B. Butterfish Assessment Report

Executive Summary

Term of Reference 1:

Landings were largest in the 1970s and have been below 1000 mt since 2002. Revised discard estimates were made and included in total catch. From 1989-2008 discard estimates are made using the Standardized Bycatch Reporting Methodology (Wigley et al. 2006) and a hind-casting method was used to estimates discarding prior to 1989. The discard estimates were highly uncertain and comprise more than half of the total catch on average over the last 20 years. Recreational catches were negligible.

Term of Reference 2:

NEFSC spring, fall and winter survey data were used in the assessment. Fall and spring indices exhibited opposite trends in recent years, but the working group felt that the fall survey indices likely represent the trend in biomass more appropriately because they have better precision on average and the stock is more available to the survey during the fall. State survey data were not used due to low coverage of the stock area, and inability to form biomass indices of age 0 and 1+ fish required for the assessment model. Some state survey indices had no associated estimates of uncertainty and only two years of NEAMAP survey indices for the fall and spring are available which will not yet inform the assessment model.

Term of Reference 3:

Fishing mortality and biomass estimates are highly uncertain and also reliant on a prior distribution for the catchability of the NEFSC fall 1+ indices. While the scale of the estimates should be more appropriate than the previous assessment due to more realistic efficiency of the survey, there is still considerable uncertainty. Estimates of current (2008) fishing mortality, recruitment and spawning biomass are 0.02, 38,800 mt, and 45,000 mt, respectively.

Estimates of total mortality from survey age composition were much higher than the sum of the assumed natural mortality rate (0.8) and estimates of fishing mortality from the model. Furthermore, it appears that fishing mortality is negligible relative to natural mortality because there did not appear to be any correlation of total mortality estimates with total catch estimates.

Term of Reference 4:

The previous reference points were based on fitting a Fox surplus production model to the recruitment and biomass estimates from the assessment model (F_{MSY} = 0.38, MSY = 12,200 mt, B_{MSY} = 22,800). The working group determined that it would be beneficial to change the reference point methodology to one that uses recruitment estimates from the final model in stochastic projections under a specified fishing mortality to obtain distributions of equilibrium yield and spawning biomass. The working group proposed $F_{0.1}$= $F_{20\%}$=1.04 as an F_{MSY} proxy. Other candidate proxies included $F_{30\%}$=0.72 and $F_{40\%}$=0.52. Median equilibrium yield at $F_{0.1}$ is 36,608 mt and the median equilibrium spawning biomass is $SSB_{0.1}$ = 16,262 mt. Median equilibrium yield at $F_{30\%}$ is 33,108 mt and the median equilibrium spawning biomass is $SSB_{40\%}$ = 25,226 mt. Median equilibrium yield at $F_{40\%}$=0.52 is 29,166 mt and the median equilibrium spawning biomass is $SSB_{30\%}$ = 34,191 mt. F_{MAX} is undefined for this stock. The SARC did not accept any such equilibrium-based reference points (including those from the previous assessment) at this time for butterfish because the stock does not appear to be in equilibrium and, as such, these reference points would be inappropriate. Recruitment and spawning biomass appear to be in decline even though fishing mortality has been very low relative to natural mortality for more than 20 years.

Term of reference 5:

The estimate of current (2008) spawning biomass is 45,000 mt. The estimate of current total biomass is 88,800 mt. The current estimate of fishing mortality is 0.02. Because estimated fishing mortality has been negligible relative to natural mortality, the assessment concludes that overfishing is not likely to be occurring. The stock is in decline although this does not appear to be due to fishing mortality and the status is undefined because of uncertainty in the stock size and lack of an equilibrium-based biomass reference point.

Term of reference 6:

Total consumption of butterfish is on the same order of magnitude as estimates of butterfish stock landings. Total consumption of butterfish exhibits similar trends as landings estimates, until recent years. Instead of increasing uncertainty, incorporating information on consumption of butterfish may actually help to better inform and improve model fitting. It is feasible to calculate M in this context. Ignoring some form of dynamic M may provide misleading biological reference points, or at least result in incorrectly scaled model results (estimates of biomass, F, etc.).

Term of reference 7:

A projection methodology was proposed, but not acceptable because of the evidence that the stock was not in equilibrium. The proposed projection methodology is generally the same as that used for determining proposed reference points.

Term of Reference 8:

Several of the recommendations from the previous SARC were completed for this assessment.

Terms of Reference

1. Characterize the commercial catch including landings, effort and discards by fishery (i.e., *Loligo* fishery vs other fisheries). Characterize recreational landings. Describe the uncertainty in these sources of data. Evaluate the precision of the bycatch data with respect to achieving temporal management objectives throughout the year.
2. Characterize the survey data that are being used in the assessment (e.g., indices of abundance including RV Bigelow data, NEAMAP and state surveys, age-length data, etc.). Describe the uncertainty in these sources of data.

3. Estimate annual fishing mortality, recruitment and stock biomass (both total and spawning stock) for the time series, and characterize the uncertainty of those estimates.
4. Update or redefine biological reference points (BRPs; estimates or proxies for B_{MSY}, $B_{THRESHOLD}$, and $F_{MSY;}$ and estimates of their uncertainty). Comment on the scientific adequacy of existing and redefined BRPs.
5. Evaluate stock status with respect to the existing BRPs, as well as with respect to updated or redefined BRPs (from TOR 4).
6. Evaluate the magnitude, trends and uncertainty of predator consumptive removals on butterfish and associated predation mortality estimates and, if feasible, incorporate said mortality predation estimates into models of population dynamics.
7. Develop and apply analytical approaches and data that can be used for conducting single and multi-year stock projections and for computing candidate ABCs (Acceptable Biological Catch; see Appendix to the TORs).

   a. Provide numerical short-term projections (1-5years). Each projection should estimate and report annual probabilities of exceeding threshold BRPs for F, and probabilities of falling below threshold BRPs for biomass. In carrying out projections, consider a range of assumptions about the most important uncertainties in the assessment.
   b. Comment on which projections seem most realistic, taking into consideration uncertainties in the assessment.
   c. For a range of candidate ABC scenarios, compute the probabilities of rebuilding the stock by January 1, 2015.
   d. Describe this stock's vulnerability to having overfished status (consider mean generation time), and how this could affect the choice of ABC.

8. Review, evaluate and report on the status of the SARC and Working Group research recommendations listed in recent SARC reviewed assessments and review panel reports. Identify new research recommendations.

Introduction

Butterfish (*Peprilus triacanthus*) are distributed from the Florida to Nova Scotia, occasionally straying as far north as the Gulf of St Lawrence (Bigelow and Schroeder 2002). Butterfish is a fast growing species that schools by size, makes seasonal inshore and offshore movements, and seldom attains an age greater than 3 years. Butterfish mature at age 1, spawn during the summer months (June-August), and begin schooling at about 60 mm (Bigelow and Schroeder 2002). They exhibit a planktivorous diet, feeding mainly on zooplankton, ctenophores, chaetognaths, euphasids and other organisms. Butterfish are preyed upon by a large number of medium predatory fishes such as bluefish, weakfish, and spiny dogfish, marine mammals including pilot whales and common dolphins, seabirds such as greater shearwaters and northern gannets, large pelagic fish including swordfish, and invertebrates such as squid.

The last assessment for this stock was completed in 2003 (SARC 38, NEFSC 2004). The reference points from the assessment were fishing mortality at maximum sustainable yield, F_{MSY}=0.38, MSY = 12,200 mt and total biomass at MSY, B_{MSY}=22,800 mt.

