B. ASSESSMENT FOR ATLANTIC SEA SCALLOPS
(Placopecten magellanicus)

B1.0 CONTRIBUTORS

Invertebrate Subcommittee[1]

B2.0 TERMS OF REFERENCE

1. Characterize the commercial catch, effort and CPUE, including descriptions of landings and discards of that species.

2. 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.

3. Either update or redefine biological reference points (BRPs; proxies for B_{MSY} and F_{MSY}), as appropriate. Comment on the scientific adequacy of existing and redefined BRPs.

4. Evaluate current stock status with respect to the existing BRPs, as well as with respect to updated or redefined BRPs (from TOR 3).

5. Recommend modeling approaches and data to use for conducting single and multi-year stock projections, and for computing TACs or TALs.

6. If possible,

   a. provide numerical examples of short term projections (2-3 years) of biomass and fishing mortality rate, and characterize their uncertainty, under various TAC/F strategies and

   b. compare projected stock status to existing rebuilding or recovery schedules, as appropriate.

7. Review, evaluate and report on the status of the SARC/Working Group Research Recommendations offered in recent SARC reviewed assessments.

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[1] Meetings and members of the Invertebrate Subcommittee who helped prepare this assessment are listed in Appendix B1.

B3.0 EXECUTIVE SUMMARY

B3.1 TOR 1. Characterize the commercial catch, effort and CPUE, including descriptions of landings and discards of that species. (Completed – Section 4)

U.S. sea scallop landings averaged about 26,000 mt meats during 2002-2006, about twice their long-term average. Fishing effort reached its maximum in 1991 (at about 52,000 days absent), and then declined during the 1990s so that effort in 1999 was less than half that in 1991. Effort has been increasing in recent years, primarily due to increased landings and effort in the open access general category (day boat) sector. 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 2001-2006. Discards of sea scallops was unusually high during 2001-2004, averaging about 10% of landings (by weight), but declined during 2005-2006, probably due to changes in gear regulations that reduced catches of small individuals. Sea scallops are occasionally caught and discarded in other fisheries such as the *Loligo* squid and summer flounder fisheries but the overall discards in other fisheries is small relative to total sea scallop landings.

B3.2 TOR 2. 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. Completed (Section 5).

A dynamic size-based stock assessment model (CASA) was used as the primary model for sea scallops. This model was introduced in the previous benchmark sea scallop assessment but not used for estimation purposes due to its preliminary nature at that time. CASA was used in this assessment to estimate fishing mortality, (spawning) stock biomass and egg production.

Data used in CASA included commercial catch, LPUE, and commercial shell height compositions, the NMFS sea scallop and winter trawl surveys, the SMAST (School for Marine Sciences and Technology, University of Massachusetts, Dartmouth) small camera video survey, growth increment data from scallop shells, and shell height/meat weight data adjusted to take into account commercial practices and seasonality. Fishing mortality was also estimated using the rescaled F method employed in the last several assessments. The CASA and rescaled F methods gave similar results, especially for the most recent years.

The sea scallop stock was assessed in two components (Mid-Atlantic Bight and Georges Bank) separately and then combined. Estimates of fishing mortality were made from 1975-2006 in the Mid-Atlantic, and from 1982-2006 in Georges Bank and in the whole stock. Whole stock fishing mortality gradually increased during the 1980s, and peaked in 1992 at $F = 1.3$. Fishing mortality has generally declined afterwards, and the estimated fishing mortality $F = 0.23$ in 2006 was the lowest in the 1982-2006 time series.

Spawning stock biomass gradually increased from around 20,000 mt meats during 1982-1983 to a peak of 37,000 mt in 1990, and then declined to less than 17,000 mt meats by 1993. Biomass has been increasing since then, and the estimated 2006 biomass of 166,200 mt meats is the highest in the 1982-2006 time series.

Possible mild retrospective patterns were observed in the model in both regions, but not in the stock as a whole because the regional retrospectives were in different directions. CASA model estimates were reasonably precise: 95% confidence intervals for 2006 fishing mortality and spawning stock biomass were (0.17,0.32) and (152,182) thousands mt meats, respectively.

B3.3 TOR 3. Either update or redefine biological reference points (BRPs; proxies for B_{MSY} and F_{MSY}), as appropriate. Comment on the scientific adequacy of existing and redefined BRPs. Completed (Section 6).

The per recruit reference points F_{MAX} and biomass at F_{MAX} that are used as proxies for F_{MSY} and B_{MSY} were updated in this assessment based on new growth information and changes in fishery selectivity, using the CASA model. The new recommended fishing mortality threshold is 0.29, compared to the current reference point of 0.24. The new recommended biomass target is 108.6 thousand mt meats, and the recommended biomass threshold is half the biomass target, or 54.3 thousand mt meats. The current biomass reference points are a target of 5.6 kg/tow in the NEFSC sea scallop survey, adjusted for the assumed selectivity of the liner as in previous assessments, and a threshold of 2.8 kg/tow (adjusted).

The changes in fishery selectivity and new estimates of growth make updated yield per recruit curves flatter than previous curves so that F_{MAX} is more difficult estimate precisely and sensitive to assumption. In addition, the spatial variability in fishing mortality in the sea scallop fishery tends to cause per recruit reference points to overestimate the true (numbers-weighted) fishing mortality that maximizes yield per recruit. While this assessment recommends adoption of the new reference points, it also recommends that different types of biological reference points be considered for the next assessment.

B3.4 TOR 4. Evaluate current stock status with respect to the existing BRPs, as well as with respect to updated or redefined BRPs (from TOR 3). Completed (Section 7).

The U.S. sea scallop stock is not overfished and overfishing is not occurring, under both the existing and proposed new BRPs, and using the new and previous method of estimating fishing mortality. Fishing mortality in 2006 was F=0.23 using the CASA model, and 0.20 using the rescaled F approach. Both of these figures are below the current overfishing threshold of 0.24, and the new proposed overfishing threshold of 0.29. Stock biomass was estimated in 2006 as 166.2 thousand mt, which is above the proposed biomass target of 108.6 thousand mt meats and the new biomass threshold of 54.3 thousand mt meats. Adjusted NEFSC survey biomass in 2006 was 7.3 kg/tow, above the current biomass target of 5.6 kg/tow, and the current biomass threshold of 2.8 kg/tow.

B3.5 TOR 5,6. Recommend modeling approaches and data to use for conducting single and multi-year stock projections, and for computing TACs or TALs.

If possible, provide numerical examples of short term projections (2-3 years) of biomass and fishing mortality rate, and characterize their uncertainty, under various TAC/F strategies and compare projected stock status to existing rebuilding or recovery schedules, as appropriate. Completed (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. Two example short-term projections were conducted, both of which forecast modest increases in stock biomass and landings during 2007-2009. Sea scallop stock biomass is above its biomass target and not subject to a rebuilding or recovery plan.

B3.6 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)

Collaborators made substantial progress on a number of important research recommendations since the last assessment. In particular, new growth and shell height/meat weight data and models were incorporated into the assessment, estimates of rock chain adjustment factors for survey data as well as dredge selectivity estimates were improved, the CASA stock assessment model was tested, improved and used to estimate fishing mortality and biomass for status-determination purposes, and results from collaborative research programs (i.e. video surveys and selectivity studies) were integrated into assessment calculations.

B4.0 INTRODUCTION AND LIFE HISTORY

The Atlantic sea scallop, *Placopecten magellanicus,* is a bivalve mollusk that occurs on the eastern North American continental shelf. 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 Rago 2006). In Georges Bank and the Mid-Atlantic, sea scallops are harvested primarily at depths of 30 to 100 m, while the bulk of landings from the Gulf of Maine are from near-shore relatively shallow waters (< 40 m). 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 B3-1). Results for Georges Bank and the Mid-Atlantic are combined to evaluate the stock as a whole.

US landings during 2003-2006 exceeded 25,000 mt (meats) each year, roughly twice the long-term mean.[2] During 2005, US ex-vessel sea scallop revenues were over $430 million, which was higher than for any other US fishery. Unusually strong recruitment in the Mid-Atlantic Bight area and increased yield-per-recruit due to effort reduction measures are the key reasons for high recent landings. The mean meat weight of a landed scallop in 2006 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 B3-1). 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 2004-2006.

