000	1.0000	1.0000	.348	.388
12	1.0000	1.0000	1.0000	.391	.430
13	1.0000	1.0000	1.0000	.423	.469
14	1.0000	1.0000	1.0000	.429	.505
15	1.0000	1.0000	1.0000	.463	.537
16	1.0000	1.0000	1.0000	.495	.566
17	1.0000	1.0000	1.0000	.503	.592
18	1.0000	1.0000	1.0000	.508	.615
19	1.0000	1.0000	1.0000	.548	.636
20	1.0000	1.0000	1.0000	.558	.654
21	1.0000	1.0000	1.0000	.565	.669
22	1.0000	1.0000	1.0000	.581	.683
23	1.0000	1.0000	1.0000	.595	.696
24	1.0000	1.0000	1.0000	.583	.706
25	1.0000	1.0000	1.0000	.581	.716
26+	1.0000	1.0000	1.0000	.637	.750

Summary of Yield per Recruit Analysis for:
REDFISH UPDATED AVE WTS & FPAT, MAT VECTOR (MAYO ET AL. 1990)

Slope of the Yield/Recruit Curve at F=0.00: --> 7.5310
F level at slope=1/10 of the above slope (F0.1): -----> .059
Yield/Recruit corresponding to F0.1: -----> .1632
F level to produce Maximum Yield/Recruit (Fmax): -----> .127
Yield/Recruit corresponding to Fmax: -----> .1806
F level at 50 % of Max Spawning Potential (F50): -----> .040
SSB/Recruit corresponding to F50: --------> 4.1073

1

Listing of Yield per Recruit Results for:
REDFISH UPDATED AVE WTS & FPAT, MAT VECTOR (MAYO ET AL. 1990)

	FMORT	TOTCTHN	TOTCTHW	TOTSTKN	TOTSTKW	SPNSTKN	SPNSTKW	% MSP
	.00	.00000	.00000	20.5042	9.1737	15.7030	8.7760	100.00
F50%	.04	.34434	.14293	13.6199	4.4727	8.8513	4.1073	46.80
	.05	.38712	.15522	12.7649	3.9263	8.0041	3.5674	40.65
F0.1	.06	.41925	.16317	12.1227	3.5252	7.3690	3.1719	36.14
	.10	.51797	.17890	10.1507	2.3604	5.4286	2.0284	23.11
Fmax	.13	.55860	.18057	9.3395	1.9207	4.6377	1.6001	18.23
	.15	.58466	.17981	8.8194	1.6549	4.1345	1.3428	15.30
	.20	.62564	.17533	8.0023	1.2684	3.3532	.9718	11.07
	.25	.65370	.16973	7.4432	1.0297	2.8287	.7459	8.50
	.30	.67435	.16423	7.0323	.8698	2.4512	.5967	6.80
	.35	.69033	.15916	6.7145	.7561	2.1657	.4923	5.61
	.40	.70318	.15459	6.4593	.6714	1.9418	.4158	4.74
	.45	.71381	.15049	6.2483	.6060	1.7611	.3578	4.08
	.50	.72281	.14681	6.0696	.5540	1.6119	.3124	3.56
	.55	.73058	.14349	5.9156	.5117	1.4864	.2762	3.15
	.60	.73739	.14047	5.7808	.4765	1.3793	.2467	2.81
	.65	.74343	.13772	5.6612	.4467	1.2868	.2222	2.53
	.70	.74885	.13520	5.5540	.4212	1.2058	.2016	2.30
	.75	.75376	.13288	5.4570	.3991	1.1345	.1841	2.10
	.80	.75823	.13072	5.3685	.3797	1.0710	.1690	1.93
	.85	.76234	.12871	5.2872	.3625	1.0141	.1559	1.78
	.90	.76614	.12683	5.2122	.3471	.9628	.1444	1.65
	.95	.76967	.12506	5.1425	.3333	.9163	.1343	1.53
	1.00	.77296	.12340	5.0775	.3208	.8740	.1253	1.43

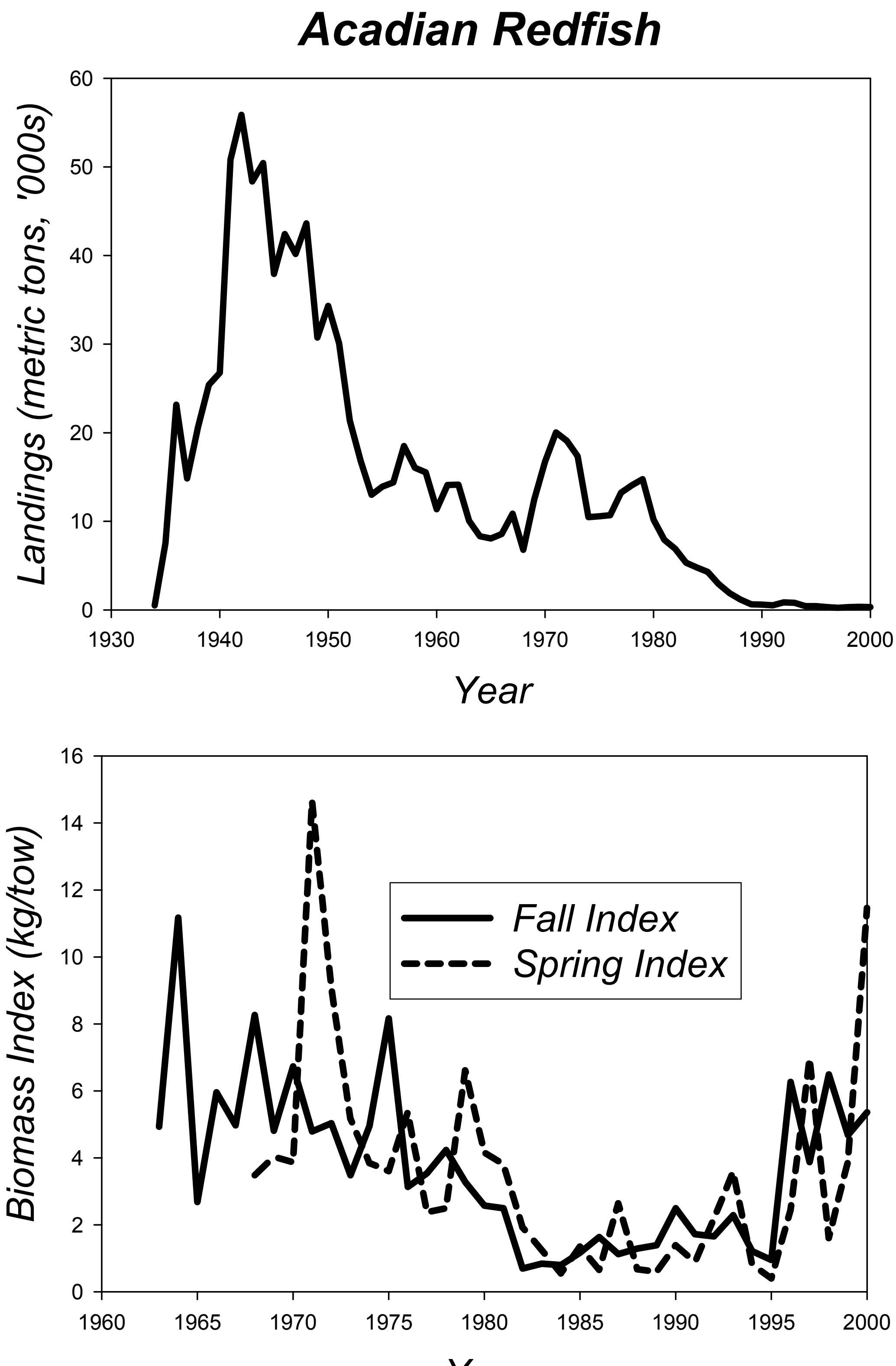
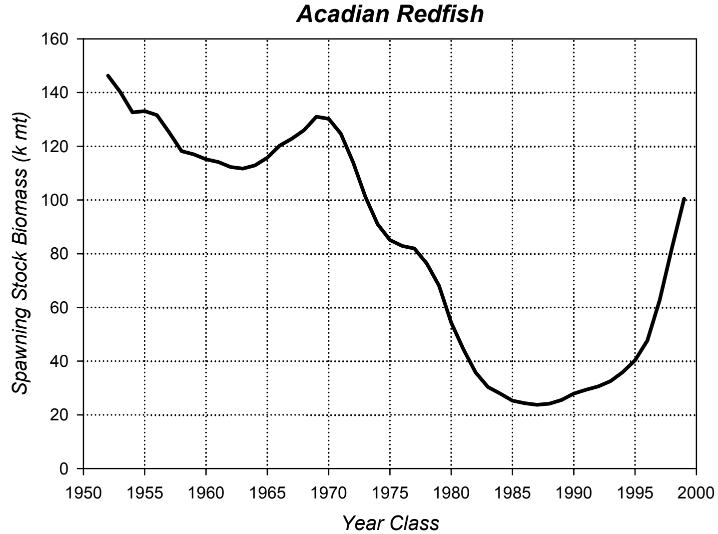
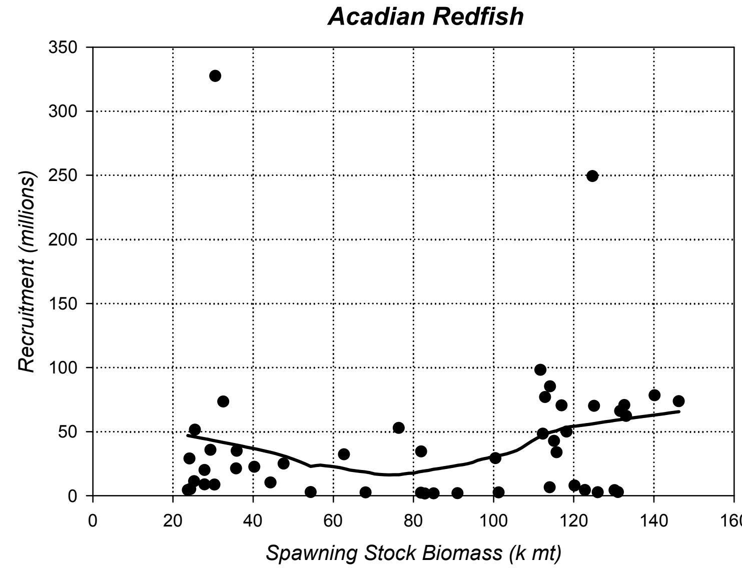


Figure 3.13.1. Landings and research vessel survey abundance indices for Acadian redfish.

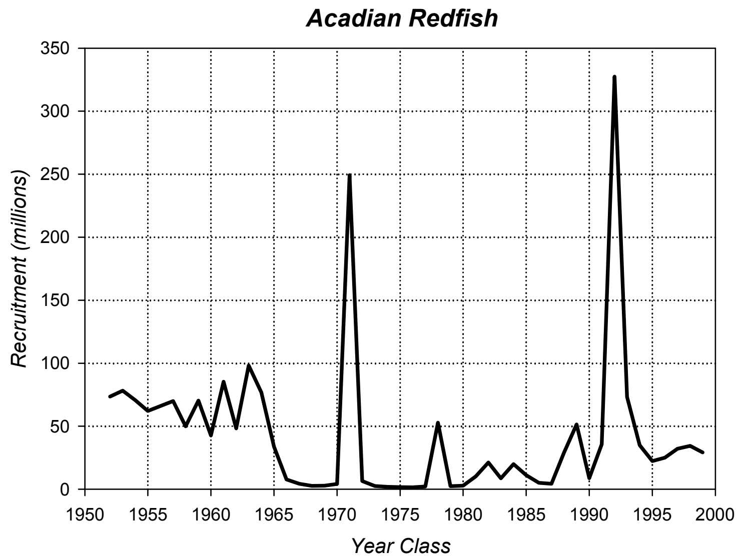
(a)



(c)



(b)



		F0.1	F50% MSP
F reference point		0.059	0.04
ssb per recruit at F		3.1719	4.1073
	Recruitment (millions)	SS Biomass at F0.1	SS Biomass at F50%
n	48	48	48
mean	42.84	135.87	175.94
min	1.56	4.95	6.41
max	327.49	1038.76	1345.10
10th %'tile	2.52	7.98	10.33
25th %'tile	4.91	15.58	20.17
50th %'tile	29.12	92.36	119.59
75th %'tile	63.12	200.20	259.24
90th %'tile	77.26	245.07	317.34
Std Dev	59.48	188.68	244.32
CV	1.39	1.39	1.39
For Top Quartile of SSB			
Mean	57.63	182.80	236.71
Median	64.11	203.34	263.31

Figure 3.13.2. Spawning stock (a), recruitment (age 1 millions, b), and scatterplot (c) for Acadian redfish. Data are the calculated spawning stock biomasses for various recruitment scenarios multiplied by the expected SSB per recruit for F0.1 and 50% MSP, assuming recent patterns of growth, maturity and partial recruitment at age (Table 3.13.1). Smoother in the stock-recruitment plot is lowess with tension = 0.5.

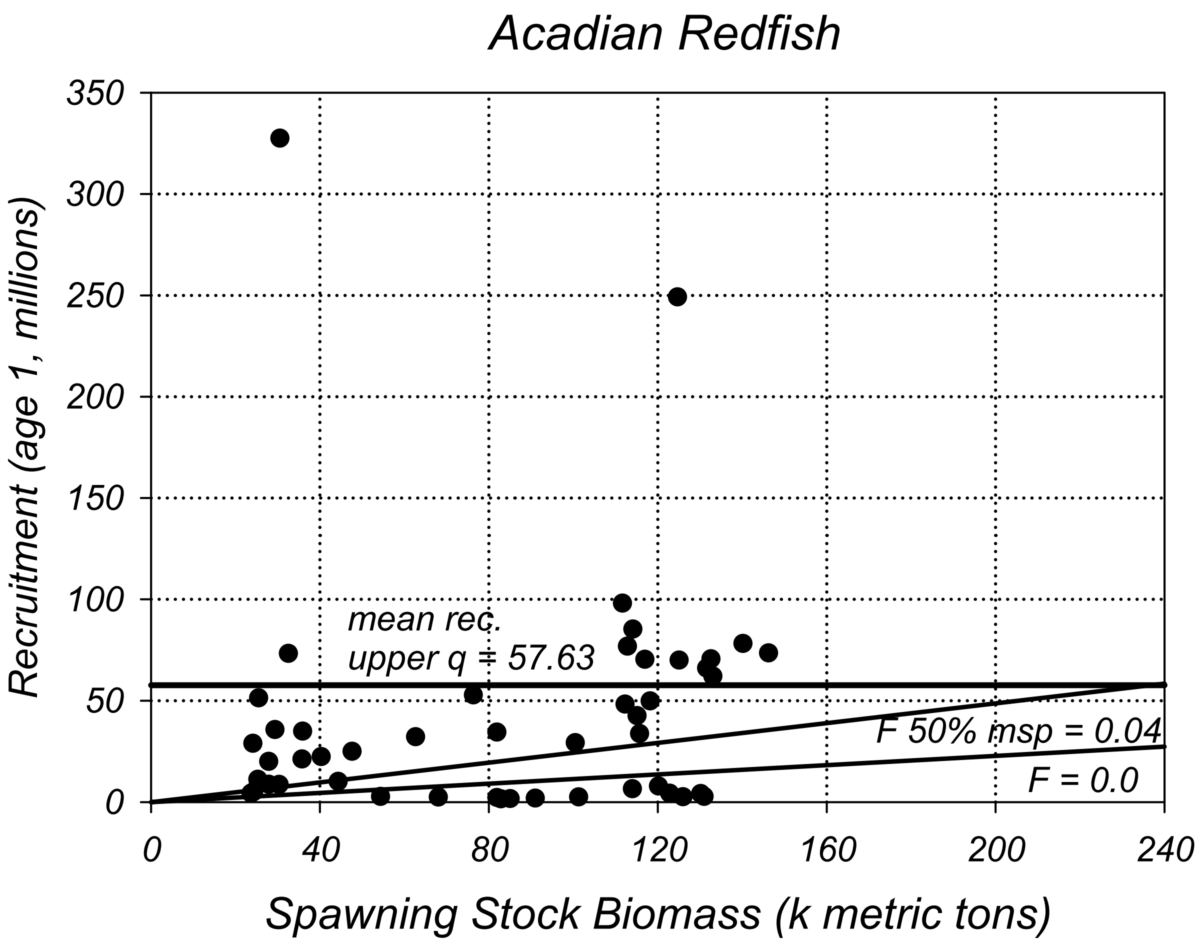


Figure 3.13.3. Stock and recruitment data for Acadian redfish, 1952-1999. For the empirical non-parametric approach the mean recruitment is plotted along with the replacement lines for F=0.0 and F 50% msp = 0.04.

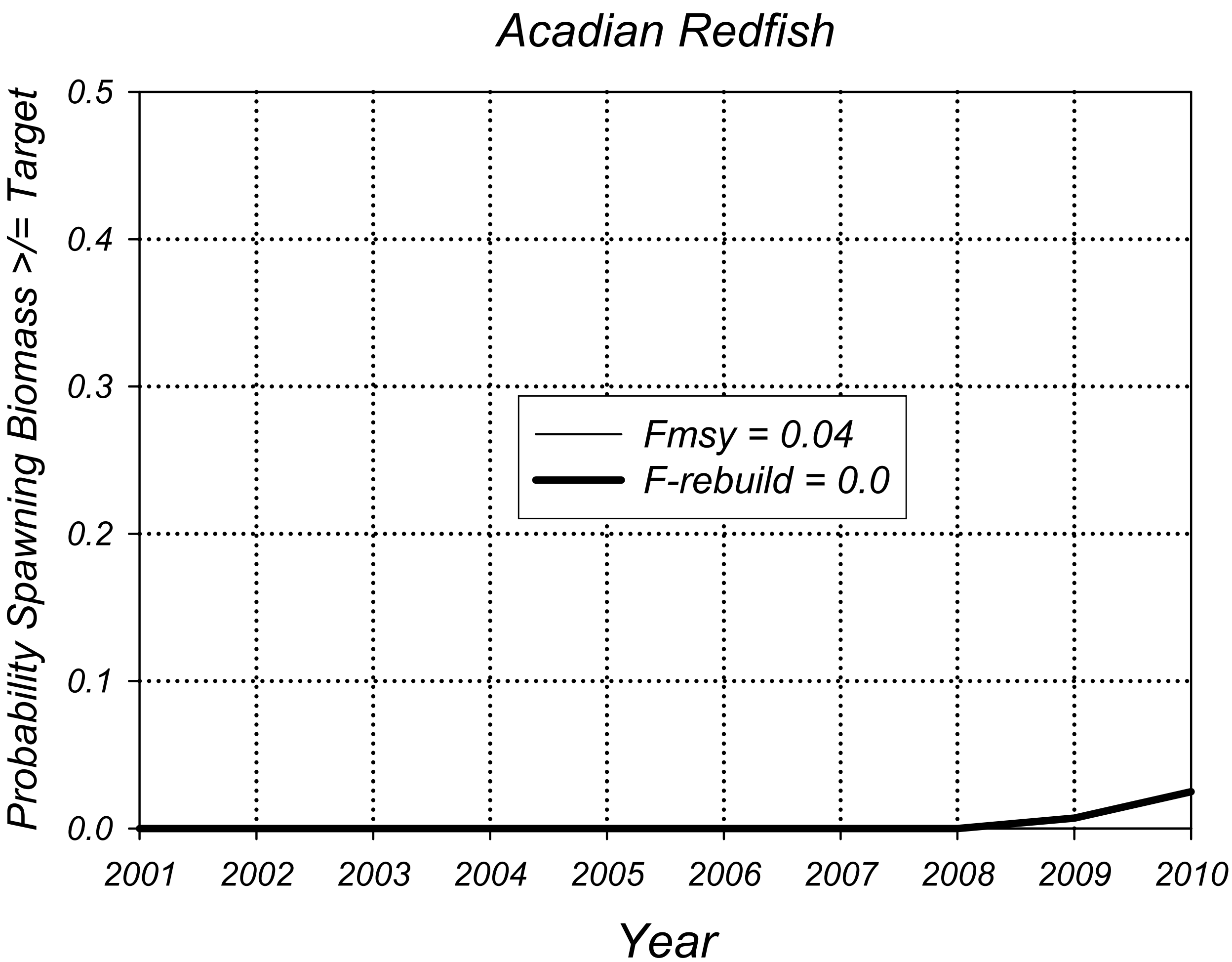


Figure 3.13.4. Probability that Acadian redfish spawning biomass will exceed Bmsy (236,700 mt) annually under two fishing mortality scenarios: Fmsy and F required to rebuild the stock to Bmsy by 2009.