Term of Reference 1: Commercial Catch

Characterize the commercial catch including landings, effort and discards by fishery (i.e., *Loligo* fishery vs other fisheries). Characterize recreational landings. Describe the uncertainty in these sources of data. Evaluate the precision of the bycatch data with respect to achieving temporal management objectives throughout the year.

The Fishery

A variety of data sources were used to derive the catch time series. Landings prior to 1963 were obtained from Murawski *et al*. (1978). Landings during 1963-2008 were obtained from the Commercial Fisheries Database System of the Northeast Fisheries Science Center. Butterfish catch data for the foreign fleets during 1963-1982 and 1983-1986 were obtained from previous stock assessment documents, Waring and Anderson (1983) and NEFSC (1990), respectively.

Landings

During the late 1800's through 1928, butterfish harvested from nearshore weirs and traps located along the coast between Cape Cod and Virginia ranged between 150 and 2,800 mt annually (Murawski *et al*. 1978). Landings increased during 1929-1962, ranging between 1,000 and 7,800 mt and averaging 4,300 mt (

Figure B1). During 1949-1958, trawlers based primarily in Point Judith and New Bedford landed butterfish in mixed-species food and industrial fisheries that occurred primarily in the coastal waters of southern New England (Edwards and Lawday 1960). During 1963-1986, foreign fleets targeting squid in offshore areas, primarily *Loligo pealeii*, reported landings of butterfish. Total catches of butterfish were dominated by the foreign fleets during 1969-1976, with most of the catch occurring in the Japanese *Loligo*/butterfish fishery (Lange and Sissenwine 1980; Murawski and Waring 1979). Catches by the foreign fleets averaged 15,400 mt during 1969-1976, with a peak catch of 31,700 mt in 1973 (Figure B2,). Butterfish landings averaged 1,976 mt during 1965-1979 without any trend. During 1980-1989 landings increased sharply to over 9,000 mt in 1982, declined, and then increased to over 11,000 mt in 1984. This rapid increase in the 1980s occurred due to heavy demand for butterfish in the Japanese market. Since 1987, butterfish catches have been solely from domestic fisheries. During 1987-2001, butterfish landings ranged between 1,400 and 4,600 mt but landings gradually tapered off and there has been no directed fishery since 2001. Since 2002, butterfish have been landed as bycatch, primarily in the small-mesh (codend mesh size = 50 mm) bottom trawl fishery for *Loligo* (MAFMC 2009), and landings ranged between 400 and 900 mt during 2002-2008. In 2008 landings were 451 mt. Preliminary butterfish landings through October of 2009 are 356 mt (Table B1) However, butterfish catches by the foreign fleets are likely underestimated because Spain and Italy did not report their butterfish bycatch from the squid fisheries during 1970-1976 and there was no US observer coverage of the fisheries until 1977 (Murawski and Waring 1979; Lange and Sissenwine 1980).

Commercial landings by the United States have remained below about 5,000 mt from 1960-2002 except for a period during the mid 1980s when landings increased to 8,837 mt in 1982 and over 11,000 mt in 1984 (Figure B2; Table B1)

Discard Estimates

Catch data between 1976 and 1986 as presented in historic assessment documents included some estimates of butterfish discards combined with landings between 1976 and 1986 (Waring and Anderson 1983, NEFSC 1990). We determined the portion of the annual total catches in these records attributable to discards by subtracting the landings obtained from the Commercial Fisheries Database System (Table B1) From descriptions of their discard estimation it appears that these discard estimates only account for discarding behavior of the directed butterfish fisheries until 1986. Because there is discarding of butterfish in other fisheries using trawl gear, it is likely that there is substantial discard not included in the reported catches.

Since the previous assessment, a Standardized Bycatch Reporting Methodology (SBRM) has been produced (Wigley *et al.* 2006) that combines landings, vessel trip report and observer sampling data to provide estimates of discard rates and total discards for specified stocks. We apply the SBRM to develop butterfish discard estimates using the “combined” ratio estimator (D2 in Wigley *et al.* 2006). Strata are defined here by quarter, gear type, and region (New England or Mid-Atlantic waters). The gear types we used in making discard estimates include “fish,” “scallop,” and “shrimp” bottom trawls (gear codes 50, 52, and 58), beach seines (gear code 70), gillnets (gear codes 100 and 110), and mid-water trawls (gear codes 170 and 370). We also stratified the data from fish bottom trawl fishing into effort using less than or greater than 4 inch mesh. Almost all estimated discards are attributable to tows where “fish” bottom trawls are used.

Annual discards between 1965 and 1988 were estimated by multiplying the regional (New England = NE or Mid-Atlantic = MA waters) average of annual discard rate estimates for “fish” bottom trawl gear using small mesh (less than 4 inches) between 1989 and 1999 and the total landings by gear type 50 in the corresponding year and region. Specifically, the estimated discard in year $y \in \{1965, \ldots, 1988\}$ is

$$\hat{D}_y = \bar{\hat{R}}_{MA,SM} L_{MA,y} + \bar{\hat{R}}_{NE,SM} L_{NE,y}$$

where $\bar{\hat{R}}_{MA,SM} = \frac{1}{11}\sum_{y=1989}^{1999} \hat{R}_{MA,SM,y}$ and $\bar{\hat{R}}_{NE,SM} = \frac{1}{11}\sum_{y=1989}^{1999} \hat{R}_{NE,SM,y}$ are the average of estimated discard rates for the small mesh fish bottom trawl in the respective regions and $L_{MA,y}$ and $L_{NE,y}$ are the landings by fish bottom trawl gear in the respective region in year y. An approximate variance estimate was obtained as

$$\hat{V}\left(\hat{D}_y\right) = \hat{V}\left(\bar{\hat{R}}_{MA,SM}\right) L^2_{MA,y} + \hat{V}\left(\bar{\hat{R}}_{NE,SM}\right) L^2_{NE,y}$$

where

$$\hat{V}\left(\bar{\hat{R}}_{MA,SM}\right) = \frac{\sum_{y=1989}^{1999}\left(\hat{R}_{MA,SM,y} - \bar{\hat{R}}_{MA,SM}\right)^2}{10}$$

and

$$\hat{V}\left(\bar{\hat{R}}_{NE,SM}\right) = \frac{\sum_{y=1989}^{1999}\left(\hat{R}_{NE,SM,y} - \bar{\hat{R}}_{NE,SM}\right)^2}{10}.$$

Only the landings by gear type 50 were estimated for this period because the other gear sectors had negligible butterfish discards observed (see Table B2 to Table B10). The

discard rate estimates for the small mesh portion of the fish bottom trawl gear type were applied to all landings previous to 1989 because it was thought by the working group that smaller mesh was used by this fleet in these early years. The discard rates from 1989 to 1999 were used because of changes in regulations for *Loligo* fishery in 2000 that the working group thought would change butterfish discarding behavior.
During the 1989-2008 period the total discard estimates varied from just over 240 mt in 2007 to as high as 8927 mt in 1999, but precision of these estimates is generally poor (Table B1). In only three years is the estimated coefficient of variation as low as 0.3. The estimated discards previous to 1989 are consistently greater than 5000 mt and reach more than 10,000 mt in 1965, 1982 and 1983, but these estimates have even poorer precision because variance estimation for these discards accounts for the indirect nature of their estimation.

Loligo landings-based discard estimates

To meet this term of reference for this SARC, we also made estimates of discard rates and total discards using landed *Loligo* from sampled and unsampled trips for expansion. Since bycatch of butterfish is almost entirely obtained from fisheries using gear classified as "fish" bottom trawl gear, we restrict attention to corresponding samples and landings (Table B11). The working group thought it better to use the discard estimates with discard ratios based on all kept species because precision of those estimates was better on average and and it would not be appropriate to use *Loligo* based discard rates for discard estimation in years prior to observer coverage.