In the Mid-Atlantic, there have been four 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 2001-2005. 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 by surveys during 2002 and 2003. The Elephant Trunk area reopened during March 2007 and preliminary reports indicate very high catch levels consistent with expectations and recent survey data. A fourth closed area (Delmarva), directly south of the Elephant Trunk area, was closed in 2007 and is scheduled to reopen in 2010.

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

B4.1 Assessment history

Early attempts to model sea scallop population dynamics (NEFSC 1992, 1995, 1997, 1999) were not useful 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 in the most recent three assessments (SARC-29,32 and 39; NEFSC 1999, 2001, 2004) was estimated using a simple rescaled *F* method which relies heavily on survey and landings data (the rescaled *F* and other models were tested by simulation as part of this assessment, see Appendix B12). In the last assessment, a length-structured forward projecting model (CASA based on Sullivan et al. 1990 and Methot 2000) was introduced for preliminary evaluation. The CASA model was refined and tested and was used as the primary model for estimating fishing mortality, biomass and biological reference points for this assessment.

B4.2 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. Larvae are planktonic for 4-7 weeks before settling to the bottom. Scallops 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 the mid-1990s.[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 B3-1).

B4.3 Age and growth

Sea scallop growth is traditionally modeled using the von Bertalanffy growth equation. Previous sea scallop assessments used the growth curves estimated by Serchuk et al. (1979), but reviewers expressed concern about lack of recent information on growth. As a result, a scallop growth study was carried out using shells collected during the 2001-2006 NEFSC scallop surveys (see Appendices B2 and 3). Growth curves based on new data have lower L_∞ and higher K values than previous estimates (see table below and Figure B3-2). The growth parameter t_0 was not estimated and its value is not relevant to this assessment.

Growth parameters for sea scallops

Source	Region	L_∞	SE	K	SE
New					
	Mid-Atlantic Bight	131.6	0.4	0.495	0.004
	Georges Bank	146.5	0.3	0.375	0.002
Serchuk et al. (1979)					
	Mid-Atlantic Bight	151.84		0.2997	
	Georges Bank	152.46		0.3374	

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

B4.4 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 ($Eggs=0.0000003396\ SH^{4.07}$). 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-early spring spawning on Georges Bank.

B4.5 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 $W=\exp(\alpha+\beta\ln(L))$, where W is meat weight in grams and L 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 the last two assessments (see table below).

Shell height/meat weight parameters

	α	β	γ
Mid-Atlantic Bight			
Haynes (1966)	-11.0851	3.0431	
Serchuk & Rak (1983)	-12.1628	3.2539	
NEFSC (2001)	-12.2484	3.2641	
Lai and Helser (2004)	-12.3405	3.2754	
New	-12.01	3.22	
New with depth effect	-9.18	3.18	-0.65
Georges Bank			
Haynes (1966)	-10.8421	2.9490	
Serchuk & Rak (1983)	-11.7656	3.1693	
NEFSC (2001)	-11.6038	3.1221	
Lai and Helser (2004)	-11.4403	3.0734	
New	-10.70	2.94	
New with depth effect	-8.62	2.95	-0.51

New shell height/meat weight data was collected during annual NEFSC sea scallop surveys during July of 2001-2006. 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 (Appendix B4). Shell height/meat weight relationships based on new data give slightly higher predicted meat weights at a given shell height than NEFSC (2001), and nearly identical values at large shell heights (Figure B3-3).

Meat weights also depend on depth, with meat weights decreasing with depth, probably because of reduced food (phytoplankton) supply. Analysis of the new data indicated that depth had a significant effect on the intercept but not the slope of the shell height/meat weight relationship. Estimated coefficients for the relationship $W=\exp(\alpha+\beta\ln(L)+\gamma\ln(D))$, where D is depth in meters, are given above (see Figure B3-4). 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.

Meat weights for landed scallops 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 and landings data were used to adjust survey shell height/meat relationships for use with the commercial catch. On select tows, observers measured the shell heights of about 100 scallops, and used a graduated cylinder to determine the total volume of the meats sampled after they were shucked in the normal manner by a crew member. Data collected at sea included the number of meats, sample weight, individual shell height measurements and the depth of the tow.

Volumetric measurements by observers were converted into meat weights assuming a conversion factor of 1.05 g/cc (Caddy and Radley-Walters 1972; Smolowitz et al. 1989). The observed average meat weight (b) for each observer sample was calculated as the sample weight divided by the number of meats in the sample. In the next step, the predicted average meat weight of the sample (p) was computed based on shell height/meat weight/depth relationships from survey data and observer shell height measurements and depth data. Anomalies (a) were computed as $a = (b - p)/p$ and averaged monthly for the Mid-Atlantic Bight and Georges Bank regions to estimate a monthly time series of meat weight anomalies (Figure B3-5). Gains in meat weight during storage on ice are highly variable and uncertain but for this assessment, meats were assumed to have gained by 3% to account for absorption of water during storage and transport when computing numbers of scallops landed (DuPaul et al. 1990).

Negative meat weight anomalies mean that fishery meat weights were less than predicted based on summer sea scallop survey relationships, and vice-versa. The mean anomaly during July in the Mid-Atlantic, and August on Georges Bank were slightly negative, probably due to loss of meat during commercial shucking. Both regions show a marked drop in meat weights between August and October, coinciding with the September-October spawning period, similar to the declines noted in Haynes (1966) and Serchuk and Smolowitz (1989).

Anomalies in the Mid-Atlantic were negative in all months, with the highest meat weight in July when the research vessel samples are taken. The monthly anomalies in Georges Bank were positive only in June and July. The estimated anomalies on Georges Bank for February through May are uncertain because they were based on a limited number of observed trips and samples.

Average monthly height/meat weight anomalies were averaged using the fraction of scallops landed during each month and year to calculated average annual shell height/meat weight anomalies for the commercial fishery, i.e. the dot-product between two vectors,

$$A_y = (L_{y1}, L_{y2}, \ldots L_{y12})\cdot(a_1, a_2, \ldots, a_{12})$$

where A_y represents the annual shell height/meat weight anomaly, L_{yk} is the fraction of the total (regional) landings in year y landed in month k, and a_k is the average shell height/meat weight anomaly in month k (Figure B3-6).

In computing numbers of sea scallops landed in the Georges Bank and Mid-Atlantic each year for this assessment, reported landings (mt meats) were divided by the average weight of individuals in the catch. The average weight of individual sea scallops in the catch was calculated based on size composition, shell-height meat relationship, annual anomaly, and adjustment for water absorption.

B4.6 Natural mortality estimates from survey "clapper" data

Following previous assessments, (e.g., NEFSC 2001, 2004), the natural mortality rate for sea scallops in this assessment was assumed to be $M = 0.1\ y^{-1}$ for scallops with shell heights > 40 mm. This estimate is 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=1.58 y^{-1} from the amount of fouling on the interior of clappers. The observed ratio C/L was about 0.066 and M was estimated to be about 0.1 y^{-1}. MacDonald and Thompson (1986) found a similar overall natural mortality rate, though they suggested that natural mortality increases at larger shell heights.

Clapper ratios were calculated for sea scallops in the Mid-Atlantic and on Georges Bank (Figure B3-7). Clapper ratios for both areas tend to be lower than observed by Merrill and Posgay (1964). It is unclear whether lower clapper ratios for recent years are because of lower natural mortality, differences in the clapper separation rate or changes in clapper catchability due to the change from an unlined to a lined dredge.

There have been recent increases in clapper ratios on Georges Bank. These may represent episodic mortality events, but also could be related to the increases in size/age in the Georges Bank stock. Larger size classes tend to have higher clapper ratios, but it is unclear whether this is due to increased separation time of larger clappers or to increased natural mortality as scallops age, or a combination of both (NEFSC 2004).

B5.0 COMMERCIAL AND RECREATIONAL CATCH (TOR 1)

The US sea scallop fishery is conducted mainly by about 350 vessels with limited access permits. However, landings have increased recently from vessels with open access general category permits, which tend to be smaller vessels that fish relatively near-shore beds. General category permits allow landings up to 400 lbs of scallop meats per trip or day (whichever is greater) without requiring a limited-access permit.

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 (Table B4-1). Recreational catch is negligible; a small amount of catch in the Gulf of Maine may be due to recreational divers.

B5.1 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. Figure B4-1 gives a timeline of all management measures implemented since 1984.

