A. MONKFISH (GOOSEFISH) STOCK ASSESSMENT FOR 2010

SAW50 Editor's Note: The SAW Chair has added comments to this monkfish assessment report, all of which use bold italicized text. These comments are included to present some opinions and decisions of the SARC50 peer review panel. The comments inserted here do not replace and are not a substitute for the complete set of reviewer reports that are available online from the SAW/SARC website (http://www.nefsc.noaa.gov/nefsc/saw/ in the SAW50 section).

Southern Demersal Working Group (WG)

The Southern Demersal Working Group prepared the stock assessment. The WG met during April 12-15, 2010 at the Northeast Fisheries Science Center, Woods Hole. MA, USA, with the following participants:

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SARC 50 Monkfish Terms of Reference

1. Characterize the commercial catch including landings, effort, LPUE and discards. Describe the uncertainty in these sources of data.
2. Report results of 2009 cooperative monkfish survey and describe sources of uncertainty in the data and results.
3. Characterize other survey data that are being used in the assessment (e.g., regional indices of abundance, recruitment, length data, state surveys). Describe the uncertainty in these sources of data.
4. Estimate annual fishing mortality, recruitment and stock biomass (both total and spawning stock) for the time series, and characterize the uncertainty of those estimates.
5. 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.
6. Evaluate stock status with respect to the existing BRPs, as well as with respect to updated or redefined BRPs (from TOR 5).
7. Evaluate monkfish diet composition data and its implications for population level consumption by monkfish.
8. 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 (through 2016). 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 to examine important sources of uncertainty in the assessment.
    b. Comment on which projections seem most realistic, taking into consideration uncertainties in the assessment.
    c. Describe this stock's vulnerability to becoming overfished, and how this could affect the choice of ABC.
9. 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.

Executive Summary

The Southern Demersal Working Group (SDWG) met in April 2010 to develop stock assessments for the northern, southern and combined management areas of the U.S. fishery resource. The SDWG met within the process of Northeast SAW 50 and addressed 10 terms of reference, as follows.

1. Characterize the commercial catch including landings, effort, LPUE and discards. Describe the uncertainty in these sources of data.

Reported total landings (live weight) increased from an average of 2,500 mt in the 1970s to 8,700 mt in the 1980s, 23,000 mt in the 1990s, 22,000 mt from 2000-2005 and 11,600 mt during 2006-2009. Total landings have declined since 2003 due to management regulations including TACs during 2007-2009 of 5,000 mt in the northern area and 5,100 mt in the southern area. Landings in 2009 were 3,255 mt in the northern area and 5,302 mt in the southern area.

Estimated total discards of monkfish during 1989-2009 have ranged between 1,600 mt (1992) and 7,500 mt (2001) per year, with a long-term discard/kept ratio of 0.15 (northern and southern areas combined). Discard rates have been highest in the scallop dredge fisheries in the southern area, and lowest in gillnets in both areas. Discard ratios and discard levels (mt) increased in both areas after 2000, and have since declined somewhat (overall discard/kept ratio for 2000-2004 =0.20; for 2005-2009=0.17).

Length composition of landings was fairly stable during 2002-2009, with modal lengths ~52 cm in the north, ~65 cm in the south and few fish larger than 85 cm in either area. Recent decreases in landings have not resulted in a broadening of the size composition of landings.

Evaluating trends in effort or catch rates in the monkfish fishery is difficult because much of the catch is taken in multi-species fisheries, and defining targeted monkfish trips is problematic. Furthermore, programmatic changes from port interviews (1980-1993) and logbooks (1994-2006) make temporal comparison of effort statistics difficult. CPUE estimated from observed tows has declined in the north since 2003-2005 and remained stable or declined since 2004 in the south; however estimates of CPUE have a high variance and may not be reliable.

Estimation of total catch for monkfish has several sources of uncertainty. Before 1980, fishery removals were primarily bycatch, but most were unreported. Therefore, evaluation of fishery development is difficult, leading to problems interpreting the state of the resource in the early years of the marketed fishery. Since 1980, the quality of landings estimates generally increased, but the series includes under-reporting and difficulties converting landed products to live weight. Historical under-reporting of landings should be considered in the interpretation of this series.

There is no information on the magnitude of discards prior to 1989. The SDWG assumed that discard rates before 1989 were similar to discard: kept ratios observed in later years; this may be problematic if discard rates were lower in later years because markets had developed. The quality of discard data generally increased in the 1989-2009 observer time series, as a result of increasingly greater coverage of fleets and improved protocols, but there were some unsampled portions of the fishery (e.g., some half-year periods in which entire gear-types were not sampled).

Characterizing size and age composition of the catch also has considerable sources of uncertainty. Length sampling by fishery observers started earlier in the time series than sampling of landings in ports (1989 vs. 1996) and was more comprehensive (NEFSC 2007a); however, sampling intensity in most years is adequate only for estimation on a half-year basis. Age samples from at-sea observers have not been processed and are on hold until the ageing method is validated.

2. Report results of 2009 cooperative monkfish survey and describe sources of uncertainty in the data and results.

A cooperative monkfish survey was conducted during Feb-Apr 2009 using two industry trawlers and 3 nets (2 flat, 1 rockhopper). The survey design differed slightly from previous cooperative surveys (in 2001, 2004) because sampling effort was allocated in proportion to stratum area rather than to spatial patterns of fishing effort. The estimates of area swept population size and biomass for 2009 are lower than those estimated from earlier cooperative monkfish surveys (2001, 2004). The estimated population length composition was similar among cooperative surveys with a mode around 34 cm in the NMA and a bimodal distribution (~32 cm and ~52 cm) in the SMA. Length frequency composition data from the 2009 cooperative survey were input into the final SCALE assessment model. Major sources of uncertainty include timing of the survey with respect to spring onshore migrations and accuracy of net efficiency estimates from depletion experiments.

3. Characterize other survey data that are being used in the assessment (e.g., regional indices of abundance, recruitment, length data, state surveys). Describe the uncertainty in these sources of data.

Several surveys sample monkfish and provide time series of relative abundance. However, no single survey (with the exception of the new NEFSC survey on the FSV Bigelow) catches large numbers of monkfish throughout either management area. The NEFSC spring and autumn bottom trawl surveys provide long-term series that sample the entire continental shelf to 300m depth, but they only catch approximately 100 monkfish in each management area per year. The NEFSC winter bottom trawl survey and scallop survey, the ASMFC shrimp survey, and the ME/NH inshore survey catch considerably more monkfish, but are shorter series, and sample only a portion of either management area.

Within the northern management area, broad trends in stock size are consistent among the five surveys conducted there. Biomass fluctuated without trend from 1963 to the early 1980s, but declined thereafter to near historic lows during the 1990's when landings reached their peak. Biomass indices increased from 2000 to 2004, but have generally decreased since then. Abundance indices in the north fluctuated without trend during 1963-1998 but spiked during 2000-2002, reflecting a strong 1999 year class.

General trends in stock size in the southern area are also consistent among surveys. Survey biomass and abundance indices were high during the mid-1960s, fluctuated around an intermediate level during the 1970s and mid-1980s, then declined to low levels since the late 1980s. Biomass indices increased slightly around 2002 but have returned to lower levels since then.

Size-based indices of abundance indicate relatively strong recruitment in the northern area during the 1990s and variable but stable recruitment in the south. Length distributions gradually truncated from the 1960s to1990, and the median size of monkfish in survey catches has remained fairly constant since the early 1990s.

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

Fishing mortality rates, recruitment and stock sizes were estimated using the SCALE statistical catch-at-length model. Estimated F in 2009 was 0.10 in the north and 0.07 in the south (0.05 combined areas). Estimated total biomass in 2009 was 66,062 mt in the north and 131,218 mt in the south (255,326 mt, combined areas). In the north, the strongest year classes were produced in 1997-1999; recruitment was generally below average in the 1980s, and has been about average since 2001. In the south, the strongest year classes were produced in 1992, 1997, and 2002; recruitment has been below average since 2004. Based on the combined-areas model, the strongest year classes were produced in 1997-1999 and recruitment has been below average since 2004.

Uncertainty in the estimates of stock size, recruitment and F stems from poorly known input data, including under-reported landings and unknown discards during the 1980s, and incomplete understanding of key biological parameters such as age and growth, longevity, natural mortality, sex ratios and stock structure, and the relatively short reference time frame (1980-2006) of the model. Further, the population models for all areas exhibit retrospective patterns that are strongest for the 2002-2006 terminal years and weaker for the 2007-2008 terminal years. The retrospective patterns are strongest for the northern area, weakest for the southern area, and intermediate for the model of combined areas.

SAW50 Editor's note: In view of the short time available for the review, the SARC50 panel declined to review the combined-areas model as it addressed a Research Recommendation rather than a Term of Reference, and because management is based on the two-areas model.

The SARC50 panel acknowledged the high degree of uncertainty in estimates from the SCALE model due to data limitations, poorly understood monkfish biology (growth, natural mortality, stock structure), and the strong retrospective pattern in the northern area.

5. 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 2007 NEFSC assessment recommended new reference points based on a revised yield-per-recruit analysis (using M=0.3) and on the results of the SCALE length-tuned model that incorporated multiple survey indices and catch data. The new reference biomass levels were based on long term trends in biomass from the SCALE model, and were adopted in Framework 5 (April 2008). The current assessment updates the SCALE model and estimates new reference points based on the methods adopted in NEFSC (2007a) and using the method applied in the New England groundfish stock complex based on projections of B_{max} at F_{max}. The BRPs all use output from the SCALE model, which is subject to high levels of uncertainty as discussed under TOR 4, therefore the BRPs are also highly uncertain.

The following table summarizes the estimates for each management area and combined areas. Adjusted refers to estimates adjusted for retrospective patterns.

Management Areas	Biomass BRPs in metric tons			
North	BRP	Basis	DPSWG 2007	SDWG 2010
	Fmax	YPR	0.31	0.43
	Bthreshold	Bloss 1980-2006	65,200	
	Bthreshold	Bloss 1980-2009		41,238
	Bthreshold	0.5*Bmax Projected		26,465
	Bthreshold	0.5*Bmax Proj Adjust		20,643
	Btarget	Bavg 1980-2006	92,200	62,371
	Btarget	Bavg 1980-2009		61,991
	Btarget	Bmax Projected		52,930
	Btarget	Bmax Proj Adjust		41,286
	MSY	Fmax Projected		10,745
South	BRP	Basis	DPSWG 2007	SDWG 2010
	Fmax	YPR	0.40	0.46
	Bthreshold	Bloss 1980-2006	96,400	
	Bthreshold	Bloss 1980-2009		99,181
	Bthreshold	0.5*Bmax Projected		37,245
	Bthreshold	0.5*Bmax Proj Adjust		28,461
	Btarget	Bavg 1980-2006	122,500	120,292
	Btarget	Bavg 1980-2009		121,313
	Btarget	Bmax Projected		74,490
	Btarget	Bmax Proj Adjust		56,922
	MSY	Fmax Projected		15,279
Combined	BRP	Basis	DPSWG 2007	SDWG 2010
	Fmax	YPR		0.37
	Bthreshold	Bloss 1980-2009		159,715
	Bthreshold	0.5*Bmax Projected		64,501
	Bthreshold	0.5*Bmax Proj Adjust		49,021
	Btarget	Bavg 1980-2009		208,190
	Btarget	Bmax Projected		129,002
	Btarget	Bmax Proj Adjust		98,041
	MSY	Fmax Projected		25,943

SAW50 Editor's note: The SARC50 panel recommended adoption of the biomass reference points based on "Bmax projected" for each management area. The word "adjust" in the table above refers to results that were adjusted for the retrospective pattern. Although the SARC50 panel did not recommend using the "adjusted" values directly, the panel was well aware and very concerned about the lack of model fit.

6. Evaluate stock status with respect to the existing BRPs, as well as with respect to updated or redefined BRPs (from TOR 5).

Estimates of total biomass for 2006 in both management areas (see table below) were greater than their respective biomass targets, therefore, based on those somewhat uncertain analyses, monkfish in both management areas were not overfished and overfishing was not occurring.

Estimates of total biomass for 2009 in both management areas and the combined area (see table below), were above $B_{threshold}$ and B_{target}, but with a smaller margin in the north than estimated in 2006. These estimates are subject to the same uncertainty as the assessment in 2006.

