

## B. ATLANTIC BUTTERFISH

### TERMS OF REFERENCE

- 1) Characterize the commercial catch including landings and discards.
- 2) Provide time series of survey catch (numbers and weight indices) for NMFS and appropriate state surveys.
- 3) Explore the influence of environmental factors on survey catch rates.
- 4) Conduct exploratory stock assessment modeling utilizing fishery catch and survey data sets.
- 5) If possible estimate fishing mortality, spawning stock biomass, and total stock biomass during the current year and characterize the uncertainty of those estimates.
- 6) Update, as appropriate, estimates of biological reference points.

### INTRODUCTION

Butterfish (*Peprilus triacanthus*) are distributed from Florida to Nova Scotia, occasionally straying as far north as the Gulf of St Lawrence (Bigelow and Schroeder 2002). Butterfish are a fast growing species that undergo seasonal inshore and offshore movements. This schooling species seldom attains an age greater than 6 and often schools by size. 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. Butterfish are preyed upon by a large number of medium-sized predatory fishes such as bluefish, weakfish, and spiny dogfish; marine mammals such as pilot whales and common dolphins; seabirds such as greater shearwaters and northern gannets; and large pelagic fish such as swordfish, throughout their range.

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  $F_{msy}$  is exceeded, but an estimate of  $F_{msy}$  is currently not available. The current overfishing definition is based on an MSY of 16,000 mt and a fishing rate of  $F_{msy}$ . An MSY of 16,000 mt represents the current estimate of long-term potential catch for the stock and was used in previous amendments to the FMP. The target fishing rate for this stock is defined as 75%  $F_{msy}$  which gives a target yield of 12,000 mt, well above the current quota specification of 5,900 mt. The biomass target for this stock is defined as  $B_{msy}$  and the minimum biomass threshold is defined as  $\frac{1}{2} B_{msy}$ . There have been a series of amendments to the MSB Fishery Management Plan; the most recent amendment (Amendment 9) does not propose any changes for butterfish.

The most recent assessment for this stock was completed in 1993 (SARC 17). Conclusions were that the stock was at a medium level of biomass and that catches were well below the MSY of 16,000 t. There was no information about exploitation rates available, but recruitment appeared to be at a high level.

Survey indices indicated a decline in 1992-93 from 1990 and adult stock had declined and was well below average.

## **THE FISHERY**

### Commercial Landings

Commercial landings by the United States have remained below about 5000 mt from 1960-2002 except for a period during the mid 1980s when landings increased to over 9,000 mt during 1982 and over 11,000 mt in 1984 (Table B1; Figure B1). Butterfish landings averaged 2,171 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. Demand waned and landings averaged only 2,790 mt during 1990-1999. More recently landings have declined markedly, averaging only 1,731 mt during 2000-2003, with very low totals in 2002 and 2003 (Table B1; Figure B1).

Reported foreign landings were much smaller than actual landings during 1965-1986 and were adjusted upward by Murawski and Waring (1979) for the years 1968-1976. . Adjusted landings from Murawski and Waring (1979) for 1968-1986 were used in the current assessment and the average ratio for adjusted landings (1968-1976; 1.437) was used to adjust reported foreign landings upward for the period 1977-1986. Since foreign landings were relatively small during this period only a small adjustment was necessary (Table B2).

Landings from the foreign fishery during 1965-1986 were relatively much larger than the USA fishery during this time, averaging over 6,800 t. Foreign landings varied from a low of 749 t in 1965 to 5,437 t in 1968 and increased the next year to 15,378 t. Foreign landings declined for a few years and peaked at 31,679 t in 1973, declining thereafter to a low of only 236 t in 1986 (Table B1).

### Commercial Length Composition

Size composition from commercial samples of butterfish ranged between 12-25 cm during 1995-2003 with a modal length at 16-17 cm, depending on the year (Figure B2). The number of fish measured was higher during the earlier years, declining during 2000-2003 (Figure B2).

### Commercial Fishery Discards

Previous assessments suggested that discarding of butterfish in the various fisheries might be a problem and recommendations by the SARC suggested that discards should be quantified if possible in future assessments. Several sources of information are available for the analyses of discards in the USA fishery. The vessel trip report (VTR) database, available since 1994, has been used to document discard rates and amounts in various assessments. Discard estimates from the VTR have not been used in assessments because it is felt that they underestimate the actual level of discards. Another source of information on discarding is the NMFS Observer program database. This source of information includes vessel trips with an observer on board the vessel with many if not most of the tows actually observed by the recorder. The general problem with this data has been the lack of a statistical design for sampling and the small number of trips that are actually covered in any given year. Previous to 1994 port agents interviewed vessel

captains at the conclusion of the trip and estimates of discards for some stocks and areas fished were obtained and logged in a vessel trip file, but this source of information is no longer available.