FMP Amendment 4 (NEFMC 1993), implemented in 1994, changed the management strategy from meat count regulation to effort control for the entire US EEZ. Effort controls were included that incrementally restricted days-at-sea (DAS), minimum ring size, and crew limits (Figure B4-1). To comply with legal requirements, 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 the Amendment 7 days-at-sea schedule was modified by Frameworks 12-15. Frameworks 11-13 permitted temporary access to the Georges Bank closed areas in 1999-2001, and Frameworks 14-16 provided for the controlled reopening of the Mid-Atlantic rotational closures.

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). 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. Limited-access scallop vessels are restricted to a 7-man crew, which tends to limit the processing power of scallop vessels because regulations require most scallops to be shucked at sea.

B5.2 Landings

Landings from the Georges Bank and the Mid-Atlantic regions dominate the fishery. Proration of total commercial sea scallop landings into Georges Bank, Mid-Atlantic, Southern New England, and Gulf of Maine regions generally followed procedures in Wigley et al. (1998).

Sea scallop landings in the US increased substantially after the mid-1940s (Figure B4-2), with peaks occurring around 1960, 1978, 1990, and 2004. Maximum US landings were 29,109 mt meats during 2004. 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 (Figure B4-3). 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.

Until recently, the Mid-Atlantic landings were lower than those on Georges Bank. Mid-Atlantic landings during 1962-1982 averaged less than 1,800 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 before declining during 2005-2006.

Landings from other areas (Gulf of Maine and Southern New England) are minor in comparison (Table B4-1). Most of the Gulf of Maine stock is assessed and managed by the State of Maine because it is primarily in state waters. Gulf of Maine landings are generally a small percentage of the total. Gulf of Maine landings in 2006 were less than 1% of the total US sea scallop landings. Gulf of Maine landings average 475 mt meats during 1982-2006. Maximum landings in the Gulf of Maine were 1,614 mt during 1980. Southern New England landings averaged 116 mt meats during 1982-2006, with a maximum of 403 mt in 2005.

B5.3 Fishing effort and LPUE

Regulatory and reporting changes cause uncertainty in comparing trends in fishing effort and catch rates before and after 1994. 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 since 1994 (Wigley et al. 1998). These problems make it difficult to precisely estimate catches and fishing effort, and to prorate catches and fishing effort among areas and gear types.

Landings per unit effort (LPUE) (Figure B4-4) 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 on Georges Bank were seen in 2005-2006, due primarily to the reopening of portions of the groundfish closed areas. 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.

Nominal fishing effort (days absent) in the US sea scallop fishery generally increased from the mid-1960s to about 1990 (Figure B4-5a). Effort decreased during the 1990s, first because of low catch rates, and later as a result of effort reduction measures. Effort increased during 2000-2006, initially due to reactivation of latent effort among limited access vessels, and more recently due to large increases in the general category fishery.

However, LPUE in the limited access fishery has averaged about 1600 lbs/day in recent years, compared to the 400 lbs per day absent (by regulation) by a general category vessel. Thus, a day absent fishing by a general category vessel does not result in the same amount of mortality as a day absent by a limited access vessel. Adjusted days absent on trips with landings less than 500 lbs was therefore calculated as pounds landed from the trip divided by the mean LPUE of trips landing more than 500 lbs that year (Figure B4-5b). After this adjustment, the increase in effort is much more modest than what would appear based on the unadjusted data.

Another factor affecting the relationship between effort and mortality is the shucking capacity of a seven-man crew. During recent years, vessels have been able to catch scallops faster than they can be shucked. Thus, these vessels often stop actively fishing to allow the crew to shuck and process the catch before putting the gear back into the water. Data from observed (open area) trips indicates that the number of hours actually fished during a day absent dropped from around 18 in the mid-1990s to 14 or less during the most recent years (Figure B4-6a). The number of hours fished during trips to formerly closed areas is considerably less (Figure B4-6b).

Spatial distribution of effort during 1998-2006 can be assessed using data from vessel monitoring systems (VMS) that are required on most sea scallop vessels (Figure B4-7). Average speed can be inferred as distance traveled between polling events (when location data are transmitted via satellite) divided by time elapsed. Vessels traveling between 1 and 5 knots were assumed to be actively fishing. Higher speeds likely indicate steaming, whereas speeds between 0-1 knots suggest that the vessel is probably processing the catch without fishing, as discussed above. Spatial distribution of fishing effort reflects limited openings of portions of the groundfish closed areas during 1999-2001 and 2004-2006, the rotational closure of the Hudson Canyon South and Virginia Beach areas from 1998-2001, and the Elephant Trunk closure between 2004-2007.

B5.4 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 during access area trips to previously closed areas. 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 (Figure B4-8, Table B4-2).

Discard to kept ratios during scallop fishing were variable. Higher discards ratios tend to be related to strong recruitment, which induce higher numbers of undersized scallops in commercial catches. Discard ratios were low during 2005-2006, probably due to new gear regulations (e.g., 4” rings) that went into effect at the end of 2004. Sea scallop discards in the sea scallop fishery were calculated as the discard to landings ratio for observed sea scallop trips times total sea scallop landings.

Sea scallops are also caught and either landed or discarded in fisheries that target finfish and other invertebrates. To estimate of the scallop bycatch in trawl fisheries for other target species, observer sea sample data from trawl trips targeting other species were used to calculate the ratio of pounds of scallops caught for every pound of the target species landed (observers ask the captain to declare the target species for each tow).

To estimate total sea scallop discard in other directed fisheries, discard to landed ratios were multiplied times total landings of target species from VTR records. The target species on a VTR record was the species with the most landings. This procedure may understate discards to some extent because VTR records may not include all landings.

The trawl fisheries with the largest bycatch of scallops for the years analyzed (1994-2006) were longfin squid, summer flounder, yellowtail, haddock, cod and monkfish. No data were available for the clam fisheries due to lack of observer coverage but hydraulic clam dredges used in the clam fishery have minimal bycatch of fish, sea scallops, and other invertebrates. Discards of scallops in other fisheries is negligible compared to landings. In total, an estimated mean of 94 mt meats of scallops were landed and 68 mt meats were discarded per year in 1994-2006 by the six fisheries targeting other species that were most likely to catch them (Table B4-3).

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 (NEFSC 2001, 2004). Though there is considerable uncertainty due to the limited data, an estimate of about 10% (on deck) + 10% (after release) = 20% total mortality of discarded sea scallops seems reasonable.

B5.5 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) $F_I < 0.05\, F_L$. For this assessment, incidental mortality was assumed to be $0.15\, F_L$ in Georges Bank and $0.04\, F_L$ in the Mid-Atlantic.

B5.6 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 fishers 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 sea samplers 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 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, sea sample data 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 2002-2006 (Figure B4-9).

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 B4-10). 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), nearly 80% of the 2006 landings were in the two largest market categories (10-20 count and under 10 count).

B5.7 Commercial gear selectivity

New gear regulations, requiring at least 4” rings on dredges with 10” twine tops, were implemented with Amendment 10 in 2004. They were required in the Hudson Canyon South Access Area in July 2004, in the groundfish closure access programs when these opened in November 2004, and in all areas since December 2004. A study was conducted to determine the selectivity of the new gear by towing a commercial dredge side by side with an NEFSC lined sea scallop survey dredge (Yochum 2006; Appendix B5). The new gear has a more gradual selectivity curve that is shifted to the right compared to the gear with 3.5” rings in use during 1996-2004 (Figure B4-11).

B5.8 Economic trends in the sea scallop fishery

Economic benefits from the sea scallop fishery have increased in recent years providing a larger supply of scallops for the consumers and higher revenue for the fishermen at lower costs. Landings from the northeast sea scallop fishery increased dramatically after 2001, surpassing all levels observed historically (Figure B4-12).[4] Scallop ex-vessel revenue fell to its lowest recorded level of $92 million during 1998 (Figure B4-13). Since 1998, revenue from scallops has increased steadily each year, exceeding $440 million in 2005 and $380 million in 2006.

Historical trends in the sea scallop fishery for three time periods are compared in the table below. The first period, from 1989 to1992, summarizes the scallop fishery during a period when annual landings averaged above 16,000 mt and revenues averaged $215 million. During the period from 1993 to1998, overfishing in the previous years combined with the effort reduction measures and closure of the Georges Bank groundfish areas resulted in a dramatic decline in scallop landings and revenues. The period from 1999 to 2006 corresponds to the rebuilding of the sea scallop biomass and the consequent increase in scallop landings, revenues and exports to historical high levels. The average revenue per year for this period, over $270 million, was more than double the average revenue of $116 million per year during 1993-1998.

