A. ASSESSMENT OF ATLANTIC STRIPED BASS

A1.0 CONTRIBUTORS

See Table 3 in the Introduction.

A2.0 TERMS OF REFERENCE (TOR) FOR STRIPED BASS

1. Characterize the commercial and recreational catch including landings and discards.
2. Characterize the fisheries independent and dependent indices of abundance.
3. Evaluate the Statistical Catch at Age (SCA) model and its estimates of F, spawning stock biomass, and total abundance of Atlantic striped bass, along with the uncertainty of those estimates.
4. Evaluate the Baranov's catch equation method and associated model components applied to the Atlantic striped bass tagging data. Evaluate estimates of F and abundance from coastwide and Chesapeake Bay-specific tag programs along with the uncertainty of those estimates.
5. Review the Instantaneous Rates Tag Return Model Incorporating Catch-Release Data (IRCR) and estimates of F on Atlantic striped bass. Provide suggestions for further development of this model for future use in striped bass stock assessments.
6. Review the Forward-Projecting Statistical Catch-At-Age Model Incorporating the Age-Independent Instantaneous Rates Tag Return Model and estimates of F, spawning stock biomass, and total abundance of striped bass. Provide suggestions for further development of this model for future use in striped bass stock assessments.
7. Evaluate the current biological reference points for Atlantic striped bass from Amendment 6 and determine stock status based on those reference points*.

EDITOR'S NOTE: In this striped bass assessment report, the meaning of TOR 7 was clarified during the independent peer review. In addition to determining stock status, the purpose of TOR 7 was to review the methods used to determine the current biological reference points, and to get the reviewer's opinion on whether the BRPs were developed appropriately and whether those approached should be continued.

A3.0 EXECUTIVE SUMMARY

A3.1 MAJOR FINDINGS FOR TOR 1 - COMMERCIAL AND RECREATIONAL CATCH INCLUDING LANDINGS AND DISCARDS

Commercial landings in the Atlantic striped bass fishery increased from roughly 313 mt (800,000 pounds) in 1990 to 3,073 mt (7.6 million pounds) in 2006. In 2005 and 2006, the commercial coastwide harvest was composed primarily of ages 4–10 striped bass, while harvest in Chesapeake Bay fisheries (Maryland, Virginia, and the PRFC) was composed mostly of ages 3–6.

The estimates of dead commercial discards were 776,951 and 216,753 fish for 2005 and 2006, respectively. The highest discard losses occurred in anchor gill net, pounds net, and hook-and-line fisheries. Most commercial dead discards since 2004 were fish aged 3–8. Total commercial striped bass removals (harvest and dead discards) were 1.7 million and 1.2 million fish in 2005 and 2006, respectively. Removals in 2005 exceeded the peak observed in 2000. Commercial harvest has generally exceeded dead discards since the mid 1990s.

Recreational harvest increased from 1,010 mt (2.2 million pounds) in 1990 to 13,814 mt (29.1 million pounds) in 2006. In numbers of fish, recreational harvest of striped bass was greater than 1.3 million fish from 1997 through 2006, and more than 2 million striped bass during 2003–2006. Coastwide recreational harvest was dominated by the 2000 (age 5) and 1996 (age 9) year-classes in 2005, and by the 2001 (age 5) and 1996 (age 10) year-classes in 2006. Ages 4–10 made up >77% of the coastwide harvest, and ages 8+ made up about 50% in both years. Recreational harvest from the coast (includes Delaware Bay) was composed mostly of ages 5–11, while harvest in Chesapeake Bay was dominated by ages 4–8.

The number of striped bass that die due to catch and release increased from 132 thousand fish in 1990 to 1.2 million fish in 1997. Releases have remained around 1.2 million fish through 2003, but increased to the series maximum of 2 million fish in 2006. Ages of coastwide recreational dead releases ranged from 0–13+, but most dead releases were ages 2–6. The dead releases were dominated by the 2001 and 2003 year-classes in both years. Recreational dead releases from the coast (includes Delaware Bay) were made up of fish ages 2–5 and ages 3–6 in 2005 and 2006, respectively, but the 2001 and 2003 year-classes dominated. In Chesapeake Bay, dead releases were composed of ages 2–4 and were dominated by the 2003 year-class in both years (ages 2 and 3). Total recreational striped bass removals (harvest and dead discards) in 2005 and 2006 were 3.9 million and 4.8 million fish, respectively. See Section A5 for details.