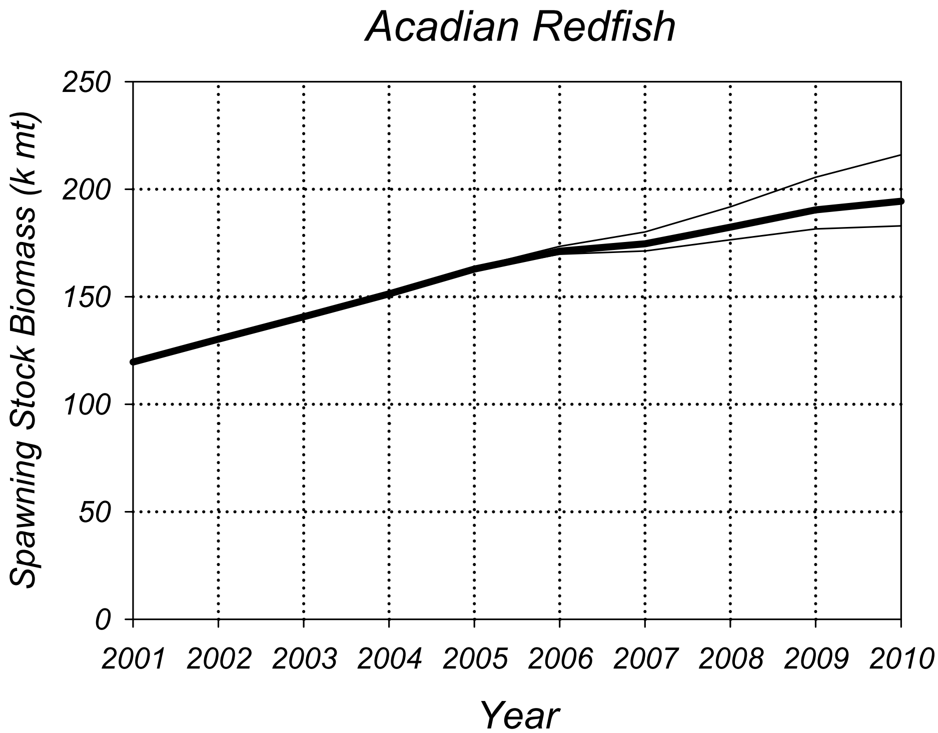


Figure 3.13.5. Median and 80% confidence interval of predicted spawning biomass for Acadian redfish F-rebuild fishing mortality rates.

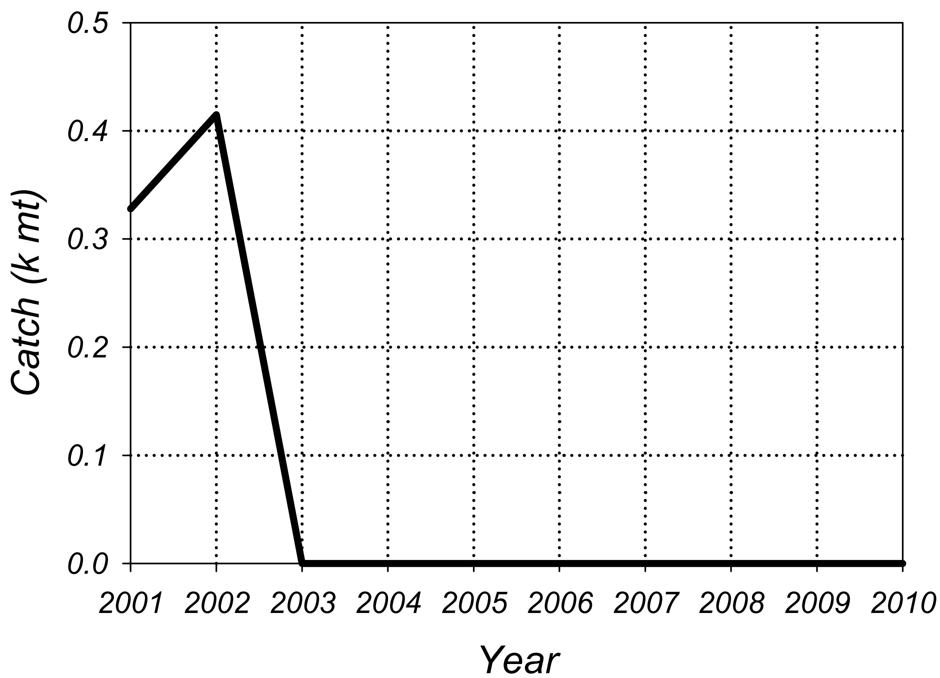


Figure 3.13.6. Median and 80% confidence interval of predicted catch for Acadian redfish under F-rebuild fishing mortality rates.

3.14 White Hake

Catch and Survey Indices

Commercial landings of white hake increased from less than 2,000 mt during the late 1960s to over 10,000 mt during the early-to-mid 1980s (Figure 3.14.1). Landings remained relatively high through the early 1990s, fluctuating between 6,000 and 10,000 mt until 1993. Landings subsequently declined, reaching 2,200 mt in 1997, and have remained between 2,000 and 3,000 mt since then (Figure 3.14.1).

NEFSC spring and autumn bottom trawl survey biomass indices for white hake increased from relatively low levels during the 1960s and fluctuated without trend for several decades thereafter (Figure 3.14.1). Both indices declined sharply during the 1990s and currently remain extremely low.

Stock Assessment

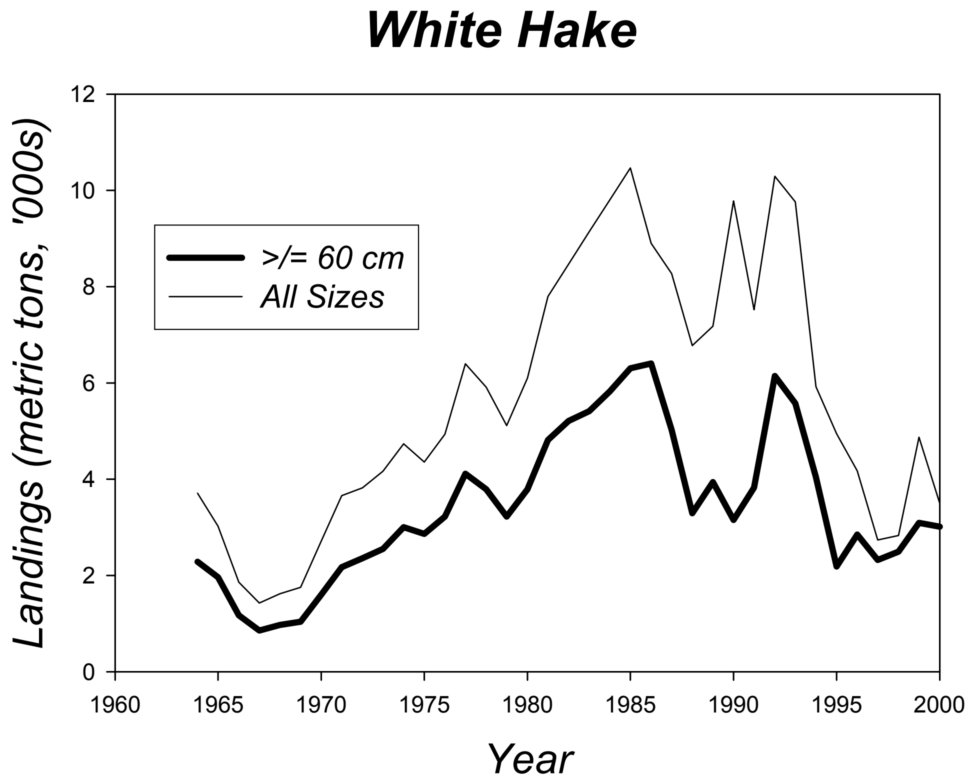
The most recent assessment of white hake was based on a biomass dynamics model (ASPIC) of catch and survey indices of >60cm fish, and the results were reviewed by the 33rd Northeast Regional Stock Assessment Workshop (33rd SAW) in June 2001 (NEFSC 2001c). These results confirmed the trends derived from the previous analyses and indicated further declines in stock biomass and increases in fishing mortality between 1998 and 2000. The biomass estimates from the model indicate that biomass increased to levels above B_{msy} in the late 1960s through the early 1980s. Biomass has since declined and is estimated to be about 20% of B_{msy}. The estimates of fishing mortality show an increasing trend from a low in 1967. The current estimate of fishing mortality is at least twice the F_{msy} estimate.

Surplus Production Analysis

A surplus production model incorporating covariates (ASPIC, Prager, 1995) was conducted on the biomass of white hake greater than 60 cm (NEFSC 2001c). The reference points from this analysis were considered to be provisionalLY acceptable, because of a concern about an increase survey catchability after 1972. B_{msy} was estimated to be 14,700 mt, F_{msy} was estimated to be 0.29, and MSY was estimated to be 4,200 mt (Figure 3.14.2).

Projections

Observed catch from January to November 2001 was 3,150mt, which corresponds to a total annual catch of 3,360mt based on proportion of 2000 landings taken in December, by gear. Assuming 200 mt of Canadian catch, and 75% of U.S. catch >60cm, the preliminary estimate of 2001 catch >60cm is 2,670mt. With an estimate of 2001 stock biomass of 3,000mt from the biomass dynamics model, the estimate of 2001 catch would severely deplete the stock, especially if the large resulting F were assumed to continue in 2002. Projections were not considered to be reliable from the biomass dynamics model, because age-aggregated models do not perform well for describing the dynamics of severely depleted, age-structured populations. However, the working group concludes that if such high levels of catches were taken in 2001 and the intense exploitation rate continues in 2002, the stock will be in a severely depleted state, well below the most recent stock status of 20%B_{MSY}.



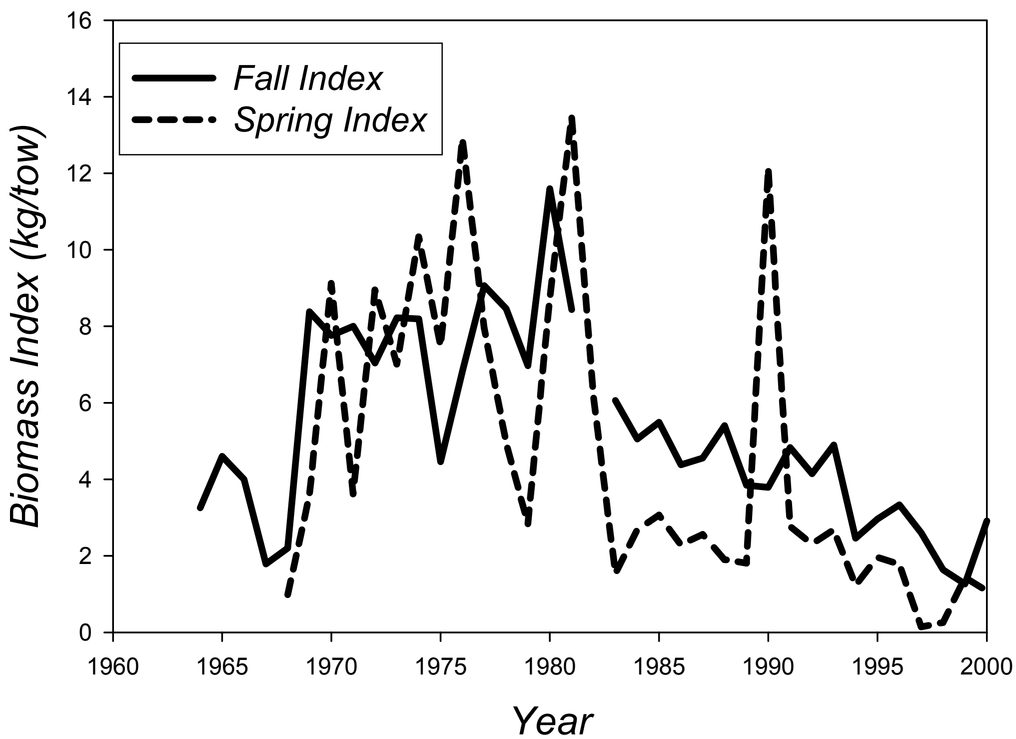


Figure 3.14.1. Landings and research vessel survey abundance indices for White hake.

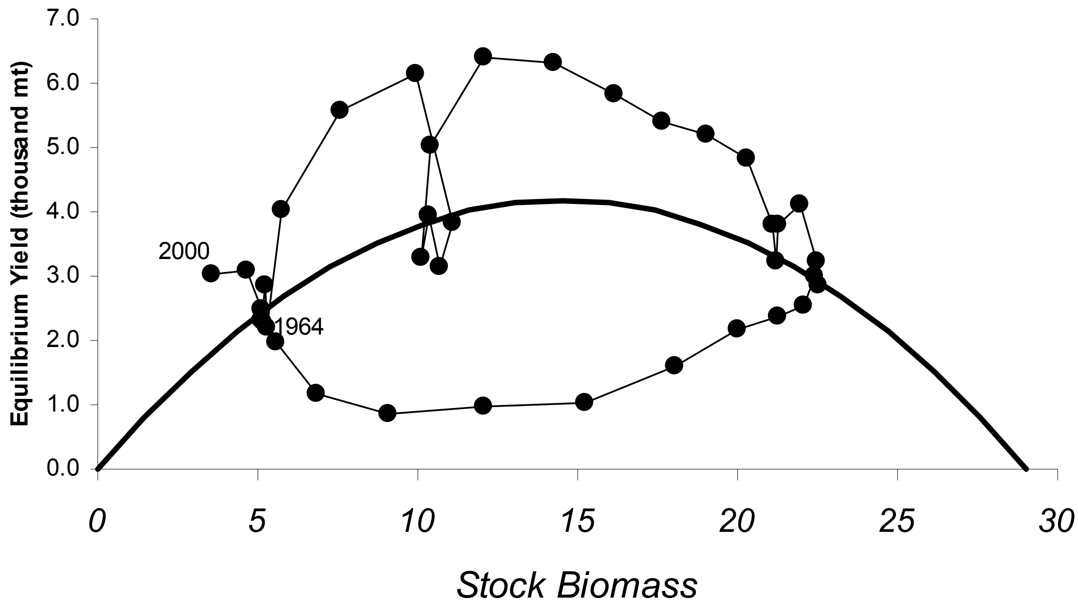


Figure 3.14.2. Results of surplus production analyses (ASPIC) for white hake

3.15 Pollock

Catch and Survey Indices

Pollock have been exploited by Canadian, USA and distant water fleets on the Scotian Shelf, in Gulf of Maine, and on Georges Bank. The total commercial catch from these areas increased from an annual average of 38,200 mt during 1972-76 to 68,800 mt in 1986 (Mayo *et al.* 1989), but has since declined to 10,000 - 15,000 mt per year. For the purposes of the present analysis, only catches from the Gulf of Maine and Georges Bank and west taken by all countries were included. Prior to 1976, fleets from all countries fished for pollock throughout the Scotian Shelf and Georges Bank, and in portions of the Gulf of Maine. Total landings increased from less than 10,000 mt per year during the 1960s to about 15,000 mt by the mid 1970s. Landings increased sharply during the late 1970s to over 20,000 mt per year, peaking at 26,500 mt in 1986 (Figure 3.15.1).

After this period of relatively high catches, total landings began to decline rapidly, and have averaged between 4,000 and 8,000 mt per year since 1994. Since 1984, the USA fishery has been restricted to areas of the Gulf of Maine and Georges Bank west of the line delimiting the USA and Canadian fishery zones. The Canadian fishery occurs primarily on the Scotian Shelf with some additional landings from Georges Bank east of the line delimiting the USA and Canadian fishery zones (Neilson et *al.* 1999).

Indices of relative biomass (ln re-transformed), derived from NEFSC autumn research vessel bottom trawl surveys have varied considerably since 1963 (Figure 3.15.1). Indices generally fluctuated between 2 and 5 kg per tow throughout most of the 1960s and 1970s, peaking at over 5-7 kg per tow during the mid-to-late 1970s, reflecting recruitment of several moderate-to strong year classes from the early 1970s. Strong year classes were also produced in 1979 and 1980, after which recruitment began to diminish during the 1980s. Biomass indices declined rapidly during the early 1980s, and continued to decline steadily through the early 1990s, reaching a minimum in 1994. Since 1994, biomass indices from the Gulf of Maine-Georges Bank region have gradually increased.

Stock Assessment

Pollock, *Pollachius virens* (L.) have generally been assessed as a unit stock from the eastern Scotian Shelf (NAFO Division 4V) to Georges Bank and the Gulf of Maine (Subarea 5). Canadian assessments (Neilson et *al.* 1999) treat the management unit within the Canadian EEZ separately. This stock was last assessed over its entire range *via* VPA in 1993 (Mayo and Figuerido 1993), and the results were reviewed at the 16th Northeast Regional Stock Assessment Workshop in 1993 (NEFSC 1993a, 1993b). At that time, spawning stock biomass had been declining since the mid-1980s, and was expected to reach its long-term average (144,000 mt). Fishing mortality was estimated to be 0.72 in 1992, above $F_{20\%}$ (0.65) and well above F_{med} (0.47).

The state of this stock was most recently evaluated in 2000 *via* index assessment (NEFSC 2001a). At that time, it was noted that biomass indices for the Gulf of Maine-Georges Bank portion of the stock, derived from NEFSC autumn bottom trawl surveys, had increased during the mid-1970s, declined sharply during the 1980s, but have been gradually increasing since the mid-1990s.

Relative Exploitation Rate Analyses

An index of relative exploitation (catch/survey biomass index) corresponding to a replacement ratio of 1.0, as described in section 2.3, was developed for the portion of the unit stock of pollock within the USA EEZ. Autumn NEFSC survey biomass indices from the Gulf of Maine and Georges Bank region from 1963 through 2000 were used to calculate the replacement ratios, and the biomass indices and total landings from the same region were used to compute the relative exploitation rates (Figure 3.15.2). The relative exploitation rates (or relative F) may be considered a proxy for Fmsy for that portion of the pollock stock considered in this analysis.

Prior to the 1980s, a high proportion of the replacement ratios equaled or exceeded 1.0. During the 1980s and early 1990s, most of the replacement ratios were less than 1.0, with ratios greater than 1.0 appearing again by the late 1990s as the biomass indices began to gradually increase from the very low levels of the mid-1990s.

The relationship between replacement ratios and relative F was evaluated by a linear regression of the Log_e replacement ratio on Log_e relative F (Figure 3.15.2, Table 4.1.1) and the results were used to derive an estimate of relative F corresponding to a replacement ratio of 1.0. Results for pollock were significant ($p<0.05$, Table 4.1.1.), and the estimate of the relative replacement F (F rel rep) has a low standard error compared to the point estimate (5.88). The regression indicates that, on average, when the relative F is greater than 5.88, the stock is not likely to replace itself in the long-term.

The data displayed in Figure 3.15.2 also provide a means to utilize the estimate of the Fmsy proxy (Relative F=5.88) to derive a biomass index which relates to the replacement ratios. In this case, it is evident that most of the replacement ratios at or above 1.0 occurred prior to the 1980s when the biomass index was greater than about 3.0. This index may be considered as the biomass proxy for Bmsy that corresponds to the relative F proxy for Fmsy.

Since the relative F relates the catch directly to survey biomass, the catch corresponding to the Bmsy proxy can be estimated from the relative F and the biomass index of Bmsy. For pollock, this computes to 3.0 * 5.88 =17.64, or 17,640 mt as a proxy for MSY. Results of these calculations are presented in Table 4.2.1.

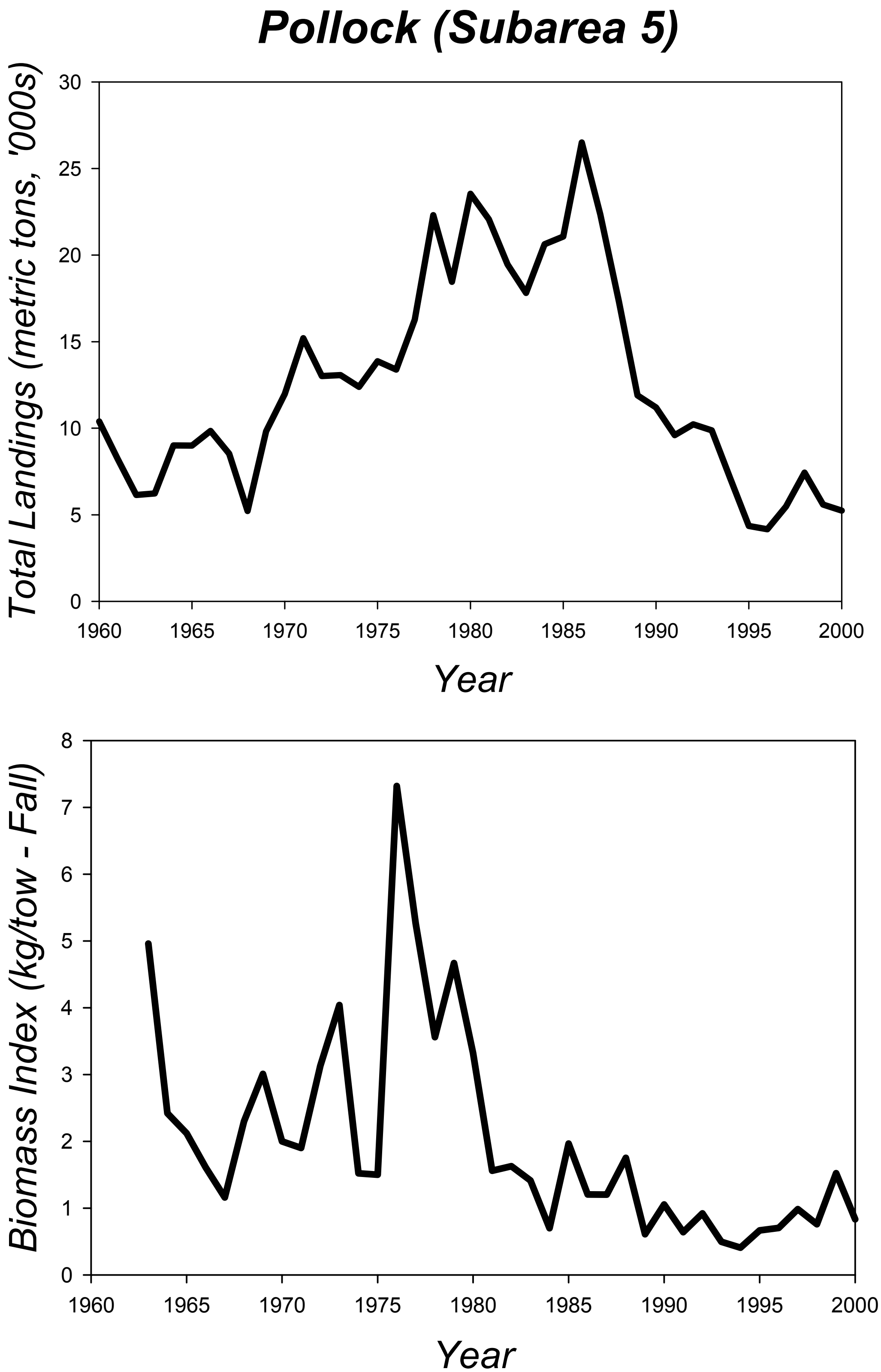


Figure 3.15.1. Landings and research vessel survey abundance indices for pollock.

