B. ATLANTIC SEA SCALLOP STOCK ASSESSMENT FOR 2010

Invertebrate Subcommittee[1]

Terms of Reference

1. Characterize the commercial catch including landings, effort, LPUE and discards. Describe the uncertainty in these sources of data.
2. Characterize the survey data that are being used in the assessment (e.g., regional indices of abundance, recruitment, state surveys, length data, etc.). Describe the uncertainty in these sources of data. Document the transition between the survey vessels and their calibration. If other survey data are used in the assessment, describe those data as they relate to the current assessment (Exclude consideration of future survey designs and methods).
3. Estimate annual fishing mortality, recruitment and stock biomass (both total and spawning stock) for the time series, and characterize the uncertainty of those estimates.
4. Update or redefine biological reference points (BRPs; estimates or proxies for B_{MSY}, $B_{THRESHOLD}$, and $F_{MSY;}$ and estimates of their uncertainty). Comment on the scientific adequacy of existing and redefined BRPs.
5. Evaluate stock status with respect to the existing BRPs, as well as with respect to updated or redefined BRPs (from TOR 4).
6. 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 2014). 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.
7. 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.

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[1] Meetings and members of the Invertebrate Subcommittee who helped prepare this assessment are listed in Appendix 1.

Executive Summary

TOR 1. *Characterize the commercial catch, effort and CPUE, including descriptions of landings and discards of that species.* (Section 4 and Appendix II)

U.S. sea scallop landings averaged about 26,000 mt meats during 2002-2009, about twice their long-term average. Landings have been particularly high in the Mid-Atlantic Bight region. Fishing effort reached its maximum in 1991, and then declined during the 1990s so that effort in 1999 was less than half that in 1991. Effort in the most recent period has been fairly stable. Landings per unit effort (LPUE) showed general declines from the mid-1960s through the mid-1990s, with brief occasional increases due to strong recruitment. LPUE more than quadrupled between 1998 and 2001, and remained high during 2001-2009. LPUE has been especially high in the Mid-Atlantic and in the Georges Bank access areas (areas that had been closed and are now under special management). Discards of sea scallops were unusually high during 2002-2004, averaging about 10% of landings (by weight), but declined since then, probably due to changes in gear regulations that reduced catches of small individuals.

TOR 2. *Characterize the survey data that are being used in the assessment (e.g., regional indices of abundance, recruitment, state surveys, length data, etc.). Describe the uncertainty in these sources of data. Document the transition between the survey vessels and their calibration. If other survey data are used in the assessment, describe those data as they relate to the current assessment (Exclude consideration of future survey designs and methods).* (Section 5 and Appendices III, IV, V, VI, IX, X, XIV).

Direct and indirect comparisons between the *R/V Albatross IV*, which conducted the NEFSC sea scallop surveys until 2007, and the *R/V Hugh Sharp*, which conducted the 2008-2009 surveys, indicated no statistically significant differences in the catch rates of the two vessels (Appendix IV). However, dredge sensor data indicated that the tow path of the *R/V Hugh Sharp* was about 5% longer than that of the *R/V Albatross IV*, so catches in the time-series were reduced by that amount during 2008-2009.

Comparison of about 140 paired stations between catches of the lined survey dredge and underwater towed camera images (HabCam) gave estimates of survey dredge efficiency of 0.38 in survey strata containing substantial amounts of coarse sediment (gravel, cobble, rock), and 0.44 in all other strata, containing mostly sandy sediments (Appendices IX and X). Edge effects were examined for the SMAST drop camera survey which led to a re-estimation of scallop densities for this survey (Appendix III).

NEFSC sea scallop dredge survey indices were generally low from 1979-1995, and size-frequencies indicated a truncated size distribution with few large scallops. On Georges Bank, abundance and biomass rose substantially in the late 1990s, and then leveled off. After a decline between 2005-2007, indices increased again after strong recruitment was observed during 2007-2009. In the Mid-Atlantic, NEFSC survey indices increased substantially between 1997 and 2003, and have been stable or increased slightly since then. Substantial broadening of the size-structure was observed in both regions starting in the mid-to-late 1990s. SMAST drop video camera survey indices were fairly steady on Georges Bank during 2003-2009. In the Mid-Atlantic, the video estimates declined sharply between 2003 and 2004, and have declined slowly since then. Declines in abundance between 2003 and 2004 were also observed in the lined dredge and the NEFSC winter bottom trawl surveys. These declines are either due to overestimation of the large year class in the 2003 survey indices or high natural or fishing induced mortality of this year class or some combination of these effects.

TOR 3. *Estimate fishing mortality, spawning stock biomass, and total stock biomass for the current year and characterize the uncertainty of those estimates. If possible, also include estimates for earlier years.* (Section 6 and Appendix XI).

A dynamic size-based stock assessment model (CASA) was used to estimate biomass, abundance and fishing mortality. This model was introduced in a preliminary version in NEFSC (2004) and used as the primary assessment model in NEFSC (2007). Data used in CASA included commercial catch, LPUE, and fishery shell height compositions, the NEFSC sea scallop and winter trawl surveys, the SMAST large camera video survey, growth increment data from scallop shells, and shell height/meat weight data adjusted to take into account commercial practices and seasonality. Because both the video and lined dredge survey (via the paired dredge/camera experiment) give estimates of scale (absolute abundances), prior estimates for efficiencies of these two surveys were used in the CASA model.

The sea scallop stock was assessed in two components (Georges Bank and Mid-Atlantic) separately and then combined. Estimates of fishing mortality were made from 1975-2009 for both regions. The models generally gave good fits to survey and commercial data, but there was tension in the Mid-Atlantic Bight model between the efficiency priors (especially for the video survey) and the recent stable or declining trends observed in surveys. Possible mild retrospective patterns were observed in the model, especially in the Mid-Atlantic Bight.

Model output and fishery size composition data indicate a substantial shift in selectivity towards larger scallops Fishing mortality rates in 2009 are comparable to revised reference points but they are not comparable among fishery selectivity periods except as measures of fishing mortality on the fully selected individuals because of the shifts in selectivity. Whole stock fully recruited fishing mortality increased from 1975-1992, reaching a peak of 1.47 in 1992, rapidly declined during the late 1990s, and has been fairly stable since 2002. Estimated fishing mortality in 2009 was 0.18 (Georges Bank), 0.60 (Mid-Atlantic) and 0.378 for the whole stock.

Combined model estimated abundances and biomass increased rapidly in the decade starting in 1994, and have been stable or slightly increasing since then. July 1, 2009 estimated biomasses were 62,470 mt meats for Georges Bank and 67,233 mt meats in the Mid-Atlantic. Whole stock abundance and biomass estimates for July 1 2009 were 4,446 billion scallops and 129,703 mt meats. Both abundance and biomass for 2009 were at the maximum of the 1975-2009 time series.

TOR 4. *Update or redefine biological reference points (BRPs; estimates or proxies for B_{MSY}, $B_{THRESHOLD}$, and F_{MSY}; and estimates of their uncertainty). Comment on the scientific adequacy of existing and redefined BRPs.* (Section 7).

The per recruit reference points F_{MAX} and B_{MAX} had been used as proxies for F_{MSY} and B_{MSY} in previous assessments. NEFSC (2007) estimated F_{MAX} = 0.29 and B_{MAX} = 109,000 mt meats (January 1 biomass). These estimates were updated in this assessment using new data and the current CASA model: F_{MAX} = 0.30 and B_{MAX} = 125,000 mt meats, based on January 1 biomass as was used in NEFSC (2007).

During the last benchmark assessment (NEFSC 2007), it was recommended that alternative reference points be explored because the changes in selectivity have made yield per recruit curves increasingly flat, which makes F_{MAX} more difficult to estimate and sensitive to small changes in assumed parameters.

A new method for estimating reference points is proposed in this assessment (SYM – Stochastic Yield Model) which explicitly takes into account uncertainties in per recruit and stock-recruit relationships to estimate F_{MSY} and B_{MSY} using Monte-Carlo simulations. This model estimated whole-stock F_{MSY} = 0.38, B_{MSY} = 125,358 mt meats (July 1 biomass), and MSY = 24,975 mt meats. This assessment used July 1 model biomass since it is a more representative of the actual biomass in the population. July 1 model abundance and biomass are always lower than those on January 1 because all growth and recruitment in the model occur on January 1.

TOR 5. *Evaluate stock status with respect to the existing BRPs, as well as with respect to updated or redefined BRPs (from TOR 4).* (Section 8).

According to the Amendment 10 overfishing definition (NEFMC 2003), sea scallops are overfished when the survey biomass index for the whole stock falls below 1/2 B_{TARGET}. The target biomass estimated in NEFSC (2007), B_{TARGET} = 109,000 mt on January 1, was calculated as the median recruitment in the survey time series times BPR_{MAX}, the biomass per recruit obtained when fishing at F_{MAX}. NEFSC (2007) estimated F_{MAX}= 0.29, which has been used since then as the overfishing threshold. The updated values in this assessment are F_{MAX} = 0.30 and B_{MAX} = 85,000 mt (July 1 biomass). The new proposed stochastic MSY reference points are F_{MSY} = 0.38 and B_{MSY} = 125,358 mt (July 1).

Estimated whole-stock biomass in for January 1, 2009 was 158,610 mt meats, and 129,703 mt for July 1. These estimates are above the biomass target of 109,000 mt meats from NEFSC (2007) as well as the new biomass targets (85,000 mt meats July 1 using per recruit analysis, 125,358 mt meats using the stochastic yield approach). Thus, the current estimated biomass is more than twice the biomass threshold of 1/2 B_{TARGET}, regardless of which reference point approach is used. The sea scallop stock was therefore not overfished in 2009.

Estimated whole stock fishing mortality was 0.38 for the whole stock (to three decimal places 0.378), which is above the NEFSC (2007) overfishing threshold of 0.29 and its updated value of 0.30, but equal to the proposed estimate of F_{MSY} = 0.38. Therefore, overfishing was not occurring in 2009 based on the new recommended overfishing definition; however, overfishing would be occurring if the previous definition or its updated value had been used.