A3.2 MAJOR FINDINGS FOR TOR 2 – FISHERIES-DEPENDENT AND FISHERIES-INDEPENDENT INDICES

States provided age-specific and aggregate indices from fisheries-dependent and fisheries-independent sources that were assumed to reflect trends in striped bass relative abundance. A formal review of age-2+ abundance indices was conducted by ASMFC at a workshop in July of 2004. The 2004 workshop developed a set of evaluation criteria and tasked states with a review of indices. Both the Striped Bass Technical Committee and the Management Board approved of the criteria and of the review. The resulting review led to revisions and elimination of some indices used in previous stock assessments. All indices were given equal lambda weight. However, each survey's annual coefficients of variation (CV) were incorporated into the likelihood function, so if a survey produced poor estimates, the estimates were down-weighted by the CVs. See Section A6 for details. The following sources were used as tuning indices in the current stock assessment:

- Massachusetts Commercial Total Catch Rate Index
- Connecticut Recreational CPUE
- MRFSS Total Catch Rate Index
- Maryland Gillnet Survey
- New York Ocean Haul Seine Survey
- Northeast Fisheries Science Center Bottom Trawl Survey
- All Young-of-the-Year and Age 1 Indices
- Connecticut Bottom Trawl Survey
- New Jersey Bottom Trawl Survey
- Delaware Electrofishing Spawning Stock Survey

A3.3 MAJOR FINDINGS FOR TOR 3 – STATISTICAL CATCH AT AGE MODEL AND ITS ESTIMATES OF FISHING MORTALITY, SPAWNING STOCK BIOMASS, AND TOTAL ABUNDANCE OF ATLANTIC STRIPED BASS

The estimate of fully-recruited (age 10) fishing mortality from the SCA model (preferred catch-at-age model method) in 2006 was 0.32 and its CV was 0.13. The 2006 average fishing mortality rate (F) for ages 8 through 11, which is compared to target and threshold reference points, equaled 0.31. Annual estimates for 1982 to 2005 range from 0.08 to 0.28. Average F on ages 3–8, which are generally targeted in producer areas (Chesapeake Bay, Delaware Bay, and Hudson River), was 0.23. Among the individual age groups, the highest values of F in 2006 (0.31–0.32) were estimated for ages 9–13+. Striped bass total abundance (1+) increased steadily from 1982 through 1997 when it peaked around 65 million fish. Total abundance declined thereafter and has averaged 57 million fish since 2000. The 2003 cohort remained strong at 16 million fish at age 3 in 2006 and exceeded the sizes of the strong 1993 and 2001 year classes at the same age. Abundance of striped bass age 8+ increased steadily through 2004 to 8.5 million, but has since declined to 6.2 million fish in 2006. Female SSB grew steadily from 1982 through 2003 when it peaked at about 33 thousand mt. Female SSB has declined since then and was estimated at 25 thousand mt in 2006. Retrospective bias was evident in estimates of fully-recruited F, SSB, and age 8+ abundance of SCA suggesting F is overestimated and abundance estimates were underestimated. ADAPT and ASAP modeling confirms the general trend and magnitudes of fishing mortalities. See Section A7 for details.

A3.4 MAJOR FINDINGS FOR TOR 4 - BARANOV'S CATCH EQUATION METHOD APPLIED TO THE ATLANTIC STRIPED BASS TAGGING DATA AND ESTIMATES OF F AND ABUNDANCE FROM COASTWIDE AND CHESAPEAKE BAY SPECIFIC TAG PROGRAMS

Estimates of F obtained via Baranov's catch equation (the preferred tag-based model method) in 2006 for the fully-recruited fish (≥28 inches) were 0.15 ± 0.06 (95% CI) in the coastal areas and 0.17 ± 0.08 in the producer areas (Chesapeake Bay, Delaware Bay, and Hudson River), resulting in a coastwide mean of 0.16. The 2006 estimate of F for fish ≥ 18 inches was

0.16 ± 0.07 in producer area programs and 0.09 ± 0.03 for the coastal programs, resulting in a coastwide mean of 0.12. F estimates peaked for both size groups in the late 1990's and were at or below the target (0.30) for all years of the time series. Retrospective analyses for the MARK estimates were not attempted because reducing the tag recovery matrices and models was very laborious. Abundance of striped bass age 7+ (comparable to fish ≥ 28 inches) exhibited fair stability with a period of rapid stock growth around 2000. The 2006 estimate of 13 million fish has been approximately stable since 2002. Stock size estimates for fish age 3+ (comparable to fish ≥18 inches) showed fairly consistent growth and the 2006 value is the highest in the time series at 47.9 million fish.