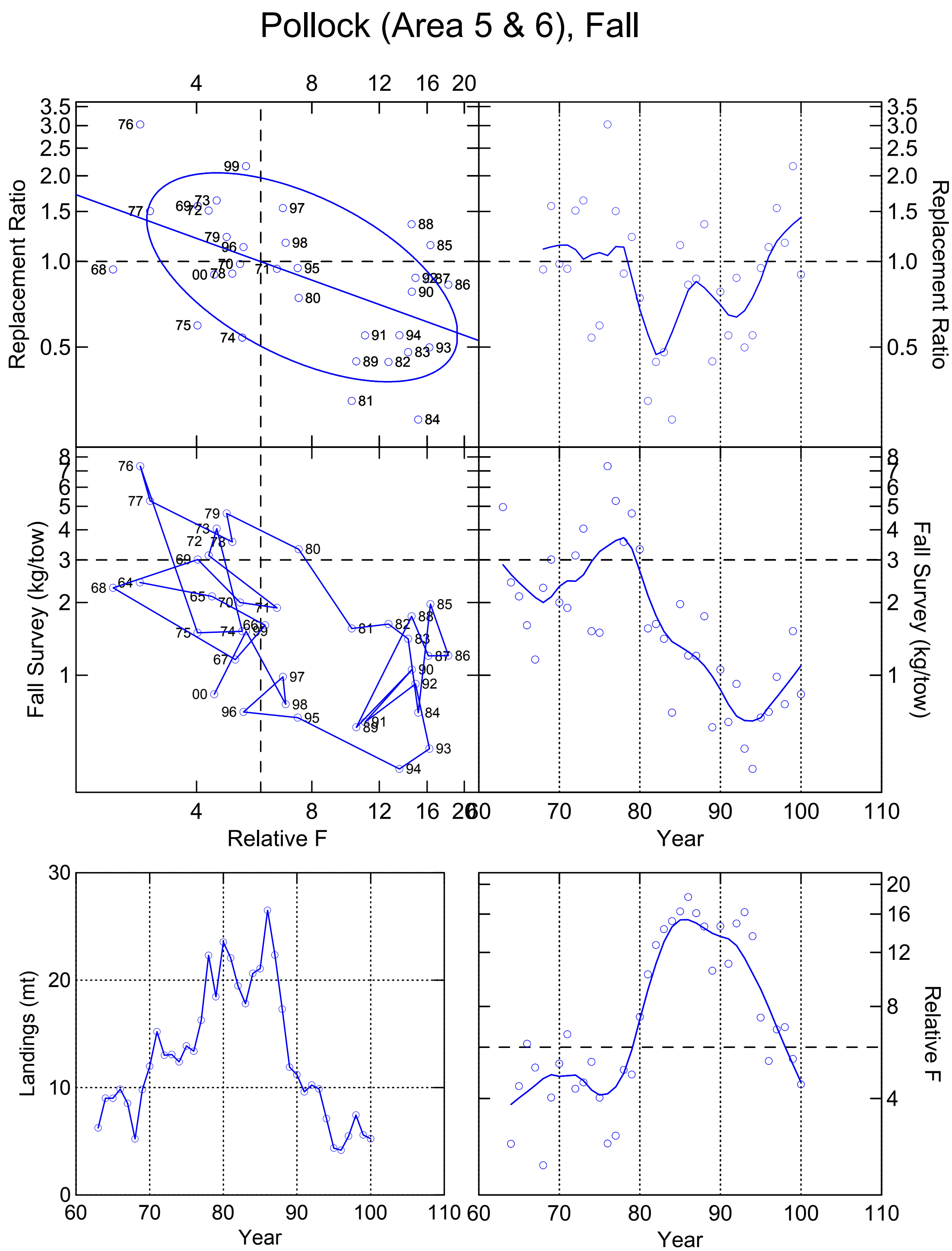


Figure 3.15.2. Trends in relative biomass, landings, fishing rate mortality rate indices (landings/ survey index) and replacement ratios for pollock. Dashed lines indicate proposed biomass and fishing mortality rate proxies of Bmsy and Fmsy. Landings are all reported in Subareas 5&6, by all countries.

3.16 Northern Windowpane Flounder (Gulf of Maine - Georges Bank)

No stock structure information is available. Therefore, a provisional arrangement has been adopted that recognizes two stock areas based on apparent differences in growth, sexual maturity, and abundance trends between windowpane flounder from Georges Bank and from Southern New England. The proportions of total landings contributed by the Gulf of Maine and Mid-Atlantic areas are low (less than 7%), so data from these areas are combined with those from Georges Bank and Southern New England, respectively.

Catch and Survey Indices

Since 1975, when landings of this species were first recorded, the majority of the total landings have been harvested from the Gulf of Maine-Georges Bank stock. Following a 1991 record high of 2,900 mt, landings declined to 300 mt in 1994. Landings have also been declining since 1996 and reached a record low of 46 mt in 1999 and remained at less than 200 mt in 2000 (Figure 3.16.1). High landings during the early 1990s probably reflect an expansion of the fishery to offshore areas, as well as the targeting of windowpane flounder as an alternative to depleted groundfish stocks.

Stratified mean weight (kg) per tow of windowpane flounder from the NEFSC autumn bottom trawl surveys are presented in Figure 3.16.1 for the Gulf of Maine-Georges Bank stock. Survey biomass indices are highly variable, but in general, show an increasing trend since 1991. The large increase in the 1998 survey index is primarily attributable to a large catch of windowpane at one station.

Stock Assessment

The northern windowpane flounder stock, which includes the Gulf of Maine and Georges Bank regions, has never been assessed through the SAW/SARC process. The state of this stock was most recently evaluated in 2000 via index assessment (NEFSC 2001a). At that time, it was noted that biomass indices for the Gulf of Maine-Georges Bank stock, derived from NEFSC autumn bottom trawl surveys, had increased since 1991 while the exploitation ratio (catch/survey biomass index) appears to have declined.

Relative Exploitation Rate Analyses

The replacement ratio analysis for northern windowpane flounder provided and estimate of the exploitation index (Relative F) that would allow the stock to replace itself. However, the regression was not significant ($p=0.197$) and the standard error was greater than the estimate (CV= 130%; Table 4.1.1, Figure 3.16.2). As the relationship between the replacement ratio and relative F is poorly defined, these data do not provide any basis to revise the existing reference points (Table 4.2).

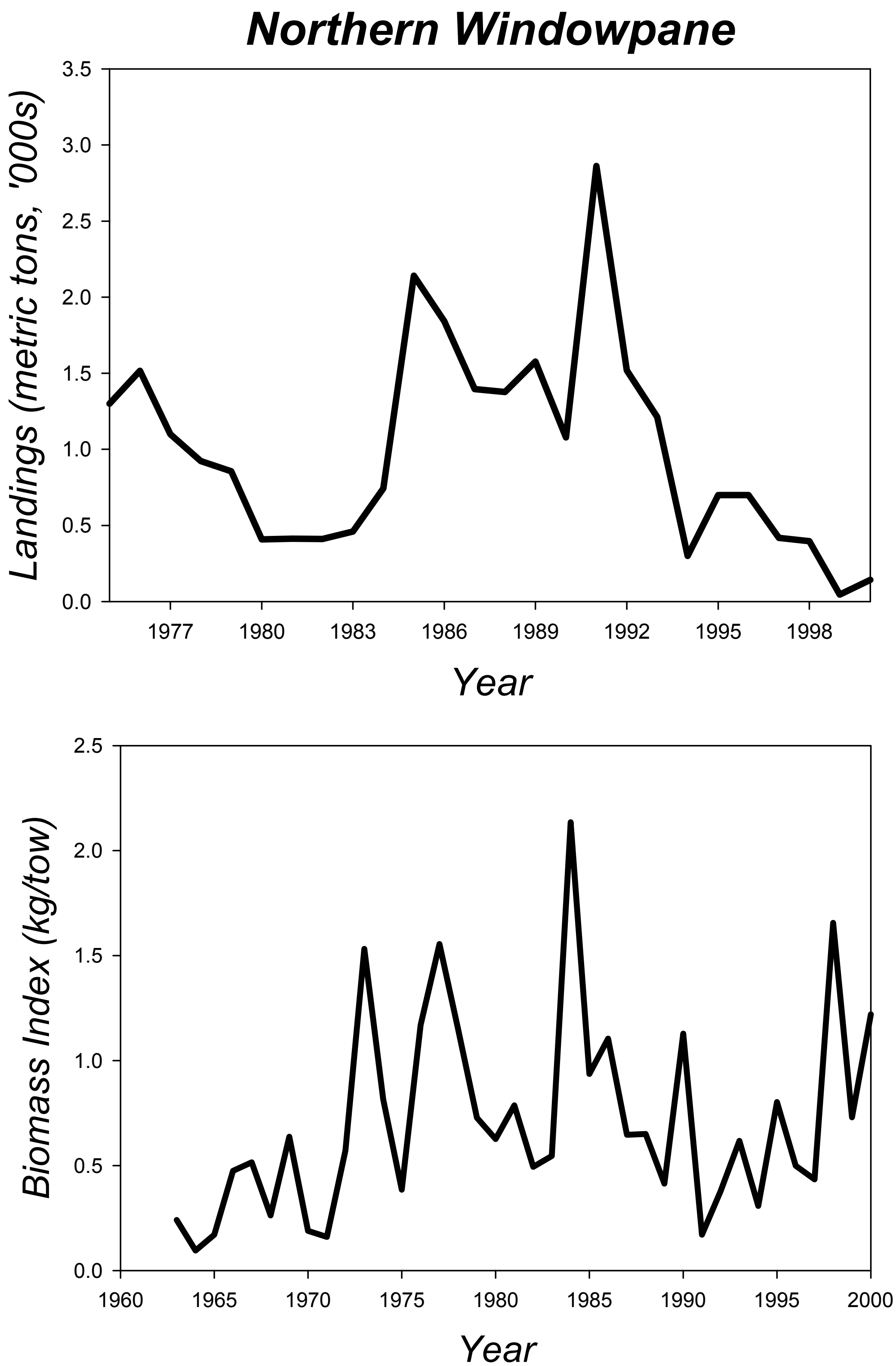


Figure 3.16.1. Landings and research vessel survey abundance indices for Northern windowpane.

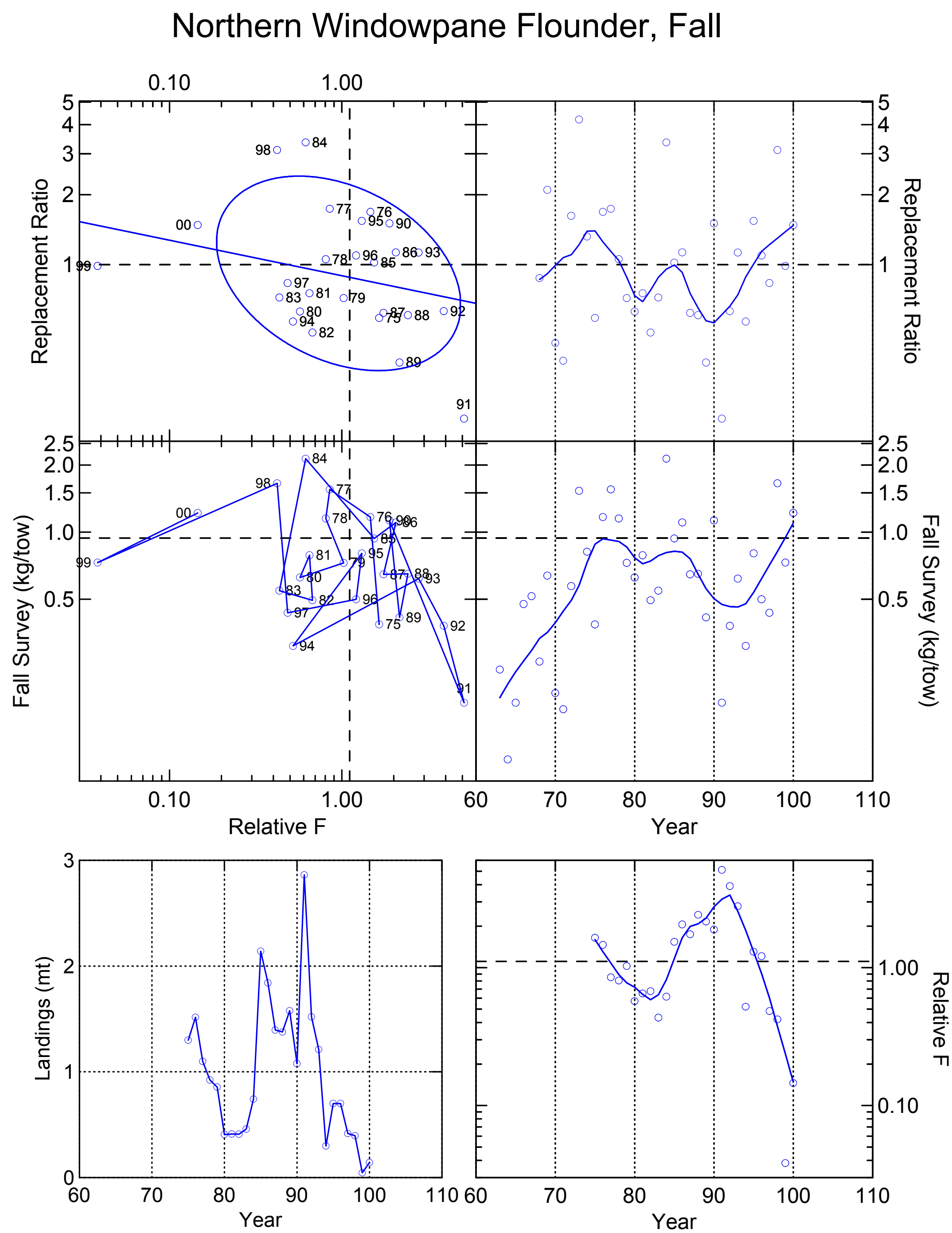


Figure 3.16.2. Trends in relative biomass, landings, fishing rate mortality rate indices (landings/ survey index) and replacement ratios for Northern windowpane. Dashed lines indicate proposed biomass and fishing mortality rate proxies of Bmsy and Fmsy.

3.17 Southern windowpane flounder

No stock structure information is available. Therefore, a provisional arrangement has been adopted that recognizes two stock areas based on apparent differences in growth, sexual maturity, and abundance trends in fish from Georges Bank and from Southern New England. The proportions of total landings contributed by the Gulf of Maine and Mid-Atlantic areas are low (less than 7%), so data from these areas are combined with those from Georges Bank and Southern New England, respectively.

Catch and Survey Indices

Commercial landings from this stock exceeded those from the Gulf of Maine-Georges Bank stock during 1980-1984, and reached a record high of 2,100 mt in 1985 (Figure 3.17.1). Landings declined rapidly between 1988 and 1995, from 2,100 mt to a record low of 100 mt around1995 and have remained at that level through 2000.

Stratified mean weight (kg) per tow of windowpane flounder from the NEFSC autumn bottom trawl surveys are presented in Figure 3.17.1 for the Southern New England - Mid-Atlantic stock. The survey biomass indices appear to have stabilized since 1995 at the lowest level on record.

Stock Assessment

The southern windowpane flounder stock, which includes the southern New England and Mid-Atlantic Bight regions, has never been assessed through the SAW/SARC process. The state of this stock was most recently evaluated in 2000 via index assessment (NEFSC 2001a). At that time, it was noted that biomass indices for the Southern New England - Mid-Atlantic stock, derived from NEFSC autumn bottom trawl surveys, had recently declined to record-lows following a period of relatively high exploitation ratios (catch/survey biomass index).

Relative Exploitation Rate Analyses

The replacement ratio analysis for southern windowpane flounder suggests that this stock can replace itself at an exploitation index (Relative F) of 0.98 (SE = 0.45, CV of 48% and marginally significant correlation of replacement ratio and relative F, p=0.101; Table 4.1.1, Figure 3.17.2). Examination of the entire landings data set indicates that the existing estimate of MSY (900 mt) is consistent with potential productivity of this stock. Therefore, the existing eatimate of MSY was divided by the relative F consistent with the replacement ratio analysis to derive a revised estimate of the survey biomass index proxy for Bmsy. Based on these analyses the revised relative F for southern windowpane flounder is 0.98 and the revised Bmsy proxy is 0.92 kg/tow (Table 4.2).

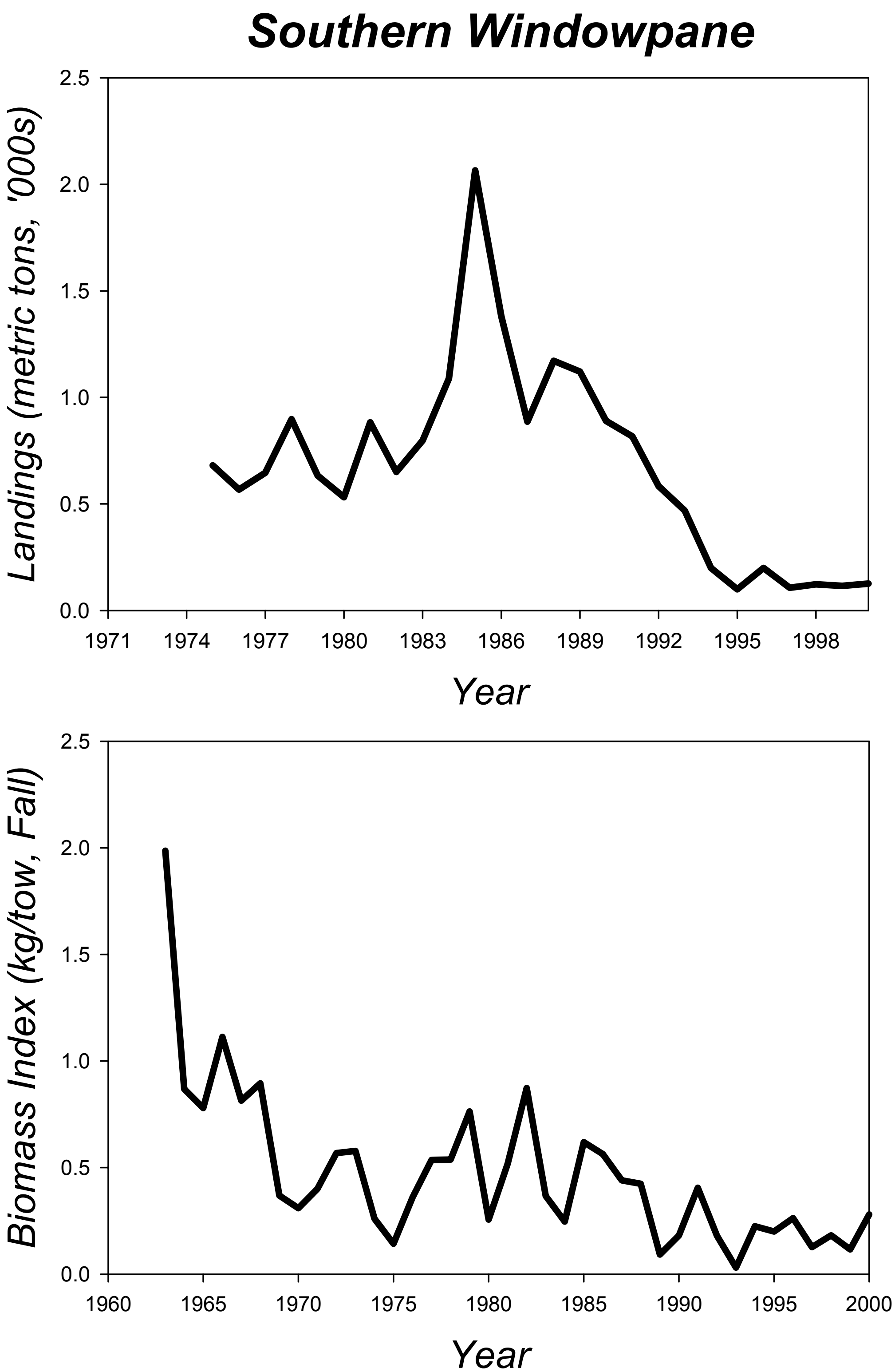


Figure 3.17.1. Landings and research vessel survey abundance indices for Southern windowpane.