Butterfish are caught in a variety of fisheries and may be retained or discarded depending on the particular demand in that fishery. Butterfish are often unwanted by-catch in many fisheries such as squid, silver hake, and mixed groundfish. Discards from these sources can be substantial and the total from all such fisheries can be large. To obtain information on the source of discards from various sources, several fisheries were defined based on a target species or mix of species (10 fisheries) and the percent and frequency of butterfish catches in those fisheries during 1989-2002 was calculated. Butterfish were caught frequently in the Fluke, squid, mixed groundfish, and silver hake fisheries (Table B2). These results of course varied by year and were often related to the demand for butterfish and also the other species during that particular year.

On an annual basis the fishery for squid produced the highest level of butterfish discards over the entire period (Table B3). Other important categories were mixed groundfish, Fluke, and Other. Discards in the silver hake target fishery were relatively large during 1989-1993, but declined considerably thereafter (Table B3).

Patterns in butterfish landings were examined by aggregating over a set of observed trips that caught butterfish during 1989-2003. The distribution of landings was highly skewed so upon examination of the data an arbitrary cutoff of 600 lbs was chosen to stratify butterfish trips for analysis (Figure B3). The distribution suggested that a large number of trips landed a small amount of butterfish and many fewer trips accounted for the largest landings.

Discard ratios were calculated using the VTR database for 1994-2002. Only trips that reported some discard of any species were used in the analysis. Initially all gears that captured butterfish were examined for discards, but only data for otter trawls were included in subsequent analyses because discards by other gears such as gill nets were negligible. The data were stratified into half-year intervals and two categories of landings, 600 lbs or less and greater than 600 lbs. An aggregate approach was used to allocate landings and discards into the appropriate categories, so that all trips with some amount of landings or discard were included in the analyses. Sample sizes in each cell were relatively large under this stratification scheme. Discard ratios were calculated by dividing discard by landings.

Results from this approach indicate that discard ratios averaged less than 1 for both categories of landings (Table B4). In many cases discard rates were very small on an annual basis indicating that reporting rates for discards in vessel logbooks may be relatively low. These results have been reported for others species in similar analyses of vessel logbook data. (NEFSC 2002). Therefore we did not use the VTR data to estimate discards in this assessment.

Another analysis was completed using the NMFS Observer database. Only data from observed tows were used in the analysis and only otter trawl trips were analyzed for the same reason as above. Data were stratified into half-year intervals and categories of 600 lbs or less and greater than 600 lbs. An aggregate approach including all trips with some landings or discard of butterfish was used to allocate trips into one of the four cells for each year during 1989-2002. Under this scheme since only observed trips were used, sample sizes were much smaller (Table B5).

Results showed that on average discard ratios were greater than 1 and in most cases significantly greater. With a few exceptions such as for some of the larger cells during 1997-2001, discard rates were greater than 1 (Table B5). Discard ratios in the 600 or less category during 1998-2002 were largest.

Since the data are skewed another, perhaps more appropriate analysis, using a log transformation, was completed. Only trips with matched landings and discard were used with the same four categories of season and trip size. The data were log transformed ( $\ln(x+1)$ ), and discard ratios were calculated on a per trip basis. Discard ratios were averaged in each cell and retransformed to the arithmetic scale. No correction for transformation bias was attempted since earlier studies indicated that variances were relatively high and the retransformed discard ratios would be too high to be useful (NEFSC 2002). It is likely that the backtransformed values are biased low so that discards are underestimated. Since only matched trips were used for this analysis fewer samples were available for this analysis, especially in the higher categories (Table B6).

Results from this approach produced discard ratios that were much less variable ranging from 0.47-4.61, and averaging 4.16 for <600 lbs and 1.67 for > 600 lbs (Table B6). These discard ratios were used along with otter trawl landings by half year and the same landings categories to estimate discards (tonnes) for each cell in each year and then totaled for the year. Discards ranged between 1,809-8,599 mt during 1989-2002 (Table B7). Discards were 4,442 mt in 1989, declined to 3,020 mt in 1990 and then increased steadily to 8,478 mt in 1993. After a decline to 3,701 mt in 1994, discards increased to 8,599 mt in 1995, followed by an almost steady decline to 2,427 mt in 2000 (Table B7). After increasing to 7,262 mt in 2001, discards declined to 1,809 mt in 2002.

Discards for 1965-1988 were estimated by calculating an average discard ratio for each half year and landings category for 1989-2002. These average ratios were multiplied times otter trawl landings using the same stratification to produce an estimate of discard (tonnes) during 1965-1988. Discards were low, less than 2000 mt during 1965-1977 and increased markedly from the early to mid 1980s (Figure B4). Discards reached a peak in 1984 of 18,959 mt.

### Size Composition of Discards

Data from observed otter trawl 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 from 4-24 cm depending on the year and the fishery, but discarded fish were generally less than 16 cm (Figure B5). The kept fraction of trips ranged from 10-22 cm and usually had a modal length from 16-18 cm (Figure B5). Sampling intensity was generally moderate to high during 1989-1991, low in 1992, and moderate from 1993-2000. Sampling intensity declined during 2001-2002, but may have increased in 2003 due to more trips being observed.