In the Chesapeake Bay specific analysis, F in 2006 for both Maryland and Virginia individually and bay-wide were all below the target value of 0.27. The 2006 estimate for Maryland was 0.14; Virginia was 0.16. F estimates in Maryland steadily increased to a peak in 1998 (0.19), then declined and have fluctuated between 0.11–0.14 without trend since that time. Estimates of F from Virginia data vary without trend between 0.06–0.16 over the time series. The bay-wide F, calculated as a weighted mean, shows a trend similar to Maryland with a 2006 value of 0.14 ± 0.12. See Section A8 for additional details.

A3.5 MAJOR FINDINGS FOR TOR 5 – REVIEW INSTANTANEOUS RATES TAG RETURN MODEL INCORPORATING CATCH-RELEASE DATA AND ESTIMATES OF F

In the first year of using the Instantaneous Rates - Catch and Release (IRCR) model, estimates of F were at or below the target (0.30) for all years of the time series. The 2006 estimate for the fully-recruited fish (≥ 28 inches) was 0.13 ± 0.015 (95% CI) in both the coastal areas and producer areas, which resulted in a coastwide mean F of 0.13. The 2006 estimate of F for fish ≥18 inches was 0.10 ± 0.03 in producer area programs and 0.09 ± 0.015 for the coastal programs, resulting in a coastwide mean of 0.09. Estimates from the IRCR model showed the same trends as those from the catch equation. Stock size estimates for fish age 7+ (≥28 inches) exhibited fair stability with a period of rapid stock growth around 2000. The 2006 estimate for fish ≥28 inches (16.6 million fish) has been approximately stable since 2003. Stock size estimates for fish age 3+ (≥18 inches) have shown fairly consistent growth and the 2006 value is the highest in the time series at 60.8 million fish.

In the Chesapeake Bay specific analysis, F estimates obtained using the IRCR model varied depending on model structure. F estimates produced when natural mortality (M) is assumed constant over the time series are lower in more recent years than those produced when the model allows for two or three periods of M. However, in all scenarios, the estimates of F for Maryland and Virginia and bay-wide were all below the target value of 0.27. Bay-wide average F values were as follows: 0.05 ± 0.015 for one period of M, 0.11 ± 0.02 for two periods of M and 0.12 ± 0.03 for three periods of M. See section A9 for additional details.

A3.6 MAJOR FINDINGS FOR TOR 6 – REVIEW FORWARD-PROJECTING STATISTICAL CATCH-AT-AGE MODEL INCORPORATING AGE-INDEPENDENT INSTANTANEOUS RATES TAG RETURN MODEL

An age-structured statistical catch-at-age model incorporating tag return data for the Atlantic coast migratory stocks of striped bass was constructed as an alternative to separate catch-at-age model and tag return analyses. The same structure as the SCA model was used and the age-independent model of Jiang et al. (2007) is used as a bridge between the catch-at-age and tag return data. The link between the two models is fully-recruited F. The benefits of this instantaneous rates model are that data from tagged fish that are recaptured and released alive are directly incorporated in the estimation of fishing mortality. The 2006 average F for ages 8–11 equaled 0.14, much lower than the value obtained in the SCA model. The assumption that fish ≥28 inches are fully-recruited may be violated in early years of the time series and it is recommended that a fully age-structured tag model be used in the future.

A3.7 MAJOR FINDINGS FOR TOR 7 – EVALUATE THE CURRENT BIOLOGICAL REFERENCE POINTS FOR ATLANTIC STRIPED BASS FROM AMENDMENT 6 AND DETERMINE STOCK STATUS BASED ON THOSE REFERENCE POINTS

The existing reference points for striped bass, as defined in Amendment 6 to the FMP (ASMFC 2003) are:

Female Spawning Stock Biomass Threshold ($SSB_{Threshold}$) = 14,000 mt
Female Spawning Stock Biomass Target (SSB_{Target}) = 17,500 mt
Fishing Mortality Rate Threshold (F_{MSY}) = 0.41
Fishing Mortality Rate Target (F_{Target}) = 0.30*
**The target fishing mortality rate for Chesapeake Bay is F_{Target} = 0.27.*

Estimates of fully recruited F in 2006 from the catch equation method (F for fish ≥28 inches = 0.16) and the SCA model ($F_{age\ 8\text{-}11}$ = 0.31) are both below the Amendment 6 threshold. Therefore, overfishing is not occurring on the coastal migratory stocks of Atlantic striped bass. The 2006 estimate of spawning stock biomass is above both the $SSB_{Threshold}$ and SSB_{Target} and therefore striped bass are not overfished.