Total Catch

Total catches of butterfish increased from 14,500 mt in 1965 to a peak of 39,300 mt in 1973 and were dominated by catches from the offshore foreign fleets. Total catches then declined to 11,200 mt in 1977, as effort in the foreign fisheries was reduced. Catches increased to a second peak of 21,600 mt in 1984, with the development of a domestic trawl fishery for butterfish, but then declined to 2,800 mt in 1990 as the Japanese market demand waned. During 1991-2001, catches ranged between 3,800 mt and 12,200 mt. Catches declined during 2002-2008 due to the lack of a directed fishery and ranged between 900 mt and 3,200 mt. Similar to the foreign fishery for *Loligo*, discarding of butterfish occurs primarily in the US *Loligo* fishery (Figure B3), but discarding also occurs to a lesser extent in the small-mesh fisheries for *Illex* and silver hake. Discards comprise a majority of the total butterfish catch, averaging 59% during 1987-2001 and 63% during 2002-2008 and poor precision of discard estimates results in poor precision of total catch estimates (Figure B4). Since 2002, butterfish have been landed as bycatch, primarily in the small-mesh (codend mesh size = 50 mm) bottom trawl fishery for *Loligo* (MAFMC 2009).

Recreational Catch

Recreational catch was investigated, but it was insignificant as measured by the Marine Recreational Fishery Statistics Survey (MRFSS).

Commercial Length Composition

Size composition from commercial samples of butterfish generally ranged 12-25 cm during 1995-2008 with a modal length at 16-17 cm (Figure B5 and Figure B6) The number of commercial samples and fish measured was highest in 1997 and 2007 at over 6000, but the number of length samples has been greater than 1000 annually (Table B12).

Size Composition of Discards

Data from observed trips were assembled to examine the size composition of the discarded and kept fraction of trips where butterfish were caught. The size composition of discarded butterfish ranged form 4-24 cm depending on the year and the fishery, but most discarded fish were less than 16 cm (

Figure B7and Figure B8). The length in kept fraction of trips was generally greater than 10 cm and usually had a modal length from 16-18 cm.

Term of Reference 2: Survey data

Characterize the survey data that are being used in the assessment (e.g., indices of abundance including RV Bigelow data, NEAMAP and state surveys, age-length data, etc.). Describe the uncertainty in these sources of data.

Research Survey Indices

Research survey abundance and biomass indices are available from several sources for assessing the status of the butterfish resource. In the last assessment, survey indices from NMFS bottom trawl surveys for the winter in 1992-2002, for the spring in 1968-2002, and fall in 1968-2002 were used (NEFSC 2004). In this assessment the working group chose to use the same surveys. The spring indices used only offshore strata 1-14, 16, 19, 20, 23, 25, and 61-76 (Figure B9). The fall strata were expanded to include inshore strata 1-92, but the time period of this series of indices now starts in 1975 because inshore strata were not consistently covered prior (Figure B10). The winter strata were reduced to offshore strata 1-14 because other previously included strata were not consistently covered (Figure B11).

For spring surveys conducted during years 1973 through 1981 there was usage of a Yankee 41 trawl as well as the usual Yankee 36. Sissenwine and Bowman (1978) found that the Yankee 41 trawl caught on average 35% more biomass per tow, but found no evidence of differences in numbers per tow between the two gears. Our estimates of average biomass per tow for the spring surveys are expanded by this percentage when the Yankee 41 trawl was used. In the previous assessment there was no conversion of catches made using the Yankee 41 gear, but different catchability parameters were estimated in the assessment model. Byrne and Forrester (1991) analyzed differences in expected catches of species when different doors were used on the survey in 1985, but found no evidence for differences in catchability for butterfish. As such, we assume the same catchability of butterfish for both types of doors.

Indices are also available for several state survey programs, notably Massachusetts Division of Marine Fisheries (MADMF), Rhode Island Division of Fish and Wildlife, Connecticut Department of Environmental Protection, New Jersey Bureau of Marine Fisheries, and Virginia Institute of Marine Science (VIMS). The annual coverage for these surveys spans the period from 1978-2002 although some do not start until after 1978. In the short time available for this assessment, only data for the MA and CT surveys were readily obtained, so only these surveys will be presented. All of the MADMF survey strata were included to form indices. The VIMS survey collects abundance indices (number/tow), but biomass indices are required for the current butterfish assessment model.

The Northeast Area Monitoring and Assessment Program (NEAMAP) survey covers inshore waters from Cape Hatteras to Rhode Island and has been performed with consistent strata coverage from fall 2007. As such, only two years of survey indices for the fall and spring are available which will not yet inform the assessment model (Table B13).

NEFSC Surveys

The spring survey abundance indices (stratified mean number per tow) ranged from a low of 9.9 to a high of 228 during 1968-1979, from 13.4-66.2 during 1980-1989, 8.9-112.9 during 1990-1999 and 36.8-141.4 for 2000-2008 (Table B14, Figure B12). Spring biomass indices (stratified mean wt/tow in kg) were generally highest in the early 1970s and early to mid 1980s (Table B14; Figure B13). Spring biomass indices increased slightly in the late 1990s and exhibit a slight increasing trend in the last few years.

Fall survey abundance indices were generally much higher than the winter and spring indices because of the presence of the age 0 fish in the autumn. Abundance indices were moderately high but fluctuating during 1975-1978 and very high from 1979-1990 (Table B15, Figure B12). Abundance indices exhibit declining trend since 1991. Fall biomass indices exhibit the same pattern over time as the abundance indices (Table B15; Figure B13).

The NEFSC winter survey covers 1992-2007 with abundance indices ranging from 22-186 and biomass indices range from 0.9-6.9 (Table B16, Figure B12 and Figure B13). The winter abundance indices reached highest values in 1994 and 2004 and biomass indices reached highest values in 1994 and 2000.

The estimated precision of annual survey biomass indices is poorest (average CV was 0.44) for the spring series (Table B14 to Table B16, Figure B14). The fall and winter biomass indices have similar precision with average CVs of 0.25 and 0.34, respectively.

Aged NEFSC Survey Indices

Spring survey abundance at age indices show that this survey generally catches age groups 1-3 and usually some fish from age group 4 (Table B17, Figure B15). Abundance at age indices for the fall during 1982-2008 show that this survey generally catches age groups 0-3 with the age 0 catch dominating the total catch (Table B18, Figure B16 to Figure B19).

The delay-difference biomass model (KLAMZ, see Appendix A of NEFSC 2004) used for this assessment approximates an age structured model and utilizes biomass per tow indices for two age groups (age 0 and age 1+). Aged butterfish data from NEFSC spring and fall surveys are available from 1982-2008. Because the NEFSC spring and winter surveys occur after January 1 (the assigned birth date) and prior to spawning (which occurs in the summer), all butterfish are assumed to have a nominal age greater than 0 and so these biomass indices reflect 1+ individuals only.

To obtain biomass indices for 0 and 1+ butterfish in the fall survey between 1982 and 2008, the weight at age from the fitted Schnute growth model (described below) was applied to the numbers at age in Table B18 and the 1+ biomass indices were the sum of the biomass/tow at individual ages. Indices for 1975-1981 were calculated from the relative proportions of biomass/tow of age 0 and 1+ butterfish in the respective year. The numbers at age/tow in Table E5 from SARC 17 assessment (NEFSC 1993) were multiplied by the weight/fish at age from the Schnute growth model and the proportion of biomass/tow at ages 1-4 was multiplied by the biomass/tow indices in Table B15 to get the biomass of 1+ butterfish per tow. The remainder is the annual biomass/tow index of age 0 butterfish (Table B19). The weight per fish at age for the entire series accounted for the time of year of the fall survey by adding to the nominal age the fraction of the year at which the midpoint of the survey occurred.