### Total Catch

Landings from the USA, USA discards, and foreign landings during 1965-2002 were summed to estimate total catch over that period (Figure B6). Catches increased steadily from 1965-1973, reaching a peak of 34,265 mt in 1973. Catches declined after 1973 reaching about 7,200 mt in 1977 and then began another increasing period starting in 1979, reaching 31,500 mt in 1984 (Figure B6). After 1984 catches declined

and stayed in a fairly steady pattern between 5,000 and 13,000 mt during 1987-2002. Recent catches have all been around 5,000 mt except during 2001 when the catch reached 11,700 mt (Figure B6).

## RESEARCH SURVEY ABUNDANCE AND BIOMASS INDICES

Research survey abundance and biomass indices are available from several sources for assessing the status of the butterfish resource. Survey indices are available from NMFS surveys for the winter 1992-2002, Spring 1968-2002, and Autumn 1968-2002. The autumn period during 1963-1966 was not covered in the southern Mid-Atlantic Bight region so no indices are available for butterfish during this period. A new set of survey strata were used in this assessment because the set in the previous stock assessment included inshore strata 1-46 for the period 1968-1993. These inshore strata were not covered during 1968-1972 and were sporadically covered thereafter, so a set of offshore strata (1-14, 16, 19, 23, 25, 61-76) was used instead. Indices are also available for several state survey programs, notably Massachusetts DMF, Rhode Island DFW, Connecticut DEP, New Jersey BMF, 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, RI, CT, and VIMS surveys were available, so only these surveys will be presented.

### NEFSC Surveys

The NEFSC winter survey covers 1992-2002 with number per tow ranging from 38-169 and weight per tow from 0.8-6.2 (Table B8; Figure B7). With the exception of 1994-1995 and 2000 relative abundance has been moderate during this period and biomass has been moderate with a few low years (Table B8). The spring survey in 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 36.8-61.2 for 2000-2002 (Table B8; Figure B7). Spring indices in wt/tow (kg) were generally higher in the early 1970s and early to mid 1980s than during the late 1980s and early 1990s (Table B8; Figure B8). Spring wt/tow (kg) indices increased slightly in the late 1990s and then declined again. Autumn survey indices in number/tow were generally much higher than the winter and spring indices because of the presence of the age 0 fish in the autumn. Catch per tow in number was moderately high but fluctuating during 1968-1978 and very high from 1979-1990 (Table B8; Figure B7). Indices declined slightly during 1991-2000 and then declined again in 2001-2002. Autumn indices in wt/tow (kg) were highest during 1979-1990, declining during 1991-1999 and then dropping to lower levels in 2001-2002 (Table B8; Figure B8).

### Aged NEFSC Survey Indices

Aged butterfish survey data from NEFSC Spring and autumn surveys are available from 1982-2002. The delay difference biomass model used in this assessment is a partial age structured model, utilizing biomass per tow indices for two age groups, at age 0 and age 1+. Survey indices in both number and weight per tow (kg) at age were run to allow for the estimation of survey Z's and for use in the delay difference model.

Spring survey number-per-tow at age is shown in Table (B9). This survey generally catches age groups 1-3 and some fish from age group 4. Survey indices in number-per-tow at age for the autumn during

1982-2002 are shown in Table (B10). This survey generally catches age groups 0-3 with the age 0 catch dominating the total catch in number.

The autumn survey catch in weight per tow (kg) is shown in Table (B11) for age groups 0-3. Indices in weight for age 0 and aggregated 1+ for 1982-2002 were calculated from the table. Indices for 1968-2002 were calculated from the relative proportion of age 0's from Table E5 from the last assessment (NEFSC 1993). The relative proportions were applied to the catch/tow from the new strata set to get the numbers of 0's. These numbers were converted to weight (kg) by applying the average weight of an age 0 butterfish and then subtracting this wt from the total 1+ weight. The values for age 0 and 1+ were calculated for 1968-1981 and are shown in Table (B11).

### Additional Survey Analyses

Several additional analyses were performed on the NEFSC spring and autumn survey time-series. Survey wt/tow indices were bootstrapped using the method of Smith (1997) to produce confidence intervals for spring and autumn during 1968-2002. Results indicate that both series have prominent confidence bands around their mean values (Figures B9;10). It also appears that the variance of the wt/tow values increases with increases in the mean. A plot for the autumn survey, showing the relationship between mean wt/tow and variance in mean wt/tow, confirms this (Figure B11). This is a common result, variance often increases as populations grow larger. The effect of stratification and sample allocation was also investigated. Results from this approach indicate that there were no persistent gains in efficiency for butterfish from the stratification scheme that is currently employed in the groundfish survey for spring and fall (Figure B12). This result is not surprising because the survey was not necessarily designed to sample species like butterfish. Depth, temperature, and day/night differences were also examined for possible links to the high variability in butterfish survey catches. No strong relationships were detected for either depth or temperature, but a reasonably strong relationship was indicated for day/night catches during the autumn. In most years survey wt/tow (kg) was higher during the daytime in the fall survey (Figure B13). There was very little difference in spring day/night catches. (Figure B13).

### State Surveys

#### *MADMF Survey*

The Massachusetts survey during Autumn 1982-2002 was relatively flat from 1978-1991, and then increased considerably to a peak of 14.5 kg/tow in 1998, declining after that (Table B12; Figure B14). Survey catch rates from this survey are comparable to the NEFSC surveys.