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[4] Although part of the increase in 2004 was due to some overfishing in the Mid-Atlantic, which is expected to decline in 2005, there is no question that increased scallop landings since 1999 were due primarily to increased scallop biomass.

Summary of economic trends in the scallop fishery (dollar values adjusted for inflation and expressed as 2006 prices)

Data - Annual averages	Period		
	1989-1992	1993-1998	1999-2006
Ex-vessel Price of scallops ($ per lb.)	4.2	5.8	5.2
Scallop Revenue ($ million)	215.0	115.9	270.6
Average meat count	37.7	36.5	21.7

There were some significant changes affecting scallop ex-vessel prices and revenues after 1999:

- In the past scallop prices increased when landings declined, and vice-versa. As Figure B4-12 shows, however, both landings and the ex-vessel price of scallops increased after 2001.
- The shifts in landings towards larger scallops that command a higher price was important factor increasing revenues after 1999 (Figure B4-10).
- Scallop revenues in 2005 and 2006 were more than three times higher than in 1994-98.

B6.0 FISHING MORTALITY AND STOCK BIOMASS (TOR #2)

NEFSC sea scallop survey data used in this assessment to estimate fishing mortality and biomass are from 1982-2006 for Georges Bank and 1975-2006 for the Mid-Atlantic. 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 B5-1). The 1975-1978 surveys used a 3.08 m (10') unlined dredge. A 2.44 m (8') survey dredge with a 4.4 cm (1.75") plastic liner has been used consistently since 1979. 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 *R/V Albatross IV* was used for all NEFSC scallop surveys except during 1990-1993, when the *R/V Oregon* 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* 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 for the *R/V Albatross IV*, *R/V Oregon* and *R/V Chapman* based on a complete randomized block gear experiment (3 vessels x 13 stations=39 tows) in stratum 34.

The *F/V Tradition* was used to complete the 1999 survey on Georges Bank. The *F/V Tradition* towed the standard NMFS scallop survey dredge as well as a New Bedford commercial scallop dredge side by side. For the purposes of computing survey trends, only data from the NEFSC survey dredge was used. NEFSC (2001) found no statistically significant differences in catch rates between the two vessels from 21 comparison stations after adjustments were made for tow path. Therefore, as in previous assessments (e.g., NEFSC 2004), survey indices for the period 1990-93 based on data from the *R/V Oregon* were used without adjustment, and survey dredge tows from the *F/V Tradition* in 1999 were used after adjusting for tow distance.

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.

B6.1 Imputed survey data

No valid tows were performed during some years for a few strata. In these cases, survey values for the missing strata were imputed using a generalized linear model (see Appendix B6). Results were very similar to the "borrowing" procedure used in previous assessments. Imputed data were supplied after all post-stratification was completed so that survey data (real or imputed) were available for every stratum assumed in calculations.

B6.2 Rock chains

Rock 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). Preliminary analysis in the last assessment (NEFSC 2004) was augmented by additional gear experiments and statistical analysis (Appendix B9) to estimate rock chain effects on survey data. Results were difficult to interpret because rock chain effects appear to have varied from year to year. However, the best overall estimate was that rock chains increased survey catches on hard grounds by 1.31 times (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 due to the rock chain adjustment was accommodated by calculating the variance of the adjusted strata means $\sigma^2 = 1.32^2 \sigma_n^2 + 0.257^2 n^2$ where *n* is the mean catch per tow for the stratum, σ_n^2 was the variance for mean catch per tow and 0.257=1.31*0.196 was the standard error of the adjustment factor.

B6.3 Stratum areas and post-stratification

NEFSC shellfish survey stratum areas calculated using GIS by NEFSC (2001) were used in this assessment (Figure B5-1). 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).

Rules for splitting strata along open/closed boundaries, assigning small portions to adjacent strata, and grouping strata into regions were the same as in NEFSC (1999) and Table B5-4 in NEFSC 2001), with a few refinements. The Closed Area II region was broken into two new regions by assigning the closed portions of survey strata 6621, 6610 and 6590 in Closed Area II to the new "Closed Area II (South)" region. All other portions of Closed Area II were assigned to the new "Closed Area II (North)" region. This allows the assessment to accommodate disparate population dynamics of the northern and southern areas of Closed Area II. The southern part of Closed Area II was heavily fished in 1999-2000. A very large (1998) year class was observed there during the 2000 and subsequent NMFS scallop surveys. By contrast, the northern portion of Closed Area II has not been fished since December, 1994.

NEFSC (2004) post-stratified the Nantucket Lightship Closed Area by defining a new stratum in the northeast corner of this area. Surveys show considerably higher recruitment and biomass in this area than elsewhere in the Nantucket Lightship area. Extra tows that have been added to the northeast corner of the Nantucket Lightship Area in surveys during recent years are random with respect to the new stratification scheme and were used to increase the accuracy of abundance estimates.

B6.4 Survey dredge selectivity

Beginning in 1979, NEFSC sea scallop surveys used a 2.44-m (8-ft) wide dredge equipped with 5.1-cm (2-in) rings and a 3.8-cm (1.5 in) plastic mesh liner. Serchuk and Smolowitz (1980) compared catches from lined and unlined survey dredges, and found that the unlined dredge caught more large (>75 mm) while the lined dredge retained more small scallops. Other experiments comparing unlined commercial gear with a lined survey dredge found similar apparent reductions in catches of large scallops (NEFSC 2001, 2004; Yochum 2006). Based on these data, NEFSC (1995; 1997) assumed that the efficiency of the lined dredge was greater at small shell heights that at larger ones, and estimated a declining logistic selectivity curve with relatively low selectivity on scallops 60+ mm SH (Figure B5-2). In retrospect, the declining logistic shape of the estimated selectivity curve used in previous assessments was due to using shell height composition data from the unlined dredge in Serchuk and Smolowitz (1980) as a standard in estimating the selectivity of the lined dredge.

Shell height data from SMAST video surveys during 2003-2006 (Appendix B8) were used in this assessment as the standard in re-estimating survey dredge selectivity. The video survey data was particularly useful in this context because video cameras sample sea scallops 40+ mm SH (small camera) and 70+ mm SH (large camera, Appendix B7) with nearly full efficiency. Results (Appendix B8) indicate that the survey dredge has constant selectivity and efficiency for sea scallops 40+ mm SH, corresponding to the 38 mm mesh liner used in the survey dredge. For this reason, no adjustment was made to dredge survey shell height composition or abundance indices in this assessment to accommodate survey dredge selectivity.

The net effect of new assumptions about survey dredge selectivity is to reduce the absolute magnitude of survey abundance indices because the relative abundance of large sea scallops is not artificially increased. More importantly, the relative abundance of small scallops is higher in unadjusted dredge survey composition data. A number of analyses in this assessment are carried out using survey data with and without the selectivity adjustment to link results from new and previous methods. However, survey time series without selectivity adjustments are preferable on technical grounds.

B6.5 Non- and fully-recruited survey indices

Following NEFSC (2004), and for comparative purposes, unadjusted dredge survey data were partitioned into non-recruited (not vulnerable to commercial dredges) and fully recruited (completely vulnerable to commercial dredges) groups by applying a commercial 3.5” dredge selectivity function developed by consensus (NEFSC 1995):

$$s_h = \begin{cases} 0 & \text{if } h \le h_{\min} \\ \dfrac{h - h_{\min}}{h_{full} - h_{\min}} & \text{if } h_{\min} < h < h_{full} \\ 1 & \text{if } h \ge h_{full} \end{cases}$$

where h_{min} = 65 mm and h_{full} = 88 mm. Note that fishery selectivity has changed over time, and the above curve approximates fishery selectivity during the mid- to late 1990s. Current fishery selectivity has shifted considerably towards larger scallops. However, non- and fully recruited abundance and biomass indices are useful in describing historical trends based on a familiar measure.

B6.6 Survey abundance and biomass trends

Biomass and abundance trends for the Mid-Atlantic Bight and Georges Bank are presented in Table B5-1 and Figure B5-3. Only random tows were used except in the post-stratified portion of the Nantucket Lightship Area (see above). Variances for strata with zero means were assumed to be zero. Confidence intervals were obtained by bootstrapping (Smith 1997, Figure B5-4).