MADMF Survey

Numbers and biomass per tow in the MADMF spring survey were low relative to the NEFSC spring survey indices and precision of annual biomass indices was even poorer on average with CVs as high as 0.8-1.0. (Table B20; Figure B20 to Figure B22). The fall abundance index varied greatly from year to year. Large fluctuations were observed between 1987 and 1989 and rapid increases and decreases in the late 1990s and early 2000s (Table B20 and Figure B20). The fall biomass indices had similar large fluctuations (Figure B21). The precision of the fall biomass indices was much better than the spring with CVs generally between 0.2 and 0.4 (Table B20 and Figure B22). Survey catch rates from the MADMF fall survey are similar to those of the NEFSC fall survey. Unfortunately, there are no age data for the MADMF fall survey, so age 0 and age 1+ indices required for the assessment model are not available.

CTDEP Survey

The CTDEP bottom trawl survey carried out in the Long Island Sound (LIS) has abundance indices starting in 1982 in the fall and 1984 in the spring. Biomass indices begin in 1992 for both seasons. However, estimates of precision are not available for any of the series of indices. Similar to the MADMF spring survey, the abundance and biomass indices for the spring LIS are low relative to the spring NEFSC indices (Table B20 and Figure B23). The fall abundance index fluctuated greatly in the 1990s but then stabilized before dropping to its lowest levels in the last two years. The fall biomass index similarly fluctuated in the 1990s, but is showing a slight increasing trend in recent years (Table B20 and Figure B24). Together, the recent trend in both the abundance and biomass indices would suggest an increase in average size of individuals available to the LIS survey in the fall. As with the MADMF fall survey, there are no age data for the LIS survey which prohibits forming age 0 and 1+ indices.

Term of Reference 3: Stock biomass and fishing mortality

Estimate annual fishing mortality, recruitment and stock biomass (both total and spawning stock) for the time series, and characterize the uncertainty of those estimates.

As in the last assessment, the KLAMZ model (see Appendix A of NEFSC 2004) is used as the assessment model. The KLAMZ model is an implementation of the delay-difference model (Deriso 1980 and Schnute 1985) developed by Dr. Larry Jacobson at the NEFSC. In short, the KLAMZ model approximates an age structured model by tracking recruiting (to the fishery) and biomass of older fish that have previously recruited through growth and mortality by specified parameters. The model assumes all individuals to be fully selected to the fishery. Survey indices supply information on trend of the two components of the population and annual catches allow estimation of fishing mortality. We found scale of the population to be difficult to estimate without auxiliary information on the catchability of butterfish for one or more of the survey indices.

Biological data and analysis

Growth

Butterfish spawn during June-August and are assigned ages based on calendar years. Young-of-year butterfish born in the second half of 1983, for example, reach *nominal* age 1 on January 1, 1984 at a *biological* age of no more than 6 months. Butterfish grow rapidly and significant numbers are taken in commercial fisheries at nominal age zero as bycatch primarily during the second half of the year. Age data given in this report are nominal ages (as assigned by readers) unless otherwise specified.

Parameters of Schnute's (1985) growth model are required for the population dynamics model (KLAMZ) used to assess butterfish. The growth model is a reparameterization of the von Bertalanffy growth model for the delay-difference model and it is the same as Schnute and Fournier's (1980) length-based growth model,

$$w_a = v + \left(V - v\right)\frac{1-\rho^{1+a-k}}{1-\rho}$$

where k is the age at recruitment, w_a is weight at age $a \geq k$, v is the weight at age k-1, V is the weight at age k, and $\rho = e^{-K}$ where K is the parameter for von Bertalanffy growth. The assessment model, uses estimates of ρ and $J=v/V$ made external to the model. Note that this growth model treats change in weight with age identically to length with age in the von Bertalanffy growth model whereas other approaches account for variable rates of change in weight with length through a length-weight relationship (e.g., Quinn and Deriso 1999, pp.139-141).

Records of age 0 butterfish from winter and spring surveys were omitted because age 0 butterfish should not be available until after June. Ages used in fitting growth models were adjusted by increasing the nominal age by the average time of year of the survey where the age sample was taken. The average time of year of a given NEFSC survey (e.g. fall) changes slightly from one year to the next (Figure B25). Data from a total of 17,920 butterfish ages (0.59-5.26) and corresponding weights (0.0001 - 0.27 kg) collected between 1992 and 2009 were used to estimate the growth curve (Table B21; Figure B26).

Modeling butterfish growth in the KLAMZ model is complicated by the differences between nominal age (based on calendar years used in the model) and biological age, and because recruitment occurs at age zero and growth is rapid. As shown above, the growth parameter v should be a positive number that estimates body weight at age k-1 one year prior to recruitment. In theory, the parameter v for butterfish would be body size at age k-1 = –1 during the January of the year before spawning occurs. Moreover v for butterfish is negative when k = 0.

To obtain useful growth parameters for modeling butterfish, we estimated growth parameters in Schnute's model by nonlinear least squares assuming k=1.5 in nominal years (k=1 in biological years). Growth parameters used in the KLAMZ model for butterfish were ρ=0.81211 and J=v/V=0.13312 (Table B21)

Due to the disparity between the true and assumed age at recruitment, large variability in weight at age and apparent lack of asymptotic growth among observed ages, future assessments may wish to consider whether this growth model is adequate.

Our approach to estimating growth parameters may underestimate the growth rate and biological productivity of age zero butterfish in the FPA model. Nevertheless, the parameter J=0.13312 implies that body weight of young-of-year butterfish increases quickly by about 1/J=7.5 times per year during the first year of life. In addition, predicted weights for age zero butterfish during the second half of the year (when age zero butterfish tend to be taken by the fishery) and weight at age for all subsequent ages appears reasonable (Figure B26).

Natural mortality

Natural mortality rates for butterfish were investigated in Murawski and Waring (1979). The best estimate from this study was M=0.8, and this value was also used in the present stock assessment. Other supporting evidence suggests that natural mortality rates for this species may be high. Overholtz *et al.* (2000) studied consumption of pelagic fishes and squids in the Northeast shelf ecosystem. This study suggested that butterfish were not only important in the diets of predatory fish in the region in general, but that during 1977-1997 butterfish may have been very important to predators during years when herring and mackerel biomass was low. Consumption by predators as a group and as individual species was certainly important during this time. Appendix B1 also provides updated estimates of consumption of butterfish by groundfish.

Some idea of the true instantaneous natural mortality rate can be gained from the relationship of natural mortality rate and instantaneous growth rate parameter K in the von Bertalanffy growth model of length (Gulland 1983, pp. 116-117, Jensen 1996). The intrinsic growth rate parameter estimated by fitting a von Bertalanffy growth model of length at age using the same data used to fit the Schnute growth model above (Table B22), is less than the assumed natural mortality rate, but is somewhat greater than 0.6-0.67 of M, suggested by Jensen (1996).