	Stock Biomass			F					
	North	South	N+S	North	South	N+S	Overfished	Overfishing	Bthreshold Basis
SCALE 2006	119,000	135,000	-	0.09	0.12		no	no	Bloss (1980-2006)
SCALE 2009	66,062	131,218	255,326	0.10	0.07	0.05	no	no	Bloss (1980-2009)

SAW50 Editor's note: The SARC50 panel acknowledged the high degree of uncertainty in estimates from the SCALE model due to data limitations, poorly understood monkfish biology (growth, natural mortality, stock structure), and the strong retrospective pattern in the northern area. This uncertainty affects not only the current estimates of biomass but the estimates of the BRPs as well.

7. Evaluate monkfish diet composition data and its implications for population level consumption by monkfish.

Diet composition, per capita consumption, total consumption, and the amount of prey removed by monkfish were calculated from basic monkfish food habits data. Based on recent energy budgets, the amount of food consumed by monkfish is 0.005-0.02% of all energy flows in the system, and monkfish account for 2-6% of the total consumption by all finfish in the ecosystem (1-4 % in the northern area, 2-8% in the southern area).

The total amount consumed and per capita consumption peaked in the early 1980s for both stocks, driven by larger fish. Monkfish consumption of mackerel and herring is potentially 20-50% of landings, about equal to landings for squids, and potentially greater than the landings of silver hake and skates. Monkfish is an important piscivore in the ecosystem.

8. 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 (through 2016). 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 to examine important sources of uncertainty in the assessment.
    b. Comment on which projections seem most realistic, taking into consideration uncertainties in the assessment.

c. Describe this stock's vulnerability to becoming overfished, and how this could affect the choice of ABC.

SCALE model results and AGEPRO projections were used to evaluate stock trends during 2011-2016 with $F=F_{threshold}$ and at proposed ACTs and ABCs assuming stochastic long-term recruitment. The projections indicate that the northern area is the most vulnerable to overfishing or becoming overfished during 2011-2016 if total catches approach the proposed ABC, while the southern area is the least vulnerable.

Projections for the northern area (NMA) are the most likely to be unrealistic, given the uncertainty of stock status due mainly to the relatively strong retrospective observed since 2002. The southern area (SMA) projections are the most likely to be realistic, given the moderate retrospective observed for that area. The combined area projections are intermediate with respect to the current management areas, as the relative scaling of the two populations is maintained when the areas are combined in one model.

SAW50 Editor's note: The SARC50 panel acknowledged the high degree of uncertainty in the projections due to uncertainty in the starting conditions (output from the SCALE model).

9. 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.

A list of 26 research recommendations generated since SAW 34 in 2001 was reviewed and results summarized where available. Of these, 14 had either been addressed or were considered no longer relevant. One new recommendation was added by the SDWG in 2010.

Introduction

Life History

Monkfish (*Lophius americanus*), also called goosefish, are distributed in the Northwest Atlantic from the Grand Banks and northern Gulf of St. Lawrence south to Cape Hatteras, North Carolina (Collette and Klein-Macphee 2002). Monkfish may be found from inshore areas to depths of at least 900 m (500 fathoms). Seasonal onshore-offshore migrations occur and appear to be related to spawning and possibly food availability (Collette and Klein-MacPhee 2002).

Monkfish rest partially buried on soft bottom substrates and attract prey using a modified first dorsal fin ray that resembles a fishing pole and lure. Monkfish are piscivorous and commonly eat prey as large as themselves. Despite the behavior of monkfish as a demersal 'sit-and-wait' predator, recent information from electronic tagging suggests seasonal off-bottom movements (Rountree et al. 2006). Growth is rapid at about 10 cm per year, and is similar for both sexes up to age 6 and lengths of around 60 cm (Richards et al. 2008). Few males are found older than age 7, but females can live to 12-14 years or older. Monkfish as large as 138 cm have been captured in NEFSC bottom trawl surveys.

Female monkfish begin to mature at age 4 and 50% of females are mature by age 4.7 (about 41 cm). Males mature at slightly younger ages and smaller sizes (50% maturity at age 4.2 or 37 cm (NEFSC 2002; Richards et al. 2008). Spawning takes place from spring through early autumn, progressing from south to north, with most spawning occurring during the spring and early summer. Females lay a buoyant mucoid egg raft or veil which can be as large as 12 m long and 1.5 m wide and only a few mm thick. The eggs are arranged in a single layer in the veil, and the larvae hatch after about 1-3 weeks, depending on water temperature. The larvae and juveniles spend several months in a pelagic phase before settling to a benthic existence at a size of about 8 cm (Collette and Klein-MacPhee 2002).

Stock Identification

The Fishery Management Plan defines two management areas for monkfish (northern and southern), divided roughly by a line bisecting Georges Bank (Figure A1). The two assessment and management areas for monkfish were defined based on differences in temporal patterns of recruitment (estimated from NEFSC surveys), perceived differences in growth patterns, and differences in the contribution of fishing gear types (mainly trawl, gill net, and dredge) to the landings.

Genetic studies suggest a homogeneous population of monkfish off the U.S. east coast (Chikarmane et al. 2000). Monkfish larvae are distributed over deep (< 300 m) offshore waters of the Mid-Atlantic Bight in March-April, and across the continental shelf (30 to 90 m) later in the year, but relatively few larvae have been sampled in the northern management area (Steimle et al. 1999). NEFSC surveys continue to indicate different recruitment patterns in the two management units in recent years.

The perceived differences in growth were based on studies about 10 years apart and under different stock conditions (Armstrong et al. 1992: Georges Bank to Mid-Atlantic Bight, 1982-1985; Hartley 1995: Gulf of Maine, 1992-1993). Age, growth, and maturity information from the NEFSC surveys and the 2001, 2004 and 2009 cooperative monkfish surveys indicated only minor differences in age, growth, and maturity between the areas (Richards et al., 2008; Johnson et al., 2008). The recent biological evidence (growth, maturity, and genetic information) suggests that use of a single stock hypothesis in the assessment might be appropriate. However, substantial differences in the fisheries exist, and current management maintains separate regulatory areas to accommodate these differences.

The southern deepwater extent of the range of American monkfish (*L. americanus*) overlaps with the northern extent of the range of blackfin monkfish (*L. gastrophysus*; Caruso 1983). These two species are morphologically similar, which may create a problem in identification of survey catches and landings from the southern extent of the range of monkfish. The potential for a problem however is believed to be small. The NEFSC closely examined winter and spring 2000 survey catches for the presence of blackfin monkfish and found none. The cooperative monkfish survey conducted in 2001 caught only eight blackfin monkfish of a total of 6,364 monkfish captured in the southern management area.

Fisheries Management

Commercial fisheries for monkfish occur year-round using gillnets, trawls and scallop dredges. No significant recreational fishery exists. The primary monkfish products are tails, livers and whole gutted fish. Peak fishing activity occurs during November through June, and value of the catch is highest in the fall due to the high quality of livers during this season.

U.S. fisheries for monkfish are managed in the Exclusive Economic Zone (EEZ) through a joint New England Fishery Management Council - Mid-Atlantic Fishery Management Council Monkfish Fishery Management Plan (FMP). The primary goals of the Monkfish FMP are to end and prevent overfishing and to optimize yield and economic benefits to various fishing sectors involved with the monkfish fisheries (NEFMC and MAFMC 1998; Haring and Maguire 2008).

Current regulatory measures vary with type of permit but include limited access, limitations on days at sea, mesh size restrictions, trip limits, minimum size limits and other measures (Tables A1 and A2).

Biological reference points for monkfish were established in the original Fishery Management Plan (FMP), but were revised according to the conclusions of SAW 34 (NEFSC 2002) and again by the Data Poor Stocks Working Group (DPSWG) in 2007 (NEFSC 2007a). The overfishing definition is F_{max}. Prior to 2007, $B_{threshold}$ was defined as one-half of the median of the 1965-1981 3-year average NEFSC autumn trawl survey catch (kg) per tow). After acceptance of an analytical assessment in 2007 (NEFSC 2007a), B_{target} was redefined as the average of total biomass for the model time period (1980-2006) and $B_{threshold}$ as the lowest observed value in the total biomass time series from which the stock has then increased (termed "B_{Loss}"). According to the earlier (survey index-based) reference points, monkfish were overfished and overfishing status could not be determined (NEFSC 2005); however, with adoption of the analytical assessment in 2007, monkfish status was no longer overfished and overfishing was not occurring.

2007 DPSWG Assessment

The DPSWG accepted a length-tuned analytical model (SCALE) for monkfish assessment and status determination, and adopted a value of M=0.3 (vs. M=0.2). However, the WG emphasized that the assessment was highly uncertain due to under-reported landings, unknown discards during the 1980s, incomplete understanding of key biological parameters such as age and growth, longevity, natural mortality and stock structure, the shorter reference time frame (1980-2006) than in previous assessments (1963-2006), and the relatively recent development of the assessment model. The WG concluded that uncertainties in historical catch data precluded application of long-term models that rely on episodes of depletion and recovery to estimate stock size.

2010 SAW 50 Assessment

The 2010 Southern Demersal Working Group (SDWG) updated the SCALE model to assess the status of monkfish using data through 2009. Further developments included examination of retrospective patterns in the SCALE estimates, and development of short-term stochastic age-based projections. Data from a cooperative monkfish survey conducted during winter/spring of 2009 were analyzed and included in the assessment model, along with data collected on the new NEFSC survey vessel, starting in spring 2009, which was adjusted using calibration coefficients developed for monkfish. Length frequency composition data from the 2009 cooperative survey were input into the final SCALE assessment model.

SAW50 Editor's note: The SARC50 panel discussed the relative merits of adjusting for retrospective patterns and decided against making a direct adjustment for the pattern in the current assessment.

TOR 1. Characterize the Commercial Catch including landings, effort, LPUE and discards. Describe the uncertainty in these sources of data.

Landings

Landings statistics for monkfish are sensitive to conversion from landed weight to live weight, because a substantial fraction of the landings occur as tails only (or other parts). The conversion of landed weight of tails to live weight of monkfish in the NEFSC weigh-out database is made by multiplying landed tail weight by a factor of 3.32. Recently concerns have been raised that monkfish landings reported as 'round' (no conversion) may actually be 'head-on, gutted', which has a conversion factor of 1.14, in which case live weight of landings would be underestimated. Assuming all landings classified as 'round' are actually 'head-on, gutted', the difference in live weight landings would be less than 0.8% on average since the 'round' category appeared in 1989. The working group concluded that this was not likely an important source of error in the assessment.

Early catch statistics are uncertain, because many of the monkfish caught were sold outside of the dealer system or used for personal consumption until the mid-1970s. For 1964 through 1989, there are two potential sources of landings information for monkfish; the NEFSC 'weigh-out' database, which consists of fish dealer reports of landings, and the 'general canvass' database, which contains landings data collected by NMFS port agents (for ports not included in the weigh-out system) or reported by states not included in the weigh-out system (Table A3). All landings of monkfish are reported in the general canvass data as 'unclassified tails.' Consequently, some landed weight attributable to livers or whole fish in the canvass data may be inappropriately converted to live weight. This is not an issue for 1964-1981 when only tails were recorded in both databases. For 1982-1989, the weigh-out database contains market category information which allows for improved conversions from landed to live weight. The two data sources produce the same trends in landings, with general canvass landings slightly greater than weigh-out landings. It is not known which of the two measures more accurately reflects landings, but the additional data sources suggest that the general canvass is most reliable for 1964-1981 landings, whereas the availability of market category details suggest that the weigh-out database is most reliable for 1982-1989.

Beginning in 1990, most of the extra sources of landings in the general canvass database were incorporated into the NEFSC weigh-out database. However, North Carolina reported landings of monkfish to the Southeast Fisheries Science Center and until 1997 these landings were not added to the NEFSC general canvass database. Since these landings most likely come from the southern management area, they have been added to the weigh-out data for the southern management area for 1977-1997 for the landings statistics used for stock assessment.

Beginning in July 1994, the NEFSC commercial landings data collection system was redesigned to consist of vessel trip reports (VTR) and dealer weigh-out records. The VTRs include area fished for each trip which is used to apportion dealer-reported landings to statistical areas. The northern management area includes statistical areas 511-515, 521-523 and 561; and the southern management area includes areas 525-526, 562, 537-543 and 611-636 (Figure A1). Each VTR trip should have a direct match in the dealer data base, but this is not always true. VTR records with no matching dealer landings were excluded, but dealer landings with no matching VTR were included in landings statistics, apportioning the unmatched landings to management area using proportions calculated from matched trips pooled over gear, state and quarter.