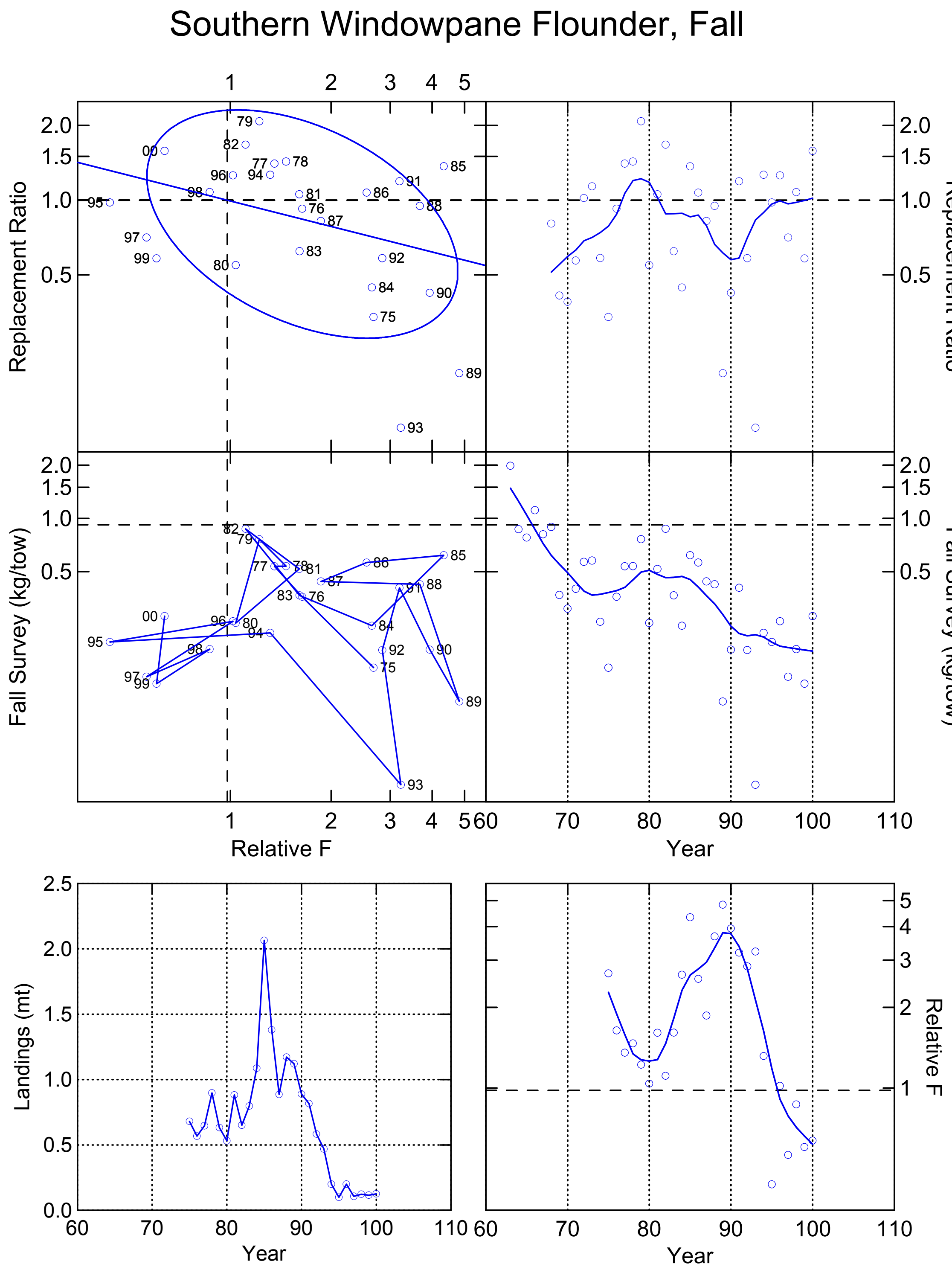


Figure 3.17.2. Trends in relative biomass, landings, fishing rate mortality rate indices (landings/ survey index) and replacement ratios for Southern windowpane. Dashed lines indicate proposed biomass and fishing mortality rate proxies of Bmsy and Fmsy.

3.18 Ocean Pout

Catch and Survey Indices

Commercial interest in ocean pout has fluctuated widely. Ocean pout were marketed as a food fish during World War II, and landings peaked at 2,000 mt in 1944. However, an outbreak of a protozoan parasite that caused lesions on ocean pout eliminated consumer demand for this species. From 1964 to 1974, an industrial fishery developed, and nominal catches by the U.S. fleet averaged 4,700 mt. Distant-water fleets began harvesting ocean pout in large quantities in 1966, and total nominal catches peaked at 27,000 mt in 1969. Foreign catches declined substantially afterward, and none have been reported since 1974. United States landings declined to an average of 600 mt annually during 1975 to 1983. In the mid-1980s, landings increased to about 1,400 mt due to the development of a small directed fishery in Cape Cod Bay supplying the fresh fillet market. Landings have declined more or less continually since 1987, and remain at record low levels (Figure 3.18.1).

Commercial landings and the NEFSC spring research vessel survey biomass index followed similar trends during 1968 to 1975 (encompassing peak levels of foreign fishing and the domestic industrial fishery); both declined from very high values in 1968-1969 to lows of 300 mt and 1.3 kg per tow, respectively, in 1975. Between 1975 and 1985, survey indices increased to record high levels, peaking in 1981 and 1985. Since 1985, survey catch per tow indices have generally declined, and are presently less than the long-term survey average (3.9 kg per tow; Figure 3.18.1).

Stock Assessment

Ocean pout is assessed as a unit stock from Cape Cod Bay south to Delaware. An index assessment for this species was conducted and reviewed at SAW 11 in 1990 (NEFSC 1990). The status of this stock was most recently evaluated in 2000 (NEFSC 2001a). At that time, the three year average spring biomass index (1997-1999 average = 1.98 kg/tow) was approximately 40% of the current Bmsy proxy (1980-1991 median = 4.9 kg/tow) and below the biomass threshold (1/2Bmsy = 2.4 kg/tow). Since1991, the exploitation ratios (landings/three year average spring survey biomass) have declined. The 1999 exploitation index (0.009) was the lowest in the time series and well below the Fmsy proxy (0.31), derived as the MSY proxy (1,500 mt) divided by the Bmsy proxy. Since discards have not been estimated, and landings, not catch, were used to derive exploitation ratios, the exploitation ratios may be underestimated.

Relative Exploitation Rate Analyses

The replacement ratio analysis suggest that the input data for this stock may be imprecise given the weak relationship between the replacement ratio and the relative F as indicated by the circular shape of the ellipse (Figure 3.18.2). The relative F where replacement ratio = 1.0 was estimated to be 0.01 (SE 0.03) and the relative F where replacement ratio = 1.1 was estimated to be 0.00 (SE 0.01; Table 4.1.1). Given that the randomization test for this analysis was not significant (0.118; Table 4.1.1) and that the precision of the relative F was three times larger than the point estimate, it was concluded that, for this stock, these analyses were not informative upon which to base recommendations for Bmsy, Fmsy, and MSY.

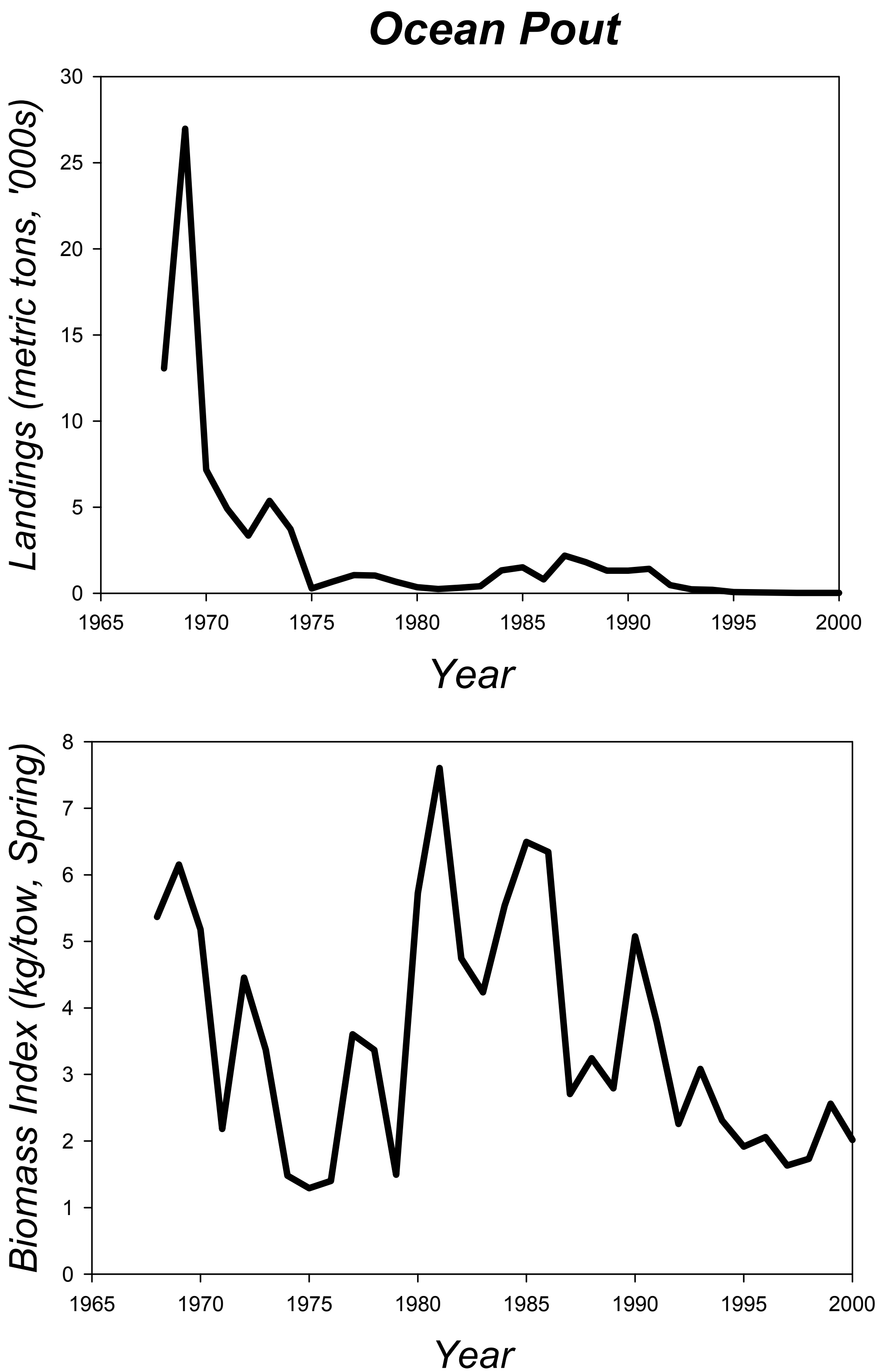


Figure 3.18.1. Landings and research vessel survey abundance indices for Ocean pout.

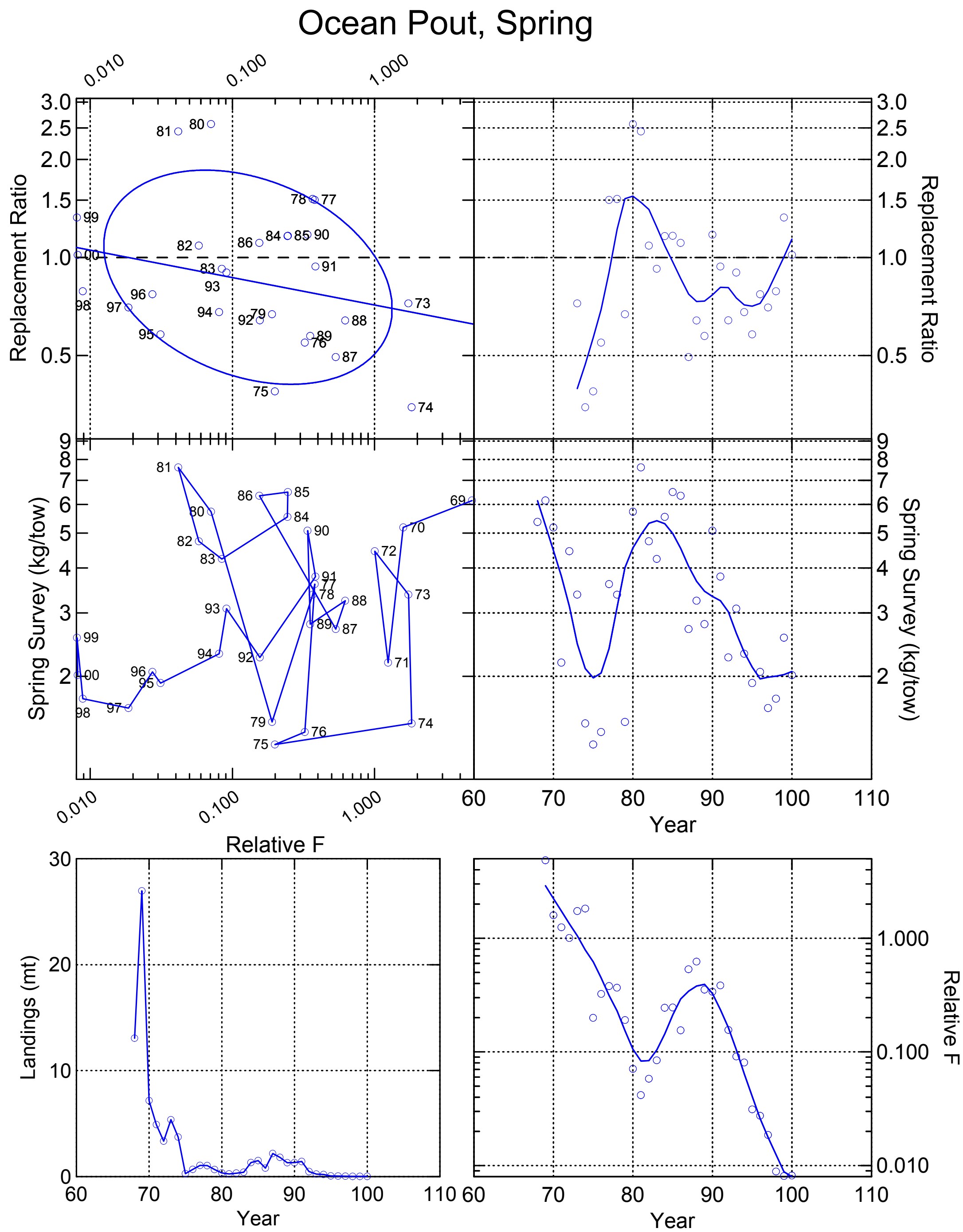


Figure 3.18.2. Trends in relative biomass, landings, fishing rate mortality rate indices (landings/ survey index) and replacement ratios for ocean pout. Dashed lines indicate current biomass and fishing mortality rate proxies of Bmsy and Fmsy.

3.19 Atlantic Halibut

Catch and Survey Indices

The Atlantic halibut (*Hippoglossus hippoglossus*) is distributed from Labrador to southern New England in the northwest Atlantic (Bigelow and Schroeder 1953; Wise and Jensen 1959). The Atlantic halibut stock within Gulf of Maine and Georges Bank waters (NAFO Subarea 5) has been exploited since the 1830s. This resource is currently depleted and is not expected to rebuild in the near future (NEFMC 1998).

Records of Atlantic halibut landings from the Gulf of Maine and Georges Bank begin in 1893 (Figure 3.19.1). Substantial landings occurred prior to this, however, as the halibut fishery declined in the late 1800s (Hennemuth and Rockwell 1987). Landings have decreased since the 1890s as components of the resource have been sequentially depleted. Annual landings averaged 662 mt during 1893-1940 and declined to an average of 144 mt during 1941-1976. Since 1977, landings have averaged 95 $mt \cdot yr^{-1}$. Reported landings in 1999 were 20 mt. Of these, 12 mt were landed by domestic fishermen (60%) with the remainder landed by Canadian fishermen (Division 5Zc).

The Northeast Fisheries Science Center spring and autumn bottom trawl surveys provide measures of the relative abundance of Atlantic halibut within the Gulf of Maine and Georges Bank (Offshore survey strata 13-30 and 36-40). Both indices have high inter-annual variability since relatively few halibut are captured during these surveys; in some years, no halibut are caught. The survey indices suggest that relative abundance increased during the 1970s to early 1980s and subsequently declined in the 1990s. It is unknown whether abundance trends in the Gulf of Maine and Georges Bank have been influenced by changes in the seasonal distribution and availability of Atlantic halibut, however.

Stock Assessment

Based on updated spring and autumn survey data, Atlantic halibut biomass within the Gulf of Maine and Georges Bank remains very low. Swept-area biomass indices in spring 2000 and autumn 1999 were both less than 100 mt (Figure 3.19.2). Thus, even if survey catchability was as low as 25%, current stock biomass, as indexed by the 5-year moving average of swept-area biomass, would be below the biomass threshold of 2,700 mt. Although no estimates of fishing mortality are available, exploitation rate indices (annual landings/5-year moving average of survey index) suggest that exploitation rates have probably been stable since the 1970s, and may have declined during the 1990s. Thus, the Atlantic halibut stock in the Gulf of Maine and Georges Bank remains depleted and exploitation rates do not appear to have increased since the 1970s.

In the 1998 report on overfishing definitions and its Supplement (NEFMC 1998), the overfishing review panel recommended proxies for the stock biomass (B_{MSY}) and fishing mortality rate (F_{MSY}) that would produce the largest long-term potential yield. Based on yield-per-recruit and biomass-per-recruit calculations, the panel concluded that B_{MSY} was roughly 5,400 mt and that F_{MSY} was about 0.06 per year with an associated long-term potential yield of 300 mt per year. Accordingly, the panel recommended that the biomass threshold ($B_{THRESHOLD}$) be set to ½ of B_{MSY}

so that $B_{THRESHOLD}$=2,700 mt and that the target fishing mortality rate (F_{TARGET}) be set to 60% of F_{MSY} so that F_{TARGET}=0.04 per year. The panel also recommended that an appropriate harvest control rule would be to keep fishing mortality as close to zero as practicable until the Gulf of Maine and Georges Bank stock was rebuilt. To evaluate the harvest control rule, the review panel compared swept-area biomass estimates from the NEFSC spring and autumn surveys with the threshold. The panel concluded that the stock was depleted because, on average, the swept-area biomass index was far below $B_{THRESHOLD,}$ given an implicit assumption that survey catchability was probably on the order of 25-50%.

Yield and SSB per Recruit Analysis

A preliminary yield and SSB per recruit analysis was conducted using revised estimates of growth parameters from Sigourny (MS 2002). Catch mean weights were set equivalent to stock mean weights. Stock mean weights at age were derived from a Gompertz growth curve (L_{inf}=182 cm, K=0.2229, t_0=4.4317) and a log-log length-weight relationship (ln length = -11.7535 + 3.0658* ln length) for females only . Plus mean weights for ages 25+ were derived from an expanded age structure to age 38 (oldest age observed in survey) at F =0.1 and M = 0.1. The partial recruitment vector was considered to be knife-edge at age 6 based on the minimum size limit of 36". The maturity ogive was derived from pooled 1977-2000 female data presented graphically in Sigourny (MS 2002).

If $F_{40\%}$ is considered as a proxy for F_{MSY}, the newly estimated $F_{40\%}$=0.08 is similar to the previously estimated F_{MSY} =0.06. This analysis will not be accepted, however, until further analyses are conducted regarding the partial recruitment and maturity at age schedule.

Reference Points.
The reference points will remain as F_{MSY} = 0.06, B_{MSY} =5,400 mt and MSY = 300 mt.