In the Mid-Atlantic Bight, abundance and biomass were at low levels during 1975-1997, 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 during 2003 to 2006. In Georges Bank, biomass and abundance increased during 1995-2000 after implementation of closures and effort reduction measures. Abundance and biomass have been modestly declining during recent years, due to poor recruitment and to reopening of portions of the groundfish closed areas. Survey shell height frequencies show a trend to larger shell heights in both regions in recent years, coinciding with the period of increased biomass and abundance and recent recruitment levels (Figure B5-5).

Sea scallop biomass during 1994 (just before the Georges Bank closed areas and effort reduction measures were implemented), and during the most recent 2006 survey (Figure B5-6), shows considerable increases since 1994 in most areas. Increases are especially pronounced in the Georges Bank closed areas and the Elephant Trunk area that was closed during 2004-2007 after exceptional recruitment was observed there.

B6.7 SMAST video survey

Video survey data collected by the School for Marine Sciences and Technology (SMAST), University of Massachusetts, Dartmouth during May-September of 2003-2006 was used in this assessment. SMAST survey data are counts and shell height measurements from images that were recorded by two types of video camera. The “large” camera was mounted 1.575 m above the bottom in the center of the sampling frame with an effective sampling area of 3.235 m^2 of sea bottom. The “small” camera was mounted 0.7 m above the bottom with an effective sample area of 0.788 m^2. The effective sampling area includes the area within the sample frame plus an extra 75 mm around the edge of the frame to account for scallops on the edge of the frame. Data from the small camera were used to estimate the size selectivity of the NEFSC scallop dredge (Appendix B8), the large camera (Appendix B7) and as an input to the CASA model. All calculations assume that the small camera has 100% sampling efficiency and flat selectivity for sea scallops 40+ mm SH. Selectivity of the large camera is >90% for scallops 70+ mm SH (Appendix B7).

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” 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 work in progress (K. Stokesbury, SMAST, pers. comm.) 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 (see NEFSC 2004, Appendix 1). The standard deviation of measurements from small camera images is assumed in this assessment to be 6.1 mm also for lack of better information.

Video survey data (Tables B5-2 and B5-3) in this assessment are expressed as densities (number m^{-2}). Variances for estimated densities are approximated from the variance among station means in each year. Areas sampled in the video survey differ somewhat from the areas sampled in the dredge survey (Figure B5-7). There was some variability in the areas covered during each year (Figure B5-7 and Tables B5-2 and B5-3).

B6.8 Simple biomass and fishing mortality estimates

The NEFSC survey can be used to obtain an estimate of absolute biomass provided dredge efficiency can be estimated. Commercial dredge efficiency has been estimated at 0.4 – 0.55 in Georges Bank and 0.57 in the Mid-Atlantic (NEFSC 1999, 2001; Gedamke et al. 2004, 2005). Based on the data discussed above, a liner reduces the efficiency of the survey dredge by a factor of about 0.715. Thus, these commercial dredge efficiencies translate into survey dredge efficiencies of about 0.29-0.36 in Georges Bank and 0.41 in the Mid-Atlantic. Comparison of abundances between the NEFSC dredge and SMAST video survey suggests that survey dredge efficiency is about 0.38 on Georges Bank and 0.43 in the Mid-Atlantic (Appendix B8). Based on these figures, the survey swept area biomasses and abundances were calculated using an estimated survey dredge efficiency of 0.36 on Georges Bank and 0.42 in the Mid-Atlantic, and using an estimated mean tow path of 4516 m^2 (NEFSC 2004), using the formula

$$B_y^* = \frac{b_y A}{a\ e}$$

where b_y is mean meat weight per tow from the survey in year y, B_y^* is survey stock biomass, a is the area (nm^2) swept by a standard tow, e is efficiency, and A is the size (nm^2) of the stock area or region.

Fishing mortality rates ${}^cF_y$ (biomass-weighted) can then be estimated as:

$${}^cF_y = \frac{C_y}{B_y^*}$$

where C_y is the meat weight of scallops killed by fishing during the calendar year (Ricker 1975). The survey is conducted during July-August, approximating the average annual biomass. However, C_y represents reported landings only, and the mortality estimate will be biased low if there were non-reported landings, or if there was non-yield fishing mortality. Additionally, these estimates are biomass-based mortality rates, which tend to be biased low compared to numbers-based mortality rates, particularly when there is spatial heterogeneity in fishing mortality (Hart 2001). Because of these issues and uncertainty in the estimates of dredge efficiency, this simple fishing mortality estimator is used only as an indicator of fishing mortality trends (NEFSC 1999, 2001, 2004).

B6.9 Survey-based (two-bin) method

The survey-based approach divides the survey data for each year into two shell height size bins. The first bin approximates the size range of new recruits to the fishery. The second bin includes sea scallops of all larger sizes.

Based on updated growth information, the first bin for Georges Bank consisted of scallops of 80-100.8 mm shell height and the second bin consisted of all scallops larger than 100.8 mm. An 80 mm sea scallop was almost fully recruited to the fishery (except during the most recent period) and will grow to 100.8 mm in one year, according to growth increments from collected shells. For the Mid-Atlantic region, the first bin consisted of 80-98 mm scallops and the second bin consisted of scallops larger than 98 mm. Using these data, survey-based fishing mortalities were calculated:

$$^{s}F_t = -\ln\left(\frac{P_{t+1}}{R_t + P_t}\right) - M,$$

where R_t was the mean population number of scallops per standard survey tow in the first bin (new recruits) during survey year *t*, and P_t was the mean number of scallops per standard survey tow in the second bin. Survey years are the annual period between NEFSC sea scallop surveys (summer to summer).

B6.10 Rescaled catch-biomass method

Rescaled catch-biomass estimates were used during the last three assessments as the primary estimator of fishing mortality rates (NEFSC 1999, 2001, 2004; Hart 2006), Rescaled survey-based estimates were computed as:

$$^{r}F_y = {}^{c}F_y\left(\frac{^{s}\overline{F}}{^{c}\overline{F}}\right)$$

where average catch-biomass $^{c}\overline{F}$ and survey-based $^{s}\overline{F}$ fishing mortality rates were for a time period of many years that contains year *y*. This estimator is based on the idea that the catch-biomass estimate tracks the trend in fishing mortality accurately, while the appropriate overall scale is given by mean survey fishing mortality rates. The rescaled *F* gives a smoother trend than the survey fishing mortalities, and, unlike the simple catch/biomass method, is numbers based and does not require assumptions about dredge efficiency and incidental mortality. For this assessment, survey and landings data from 1979-2006 for sea scallops in the Mid-Atlantic and 1982-2006 for sea scallops on Georges Bank were used to estimate the ratio of $^{c}\overline{F}$ and $^{s}\overline{F}$.

As in NEFSC (2004), coefficients of variation (CVs) for rescaled fishing mortality estimates were approximated considering variability in the survey data (measured by CVs for random stratified means), and landings data (assumed CV of 10%).

B6.11 Whole-stock rescaled F estimates

Because of differences in e.g., growth rates, between Georges Bank and the Mid-Atlantic, fishing mortalities were calculated separately for the two areas. Whole-stock estimates of fishing mortality are required, however, for comparison to biological reference points used to identify overfishing and overfished stock conditions.

Whole stock estimates were calculated by averaging estimates for Georges Bank and the Mid-Atlantic using the area surveyed in the NEFSC dredge survey in each region as weights. A variety of evidence indicates that dredge efficiency on Georges Bank is lower than in the Mid-Atlantic, so swept-area abundances in the Mid-Atlantic were multiplied by 0.875 before averaging (0.875 is approximately the ratio of survey dredge efficiencies between the two areas, see Appendix B8). Results for the whole stock were only very slightly sensitive to the assumed value of this factor.

Survey-based and rescaled *F* estimates both show generally increasing fishing mortality until the early 1990s, with reductions during 1994-2006 (Table B5-4, Figure B5-8).