TOR 6. *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 2014). 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. (Section 8)

The recommended projection model is spatially explicit and accommodates differences among regions in recruitment, growth, initial size structure, shell height/meat weight relationships, management approach (open vs. closed areas and catch quota vs. limits on fishing effort), intensity of fishing effort, and other factors. Projections done assuming status-quo management but varying initial conditions, natural mortality and recruitment indicate that biomass and landings are expected to increase modestly until 2012, and then level off. There is less than a 0.1% chance of the stock becoming overfished by 2014. The stock has low vulnerability to becoming overfished.

TOR 7. *Review, evaluate and report on the status of the SARC/Working Group Research Recommendations offered in recent SARC reviewed assessments.* Completed (Section 9)

Progress has been made on some of the recommendations, such as estimation of natural mortality and seasonal growth models. But no progress has been made on others, such as obtaining better estimates of discard and incidental mortality.

Introduction

Life History

The Atlantic sea scallop, *Placopecten magellanicus,* is a bivalve mollusk that occurs on the eastern North American continental shelf north of Cape Hatteras. Major aggregations in US waters occur in the Mid-Atlantic from Virginia to Long Island, on Georges Bank, in the Great South Channel, and in the Gulf of Maine (Hart and Chute 2004). In Georges Bank and the Mid-Atlantic, sea scallops are harvested primarily at depths of 30 to 100 m, whereas the bulk of landings from the Gulf of Maine are from near-shore waters. This assessment focuses on the two main portions of the sea scallop stock and fishery, Georges Bank in the north and the Mid-Atlantic in the south (Figure B-1). Results for Georges Bank and the Mid-Atlantic are combined to evaluate the stock as a whole. Assessments of the Gulf of Maine populations can be found in Appendices V and VI.

US landings during 2003-2009 exceeded 24,000 mt (meats) each year, roughly twice the long-term mean.[2] US ex-vessel sea scallop revenues during 2005-2009 averaged $389 million, making it the most valuable US fishery during this time. Unusually strong recruitment in the Mid-Atlantic Bight area and increased yield per recruit due to effort reduction and fishing gear modification measures are the key reasons for high recent landings. The mean meat weight of a landed scallop during 2005-2009 was over 25 g, compared to less than 14 g during the early to mid 1990s.

Area closures and reopenings have a strong influence on sea scallop population dynamics (Figure B-1). Roughly one-half of the productive scallop grounds on Georges Bank and Nantucket Shoals were closed to both groundfish and scallop gear during most of the time since December 1994. Limited openings to allow scallop fishing in closed areas contributed more than half of Georges Bank landings during 1999-2000 and since 2004.

In the Mid-Atlantic, there have been five rotational scallop closures. Two areas (Hudson Canyon South and Virginia Beach) were closed in 1998 and then reopened in 2001. Although the small Virginia Beach closure was unsuccessful, scallop biomass built up in Hudson Canyon Closed Area while it was closed, and substantial landings were obtained from Hudson Canyon during 2001-2007. This area was again closed in 2008, and will likely reopen in 2011. A third rotational closure, the Elephant Trunk area east of Delaware Bay, was closed in 2004, after extremely high densities of small scallops were observed in surveys during 2002 and 2003. About 30,000 mt of scallops have been landed from that area since it reopened in 2007. A fourth closed area (Delmarva), directly south of the Elephant Trunk area, was closed in 2007 and was reopened in 2009.

[2] In this assessment, landings and biomass figures are metric tons (mt) of scallop meats, unless otherwise indicated.

Early attempts to model sea scallop population dynamics (NEFSC 1992, 1995, 1997, 1999) were not successful because biomass estimates were less than the minimum swept area biomass obtained from the NEFSC scallop survey (NEFSC 1999). In lieu of model based estimates, fishing mortality was estimated in NEFSC (1999, 2001 and 2004) using a simple rescaled *F* method which relies heavily on survey and landings data. A size-structured forward projecting model (CASA, based on Sullivan et al. 1990) was used in the last sea scallop benchmark assessment in 2007 as the primary methodology. A slightly refined version of this model is used in this assessment as well (Table B-1).

Life History and Distribution

Sea scallops are found in the Northwest Atlantic Ocean from North Carolina to Newfoundland along the continental shelf, typically on sand and gravel bottoms (Hart and Chute 2004). Sea scallops feed by filtering phytoplankton, microzooplankton, and detritus particles. Sexes are separate and fertilization is external. Sea scallops typically become mature at age 2, but gamete production is limited until age 4. Larvae are planktonic for 4-7 weeks before settling to the bottom. Scallops fully recruit to the NEFSC survey at 40 mm SH, and to the current commercial fishery at around 90-105 mm SH, although sea scallops between 70-90 mm were common in landings prior to 2000.[3]

According to Amendment 10 of the Atlantic Sea Scallop Fishery Management Plan, all sea scallops in the US EEZ belong to a single stock. However, the US sea scallop stock can be divided into Georges Bank, Mid-Atlantic, Southern New England, and Gulf of Maine regional components based on survey data, fishery patterns, and other information (NEFSC 2004, Figure B-1). For assessment modeling purposes, Southern New England is considered to be part of the Georges Bank region.

Age and growth

Sea scallop assessments prior to 2007 estimated growth using the von Bertalanffy growth parameters from Serchuk et al. (1979). During the 2007 assessment, new analysis of shells collected during the 2001-2006 NEFSC scallop surveys was introduced (NEFSC 2007). This approach was based on growth increments inferred by successive rings on shells. The shell rings have been confirmed as annual marks (NEFSC 2007, Hart and Chute 2009a). Von Bertalanffy growth parameters were estimated in NEFSC (2007) using data from surveys from 2001 to 2006 using a mixed-effects model. Hart and Chute (2009b) gave a slightly refined version of this model that also included shells collected in 2007. Here we updated these estimates to include shells collected in 2008, using the same methodology as Hart and Chute (2009b). The current growth curves have lower mean L_∞ and higher mean K values than Serchuk et al. (1979). Differences between the current estimates and that of NEFSC (2007) are minor, and that between current estimates and Hart and Chute (2009b) are almost negligible (Figure B-2). Note that growth parameter t_0 cannot be estimated using growth increments, but it is not used in this assessment.

[3] Scallop body size is measured as shell height (SH, the maximum distance between the umbo and shell margin).

Mean growth parameters for sea scallops

Source	Region	L_∞	SE	*K*	SE
New (NEFSC 2010)	Mid-Atlantic	132.1	0.3	0.527	0.004
	Georges Bank	144.0	0.3	0.429	0.002
Hart & Chute (2009)	Mid-Atlantic	133.3	0.4	0.508	0.004
	Georges Bank	143.9	0.3	0.427	0.002
NEFSC (2007)	Mid-Atlantic	131.6	0.4	0.495	0.004
	Georges Bank	146.5	0.3	0.375	0.002
Serchuk et al. (1979)	Mid-Atlantic	151.84		0.2997	
	Georges Bank	152.46		0.3374	

Maturity and fecundity

Sexual maturity commences at age 2; sea scallops > 40 mm that are reliably detected in the surveys used in this assessment are all considered mature individuals. Although sea scallops reach sexual maturity at a relatively young age, individuals younger than 4 years may contribute little to total egg production (MacDonald and Thompson 1985; NEFSC 1993).

According to MacDonald and Thompson (1985) and McGarvey et al. (1992), annual fecundity (reproductive output, including maturity, spawning frequency, oocyte production, etc.) increases quickly with shell height in sea scallops

($Eggs=0.00000034\ SH^{4.07}$). Spawning generally occurs in late summer or early autumn. DuPaul et al. (1989) found evidence of spring, as well as autumn, spawning in the Mid-Atlantic Bight area. Almeida et al. (1994) and Dibacco et al. (1995) found evidence of limited winter-spring spawning on Georges Bank.

Shell height/meat weight relationships

Shell height-meat weight relationships allow conversion from numbers of scallops at a given size to equivalent meat weights. They are expressed in the form $W=\exp(\alpha+\beta\ln(H))$, where *W* is meat weight in grams and *H* is shell height in mm. NEFSC (2001) combined the shell height/meat weight relationships from Serchuk and Rak (1983) with relationships from NEFSC (1999; later published as Lai and Helser 2004) to obtain "blended" estimates that were used in NEFSC (2001) and NEFSC (2004).

New shell height/meat weight data was collected during annual NEFSC sea scallop surveys during 2001-2009. Unlike previous studies, where meats were either frozen or brought in live and then weighed on land, meats were weighted at sea just after they were shucked. Estimates based on the 2001-2006 data were used in NEFSC (2007). This assessment updates these estimates by adding 2007-2008 data (see table below,

Figure B-3 and Appendix VII). Due to the change in timing of the survey, 2009 data were not used.

Meat weights also depend on covariates such as depth and latitude. Meat weights decreasing with depth, probably because of reduced food (phytoplankton) supply. Analysis of the new data indicated that depth and (at least in some cases) latitude had a significant effect on the the shell height/meat weight relationship (Appendix VII). Estimated coefficients for the relationship $W=\exp(\alpha+[\beta+\rho\ln(D)]\ln(H)+\gamma\ln(D)+\delta\ln(L))$, where *D* is depth in meters and *L* is latitude, are given below. In this assessment, depth-adjusted shell height/meat weight relationships were used to calculated survey biomass information, and traditional relationships were used in the models (CASA and SAMS), where depth is not explicit.