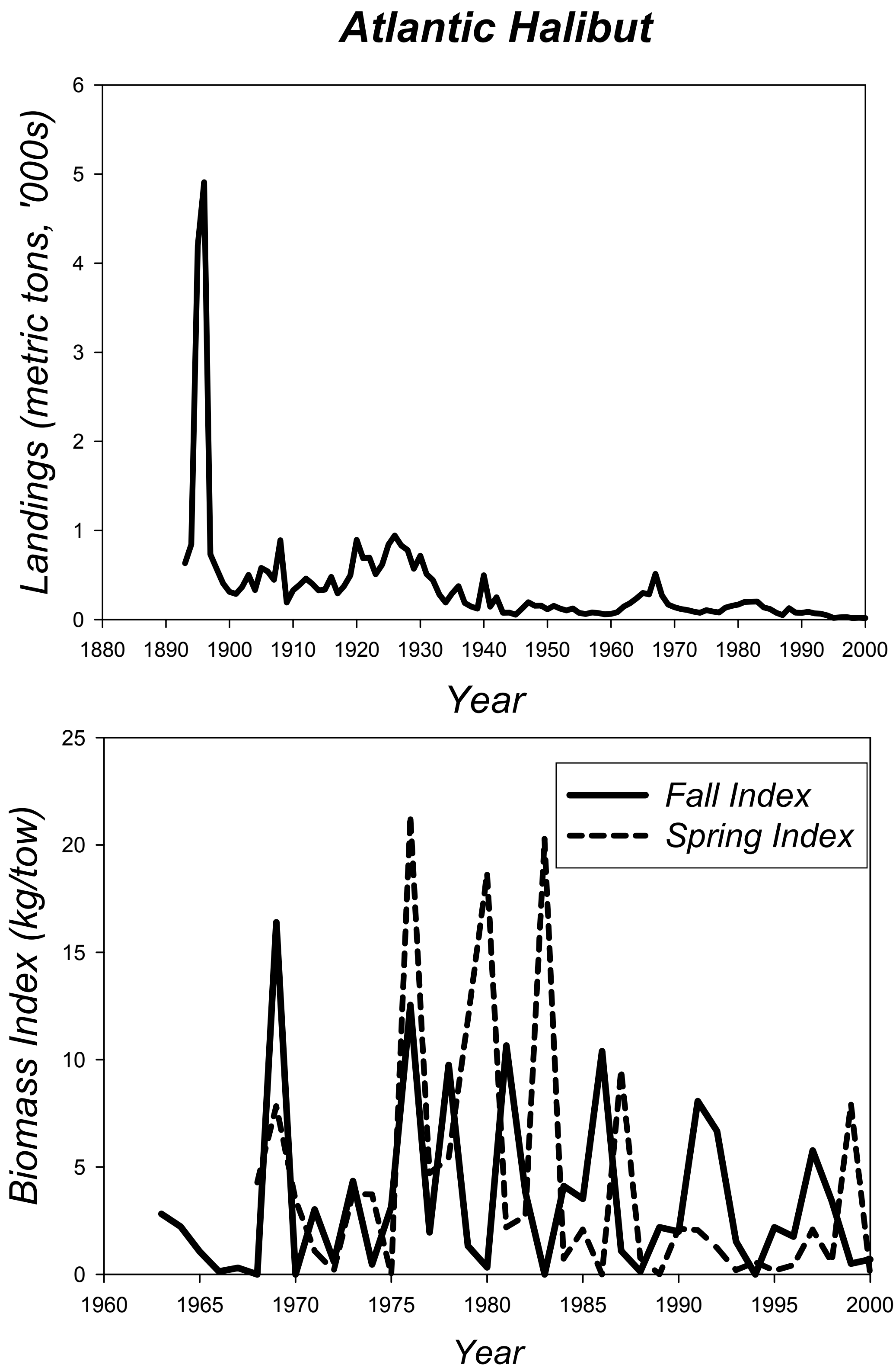


Figure 3.19.1. Landings and research vessel survey abundance indices for Atlantic halibut.

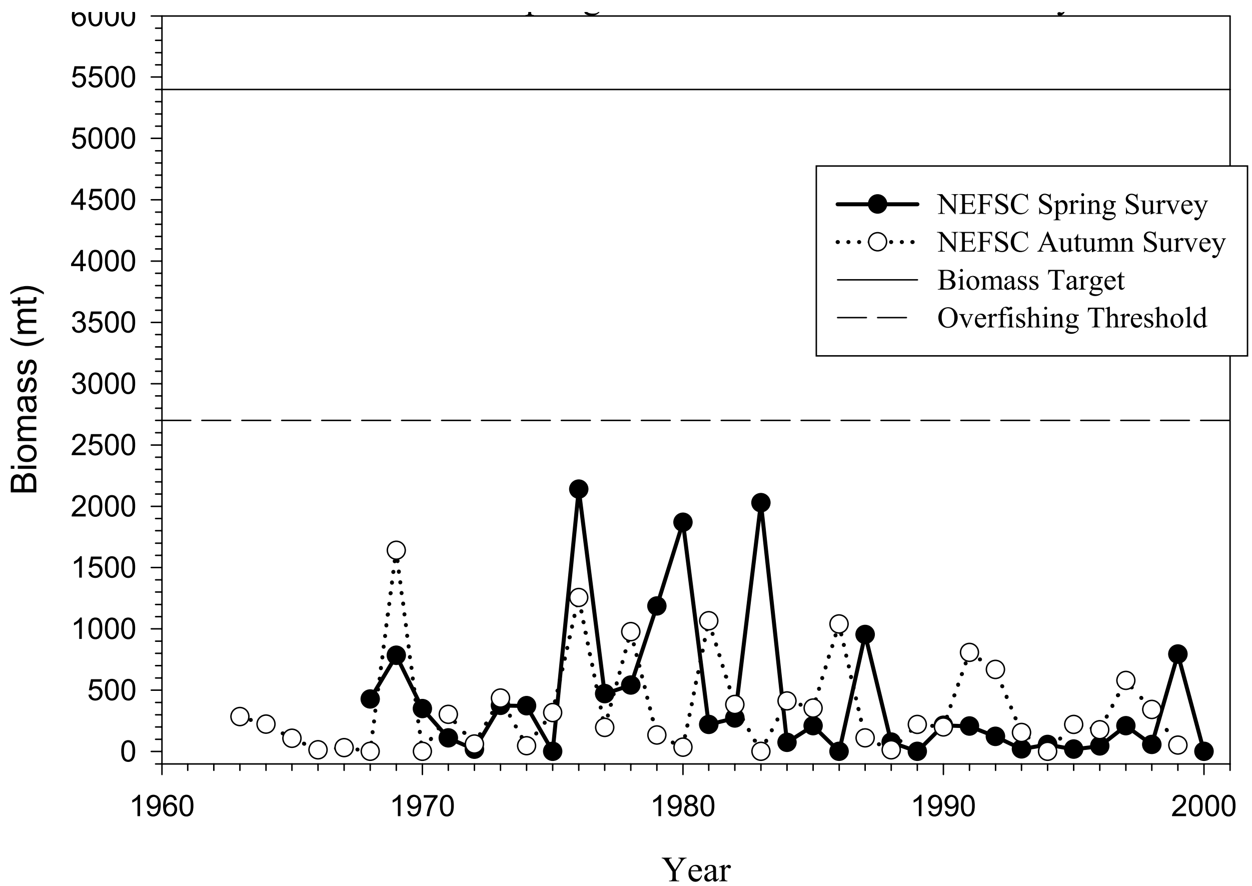


Figure 3.19.2. Trends in swept-area biomass indices (mt) of Atlantic halibut from NEFSC spring and autumn bottom trawl surveys. Current biomass targets and thresholds Are indicated.

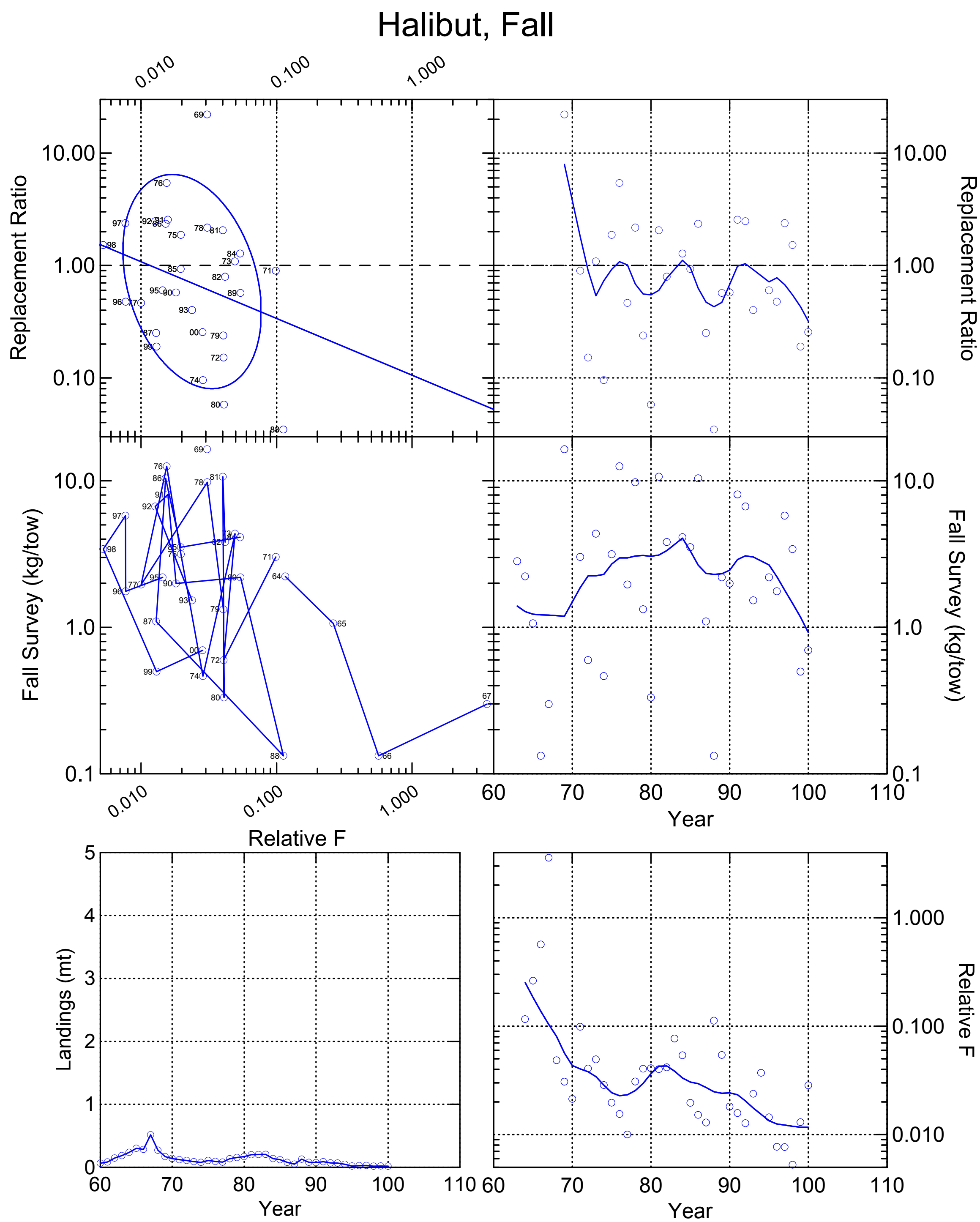


Figure 3.19.3. Trends in relative biomass, landings, fishing rate mortality rate indices (landings/ survey index) and replacement ratios for Atlantic halibut.

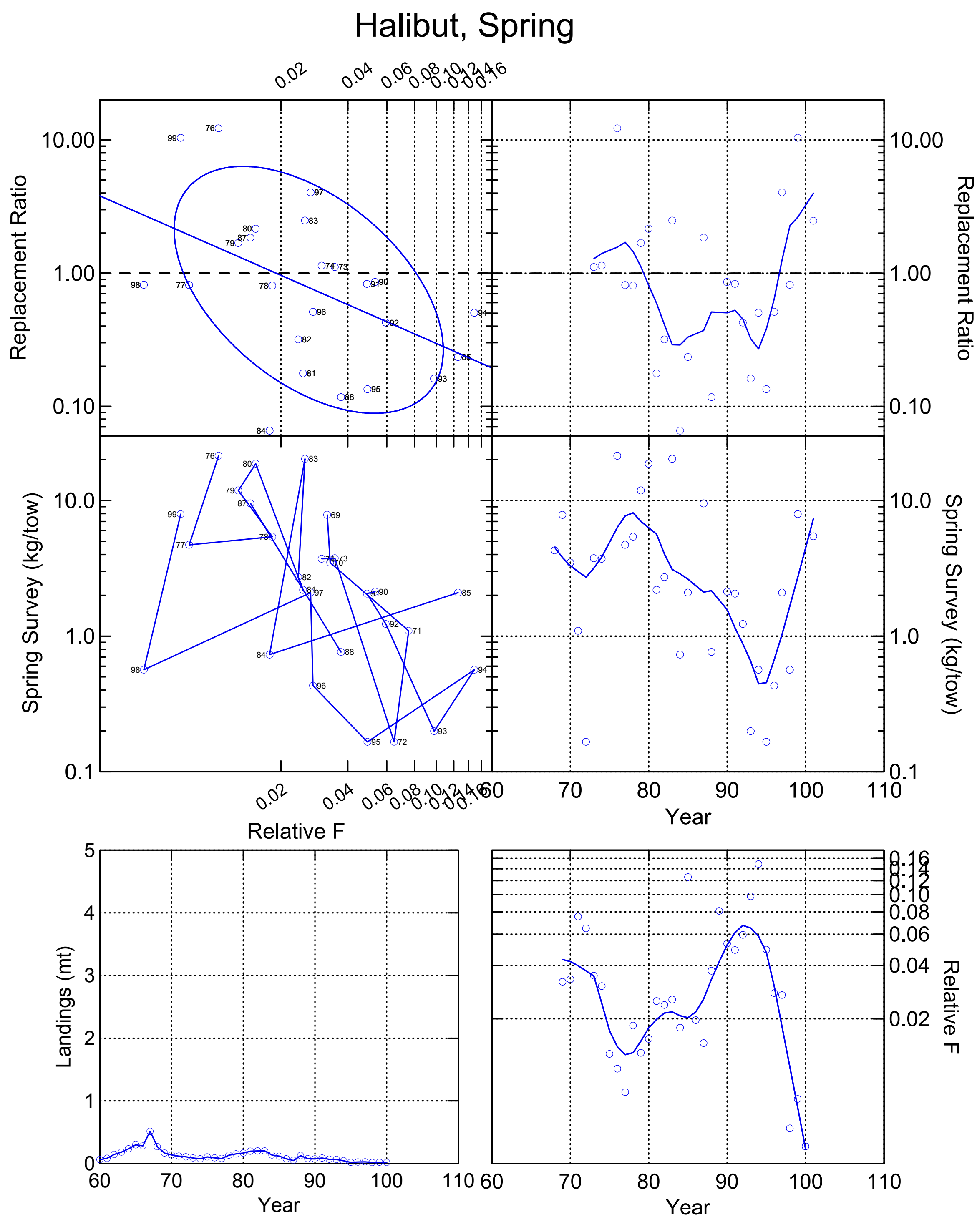


Figure 3.19.4. Trends in relative biomass, landings, fishing rate mortality rate indices (landings/ survey index) and replacement ratios for Atlantic halibut.

4.0 Summary and Discussion of the Implications of Re-Calculated Reference Points

4.1 Index-Based Methods Applied to all Stocks and Surveys

Estimates of relative F at replacement, generated for all stocks and surveys, are summarized in Table 4.1.1. In addition the estimates of the relative F necessary for a 10% growth rate of the population are provided in Table 4.1.1. The 10% criterion for population growth should not be construed as a fixed value or scientific recommendation. Rather, it provides a rough measure of the population's capacity for growth that is consistent with the available data. The precision of this estimate as well as the relative F at replacement is provided along with the results of the randomization tests to test for spurious correlations. In general, low precision of the estimates of relF at replacement are associated with uninformative times series. These times series also suggest a weak relationship between the replacement ratio and relative F. In most instances the analyses for the NMFS spring trawl survey mirror the results for the longer time series of autumn (fall) indices. Table 4.1.1 also provides a comparison between the current 3yr average of relative F and the predicted relative F s at replacement and at 10% growth rate. The ratio of the current relative F to these nomimal target levels provides an alternative measure of the relative magnitude of fishing mortality.

The index based method can also be used to generate simple projections of landings over the period 2002-2009. Catch estimates are obtained by multiplying the current population value (in kg/tow) by the target relative F (000 mt/(kg/tow)) in Eq. 10. Thus:

$$\hat{C}_t = relF_{target}\ I_t$$

By definition, application of $\mathbf{relF_{target}}$ to the population results in 10% rate of increase per year. Of course this assumption is appropriate for a limited number of years. A 10% rate of population increase implies a doubling of the population in roughly 8 years. In more formal notation, we can project the population status as:

$$\hat{I}_{t+1} = 1.1 * I_t(F = relF_{target})$$

Recursive application of the above two equations allows for projection of the population status (in units of kg/tow) and catch (in thousands of mt; Table 4.1.2). Comparisons of recent average catches with the average during the rebuilding period suggest that landings would have to be reduced for most species. Note however, that these catch projections are not defined in terms of a target index biomass at the end of 2009.

Due to the developmental nature of these analyses, they should not necessarily be considered reliable for the purposes of management. Initial comparisons however, between these projections and those generated by the age-structured models, suggest reasonable coherence.

Table 4.1.1. Summary of replacement ratio analyses for 19 stocks. Estimates of replacement ratios are based on robust regression of the model ln(RR)=a + b ln(relF). Replacement F is estimated as the point where the replacement ratio equals 1.0. Asymptotic standard errors of the estimate are approximate. Significance test is based on randomization test.

								Current Stock Conditon		
Stock	Species	Survey	relF where Replacement ratio =1.0	SE(F_replace)	relF where replacement ratio = 1.1	SE (F grow)	Significance Level based on Randomization test	Average Relative F	Ratio of current relF to replacement rel F.	Ratio of current relF to 10% Increase rel F.
Georges Bank	Cod	Fall	2.04	0.58	1.64	0.56	0.113	3.91	1.92	2.39
		Spring	1.10	0.30	0.93	0.29	0.112	1.29	1.17	1.38
	Haddock	Fall	0.72	0.08	0.65	0.08	0.001	0.44	0.61	0.68
		Spring	0.58	0.08	0.51	0.08	0.001	0.59	1.03	1.16
	N. Windowpane	Fall	0.37	0.48	0.17	0.32	0.197	0.20	0.54	1.17
	Winter Flounder	Fall	1.18	0.11	1.06	0.11	0.001	0.62	0.52	0.58
	Yellowtail Flounder	Fall	2.42	0.36	2.13	0.33	0.001	0.77	0.32	0.36
		Spring	1.96	0.40	1.68	0.36	0.003	0.72	0.37	0.43
Gulf of Maine	American Plaice	Fall	1.40	0.60	0.90	0.62	0.460	1.49	1.06	1.66
		Spring	2.56	0.59	2.06	0.55	0.132	2.43	0.95	1.18
	Cod	Fall	0.67	0.30	0.45	0.27	0.012	1.41	2.10	3.16
		Spring	0.94	0.35	0.70	0.35	0.269	0.99	1.05	1.40
	Haddock	Fall	0.23	0.05	0.20	0.05	0.004	0.15	0.67	0.76
		Spring	0.83	0.35	0.67	0.29	0.010	0.79	0.95	1.18
	Halibut	Fall	0.01	0.01	0.01	0.01	0.284	0.02	1.21	1.45
		Spring	0.02	0.01	0.02	0.01	0.665	0.01	0.29	0.33
	Pollock (all)	Fall	15.48	3.67	12.01	3.36	0.050	12.93	0.84	1.08
	Pollock (USA)	Fall	3.57	0.97	2.70	0.87	0.050	4.33	1.21	1.60
	Pollock (5&6)	Fall	5.88	1.05	4.83	1.00	0.024	5.56	0.94	1.15
	Redfish	Fall	0.83	0.35	0.51	0.23	0.005	0.06	0.08	0.13
		Spring	0.42	0.22	0.31	0.17	0.030	0.06	0.14	0.20
	White Hake	Fall	0.54	0.07	0.42	0.07	0.036	0.80	1.48	1.89
		Spring	0.57	0.15	0.48	0.15	0.040	1.54	2.68	3.19
	Witch flounder	Fall	1.34		0.92		0.346	3.27		
		Spring					0.554	2.26	1.68	2.45
	Yellowtail Flounder	Fall	0.44	0.19	0.34	0.18	0.472	0.25	0.57	0.75
		Spring	0.30	0.36	0.23	0.35	0.686	0.35	1.17	1.54

Southern New England	Mid Atl Yellowtail	Fall	0.33	0.16	0.30	0.15	0.108	1.19	3.60	4.02
		Spring	0.09	0.06	0.07	0.05	0.194	0.55	6.22	7.33
	Ocean pout	Spring	0.01	0.03	0.00	0.01	0.118	0.01	0.60	2.00
	Windowpane	Fall	0.98	0.45	0.73	0.42	0.101	0.70	0.72	0.96
	Winter Flounder	Fall	5.14	1.00	4.40	0.91	0.004	2.15	0.42	0.49
		Spring	6.97	0.53	6.51	0.52	0.001	4.44	0.64	0.68
	Yellowtail Flounder	Fall	0.47	0.61	0.35	0.52	0.461	1.10	2.33	3.12
		Spring	0.37	0.44	0.28	0.39	0.498	0.48	1.31	1.71

Table 4.1.2. Catch projections based on index model. Catches for 2002 represent status quo relative F, rel F at replacement, and rel F at 10% growth rate. Catches for 2003-2009 assume that rel F is set at F_grow and that population grows at 10% per year