Total U.S. landings (live weight) remained at low levels until the middle 1970s, increasing less than 1,000 mt to around 6,000 mt in 1978 (Table A3, Figure A2). Annual landings remained stable at between 8,000 and 10,000 mt until the late 1980s. Landings increased from the late 1980s to over 20,000 mt per year 1992-2004, peaking at 28,500 mt in 1997. Landings have declined steadily since 2003, to 8,600 mt in 2009. By region, landings began to increase in the north in the mid-1970s, and began to increase in the south in the late

1970s. Most of the increase in landings during the late 1980s through mid-1990s was from the southern area. Historical under-reporting of landings shold be considered in the interpretation of this series.

Trawls, scallop dredges and gill nets are the primary gear types that land monkfish (Table A4, Figure A3). Trawls have contributed approximately half of the landings. Prior to 1994, gillnets contributed less than 10% of total landings, but landings from gillnets generally increased to account for >35% of the recent fishery, with an associated decrease in monkfish landings from the scallop dredge fishery.

Until the late 1990s, total landings were dominated by landings of monkfish tails. From 1964 to 1980 landings of tails rose from 19mt to 2,302mt, and peaked at 7,191mt in 1997 (Table A5). Landings of tails declined after 1997, but are still an important component of the landings. Landings of gutted whole fish have increased steadily since the early 1990s and are now the largest market category on a landed-weight basis. On a regional basis, more tails were landed from the northern area than the southern area prior to the late 1970s (Tables A6 and A7). From 1979 to 1989, landings of tails were about equal from both areas. In the 1990's, landings of tails from the south predominated, but since 2000, landings of tails have been greater in the north.

Beginning in 1982, several market categories were added to the system (Table A5). Tails were broken down into large (> 2.0 lbs), small (0.5 to 2.0 lbs), and unclassified categories and the liver market category was added. In 1989, unclassified round fish were added, in 1991 peewee tails (<0.5 lbs) and cheeks, in 1992 belly flaps, and in 1993 whole gutted fish were added. Monkfish livers have become a very valuable product. Landings of livers increased from 10mt in 1982 to an average of over 600mt during 1998 - 2000. During 1982-1994, ex-vessel prices for livers rose from an average of $0.97/lb to over $5.00/lb, with seasonal variations as high as $19.00/lb. Landings of unclassified round (whole) or gutted whole fish jumped in 1994 to 2,045mt and 1,454mt, respectively; landings of gutted fish continued to increase through 2003. The tonnage of peewee tails landed increased through 1995 to 364mt and then declined to 153mt in 1999 and 4mt in 2000 when the category was essentially eliminated by regulations.

Foreign Landings

Landings (live wt) from NAFO areas 5 and 6 by countries other than the US are shown in Table A3 and Figure A2. Reported landings were high but variable in the 1960s and 1970s with a peak in 1973 of 6,818mt. Landings were low but variable in the 1980s, declined in the early 1990s, and have generally been below 300mt in recent years.

Discard Estimates

Catch data from the fishery observer and VTR databases were used to investigate discarding frequencies and rates. The number of trips with monkfish discards available for analysis varied widely among management areas and gear types (Table A8). In the previous assessment (NEFSC 2007a), three methods were considered for the estimation of discards: 1) observed discard-per-kept-monkfish expanded to total discards using total monkfish landings; 2) observed discard-per-all-kept-catch expanded to total discards using total landings (Rago et al. 2005, Wigley et al. 2007); and 3) observed discard-per-days-absent expanded to total discards using total days-absent (Rago et al. 2005, Wigley et al. 2007). All three methods were done on a gear, half-year and management area basis. The effort-based method (#3) was considered inappropriate, because much of the monkfish is bycatch taken incidentally or targeted on a tow-by-tow basis rather than on a trip basis. Predicting discards using kept catch assumes a linear relationship between kept and discarded catch and no discarding when there is no catch (i.e., the linear relationship passes through the origin). Inspection of the relationship between observed monkfish discards and monkfish kept (method #1) and total catch (method #2) by gear and year indicated weak correlation in general, but the relationships between kept and discarded monkfish (method #1) for trawls and gillnets conformed to the statistical assumptions best (NEFSC 2007a). Therefore, discard estimates were based on discard-to-kept-monkfish for trawls and gillnets but were based on discard-per-all-kept-catch for shrimp trawls and dredges, which do not currently target monkfish. This method, (NEFSC 2007a) was continued in the current assessment.

Discards for 1980-1988 (before observer sampling) were estimated by applying average discard ratios by management area and gear type (trawl, shrimp trawl, gillnet, dredge) from 1989-1991 to landings for 1980-1988. If insufficient samples were available, additional years of observer data were included until a sample size (number of trips) of at least 20 was reached. The resulting time periods entering the 1980-1988 discard ratio estimates were as follows:

Area	**Shrimp Trawls**	**Trawls**	**Gillnets**	**Dredges**
North				
Years included	1989-1991	1989-1991	1989-1991	1992-1997
Number of trips	124	180	852	20
South				
Years included	n/a	1989-1991	1991-1992	1991-1993
Number of trips		231	103	30

The overall annual discard ratio (discarded monk / kept monk) decreased in the northern area, from an average of 16% of total catch in the 1980s to an annual average of 8% during 2002-2006, but was slightly higher on average (~10%) during 2007-2009 (Table A9, Figure A4). The proportion of discards in the southern area generally increased since 1980, with an annual average of 23% during 2002-2006, but a slight decrease during 2007-2009 (to ~14%) (Table A9, Figure A5). Gill nets consistently have had the lowest discard ratios. Some of the trends in discarding may reflect imposition of size limits starting in 2000 and decreased trip limits in the south starting in 2002. The DPSWG (NEFSC 2007a) noted a potential bias in discard estimates due to increased observer sampling in the multispecies groundfish fishery. Monkfish discard rates may differ between the directed monkfish fisheries and bycatch fisheries. The most frequent discard reasons were that fish were too small for regulations or the market. The estimates of total catch for 1980-2009 are shown in Figure A6 and Table A10.

Size and Age Composition of U.S. Catch

Tail lengths were converted to total lengths using relations developed by Almeida et. al.(1995). As in NEFSC (2007a), length composition of landings and discard were estimated from fishery observer samples by management area, year, gear-type (trawls, dredges and gillnets) and catch disposition (kept or discarded; Figures A7 – A13). Observer sampling data for December 2009 were not yet available, so the sample set for 2009 is incomplete. Landings in unknown gear categories were allocated proportionately to the 3 major gear types before assigning lengths. The stratification used for assigning lengths within area and gear type for

2007-2009 is shown in Table A11. Discards were generally between 20-40 cm, while kept fish were greater than 40 cm; however, there were some exceptions to this pattern in recent years.

Age composition of the catch was not estimated for 2007-2009 due to uncertainties in the aging method that were highlighted during the previous assessment (NEFSC 2007a) and because the operational model for monkfish (SCALE) is length-based.

Effort and CPUE

Evaluating trends in effort or catch rates in the monkfish fishery is difficult for several reasons. Much of the catch is taken in multi-species fisheries, and defining targeted monkfish trips is difficult. There have been programmatic changes in data collection from port interviews (1980-1993) to logbooks (1994-2009), and comparison of effort statistics among programs is difficult. Catch rates may not reflect patterns of abundance, because they have been affected by regulatory changes (e.g., 1994 closed areas, 2000 trip limits, 2006 reductions in trip limits). However, evaluation of catch rates (kept + discarded) from observed tows that caught monkfish in the NFMA showed a peak in 2003 in the trawl fishery and in 2005 in the gillnet fishery, probably reflecting the strong 1999 yearclass. CPUE has since declined in the north (Figure A14). In the SFMA, CPUE indices have been relatively flat in the trawl and dredge fisheries for the past decade; however, gillnet indices increased steadily during 1999-2004, and have since held steady or declined slightly (Figure A14).

TOR 2. Report results of 2009 cooperative monkfish survey and describe sources of uncertainty in the data and results.

Methods - 2009 Monkfish Cooperative Survey

Survey Design and Protocols

The survey used a stratified random design with allocation proportional to stratum area (n=175 planned tows). An additional 35 tows (~17% of the total) were randomly selected in strata selected by industry members. In previous monkfish cooperative surveys (2001, 2004), sampling effort was allocated according to fishing effort patterns; however, this led to problems with interpretation of the 2004 survey which experienced extensive weather delays. Allocation of sampling effort using stratum area in 2009 addressed this concern and provided a basis for more direct comparison with the NEFSC 2009 spring survey conducted on the *FSV Henry Bigelow*.

Standard operating procedures were used on each vessel, including 30 minute tows (from time winches locked to time winches re-engaged for haul back) at 2.5 knots designated speed. Tow paths followed the depth contour. If pre-determined locations could not be sampled (due to fixed gear, bad bottom, etc.), stations were relocated as close as possible at a similar depth. A standard scope ratio of 2* tow depth plus 25 fathoms of wire was used for all nets.

The location of successful survey tows is shown in Figure A15. All survey tows were completed during Feb. 10 – Apr 26, 2010.

Ships and Gear

Two monkfish trawl vessels were contracted for the survey, both out of New Bedford. The *FV Endurance* (“ER”, 107 ft. stern trawler) sampled primarily the northern monkfish management area (U.S. waters of the Gulf of Maine and northern portion of Georges Bank) using two nets, one fitted with a cookie sweep for soft bottom, and one with roller gear for hard bottom (Figures A16 and A17). Both nets had a tickler chain (38 m of 3/8” chain). The *FV Mary*

K ("MK", 96 ft. stern trawler) sampled in the southern management area (southern portion of Georges Bank and middle Atlantic Bight) using a net with a cookie sweep (Figure A18).

Sensor packages (Furuno on *Endurance*, NorthStar on *Mary K*) collected streams of data during each tow which included course over ground, speed over ground, GPS location (latitude, longitude), wingspread, bottom contact, depth and temperature. All types of data were not successfully collected for each tow. The number of tows with each type of sensor data is shown in Table A12 for each net type. Due to difficulties with obtaining wingspread measurements on the *Mary K* net, a set of dedicated mensuration tows were conducted to develop depth-wingspread relationships for the *Mary K*.

Analysis

Monkfish population estimates (biomass, numbers) were developed by estimating area swept during sampling in each stratum, converting this to monkfish density (kg, number caught per area swept), multiplying density by stratum area for each stratum, and summing over strata to derive total biomass and population size of monkfish in the two monkfish management areas. Population estimates were made using winch lock and winch re-engage to define tow duration ("nominal tow") or using sensor data to define tow duration ("sensor tow"). Nominal and sensor tow population estimates were generated under different assumptions of net capture efficiency.

Area Swept Population Estimates

Area swept by each tow was calculated as

$$AS = TDis * WS$$

where

$$TDis = TDur * \overline{SOG}$$

and

AS = area swept (nmi^2)
$TDis$ = distance covered by each tow in nmi
WS = wing spread in nmi
$TDur$ = tow duration (nominal or sensor)
SOG = speed over ground during tow

To estimate population biomass and number, we calculated monkfish densities in each stratum as the sum of the numbers caught divided by the sum of the area swept. Biomass in each stratum was estimated as the product of number of fish and mean weight of fish in the stratum. Biomass and numbers were summed over strata to arrive at minimum biomass and population size. Biomass and population size were also estimated under two assumptions regarding net efficiencies.

$$N = \sum_h n_h$$

$$B = \sum_h n_h * \overline{w}_h$$

where

$$n_h = \left(\sum (n_i / c_j) / \sum a_i\right) * A_h$$

and

N= population size
B= biomass
n_h= number in stratum h
$\overline{w}_h$= mean weight in stratum
i=tow number
c_j=efficiency of net j (proportion retained)
a_i=area swept during tow i
A_h=total area of stratum h

We used tows that had good quality sensor data to develop estimates of sensor tow data from nominal tow data, as follows:

To develop wingspread estimates for MK cookie, we applied a regression of wingspread against tow depth (Figure A19) developed from the mensuration experiments. Bottom contact readings were used to define the start of the tow, and winch re-engage (nominal stop time) was used to define the end of the tow; this generally coincided with tow end defined by bottom contact indicators because of the use of a separate winch engine on the Mary K. The deepest station for which we had wingspread measurements was 271 m. Approximately 13 % of stations were deeper than this (max. 480 m). Therefore we assumed a wingspread at 400 m equal to the average for tows greater than 200 m (n=4); this caused the predicted wingspread to decline at greater depths as would be expected (Weinberg and Kotwicki 2008).