#### *RIDFW Survey*

The Rhode Island survey covered the period from 1981-2002 with survey trends from 1981-1991 also being relatively flat (Table B12; Figure B14). Survey indices increased slightly to a peak of 9.3 kg/tow in 1997 and then declined to much lower levels after that. Survey catch per tow from this survey are about the same magnitude as the NMFS surveys although they cover a much smaller area.

### *CTDEP Survey*

The Connecticut bottom trawl survey that was available had available indices in number/tow during 1984-2002. These indices were converted to wt/tow by multiplying by the average weight (0+) from the NMFS Autumn surveys for each year. Since this survey catches relatively large numbers of butterfish, the indices in weight are relatively large (Table B12; Figure B14). This survey shows a variable but increasing trend from 1984-2002.

### *VIMS Survey*

The Virginia Institute of Marine Science bottom trawl survey in Chesapeake Bay catches a small number of age 0 butterfish during the autumn. This survey was available for the period from 1988-2001 and also was converted to a weight/tow index by applying the USA Autumn age 0 weight to each year. This survey shows a variable, but downward trend in biomass from 1988-2001 (Table B12; Figure B15).

### Survey Indices for Scale

It is often necessary, especially for age-structured models, to constrain solutions to feasible regions so that useful results are produced. Several time-series were available for possible scaling of model results for the butterfish stock assessment. Murawski and Waring (1979) produced biomass estimates in a butterfish stock assessment (Figure B16). Minimum swept-area biomass estimates from the NEFSC Autumn survey were also prepared as a possible scale variable for the model. Waring (1970) used a ratio between day and total survey catch to produce a minimum biomass estimate for butterfish. The ratio of survey day catches (07:00-17:00) to total survey catch for each year in the autumn survey was computed. These ratios were averaged and each annual minimum biomass estimate was multiplied by this average ratio (1.54). Autumn survey minimum biomass tracks the autumn survey wt/tow index, but is scaled upward (Figure B17). The final series of data that are available is a set of autumn survey survival rates computed from the autumn survey number/tow indices. This index is calculated as a Heinke ratio between age 1+ in year t+1 and age 0+ in year t. These estimates are shown in Figure (B18).

## **BIOLOGICAL DATA AND ANALYSES**

### Growth

Starting in 1992 butterfish have been individually weighed while at sea during groundfish cruises. This database was used to fit Length-Weight equations for each year and each survey from 1992-2002. Plots of spring and Autumn LW relationships suggest that there were no changes in patterns of growth for this species during this period (Figures B19; 20). On this basis common LW relationships were computed for spring and autumn as a weighted average of the a and b parameters for each year. These average LW parameters were used in SURVAN runs to produce mean wt/tow for 1982-2002.

We also needed to estimate Von-Bertalanffy growth parameters for use in the delay-difference model so we used an aggregate approach for all the data. 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.

The KLAMZ (FPA) 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 FPA model for butterfish are hypothetical figures that include the amount of hypothetical age zero biomass necessary (considering growth and mortality) to explain subsequent catch data and survey trend data. To avoid using hypothetical biomass levels, it is probably better to track butterfish population dynamics in terms of average annual total biomass (ages 0+ at some point mid-year) or escapement biomass (ages 1+ on January 1) which are also estimated in the FPA model. Approaches to modeling growth and population dynamics for species like butterfish that recruit at age zero and grow quickly is a topic for future research.

Butterfish in NEFSC fall and spring surveys have been individually weighed at sea since 1992. A length-weight relationship was estimated based on all available length and individual weight data (see below).

\*\*\* Nonlinear Regression Model \*\*\*

Formula: INDWT ~ alpha \* LENGTH^beta

Parameters:

	Value	Std. Error	t value
alpha	0.0000158953	3.50244e-007	45.3836
beta	3.0854500000	7.90770e-003	390.1830

Residual standard error: 0.00771297 on 11552 degrees of freedom

Correlation of Parameter Estimates:

alpha	
beta	-0.998

The estimated length-weight parameters were used to calculate individual body weights for all butterfish taken in spring, fall and winter surveys and aged since 1963. Records for eleven age 0 butterfish from winter and spring surveys were omitted because age 0 butterfish should not be available until after June. Data from a total of 21,765 butterfish ages 0.78-6.3 years were used to estimate growth curves (Figure B21).

The average Julian date of survey tows in butterfish strata for spring surveys during 1968-2002 was 95 days and the average Julian date for fall surveys was 284 days. Therefore, ages used in fitting growth models were adjusted by increasing the nominal age by  $95/365=0.26$  y for butterfish taken in spring surveys, by  $47/365=0.13$  y in winter surveys, and by  $284/365=0.78$  y for butterfish taken in fall surveys (see below).

Schnute's (1985) general growth model used in derivation of the delay difference model in FPA is:

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

where  $k$  is the age at recruitment,  $w_a$  is weight at age  $a \geq k$ ,  $v$  is the predicted value of  $w_{k-1}$ ,  $V$  is the predicted value of  $w_k$ , and  $\rho = e^{-K}$  where  $K$  is the parameter for von Bertalanffy growth in weight. The FPA model, in turn, uses the growth parameters  $\rho$  and  $J=v/V$ .