B6.12 Model-based fishing mortality and biomass estimates

CASA model estimates are the best scientific information about sea scallop population dynamics available in this assessment (a complete technical description of the CASA model is in Appendix B10). A CASA model for sea scallops was presented for preliminary review in the last stock assessment (NEFSC 2004) and received positive comments. Simulation testing described in this assessment indicates generally good model performance. Base case model estimates for Georges Bank and the Mid-Atlantic Bight use all of the available data and appear reasonable in comparison to estimates from the rescaled *F* model used previously (see below). Sensitivity analyses (see below) suggest that base case estimates for sea scallops are reasonably robust. CASA models in this assessment are used to estimate fishing mortality, biomass and biological reference points based on the same assumptions and using the same computer code, ensuring that the fishing mortality and biomass measures are comparable to biological reference points. CASA model estimates appear relatively precise.

B6.13 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 $C = F\overline{N}$.

Asymptotic delta method variances calculated in CASA with AD-Model Builder software were used to compute variances and coefficients of variation (CV) for whole stock estimates 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 $CV_F = \sqrt{CV_C^2 + CV_{\bar{N}}^2}$, which is exact if catch number C_N and average abundance $\overline{N}$ are independent (Deming 1960). The CV for measurement errors in catch for each region was 0.05, the same as assumed in fitting the CASA model.

Whole stock estimates indicate that annual abundance, annual egg production and biomass (Table B5-5 and Figures B5-9 to B5-11) were relatively high during 2006. In contrast, recruitment was relatively low during 2006 (Table B5-5 and Figure B5-12). Fishing mortality during 2006 (Table B5-5) was similar to rescaled *F* fishing mortality estimates used in the last assessment (Figure B5-13). CV values indicate that abundance, biomass and fishing mortality estimates were relatively precise for individual regions and for the stock as a whole (Table B5-6 and Figure B5-14). The relatively small CVs but likelihood profiles and MCMC probability intervals (not shown) confirmed the asymptotic variances for recent biomass and fishing mortality.

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. However, estimates were relatively precise because of the long time series of relatively precise dredge survey data (CVs averaging 23% for Georges Bank during 1982-2006 and 12% for the Mid-Atlantic Bight during 1979-2006) and recent video survey data (overall CVs averaging 14% during 2003-2006). The assumption of flat selectivity curves for the two surveys substantially enhances precision, as does the prior information about sampling efficiency in the video survey.

B6.14 Retrospective patterns

CASA model runs for Georges Bank and the Mid-Atlantic show possible retrospective patterns that cancel out when estimates for the two areas were combined (Figure B5-15). The possible retrospective tendencies may be due to anomalously high dredge survey abundance for Georges Bank in 2000 and anomalously high dredge and video survey abundances for Mid-Atlantic Bight during 2003. Bootstrapped survey estimates show unusually high variances for survey data during these years (Figure B5-3). When areas are combined, effects of unusual survey data and possible uncertainties in allocating landings between the two areas are diminished. The closure of the Elephant Trunk area during 2004-2006, and closures and reopenings on Georges Bank may be partially responsible for the retrospective patterns. Preliminary model runs that included spring and fall bottom trawl survey data for the Mid-Atlantic Bight (not shown) showed no evidence of retrospective patterns.

B6.15 CASA models for the Mid-Atlantic Bight and Georges Bank

CASA models for the Mid-Atlantic Bight and Georges Bank were configured as described in Table B5-7. Estimated parameters and asymptotic standard deviations are given in Tables B5-8 and B5-9. Diagnostics indicate that base case models for both areas fit reasonably well in most cases (Figures B5-16 to B5-19).

There was a noticeable lack of fit to commercial shell height composition data for 1975-1980 in the Mid-Atlantic Bight because shell height composition data from the 10 ft unlined dredge survey for 1975, and 1977-1978 showed a different pattern with higher frequencies of large scallops (Figure B5-19). In retrospect, the commercial fishery during the late 1970s would have been better modeled with a separate dome-shaped fishery selectivity pattern with low selectivity on the largest scallops which were probably outside of traditional fishing grounds. However, sensitivity analysis showed that estimates were almost unchanged when data 1975-1978 were omitted (see below). Commercial shell height composition data during the late 1970s probably had little effect because the data were down-weighted using low effective sample sizes in goodness of fit calculations. Sea scallop population dynamics during years prior to 1979 and the advent of the modern sea scallop dredge survey is an important topic for future research.

B6.15.1 Likelihood profile analysis

Likelihood profile analysis indicates that base case CASA models for sea scallops on Georges Bank and in the Mid-Atlantic Bight struck a reasonable balance between different sources of information and key data sources generally supported similar estimates of recent fishing mortality and biomass. Likelihood profiles are useful because they identify the statistical support among various data sources for a range of recent biomass and fishing mortality estimates (Tables B5-10 and B5-11). Profiles were constructed by holding the survey scaling parameter (catchability coefficient) for the SMAST video small camera survey fixed at a series of values while estimating all other parameters in the model. The scaling parameter for the SMAST video survey was ideal for this purpose because it would be expected to have values near 0.5 and because this parameter has a direct impact on recent biomass and fishing mortality estimates. At each point in the likelihood profile, estimated 2006 biomass and fishing mortality and “naked” (unweighted) likelihood were recorded for each type of data and constraint.

In interpreting likelihood profiles, it is useful to know that a difference of 1.92 likelihood points is often used to identify differences that are statistically significant at the p=0.05 level. The 1.92 rule of thumb is approximate and based on asymptotic arguments.

The total likelihood for the base case Georges Bank model had a well defined minimum around the base case solution (Table B5-10). The trend in the dredge survey, which is the most important source of trend information, and short trend in video survey data fit best near the base case solution. Commercial landings and LPUE data and the constraint on recruitment support higher 2006 biomass levels, although the likelihoods for commercial catch and LPUE were relatively flat. The likelihood for the prior on efficiency of the SMAST video survey was lowest at 0.5 (as expected) supporting a higher 2006 biomass estimate. All three types of shell height composition data support lower 2006 biomass estimates but the likelihoods for shell height composition data were relatively flat.

The total likelihood for the base case Mid-Atlantic Bight model had a well defined minimum around the base case solution (Table B5-11). The trend in the dredge survey, which is the most important source of trend information in the model, and short trend in video survey data fit best near the base case solution. In contrast, the winter bottom trawl survey fit best at lower 2006 biomass levels and the short trend in unlined 10 ft scallop dredge survey data fit best at higher 2006 biomass levels, although the likelihood surface for both was relatively flat. Fall and spring bottom trawl survey data (which did not affect model estimates) support lower 2006 biomass estimates. Commercial landings and LPUE data and the constraint on recruitment deviations fit best at lower 2006 biomass levels although the likelihood surface for catch and LPUE was relatively flat. The likelihood for the prior on efficiency of the SMAST video survey was lowest at 0.5 (as expected) supporting a higher 2006 biomass estimate. Commercial and survey shell height composition data, with the exception of the unlined 10 ft scallop dredge survey, support higher biomass 2006 estimates although likelihood surfaces were relatively flat for the dredge and winter bottom trawl shell height composition data.

B6.15.2 Sensitivity analysis

Several alternative model runs were carried out with CASA models for the Mid-Atlantic Bight to identify uncertainties and affects of modeling decisions. Mid-Atlantic Bight models were used for sensitivity analysis because of the similarity in structure between models for the two areas and because more types of information were available for the Mid-Atlantic Bight.

Results indicate that biomass estimates for sea scallops in the Mid-Atlantic Bight region were robust to uncertainties and modeling decisions (Table B5-12 and Figure B5-20). The only sensitivity analysis run with substantially different recent biomass and fishing mortality estimates was one that included fall and spring bottom trawl trend and shell height composition in fitting the model. As described under profile analysis, the fall and spring trend data support lower biomass estimates than the base case model.

B7.0 BIOLOGICAL REFERENCE POINTS (TOR 3)

Biological reference points, fishing mortality rates and biomass estimates used in status determination here are for the entire US sea scallop stock. Because of the lack of well-defined stock-recruitment relationships for sea scallops, per recruit reference points F_{MAX} and B_{MAX} are used by managers 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} for sea scallops is the product of BPR_{MAX} (biomass per recruit at $F= F_{\mathrm{MAX}}$, from yield-per-recruit analysis) and median numbers of recruits.