Estimates of mortality and stock size

Because of the poor precision of the discard estimates prior to observer coverage (start in 1989) and the short generation time for butterfish, the working group thought it beneficial to begin the assessment model as close as possible to 1989. However, the previous assessment used 1965 as the starting year. The working group thought the fall survey to be the best indicator of trend in butterfish biomass because of evidence of low and perhaps inconsistent availability of butterfish to the spring and winter surveys. From survey data and observed commercial fishing tows, there appears to be far less butterfish density inshore and on the shelf during winter and spring months (Figure B27 to Figure B30). The fall indices in this assessment begin in 1975 because of the inclusion of inshore strata so poor survey information would be available to the model in the early years with a 1965 start year. There was also a concern to capture the largest scale of exploitation which occurred in the early 1970s. Furthermore, there were effects of the starting year on proposed equilibrium-based reference points. The largest recruitments were observed prior to 1989 and so average recruitment was highest during the early period which in turn affects estimates of equilibrium yield and spawning biomass at a given fishing mortality. The working group decided to compromise between the need to include these large recruitments (between 1965 and 1988) for reference point determination and the large catches in the 1970s and the reluctance to include uncertain total catches prior to 1989 by using the 1973 model start year.

The KLAMZ model for butterfish was set up on a calendar year basis using nominal ages. In the model, new recruits are age 0 butterfish that recruit to the stock on January 1. Estimates of total biomass (ages 0+) on January 1 from the KLAMZ model for butterfish include the amount of age 0 biomass necessary (considering growth and mortality) to explain subsequent catch data and survey trend data.

Growth

Growth in weight is modeled as a von Bertalanffy process (Schnute parameterization) with parameter estimates as described above, $\rho = 0.81211$, and $J = v / V = 0.13312$ for 1973-2008.

Maturity

Maturity was assumed to be 0 at age 0 and 1 for age 1+ butterfish. The model only allows two age groups and the range of potential assumptions for maturity is therefore limited. In future assessments, exploration of the sensitivity of results to this assumption would be useful particularly if other models are explored.

Natural Mortality

Natural mortality was assumed to be 0.8 as in previous assessments. The model program allows for the estimation of annual changes in M by modeling it as deviations from a mean value, but this feature was not used in the current approach due to focusing on other aspects of the assessment.

Recruitment

Recruitment can be modeled in 4 ways in the assessment model. Options include a Beverton-Holt or Ricker stock-recruitment model, random walk in recruitment and freely varying recruitment over time (independent recruitment events). The latter option was used in this and the previous assessment. The Beverton-Holt assumption was explored but not used.

Catch

The total estimated catch (Table B1 and Figure B1) from 1973-2008 including components for landings and discards was used in the assessment model. The variance of the discard estimates was assumed as the variance of the catches which were used as weights on each of the annual catches. However, this was complicated by the required specification of a CV applied to the entire catch series. This was set to 0.1 as in the last assessment. Ultimately, this matters little because there is little if any error in the predicted catches.

Research Surveys for Trend

Four sets of NMFS surveys indices were used in the butterfish KLAMZ model. These surveys included a winter 1+ (adult) survey, a spring 1+ (adult) survey, a fall age 0 (recruit) survey, and a fall 1+ (adult) survey. The winter and spring aggregate biomass indices were assumed to be sampling adult individuals because the nominal age of fish available to the surveys at these times of the year is at least 1. Massachusetts and Connecticut state surveys were evaluated, but these surveys cover a very small portion of the entire range of the stock and there is no ability to partition fall indices into 0 and 1+ series without strong assumptions. These surveys were not included in the analysis, however, their use in future butterfish assessments should be considered.

For initial fit of the final model, the CV estimates for each of the annual survey indices were used to weight these data. For the winter and spring indices, only 1+ fish are observed so the variance estimate based on the stratified design is an appropriate weight for these indices. However, the fall biomass indices are partitioned into 0 and 1+ biomass indices based on the estimated age composition. The uncertainty in the resulting indices is unknown, but we applied the variance estimates for the aggregate biomass indices to the partitioned indices. For example, the CV of the fall biomass index in 1999 was assumed for the 0 and 1+ indices in 1999. The CV of each of the yearly 0 or 1+ indices is probably higher because of sub-sampling for ages, but the correct weighting of one year relative to another within a series is likely to be retained. The final model has each of the series CVs rescaled to ensure that each of the surveys were informing the model.

Swept area biomass and estimating catchability

Throughout the model development process there was difficulty in determining scale for the butterfish population. As such, we decided to use an approach used in the longfin squid assessment at SARC 34 (NEFSC 2002) that allows for uncertainty in the relationship between the index and butterfish population biomass, but also includes information about the efficiency of the survey vessel. The KLAMZ model allows for a prior distribution to be specified for any of the survey catchability parameters. We chose to consider priors for the NEFSC fall 1+ index since it covers the largest portion of the stock area and is more precise than the NEFSC spring series.

We start from first principles of the relationship between biomass and the index. Following Paloheimo and Dickey (1964) , the linear mean relationship of index and biomass is through the "catchability" parameter Q which can be broken into the efficiency of the survey δ_S, the swept area of a single tow a_S, the covered survey area A_S, and the ratio of survey area to stock area ρ,

$$I_t = QB = \delta_S \frac{a_S}{A_S} \rho C B_t .$$

The constant $C = 10^6$ is a change of units as necessary between those for the index (kg) and those for the biomass (10^3 mt). When the survey is completely efficient ($\delta_S = 1$) and the survey area is equal to the stock area ($\rho = 1$),

$$I_t = \frac{a_S}{A_S} C B_t .$$

From a calibration study completed this year (Miller *et al.* 2009), we have an estimate of the efficiency of the survey vessel and gear used to collect data used in the butterfish assessment (*Albatross IV*) relative to that of the new research vessel (*Henry B. Bigelow*). This study actually estimated calibration factors for abundance and biomass indices that reflect the relative efficiency of the *Henry B. Bigelow* relative to the *Albatross IV*. To make use of this information, we can rewrite the equation in terms of two efficiency parameters,

$$I_t = \delta_{A|B}\delta_B \frac{a_S}{A_S}\rho C B_t$$

where $\delta_{A|B}$ is the efficiency of the *Albatross IV* relative to the *Henry B. Bigelow* and δ_B is the efficiency of the *Henry B. Bigelow*. Note that $\delta_{A|B}$ is the inverse of the calibration factor (say $\delta_{B|A}$) estimated by Miller *et al.* (2009). In their study, the calibration factor for biomass indices was parameterized as the product of the calibration factor for abundance and a calibration factor for average weight per fish, so

$$\delta_{A|B} = \frac{1}{\delta_{B|A}} = \frac{1}{\delta_{B|A,N}\delta_{B|A,\bar{w}}}.$$

The study fitted models where calibration factors (abundance and average weight per fish) were constant across seasons and where they differed by season. For butterfish, the best beta-binomial model based on likelihood ratio tests or AIC had abundance calibrations factor constant across season ($\delta_{B|A,N} = 1.7936$, SE = 0.1367). The best gamma model for average weight per fish had separate calibration factors for fall and spring. The estimated factor for average weight per fish in the fall was $\delta_{B|A,\bar{w}} = 0.9342$ (SE = 0.0574). The inverse of the product of these two calibration factors is the estimated relative efficiency of the *Albatross IV* for biomass in the fall $\delta_{A|B} = 0.5968$ (SE = 0.0978). The variance of the relative efficiency parameter was obtained by the delta method.