Modeling butterflyfish growth in the FPA 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  $\nu$  should be a positive number that estimates body weight at age  $k-1$  one year prior to recruitment. In theory, the parameter  $\nu$  for butterflyfish would be body size at age  $k-1 = -1$  during the January of the year before spawning occurs. Moreover  $\nu$  for butterflyfish is negative when  $k = 0$  (see below).

To obtain useful growth parameters for modeling butterflyfish, we estimated growth parameters in Schnute's model by nonlinear regression assuming that butterflyfish recruit at a nominal age of 1.5 in nominal years (age 1 in biological years). Results (see below) were statistically significant although butterflyfish growth is highly variable. Growth parameters used in the FPA model for butterflyfish were  $\rho=0.81605800$  and  $J=\nu/V=0.09675675$  (see below).

```

*** Nonlinear Regression Model ***
Formula: calcwt ~ schnute(newage, littlev, bigv, rho, k = 1.5)

Parameters:
      Value Std. Error t value
littlev 0.00507862 0.000375370 13.5296
  bigv 0.05248860 0.000230723 227.4960
   rho 0.81605800 0.009812100 83.1685

Residual standard error: 0.0229647 on 21762 degrees of freedom

Correlation of Parameter Estimates:
      littlev  bigv
bigv -0.318
rho 0.729 -0.728

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Our approach to estimating growth parameters may underestimate the growth rate and biological productivity of age zero butterflyfish in the FPA model. Nevertheless, the parameter  $J=0.09675675$  implies that body weight of young-of-year butterflyfish increases quickly by about  $1/J=10.3$  times per year during the first year of life. In addition, growth curve predicted weights for age zero butterflyfish during the second half of the year (when age zero butterflyfish tend to be taken by the fishery) and weight at age for all subsequent ages appears reasonable (see below).

For potential future use, we fit a conventional von Bertalanffy growth model using nonlinear regression and the same data (see below). As expected (Schnute 1985), the resulting von Bertalanffy growth curve was indistinguishable from the Schnute growth curve.

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*** Nonlinear Regression Model ***
Formula: calcwt ~ vb(newage, winf, vbk, tzero)

Parameters:
      Value Std. Error t value
winf 0.262838 0.01167340 22.5160
  vbk 0.203254 0.01202370 16.9045
tzero 0.403999 0.00840727 48.0535

Residual standard error: 0.0229647 on 21762 degrees of freedom

Correlation of Parameter Estimates:
      winf  vbk
vbk -0.996
tzero -0.742 0.787

```

## 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 and Link (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. For example, a significant amount of butterfish is consumed by weakfish, spiny dogfish, and silver hake (Figures B22-24).

## **ESTIMATES OF MORTALITY AND STOCK SIZE**

### Total Instantaneous Mortality from Surveys.

Total mortality rates ( $Z$ ) were estimated from both spring and autumn bottom trawl survey number/tow at age data from 1982-2002 assuming all age groups were equally available to NEFSC survey gear. Since total mortality is so high over each age group for butterfish, it is possible to estimate age specific values rather than the traditional Heinke aggregated estimate. Survey  $Z$ 's were very high in the Spring survey, ranging from 0.451-3.65 for age 1, 0.381-3.965 for age 2 and averaging greater than 1.7 for ages 1-2 (Table B13). Estimates for age 3 ranged from .096-4.673, averaging almost 3.0 (Figure B13). Survey  $Z$ 's followed a similar pattern for the autumn survey. Estimates of  $Z$  ranged from 0.822-4.139 for age 0, .0689-3.294 for age 2, averaging 1.789 for age 1 and 1.487 for age 2 (Table B14). Estimates for age 3 ranged from 1.296-6.332, averaging 2.335. These total mortality rates indicate that few butterfish survive beyond age 4 in the spring.

### Survey Exploitation Rate Index

Survey exploitation rate indices were calculated by dividing annual butterfish catch by survey indices for spring and autumn. These indices were calculated by using the spring age 1+ wt/tow indices and the autumn age 0+ wt/tow indices for 1968-2002.

The spring exploitation index is variable, but relatively flat over the period (Figure B25). There is some indication that exploitation rates have dropped in the more recent years from 1997-2002. The autumn exploitation index is also variable, but appears to have declined over time through 1990 (Figure B26). More recently, the index is again variable, increasing to a higher point in 1996 and 2001, but otherwise less than half of some of the values observed in the late 1960s and early 1970s.