			Current Stock Condition		Predicted Catch for 2002			Predicted Catches (mt) with rel F = F_grow and population growth of 10% per year.								
Stock	Species	Survey	Average Relative Biomass (kg/tow)	Average Relative F (mt/(kg/tow))	Predicted Catch in 2002 (mt)	Catch at replacement rel F	Catch at 10% growth F	2003	2004	2005	2006	2007	2008	2009	average catch during rebuild period	Average Catch1998-2000
Georges Bank	Cod	Fall	2.4	3.91	9.4	4.9	3.9	4.3	4.8	5.2	5.8	6.3	7.0	7.7	5.6	9.30
		Spring	8.2	1.29	10.5	9.0	7.6	8.4	9.2	10.1	11.1	12.3	13.5	14.8	10.9	9.30
	Haddock	Fall	14.8	0.44	6.6	10.7	9.6	10.6	11.6	12.8	14.0	15.4	17.0	18.7	13.7	6.80
		Spring	10.6	0.59	6.3	6.1	5.4	5.9	6.5	7.2	7.9	8.7	9.6	10.5	7.7	6.80
	N. Windowpane	Fall	1.2	0.20	0.2	0.4	0.2	0.2	0.2	0.3	0.3	0.3	0.4	0.4	0.3	0.19
	Winter Flounder	Fall	2.3	0.62	1.4	2.7	2.4	2.7	2.9	3.2	3.6	3.9	4.3	4.7	3.5	1.41
	Yellowtail Flounder	Fall	6.1	0.77	4.7	14.7	12.9	14.2	15.6	17.2	18.9	20.8	22.8	25.1	18.4	4.81
		Spring	6.1	0.72	4.4	12.0	10.2	11.3	12.4	13.6	15.0	16.5	18.1	19.9	14.6	4.81
Gulf of Maine	American Plaice	Fall	2.5	1.49	3.8	3.5	2.3	2.5	2.7	3.0	3.3	3.7	4.0	4.4	3.2	3.69
		Spring	1.5	2.43	3.7	3.9	3.2	3.5	3.8	4.2	4.6	5.1	5.6	6.2	4.5	3.69
	Cod	Fall	3.2	1.41	4.6	2.2	1.4	1.6	1.7	1.9	2.1	2.3	2.6	2.8	2.1	4.34
		Spring	4.2	0.99	4.1	3.9	2.9	3.2	3.6	3.9	4.3	4.7	5.2	5.7	4.2	4.34
	Haddock	Fall	7.3	0.15	1.1	1.7	1.5	1.6	1.8	1.9	2.1	2.4	2.6	2.8	2.1	0.78
		Spring	1.0	0.79	0.8	0.8	0.7	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.0	0.78
	Halibut	Fall	1.5	0.02	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.02
		Spring	3.5	0.01	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.02
	Pollock (all)	Fall	1.0	12.93	13.4	16.1	12.5	13.7	15.1	16.6	18.2	20.1	22.1	24.3	17.8	14.13
	Pollock (USA)	Fall	1.0	4.33	4.5	3.7	2.8	3.1	3.4	3.7	4.1	4.5	5.0	5.5	4.0	4.74
	Pollock (5 &6)	Fall	1.0	5.56	5.8	6.1	5.0	5.5	6.1	6.7	7.3	8.1	8.9	9.8	7.2	6.09
	Redfish	Fall	5.5	0.06	0.4	4.6	2.8	3.1	3.4	3.7	4.1	4.5	4.9	5.4	4.0	0.33
		Spring	5.7	0.06	0.3	2.4	1.7	1.9	2.1	2.3	2.5	2.8	3.1	3.4	2.5	0.33
	White Hake	Fall	4.8	0.80	3.8	2.6	2.0	2.2	2.5	2.7	3.0	3.3	3.6	4.0	2.9	3.73
		Spring	3.1	1.54	4.8	1.8	1.5	1.7	1.8	2.0	2.2	2.4	2.7	2.9	2.2	3.73
	Witch flounder	Fall	0.6	3.27												
		Spring	0.8	2.26	1.9	1.1	0.8	0.8	0.9	1.0	1.1	1.2	1.3	1.5	1.1	2.52
	Yellowtail Flounder	Fall	6.3	0.25	1.6	2.8	2.1	2.3	2.6	2.8	3.1	3.4	3.8	4.1	3.0	1.71
		Spring	6.6	0.35	2.3	2.0	1.5	1.6	1.8	2.0	2.2	2.4	2.6	2.9	2.1	1.71

Southern New England	Mid Atl Yellowtail	Fall	0.2	1.19	0.3	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.30
		Spring	0.5	0.55	0.3	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.30
	Ocean pout	Spring	2.1	0.01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.02
	Windowpane	Fall	0.2	0.70	0.1	0.2	0.1	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.2	0.12
	Winter Flounder	Fall	2.0	2.15	4.2	10.2	8.7	9.6	10.5	11.6	12.7	14.0	15.4	16.9	12.4	4.23
		Spring	0.9	4.44	4.2	6.6	6.2	6.8	7.5	8.2	9.0	9.9	10.9	12.0	8.8	4.23
	Yellowtail Flounder	Fall	0.7	1.10	0.7	0.3	0.2	0.3	0.3	0.3	0.3	0.4	0.4	0.5	0.3	0.68
		Spring	1.4	0.48	0.7	0.5	0.4	0.4	0.5	0.5	0.6	0.6	0.7	0.7	0.5	0.68

4.2 Summary of Revised Reference Points

The Working Group recommendations for revised biomass and fishing mortality rate reference points are summarized in Table 4.2.1. 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 4.2.2 and Figure 4.2.1. In several cases (witch flounder, Georges Bank winter flounder) fishing at the proposed Fmsy will 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 2.5). 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 4.2.2).

Current (year 2000) biomass levels as a ratio of proposed Bmsy values are presented in Figure 4.2.3. The comparison of Bmsy to biomass in 2000 represents, in most cases, the most recent year that analytical assessments actually estimate spawning stock biomasses. Projections give estimated biomasses in subsequent years (2001, 2002) that could be compared with Bmsy, although the latter comparisons are less reliable than with the results of assessment updates. Estimated catches in 2001 (Table 4.2.3) are compared to proposed MSY values in Figure 4.2.4. 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).

Interestingly, there were no cases where a Ricker curve was used to calculate parametric MSY-based reference points. In practice, it is often impossible to discern between Beverton-Holt and Ricker curves based solely on statistical goodness-of-fit criteria (Brodziak 2002). Nonetheless, least squares estimation procedures combined with AIC criteria, similar to those used in this report, have been found to have an inherent bias towards selection of Ricker curves when the actual curve was Beverton-Holt in recent simulation studies (de Valpine and Hastings 2002). Thus, strict adherence to goodness-of-fit criterion to choose a parametric model could be misleading and it is very important to apply common sense when judging the adequacy of fisheries models (Schnute and Richards 2001).

In this report, most Ricker models implied a calculated value of F_{MSY} that substantially exceeded F_{MAX}. For this to be true, it must be the case that growth overfishing is relatively unimportant in contrast to the counterintuitive concept of "recruitment underfishing", which is simply the notion that high numbers of spawners reduce intraspecific juvenile survival through some overcompensatory density-dependent mechanism. One possible mechanism for strong density-dependent intraspecific interactions is cannibalism. Cannibalism in the primary New England groundfish stocks examined in this report appears to be relatively minor. Food habits data collected during spring and autumn NEFSC surveys during 1973-1997 (Dr. J. Link, Northeast Fisheries Science Center, Pers. comm.) show that the observed incidence of cannibalism in cod and haddock is very low. Out of 12,305 Atlantic cod stomachs examined, only 16 contained cannibalized cod (<0.2%) and the average percent composition by weight of the cannibalized cod was less than 0.1%. Similarly, out of 3,537 haddock stomachs examined only 1 contained cannibalized haddock (<0.1%) and the average percent composition by weight of cannibalized haddock was less than 0.1%. For benthic feeding flatfishes, such as yellowtail and winter flounder, the incidence of cannibalism was virtually nil. Thus, the observed data on groundfish food habits do not support the hypothesis that cannibalism is a viable mechanism for overcompensatory stock-recruitment dynamics in primary New England groundfish stocks.

It is unknown whether application of $F_{40\%}$ as a F_{MSY} proxy for Georges Bank haddock, Georges Bank and Southern New England yellowtail flounder, American plaice, witch flounder, and Cape Cod yellowtail flounder would result in B_{MSY} values that are substantially different from 40% of unfished biomass. If stock-recruitment dynamics for these resources are more closely approximated by a Beverton-Holt curve, then it may be expected that the resulting B_{MSY} values would be lower than 40% of unfished biomass (Goodyear 1993). In contrast, if stock-recruitment dynamics for these stocks are more closely approximated by a Ricker curve, then the resulting B_{MSY} values could be greater than or less than 40% of unfished biomass depending upon the curve's slope at the origin. The same is true of the proxy B_{MSY} value for redfish based on $F_{50\%}$. This uncertainty is likely to persist until more information on the stock-recruitment dynamics of these stocks, especially at higher spawning stock biomasses, is available.

Table 4.2.1. 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[5]	4,200[5]	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

Table 4.2.2. Summary of estimated 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	0.0[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 4.2.3 Total catch (mt) and catch components estimated for 2001. The estimated total catch was used to determine fishing mortality in 2001for those stocks for which rebuilding projections were performed.

Stock	U. S. Commercial Landings	CDN Commercial Landings	U.S. Commercial Discard	U.S. Recreational Landings	U.S. Recreational Discard	Total Catch
Gulf of Maine Cod	4,016	—	1,362	2,616	—	7,994
Georges Bank Cod	10,631	2,134	—	—	—	12,765
Georges Bank Haddock	4,842	6,712	—	—	—	11,554
Gulf of Maine Haddock	946	—	—	—	—	946
Georges Bank Yellowtail fl.	4,172	2,890	678	—	—	7,740
So. New Engl. Yellowtail fl.	830	—	203	—	—	1,033
Cape Cod Yellowtail fl.	2,224	—	347	—	—	2,571
Mid-Atl Yellowtail fl.	206	—	206	—	—	206
Georges Bank Am. plaice	4,369	45	956	—	—	5,370
Witch flounder	2,931	—	528	—	—	3,459
So. New Engl. Winter fl.	3,917	—	274	531	24	4,746
Georges Bank Winter fl.	2,070	590	—	—	—	2,670
Acadian redfish	325	—	—	—	—	325
White hake	3,360	200	—	—	—	3,560
Pollock	3,901	—	—	—	—	3,901
No. Windowpane fl.	44	—	—	—	—	44
So. Windowpane fl.	112	—	—	—	—	112
Ocean pout	18	—	—	—	—	18
Atlantic halibut	10	—	—	—	—	10

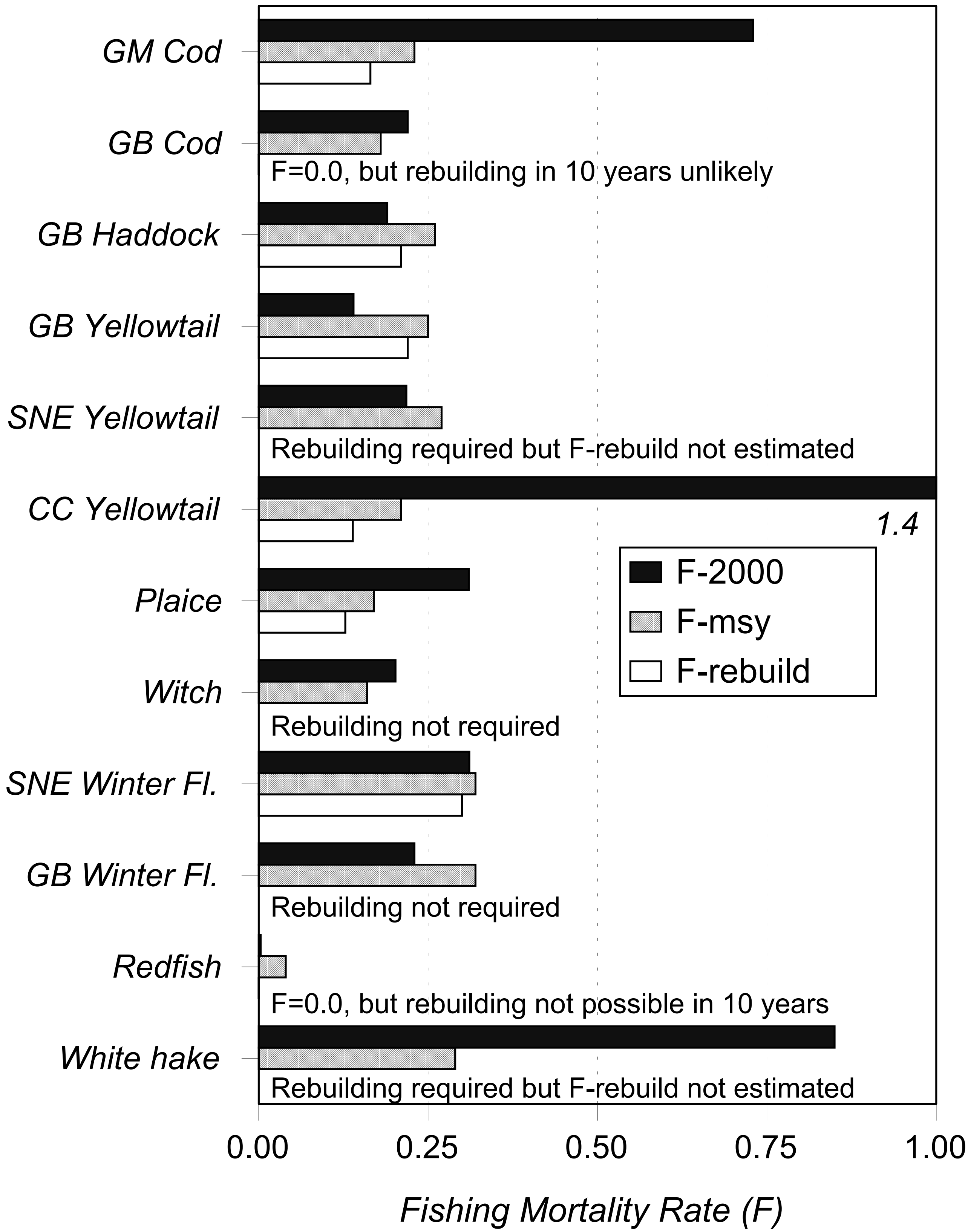


Figure 4.2.1. Estimates of F in 2000, Fmsy (or proxy) and corresponding fishing mortality rates needed to reach Bmsy by 2009 with >50% probability (F-rebuild). Data are only for stocks with analytical assessments (e.g., non index-based).

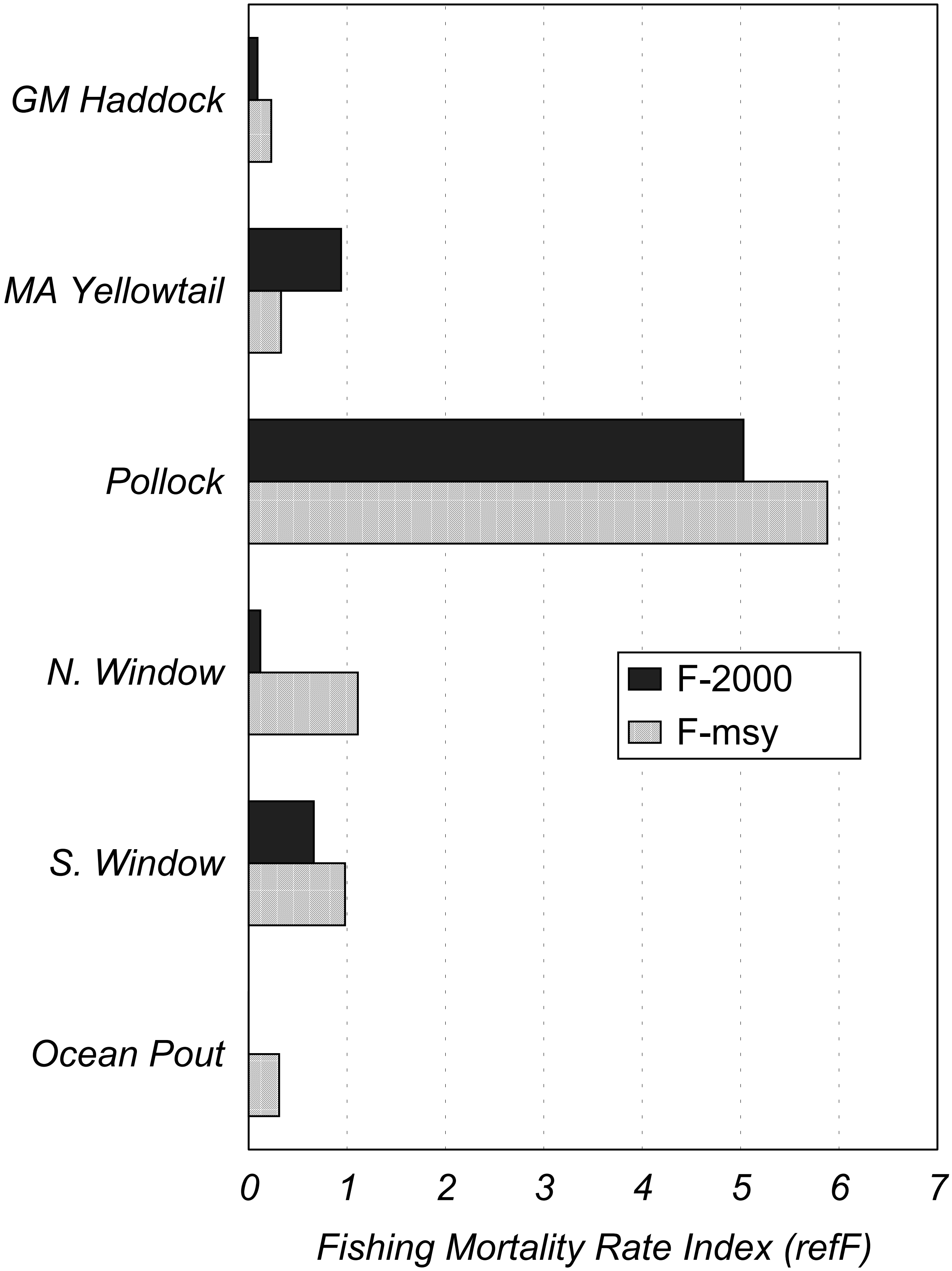


Figure 4.2.2. Estimates of fishing mortality rate indices (relF) in 2000 and the Fmsy proxy for six New England groundfish stocks Data are only for stocks with index-based assessments.

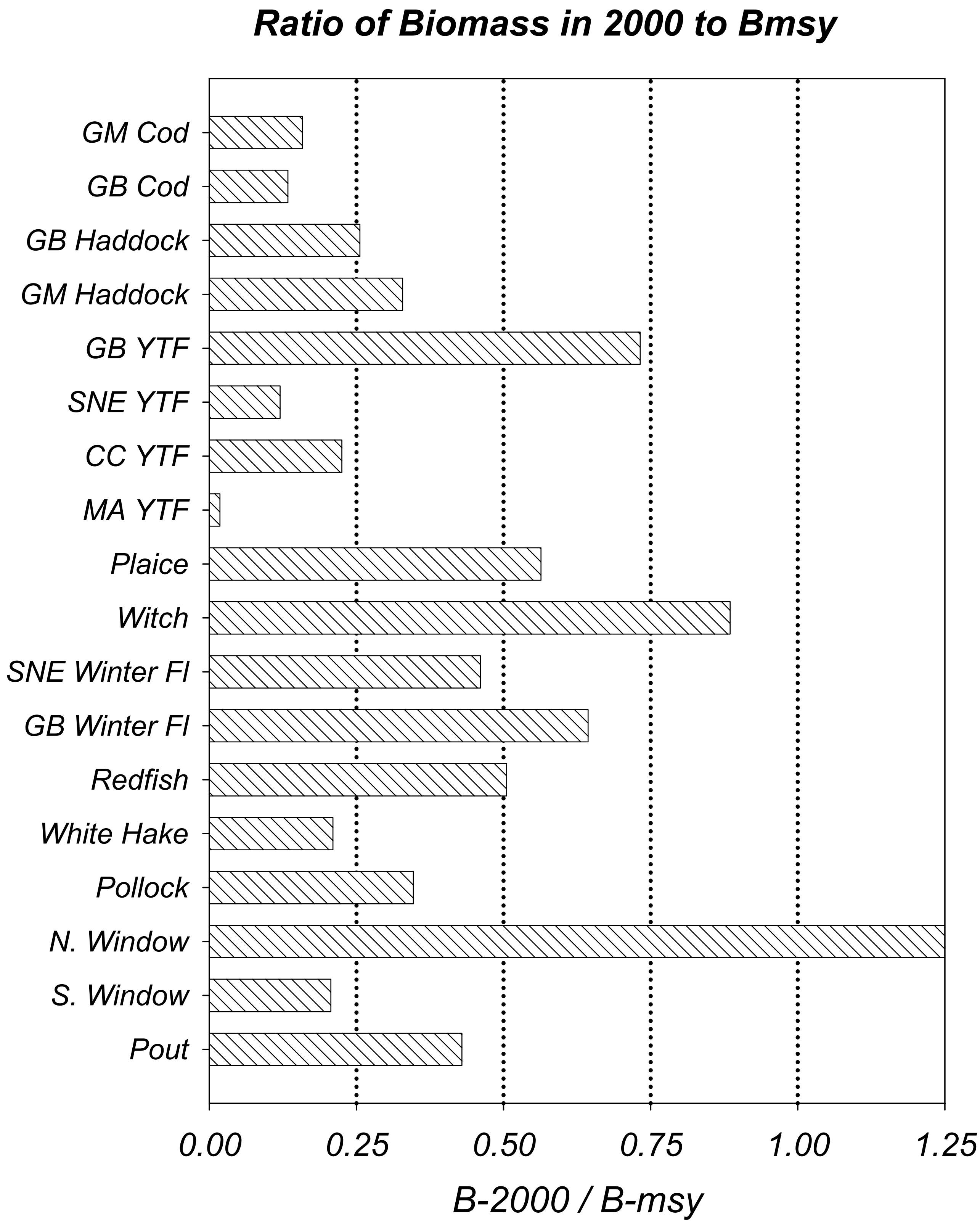


Figure 4.2.3. Ratios of the biomasses in 2000 to Bmsy for 18 groundfish stocks.