We do not know the efficiency of the *Henry B. Bigelow*, nor the ratio of the survey area to stock area, so we used a composite prior approach (NEFSC 2002) where we assumed a beta distribution for the product $\delta_{A|B}\delta_B\rho$ which was parameterized by the mean and variance of the product of each treated as independent random variables. We assumed uniform distributions for δ_B and ρ and a beta distribution for $\delta_{A|B}$ and bounds on the range of plausible values for these parameters. The bounds determined by consensus of the working group were $0.05 < \delta_{A|B} < 1$, $0.1 < \delta_B < 0.9$ and $0.5 < \rho < 0.9$, but we explored the sensitivity of the results to the maxima of the uniform distributions on ρ and δ_B using values of 0.85 and 0.95. The above ranges imply that we are certain that the efficiency of the *Albatross IV* relative to the *Henry B. Bigelow* is between 5 and 100%, the efficiency of the *Henry B. Bigelow* is between 10 and 90%, and that the survey area is anywhere between half and 90% of the stock area. The sensitivities consider the effect of assuming the efficiency of the *Henry B. Bigelow* and the ratio of survey to stock area being at most 85% or 95%. The actual ranges of the beta distribution for $\delta_{A|B}$ are not as important because the standard error of the estimates from the calibration study induce negligible probability at the limits. We assume the mean and variance of the beta distribution for $\delta_{A|B}$ are the estimates from the calibration study. The approximate area covered by the fall survey is 46,388 nm and the approximate area swept by the average tow is 0.0112 nm, thus the product of the change of units constant and the ratio of tow area to survey area is

$$\frac{a_S}{A_S}C = 0.2414 .$$

The resulting distribution of the catchability parameter as a product of random variables and scalars, $Q = \delta_{A|B}\delta_B \frac{a_S}{A_S}\rho C$, has nearly all of the probability of values at the lower end of range (Figure B31). The mean of the swept area catchability distribution (top axis of Figure B31) is 0.21 when the maxima on the uniform distributions is 0.9. Our prior on the catchability parameter implies that the expected efficiency of the *Albatross IV* is about 20%.

Assessment Model Run Results

Sensitivity Analysis Results

Various sensitivity runs were completed to narrow model choices to a few candidates for a final model; the 1973-1986 discards, the prior distribution for catchability, and the natural mortality rate were the inputs the model that we explored.

1973-1986 Discards

Because the discard estimates in early assessments (e.g., NEFSC 1990) for years previous to observer coverage were much smaller than those we estimated we fit model where total catch included either the new discard estimates previous to 1987 or the discard estimates from the early assessments (Figure B32). As might be expected, the spawning and recruitment biomass estimates are lower when the early discard estimates are used because the size of the population is well defined by the prior on the fall 1+ catchability parameter and if there were fewer fish caught, then there were fewer fish alive (Figure B33 to Figure B34). Likewise, the fishing mortality estimates are lower during the period prior to 1987 because the catches were not as great using the early discard estimates (Figure B35). The later fishing mortality estimates are higher because the biomass levels are lower during this period but the catches are the same.

Prior distributions for catchability

As mentioned above, the working group thought it useful to compare model results at different assumed values for the maxima of the uniform distributions used as priors for the efficiency of the Bigelow and the ratio of the survey to stock area. When the maxima of the two uniform distributions are decreased to 0.85, the expected value of the prior distribution on the catchability parameter will also decrease. Likewise the expected value of the prior distribution will increase when the maxima are set at 0.95. As expected, when the lower maxima are used, the spawning and recruitment biomass estimates are higher because the expectation of the prior and estimated catchability are lower (Figure B36 to Figure B37). Similarly, the biomass estimates are lower when the higher maxima are used. The inverse relationship occurs for the fishing mortality rate estimates because the catches are constant (Figure B38). With larger biomasses, the same catch is obtained with lower fishing mortality and vice versa.

Both the spring and winter indices are better fit with higher maxima on the uniform distributions (Table B23). However, the fall indices are better fit with lower maxima. The total maximized objective function value decreases with increased maxima, but the prior on the catchability parameter is included.

Natural Mortality

The final model assumes the natural mortality rate is 0.8 as in previous assessments. We fit alternative models where the natural mortality rate was 0.6, 0.7, 0.9 and 1.0. Based on the maximized total objective function value, the higher values of natural mortality provide better fit (Table B24). The spring and winter survey data are fit slightly better at higher values of natural mortality, but both the fall 0 and 1+ survey data are fit better at lower values of natural mortality. The catch data are fit slightly better at higher natural mortality values, but these data are fit almost exactly in all cases. The resulting spawning biomass estimates did not trend in a constant direction upward with increased natural mortality (Figure B39), but the recruitment biomass estimates did (Figure B40). Fishing mortality estimates generally decreased at higher natural mortality (Figure B41).

Retrospective analysis

We also fit models to discover whether retrospective patterns in biomass and fishing mortality exist. We fit models to data with terminal years of 2003 to 2008. From these fits there is not consistent pattern in terminal year spawning biomass, recruitment biomass or fishing mortality estimates and the annual estimates do not change dramatically as subsequent years of data are made available (Figure B42 to Figure B44).

Final Model

The final model uses the new discard estimates, natural mortality rate of 0.8, and the base case prior distribution on the catchability parameter for the NEFSC fall 1+ indices.

Biomass

The spawning biomass estimates are substantially greater than those estimated at the last assessment due to the use of the prior distribution on the fall 1+ catchability (Table B25 and Figure B45). The catchability estimate for the fall 1+ indices from the last assessment implies that the efficiency of the survey is greater than 100%. From the final model, the highest spawning biomass estimate was around 200,000 mt in 1975, but the current spawning biomass estimate (2008) is 45,000 mt. Recruitment estimates are also substantially higher than those estimated in the last assessment on average and are highly variable (Table B25 and Figure B46). The largest estimated recruitment was around 185,000 mt in 1974 and dropped to around 16,000 mt in the following year. Both spawning and recruitment biomass estimates have been in decline on average over the period of the analysis.

As a check of the plausibility of the biomass estimates from the model, an heuristic method described in Appendix B that takes fishing mortalities and survey efficiencies as inputs with catches and fall biomass indices was used to create an "envelope" or range of independent plausible annual biomass values over time. This analyses concludes that the annual biomass estimates from the KLAMZ model were generally within the envelope of independent plausible values.

Fishing Mortality

The estimated fishing mortality rates were much lower than the previous assessment (Table B25 and Figure B47). This again is a result of the use of the prior on the fall 1+ catchability parameter. Since the total catches have not changed dramatically from the previous assessment, but the biomass available to fishing has increased substantially, a lower fishing mortality is required to obtain the same catch. The highest estimated fishing mortality (0.21) occurred in the year with the greatest catch (1973) and fishing mortality generally remained greater than 0.1 until 1978. Since then, fishing mortality has generally stayed below 0.1 and current (2008) estimated fishing mortality is 0.02.

Stock Recruitment

As determined in the last assessment, meaningful estimation of a stock-recruitment relationship for butterfish is not feasible due to highly variable recruitment over the range of estimated spawning biomasses (Figure B48). Furthermore, these relationships are likely to be estimated with non-negligible bias in most cases due to usage of estimates of spawning biomass rather than true values (e.g., Walters and Ludwig 1981, Ludwig and Walters 1981).

Recruitment biomass has been highly variable for the butterfish stock over a range of about 40,000-200,000 mt of spawning biomass. Average recruitment during 1974-2008 was around 65,000 mt. Average recruitment in the last 10 years (1999-2008) is around 40,500 mt.

Both spawning biomass and recruitment estimates have been declining over time and the trajectory of the stock-recruitment relationship for butterfish reveals that these declines do not appear to be related to either fishing mortality (Figure B49) or known sources of predation. The equilibrium replacement lines corresponding to $F_{0.1} = 1.04$ (See TOR 4) and F=0 suggest that population would be declining even in the absence of fishing mortality. The $F_{0.1}$ replacement line exceeds all historical values, suggesting that fishing mortality rates this high would accelerate population decline. Results further support the notion that either natural mortality is much greater than the assumed M=0.8 or that an increasing trend in natural mortality has occurred.