	α	β	γ	δ	ρ
Mid-Atlantic Bight					
Haynes (1966)	-11.09	3.04			
Serchuk and Rak (1983)	-12.16	3.25			
NEFSC (2001)	-12.25	3.26			
Lai and Helser (2004)	-12.34	3.28			
NEFSC (2007)	-12.01	3.22			
NEFSC (2007) with Depth effect	-9.18	3.18	-0.65		
NEFSC (2010)	-10.80	2.97			
NEFSC (2010) with Depth effect	-8.94	2.94	-0.43		
NEFSC (2010) with Depth effect and interaction	-16.88	4.64	1.57	-	-0.43
Georges Bank					
Haynes (1966)	-10.84	2.95			
Serchuk and Rak (1983)	-11.77	3.17			
NEFSC (2001)	-11.60	3.12			
Lai and Helser (2004)	-11.44	3.07			
NEFSC (2007)	-10.70	2.94			
NEFSC (2007) with Depth effect	-8.62	2.95	-0.51		
NEFSC (2010)	-10.25	2.85			
NEFSC (2010) with Depth effect	-8.05	2.84	-0.51		
NEFSC (2010) with Depth, Latitude and subarea effect	14.380	2.826	-0.529	5.980	0.051[b]

Meat weights for scallops in the commercial fishery may differ from those predicted based on research survey data for a number of reasons. First, the shell height-meat weight relationship varies seasonally, in part due to the reproductive cycle, so that meat weights collected during the NEFSC survey in July and August may differ from those in the rest of year. Additionally, commercial fishers concentrate on speed, and often leave some meat on the shell during shucking (Naidu 1987, Kirkley and DuPaul 1989). On the other hand, meats may gain weight due to water uptake during storage on ice (DuPaul et al. 1990). Finally, fishers may target areas with relatively large meat weight at shell height, and thus may increase commercial meat weights compared to that collected on the research vessel.

Observer data was used to adjust meat weights for seasonal variation and for commercial practices (Appendix VIII). Annual commercial meat weight anomalies were computed based on the seasonal patterns of landings together with the mean monthly commercial meat weight at shell height (Figure B-4).

Natural mortality

Previous assessments assumed a natural mortality of $M = 0.1$ based on Merrill and Posgay (1964), who estimated M based on ratios of clappers to live scallops in survey data. Clappers are shells from dead scallops that are still intact (i.e., both halves still connected by the hinge ligament). The basis of the estimate (Dickie 1955) is an assumed balance between the rate at which new clappers are produced ($M \cdot L$, where L is the number of live scallops) and the rate at which clappers separate ($S \cdot C$, where S is the rate at which shell ligaments degrade, and C is the number of clappers). At equilibrium, the rates of production and loss must be equal, so that $M \cdot L = S \cdot C$ and:

$$M=C/(L \cdot S).$$

Merrill and Posgay estimated S=33 weeks from the amount of fouling on the interior of clappers. The observed ratio C/L was about 0.066 and M was thus estimated to be $0.104 \approx 0.1\ y^{-1}$. However, the estimate of S is highly uncertain; for example Dickie (1955) estimated S to be 14.3 weeks based on tank experiments. The high level of uncertainty in the denominator implies that the estimator for M using the point estimated of S is biased low. If the standard error in the estimate of S is 12 weeks, an unbiased estimate of M is slightly more than 0.12. For this assessment, we use an estimate of $M = 0.12$ for Georges Bank. As shown below, this new assumption is supported by a number of modeling results.

No direct estimate of M is available for Mid-Atlantic sea scallops. The ratio of the growth coefficient K to M is generally regarded as a life history invariant that should be approximately constant for similar organisms (Beverton and Holt 1959, Chernov 1993). Applying this idea indicates that sea scallop natural mortality in the Mid-Atlantic should be about 0.527/0.429 that of Georges Bank (see the estimates of growth coefficients above). Using $M = 0.12$ in Georges Bank implies that natural mortality in the Mid-Atlantic is 0.12*0.527/0.429, or about 0.15. This is the estimate used in this assessment.

TOR 1: Commercial and Recreational Catch

The US sea scallop fishery is currently conducted mainly by about 350 vessels with limited access permits. Two types of allocation are given to each vessel. The first are trips (with a trip limit, typically of 18,000 lbs meats) to rotational access areas that had been closed to scallop fishing in the past. The second are days at sea, which can be used in areas outside the closed and access areas. Vessels fishing under days at sea are restricted to a 7 man crew in order to limit their processing power. The percentage of landings from the access trips have increased since the access area programs began in 1999; in recent years, about 60% of landings are from the access areas. Landings from 1964-2009 are given in Table B-2.

The remainder of landings come from vessels operating under "General Category" permits that are restricted to 400 lbs per trip, with a maximum of one trip per day. Landings from these vessels were less than 1% of total landings in the late 1990s, but increased to 10% or more of landings during 2007-2009. This type of permit had been open access, but was converted to an individual transferable quota (ITQ) fishery in March 2010.

Principal ports in the sea scallop fishery are New Bedford, MA, Cape May, NJ, and Hampton Roads, VA. New Bedford style scallop dredges are the main gear type in all regions, although some scallop vessels use otter trawls in the Mid-Atlantic. Recreational catch is negligible; a small amount of catch in the Gulf of Maine may be due to recreational divers.

Management history

The sea scallop fishery in the US EEZ is managed under the Atlantic Sea Scallop Fishery Management Plan (FMP), implemented on May 15, 1982. From 1982 to 1994, the primary management control was a minimum average meat weight requirement for landings.

FMP Amendment 4 (NEFMC 1993), implemented in 1994, changed the management strategy from meat count regulation to limited access, effort control and gear regulations for the entire US EEZ. Incremental restrictions were made on days-at-sea (DAS), minimum ring size, and crew limits (Table B-3). In addition, three large areas on Georges Bank and Nantucket Shoals were closed to groundfish and scallop fishing in December 1994 (Figure B-1). Scallop biomass rapidly increased in these areas. Two areas in the Mid-Atlantic were closed to scallop fishing in April 1998 for three years in order to similarly increase scallop biomass and mean weight.

Sea scallops were formally declared overfished in 1997, and Amendment 7 was implemented during 1998 with more stringent days-at-sea limitations and a mortality schedule intended to rebuild the stocks within ten years. Subsequent analyses considering effects of closed areas indicated that the stocks would rebuild with less severe effort reductions than called for in Amendment 7, and this days at sea schedule was thus modified. A combination of the closures, effort reduction, gear and crew restrictions led to a rapid increase in biomass (Hart and Rago 2006), and sea scallops were rebuilt by 2001. Prior to 2004, there were a number of ad hoc area management measures, including the Georges Bank and Mid-Atlantic closures in 1994 and 1998, limited reopenings of portions of the Georges Bank areas between June 1999 and January 2001, and reopening of the first Mid-Atlantic rotational areas in 2001.

A new set of regulations was implemented as Amendment 10 during 2004. This amendment formalized an area based management system, with provisions and criteria for new rotational closures, and separate allocations (in days-at-sea or TACs) for reopened closed areas and general open areas. Amendment 10 closed an area offshore of Delaware Bay (the Elephant Trunk area) where high numbers of small scallops were observed in the 2002 and 2003 surveys. This area reopened in 2007, when an area directly to the south was closed (Delmarva closure). One of the original Mid-Atlantic rotational closures, Hudson Canyon South, which had been closed in 1998 and reopened in 2001, was closed again in 2008, and is scheduled to reopen in 2011.

Amendment 10 also increased the minimum ring size to 4” and, together with subsequent frameworks, allowed limited reopening of portions of the groundfish closed areas.

Landings

Sea scallop landings in the US increased substantially after the mid-1940’s (Figure B-5), with peaks occurring around 1960, 1978, 1990, and 2004. Maximum US landings were 29,109 mt meats in 2004.

Proration of total commercial sea scallop landings into Georges Bank, Mid-Atlantic, Southern New England, and the Gulf of Maine regions used the standard allocation procedures of the NEFSC (Wigley et al. 2008). Landings from the Georges Bank and the Mid-Atlantic regions have dominated the fishery since 1964 (Table B-2 and Figure B-6). US Georges Bank landings had peaks during the early 1960’s, around 1980 and 1990, but declined precipitously during 1993 and remained low through 1998 (Table B-2 and Figure B-6). Landings in Georges Bank during 1999-2004 were fairly steady, averaging almost 5000 mt annually, and then increased in 2005-2006, primarily due to reopening of portions of the groundfish closed areas to scallop fishing. Poor recruitment in the middle of the decade and the reduction of biomass in the Georges Bank access areas have led to reductions in landings in the most recent years.

Until recently, the Mid-Atlantic landings were lower than those on Georges Bank. Mid-Atlantic landings during 1962-1982 averaged less than 1800 mt per year. An upward trend in both recruitment and landings has been evident in the Mid-Atlantic since the mid-eighties. Landings peaked in 2004 at 24,494 mt.

Landings from other areas (Gulf of Maine and Southern New England) are minor in comparison (Table B-2). Most of the Gulf of Maine scallop population is assessed and managed by the State of Maine because it is primarily in state waters (see Appendices V and VI). Gulf of Maine landings in 2009 were less than 1% of the total US sea scallop landings. Maximum landings in the Gulf of Maine were 1,614 mt during 1980.

Fishing effort and LPUE

Prior to 1994, landings and effort data were collected during port interviews by port agents and based on dealer data. Since 1994, commercial data are available as dealer reports (DR) and in vessel trip report (VTR) logbooks. DR data are total landings, and, since 1998, landings by market category. VTR data contain information about area fished, fishing effort, and retained catches of sea scallops. Ability to link DR and VTR reports in data processing is reduced by incomplete data reports and other problems, although there have been significant improvements recently. A standardized method (Wigley et al. 2008) for matching DR to VTRs and assigning areas to landings was used to allocate landings to region for 1994-2008. The method used in previous assessments (e.g., NEFSC 2007) that stratified landings and VTR by state was used for 2009, since the allocation tables for 2009 have not yet been completed.