The assessment covers the entire stock of the Atlantic coast migratory striped bass. The EEZ is managed under Federal authority and is closed to fishing for striped bass whereas fisheries in state waters are managed under the authority of the ASMFC. Although the EEZ is managed separately, striped bass present in these waters are still considered part of the coastal migratory stock. The estimates of fishing mortality and biomass obtained from the stock assessment are intended to represent the status of the entire stock of striped bass.

A4.0 INTRODUCTION

A4.1 MANAGEMENT HISTORY

Striped bass (*Morone saxatilis*) has been the focus of fisheries from North Carolina to New England for several centuries and has played an integral role in the development of numerous coastal communities. Striped bass regulations in the United States date to pre-Colonial times, when striped bass were prohibited from being used as fertilizer (circa 1640). During the 20th century, initial attempts at regulation were made by states during the 1940s, when size limits were imposed. Minimum size limits ranged from 16 inches for many coastal states to 10 inches in some southern states. By the 1970s it became increasingly evident that stronger regulations would be needed to maintain stocks at a sustainable level. Recruitment in the Chesapeake Bay stock had reached an all time low, as determined by a juvenile survey conducted by Maryland Department of Natural Resources since 1954. In response to the decline, the Atlantic States Marine Fisheries Commission (ASMFC) developed a fisheries management plan (FMP) in 1981 to increase restrictions in commercial and recreational fisheries. Two amendments were passed in 1984 recommending management measures to reduce fishing mortality. To strengthen the regulations, a federal law was passed in late 1984, which mandated that coast wide regulations already implemented would be adhered to by Atlantic states between North Carolina and Maine (for striped bass management, the areas under the jurisdiction of ASMFC include coastal waters of North Carolina, Virginia, the Potomac River Fisheries Commission, the District of Columbia, Maryland, Delaware, Pennsylvania, New Jersey, New York, Connecticut, Rhode Island, Massachusetts, New Hampshire, and Maine).

The first enforceable version of the ASMFC plan to restore striped bass (Amendment 3 in 1985) called for size regulations to protect the 1982 year class, which was the first modest-sized cohort since the previous decade. The objective was to increase size limits to allow at least 95% of the females in the cohort to spawn at least once. This required an increase in the size limit as the cohort grew, and resulted in a 36-inch size limit by 1990. However, estuaries have traditionally been considered producer areas and have been managed under different minimum sizes than coastal waters. The rationale is that the migration of fish out of the producer areas after spawning reduces the availability of larger fish. Several states, beginning with Maryland in 1985, opted for a more conservative approach and imposed a total moratorium on striped bass landings. By 1989, Massachusetts was the only state with an active commercial fishery.

Most of the restrictive regulations were intended to restore production in Chesapeake Bay. The Hudson stock did not suffer the same decline in production, in part because the fishery in the river was closed in the 1970s due to PCB contamination.

In addition to the restrictions, Amendment 3 contained a trigger mechanism to reopen the fisheries when the 3-year moving average of the Maryland juvenile index exceeded an arithmetic mean of 8.0. That level was attained with the recruitment of the 1989 year class. Consequently the management plan was amended for the fourth time to allow state fisheries to reopen in 1990 under a target F of 0.25, which was half the 1990 F_{msy} estimate of 0.5.

Amendment 4 to the FMP would allow an increase in the target F once the spawning stock biomass (SSB) was restored to levels estimated during the late 1960s and early 1970s. The dual size limit concept was maintained with a 28-inch minimum size limit in coastal jurisdictions and 18 inches in producer areas. In 1995, striped bass were declared restored by the ASMFC. The basis was the results of a model simulation of the increase in spawning stock biomass. The model, known as the SSB model, was a life history model resulting in a relative index of SSB (Rugolo et al. 1994). When the time series of SSB crossed the level comparable to the 1960–1972 average, the stock reached the criteria for a restored stock. Consequently, under Amendment 5 (adopted in 1995), target F was increased to 0.31, midway between the initial F (0.25) and $F_{msy,}$ which was revised to equal 0.4.