A similar approach was used for ER tows that had no wingspread readings, except that bottom contact data were used to define the end of the tow as well as the beginning. For ER cookie, there were only 4 tows with both bottom contact and wingspread measurements, therefore we used wingspread during the nominal tow time to develop the depth-wingspread relationship (Figure A20). We used senor tow durations for the ER roller net, however, the relationship with depth was very similar to that derived from nominal tow times (Figure A20).

To develop tow duration for tows with no bottom contact sensor data, we adjusted tow duration according to relationships between depth and the relative difference between nominal and senor-defined tow durations (Figure A21). This relationship was relatively tight for the MK cookie sweep (r2=0.80), but much weaker and of smaller magnitude for the ER roller gear. Too few tows were available for the ER cookie sweep to estimate a relationship between nominal and sensor tow durations, so we applied the relationship for ER roller to ER cookie. The reason for the negative slope for MK cookie was that most sensor start times were after nominal start times, but sensor end times coincided with nominal end times, so sensor tows were generally shorter than nominal tows. For the ER, sensor start and end were both generally after nominal start and end (Appendix A2).

The following table summarizes the corrections applied to derive sensor tow durations and wingspread estimates for tows lacking sensor data.

Net	Wingspread predicted from	Sensor tow duration predicted from
MK Cookie	depth-wspread relation - MK cookie sensor data	depth-% difference relation - MK cookie sensor data
ER Cookie	depth-wspread relation - ER cookie nominal data	depth-% difference relation - ER roller sensor data
ER Roller	depth-wspread relation - ER roller sensor data	depth-% difference relation - ER roller sensor data

An additional adjustment was made to average tow speed for tows with no bottom contact data using relationships between nominal tow speed and tow speed during the sensor-defined tow period (Figure A22). This resulted in slower average tow speed during sensor-defined tows on the Endurance because speed dropped abruptly after winch lock, but bottom contact continued for a short period, thus bringing down the average speed for sensor tows. This pattern was not seen on the *Mary K*, which has an independent winch engine, thus nominal and sensor tow end occurred at the same time.

Net Efficiency

Depletion experiments were used to estimate efficiency of the 3 nets in capturing monkfish. The experiments were done by repeatedly towing over the same tow path, always in the same direction, until the monkfish catch approached zero. Eight depletion experiments were completed (4 for the *Mary K* cookie sweep, and 2 for each of the Endurance nets). The method used for data analysis is described in Rago et al. (2006). The location of the depletion experiments is shown in Figure A23.

Results

A total of 204 survey stations were successfully completed, and an additional 91 tows were made for depletion experiments and mensuration studies (Table A13). Figures A24-A26 show nominal catch rates (kg per tow, # per tow) for the survey stations. Figure A27 shows the depth distribution of sampling locations for survey tows.

Net Efficiency

The efficiency estimates derived from the depletion experiments are summarized in Table 14. For detailed description of the net efficiency analysis and results, see Appendix A1.
For three of the efficiency experiments, the estimation procedure was not successful (Appendix A.1) and the results were excluded from further analysis. Net efficiencies used to estimate population biomass and numbers were the average of experiments 1, 3, and 4 for the *Mary K* cookie sweep and experiments 5 and 7 for the *Endurance* cookie sweep. For the *Endurance* roller sweep, there were no successful experiments, so the results of experiments conducted during the 2001 cooperative survey comparing roller and cookie sweeps were used. These experiments found that the roller was 92% as efficient as the cookie sweep. We therefore used the average efficiency of the *Endurance* cookie sweep 0.249 * 0.92 = 0.229 as the efficiency of the 2009 net with roller gear. The efficiency estimates, called 'intermediate' in this report to correspond with earlier cooperative survey reports which additionally reported estimates based on a range (low and high) of efficiency estimates.

Population Estimates

Swept-area population point estimates are shown in Table A15 and Figure A29, and were on the order of 114-116 thousand mt (60-62 million fish) for the entire survey area assuming intermediate net efficiencies. Minimum estimates showed approximately 30% of the stock in the northern management area (which contains 42% of the survey area).

Differences between estimates derived from sensor tow durations were slightly higher (~8 %) than nominal estimates in the north and slightly lower (~6%) in the south (Table A15). In the north, the differences can be attributed to slower average speeds and shorter tow durations for sensor tows, which reduced the estimate of area swept and increased the estimate of density (Figure A28). In the south, adjustments to average speed and tow duration essentially cancelled each other, resulting in little difference in tow distance between nominal and senor estimates. Sensor-derived monkfish densities were lower than nominal densities because wingspread estimates were higher in sensor tows, thus increasing area swept and decreasing the density estimate (Figure A28).

The point estimates of area swept population size and biomass for 2009 are lower than those estimated from the 2001 survey (Table A15, Figure A29), with the exception of the south for efficiency-corrected and sensor-based estimates. (The 2004 survey is difficult to interpret due to extensive delays in completing the survey due to weather, but the 2001 survey is more comparable to the 2009 survey in that the two management areas were sampled simultaneously and the survey completed during Feb-April). The lower estimates for 2009 are driven by consistently lower densities (nominal # per nominal nmi swept) in the NFMA (Figure A30), which could be related to earlier start dates in that area than in 2001 (Table A15). In the south, there is no consistent difference between stratum densities in 2001 and 2009; however, the overall density is slightly lower in 2009 (Figure A31). Densities in the mid-Atlantic Bight (Hudson Canyon area and south) are higher in the deep water strata (greater than 200 fa) in 2009 than in the previous two surveys, suggesting that more monkfish may have been in deep water at the time of the 2009 cooperative survey.

In addition to density differences among years, the proportion of zero tows is higher in 2009 than in the earlier surveys (Table A15). This may be due in part to the change in allocation of sampling effort in 2009 (Figure A32).

The coefficient of variation developed by bootstrapping for the 2009 area swept population estimates was very low (Figure A33). This likely underestimates the true variance because of the relatively small number of tows in each stratum (and thus a small number to be drawn from in the bootstrapping).

Further bootstrapping analyses were used to compute the sampling distribution of biomass estimates in each management area from the 2001, 2004 and 2009 cooperative surveys using each of the valid depletion experiments within each year. Average monkfish density by management area was estimated from 1000 bootstrap samples. The distribution of efficiency estimates for each experiment was developed from 1000 bootstrap samples of the 95% confidence interval for the mean efficiency for each experiment. Each bootstrapped realization of density was divided by the corresponding bootstrapped efficiency estimate to develop 1000 estimates of population number, from which the mean and confidence intervals for each year, management area and experiment were derived. The estimated population numbers were converted to biomass using the mean fish weight for each year and management area. The resulting estimates are shown in Table A16.

Length, Age, Maturity

Expanded length frequencies from the cooperative survey (Figure A34) suggest a unimodal distribution in the north with the mode at around 35cm, and a bimodal distribution in the south with modes around 33 and 57 cm.

Samples were collected for aging studies but were not processed for this assessment due to uncertainty concerning validity of the aging method (NEFSC 2007a). However, a small number (n=25) of monkfish $\geq$80 cm were aged using the vertebral method for comparison with earlier samples (Figure A35).

Length-weight relationships for males and females from each management area are shown in Figure A36 and the parameters are listed in Table A17 along with parameters estimated from earlier studies. Maturation ogives are shown in Figure A37 and the parameters listed in Table A18 with estimates from earlier studies.

Comparison with NEFSC 2009 Spring Survey

The NEFSC spring survey was conducted during March 4 – May 8, 2010, generally proceeding from south to north. The spatial distribution of catches in the NEFSC survey was similar to catches from the cooperative surveys (Figure A38). Length frequencies from the NEFSC survey (Figure A39) reflect the gear's greater retention of smaller monkfish and lower overall catch rates (NEFSC total number of monkfish caught = 638, cooperative survey = 3,050). However, nominal minimum area swept estimates of biomass and population size were very similar for the northern area from the two surveys (Table A19). In the south, the estimates from the cooperative survey were approximately double those from the NEFSC survey for both biomass and population numbers.

Finding differences between results from the two surveys is not surprising because a number of operational characteristics differ. The NEFSC survey net has a codend liner with 1" mesh, while the cooperative survey nets used 6" mesh in the codend with no liner, thus the NEFSC survey captures smaller fish. The average tow speed was 3.1 kt during 20 minute tows (NEFSC) vs. 2.6 kt during 30-minute tows (Coop). Differences in net efficiency likely result from differences in the configuration of the net sweeps. In particular, the NEFSC survey net used roller gear for all tows whereas the cooperative survey net in the south used a cookie sweep which would be expected to tend bottom more closely and thus capture a higher proportion of the monkfish encountered. This may be important in the difference between surveys in estimates in the south. Finally, the cooperative survey sampled the southern Mid-Atlantic Bight in February, when monkfish are present across the shelf, while the Bigelow started a month later when monkfish have begun moving out of that area (Figure A40).

TOR 3. Characterize other survey data that are being used in the assessment (e.g., regional indices of abundance, recruitment, length data, state surveys). Describe the uncertainty in these sources of data.

Additional resource surveys used in the assessment include 2001 and 2004 cooperative monkfish surveys, NEFSC winter, spring and autumn offshore surveys, NEFSC scallop surveys (SFMA only), Northern Shrimp Technical Committee (NSTC) shrimp surveys (NFMA only), and ME/NH inshore surveys.

The NEFSC survey strata used to define the northern and southern management areas are:

Survey	Northern Area	Southern Area
NEFSC Offshore bottom trawl	20-30, 34-40	1-19, 61-76
NSTC Shrimp	1,3,5-8	
Shellfish		6,7,10,11,14,15,18,19,22-31,33-35,46,47,55,58-

NEFSC spring and autumn bottom trawl survey indices were standardized to adjust for statistically significant effects of trawl type (Sissenwine and Bowman 1977) on catch rates. The trawl conversion coefficients apply only to the spring survey during 1973-1981.

NEFSC indices derived from surveys on the FSV Henry Bigelow (starting spring 2009) were adjusted using calibration coefficients estimated during experimental work (Miller et al. 2009). The FSV *Henry B. Bigelow,* which became the main platform for NEFSC research surveys in spring 2009, has significantly different size, towing power, and fishing gear characteristics than the previous survey platform (*Albatross IV)*, resulting in different fishing power and catchability for most species. Calibration experiments to estimate these differences were conducted during 2008 (Brown 2009, NEFSC 2007b), and were peer reviewed by a Panel of three non-NMFS scientists during the summer of 2009 (Anonymous 2009). The objective was to develop specific protocols for guidance in the selection and use of appropriate estimators based on the amount of data available and the relative performance of two candidate estimators. The Panel developed general guidance on which estimator to use given sample sizes for each species. Following these guidelines, monkfish catches were converted using a simple ratio estimator without a seasonal (spring vs. fall) correction. The coefficients for monkfish were 7.1295 for numbers and 8.0618 for weight (kg) (Anonymous 2009; Miller et al. 2009).

Geographic distributions of survey catches are shown in Figures A40 to A42.

Northern Area

Indices from NEFSC autumn research trawl surveys indicate that biomass fluctuated without trend between 1963 and 1975, appears to have increased briefly in the late 1970's, but declined thereafter to near historic lows during the 1990's (Table A20, Figures A43 – A44). From 2000 to 2003, the index was greater than 2 kg/tow, but decreased to less than 1 kg/tow by 2008. Indices from the NEFSC spring research trawl surveys reflect similar trends of relatively high biomass levels in the mid 1970s (but with possible declines in the late 1970s), a declining trend from the early 1980s to the lowest values in the time series in 1998 an increase to relatively high biomass from 2001 to 2005, and somewhat lower levels since then (Table A21, Figures A43 and A45).

Abundance indices declined during the early 1960s, and then fluctuated without trend until the late 1980s. Abundance increased steadily from the late 1980s to a peak in 1994, declined during the late 1990s, and then peaked in 2000, reflecting a relatively strong 1999 yearclass. Abundance has declined steadily since 2000, but remains high relative to the earlier part of the time series.

Length distributions have become increasingly runcated over time (Figure A48). By 1990, fish greater than 60 cm long were uncommon in length frequency distributions. The minimum, median and maximum lengths in the trawl surveys declined steadily from the early 1980s until around 2000, when they began to increase again (Figure A49). Several modes potentially representing strong yearclasses have appeared consistently in survey distributions in recent years (Figures A48, A50).