Landings per unit effort (LPUE, computed as landings per day fished) (Figure B-7) shows a general downward trend from the beginning of the time series to around 1998, with occasional spikes upward probably due to strong recruitment events. LPUE increased considerably from 1999-2003 as the stock recovered; further increases in LPUE have been seen in recent years in the Mid-Atlantic, likely due to strong recruitment. Note the close correspondence in most years between the LPUE in the Mid-Atlantic and Georges Bank, probably reflecting the mobility of the fleet; if one area has higher catch rates, it is fished harder until the rates are equalized. Although comparisons of LPUE before and after the change in data collection procedures during 1994 need to be made cautiously, there is no clear break in the LPUE trend in 1994.

Fishing effort (days fished) in the US sea scallop fishery generally increased from the mid-1960s to about 1991, and then decreased during the 1990s, first because of low catch rates, and later as a result of effort reduction measures (Figure B-8). Effort increased in the Mid-Atlantic during 2000-2005, initially due to reactivation of latent effort among limited access vessels, and then due to increases in general category effort. Total effort since 2005 has remained fairly stable, though there have been shifts between regions.

Discards and discard mortality

Sea scallops are sometimes discarded on directed scallop trips because they are too small to be economically profitable to shuck, or because of high-grading, particularly during access area trips. Ratios of discard to total catch (by weight) were recorded by sea samplers aboard commercial vessels since 1992, though sampling intensity on non-access area trips was low until 2003; see Appendix II for detailed estimates.

Discarded sea scallops may suffer mortality on deck due to crushing, high temperatures, or desiccation. There may also be mortality after they are thrown back into the water from physiological stress and shock, or from increased predation due to shock and inability to swim or shell damage (Veale et al. 2000, Jenkins and Brand 2001). Murawski and Serchuk (1989) estimated that about 90% of tagged scallops were still living several days after being tagged and placed back in the water. Total discard mortality (including mortality on deck) is uncertain but has been estimated as 20% in previous assessments (e.g., NEFSC 2007); this assessment also makes this assumption. However, discard mortality may be higher during the Mid-Atlantic during the summer due to high water and deck temperatures.

Incidental mortality

Scallop dredges likely kill and injure some scallops that are contacted but not caught, primarily due to damage (e.g., crushing) caused to the shells by the dredge. Caddy (1973) estimated that 15-20% of the scallops remaining in the track of a dredge were killed. Murawski and Serchuk (1989) estimated that less than 5% of the scallops remaining in the track of a dredge suffered non-landed mortality. Caddy's study was done in a relatively hard bottom area in Canada, while the Murawski and Serchuk study was in sandy bottom off the coast of New Jersey. It is possible that the difference in indirect mortality estimated in these two studies was due to different bottom types (Murawski and Serchuk 1989).

In order to use the above estimates to relate landed and non-landed fishing mortality in stock assessment calculations, it is necessary to know the efficiency e of the dredge (the probability that a fully recruited scallop in the path of a dredge is captured). Denote by c the fraction of scallops that suffer mortality among sea scallops in the path of the dredge but not caught. The best available information indicates that $c = 0.15\text{-}0.2$ (Caddy 1973), and $c < 0.05$ (Murawski and Serchuk 1989). The ratio R of scallops in the path of the dredge that were caught, to those killed but not caught is:

$$R = e/[c(1-e)]$$

If scallops suffer direct (i.e., landed) fishing mortality at rate F_L, then the rate of indirect (non-landed) fishing mortality will be (Hart 2003):

$$F_I = F_L / R = F_L\, c\, (1-e)/e.$$

If, for example, the commercial dredge efficiency e is 50%, then $F_I = F_L\, c$, where F_L is the fully recruited fishing mortality rate for sea scallops. Assuming c = 0.15 to 0.2 (Caddy 1973) gives F_I = 0.15 F_L to 0.2 F_L. With $c < 0.05$ (Murawski and Serchuk 1989) $F_I < 0.05\, F_L$. Because there may be unobserved damage, actual incidental mortality may be higher than that observed in these studies. For this assessment, incidental mortality was assumed to be 0.2 F_L in Georges Bank and 0.1 F_L in the Mid-Atlantic.

Commercial shell height data

Since most sea scallops are shucked at sea, it has often been difficult to obtain reliable commercial size compositions. Port samples of shells brought in by scallopers have been collected, but there are questions about whether the samples were representative of the landings and catch. Port samples taken during the meat count era often appear to be selected for their size rather than being randomly sampled, and the size composition of port samples from 1992-1994 differed considerably from those collected by at-sea observers during this same period. For this reason, size compositions from port samples after 1984 when meat count regulations were in force are not used in this assessment.

Sea samplers (observers) have collected shell heights of kept scallops from commercial vessels since 1992, and discarded scallops since 1994. Although these data are likely more reliable than that from port sampling, they still must be interpreted cautiously for years prior to 2003 (except for the access area fisheries) due to limited observer coverage.

Shell heights from port and sea sampling data indicate that sea scallops between 70-90 mm often made up a considerable portion of the landings during 1975-1998, but sizes selected by the fishery have increased since then, so that scallops less than 90 mm were rarely taken during 2002-2009 (Figure B-9).

Dealer data (landings) have been reported by market categories (under 10 meats per pound, 10-20 meats per pound, 20-30 meats per pound etc) since 1998 (Figure B-10). These data also indicate a trend towards larger sea scallops in landings. While nearly half the landings in 1998 were in the smaller market categories (more than 30 meats per pound), about 75% of the 2009 landings were below 20 count and about 99% were below 30 count.

Economic trends in the U.S. sea scallop fishery

This section describes the trends in landings, revenues, prices, producer surplus and profits for the sea scallop fishery since 1994.

Trends in landings, prices and revenues

In the fishing years 2002-2008, the landings from the northeast sea scallop fishery stayed above 50 million pounds, surpassing the levels observed historically (Figure B-11). The recovery of the scallop resource and consequent increase in landings and revenues was striking given that average scallop landings per year were below 16 million pounds during the 1994-1998 fishing years, less than one-third of the present level of landings. The increase in the abundance of scallops coupled with higher scallop prices increased the profitability of fishing for scallops by the general category vessels. As a result, general category landings increased from less than 0.4 million pounds during the 1994-1998 fishing years to more than 4 million pounds during the last four fishing years (2005-2008), peaking at 7 million pounds in 2005 or 13.5% of the total scallop landings.

Figure B-12 shows that total fleet revenues tripled from about \$100 million in 1994 to over \$350 million in 2008 (in inflation-adjusted 2008 dollars). Scallop ex-vessel prices increased after 2001 as the composition of landings changed to larger scallops that in general command a higher price than smaller scallops. However, the rise in prices was not the main factor that led to the increase in revenue in the recent years compared to 1994-1998 and in fact, the inflation adjusted ex-vessel price of scallops in 2008 was lower than the price in 1994 (Figure B-12). The increase in total fleet revenue was mainly due to the increase in scallop landings and the increase in the number of active limited access vessels during the same period. Fig B6-9 shows that average landings and revenue per limited access vessel more than doubled in recent years compared to the period 1994 -1998. The number of active limited access vessels increased by 50 % (from about 220 in 1994 to 345 in fishing year 2008) resulting in tripling of total fleet scallop landings and revenue in 2008 compared to 1994 (Figure B-12 and Figure B-13).

Figure B-13 shows that average scallop revenue per limited access vessel more than doubled from about $400,000 in 1994 to about $950,000 despite the fact that inflation adjusted ex-vessel price per pound of scallops was slightly higher in 1994 ($7.15 per pound) compared to the ex-vessel price in 2008 ($6.92 per pound). In other words, the doubling of revenue was the result of the doubling of the average scallop landings per vessel in 2008 (over 136,000 pounds) from its level in 1994 (over 57,000 pounds). The total fleet revenue for all the limited access vessels more than tripled during the same years as new vessels became active. Average scallop revenue per full-time vessel peaked in the 2005 fishing year to over $1.1 million as a result of higher landings combined with an increase in ex-vessel price to about $8.50 per pound of scallops (in terms inflation adjusted 2008 prices).

Trends in the meat count and size composition of scallops

Average scallop meat count has declined continuously since 1999 as a result of effort-reduction measures, area closures, and an increase in ring sizes implemented by the Sea Scallop FMP. The share of larger scallops increased with the share of U10 scallops rising to over 20% since 2006. The share of 11-20 count scallops increased from 12% in 1999 to 53% in 2008. On the other hand, the share of 30 or more count scallops declined from 30% in 1999 to 1% in 2008 (Figure B-10 and tables below). Larger scallops priced higher than the smaller scallops contributed to the increase in average scallop prices in recent years despite larger landings (Figure B-12 and tables below).

Size composition of scallops

YEAR	Under 10 count	11-20 count	21-30 count	30 count and over	Unclassified
1999	17%	12%	25%	35%	12%
2000	7%	18%	44%	20%	11%
2001	3%	24%	49%	11%	13%
2002	5%	15%	65%	5%	11%
2003	6%	21%	56%	3%	13%
2004	7%	41%	42%	2%	8%
2005	13%	57%	21%	2%	7%
2006	23%	52%	18%	1%	6%
2007	24%	52%	13%	4%	8%
2008	23%	53%	18%	1%	4%

Price of scallop by market category (in 2008 inflation adjusted prices)

YEAR	<=10 count	11-20 count	21-30 count	>30 count
1999	7.8	7.9	7.3	6.4
2000	8.7	6.8	5.9	6.1
2001	7.2	4.7	4.4	4.7
2002	6.7	4.8	4.5	5.1
2003	5.7	4.8	4.8	5.3
2004	6.8	5.8	5.5	5.7
2005	8.8	8.6	8.5	8.3
2006	6.6	7.3	7.6	7.6
2007	7.2	6.9	6.8	6.2
2008	7.2	6.9	6.8	6.4

Trends in Foreign Trade

One of most significant change in the trend for foreign trade for scallops after 1999 was the striking increase in scallop exports. The increase in landings especially of larger scallops led to a tripling of U.S. exports of scallops from about 5 million lb. in 1999 to over 20 million lb. per year since 2005 (Figure B-14). Figure B-14 shows exports from New England and Mid-Atlantic ports combined including fresh, frozen and processed scallops. Although exports include exports of bay, calico or weathervane scallops, it mainly consists of sea scallops. France and other European countries were the main importers of US scallops. The exports from all other states and areas totaled only about $1 million in 2006 and 2007, and thus were not considered significant. Imports of scallops fluctuated between 45 million lb. and 60 million lb. during the same period.