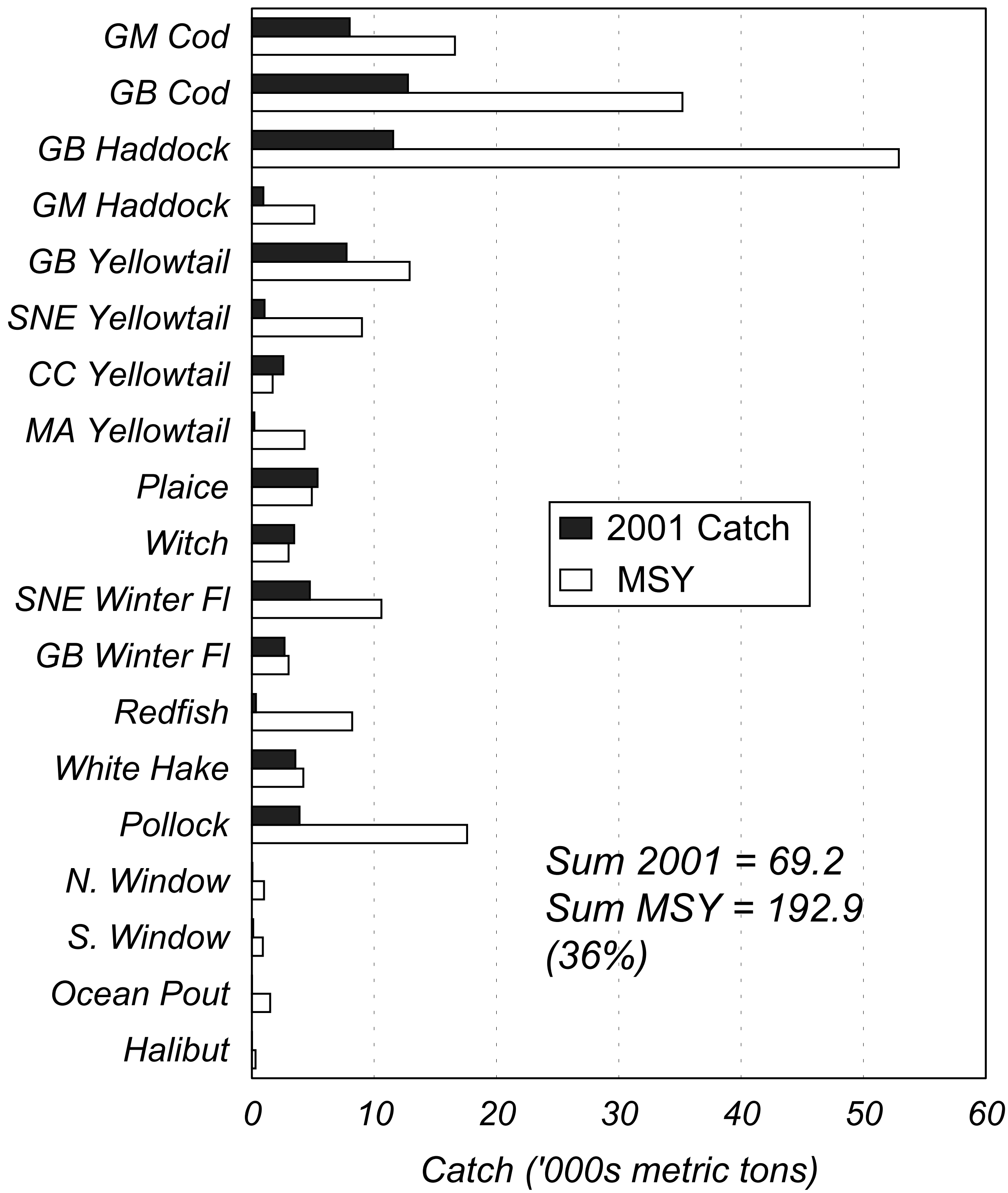


Figure 4.2.4. Estimated catches in 2001 and MSY values for 19 New England groundfish stocks.

4.3 Ecosystem Implications of Revised Biomass targets

The question of whether or not species interaction strengths are sufficiently strong to preclude the simultaneous attainment of B_{MSY} across the suite of primary groundfish stocks is important. Data presented in Figures 4.3.1-4.3.6 summarize the biomass histories of each of the regulated stocks as a function of the biomasses of all the other stocks inhabiting similar stock areas. In most cases it is clear that the stocks themselves have coexisted at much higher biomasses in the past.

While Brown et al.'s (1976) surplus production analyses suggested the possibility that MSY may not be obtainable across a suite of species in the northeast U.S. continental shelf community, this analysis does not include recent data and was based on relatively short data series. Analyses based on the entire time series of fishery independent data do not clearly support the notion that strong species interactions may preclude stock rebuilding or simultaneous attainment of MSYs. In particular, the single species versus multispecies survey abundance plots show that there is strong coherency by region. For the Gulf of Maine, the spring and autumn survey indices show that abundances of cod, haddock, redfish, plaice, and witch flounder stocks have positive coherence. This indicates that these stocks have simultaneously existed at higher abundances in the past, relative to their current levels. Similar patterns of coherence are evident for Georges Bank cod, haddock, and yellowtail, as well as for Southern New England yellowtail and winter flounder and Mid-Atlantic yellowtail flounder. The implication of these fishery-independent data is that these stocks coexisted at higher abundances in the 1960s-1970s which suggests that B_{MSY} values that lie within the range of implied survey abundances could be realized. Similarly, in a recent study of structure of food web of the northeast U.S. continental shelf community, Link (1999) found a higher degree of complexity and connectivity than other food webs where community structure has been documented. The relatively high connectance and species richness suggests that this marine ecosystem may be highly persistent and resistant to perturbations, in comparison to other studied systems. Link (1999) also found that the interactions implied by the community interaction matrix of the food web of the northeast U.S. continental shelf ecosystem were relatively weak in comparison to other less complex systems. Taken together with the observed increases in the relative abundances of depleted sea scallop, haddock, and yellowtail flounder stocks on Georges Bank under large-scale closed area management (Murawski et al. 2000), the available data suggest that trophic interactions are moderate in strength and are probably not strong enough to limit the rebuilding of primary New England groundfish stocks.

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? Much of the recent literature has chronicled the large changes in biomass in the Northeast ecosystem that have occurred during 1961-2000 (Clark and Brown 1977; Overholtz et al 1995; Link et al 2001). Most studies have concluded that the cause for these changes in the ecosystem are related directly to serial depletion of individual resources resulting from high fishing rates during the ICNAF fishery years (Brown et al. 1976; Clark and Brown 1977; Anthony and Waring 1980; Anthony1993) and subsequently through intense fishing by vessels from the United States (Anthony 1990: NEFSC 1991; Anthony 1993; Overholtz et al 1995; Link et al 2001). Serial depletion as such has nothing to do with the coexistence question, but it is important since some researchers have concluded that changes in the ecosystem are related to community interactions. There is little evidence for this, however, with a few exceptions (Fogarty and Cohen 1991).

Information from several lines of evidence suggests that all the major groups of fishes (flatfish, gadids, pelagics, and spiny dogfish) can exist simultaneously at high biomass in the Northeast shelf ecosystem. Results from the multi year food habits data base at the NEFSC suggest that in the 1960's groundfish were present in the diets of piscivorus fish in low percentages (Langton and Bowman 1980), while recently the proportion of groundfish in diets is even lower than in the past (Overholtz et al. 2000). This indicates that large numbers of groundfish were likely present during the earlier time period because the diet composition of piscivores in the region generally reflects the more abundant prey fishes that are available (Overholtz et al 2000) Herring and mackerel were also present in the diets of predatory fish in the 1960s in higher percentages than groundfish (Langton and Bowman 1980) back before these pelagic stocks collapsed (NEFSC 2001).

Another general conclusion from the NEFSC food habits data is that flatfish, groundfish, pelagics, and spiny dogfish have weakly connected diets (Link 1999). This may be related to spatial, temporal, and size related segregation that tends to prevent direct competition for food resources. Coupled with the fact that this ecosystem is rather open in terms of nutrients, prey fishes, and other food resources, the evidence suggests that the system can support a large biomass of different species (Link et al 2001).

Cumulative landings during the ICNAF era (1963-1977) for cod, haddock, silver hake, mackerel, herring, and other species indicate that the individual biomass of each of these species was large and that these species occurred simultaneously in the region (Clark and Brown 1977; Anthony and Waring 1980). Cumulative landings of mackerel and herring alone were about 3 million mt each during this period (Anthony and Waring 1980; NEFSC 2000).

Finally, trends in relative abundance indices from NEFSC groundfish surveys indicate that a large biomass of cod, haddock, flatfish, mackerel, silver hake , and herring were present simultaneously during the 1960's (Brown et al. 1976; Clark and Brown 1977). Recent trends in survey indices suggest that large biomasses of herring, mackerel, and dogfish were present during the late 1980s and early 1990s, before the fishery began on dogfish in 1994 (NEFSC 2001b).

Based on the above considerations, there do not appear to be trophic limitations to the recovery of groundfish biomasses to the targets recommended herein.

4.4 Adaptive Approaches for Determining Long-Term Biomass and Mortality Targets

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

Gulf of Maine -Fall Survey Indices (kg/tow)

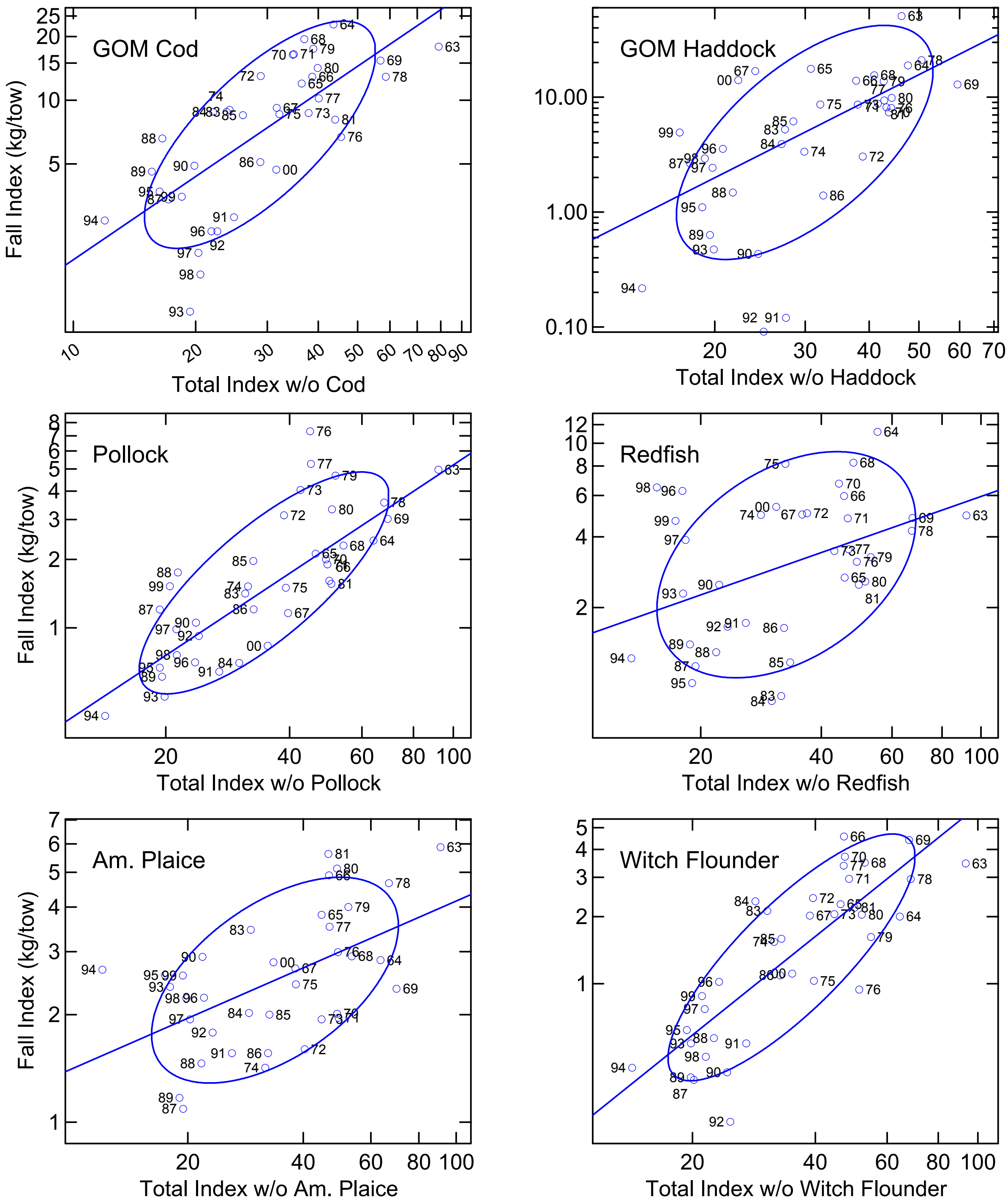
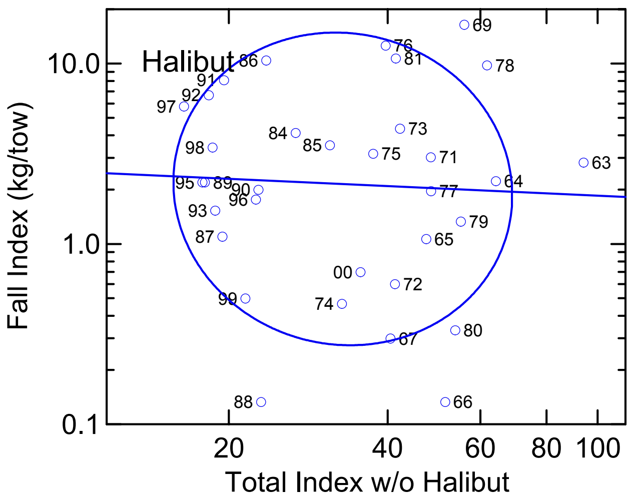


Figure 4.3.1. Relationship between fall survey indices for individual stocks and the sum of all other regulated groundfish stocks in the Gulf of Maine region, 1963-2000.

Gulf of Maine-Fall Survey Indices (kg/tow) [cont.]



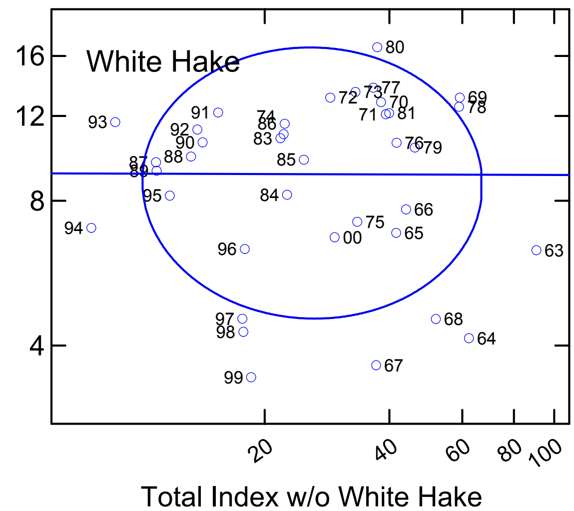


Figure 4.3.1 (continued). Relationship between fall survey indices for individual stocks and the sum of all other regulated groundfish stocks in the Gulf of Maine region, 1963-2000.

Gulf of Maine -Spring Survey Indices (kg/tow)

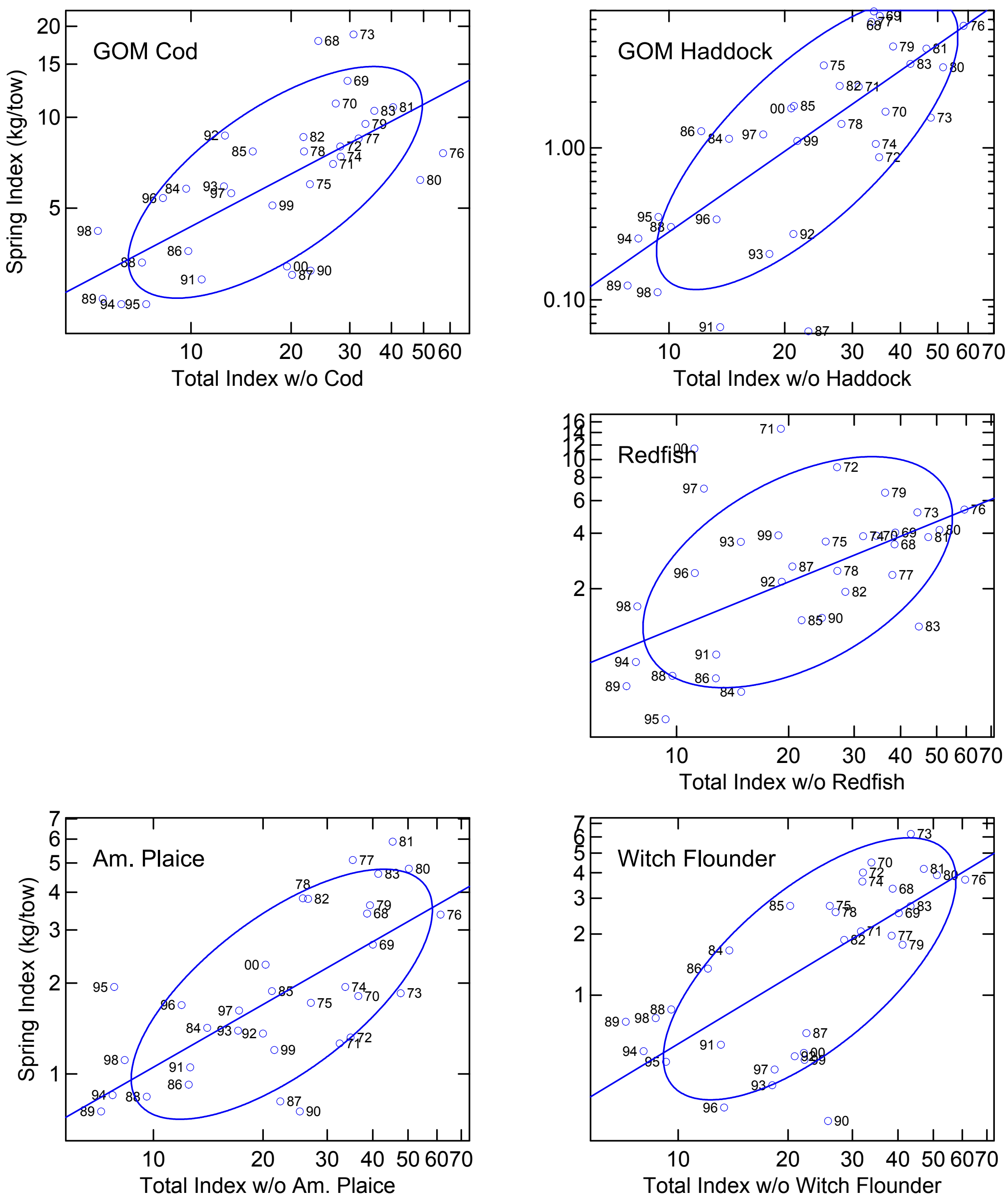


Figure 4.3.2. Relationship between spring survey indices for individual stocks and the sum of all other regulated groundfish stocks in the Gulf of Maine region, 1968-2000.

Gulf of Maine-Spring Survey Indices (kg/tow) [cont.]

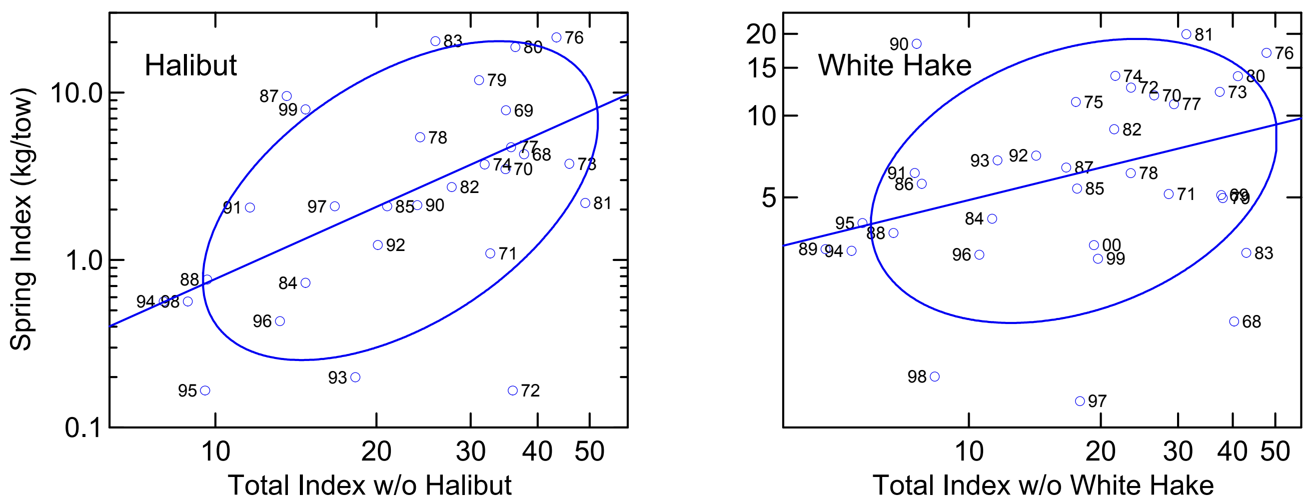


Figure 4.3.2 (continued). Relationship between spring survey indices for individual stocks and the sum of all other regulated groundfish stocks in the Gulf of Maine region, 1968-2000.