### An Index Method (AIM)

An Index Method (AIM), part of the Woods Hole Toolbox modeling package, provides a more formal method for investigating the relationship between catch and survey indices than the simple exploitation index method. AIM allows for an investigation of the relationship based on a statistical fitting procedure and for the estimation of a replacement level of  $F$  to serve as a reference point for a stock. Butterfish

catch and spring and autumn survey indices in wt/tow for 1968-2002 were used in the method to discover if any useful signal was present in these data. Auto-correlation analysis indicated that several significant lags were present between the replacement ratios and the relative F's for butterfish from both the surveys and especially the fall (Figure B27). Randomization tests indicated that this relationship was not significant for both surveys. The relationship between relative F and replacement ratio was reasonably good for the spring and the relative F was estimated as  $F=6.06$  (Figure B28). The bootstrap distribution of relative F was fairly broad with an 80% confidence interval between 4.98-7.26 (Figure B28). The relationship between relative F and replacement ratio was somewhat poorer for the fall with the replacement F estimated as 1.50 (Figure B29). The bootstrap distribution of relative F was tighter than the spring with an 80% confidence band between 1.02-2.01 (Figure B29). The six-panel plot for the spring suggests that replacement ratios have been variable over time, and the current relative F is below the replacement F (Figure B30). The corresponding plot for the fall suggests that the replacement ratio has declined steadily over time and the current relative F is slightly above the replacement F (figure B31).

### *Forward Projection Analysis (FPA) Description*

Details of the FPA approach are provided in Appendix A1 (Ocean quahogs). The analysis starts in 1965 and projects forward through 2002. Total biomass, average biomass, recruitment biomass, fishing mortality, and surplus production are estimated in the model.

### *Growth*

Growth is modeled as a Von-Bertalanffy process with  $k=0.2033$  and a constant J ratio of  $J=0.09677$  for 1965-2002.

### *Maturity*

Maturity was assumed to be 0 at age 0 and 1 for age 1+ butterfish.

### *Natural Mortality*

Natural mortality was assumed to be 0.8 as in previous assessments. The FPA allows for the estimation of annual changes in M by modeling it as deviations from a mean value (see appendix A1), but this feature was not used in the current approach.

### *Recruitment*

Recruitment can be modeled in several ways in the FPA. A Beverton-Holt stock-recruitment model was used to model recruitment with the alpha and beta parameters estimated internally in the model (see appendix A1 for details). This formulation was used in initial model runs, but was not used in the final model formulation. The final model estimated recruitment biomass as deviations around the mean recruit biomass during 1965-2002.

### *Surplus Production*

Surplus production for the butterfish stock was estimated with an external Fox (1975) model fit to surplus production and average biomass estimates (Jacobson et al. 2002). Parameters were estimated internally and lambda was set at 0.0001. This allows the parameters to be estimated, but not influence the model fit to any appreciable degree.

### *Catch*

The total estimated catch (Figure B6) including components for landings and discards was used in the FPA model.

### *Research Surveys for Trend*

The four NMFS surveys were used to tune the butterfish FPA model. These surveys included a Winter 1+ survey, a Spring 1+ survey, an autumn age 0 survey, and an Autumn 1+ survey. The four state surveys were added to the model formulation, but due to time constraints and unresolved residual patterns they were not used in final model runs. This however, does not preclude their use in future modeling exercises for butterfish.

### *Time-Series for Scale*

Three time-series were available for scaling model results in the FPA runs. The biomass estimates from Murawski and Waring (1979) for 1968-1976 (Figure B16), the minimum swept area biomass estimates for the autumn survey for 1968-2002 (Figure B17), and the survey survival rates (S) for the autumn survey 1982-2002 (Figure B18). Although these scalar series were not used in the final model run, they were very useful in profile analyses for determining the best overall model.

### *Survey Covariates*

We hypothesized that the inclusion of the polyvalent doors in 1985 may have affected the catch of butterfish in the spring and autumn surveys. The coefficient for weight per tow for butterfish was not significant ( $p=.866$ ) (Byrne and Forrester 1991) from the door conversion experiments that were conducted. However, the experiments were not designed to estimate the effects of the door change on pelagic fishes such as butterfish and herring. So, we used a covariate for the door conversion for butterfish; an indicator variable approach was chosen for introducing this variable to the likelihood function as:

$$q' = qe^{\delta D}$$

Where  $\delta$  is the estimated parameter and D is 1 during 1985-2002 and 0 for all other years in the spring and autumn surveys. Door parameters for the spring and Fall 1+ were examined and found to not be significant and therefore were not included in the final model. A door parameter for the fall age 0 was retained because it was significant and the adjustment in catchability that was predicted was in the correct direction (Figure B32).

We also added a covariate for the change in gear that took place in the spring survey during 1977-1981. In gear comparison studies on the difference between the 36 and 41 trawl; the 41 net caught significantly

more butterfish ( $p=0.05$ ) (Sissenwine and Bowman 1978). This covariate was also added as an indicator variable. The parameter for Spring1+ net was significant and the adjustment for the change to the 41 net was also in the correct direction (Figure B33). The addition of these two survey covariates improved the model fits and residual patterns for the spring age 1+ and especially for the fall age 0 surveys.

## FPA RESULTS

### Profile and Sensitivity Analysis Results

A series of profile and sensitivity runs were completed to narrow model choices to a few candidates for a final model. Choices included an unconstrained run, runs constrained to particular values of  $q$  for Survey Survival (S) and runs that allowed catch to be estimated. The Working Group felt that a profile run over M would also be useful. Values of emphasis coefficients ( $\lambda$ 's) that were used to accomplish these various runs are listed in Table (B15).