TOR 2: Survey Data

Sea scallop surveys were conducted by NEFSC in 1975 and annually after 1977 to measure abundance and size composition of sea scallops in the Georges Bank and Mid-Atlantic regions (Figure B-1). The 1975-1978 surveys used a 3.08 m (10’) unlined dredge with 50 mm rings. A 2.44 m (8’) survey dredge with 50 mm rings and a 38 mm plastic liner has been used consistently since 1979. The lined survey dredge was judged to be unselective for scallops greater than 40 mm by comparing its catches to observations from sea floor video (NEFSC 2007). The northern edge of Georges Bank was not surveyed until 1982, so survey data for this area are incomplete for this area during 1975-1981. The 1979-1981 data were supplemented with Canadian survey data that covered much of the unsurveyed area (see Appendix XIII), allowing an extension of the lined survey dredge time series back to 1979.

The *R/V Albatross IV* was used for all NEFSC scallop surveys from 1975-2007, except during 1990-1993, when the *R/V Oregon II* was used instead. Surveys by the *R/V Albatross IV* during 1989 and 1999 were incomplete on Georges Bank. In 1989, the *R/V Oregon II* and *R/V Chapman* were used to sample the South Channel and a section of the Southeast Part. Serchuk and Wigley (1989) found no significant differences in catch rates between the *R/V Albatross IV*, *R/V Oregon II* and *R/V Chapman.*

The *F/V Tradition* was used to complete the 1999 survey on Georges Bank. NEFSC (2001) found no statistically significant differences in catch rates between the *F/V Tradition and R/V Albatross IV* from 21 comparison stations after adjustments were made for tow path length. Therefore, as in previous assessments (e.g., NEFSC 2004), survey indices for the period 1990-93 based on data from the *R/V Oregon II* were used without adjustment, and survey dredge tows from the *F/V Tradition* in 1999 were used after adjusting for tow distance.

In 2008-2009, the NEFSC scallop survey was conducted on the *R/V Hugh Sharp*. Direct and indirect comparisons between the catches of these vessels showed no significant differences (Appendix IV). However, examination of tow path length from dredge sensor data indicates that the tow path of the dredge on the R/V Sharp is about 5% longer than the R/V Albatross. Thus, survey catches in 2008-9 were reduced by 5%. Rock excluder chains have been used on the NEFSC sea scallop survey dredge since 2004 in certain hard bottom strata to enhance safety at sea and increase reliability (NEFSC 2004). Based on pair tows with and without the excluders, the best overall estimate was that rock chains increased survey catches on hard grounds by a factor of 1.31 (cv = 0.196). To accommodate rock chain effects in hard bottom areas, survey data collected prior to 2004 from strata 49-52 were multiplied by 1.31 prior to calculating stratified random means for larger areas; variance calculations in these strata include a term to account for the uncertainty in the adjustment factor (NEFSC 2007).

Calculation of mean numbers of scallops per tow, mean meat weight per tow and variances in this assessment were standard calculations for stratified random surveys (Serchuk and Wigley 1989; Wigley and Serchuk 1996; Smith 1997) with some extensions described below.

Relatively high abundance of sea scallops in closed areas makes it necessary to post-stratify survey data by splitting NEFSC shellfish strata that cross open/closed area boundaries. After post-stratification, adjacent strata were grouped into regions corresponding to the various open and closed areas. Finally, in cases where the closed or open portion of an NEFSC survey stratum was very small, it was necessary to combine the small portion with an adjacent stratum to form a new slightly larger stratum (NEFSC 1999).

Survey abundance and biomass trends

Biomass and abundance trends for the Mid-Atlantic Bight and Georges Bank are presented in Table B-4 and Figure B-15 and Figure B-16. Variances for strata with zero means were assumed to be zero.

In the Mid-Atlantic Bight, abundance and biomass were at low levels during 1979-1997, and then increased rapidly during 1998-2003, due to area closures, reduced fishing mortality, changes in fishery selectivity, and strong recruitment. Biomass was relatively stable since 2003. In Georges Bank, biomass and abundance increased during 1995-2000 after implementation of closures and effort reduction measures. Abundance and biomass declined from 2004-2007 because poor recruitment and reopening of portions of the groundfish closed areas. Abundances, and to a lesser extent, biomasses, increased since 2007 due to strong recruitment. Survey shell height frequencies show a trend to larger shell heights in both regions in recent years (Figure B-17).

Video survey data collected by the School for Marine Sciences and Technology (SMAST), University of Massachusetts, Dartmouth between 2003-2009 (Table B-5, Table B-6 and Figure B-18). SMAST survey data are counts and shell height measurements from images that were recorded by two video cameras. The "large" camera was mounted 1.575 m above the bottom in the center of the sampling frame while the "small" camera was mounted 0.7 m above the bottom. Adjustments have been made in this assessment to the estimated observed area of a quadrat, which is the area viewed by the large camera and to the number of sea scallops actually counted (Appendix III).

The SMAST survey is based on a systematic sampling pattern with stations centered on a 5.6 x 5.6 km grid pattern (Stokesbury et al. 2004). Four quadrats (drops) are sampled at each station and one image taken with each camera is analyzed from each quadrat. The sampling frame and cameras are placed on the bottom at the center of the grid where video footage from the first quadrat is collected. The sampling frame is then raised until the sea floor is no longer visible and the ship is allowed to drift approximately 50 m in the current before the sampling frame is lowered and video footage from the second quadrat image is collected. The third and fourth images are collected in the same manner. All scallops with any portion of their shell lying within the sample area are counted. Measurements are taken from images projected on a digitizing tablet from all specimens where the umbo and shell margins are clearly visible. The precision of measurements must be considered in interpreting video shell height data. Based on Jacobson et al. (2010) and NEFSC (2004), video shell height measurements from the large camera have a standard deviation of 6.1 mm across a wide range of sea scallop shell heights.

Video survey data in this assessment are expressed as densities (number m^{-2}). Variances for estimated densities are approximated using the estimator for a simple random survey applied to station means. There was some variability in the areas covered during each year (Table B-5 and Table B-6).

Dredge efficiency calibration

During 2007-2009, approximately 140 NEFSC scallop survey tows were also sampled using the HabCam towed digital camera system (Appendices IX and X). Analysis of these tows indicates that the lined survey dredge has an efficiency of about 0.44 in sandy areas and 0.38 in survey strata with a substantial fraction of gravel/cobble/rock substrate (Appendix X). These estimates are reasonably consistent with previous efficiency estimates (Table B-7).

TOR 3: Fishing Mortality, Biomass, and Recruitment Estimates

A catch at size analysis (CASA, Sullivan et al 1990) was used as the primary assessment model. CASA models growth using a stochastic growth matrix, which can be estimated using shell growth increment data. A CASA model for sea scallops was presented for preliminary review in (NEFSC 2004) and was used as the primary assessment model in the last assessment (NEFSC 2007). Simulation testing generally indicated good model performance (NEFSC 2007). CASA models for both stocks were run between 1975-2009. Shell heights were modeled with 5mm shell height bins starting at 20mm, but only scallops larger than 40mm were used in tuning to the data. The final (plus) group were the bins that included L_∞; this bin were given special plus group weights based on the mean observed weight in the NEFSC survey in that year for scallops in the plus group (Figure B-19). Transition matrices were derived directly from shell increment data, as in the last assessment. Population shell height/meat weight conversions were based on 2001-2008 research vessel derived parameters, and fishery meat weights were adjusted based on estimated seasonal anomalies and the seasonal distribution of landings in that year (see Appendix VIII). Commercial shell heights data was obtained from 1975-1984 from port samples, and from 1992-2009 from sea samples (observers). Asymptotic delta method variances calculated in CASA with AD-Model Builder software were used to compute variances and coefficients of variation (cvs).

CASA model for Georges Bank

The model time-series for this assessment was 1975-2009, compared to 1982-2009 in NEFSC (2007). Three surveys were used for both trends and shell heights: the NEFSC lined dredge survey (1979-2009), the SMAST large video camera survey (2003-2009) and the NEFSC unlined dredge survey (1975-1978). The selectivity of the lined dredge survey was assumed flat (NEFSC 2007), and the selectivity of the video and unlined dredge survey was fixed on the basis of experimental evidence (NEFSC 2007, Serchuk and Smolowitz 1980). Priors with a cv of 0.15 were assumed for the NEFSC dredge (assuming a mean dredge efficiency of 0.41, see Appendix X), and for the large camera video survey (assuming 100% detectability of fully selected scallops). The prior distributions were implemented using symmetrical beta distributions. Fishery selectivity periods were 1975-1995, 1996-1998, 1999-2000, 2001-2003, and 2003-2009. Domed (double logistic) selectivity was assumed for the 1996-1998 and 2001-2003 periods, when there was no fishing access in the closed areas, so that large scallops were not fully selected to the fishery. LPUE was not used as an index of abundance. Natural mortality was set at $M = 0.12$ and incidental fishing mortality at 0.2 times fully recruited fishing mortality.

Model predicted trends and shell heights generally fit observations well (Figure B-20 to Figure B-23). This is also reflected in the relatively high implied effective sample sizes for the shell height data (Figure B-24). Mean posterior estimated efficiency for the lined dredge was 0.464, slightly higher than the 0.41 efficiency prior (Figure B-25). The large camera posterior mean was 1.5, indicating that the model estimates were lower than the camera data.