Georges Bank-Fall Survey Indices (kg/tow)

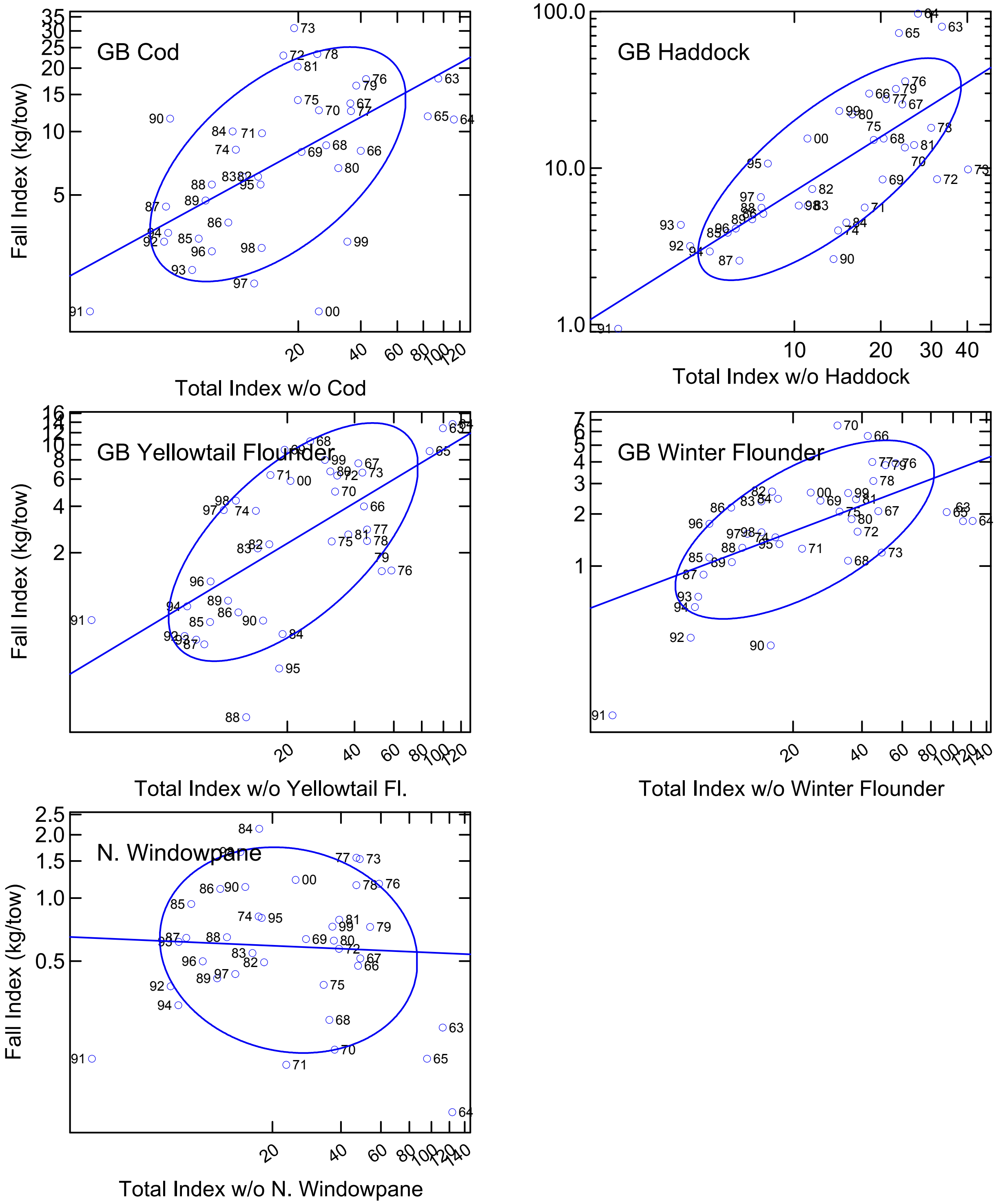


Figure 4.3.3. Relationship between fall survey indices for individual stocks and the sum of all other regulated groundfish stocks in the Georges Bank region, 1963-2000.

Georges Bank-Spring Survey Indices (kg/tow)

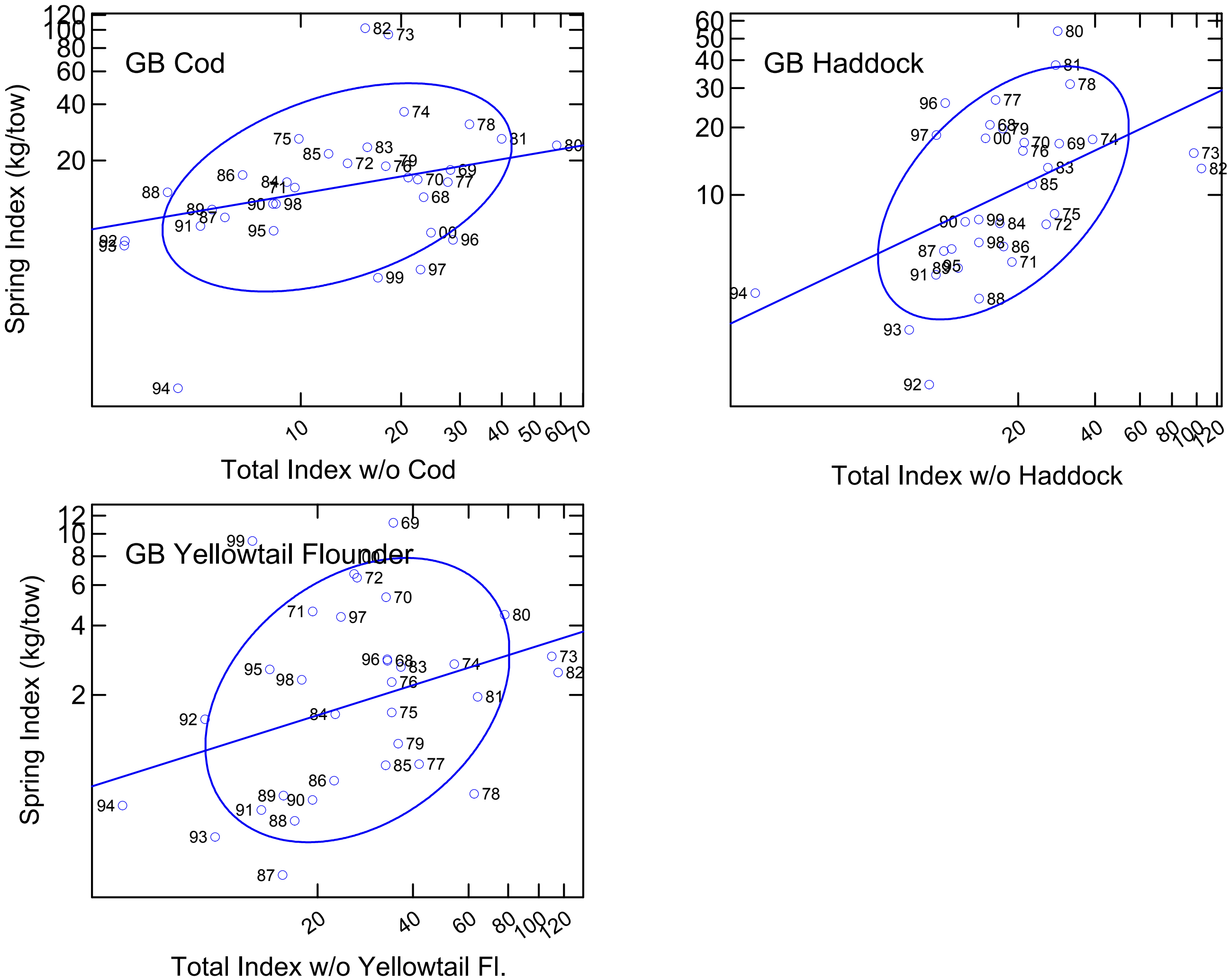


Figure 4.3.4. Relationship between spring survey indices for individual stocks and the sum of all other regulated groundfish stocks in the Georges Bank region, 1968-2000.

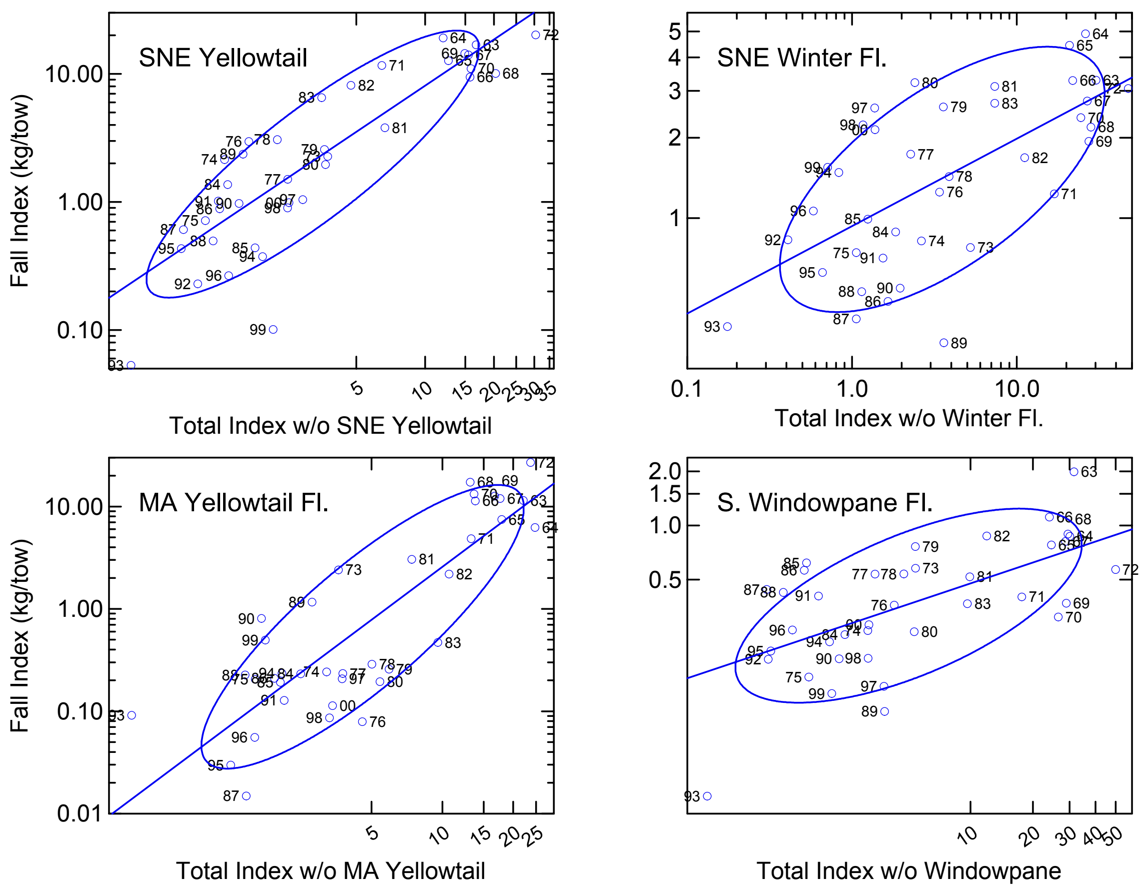


Figure 4.3.5. Relationship between fall survey indices for individual stocks and the sum of all other regulated groundfish stocks in the Southern New England region, 1963-2000.

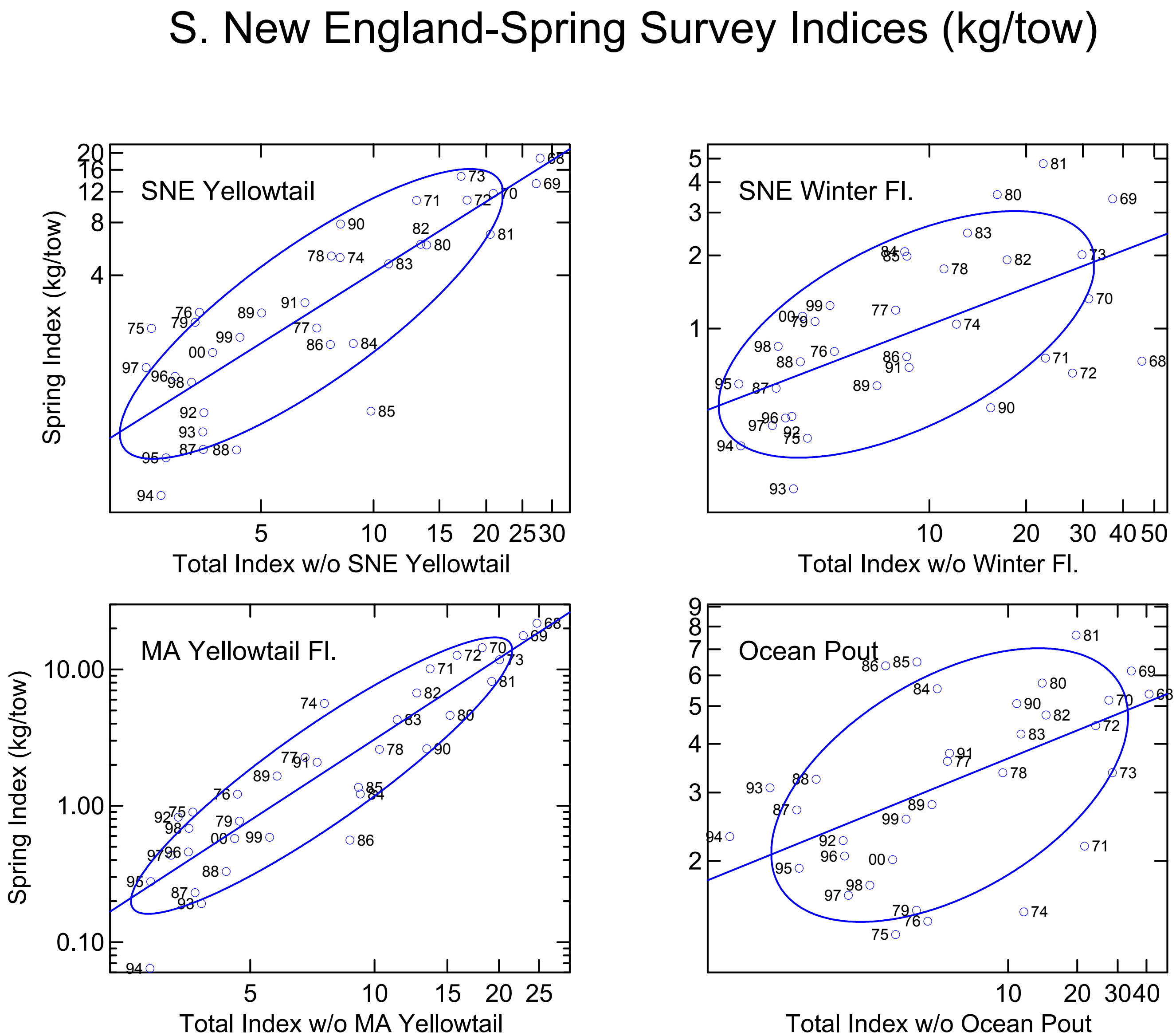


Figure 4.3.6. Relationship between spring survey indices for individual stocks and the sum of all other regulated groundfish stocks in the Southern New England region, 1968-2000.

implications of higher biomasses and to find the point of diminishing returns to yields as a function of increased stock density. The adaptive approach recommended is to build the spawning stock biomasses by reducing fishing mortality (or in some cases maintaining current rates) such that the realized recruitments at high spawning stock biomasses are observed. This will allow direct examination of recruitment associated with maximum sustainable yield and thus the appropriateness of recruitment levels used to set biomass reference points.

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. This will allow direct estimation of realized spawning biomass per recruit used to set the reference points. 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. Thus, the panel recommends that the NEFSC adopt the revised biological reference points recommended herein, and evaluate the rebuilding process at periodic intervals. Changes in vital rates in relation to stock density, or lack thereof, will dictate necessary refinements in Bmsy and Fmsy, either up or down.

5.0 Conclusions

The Working Group developed a systematic approach to the re-estimation of biomass and fishing mortality reference points using a hierarchy of methods dictated by available population and fishery data. Proposed biomass and fishing mortality reference points have been updated for 15 of the 19 stocks considered. For the remaining four, there was no basis for recommending changes.

For only two stocks, the surplus production estimates of Bmsy and Fmsy are retained (GB Winter Flounder, white hake), while assessment types were changed for several others (e.g. pollock was changed from age-based to index-level, based on the lack of recent VPA updates).

For all stocks, reference points were re-estimated within analytical frameworks that are compatible with the monitoring tools used to determine stock status (e.g., we eliminated surplus production estimates of Bmsy and Fmsy for stocks monitored using age-based methods). This should allow more consistent and interpretable advice to managers and the public.

Based on analyses undertaken by the Working Group, and relevant literature on the subject, it is unlikely that multispecies interactions between various components of the fish community are strong enough to inhibit continued rebuilding to the groundfish complex, at least to levels seen last in the early 1960s.

Projections of medium-term stock status in relation to biomass targets are critically dependent on the realized recruitments to the various stocks. Making one set of most likely projections is difficult for stocks that exhibit infrequent high recruitment followed by long periods of recruitment failure (e.g., Southern New England yellowtail flounder). For Southern New England yellowtail flounder and white hake, the Working Group did not feel sufficiently confident in the basis for such projections and they have not been given.

Last, the Working Group recognizes 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 recommends 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 (e.g. sea scallop, and summer flounder). An adaptive approach to understanding the limits of groundfish stock productivity at higher biomasses is recommended as a prudent step forward.

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Publications and Reports of the Northeast Fisheries Science Center

The mission of NOAA's National Marine Fisheries Service (NMFS) is "stewardship of living marine resources for the benefit of the nation through their science-based conservation and management and promotion of the health of their environment." As the research arm of the NMFS's Northeast Region, the Northeast Fisheries Science Center (NEFSC) supports the NMFS mission by "planning, developing, and managing multidisciplinary programs of basic and applied research to: 1) better understand the living marine resources (including marine mammals) of the Northwest Atlantic, and the environmental quality essential for their existence and continued productivity; and 2) describe and provide to management, industry, and the public, options for the utilization and conservation of living marine resources and maintenance of environmental quality which are consistent with national and regional goals and needs, and with international commitments." Results of NEFSC research are largely reported in primary scientific media (*e.g.*, anonymously-peer-reviewed scientific journals). However, to assist itself in providing data, information, and advice to its constituents, the NEFSC occasionally releases its results in its own media. Those media are in four categories:

NOAA Technical Memorandum NMFS-NE -- This series is issued irregularly. The series typically includes: data reports of long-term or large area studies; synthesis reports for major resources or habitats; annual reports of assessment or monitoring programs; documentary reports of oceanographic conditions or phenomena; manuals describing field and lab techniques; literature surveys of major resource or habitat topics; findings of task forces or working groups; summary reports of scientific or technical workshops; and indexed and/or annotated bibliographies. All issues receive internal scientific review and most issues receive technical and copy editing.

Northeast Fisheries Science Center Reference Document -- This series is issued irregularly. The series typically includes: data reports on field and lab observations or experiments; progress reports on continuing experiments, monitoring, and assessments; background papers for scientific or technical workshops; and simple bibliographies. Issues receive internal scientific review, but no technical or copy editing.

Fishermen's Report -- This information report is a quick-turnaround report on the distribution and relative abundance of commercial fisheries resources as derived from each of the NEFSC's periodic research vessel surveys of the Northeast's continental shelf. There is no scientific review, nor any technical or copy editing, of this report.

The Shark Tagger -- This newsletter is an annual summary of tagging and recapture data on large pelagic sharks as derived from the NMFS's Cooperative Shark Tagging Program; it also presents information on the biology (movement, growth, reproduction, etc.) of these sharks as subsequently derived from the tagging and recapture data. There is internal scientific review, but no technical or copy editing, of this newsletter.

OBTAINING A COPY: To obtain a copy of a *NOAA Technical Memorandum NMFS-NE* or a *Northeast Fisheries Science Center Reference Document*, or to subscribe to the *Fishermen's Report* or the *The Shark Tagger*, either contact the NEFSC Editorial Office (166 Water St., Woods Hole, MA 02543-1026; 508-495-2228) or consult the NEFSC webpage on "Reports and Publications" (*http://www.nefsc.nmfs.gov/nefsc/publications/*).