Abundance indices were estimated for monkfish of lengths corresponding to ages 1 and 2 to help identify potential recruitment patterns (Figure A51). To the extent that these indices reflect recruitment, recruitment in the northern area has increased in the past decade. Relatively strong yearclasses were produced in 1993 and 1999. Survey abundance at age data (available since the mid 1990s) corroborates the suggestion of relatively strong 1993 and 1999 yearclasses in the northern area. Survey age data are available for 1993-2006 from the autumn trawl survey and for 1995-2006 for the spring trawl survey (NEFSC 2007a). Within the range of ages observed in the surveys, growth is essentially linear and there are no obvious differences with gender or management area. Other surveys which catch monkfish in the northern area include the ASMFC shrimp survey, the Massachusetts Division of Marine Fisheries fall and spring surveys, and ME/NH inshore surveys. These surveys sample only a portion of the stock area and may be affected by inconsistent coverage over time.

The shrimp survey samples the western Gulf of Maine during summer and caught more monkfish than the spring or fall surveys prior to 2009 (when the FSV Bigelow survey series began) (Table A22, Figures A43 and A46). Patterns of abundance and biomass have been relatively consistent among the spring, fall and shrimp surveys (NEFSC 2007a). The Massachusetts surveys catch few monkfish and were not considered to reflect patterns of abundance for the entire management area; therefore are not reported in the assessment (NEFSC 2007a). ME/NH inshore surveys began in 2000 and are conducted in spring and fall (Figure A47). Indices show similar trends to those from NEFSC and shrimp surveys (Table A23, Figure A43 and A.46).

Southern Area

Biomass indices from the NEFSC autumn research survey were high during the mid-1960s, fluctuated around an intermediate level during the 1970s-mid 1980s, then declined to consistently low levels since the late 1980s (Table A24, Figures A52 and A53). The biomass index increased slightly above the existing biomass threshold in 2001 and has been relatively stable, or declining slightly since then. NEFSC spring surveys reflect similar trends as the autumn series: biomass remained fairly high during the mid 1970s - early 1980s, but fluctuated around lower levels thereafter (Table A25, Figures A52 and A54). A spike in biomass was observed in 2003, but subsequent indices have returned to lower values. Biomass and abundance indices based on the NEFSC winter flatfish survey (conducted during 1992-2007) fluctuated without trend (Table A26, Figures A52 and A55). Although the winter survey series had a short duration, the gear used in the winter survey was more effective for capturing monkfish than the gear used in autumn or spring surveys. Abundance indices based on the NEFSC sea scallop survey show an increasing trend during 1984-1994 followed by a rapid decline from 1994-1998 and fluctuations around a relatively level during 2006-200 (Table A27, Figure A56).

Inconsistent geographic coverage should be considered in the interpretation of southern survey indices. For example the fall survey did not sample southern strata until 1967. The winter survey sampled Georges Bank inconsistently and did not sample deep strata before 1998. The scallop survey does not currently sample the entire southern management area.

Abundance (numbers per tow) shows trends similar to biomass, with a spike in 1972, fluctuations around a relatively low level since the mid-1970s, a slight increase in 2002 and 2003 followed by a return to lower levels. Length distributions from the southern area showed increasing truncation over time, but the size distribution appears to have stabilized in recent years (Figure A57). Maximum lengths declined by approximately 20 cm or more over the time series (Figure A58). As in the northern area, fish greater than 60 cm have been rare since the 1980s, especially when compared to the 1960s. Any recent strong recruitment does not appear to survive long enough to contribute substantially to increased stock biomass. Survey age data are available for 1993-2006 from the autumn trawl survey, 1995-2006 for the spring trawl survey and 1997-2007 for the winter trawl survey (NEFSC 2007a). Age samples collected since the 2006 survey have not been processed due to uncertainties regarding validity of the aging method (NEFSC 2007a).

Combined Management Areas

Survey indices for combined management areas for spring and fall are shown in Table A28 and A29, and Figures A59 – A61. Length composition trends are shown in Figures A62-A63.

TOR 4. Estimate annual fishing mortality, recruitment and stock biomass (both total and spawning stock) for the time series, and characterize the uncertainty of those estimates.

Several candidate modeling approaches were investigated by the Data Poort Stocks Working Group (NEFSC 2007a), but the only one considered suitable was a relatively new approach called SCALE (for Statistical Catch-At-Length Analysis). Results from this model were used in 2007 to estimate fishing mortality, recruitment and stock biomass and to redefine reference points. The SCALE model was updated and serves as the primary basis for the current assessment.

Monkfish SCALE Model

Introduction

Incomplete or lacking age-specific catch data and survey indices often limit the application of a full age-structured assessment (e.g. Virtual Population Analysis and many forward projecting age-structured models). Stock assessments often rely on the simpler size/age aggregated models (e.g. surplus production models) when age-specific information is lacking. However these models may not utilize all of the available information for a stock assessment. Knowledge of a species growth and lifespan, along with total catch data, size composition of the removals, recruitment indices and indices on numbers and size composition of the recruited fish in a survey can provide insights on population status using a simple model framework.

The Statistical Catch At Length (SCALE) model, is a forward projecting age-structured model tuned with total catch (mt), catch at length or proportional catch at length, recruitment at a specified age (usually estimated from first length mode in the survey), survey indices of abundance of the larger/older fish (usually adult fish) and the survey length frequency distributions. The SCALE model was developed in the AD model builder framework. The model parameter estimates are fishing mortality and recruitment in each year, fishing mortality to produce the initial population (Fstart), logistic selectivity parameters for each year or blocks of years and Qs for each survey index.

The SCALE model was developed as an age-structured model that does not rely on age-specific information on a yearly basis. The model is designed to fit length information, abundance indices, and recruitment at age which can be estimated by using survey length slicing. However the model does require an accurate representation of the average overall growth of the population which is input to the model as mean lengths at age. Growth can be modeled as sex-specific growth and natural mortality or growth and natural mortality can be modeled with the sexes combined. The SCALE model will allow for missing data.

Model Configuration

The SCALE model assumes growth follows the mean input length at age with predetermined input error in length at age. Therefore a growth model or estimates of the average mean length at age is essential for reliable results. The model assumes static growth and therefore population mean length/weight at age are assumed constant over time.

The SCALE model estimates logistic parameters for a flattop selectivity curve at length in each time block specified by the user for the calculation of population and catch age-length matrices or the user can input fixed logistic selectivity parameters. Presently the SCALE model cannot accommodate a dome shaped selectivity pattern.

The SCALE model computes an initial age-length population matrix in year one of the model as follows. First the estimated populations numbers at age starting with age-1 recruitment are normally distributed at 1 cm length intervals using mean length at age with the assumed standard deviation. Next the initial population numbers at age are calculated from the previous age at length abundance using the survival equation. An estimated fishing mortality (Fstart) is also used to produce the initial population. This F can be thought of as the average fishing mortality that occurred before the first year in the model. Now the process repeats itself with the total estimated abundance at age being redistributed according to the mean length at age and standard deviation in the next age (age+1).

This two step process is used to incorporate the effects of length specific selectivities and fishing mortality. The initial population length and age distribution is constructed by assuming population equilibrium with an initial value of F, called F_{start}. Length specific mortality is estimated as a two step process in which the population is first decremented for the length specific effects of mortality as follows:

$$N^*_{a,len,y_1} = N_{a-1,len,y_1} e^{-\left(PR_{len}F_{start}+M\right)}$$

In the second step, the total population of survivors is then redistributed over the lengths at age *a* by assuming that the proportions of numbers at length at age *a* follow a normal distribution with a mean length derived from the input growth curve (mean lengths at age).

$$N_{a,len,y_1} = \pi_{len,a} \sum_{len=0}^{L_\infty} N^*_{a,len,y_1}$$

where

$$\pi_{len,a} = \Phi\left(len+1 \mid \mu_a, \sigma_a^2\right) - \Phi\left(len \mid \mu_a, \sigma_a^2\right)$$

where

$$\mu_a = L_\infty \left(1 - e^{-K(a-t_0)}\right)$$

Mean lengths at age can be calculated from a von Bertalanffy model from a prior study as shown in the equation above or mean lengths at age can be calculated directly from an age-length key. Variation in length at age a = σ_s^2 can often be approximated empirically from the growth study used for the estimation of mean lengths at age. If large differences in growth exist between the sexes then growth can be input as sex-specific growth with sex-specific natural mortality. However catch and survey data are still fitted with sexes combined.

This SCALE model formulation does not explicitly track the dynamics of length groups across age because the consequences of differential survival at length at age a do not alter the mean length of fish at age a+1. However, it does realistically account for the variations in age-specific partial recruitment patterns by incorporating the expected distribution of lengths at age.

In the next step the population numbers at age and length for years after the calculation of the initial population use the previous age and year for the estimate of abundance. Here the calculations are done on a cohort basis. As in the previous initial population survival equation, the partial recruitment is estimated on a length vector.

$$N^*_{a,len,y} = N_{a-1,len,y-1} e^{-\left(PR_{len} F_{y-1} + M\right)}$$

second stage

$$N_{a,len,y} = \pi_{len,a} \sum_{len=0}^{L_\infty} N^*_{a,len,y}$$

Constant M is assumed along with an estimated length-weight relationship to convert estimated catch in numbers to catch in weight. The standard Baranov=s catch equation is used to remove the catch from the population in estimating fishing mortality.

$$C_{y,a,len} = \frac{N_{y,a,len} F_y PR_{len} \left(1 - e^{-\left(F_y PR_{len} + M\right)}\right)}{(F_y \;\; PR_{len}) + M}$$

Catch is converted to yield by assuming a time invariant average weight at length.

$$Y_{y,a,len} = C_{y,a,len} W_{len}$$

The SCALE model results in the calculation of population and catch age-length matrices for the starting population and then for each year thereafter. The model is programmed to estimate recruitment in year 1 and estimate variation in recruitment relative to recruitment in year 1 for each year thereafter. Estimated recruitment in year one can be thought of as the estimated average long term recruitment in the population since it produces the initial population. The residual sum of squares of the variation in recruitment $\sum(\mathrm{Vrec})^2$ is then used as a component of the total objective function. The weight on the recruitment variation component of the objective function (Vrec) can be used to penalize the model for estimating large changes in recruitment relative to estimated recruitment in year one.

The model requires an age-1 recruitment index for tuning or the user can assume relatively constant recruitment over time by using a high weight on Vrec. Usually there is little overlap in ages at length for fish that are one and/or two years of age in a survey of abundance. The first mode in a survey can generally index age-1 recruitment using length slicing. In addition numbers and the length frequency of the larger fish (adult fish) in a survey where overlap in ages at a particular length occurs can be used for tuning population abundance. The model tunes to the catch and survey length frequency data using a multinomial distribution. The user specifies the minimum size (cm) for the model to fit. Different minimum sizes can be fit for the catch and survey data length frequencies.

The number of parameters estimated is equal to the number of years in estimating F and recruitment plus one for the F to produce the initial population (Fstart), logistic selectivity parameters for each year or blocks of years, and for each survey Q. The total likelihood function to be minimized is made up of likelihood components comprised of fits to the catch, catch length frequencies, the recruitment variation penalty, each recruitment index, each adult index, and adult survey length frequencies:

$$\mathrm{L}_{\mathrm{catch}} = \sum_{years}\left(l\,\mathrm{n}(Y_{\mathrm{obs,y}} + 1) - \ln\left(\sum_{a}\sum_{len} \mathrm{Y}_{\mathrm{pred,len,a,y}} + 1 \right)\right)^2$$

$$L_{catch\_lf} = -N_{eff} \sum_{y} \left(\sum_{inlen}^{L_\infty} \left(\left(C_{y,len} + 1\right) \ln\left(1 + \sum_{a} C_{pred,y,a,len} \right) - \ln\left(C_{y,len} + 1\right) \right) \right)$$

$$\mathrm{L}_{\mathrm{vrec}} = \sum_{y=2}^{Nyears} \left(Vrec_y\right)^2 = \sum_{y=2}^{Nyears} \left(R_1 - R_y\right)^2$$

$$\sum L_{rec} = \sum_{i=1}^{Nrec} \left[\sum_{y}^{Nyears} \left(\ln\left(I_{rec_i,inage_i,y}\right) - \ln\left(\sum_{len}^{L_\infty} N_{y,inage_i,len} * q_{rec\,i} \right) \right)^2 \right]$$

$$\sum L_{adult} = \sum_{i=1}^{Nadult} \left[\sum_{y}^{Nyears} \left(\ln\left(I_{adult_i,inlen+_i,y}\right) - \left(\sum_{a} \sum_{inlen_i}^{L_\infty} \ln\left(N_{pred,y,a,len} * q_{adult\,i}\right) \right) \right)^2 \right]$$

$$\sum L_{lf} = \sum_{i=1}^{Nlf} \left[-N_{eff} \sum_{y} \left(\sum_{inlen_i}^{L_\infty} \left(\left(I_{lf_i,y,len} + 1\right) \ln\left(1 + \sum_{a} N_{pred,y,a,len} \right) - \ln\left(I_{lf_i,y,len} + 1\right) \right) \right) \right]$$

In equation L_{catch_lf} calculation of the sum of length is made from the user input specified catch length to the maximum length for fitting the catch. Input user specified fits are indicated with the prefix "in" in the equations. LF indicates fits to length frequencies. In equation L_{rec} the input specified recruitment age and in L_{adult} and L_{lf} the input survey specified lengths up to the maximum length is used in the calculation.

$$Obj\ fcn = \sum_{i=1}^{N} \lambda_i L_i$$

Lambdas represent the weights to be set by the user for each likelihood component in the total objective function.