Amendment 5 retained the same size regulations in coastal waters (28-inch minimum size, two fish per day, and commercial quota) but allowed two fish per day at 20 inches and commercial quota in producer areas.[1] Commercial fisheries have operated under quotas based on state allocations during the period 1972–1979 (with the exception of Maryland, which calculated quotas based on estimated biomass). States may adjust the minimum size as long as

[1] Size limits on the coast were increased to 34” in 1994, but reduced to 28” in 1995.

the size change is compensated with a change in season length, bag limits, commercial quota, or a combination of changes. However, no size limit could be less than 18 inches.

Amendment 6 was approved in 2003. It addressed five limitations within the previous management program: potential inability of the management program contained in Amendment 5 to prevent the exploitation target in Amendment 5 from being exceeded; perceived decrease in availability or abundance of large striped bass in the coastal migratory population; a lack of management direction with respect to target and threshold biomass levels; inequitable impacts of regulations on the recreational, commercial, coastal, and producer area sectors of the striped bass fisheries; and excessively frequent changes to the management program.

Amendment 6 established a control rule that sets both a target and a threshold for the F rate and female spawning stock biomass. Based on the targets and threshold, as well as juvenile abundance indices, Amendment 6 implemented a list of management triggers, which if any (or all) are reached in any year will require the Management Board to alter the management program to ensure achievement of the Amendment 6 objectives. A planning horizon established the beginning of 2006 as a time at which any management measures established by the Management Board would be maintained by the states for three years, unless a target or threshold is violated.

	FISHING MORTALITY RATE	FEMALE SPAWNING STOCK BIOMASS
TARGET	F = 0.30*	17,500 mt (38.6 million pounds)
THRESHOLD	F = 0.41	14,000 mt (30.9 million pounds)

**The target fishing mortality rate for the Chesapeake Bay and Albemarle-Roanoke stock is F=0.27*

The assessment covers the entire stock of the Atlantic coast migratory striped bass. The EEZ is managed under federal authority and is closed to fishing for striped bass whereas fisheries in state waters are managed under the authority of the ASMFC. Although the EEZ is managed separately, striped bass present in these waters are still considered part of the coastal migratory stock. The estimates of F and biomass obtained from the stock assessment are intended to represent the status of the entire stock of striped bass.

The recreational striped bass fisheries are constrained by minimum size limits meant to achieve target fishing mortalities, rather than annual harvest quotas or caps. Most recreational fisheries are constrained by a two fish creel limit, a 365-day fishing season, and a 28-inch minimum size limit. Through Management Program Equivalency, Albemarle Sound/Roanoke River, and Chesapeake Bay are granted the ability to employ different creel limits and smaller minimum size limits (18 inches) with the penalty of a target F rate of 0.27.

The commercial striped bass fisheries are constrained by minimum size limits and state-by-state quotas. The same size standards regulate the commercial fisheries as the recreational fishery, except for a 20 inch size limit in the Delaware Bay shad gillnet fishery. Amendment 6 restores the coastal commercial quotas to the average reported landings from 1972-1979, except for Delaware's coastal commercial quota, which remains at the level allocated in 2002. The Chesapeake Bay and Albemarle Sound/Roanoke River commercial fisheries are managed to not exceed the 0.27 F target.

States are granted the flexibility to deviate from these standards by submitting proposals for review by the Striped Bass Technical Committee and Advisory Panel and contingent upon the approval of the Management Board. Alternative proposals must be "conservationally equivalent" to the management standards, which has resulted in some variety of regulations among states

(Table A4.1). These management measures were intended to maintain the fishing mortality at or below the target F (0.30).

Fishing in the Exclusive Economic Zone (EEZ) was closed in 1990 and has remained closed to the harvest and possession of striped bass by both commercial and recreational fishermen.

A4.2 MANAGEMENT UNIT DEFINITION

The management unit includes all coastal migratory striped bass stocks on the East Coast of the United States, excluding the EEZ (3–200 nautical miles offshore), which is managed separately by NOAA Fisheries. The coastal migratory striped bass stocks occur in the coastal and estuarine areas of all states and jurisdictions from Maine through North Carolina. Inclusion of these states in the management unit is also congressionally mandated in the Atlantic Striped Bass Conservation Act (PL 98–613; Figure A4.1).