### Natural Mortality

Since the assumed natural mortality rate in the FPA model for butterfish is very high ( $M=0.8$ ), a profile analysis was completed to decide if this rate is reasonable. The model was run in increments of M of 0.1, from 0.6-1.4. Results show that the model fits, based on total survey likelihood (Surveys-All) and total likelihood (Total Log Likelihood) were better for values of M of 0.8 or greater (Table B16). When M was reduced below 0.8, the total negative log likelihood increased rapidly. The Working Group concluded that a value for M of 0.8 was reasonable for modelling the butterfish stock.

### Survey Survival Rates

One important time-series of information available for scaling model results are survey survival rates (S) (Figure B18). The model was run by placing a large emphasis coefficient ( $\lambda$ ) on  $q$  ( $q=10000$ ) for survival rates and completing a series of model runs. The  $q$  for Survival rate parameter was incremented by 0.1 from  $q=0.2-1.0$  and survey covariates for net and doors were switched on. Likelihood terms for the total survey likelihood (Survey\_trends), individual surveys (for example Trend\_Winter.Survey.Age.1+) and the total likelihood (Total\_LogLikelihood) were examined. Values for MSY, Bmsy, average biomass during 2000-2002 (av biomass last 3 yrs) and average F (av F last 3 yrs) were also scrutinized by the Working Group. There is a pronounced bottom in both total survey and total likelihood at a  $q=0.4$  (Table B17). Values of MSY, Bmsy etc are also infeasible at  $q$ 's  $< 0.4$ , and total likelihood increases beyond a  $q$  of 0.4. On this basis the Working group concluded that a model run using unconstrained results ( $q=0.446$ ) would be a possible candidate for a final model.

### Estimation of Catches

The Working Group also wanted to examine a set of model runs that allowed for the assumption that catch is measured without error to be relaxed. Since discards are such an important component of the catch in the butterfish assessment, this is a very important issue to resolve. A sensitivity analysis was conducted on the coefficient of variation (CV) of catch to determine the best model and appropriate CV to

use if catch is estimated. The model was stepped through CV's of 0.1-0.5 in 0.1 increments and survey covariates for net and doors were switched on.

The model had trouble converging at CV's greater than 0.3, giving infeasible results (Table B18). After examining the feasible runs between 0.1-0.3, the Working Group concluded that a model run with a CV=0.1 was the best case for an overall model that estimates catches with some error. This model was chosen based on the catch likelihood term (0.259), and its relative stability for biomass and F. When trends in average biomass and fishing mortality were examined, runs with CV's greater than 0.1 were rejected (Figures B34; 55).

The Working Group also looked at a sensitivity run for catch CV's with the survey covariates switched off. The total likelihood was much larger for these runs indicating that including these covariates provided for better model fits. Model goodness of fit measures are better as well as residual patterns for model formulations with the survey covariates for net and doors included.

### Final Model

Model outputs for the no constraints case and the catch CV=0.1 case are very similar (Table B19). The Working Group decided that the model that estimated catch with some error was a better choice than the model scaled to survey survival rates (S) because discards play a major role in this assessment. However, although initial runs for the catch estimation model converged, later runs with average biomass, spawning biomass, and recruitment did not converge. Therefore, the SARC decided to accept the unconstrained run as the final model (Table B19). Values of lamda's used in the final model run are shown in Table (B20). Parameter values estimated in the final model run are shown in Table (B21).

### Average Biomass

Average biomass was variable during 1968-2002, reaching numerous short-term peaks and lows during the period (Figure B36). Average biomass ranged between 7,817-77,189 mt and averaged 33,399 mt during this period (Figure B36). Average total biomass during 2000-2002 was 18,714 mt and 7,817 mt in 2002.

### Spawning Biomass

Spawning biomass was also variable during 1968-2002 reaching several periodic peaks and lows during this period (Figure B37). Spawning biomass ranged between 7,843-62,914 mt and averaged 23,239 mt during this period (Figure B37). Spawning biomass averaged 19,100 mt during 2000-2002 and was 8,681 mt in 2002.

### Fishing Mortality

Fishing mortality was relatively high during 1968-1976, dropping after that to an average of about 0.3 during 1977-2002 (Figure B38). Fishing rates were more variable recently, from a low of 0.12 in 2000 to a high of 0.70 in 2001 (Figure B38). The average fishing rate during 2000-2002 was 0.39 and F in 2002 was 0.34..

### Stock Recruitment-Recruitment Biomass

Recruitment biomass has been highly variable for the butterfish stock over a range of spawning biomass between about 10,000-50,000 t (Figure B39). Recruitment biomass ranged between 2,812-61,062 mt during 1968-2002 and averaged 23,179 mt (Figure B40). The recent average was 7,988 mt and recruitment biomass in 2002 was 2,974 mt (Figure B40). Recent recruitment has been below average and recruitment in 2001 and 2002 are among the lowest in the series.

### Surplus Production

Surplus production was estimated with an asymmetric Fox (1975) model. Reference points for this model were  $MSY=12,175$  mt,  $B_{msy}=22,798$  mt and  $F_{msy}=0.38$  (Figure B41).