Monkfish SCALE Model Configuration and Results

No new information on growth and natural mortality exists for this assessment. Growth, variation in mean length at age, and natural mortality (M=0.3) did not change from the assumptions used in the 2007 assessment (NEFSC 2007a). Mean and variance in monkfish length at age were estimated from industry-based surveys (2001 and 2004), and NEFSC winter, spring, and fall surveys for management areas combined (Table A30). No significant differences in growth were observed between the management units in the 2001 and 2004 cooperative surveys. The standard deviation for age 1 was 2.9; for older ages a standard deviation of 4.5 was assumed. The overall standard deviation on mean lengths at age was estimated directly from the age data. The oldest aged fish from surveys and commercial samples was age 12. Mean lengths at age for the older fish (10-12) was supplemented with data collected from a study of large monkfish (Johnson et al. 2008).

Age modes in the predicted length frequencies are seen for most ages due to the linear nature of monkfish growth and the model structure that uses a single annual growth time step (Appendix A1). The absence of a decline in growth with age in monkfish produces this process error in the SCALE model fits. This can be concealed by increasing the variance on mean lengths at age by increasing the assumed variance on the mean lengths at age. However, as in the 2007 assessment, an increase in the variance on the mean lengths at age beyond what is supported by the raw growth data was not done due to concerns on its effect on the estimated selectivity.

Relative abundance trends for recruits (ages 1, 2, and/or 3) and adults (40+ cm) in each management unit were updated and are shown in Figures A64 through A69. The length interval specific to each survey used as a proxy for the recruitment ages are shown in the plots. For both management units, the model was fit to spring, fall and industry-based survey length frequencies (30+ cm), 40+ cm adult indices, and recruitment indices at age. The northern area had additional inputs from a shrimp trawl survey (1991-2009) and the southern area used the NEFSC winter trawl (1992-2007) and NEFSC scallop dredge (1984-2009) surveys. Inputs from the fall inshore ME/NH trawl survey (2000-2009) were added to the northern management area in this assessment (Figures A70 and A71). The use of the Fall MDMF bottom trawl survey was also investigated in this assessment but was dropped as an index of abundance (Figure A72). The working group concluded that this index was unreliable for monkfish due to the low numbers of fish caught in the survey.

Indices at age and adult 40+ cm abundance indices were scaled using the approximate area (nm^2) of the survey divided by the average coverage of the survey's tow (Table A31). The survey catchability estimates from the model were used as a diagnostic check for the interpretation of survey efficiencies. Survey indices from the R/V Bigelow were converted to Albatross units for 2009 (numbers per tow / 7.2). An additional diagnostic run for each management area (north, south and combined) that included the absolute estimates of the cooperative monkfish 40+ cm estimates for all three years was investigated. An assumed 50 percent efficiently was used for the 2009 cooperative monkfish survey. The estimated q's from the model for the cooperative monkfish survey ranged from 0.68 to 1.18 but the model could not fit the large fluctuation in abundance between survey years (Figure A73).

There is no evidence of strong recruitment in the age-specific indices over the last three years (2007-2009). The 40+ cm indices also indicate a decline in abundance in comparison to the previous three years. There was little change in the survey and catch length frequency distributions since the 2007 assessment (Appendix A1).

In the 2007 assessment a single selectivity block (1980-2009) was estimated for the northern management unit and three selectivity blocks were estimated for the southern management unit. A single selectivity block for the north was retained for this assessment. Shifting the second selectivity block from 2003-2004 (2007 assessment) to 2001-2002 (current assessment) in the south provided a better fit to the catch length frequency data and corresponded better to the shift to gillnet gear in the fishery. The first selectivity block in the southern area (1980-1995) that was established in the 2007 assessment has only two years of length information and appears to produce unstable selectivity estimates in this assessment, therefore it was eliminated in the final southern run 8.

For the 2007 assessment a variety of conditions and assumptions were tested using sensitivity runs and a similar approach was taken for SARC 50. Comparisons of the configuration and results of the final and sensitivity SCALE runs for this assessment are shown in Tables A32 through A34 and Figures A74 through A80. The influence of three additional years of data to the final configuration of the 2007 assessment was determined in run 1 in both the north and southern management areas. In the north run 2 determined the influence of adding both the ME/NH survey and the MA DMF survey. In runs 3 and greater the MDMF survey was dropped from the model. The model was allowed to estimate Fstart in runs 4 to 7 and runs 6 and 7 were done to test sensitivity to the Vrec (recruitment variation) penalty weight. In the south, runs 2 to 7 allowed estimation of Fstart; runs 3 to 5 also tested alternative selectivity blocks.

Similar to the 2007 assessment, models for both the north and south had difficulty in fitting the catch length frequency data in the last few years. Fits to the catch length frequencies can be seen Appendix A1. A significant decline in the catch has occurred in the last three years of the model. However there is no evidence of an increase in the number of larger fish in the catch or in any of the survey length frequency distributions from 2007 to 2009. The model could not reconcile the effects of a decline in catch with the lack of a corresponding shift in the length distributions. Sensitivity run 5 in the north and runs 6 and 7 puts higher weight on the length distributions in the model. This resulted in a lack of fit to the catch (Figure A80).

The sensitivity runs of the SCALE model produced similar trends in F and biomass. As in the 2007 assessment the trade-off between shifts in the estimated selectivity and other weighting components of the model still exist.

Combining the northern and southern areas into a single assessment model was investigated in this assessment. In general the combined assessment model results were intermediate between the northern and southern model runs (Figure A79). Combined biomass estimates approximated the sum for the two area runs.

The final working group model runs retained for the 2007 assessment assumed fixed parameters for Fstart (North at 0.01, South at 0.2). The northern area results suggested there were at least two strong recruitment pulses during the 1990s that fueled subsequent increases in the catch (Figures A75 and A80). These strong recruitment events were not evident in the south (Figures A78 and A80). The final northern run estimated lower abundance with a shift in selectivity to larger fish relative to the 2007 assessment. The northern final model estimated much lower abundance in the terminal year than what was projected from the 2007 assessment; 144,000 tons in 2007 versus 66,000 tons in the current assessment (Figure A75). The final model for the southern area estimated relatively low recruitment in the last five years (2005-2009) of the model. However biomass and F predictions were similar to estimates from the 2007 assessment. Recruitment, biomass and fishing mortality estimates from the current assessment final runs are listed in Table A35.

The estimates of total biomass from the SCALE model fall within the confidence intervals (25^{th}-75^{th} percentile) of biomass estimates from the cooperative surveys for 2001 and 2004 (Table A16); however, the 2009 estimates from the SCALE model are approximately double the absolute biomass estimates from the cooperative survey for 2009. The effect of the retrospective pattern in the SCALE estimates has not been factored into these comparisons.

Monkfish SCALE model Uncertainty

Assessment of monkfish is difficult because of the often-poor quality of data available. Survey data provide a long-term picture, but there is high variability in the survey trends due to the low numbers of fish caught in many of the surveys. Landings were historically under-reported and discard data were not available until relatively recently. Age samples were not taken in surveys until 1994 and from landings until 2000, and the landings are sparsely sampled for age even at present because removing vertebrae compromises product quality. Important aspects of monkfish biology are poorly understood, including stock structure and movement patterns, growth rates and longevity. Ageing methods have not been validated using known-age individuals. Effects of the process error within the model due to the linear growth trend are unknown. There is uncertainty surrounding the lack of an explanation for the consistent sex ratio patterns that occur with size in multiple surveys (Richards et al., 2008).

Given the litany of data limitations, it is not surprising that most of the assessment approaches applied were not successful during the 2007 Data Poor Stocks Working Group assessment. The SCALE model was considered useful at that assessment because it integrated the available information and the resulting estimates appeared reasonable (e.g. biomass estimates consistent with empirically-estimated biomass from industry-based surveys). This is still true in the current assessment. However, in this assessment substantial uncertainty remains surrounding the lack of evidence for rebuilding of the size structure with the observed decline in the catch.

Retrospective analyses suggest there is higher uncertainty with the northern management model relative to the southern management assessment (Figures A81 and A82). The northern model exhibits strong retrospective patterns in fishing mortality and stock size. If the fishing mortality estimated for 2009 is adjusted upward to account for the average retrospective underestimation of -66% for the 2002-2008 terminal years, the estimate for 2009 changes from 0.10 to 0.17. If the total biomass estimated for 2009 is adjusted downward to account for the average retrospective overestimation of +108% for the 2002-2008 terminal years, the estimate for 2009 changes from 66,062 mt to 31,761 mt. The model for the southern area exhibits moderate retrospective patterns in fishing mortality and stock size. If the fishing mortality estimated for 2009 is adjusted upward to account for the average retrospective underestimation of -13% for the 2002-2008 terminal years, the estimate for 2009 changes from 0.07 to 0.08. If the total biomass estimated for 2009 is adjusted downward to account for the average retrospective overestimation of +16% for the 2002-2008 terminal years, the estimate for 2009 changes from 131,218 mt to 113,119 mt. The model for the combined area exhibits intermediate retrospective patterns in fishing mortality and stock size with respect to the separate areas (Figure A83). Age specific retrospective adjustments using seven peels are summarized in Table A36.

Potential explanations for the lack of fit and/or retrospective pattern in the SCALE model are summarized in Table A37. The explanations deemed most likely to cause underlying problems with the model were (1) the growth model is incorrect (ie. growth is not linear with age) and (2) setting M=0.3 is inappropriate (ie. monkfish longevity may be greater than currently assumed).

Improvements to the SCALE model allow for estimation of within model uncertainty on fishery selectivity and stock numbers through the MCMC procedure. However, uncertainty in F could not be estimated with the MCMC for monkfish because fishing mortality is set equal to model results in the MCMC. Therefore all of the within model uncertainty is not accounted for in the MCMC results. The high uncertainty surrounding this assessment will be largely underestimated by within model uncertainty estimates and probably should not be solely used for the determination of the uncertainty in setting ABCs. As in the 2007 assessment, the results are dependent on the input mean lengths at age as an appropriate approximation for monkfish growth.

Spawning biomass is not output directly by the SCALE model, but was estimated as the product of population numbers at length (SCALE), maturity at length (Richards et al. 2008), weight at length (SCALE) and fraction female at length (based on data in Richards et al. 2008). The fraction female at length was estimated two ways: (1) using observed patterns of proportion female vs. length in the south and north (e.g. Richards et al. 2008) and (2) assuming sex ratio=50:50 up to 70 cm, then 100% female for fish ≥ 70 cm. Ogives were averaged to develop estimates for the combined stock areas. Trends in spawning biomass are shown in Figure A84.

SAW50 Editor's note: The SARC50 panel acknowledged the high degree of uncertainty in estimates from the SCALE model due to data limitations, poorly understood monkfish biology (growth, natural mortality, stock structure), and the strong retrospective pattern in the northern area. The panel did not favor directly adjusting for the retrospective pattern. Despite the high uncertainty, the model was accepted, but with strong precautionary caveats.

TOR 5. 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.