Fishery selectivity was strongly domed during the period that the closed areas were unavailable to the fishery (Figure B-26). Otherwise, selectivity has shifted over time toward larger shell heights. Biomass and abundance generally declined from 1975-1994 and then increased rapidly and reaching a peak in 2005 (Table B-8, Figure B-27). Biomass then fell through 2008, but increased from 2008 to 2009. Biomass in 2009 was 62470 mt. Recruitment appears to be cyclic, with several years of strong recruitment followed by several years of weaker recruitment. Fully recruited fishing mortality increased from 1975 to a peak of over 1.7 in 1992 and then declined. Fully recruited fishing mortality in 2009 was 0.18. As a result of the changes in selectivity and fully recruited fishing mortality, survival to large shell heights has increased substantially in recent years (Figure B-28). During 1975-1995, 100mm scallops were nearly fully selected, and 80 mm scallops were about 80% selected (Figure B-29). By contrast, 100 mm scallops were only about 40% selected during 2004-2009, whereas 80 mm scallops were essentially not selected at all.

Model abundance and biomass estimates correspond well to the expanded estimates from the lined dredge survey, but in most years are modestly below the large camera survey (Figure B-30). Model estimates of fishing mortality are consistent with the Beverton-Holt (1956) length-based equilibrium estimator (Figure B-31). The model 80+mm exploitation index (numbers caught/population numbers > 80mm), is similar to an empirical estimate of the same quantity, estimated directly from fishery and lined dredge survey data, expanded using a dredge efficiency of 0.41 (Figure B-31).

CASA Model for Mid-Atlantic

The Mid-Atlantic CASA model uses the same three survey time series as in Georges Bank, plus the NEFSC winter bottom trawl survey, conducted between 1992-2007. This survey uses "flat net" trawl gear similar to that used by commercial flounder and scallopers and should fairly reliably catch scallops. Preliminary runs with domed selectivity for this survey could not obtain reliable estimates for the declining portion of the dome, so selectivity was modeled by a logisitic curve with estimated parameters. However, residuals and direct comparisons between dredges and trawls (Rudders et al. 2000) suggest the possibility that some doming exists. Priors and selectivity assumptions for the other three surveys was as in Georges Bank. Selectivity periods were 1975-1979, 1980-1997, 1998-2001, 2002-2004, 2005-2009. The first period was modeled as domed (double logistic) selectivity due to the predominance of small scallops in fishery length data, whereas all the other periods were assumed to have logistic selectivity.

The model trend fit the lined dredge survey well, but was contrary to the large camera survey, which decreased while the model trend generally increased during 2003-2009 (Figure B-32). Predicted shell heights usually fit the data well, except for incoming strong year classes, which tended to be overestimated in the surveys relative to the model (Figure B-33, Figure B-34, Figure B-35, Figure B-36). Mean posterior efficiency for the dredge was 0.68, somewhat higher than the 0.44 estimated by the paired dredge/habcam experiment. Mean posterior efficiency for the large camera was 1.41, again indicating the model estimated abundances were generally less than those from the camera (Figure B-37). One cause of this is the downward trend in the large camera survey, which tends to pull the model estimate lower.

Selectivity was strongly domed during 1975-1979; selectivity moved father to the right during subsequent periods so that in the 2005-2009 period, only the plus group was fully selected (Figure B-38). Model estimated abundance and biomass were relatively low during 1975-1998, and then rapidly increased from 1998-2003 and has been steady to slightly increasing since then (Table B-8; Figure B-39). Recruitment has been much greater since 1998 than before this year. Fully recruited fishing mortality was between 0.5 and 1.2 in most years between 1975-1996. Since then, fishing mortality has ranged between 0.35 and 0.87. However, the force of fishing mortality is much less than this on most scallops because of the selectivity patterns. This is illustrated by the dramatic increase in survival since 1998 (Figure B-40), and the reductions in fishing mortality on 80 and 100 mm SH scallops (Figure B-41).

Model abundance and biomass estimates generally agree well with those of the lined dredge survey (expanded using a dredge efficiency of 0.44) except in the most recent period, when the dredge survey is modestly higher (Figure B-42). Model estimates were well below the large camera survey for 2003-2005, but well above them for 2009, again reflecting the conflicting trend. Model estimates of fishing mortality and exploitation agree reasonably well with simple empirical based estimates of these quantities, especially in the most recent years (Figure B-43).

Whole stock biomass, abundance and mortality

Biomass, egg production, abundance, recruitment and fishable mean abundance were estimated for the whole stock by adding estimates for the Mid-Atlantic Bight and Georges Bank. Whole stock fishing mortality rates for each year were calculated $F = \left(C_M + C_G\right)/\left(\overline{N}_M + \overline{N}_G\right)$ where C_M and C_V are catch numbers for the Mid-Atlantic Bight and Georges Bank. Terms in the denominator are average fishable abundances during each year calculated in the original CASA model $\overline{N} = \sum_L \frac{N_L\left(1-e^{-Z_L}\right)}{Z_L}$ with the mortality rate for each size group (L) adjusted for fishery selectivity. The simple ratio formula used to calculate whole stock F is an "exact" solution because the catch equation implies that $C = F\overline{N}$.

Whole stock variances and coefficients of variation were calculated assuming that estimation errors for Georges Bank and the Mid-Atlantic Bight were independent. In particular, variances for biomass, abundance and catch estimates were the sum of the variances for Georges Bank and the Mid-Atlantic Bight. CVs for the ratios estimating whole stock F were approximated $CV_F = \sqrt{CV_C^2 + CV_{\overline{N}}^2}$, which is exact if catch number C_N and average abundance

$\overline{N}$ are independent and lognormally distributed (Deming 1960). The CV for measurement errors in catch for each region was 0.05, the same as assumed in fitting the CASA model.

Like the individual populations, whole-stock fishing mortality generally increased from 1975-1992 and then declined (Table B-8 and Figure B-44). Whole stock biomass, abundance and fishing mortality in 2009 were respectively 129,703 mt meats, 7446 billion (both on July 1) and 0.38. The biomass and abundance in 2009 were the highest in the 1975-2009 time series.

Variances for the stock as a whole depend on the assumption that model errors in Georges Bank and the Mid-Atlantic are independent; these variance would be higher if a positive correlation between model errors exists, and lower if they are negatively correlated.

The apparent precision of the estimates for sea scallops may be surprising and the cvs calculated in this assessment certainly do not capture all of the underlying uncertainties. Estimates were relatively precise because of the long time series of relatively precise dredge survey data and recent video survey data, together with the assumptions of known survey selectivities and prior information on survey efficiencies probably contributed to the small cvs. Retrospective and sensitivity analyses as well as likelihood profiles can help elucidate the uncertainties in the assessment.

Retrospective patterns

CASA model runs for Georges Bank and the Mid-Atlantic show moderate retrospective patterns, with biomass tending to decrease and fishing mortality tending to increase, with the additional years of data (Figure B-45 and Figure B-46). The pattern is stronger in the Mid-Atlantic, likely because of the downward re-estimation of the large year class observed in 2003 and the steep drop in the large camera survey in 2009.

Historical retrospective

Comparisons between the current estimates of fishing mortality and biomass and ones made in previous assessments indicate that estimates on Georges Bank have been fairly stable but there is a tendency in the Mid-Atlantic for estimates fishing mortality to increase and biomass to decrease over time (Figure B-47 and Figure B-48).

Likelihood profile analysis

Likelihood profiles were constructed for natural mortality (*M*) and mean of large camera survey *q* (Figure B-49 and Figure B-50). On Georges Bank, minimum –log-likehoods for natural mortality occur at about the estimated $M = 0.12$ for survey length compositions, and only slightly higher for survey trends, whereas the priors and commercial catches suggest a higher natural mortality. Most data sources tend to suggest a higher than estimated prior for the large camera survey.

In the Mid-Atlantic, survey trends and shell heights suggest the best estimate of natural mortality slightly below the estimated value (0.15), but the priors and commercial landings show minimums at larger values of *M*. Most sources of data tend to suggest a higher mean value for dredge efficiency than assumed in the prior, again demonstrating the tension between the survey priors and the other data sources.

Sensitivity analysis

The fact that survey estimated abundances tend to be somewhat higher than model estimates, especially in the Mid-Atlantic, suggest the possibility that there is some source of mortality, such as unreported landings, discard or incidental fishing mortality or natural mortality, the is greater than that assumed in the model. Alternatively, growth curves are based on data from the most recent period only (2001-2008); there would be model misspecification if growth was different in previous periods (e.g., because the heavy fishing affected growth, see the discussion in Hart and Chute 2009b). Violation of the assumption of spatial uniformity may also play a role in the conflict. Finally, it is possible that some systematic error in camera surveys could also explain at least part of the conflict (e.g., see Appendix III).

To estimate the uncertainty surrounding two key model imputs, sensitivity analyses were performed on input natural mortality and the assumed mean prior efficiencies of the lined dredge and large camera surveys (Figure B-51 and Figure B-52). For natural mortality, runs were conducting using the 5^{th}, 25^{th}, 75^{th}, and 95^{th} percentiles of the natural mortality distribution used in the stochastic reference point models.

Changing natural mortality modestly altered estimates, especially during the 1995-2005 period, but had little effect on the estimates of 2009 biomasses or fishing mortalities. Relaxing the assumptions on priors had almost no effect on 1975-1999 estimates, but did affect estimates in the most recent years, largely because that is when the large camera data occurs. Relaxing the priors gave lower biomasses and higher fishing mortalities than the basecase.

TOR 4: Biological Reference Points

In previous assessments, per recruit reference points F_{MAX} and B_{MAX} were used as proxies for F_{MSY} and B_{MSY}. F_{MAX} is the fishing mortality rate for fully recruited scallops that generates maximum yield-per-recruit. B_{MAX} was defined as the product of BPR_{MAX} (biomass per recruit at $F= F_{\mathrm{MAX}}$, from yield-per-recruit analysis) and median numbers of recruits. NEFSC (2007) reported January 1 biomass units, and estimated $F_{\mathrm{MAX}} = 0.29$ and $B_{\mathrm{MAX}} = 109{,}000$ mt meats as overall reference points, estimated from the CASA model.