### Loss to Natural Mortality

For many fish stocks it is common for landings to greatly exceed losses to natural mortality, not so for pelagic species. Natural mortality rates are generally higher, hence a much larger fraction of the stock is removed by natural causes, usually predation, but disease and other causes can be important. Since this component of total mortality can be important for butterfish, it is worth quantifying this loss. Biomass lost to M ranged from 5,237-42,323 mt and averaged 21,382 mt during 1968-2002 (Figure B42). This metric is useful for understanding the large fluctuations in biomass and relatively low surplus production for this stock.

### Precision of FPA Estimates

The relative precision of the estimates for average biomass and fishing mortality and their 80% confidence intervals were calculated using a bootstrap procedure. One thousand bootstrap runs were completed and the results were summarized in frequency and cumulative distribution plots. Results indicate that estimates for both average biomass and F are relatively imprecise. Estimates for average biomass ranged from 655-49,127 mt with an 80% CI between 2,606-10,874 mt (Figure B43). Estimates for F ranged from 0.055-4.08 with an 80% CI between 0.246-1.03 (Figure B44). Although the percent of bias was not specifically estimated, results suggest that average biomass was biased low and F was biased high.

### Model Diagnostics

Plots of survey residuals for the four NEFSC surveys used to tune the FPA model for trend were produced as a diagnostic measure of goodness of fit. Plots of observed vs. predicted data series and residual trajectories (residuals vs. time), and residuals vs. predicted values were produced and are shown in Figure (B45).

## SARC COMMENTS

The SARC discussed the methods used for estimating discards. Discards were estimated as a significant proportion of the total catch (about 2/3 of the total catch since 1980). Examination of alternative stratification of the discard data should be made in future assessments. Stratification by target species and/or combining data temporally to increase the sample size may provide better discard estimates. Variance estimates of discard ratios can be used as a diagnostic for determining the reliability of the estimates. A plot of estimated ratios revealed little trend over time and suggested that time averaging of the ratio may be appropriate. Statistical tests between the stratified discard estimates should be made to justify the stratification used. The discard estimate should be considered a minimum estimate of discards since the estimate was limited to observer trips, which possessed both, landed and discards of butterfish. The SARC noted that the high 1995 discard ratio was primarily due to several trips, which landed a relatively small amount of butterfish landings. Although there is uncertainty in the discard estimates the SARC felt the scale of the discards is clear. The SARC accepted the use of the discard estimates for the assessment while recommending further investigation on discards be done in future assessments.

The SARC reviewed an index method (AIM) for assessing butterfish. The SARC noted the relatively weak correlation between the replacement ratio and the relative F in the model and questioned the utility of the model for this species. It was suggested that limiting the survey index to fully recruited fish (omitting age 0 fish in the Fall survey) might result in a better relationship between the biomass index and the rate of removals by the fishery.

The SARC reviewed a delay-difference model for butterfish. A profile on natural mortality suggests an improvement in model fit as M increases, indicating that M was not estimable. The SARC suggested exploring alternative methods for estimating natural mortality external from the model. Given the uncertainty in estimated discards it was thought that a model with estimation of catch with error is warranted. However, a profile on changes in the assumed CV on catch (estimated with error) estimated Qs for adjusted biomass, which were biologically unrealistic ( $>1$ ). Questions on the proportion of the stock coverage by the survey and day night differences in catch should result in a lower estimate of Q in the absence of herding.

It was noted that very similar fits to the data exist in the final set of model runs but these runs produced very different stock status determinations. The SARC questioned whether the number of parameters in the model allows for alternative states of nature to be fit equally well particularly with a species that possesses large fluctuations in the survey indices. The SARC requested that the diagnostics for using survey covariates be included in the document. It was noted that the final model run proposed by the working group does produce estimates of average biomass in the last three years which match the estimates of Fall minimum swept area biomass. The SARC noted a lack of coherence between the spring and fall survey by age (0 and 1+).

The SARC requested a table of estimated model parameters and CVs. The lack of convergence for the model run, which estimated catch with error, deemed this run as unreliable. The SARC noted that the estimated net covariate parameter from the model was very similar to the published Yankee 44 net conversion factor. However the SARC felt the door covariates parameters were not significant and should be omitted in the final run. The SARC concluded that the status determination of the stock should be made by using the ratios of the point estimates to the reference point.

## **SOURCES OF UNCERTAINTY**

- 1) The estimate of natural mortality is uncertain.
- 2) Observer sampling of the trawl fishery has been low and increases the uncertainty of the discard estimates.
- 3) The lack of coherence between the spring and fall surveys is a source of uncertainty.
- 4) The new model based estimates of biological reference points are uncertain

## **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.
- 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.
- 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.
- 4) Explore alternative methods for estimating natural mortality.
- 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).
- 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.
- 7) Explore the use of an age-based model for future assessments.
- 8) Further investigate the estimation of suitable biological reference points. Stock status determination is currently based on an Fmsy proxy ( $F_{0.1}=1.01$ , 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

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