Overfishing Reference Points

SAW 34 (NEFSC 2002) and Framework 2 of the Monkfish FMP established the overfishing definition as F_{max} and estimated it be equal to 0.2 for both management areas (assuming M=0.2). NEFSC (2007a) examined length-based and age-based YPR models and concluded that the length-based approach was not appropriate as it assumes a von Bertalanffy growth model which does not fit currently understood monkfish growth patterns. NEFSC (2007a) used the age-based YPR model to update the value of Fmax assuming M=0.3 and the current assessment updates this model again using revised selectivity patterns output from SCALE. F_{target} was not defined in the original monkfish FMP or in Framework Adjustment 2. The DPSWG (NEFSC 2007a) recommended that $F_{40\%}$ be used to define F_{target}.

Age-based YPR was calculated for each management region using the approach of NEFSC (2007a). This assumed a constant natural mortality M=0.3 and applied selectivity at age approximated from SCALE output selectivity at length for each area. Mean weights at age for the catch and stock were from SCALE output, and maturity ogives were from 2001 Cooperative Monkfish Survey data (NEFSC 2002), which were very similar to other estimates of maturity (Table A18, Figure A85). The estimates from NEFSC (2007a) and the current assessment are shown in Table A38. The difference in estimates for the two areas reflects differing selectivity of gillnets and trawls; more monkfish are landed using gillnets in the south than in the north. The differences between years reflect the changes in selectivity patterns estimated by the SCALE model.

Biomass reference points

Biomass reference points were developed by NEFSC (2007a) using results of the SCALE model. The recommended $B_{threshold}$ was the lowest observed value in the total biomass time series (1980-present) from which the stock has then increased (termed "B_{Loss}"), estimated in 2006 to be 65,000 mt in the north and 96,000 mt in the south. The recommended B_{target} was the average of total biomass for the time period (1980-present), estimated in 2006 to be 92,000 mt in the north and 123,000 mt in the south.

The 2010 assessment updated biomass reference points developed by NEFSC (2007a) based on results of the 2009 SCALE population model (Table A39). Using the current FMP definitions, updated estimates of $B_{threshold}$ are 41,238 mt of total stock biomass in the northern area and 99,181 mt in the southern area. Estimates of B_{target} (average of 1980-2006 estimates) are 62,371 mt of total stock biomass in the northern area and 120,292 mt in the southern area. Biomass reference points for the combined areas approximated the sum for the two existing management areas (i.e., relative scaling persisted). Using the current FMP definitions, the combined area estimate of $B_{threshold}$ is 159,715 mt (average of 1980-2009 estimates) and the combined area estimate of B_{target} (average of 1980-2009 estimates) is 208,190 mt.

Biomass reference points for New England groundfish stocks have recently been based on the long-term projected biomass corresponding to F_{MSY} or its proxy, which for monkfish would be F_{max}. In keeping with this practice, proposed total biomass targets (i.e., B_{max} at F_{max}) and thresholds ($0.5*B_{max}$) were calculated for monkfish for the northern, southern and combined areas (Table A39). Using this approach, proposed estimates of B_{target} are 52,930 mt in the northern area and 74,490 mt in the southern area, and estimates of $B_{threshold}$ are 26,465 mt in the northern area and 37,245 mt in the southern area. The combined area estimate of B_{target} 129,002 mt and the estimate of $B_{threshold}$ is 64,501 mt. The total catch produced from the long-term Btarget at the respective values of F_{max} (i.e., proxy for F_{MSY}), is 10,745 mt for the northern area, 15,279 mt for the southern area, and 25,943 mt for the areas combined.

All of the BRPs are based on results of the SCALE model (including F reference points from the YPR which uses selectivity curves estimated by SCALE), therefore the BRPs are subject to the same high level of uncertainty that surrounds the SCALE model results. The BRPs developed by NEFSC (2007a) were *ad hoc* and are problematic in that BRPs change with every update or modification of the model. Further, the results for the southern management area indicate that biomass approached overfished status in the mid-1990s even though F remained below F_{target}. This suggests that those BRPs were unreliable. The BRPs based on projected biomass at F_{max} are also subject to high uncertainty due to reliance on projections of SCALE model results and the high estimate of F_{max} due to the assumption of M=0.3 in the YPR model. The biomass reference points using the current method are much lower, which accounts for the more optimistic view of stock size relative to the biomass target and biomass threshold.

SAW50 Editor's note: The SARC50 panel recommended adoption of the biomass reference points based on "Bmax projected".

TOR 6. Evaluate stock status with respect to the existing BRPs, as well as with respect to updated or redefined BRPs (from TOR 5).

Based on the existing biological reference points from the 2007 stock assessment and the Monkfish Fishery Management Plan (FMP), monkfish would be considered not overfished with no overfishing occurring for both the northern and southern stock management areas (Figure A86, Table A39). In the northern area, the existing $B_{threshold}$ is 65,200 mt of total stock biomass and the existing $F_{threshold}$ is $F_{max} = 0.31$. The estimated 2009 northern area biomass is 66,062 mt, above the existing $B_{threshold}$; the estimated northern area F in 2009 is 0.10, below the existing $F_{threshold}$. In the southern area, the existing $B_{threshold}$ is 96,400 mt and the existing $F_{threshold}$ is $F_{max} = 0.40$. The estimated 2009 southern area biomass is 131,218 mt, above the existing $B_{threshold}$; the estimated southern area F in 2009 is 0.07, below the existing $F_{threshold}$.

The 2010 assessment has updated the biological reference points based on an updated yield-per-recruit analysis and the results of the SCALE length-tuned population model that incorporates multiple survey indices and catch data. Based on proposed reference points from these updated analyses, monkfish in both management areas are not overfished with no overfishing occurring (Figure A87). Using the current FMP definitions, updated estimates of

$B_{threshold}$ are 41,238 mt of total stock biomass in the northern area and 99,181 mt in the southern area. Estimates of B_{target} (average of 1980-2006 estimates) are 62,371 mt in the northern area and 120,292 mt in the southern area. Estimates of total biomass for 2009 are 66,062 mt in the northern area and 131,218 mt in the southern area, above B_{target} for both areas. The existing overfishing threshold is based on F_{max}, and this was retained in the 2010 assessment. The updated estimates of F_{max} are 0.43 per year in the northern area and 0.46 per year in the southern area. Estimates of current F (2009) are 0.10 per year in the northern area and 0.07 per year in the southern area, both less than the respective overfishing thresholds.

A combined stock area model was constructed to address a Research Recommendation from the 2007 assessment. Biomass reference points for the combined areas approximated the sum for the two existing management areas (i.e., relative scaling persisted). Using the current FMP definitions, the combined area estimate of $B_{threshold}$ is 159,715 mt of total stock biomass (average of 1980-2009 estimates) and the combined area estimate of B_{target} (average of 1980-2009 estimates) is 208,190 mt. The estimate of combined area total biomass for 2009 is 255,326 mt, above B_{target}. The combined area overfishing threshold based on F_{max} is 0.37. The combined area estimate of current F (2009) is 0.05, below the combined area overfishing threshold (Figure A88).

Biomass reference points for New England groundfish stocks have recently been based on the long-term projected biomass corresponding to F_{MSY} or its proxy, which for monkfish would be F_{max}. In keeping with this practice, proposed total biomass targets (i.e., B_{max} at F_{max}) and thresholds ($0.5*B_{max}$) were calculated for monkfish for the northern, southern and combined areas. Using this approach, proposed estimates of B_{target} are 52,930 mt in the northern area and 74,490 mt in the southern area, and estimates of $B_{threshold}$ are 26,465 mt in the northern area and 37,245 mt in the southern area (Table A39, Figure A89). The combined area estimate of B_{target} 129,002 mt and the estimate of $B_{threshold}$ is 64,501 mt. The total catch produced from the long-term B_{target} at the respective values of F_{max} (i.e., proxy for F_{MSY}), is 10,745 mt for the northern area, 15,279 mt for the southern area, and 25,943 mt for the areas combined.

The assessment results for monkfish continue to be uncertain due to likely under-reported landings and unknown discards during the 1980s and incomplete understanding of key biological parameters such as age and growth, longevity, natural mortality and stock structure. The population models for all areas exhibit retrospective patterns that are strongest for the 2002-2006 terminal years and weaker for the 2007-2008 terminal years. The retrospective patterns are strongest for the northern area, weakest for the southern area, and intermediate for the model of combined areas (Figures A81-A83). The BRPs are all based on output from the SCALE model, therefore the BRPs are also highly uncertain.

TOR 7. Evaluate monkfish diet composition data and its implications for population level consumption by monkfish.

Food habits were evaluated for monkfish as major a predator in the ecosystem. The total amount of food eaten and the type of food eaten were the primary food habits data examined. From these basic food habits data, diet composition, per capita consumption, total consumption, and the amount of prey removed by monkfish were calculated. Contrasts to total energy flows in the ecosystem and fishery removals of commercially targeted skate prey were conducted to fully address the Term of Reference.

Methods

To estimate mean stomach contents (S_i), the total amount of food eaten (as observed from food habits sampling) was calculated for each size class, temporal and/or spatial scheme. The denominator in the mean stomach contents (i.e., the number of stomachs sampled) was inclusive of empty stomachs. These means were weighted by the number of tows in a temporal and spatial scheme as part of a two-stage cluster design. Further background on food habits sampling protocols and these estimators can be found in Link and Almeida (2000). This sampling program was a part of the NEFSC bottom trawl survey program (Azarovitz 1981; NEFC 1988). Units are in g.

Estimates were calculated on an annual basis for each monkfish size class, temporal and spatial combination. The size classes were < and ≥ 40 cm for Small (S) and Large (L) size classes, respectively and the areas were southern and northern management regions. Although the food habits data collections started quantitatively in 1973, collections for monkfish weren't initiated until 1977. Key diagnostics were the number of empty stomachs over time and mean length vs. mean stomach contents weight (with ± 95% CI), which were examined to identify any major outliers in the data and to ascertain any notable patterns in variance.

To estimate diet composition (D_{ij}), the amount of each prey item was summed across all monkfish stomachs. These estimates were then divided by the total amount of food eaten in a size class, temporal and spatial scheme, totaling 100%. These estimates are proportions and were only presented for those major prey comprising >85% of the total for each size class, temporal and spatial scheme.

The approach to calculating consumption followed previously established methods, using an evacuation rate model methodology. For further details, see Durbin et al. (1983), Ursin et al. (1985), Pennington (1985), Overholtz et al. (1991, 1999, 2000, 2008), Tsou & Collie (2001a, 2001b), Link & Garrison (2002), Link et al. (2002, 2006, 2008, 2009), Link & Sosebee (2008), Overholtz & Link (2007), Tyrrell et al. (2007, 2008), Link and Idoine (2009), Moustahfid et al. (2009a, 2009b), and NEFSC (2006, 2007a, 2007b, 2008). The main data inputs are mean stomach contents (S_i) for each monkfish size-time-space scheme i, diet composition (D_{ij}) where j is the specific prey of interest, and T is the bottom temperature taken from the bottom trawl surveys (Taylor et al. 2005). Estimates of variance about all input variables were calculated.

Using the evacuation rate model to calculate consumption requires two variables and two parameters. The per capita consumption rate, C_i is calculated as:

$$C_i = 24 \cdot E_i \cdot \overline{S_i}^{\gamma} \quad ,$$

where 24 is the number of hours in a day and the evacuation rate E_i is:

$$E_i = \alpha e^{\beta T} \quad ;$$

and is formulated such that estimates of mean stomach contents (S_i) and ambient temperature (T; here used as bottom temperature from the NEFSC bottom trawl surveys (Taylor et al. 2005)) are the only data required. The parameters α and β are set as values chosen from the literature (Tsou and Collie 2001a, 2001b, Overholtz 1999, 2000). The parameter γ is a shape function is almost always set to 1. To estimate per capita consumption, the gastric evacuation rate method was used (Eggers 1977, Elliott and Persson 1978). The two main parameters, α and β, were set to 0.004 and 0.11 respectively based upon prior studies and sensitivity analyses (NEFSC 2007c, 2007d). From 1992 on (when individual weights were measured), a diagnostic of % daily ration was also calculated.

Once per capita consumption rates were estimated for each monkfish size class, temporal and spatial scheme, those estimates were then scaled up to an annual and stock wide basis, *C*:

$$C = 365 \cdot C_i \cdot N_i$$

where N_i is the estimate of abundance (from assessment results) for each monkfish size class, temporal and spatial scheme and 365 is the number of days in a year.

This total consumption was partitioned for the major prey items of monkfish by multiplying it by the diet composition of each prey (D_{ij}) to provide an estimate of prey removals. Both the total consumption and the amount of prey removed by each monkfish size class (and combined across sizes) are presented as metric tons year^{-1}. These were then summed for both areas.