Precision of Estimates

The KLAMZ model output includes variance estimates for fishing mortality and total biomass but not separately for recruitment biomass and spawning biomass (Table B26 and Table B27). There is generally large uncertainty (CV>0.5) in both the total biomass and fishing mortality indices.

Model Diagnostics

Residuals for the winter and fall age 0 surveys show no real trend over time, but the residuals for the spring indices show an increasing trend and fall age 1+ show a slight decreasing trend in the last 10 years (Table B28 to Table B31 and Figure B50). These trends in residuals occur because the fall 1+ and spring 1+ indices have opposite trend over this period (Figure B51). The residuals of the fall age 0 indices are generally small in absolute value relative to the other surveys because they are fit very well in the model. This was due to difficulty in determining the appropriate scaling factors to apply to the CVs of each of the surveys to obtain appropriately scaled residuals for all surveys simultaneously. The catches are predicted extremely accurately by the model (Figure B52).

Total Mortality Estimates from Survey Age Composition

We made annual estimates of total mortality by age from fall and spring survey age composition estimates (Table B17 and Table B18) as

$$\hat{Z}_{a,y} = \ln\left(\hat{N}_{a,y}\right) - \ln\left(\hat{N}_{a+1,y+1}\right).$$

We made mortality estimates for ages 0, 1 and 2 from fall age composition estimates and ages 0 and 1 from spring age composition estimates. Total mortality estimates varied greatly across years for a given age when estimated from either survey (Figure B53 and Figure B54). The average of mortality estimates for age 1 butterfish was approximately 1.5 when estimated from fall age composition and closer to 2.0 when estimated from spring age composition. Age 2 mortality estimates average near 2.0 and 3.0 from spring and fall age composition, respectively. Mortality estimates for age 0 from the fall age composition also average near 2.0. For all ages and surveys, there does not appear to be any trend in total mortality over time despite changes in total catch estimates over the same period. This may imply that fishing mortality is a small component of total mortality.

Summary

The biomass estimates are substantially larger and the fishing mortality estimates substantially smaller than the corresponding estimates from the last assessment (NEFSC 2004). This is primarily due to the use of a prior distribution for the NEFSC fall 1+ catchability parameter. If the catches of butterfish have not decreased due to abundance, the low estimates of fishing mortality rate are not unreasonable. Furthermore, to have fishing mortality estimates similar to those in the last assessment requires a catchability for the fall 1+ indices that is near or greater than 100%.

The magnitude of assumed natural mortality relative to estimated annual fishing mortality corresponds to the lack of trend in total mortality estimates from the survey age composition. Nevertheless, the total mortality estimates tend to be substantially larger than the sum of assumed natural mortality and estimated fishing mortality from the final KLAMZ model which may imply true natural mortality is higher than that assumed in the final model.

Term of Reference 4: Updated or redefined biological reference points

Update or redefine biological reference points (BRPs; estimates or proxies for B_{MSY}, $B_{THRESHOLD}$, and F_{MSY}; and estimates of their uncertainty). Comment on the scientific adequacy of existing and redefined BRPs.

The Mid Atlantic Fishery Management Council manages butterfish as part of the Atlantic Mackerel, Squid, and Butterfish (MSB) Fishery Management Plan. Overfishing for this species is defined as occurring when the fishing mortality rate at maximum sustainable yield (F_{MSY}) is exceeded. The current overfishing definition is based on an MSY of 12,175 mt and a fishing rate of F_{MSY}=0.38. The biomass target for this stock is defined as total biomass at equilibrium harvest of maximum sustainable yield (B_{MSY}=74,550 mt) and the minimum biomass threshold is defined as ½ B_{MSY}. ***But see below (in bold italics) for comments and decisions by the SARC-49 review panel regarding butterfish reference points (BRPs).***

Reference Point and Stock Status Methodology

The previous assessment used a Fox surplus production model (Fox 1970) to estimate reference points for the stock. There is an implicit density-dependence assumption in the Fox model, whereas the assessment model assumes no relationship between stock and recruitment nor does the projection methodology. To make reference points consistent with the assessment and projection models, we propose using deterministic projections to determine the equilibrium relationship between fishing mortality rate and resulting yield and spawning biomass per recruit. The SPROJDDIF program written in FORTRAN by Dr. Larry Jacobson at the NEFSC provides a means to make either deterministic or stochastic projections of the KLAMZ model (see Appendix A of NEFSC 2004). The SPROJDDIF program will use assumptions about recruitment that are consistent with the model used to fit the data. For butterfish we assume no relationship of spawning and recruitment biomass so SPROJDDIF will use the mean and variance of recruitment estimates provided by the KLAMZ model fit to make stochastic projections of recruitment and subsequent spawning biomass estimate under assumed constant fishing mortality rates or constant catch specifications.

Given a specified F_{MSY} proxy, the Working Group proposed to determine spawning biomass at MSY (SSB_{MSY}) and status of the stock by stochastic projections using SPROJDDIF. To do this, we completed 7,000 bootstraps for the final model using BOOTADM (see Appendix A of NEFSC 2004) and made 1 projection 50 years into the future for each bootstrap. SSB_{MSY} is the median spawning biomass in year 50 at the prescribed fishing mortality rate. Estimates of uncertainty and confidence intervals for SSB_{MSY} and stock status can also be obtained from the 7,000 projections. Stock status could either be based on the spawning biomass estimate in 2008 from fit of the final model or the median of the biomass estimates in year 0 of the projections.

To determine an F_{MSY} proxy, the Working Group performed deterministic projections for equilibrium fishing mortalities between 0 and 2. These projections provide the relationship of equilibrium fishing mortality to equilibrium yield per recruit, spawning biomass per recruit, and spawning potential ratio (Figure B55 to Figure B57). For these deterministic projections we used the same SPROJDDIF software above, but we used estimates from the final model rather than bootstraps. There was no defined F_{MAX} for butterfish due to the high rates of growth and natural mortality. $F_{0.1}$ = 1.04

resulted in a catch/recruit ratio of 0.76 and $F_{30\%}$ dropped the ratio 12% to 0.67 and $F_{40\%}$ droppped the ratio 24% to 0.58. The spawning potential ratio at $F_{0.1}$ was 20%. In lieu of an F_{MAX}, we proposed that $F_{0.1}$ = 1.04 is used as an F_{MSY} proxy ($F_{Threshold}$) and $F_{30\%}$=0.72 is used as an F_{Target}.

The Working Group performed stochastic projections for fishing mortalities at the F values corresponding to 20, 30 and 40% spawning potential ratios (Table B32). Median equilibrium yield at F_{MSY}=$F_{0.1}$=1.04 was 36,608 mt and the median equilibrium spawning biomass was 16,262 mt. Median equilibrium yield at $F_{30\%}$=0.72 was 33,108 mt and the median equilibrium spawning biomass was 25,226 mt. Median equilibrium yield at $F_{40\%}$=0.52 was 29,166 mt and the median equilibrium spawning biomass was 34,191 mt. There was large uncertainty in the equilibrium yield and spawning biomasses. Current (2008) spawning biomass was greater than the median equilibrium spawning biomass at each of the fishing mortalities and current fishing mortality was less than those fishing mortalities. The high equilibrium yields at low equilibrium spawning biomasses when F= $F_{0.1}$ or F= $F_{30\%}$ reflects the high growth rate and reproductive potential for butterfish. However, the high variability in recruitment coupled with high uncertainty in biomass and fishing mortality estimates resulted in large uncertainty in spawning biomass and yield in any given year.