Using the same methods but with updated data and CASA model, the estimates are $F_{\mathrm{MAX}} = 0.30$ and $B_{\mathrm{MAX}} = 127{,}000$ mt (Figure B-53). The increase in B_{MAX} is mostly due to the inclusion of special weights for the plus groups in the model; this feature was not in the 2007 model. The value of B_{MAX} is based on January 1 biomass, which was used to report biomass in NEFSC (2007). This assessment mainly reports model biomasses on July 1, which are less than those on January 1, because all growth and recruitment occur on that date in the model. The B_{MAX} corresponding to July 1 biomass is 85,000 mt. This value is somewhat less than the sum of the biomasses that maximize surplus production curves (Figure B-54).

As selectivity has shifted to larger scallops, yield per recruit curves have become increasingly flat, particularly in the Mid-Atlantic, making yield per recruit reference points both difficult to estimate and sensitive to small changes in parameters. Additionally, recruitment has been much stronger during the most recent period in the Mid-Atlantic when biomass has been high, suggesting that spawner-recruit relationships should be included in reference points.

This assessment introduces a stochastic model (SYM – Stochastic Yield Model) for calculating reference points and their uncertainty. It uses Monte-Carlo simulations to propagate the uncertainty of inputs to per recruit and stock-recruit calculations to the estimation of yield per recruit and yield curves. Besides its use in calculating limit reference points, a version of this model was employed to perform a risk assessment that was used to estimate Allowable Biological Catch (ABC) for the sea scallop fishery in 2010.

Description of stochastic yield model

Although the SYM model is separate from CASA, efforts were made to make the two models as compatible as possible. Recruits are initially spread out over 10 size bins (20-70 mm), and growth is modeled using a stochastic growth matrix, as in the CASA model.

Per recruit calculations depend on a number of parameters that each carry a level of uncertainty:

(1) Von Bertalanffy growth parameters K and L_∞

(2) Shell height/meat weight parameters a and b

(3) Natural mortality rate M

(4) Fishery selectivity parameters α and β

(5) The cull size of the catch and the fraction of discards that survive

(6) The level of incidental fishing mortality, i.e., non-catch mortality caused by fishing.

The mean, standard error and correlation (when applicable) for each of the parameters is given in Table B-9. Details on each of these parameters is given below.

Growth parameters K and L_∞ .

These were simulated as negatively correlated normals, using the mean and covariance from shell growth increment data, as estimated by a linear mixed-effects model (Hart and Chute 2009b), updated by including 2008 data. The level of individual variability in these two parameters was taken as estimated in the mixed-effects model without error.

Shell height/meat weight relationships.

Meat weight W at shell height H is calculated using a formula of the form:

$$W = \exp(a + b\ln(H)) \tag{1}$$

The means, variances and covariance of parameters a and b were taken from the analysis described in Appendix VII. Similar to the growth parameters, the estimates of a and b ahave a strong negative correlation. This means that the predicted meat weight at a given shell height carries less uncertainty than it would appear from the variances of the individual parameters. Meat weights vary seasonally, with the greatest meat weights during the late spring and early summer (NEFSC 2007). Haynes (1966) constructed a number of monthly shell height/meat weight relationships, and did not find any significant trend in the slopes. If this is the case, seasonality would not affect the F_{MAX} or F_{MSY} reference point. For this reason, seasonal variability was not considered a source of uncertainty for this analysis.

Natural mortality M.

As discussed in Section B3, natural mortality for sea scallops was estimated by Merrill and Posgay (1964) as

$$M = \frac{1}{S}\frac{C}{L} \tag{2}$$

where L is the number of live scallops, S is the mean clapper separation time and C is the number of clappers. Probably the greatest uncertainty in this calculation is the mean separation time S. For example, Dickie (1955) estimated S to be 100 days (14.3 weeks), less than half that estimated by Merrill and Posgay. Reflecting this uncertainty, it was assumed S was distributed as a gamma random variable, with mean 33 weeks and standard deviation 12 weeks. The resulting distribution of M has the desirable characteristic of being skewed to the right (Figure B-55). This makes sense since, for example, a natural mortality of $M = 0.2$ is possible, but an $M = 0$, or even close to zero, is not. Note that because S appears in the denominator of (2), the expected value of M is not equal to applying equation (2) with the mean value of S.

Fishery selectivity.

Fishery selectivity s was estimated using an ascending logistic curve of the form:

$$s = \frac{1}{1+\exp(\alpha - \beta H)} \tag{3}$$

where H is shell height. The means and covariances of the α and β parameters were taken as estimated by the CASA stock assessment model during the most recent selectivity period. Note that fishery selectivity reflects targeting as well as gear selectivity.

Discard mortality .

Sea scallops that are caught but are less than 90 mm are assumed to be discarded, based on observer data. Sea scallops likely tolerate discarding fairly well, provided they are returned to the water relatively promptly and they are not damaged by the capture process or their time on deck. Here, discard mortality was simulated as a gamma distribution, with a mean of 0.2 and a standard deviation of 0.15, reflecting the high uncertainty in this parameter. This feature is not included in the CASA model, but makes little difference as few scallops below 90 mm are selected in the most recent selectivity period.

Incidental fishing mortality

Incidental fishing mortality occurs when scallops are killed but not captured by the gear. Consistent with the assumptions of the CASA model, incidental mortality was estimated as 0.2 that of landed fishing mortality on Georges Bank and 0.1 in the Mid-Atlantic. Because of the considerable uncertainty in these numbers, incidental mortality was simulated here with a gamma distribution with these means and coefficients of variation of 0.75.

Stock-recruit relationships

Stock-recruit relationships were based on the basecase CASA runs and fitted to Beverton-Holt stock-recruit curves of the form:

$$R = \frac{sB}{\gamma + B}, \tag{4}$$

assuming log-normal errors (Figure B-56). Here R is recruitment, B is spawning stock biomass (or egg production), and s and γ are parameters, representing the asymptotic recruitment when B is large, and the spawning stock biomass where recruitment is half its asymptotic value, respectively. Standard errors of the stock-recruit parameters and their correlation were also estimated using the delta method.

Calculation of equilibrium yield per recruit and yield

Per recruit and stock-recruit parameters were assigned probability distributions reflecting their level of uncertainty, as discussed above. For each iteration, parameters were drawn from their distributions, and then per recruit and yield curves were calculated. This was repeated for

$n = 50000$ iterations and the results collected. The stock-recruit parameters were simulated as correlated log-normals

For each run, equilibrium recruitment at fishing mortality F is given by

$$R = s - \gamma/b(F) \tag{5}$$

where b is biomass per recruit. Total yield is therefore

$$Y(F) = y(F)R = y(F)[(s-\gamma)/b(F)] \tag{6}$$

where y is yield per recruit.

Median (and mean) per recruit and yield curves were calculated as the median (mean) of these quantities as a function of fishing mortality. The probabilistic F_{MSY} (and F_{MAX} were taken as the fishing mortality that maximizes the median yield curve. The median was preferred because it avoided strong influence by likely unrealistic model outliers. The probabilistic MSY and B_{MSY} are the median yield and biomass at F_{MSY} over all runs.

Results

Simulated yield per recruit curves on Georges Bank generally showed a distinct peak between 0.2 and 0.3, but the simulated stock-recruit curves were almost completely flat (Figure B-57). By contrast, simulated yield per recruit curves from the Mid-Atlantic were flat, with F_{MAX} highly variable among runs, which induced a high F_{MAX} (0.835) for the median yield curve (Figure B-58). The correlation between biomass and recruitment induced a much lower F_{MSY} estimate (0.43) for the median yield curve for the Mid-Atlantic. The SYM model gives overall estimates of $F_{MSY} = 0.38$, B_{MSY} = 125,358 mt and MSY = 24,975 mt (Table B-9, Figure B-59).

Estimation of Allowable Biological Catch (ABC)

Probabilistic methods such as those employed here are ideal for quantifying risk and precaution, such as that used for deriving ABCs. For the purposes of setting the 2010 sea scallop ABC, the fishing mortality corresponding to the ABC was set by the NEFMC Science and Statistical Committee at the 25th percentile of the distribution of the overall F_{MSY} (i.e., the 25th of the distribution of F_{MSY} values from the individual simulations) which at the time was estimated at 0.28. Using the current simulations, the 25th percentile of F_{MSY} is at 0.31 (Figure B-59 (b)). Equilibrium yield at 0.31 is about 0.8% less than that at F_{MSY} (Figure B-60).

Special considerations for sedentary resources under area management

The above reference point calculations are based on the assumption that fishing mortality risk does not vary among individuals. For sedentary organisms such as sea scallops, these assumptions are never even approximately true; area management such as closed areas means that the assumption of uniform fishing mortality is strongly violated (Hart 2001, 2003; Smith and Rago 2004). In such situations, mean yield-per-recruit, averaged over all recruits, may be different than yield-per-recruit obtained by a conventional per-recruit calculation performed on a recruit that suffers the mean fishing mortality risk (Hart 2001). This condition is exaggerated, as in the case of the scallop fishery, with use of rotational or long-term closures. Moreover, estimates of fishing mortality may be biased low, because individuals with low mortality risk are overrepresented in the population (Hart 2001, 2003).

TOR 5: Status Determination

According to the Amendment 10 overfishing definition (NEFMC 2003), sea scallops are overfished when the survey biomass index for the whole stock falls below 1/2 B_{TARGET}. The target biomass estimated in NEFSC (2007) is B_{TARGET} = 109,000 mt (January 1) was calculated as the median recruitment in the survey time series times BPR_{MAX}, the biomass per recruit obtained when fishing at F_{MAX}. NEFSC (2007) estimated F_{MAX}= 0.29, which has been used since then as the overfishing threshold. The updated values are F_{MAX} = 0.30 and B_{MAX} = 85,000 mt (July 1 biomass). The new recommended stochastic MSY reference points are F_{MSY} = 0.38 and B_{MSY} = 125,358 mt.