To evaluate the consumptive demands of a monkfish and the predatory removals of monkfish in a broader ecosystem context, total consumption by monkfish was compared to the amount of energy flow for the entire ecosystem. The total energy flows were calculated in a recent energy budget (Link et al. 2006, 2008, 2009). Monkfish consumption is presented as a percentage of total energy flows in the ecosystem. In addition, the total amount of commercially targeted prey eaten by monkfish was compared to fishery landings to evaluate potential competition between monkfish and fisheries.

Results & Observations

- The amount of food consumed by monkfish was 0.005-0.02% of all energy flows in the system
- Monkfish comprised 2-6% of total consumption by all finfish in the ecosystem (1-4 % in N, 2-8% in S)
- Consumption by monkfish has changed over time, mainly as a function of abundance (Figure A90)
- Consumption has been more important at times, perhaps when other piscivore species were at lower abundances; monkfish has the potential to be one of the dominant piscivores in the ecosystem
- All diagnostics were within the normal range.

Summary

- Amount of food eaten and per capita consumption peaked in early 1980s in both management areas; this was due to the greater abundance of large monkfish in the population.
- Total, scaled consumption follows the peak in 1980s for both management areas and early 2000s for the northern stock
- Some subtle shifts in diet across size classes, decades and areas were observed, but this species is categorically piscivorous and is of the more notable piscivores in the ecosystem
- Monkfish is an ecologically important piscivore in the Northwest Atlantic ecosystem
- Lots of small, other fishes eaten by monkfish
- Monkfish consumption (C) was high relative to landings of some of its prey stocks (L):

- C ~ 20-50% of L: mackerel, herring, monkfish
- C ~ L: squids
- C > L: silver hake, skates

TOR 8. Develop and apply analytical approaches and data that can be used for conducting single and multi-year stock projections and for computing candidate ABCs.

a. Provide numerical short-term projections (through 2016). 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 to examine important sources of uncertainty in the assessment.

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

c. Describe this stock's vulnerability to becoming overfished, and how this could affect the choice of ABC.

SCALE model results and AGEPRO projections were used to evaluate stock trends during 2011-2016 fishing at Fthreshold and at proposed ACTs and ABCs assuming stochastic long-term recruitment. Projections assumed that F in 2010 would equal the estimated F in 2009 from the SCALE model. Projections for the northern management area (NMA) are the most likely to be unrealistic, given the uncertainty of stock status due mainly to the relatively strong retrospective observed since 2002. The southern management area (SMA) projections are the more likely to be realistic, given the moderate retrospective pattern observed for that area. The combined area projections are intermediate with respect to the current management areas, as the relative scaling of the two populations is maintained when the areas are combined in one model. The projections indicate that the northern area is the most vulnerable to overfishing or becoming overfished during 2011-2016 if total catches approach the proposed ABC, while the southern area is the least vulnerable (Table A40 to Table A42).

SAW50 Editor's note: The SARC panel acknowledged the high degree of uncertainty in the projections due to uncertainty in the starting conditions (output from the SCALE model).

TOR 9. 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.

SAW 34 (2002) Research Recommendations

***** indicates suggested candidates for deletion from the active Research Recommendations list.

1) Research should be continued to define stock structure, including genetic studies, reproductive behavior analyses, morphometric studies, parasite studies, elemental analyses, and studies of egg and larvae transport.
- A genetic study is underway by a student at UMES using mtDNA. Results to date found genetic groupings but these are not spatially coherent (do not indicate stock separation).

- A conventional tagging study ongoing by investigators at GMRI. Results to date: monkfish tagged in fall/winter in western Gulf of Maine and southern New England were later recaptured in Mid-Atlantic Bight (see Appendix A2). Future plans include tagging in other seasons and further to the south.
- A data storage tagging study underway, joint project of NOAA and GMRI. ~150 tagged monkfish released during 2009, no recaptures yet.
- An otolith elemental composition study is ongoing using otoliths collected during 2004 cooperative monkfish survey. Otoliths have been processed but further work has been stalled due to change in responsibilities of primary PI.
- Web site established to gather information on location of egg veils – launched spring 2007. http://www.nefsc.noaa.gov/read/popdy/monkfish/MonkfishEggveilReporting/
Results: very little response to date.
*2) The SARC recommends changing the overfishing definitions for monkfish. Research on yield per recruit for monkfish should examine the effect and possible causes of differential natural mortality rates by sex, methods to estimate gear selectivity, and the incorporation of discards.
- OF definition was changed in 2003 via Framework 2 based on results of SAW 34 and again in 2008 based on the results of NEFSC (2007a).
- NEFSC (2007a) assessment explored length-based and age-based YPR with estimates of gear selectivity from SCALE model, incorporated discards, and examined higher M to reflect shorter longevity of males. NEFSC (2007a) accepted age-based model with M=0.3, which was used to revise reference points.
*3) Surplus production modeling should continue with special emphasis placed on uncertainty in under-reported catches and population size prior to 1980.
- Bayesian surplus production was explored unsuccessfully for SAW 40 (2005) and NEFSC (2007a). The DPSWG concluded that long-term production models were inappropriate for status determination of monkfish because of the general lack of correspondence between reported catch and survey trends.
*4) Size selectivity studies should be conducted in the trawl fishery to investigate the potential effectiveness of minimum mesh size and shape regulations to reduce discards of undersize monkfish. Additionally, comparative studies of the size selectivity and catchability of trawls and gill nets should be undertaken in order to understand the differences in the numbers of large fish captured in the two gear types.
- A study using 12" diamond and square mesh was completed in 2006 (Raymond and Glass 2006). The study showed reduced catch rates of groundfish in the experimental nets compared to controls (6-6.5" mesh) and reduced discard of monkfish in the experimental nets. Monkfish was 35% of the catch (kg) in control nets and 73% in experimental nets. Discard of monkfish was reduced from 15% to 6%.
*5) Another cooperative survey for monkfish should be conducted in 2004.
- Additional cooperative surveys were conducted during 2004 and 2009. The new NEFSC survey gear is much more effective for monkfish than the previous survey gear, thus reducing the need for further cooperative surveys.
*6) Improved sampling rates (as observed in 2000-2001) for commercial landings should be maintained, which should eventually lead to an age-based assessment approach for this species.
- age sampling rates have been variable.
Observer sampling was considered more useful for monkfish by NEFSC (2007a).

NEFSC (2007a) raised concerns over the validity of ageing methods for monkfish.
7) Tagging studies should be considered as a basis to evaluate adult movement and rates of growth.
- conventional tagging study ongoing by investigators at GMRI. Results to date: monkfish tagged in fall/winter in western Gulf of Maine and southern New England were later recaptured in Mid-Atlantic Bight (see Appendix A2). Future plans include tagging in other seasons and further to the south.
- estimates of growth from conventional tagging study to date are too imprecise to estimate growth rate accurately.
- Data storage tagging study underway, joint project of NOAA and GMRI. ~150 tagged monkfish released during 2009, no recaptures yet. Fish are being marked with OTC when released for age validation studies (reward is for return of entire fish plus tags).
8) Spatial distribution of mature and immature fish and the potential effects of size limits on fishing behavior should be evaluated as a basis for advising on strategies to minimize catch and discard of immature fish.
- not done
9) Indices of abundance should be developed from industry "study fleets," including coverage from outside the depth and spatial range of the NEFSC research surveys.
- not addressed

SAW 40 Research Recommendations
*(1) An examination of the influence of fixed stations on the estimate of biomass from the cooperative research survey should be undertaken.
- As part of the 2006 cooperative monkfish survey review, catch rates, average monkfish size and density were compared between industry stations and random stations. Inclusion of the industry stations was judged to have had minimal impact on the population estimates.
*(2) An exploration of a geostatistical approach to estimate biomass from the cooperative survey would also be of value.
- not done
(3) There are some concerns with the ageing results. An ageing validation study should be undertaken to confirm the accuracy of catch at age estimates.
- Direct validation studies (e.g. tetracycline marking) have begun as part of a data storage tagging study, but no recaptures to date.
- SMAST UMass Dartmouth student working on age validation, developing tank studies (but difficult due to high mortality of captive monkfish).
- Indirect criteria have been satisfied (Armstrong et al. 1992)
*(4) The changes in the distribution in the fishery over time may be influencing the results of the assessment. This should be examined more thoroughly.
- this has not been addressed.
*(5) The assessment lacks a reliable forecast. Since commercial catch-at-age data and survey catch-at-age data exist and assuming that ageing can be validated, alternative forward-projecting age structured models should be investigated.
- a forward projecting length-tuned model (SCALE) was used to provide forecasts in the 2007 assessment and in the current assessment..
*(6) An examination of transect survey data for changes in the distribution of the population by depth would be informative.

- not done

(7) Further, consideration should be given to a more complete treatment of the Canadian portion of this stock, with possibly some interaction with the team doing the assessment of monkfish in NAFO Divisions 4VWX5Zc, possibly through the TRAC process.

- not done. There is no longer a Canadian assessment scientist assigned to monkfish; however, we have estimated survey indices from Canadian surveys on the Scotian shelf, but not incorporated them into the model.

*(8) Ways of estimating of fishing mortality at age should be investigated. This could take the form of a general linear modeling approach with survey age and year effects in an analysis of Z. Alternatively a more fully specified population model based on survey-at-age data such as the RCRV1A model of Cook (1997) and recent developments described under SURBA may be applicable.

- SCALE model is being used to estimate mortality. Survey ages alone are too variable to reliably estimate Z due to low monkfish catch rates in surveys up through 2008. With the development of a time series on the FSV Bigelow, this approach may become viable in the future.

*(9) The cooperative survey should be continued as it is informative and can be used in the Bayesian surplus production model and may provide a means of calibrating the NEFSC survey data when the survey vessel is replaced.

- A cooperative survey was conducted in 2009. Results of the 2001 and 2004 surveys were used in the surplus production models, but the modeling approach still was not successful (see SAW 34, recommendation 3). The current assessment compares the 2009 cooperative survey with the NEFSC 2009 spring survey.

2007 Data-Poor Workshop, Research Recommendations

Working Group I

(1) Observer samples should be aged.

- No further ageing has been done since NEFSC (2007a) due to questions raised about the validity of the current ageing method and because a length-based model for was adopted for the assessment.

(2) Applications of the SCALE model for monkfish assessment should be developed further, including:

*a) Explore alternative growth functions (sigmoid etc.) since von Bertalanffy growth does not fit length-at-age data

- SCALE used mean length at age, not a growth function. At present, the only growth model that would be appropriate is a linear one.

*b) Explore changing weighting on catch in relation to reliability of catch data (more uncertainty in early part of time series)

-SCALE is not currently configured to be able to do this.

*c) Explore using the same M for males and females up to age 7, and then increasing M for males to account for the lack of males over age 7

-SCALE is not currently configured to be able to do this.

*d) Bin lengths into 2cm or 5 cm increments in order to eliminate zeros in survey length frequencies

-SCALE is not currently configured to be able to do this.

e) Develop independent estimates of selectivity for application to SCALE

-*No new work has been done.*
*(3) Length-based mortality:
-Examine effects of vonBertalanffy growth assumption on Gedamke-Hoenig mortality estimates.
- not done, this method was not pursued because of the adoption of the SCALE model.
Working Group II
*(1) Investigate foreign landings and reporting rates if possible.
- not done, not clear what is being asked for here.
(2) Examine aging further and develop tagging studies to validate M, growth rates and Longevity
- studies are in progress, as described above
(3) Estimate biomass by sex since age 6+ fish that are predominantly female appear to be decreasing in biomass at a greater rate
- not done, but could be feasible as FSV Bigelow time series accumulates
(4) SCALE model:
a) develop objective methods for weighting input series (e.g. inverse variance weighting)
- not done
b) do some runs with combined management areas
- done for current assessment
c) develop a two-sex model
- explored in NEFSC (2007a), but problematic because males still remain in model after none are observed in reality
d) incorporate cannibalism in SCALE model
- not done
(5) examine commercial sampling length modes in more detailed time steps (e.g. quarterly) to see if cohorts can be tracked (to indicate whether there are significant problems with aging).
- not done.

SAW 50 Southern Demersal Working Group Research Recommendations

1. Conduct a net efficiency experiment on the FSV Bigelow to help parameterize the population models for a range of species, including monkfish.

   SAW50 Editor's note: The SARC50 panel did not comment on the Research Recommendations.

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