When the stock is in equilibrium, this methodology is preferred for both reference determination and stock projection because it puts the determination of both current and future status of the stock within a consistent framework.

When the Fox surplus production model was fit to the biomass and surplus production estimates resulting from the final model, F_{MSY} = 0.233, MSY = 17,400 mt and B_{MSY} = 74,550 mt (Table B32). However, the fit was very poor and the B_{MSY} (and consequently F_{MSY}) estimates were very poorly defined (Figure B58). Note also that the biomass reference point was for total rather than spawning biomass.

Upon review at SARC 49, the stock was determined to not be in equilibrium because of declining biomass over the entire time series of the model in the absence of significant fishing mortality. Given the lack of equilibrium the use of equilibrium-based reference points was found to be unacceptable and the proposed reference points were rejected. The reference points from the previous assessment were also found to be unacceptable for the same reason as well as the unlikely scale of the estimates biomass and fishing mortality upon which the reference points were based.

Term of Reference 5: Stock status evaluation with respect to BRPs.

Evaluate stock status with respect to the existing BRPs, as well as with respect to updated or redefined BRPs (from TOR 4).

Current (2008) spawning biomass (45,000 mt) was greater than the median equilibrium spawning biomass at the proposed F_{MSY} proxy ($SSB_{0.1}$ = $SSB_{20\%}$ = 16,262 mt) as well as at the other considered fishing mortality reference points ($F_{30\%}$=0.72, $F_{40\%}$=0.52). Similarly, current F (0.02) was lower than the candidate F_{MSY} proxies. ***However, these reference points were not accepted by the SARC panel due to the determination by reviewers that the stock is not in equilibrium. Despite the rejection of the reference points, there was a consensus at SARC 49 that overfishing was not likely to be occurring.*** There are sizable corresponding uncertainty in estimates of current fishing mortality and biomass (Table B26 and Table B27) as well as the SSB_{MSY} (Table B32) (spawning biomass with F= F_{MSY}=$F_{0.1}$).

Term of Reference 6: Predator consumptive removals and predation.

Evaluate the magnitude, trends and uncertainty of predator consumptive removals on butterfish and associated predation mortality estimates and, if feasible, incorporate said mortality predation estimates into models of population dynamics.

See Appendix B2.

Term of Reference 7: Projections

Develop and apply analytical approaches and data that can be used for conducting single and multi-year stock projections and for computing candidate ABCs (Acceptable Biological Catch; see Appendix to the TORs).

a. Provide numerical short-term projections (1-5years). Each projection should estimate and report annual probabilities of exceeding threshold BRPs for F, and probabilities of falling below threshold BRPs for biomass. In carrying out projections, consider a range of assumptions about the most important uncertainties in the assessment.

b. Comment on which projections seem most realistic, taking into consideration uncertainties in the assessment.

c. For a range of candidate ABC scenarios, compute the probabilities of rebuilding the stock by January 1, 2015.

d. Describe this stock's vulnerability to having overfished status (consider mean generation time), and how this could affect the choice of ABC.

Projection Methodology

If the stock needed to be rebuilt, the same stochastic projection methods describe above for TOR 5 could be used for short term projections. In fact, the same set of bootstraps used above for determining median equilibrium spawning biomass and yield can be used here. However, the working group suggested that recent recruitment (1999-2008) should be used for the short term projections because recruitment has been low relative to earlier in the time period. As the stock was estimated to be above the SSB at the candidate F_{MSY} proxies, projections carried out at each of the potential F_{MSY} proxies (not rebuilding fishing mortalities) with the full series of recruitments resulted in the expected probability of <0.5 of being overfished in the first few years and converge to 0.5 (Figure B59). Also as expected, the probability of being overfished increased to around 0.75 when recent recruitments (lower on average than the entire time series) were used and fishing was assumed tooccur at the F_{MSY} proxies (Figure B60). Note that the fishing mortalities used in these projections were substantially higher than the current (2008) fishing mortality (0.02). Continued fishing at the status quo with projections based on recruitment estimates for the last 10 years would result in a probability less the 0.01 of spawning biomass being below the proposed SSB_{MSY} (Figure B61). Fishing at F=0.52 resulted in 30% probability of the stock being below the proposed SSB_{MSY} whereas fishing at F=0.72 resulted in 50% probability of being below the proposed SSB_{MSY} when future recruitment was based on recent recruitment (Figure B61). Median spawning biomass climbed to 54,000 mt and yield increased to about 1400 mt when the current fishing mortality rate persists and future recruitment is based on recent recruitment (Figure B62).

The user can also specify in SPROJDDIF program constant catch to find probability of F exceeding candidate F_{MSY} proxies. When catch was assumed constant at 2008 levels fishing mortality remained at or below 0.03 whether recruitment was based on the full time series of recruitment estimates or those from the last 10 years (Table B33). If catch was assumed to double, fishing mortality remained below 0.05 in either case. When the swept area catchability for the fall 1+ indices was assumed to be 0.006 rather than 0.16 as estimated in the final model, fishing mortality rates were negligible whether catches are assumed the same as 2008 or twice the 2008 catch (Table B34). When the swept area catchability for the fall 1+ indices was assumed to be 0.49, fishing mortalities were still below 0.1 whether catches are the same or twice as large as those in 2008.

Term of Reference 8: Research Recommendations

Review, evaluate and report on the status of the SARC and Working Group research recommendations listed in recent SARC reviewed assessments and review panel reports. Identify new research recommendations.

SARC 38 Research Recommendations

1) *A study of the characteristics of inshore and offshore components should be initiated. A study of growth, morphometrics, distribution and other factors related to inshore and offshore butterfish should be conducted.*
Examination of characteristics of the inshore and offshore components has not been conducted. Comparison of seasonal distribution was examined.
2) *Further work on potential information (for example the VTR database) for the estimation of discards of butterfish from all sources should be undertaken. Other methods and stratification and time averaging of the discard data for estimating discards should be explored.*
New methods for estimation of discards based on observer data was undertaken and adopted for use in the assessment.
3) A close examination of the NMFS Observer data from 2003 was warranted for its application in the next butterfish assessment. Observer coverage was transferred to only a few vessels in the Illex fishery and hence was greatly expanded because of the transfer of effort into the scallop fishery by large Mid-Atlantic trawlers.
New methods for estimation of discards based on observer data was undertaken and adopted for use in the assessment.
4) Explore alternative methods for estimating natural mortality.
The assessment examined sensitivity and likelihood values for a variety of M values but no alternative methods of estimation were made. Trends in consumption were examined as indicative of annual variation in M.
5) Explore using landings of target species as a denominator in the discard ratio, based on VTR matched trips (trips with reported landings of target species and butterfish discards).

New methods for estimation of discards based on observer data was undertaken and adopted for use in the assessment.
6) Explore the utility of incorporating into the assessment model ecological relationships, predation, and oceanic events that influence butterfish population size on the continental shelf and its availability to the resource survey.
Predation on butterfish was examined in detail although the results were not directly incorporated into the assessment model.
7) Explore the use of an age-based model for future assessments.
The recommendation was limited by the availability of age data from commercial fisheries.
8) Further investigate the estimation of suitable biological reference points. Stock status determination is currently based on an Fmsy proxy (F0.1=1.01, Bmsy has not been previously estimated). New biological reference points were estimated in the delay-difference model for butterfish. However, there is considerable uncertainty in these estimates and they are subject to change.
Biological reference points were updated and again based on the model results for consistency. Alternative methods were also explored.

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