The current biological reference points are $F_{\mathrm{MAX}} = 0.24$ and $B_{\mathrm{MAX}} = 5.6$ kg/tow (in survey units, adjusted for the survey dredge liner as in previous assessments NEFSC 2001, 2004). The current F_{MAX} reference point was originally calculated by Applegate et al. (1998) using an age-based (Thompson-Bell) yield per recruit calculation. NEFSC (2004) found a similar value for F_{MAX} using a size-based yield per recruit calculation, and left this reference point unchanged. The current value of B_{MAX} was calculated in NEFMC (2003) as a product of BPR_{MAX} (from the per recruit calculations in NEFSC 2001) with median survey recruitment from 1979-2002 (Mid-Atlantic) and 1982-2002 (Georges Bank).

The CASA model was used to recalculate per recruit curves for Georges Bank and the Mid-Atlantic Bight assuming the selectivity patterns during 2006, growth increment data, etc. Yield and biomass per recruit curves for the two regions were fairly similar (Figure B6-1), although growth patterns are different and fishery selectivity curves for the two areas during 2006 were offset by about 10 mm (Figures B3-2 and B6-1).

Per recruit curves for the two areas were combined to approximate a per recruit model for the whole stock. The goal was to estimate curves that would have been calculated if the two regions had been modeled together. Whole stock yield- and biomass per recruit curves (Figure B6-1) were calculated by averaging yield per recruit curves for the two regions using median recruitment during 1983-2006 (the longest period with recruit estimates for both areas) as weights. F_{MAX} (F_{MSY} proxy) and B_{MAX} (B_{MSY} proxy, 40+ mm SH on January 1) are from the whole stock per recruit curves (Table B6-1). As in previous sea scallop assessments (NEFSC 2004), the B_{MSY} target reference point for the whole stock was estimated as the product of biomass per recruit at F_{MAX} and median recruitment for the whole stock during 1983-2006 (Table B6-1).

The per recruit reference points F_{MAX} and B_{MAX} are reasonable proxies for F_{MSY} and B_{MSY} provided that recruitment is independent of stock size or has reached its asymptotic value at B_{MAX}, and if fishing mortality as well as other parameters do not vary over space. There was no compelling evidence of a spawner-recruit relationship for either area that would tend to undermine F_{MAX} as an F_{MSY} proxy. As in previous assessments, the biomass threshold was $B_{MSY}/2$.

However, there are special considerations for sedentary organisms such as sea scallops where fishing mortality is not uniform and particularly when closed areas are present. In such a case, 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. Recent research indicates that the (numbers- or biomass- weighted) fishing mortality that achieves maximum or optimal yield may be less than that indicated by a conventional yield-per-recruit analysis when there is spatial variability in fishing mortality (Hart 2001, 2003).

B7.1 Examination of possible stock-recruit relationships

This section was added at the request of the SARC panel. Sea scallop recruitment and egg production for the Mid-Atlantic and Georges Bank were estimated using the CASA model (Figure B6-2, Table B5-5). Mid-Atlantic sea scallop egg production remained low from 1975-1997, but increased about 10-fold from 1997-2006. Sea scallop recruitment was poor from 1975-1981 and was moderately strong but variable from 1982-1995. The 1996-2001 year classes were all very strong; all but the 2000 year class was larger than any year class during 1975-1995. Recruitment was below average in 2002 and 2004, but was strong in 2003. The plot of recruitment vs. egg production (Figure B6-3a) suggests the possibility that the increased egg production was at least partially responsible for the strong recent recruitment. However, the period of strong recruitment started before any increase in egg production, so that autocorrelated environmental factors may also explain the increase in recruitment. A fit of a Beverton-Holt curve to the data, assuming log-normal errors, suggests the possibility that recruitment overfishing was occurring prior to 1999, when egg production was less than 20 quintillion. This fit ignores any import of larvae from Nantucket Shoals and Georges Bank, which might be significant but is not quantifiable at this time. Assuming the proposed target biomass (108.6 thousand mt meats) was equally split between Mid-Atlantic and Georges Bank, this reference point corresponds to about 60 quintillion eggs. Egg production at the target biomass appears to be sufficient to saturate the stock-recruit relationship, so that there is little concern of recruitment overfishing if biomass remains at or over the proposed target. It also appears that the biomass threshold, corresponding to about 30 quintillion eggs, is a reasonable point to take action to prevent possible recruitment overfishing.

Georges Bank egg production was relatively low from 1982-1995, but has increased substantially since then (Figure B6-2b). Recruitment appears fairly trendless, with strong recruitment during the late 1980s, and a very strong 1998 year class. Except for the 2001 year class, recruitment during 1999-2004 has been below average. A plot of recruitment vs. egg production (Figure B6-3b) gives no indication that the recent increase in egg production has led to an increase in recruitment. A fit of these data to a Beverton-Holt stock-recruit curve, assuming log-normal errors, suggests that the stock-recruit curve is already saturated at 20 quintillion eggs, about the number of eggs released in 1996-1997, so that the subsequent increases in egg production had little effect. However, this analysis neglects the egg production in the Canadian side of Georges Bank which in many years may have contributed 30-50% of the total egg production. Additionally, there are no observations below the estimated half-saturation point of the stock-recruit curve, so that the half-saturation point cannot be well estimated. However, again it can be concluded that there is little concern regarding recruitment overfishing if biomass is at or over its target (corresponding to about 60 quintillion eggs on Georges Bank) or even at the biomass threshold (corresponding to about 30 quintillion eggs).

B8.0 STATUS DETERMINATION (TOR 4)

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_{MAX}. Overfishing occurs if fishing mortality exceeds F_{MAX}. As described above, managers use F_{MAX} from yield-per-recruit analysis and B_{MAX} 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 (see above). The current target biomass level B_{TARGET} was calculated as the median recruitment in the survey time series times BPR_{MAX}, the biomass per recruit obtained when fishing at F_{MAX}. The current management reference points are $F_{MAX} = 0.24\ \mathrm{y}^{-1}$ and $B_{TARGET} = 5.6$ kg/tow (adjusted for the liner as in previous assessments).

Overfishing was not occurring in the sea scallop stock and overfishing was not occurring during 2006, based on the reference points currently in use and the fishing mortality estimator used in previous assessments (NEFSC 2001, 2004). Based on the 2006 NEFSC scallop survey, sea scallop biomass (adjusted for assumed dredge selectivity) was about 7.3 kg/tow, well above $B_{MAX} = 5.6$ kg/tow. The overall rescaled F fishing mortality estimate for the whole stock 2006 was 0.20 (rescaled F), which is below the overfishing threshold of $F_{MAX} = 0.24$.

Based on the new recommended reference points and CASA model estimates, the US sea scallop stock was not overfished and overfishing was not occurring in 2006. This assessment proposes the new reference points of $F_{MAX} = 0.29$, a target biomass reference point of 108.6 thousand mt meats, and a biomass threshold of 54.3 thousand mt meats. The best estimate for fully recruited fishing mortality during 2006 is $F = 0.23$ (95% confidence interval 0.17-0.32, Figure B7-1), which is well below the proposed threshold $F_{MAX} = 0.29$. Based on the variance in estimated fishing mortality, there is only a 7% chance that fishing mortality was above the recommended fishing mortality threshold during 2006. Estimated stock biomass for sea scallops during 2006 was 166 thousand mt (95% confidence interval: 152-182 thousand mt, Figure B7-2). Based on the variance in estimated biomass, there is less that a 0.1% probability that the sea scallop biomass was below the biomass threshold of 54.3 mt meats.

B9.0 STOCK PROJECTIONS (TOR 5-6)

Example stock projections were made for two assumed scenarios. Under the first scenario, F=0.20 (the current target) during 2007-2009. The second set of projects assumes F=0.24 (the current F_{MSY} proxy and fishing mortality threshold, and a potential new target) during 2007-2009.

Because of the sedentary nature of sea scallops, fishing mortality of sea scallops 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

(Figure B4-7). 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. Various versions of SAMS have been used since 1999 (NEFSC 2004). Growth is modeled in SAMS and CASA in a similar manner, except that each area 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. 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. Shell height/meat weight relationships were from the 2001-2006 R/V data, adjusted using the mean annual fishery shell height/meat weight anomaly during 1997-2006 (see Appendix B4 and Figure B3-6).

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 2006 NEFSC sea scallop survey with uncertainty measured by bootstrapping as described by Smith (1997). Survey dredge efficiencies were set in SAMS so that the mean 2006 biomass matched estimates from the CASA model. Further details regarding the SAMS model are given in Appendix B11.