According to the basecase CASA run, total biomass in 2009 was 129,703 mt meats, which is above the estimated B_{MSY} or its proxy, regardless of whether the previous, updated or proposed biomass target is used. Therefore, the sea scallop fishery was not overfished in 2009. The probability the stock was below the 1/2 B_{MSY} biomass threshold is < 0.0001, regardless of which biomass reference point is used.

Overall fishing mortality was 0.38 (to three decimal places 0.378), which is above the previous (NEFSC 2007) overfishing threshold of 0.29 and its updated value of 0.30, but equal to the newly recommended (in 2010) F_{MSY} = 0.38. Therefore, overfishing was not occurring in 2009 based on the new recommended overfishing definition; however, overfishing would be occurring if the previous definition or its updated value were to be used. Using the new recommended overfishing definition, the probability that overfishing was occurring in 2009 was just under 0.50.

TOR 6: Stock Projections

Because of the sedentary nature of sea scallops, fishing mortality can vary considerably in space even in the absence of area specific management (Hart 2001). Area management such as rotational and long-term closures can make variation even more extreme. Projections that ignore such variation might be unrealistic and misleading. For example, suppose 80% of the stock biomass is in areas closed to fishing (as occurred in some years in Georges Bank). A stock projection that ignored the closure and assumed a whole-stock *F* of 0.2 would forecast landings nearly equal to the entire stock biomass of the areas remaining open to fishing. Thus, using a non-spatial forecasting model can lead to setting a level of landings that appears sustainable if all areas were fished uniformly, but is in fact unsustainable for a given area management policy.

For this reason, a spatial forecasting model (the Scallop Area Management Simulator, SAMS) was developed for use in sea scallop management (Appendix XII). Various versions of SAMS have been used since 1999 and the model was discussed at length in the last assessment (NEFSC 2007). Growth is modeled in SAMS and CASA in a similar manner, except that each subarea of Georges Bank and the Mid-Atlantic in SAMS has its own stochastic growth transition matrix derived from the shell increments collected in that area. Mortality and recruitment are also area-specific. In example calculations, natural mortality was chosen from a gamma distribution with means 0.12 (Georges Bank) and 0.15 (Mid-Atlantic), to be compatible with reference point calculations in the SYM model (see Section B7). Fishing mortality can either be explicitly specified in each area, calculated using a simple fleet dynamics model which assumes fishing effort is proportional to fishable biomass, or a combination of the two.

Projected recruitment is modeled stochastically with the log-transformed mean and covariance for recruitment in each area matching that observed in NEFSC dredge survey time series. Initial conditions were based on the 2009 NEFSC and SMAST sea scallop surveys with uncertainty measured by bootstrapping as described by Smith (1997). Survey dredge efficiencies were set in SAMS so that the mean 2009 biomass matched estimates from the CASA model. Further details regarding the SAMS model are given in Appendix XII.

Example calculations

Only example calculations can be given here but the model has and will be used by the NEFMC Scallop Plan and Development Team to evaluate possible management alternatives, which are complex for sea scallops. For the example simulations, the stock area was split into 16 subareas (Figure B-61), six in the Mid-Atlantic (Virginia Beach, Delmarva, Elephant Trunk, Hudson Canyon South, New York Bight, and Long Island) and ten on Georges Bank (Closed Area I, II and Nantucket Lightship EFH closures, Closed Area I, II and Nantucket Lightship access areas, Great South Channel proposed closure and the remainder of the Great South Channel, Northern Edge and Peak, and Southeast Part).

The EFH (Essential Fish Habitat) closures on Georges Bank were assumed to be closed for the duration of the simulations. One of the Georges Bank access areas were assumed to be fished on a rotating basis (Closed Area II in 2009 and 2012, Nantucket Lightship in 2010 and 2013, and Closed Area I in 2011 and 2014). Landings in these areas (as actually has occurred or is planned) were set at 1400 mt in 2009, and 2700 mt in 2010-2014. The Hudson Canyon South rotational closure area was assumed to be closed to fishing in 2009-2010, and then reopened with a TAC of 5400 mt in 2011-2013. It is assumed to revert to a general open area in 2014. The Elephant Trunk rotational area was assumed to have landings of 8100 mt in 2009, 5400 mt in 2010 and 2700 mt in 2011, and then reverts to be part of the open areas. Landings in the Delmarva rotational area are assumed to be 2700 mt in 2009 and 2010, 5400 mt in 2011 and 2012 and then it reverts to the open pool. All other areas (Virginia Beach, New York Bight, Long Island, South Channel areas, Northern Edge and Peak, Southeast Part). In projections, fishing effort was allocated to areas so that the overall fishing mortality rate was 0.24 in all years, consistent with current policy, and somewhat lower than the 2009 recommend ABC fishing mortality of 0.28. Fishing effort was distributed among the open areas according to a simple fleet dynamics model, where fishing mortality in each area was assumed to be proportional to fishable biomass.

A total of n=5000 projection runs were performed, with stochastically varying initial conditions, recruitment, and natural mortality. Projected mean biomass is expected to increase modestly from 2009-2012, mainly on Georges Bank due to the large year classes observed during 2007-2009, and then level off (Figure B-62). Landings are expected to be lower in 2010 than 2009, then increase somewhat, with a peak in 2012 at about 27,000 mt, and then level off to about 24,000 mt. Fishing mortality is expected to be greater in the Mid-Atlantic than in Georges Bank. Not surprisingly, uncertainty regarding biomass and landings increases over time (Figure B-63). Nonetheless, the 25th percentile of biomass is over 130,000 mt in all years, and thus over the target biomass. The minimum biomass of the 5000 runs stayed above the overfishing threshold through 2012, but dropped below it for 2013 and 2014. However, even the 0.1th percentile of the runs remained over the overfishing threshold in all years. Thus, the forecasts indicate that there is little chance of the stock becoming overfished under status quo management.

In summary, the projections indicate that the stock is stable, and biomass and landings may increase modestly from 2009 levels assuming status quo management. Especially given the recent selectivity patterns, the stock's vulnerability to being overfished is low.

TOR 7: Research Recommendations

Research Recommendations from NEFSC 2007

1) Refine estimates of natural mortality focusing on variation among regions, size groups and over time. Abundance trends in closed areas where no fishing occurs may provide important information about the overall level of natural mortality and time trends. Survey clapper catches may provide information about spatial, temporal and size related patterns in natural mortality.

This assessment contains a re-evaluation of natural mortality in sea scallops. Further work on natural mortality using the closed areas is ongoing.

2) Evaluate the within and between reader error rates in identification and measurement of growth increments on scallop shells.

This has not been done since there is at this time only a single reader.

3) Improve estimates of incidental and discard mortality rates.

This has not been done, but the results of this assessment indicate its importance, especially for the Mid-Atlantic.

4) Consider using autocorrelated recruitment in SAMS projection model runs. CASA model estimates indicate that sea scallop recruitment may be autocorrelated.

SAMS has the ability to model autocorrelated recruitment, but this was not done in the simulations presented here because of the difficulties in estimating the autocorrelation on the small scale that SAMS operates.

5) Consider modeling the spatial dynamics of the fishing fleet in the SAMS projection model based on catch rates, rather than exploitable abundance, of scallops in each area.

Not done

6) Evaluate assumptions about the spatial dynamics of the fishing fleet in the SAMS model by comparing predicted distributions to VMS data.

Work with VMS data is ongoing, but has been slowed due to problems obtaining the data.

7) Investigate the feasibility and benefits of using information about the size composition of sea scallops in predicting the spatial distribution of the fishing fleet in the SAMS projection model.

Not done.

8) Evaluate the accuracy of the SAMS projection model retrospectively by comparison to historical survey abundance trends.

This has been done in other venues. The SAMS model had a tendency to overestimate projected biomass and landings. The changes in the assumptions of growth, natural mortality and incidental mortality may make the forecasts more realistic.

9) Consider implementing discard mortality calculations in the CASA model that are more detailed and involve discarded shell height composition data from at sea observers.

This was considered, but not done due to lack of time. Discard mortality may be important during some periods, especially in the Mid-Atlantic. Additionally, empirical studies estimating discard mortality will be needed to make the modeling useful.

10) Consider implementing a two or more "morph" formulation in the CASA model to accommodate scallops that grow at different rates.

Not done.

11) Consider approaches to implementing seasonal growth patterns in the CASA model to improve fit to shell height composition data. Scallops grow quickly at small sizes and growth rates vary by season.

Considerable time was spent on implementing a CASA model with seasonal growth, but the model did not perform well with seasonal growth. Thus, this assessment still uses an annual growth model.

New Research Recommendations

1. Look into a way to fit discarded scallops, which have a different length frequency from the rest of the population, into the model.
2. Evaluate the effect of the four-inch rings on incidental mortality. Now that a larger fraction of small scallops are traveling through the mesh, has incidental mortality increased or are the scallops relatively unscathed?
3. Consider finding a better way to express the variation in the HABCAM abundance data (the data were kriged for this assessment, and the variance was calculated by summing the variance of each of the krieged grids).
4. Look at the historical patterns of the "whole stock"; how the spatial patterns of scallops and the fishery have changed over time.
5. Estimate incidental mortality by running Habcam or an AUV along dredge tracks
6. Effort should be made to make sure the survey dredge is fitted with a camera at some point during the survey to record the movements of the dredge. This will help answer some questions about when the dredge starts and stops fishing, and the determination of tow times.
7. Seasonal patterns in scallop shell growth need to be analyzed and this data incorporated into the model.
8. Stock-recruit relationships should be calculated for various sub-sections of the stock, smaller areas than just MAB and GBK to look for possible patterns or relationships.
9. Further refine the estimate of the extent of scallop habitat relative to that of the survey
10. Age archived scallop shells from the 1980s and 1990s.
11. Continue to look at patterns of seasonality in weight of the meats and gonads, and timing of spawning.

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