For these simulations, the stock area was split into 15 subareas, six in the Mid-Atlantic (Virginia Beach, Delmarva, Elephant Trunk, Hudson Canyon South, New York Bight, and Long Island) and nine on Georges Bank (Closed Area I, II and Nantucket Lightship EFH closures, Closed Area I, II and Nantucket Lightship access areas, Great South Channel, Northern Edge and Peak, and Southeast Part). The Delmarva area was closed on a rotational basis in 2007, and is assumed to be fished at 0.2 for the first year (since the simulation starts in July 2006), and then closed during the remainder of the simulation.

The Elephant Trunk area was reopened in 2007 after a three year closure, and scheduled to remain a special access area with its own TAC and target fishing mortality for the three years of the simulation. It is subject to an increasing pattern of fishing mortality during the three year simulations (0.16, 0.24, 0.32 in the first set of simulations; 0.16, 0.29, 0.38 in the second set of simulations). The Hudson Canyon South area was closed in 1998-2001 and 2007 is the last year of its special access program with estimated fishing mortality of 0.4. It is scheduled to be a part of the fully open areas in 2008-9.

The EFH closure portions of the three groundfish closed areas (Closed Area I, II and Nantucket Lightship Closed Area) are closed long-term to all bottom-tending mobile gear, and are assumed closed during the entire simulation period. Two out of three of the access portions of the groundfish closed areas are opened each year: Closed Area I and Nantucket Lightship in 2007, Closed Area II and Nantucket Lightship in 2008, and Closed Areas I and II in 2009.

Target total allowable catch (TAC) levels have already been set for the 2007 groundfish access area program (NEFMC 2005, about 2500 mt in each area). Fishing mortality in these areas in 2008-9 was assumed to be 0.2, as specified in sea scallop Amendment 10 (NEFMC 2003). All other areas (Virginia Beach, New York Bight, Long Island, South Channel, Northern

Edge and Peak, Southeast Part, and after 2007, Hudson Canyon South) are part of the open area pool.

In projections, fishing effort was allocated to areas so that the overall fishing mortality rate was 0.24 in the first year (based on current regulations described in NEFMC 2005) and 0.2 during 2008-2009 (first set of simulations) or 0.24 (second set of simulations). 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.

Under both scenarios, biomass and landings are expected to increase modestly in the next three years (Figure B8-1,2). Under the first scenario ($F = 0.20$), landings are expected to rise from a little more than 26,000 mt meats in 2006-2007, to over 32,000 mt in 2008-2009, compared to a range of 26,000 mt in 2006-2007 to over 34,000 mt in 2008-2009 in the $F = 0.24$ scenario. On the other hand, biomass is projected to increase more during 2006-2009 in the $F = 0.20$ scenario (22%) than in the $F = 0.24$ simulation (15%). Roughly 40% of the landings are projected to come from the special access areas (Elephant Trunk and the groundfish closed areas). None of the 400 model runs resulted in a biomass below the new biomass target (108.6 thousand mt) indicating that overfished stock conditions are unlikely in the near future.

Simulated landings are more variable than biomass, because the landings stream is more dependent on the abundances of a few key areas (such as the Elephant Trunk) while total biomass includes sea scallops in closed areas and areas lightly fished. Much of the variation among the simulation runs for each scenario was due to bootstrapping of survey data to set initial conditions (rather than variable recruitment) because simulated recruits did not have time during the short simulations to grow and completely recruit to the fishery.

B10.0 RESEARCH RECOMMENDATIONS (TOR 7)

Agencies, academic institutions, and contractors made considerable progress in key areas of scallop research since the last assessment. In this section, progress on recommendations in the previous assessment (NEFSC 2004) is reviewed and new research recommendations are presented.

B10.1 Research recommendations from NEFSC (2004)

1. More comparison tows between standard survey dredges and those equipped with rock chains are necessary to more precisely estimate the correction factor(s) needed to convert between survey tows with and without rock chains. *Additional field work and statistical analysis has been completed although more research would be required to precisely estimate rock chain effects, which may vary from year to year (see Appendix B9).*
2. Explore potential for surveying hard bottom areas not currently covered using survey dredges equipped with rock chains. Some experimental paired tows have been carried out on the (hard-bottom) northern edge of Georges Bank, where rocks are occasionally seen. This topic is under discussion and progress is expected when the current NEFSC sea scallop survey is replaced by a proposed optical-dredge survey after 2008.
3. Explore the use of VMS and landings data to characterize condition of the resource on grounds not covered by the survey. *Some work is underway to interpret catch rates on unsurveyed grounds using VMS and other data. Grounds covered by NEFSC surveys may be expanded after 2008.*

4. Further work is required to better characterize the selectivity of the commercial dredges with 4 inch rings relative to the standard NEFSC survey dredge. *A comprehensive paired-tow field study to estimate contact selectivity of commercial dredges with 4 inch rings was completed (see Appendix B5 and Yochum 2006). In addition, CASA model estimates for 2006 provide useful estimates of fishery selectivity that integrate the effects of contact selectivity, discard and targeting.*
5. Because assumptions about growth are important in almost any stock assessment model, better estimation of scallop growth, including variability in growth, is important in improving the precision of sea scallop stock assessments. *Appendices B2-B3 describe new growth data and growth parameter estimates. Variation among regions is accommodated and variability over time is noted.*
6. Work presented during the assessment indicates substantial variability in shell height-meat weight relationships due to depth, season, year and possibly area. Additional work on this subject may be useful, especially with respect to area-based management. *See Appendix B4 and Section 3 of this report for new data, depth based shell height/meat weight relationships, and approaches to calculating shell height-meat weight in the commercial fishery.*
7. Based on recent work on scallops in the US and Canada, there is a potential for tracking year-to-year variability in natural mortality based on clapper data. Use of clapper data in stock assessment models to estimate natural mortality should be investigated. *Work on this topic is underway but has not been completed.*
8. The statistical properties of the new "CASA" model should be fully evaluated prior to the next meeting. The properties of concern include performance in the face of process errors (e.g. variability in natural mortality and growth), measurement errors in data, and characterization of uncertainty. In addition, use of smaller time steps and shell height groups might be helpful. It may prove possible to apply the model or similar models to smaller geographic areas. *Appendices B10-B12 describe progress along these lines and software used to test the sea scallop stock assessment model.*
9. There appears to be considerable scope for reducing variability in scallop survey data by changing the allocation of tows to survey strata. *A more adaptive allocation scheme has been adopted, which has resulted in lower variance in the most recent surveys (Table B5-1).*
10. Comparison of SMAST video survey with the NEFSC survey has proved valuable in estimating efficiency of survey and commercial dredges and in improving abundance estimates. The benefits of future video surveys could be enhanced by increasing coordination in carrying out the video and NEFSC surveys on the same grounds, so that the NEFSC scallop strata are fully covered by the video survey. More intense video surveys in small areas, such as was done in 1999-2002, can help reduce the variances of the efficiency estimates. *SMAST video survey data were fully incorporated in this assessment. Cooperative analyses were carried using video and dredge survey data to characterize selectivity in both surveys and to refine estimates of dredge efficiency for sea scallops in the Mid-Atlantic and on Georges Bank (see Appendices B7-B8). A paired photographic/dredge comparison study is planned for this summer.*
11. This assessment demonstrates the potential for fully incorporating results of cooperative surveys in stock assessment models for scallops. Areas where additional information could be obtained by cooperative research include abundance in areas not normally surveyed by NEFSC, gear properties, and temporal and spatial variation in shell height/meat weight relationships, mortality, recruitment and growth. *Results of a 4 inch ring selectivity study*

conducted by the Virginia Institute of Marine Science (VIMS, Appendix B5, Yochum 2006) and SMAST video surveys (Section 5, Appendices B7-B8) were incorporated in this assessment.

B10.2 New Research Recommendations

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.
2. Evaluate the within and between reader error rates in identification and measurement of growth increments on scallop shells.
3. Improve estimates of incidental and discard mortality rates.
4. Consider using autocorrelated recruitment in SAMS projection model runs. CASA model estimates indicate that sea scallop recruitment may be autocorrelated.
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.
6. Evaluate assumptions about the spatial dynamics of the fishing fleet in the SAMS model by comparing predicted distributions to VMS 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.
8. Evaluate the accuracy of the SAMS projection model retrospectively by comparison to historical survey abundance trends.
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.
10. Consider implementing a two or more “morph” formulation in the CASA model to accommodate scallops that grow at different rates.
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.

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