The Chesapeake Bay management area is defined as the striped bass residing between the baseline from which the territorial sea is measured as it extends from Cape Henry to Cape Charles to the upstream boundary of the fall line. The striped bass in the Chesapeake Bay are part of the coastal migratory stock and are part of the coastal migratory striped bass management unit. Amendment 6 implements a separate management program for the Chesapeake Bay due to the size availability of striped bass in this area.

The Albemarle-Roanoke stock is currently managed as a non-coastal migratory stock by the state of North Carolina under the auspices of ASMFC. The Albemarle-Roanoke management unit is defined as the striped bass inhabiting the Albemarle, Currituck, Croatan, and Roanoke Sounds and their tributaries, including the Roanoke River. The Virginia/North Carolina line bound these areas to the north and a line from Roanoke Marshes Point to the Eagle Nest Bay bounds the area to the south. The Bonner Bridge at Oregon Inlet defines the ocean boundary of the Albemarle-Roanoke management area.

There has been some debate in recent years whether to continue to include the Albemarle-Roanoke stock of striped bass in the management unit based on the argument that historical and recent tagging studies have suggested very limited migration of this stock into the Atlantic Coastal area. With such little mixing of Albemarle-Roanoke fish with other coastal migratory stocks, it is difficult to include the Albemarle-Roanoke stock in current coastwide stock assessment because methods used assume that fish from various stocks are equally mixed on the coast. On the other hand, fish tagged on the spawning grounds of Chesapeake Bay, Hudson River, and Delaware River have been recovered in the Albemarle Sound-Roanoke River area.[2] This indicates that coastal migratory fish from other stocks mix with Albemarle-Roanoke fish in North Carolina waters, which argues for having the stock remain within the management unit.

A4.3 ASSESSMENT HISTORY

A4.3.1 Past Assessments

The first analytical assessment of Atlantic striped bass stocks using virtual population analysis (VPA) was conducted in 1997 for years 1982–1996 and reviewed by the 26th Stock Assessment Review Committee at the Northeast Fisheries Science Center. The results of the review were reported in the proceedings of the 26th Northeast Regional Stock Assessment Workshop (NEFSC 1998). Subsequent to this peer review, annual updates were made to the

[2] USFWS tagging data

VPA-based assessment, and in 2001 estimates of F and exploitation rates using coastwide tagging data were incorporated into the assessment. The tagging data analysis protocol was based on assumptions described in Brownie et al. (1985) and the tag recovery data was analyzed in program MARK (White and Burnham 1999). Adjusted R/M ratios (recovered tags/total number of tags released) were used to calculate exploitation rates.

The stock status and assessment procedures were reviewed once again at the 36th SAW in December 2002 and this time included review of the tag-based portion of the assessment in addition to the ADAPT VPA portion of the assessment. Since then, annual updates to the assessment were conducted from 2003 through 2005.

In the 2005 assessment, Baranov's catch equation was used with the tagging data to develop estimates of F. By using the Z values from the Brownie models and μ from R/M (recovered tags/total number of tags released), F estimates could be developed for the first time without the assumption of constant natural mortality. In addition, two changes were made to the VPA input data. Modifications were made to the suite of tuning indices used in the VPA following a comprehensive review of the various indices. In addition, current and historical estimates of recreational harvest during January and February in North Carolina and Virginia were added to the catch at age matrix.

A4.3.2 Current Assessment and Changes from Past Assessments

In the 2004 and 2005 ASMFC assessments of striped bass, the ADAPT VPA model produced high estimates of terminal-year fishing mortality. The consensus of the Technical Committee members was that the ADAPT estimates were likely overestimated given the uncertainty and retrospective bias in the terminal year estimate, especially the F on the older ages which are compared to the overfishing reference point. A recent run with data updated through 2006 showed even worse overestimation of terminal F (at age 10, F =2.2).

As an alternative to ADAPT, an age-structured forward projecting statistical catch-at-age (SCA) model for the Atlantic coast migratory stocks of striped bass was constructed and is used to estimate fishing mortality, abundance, and spawning stock biomass during 1982–2006. This is considered the preferred model over ADAPT and ASAP. See Section A7 for discussion

In addition, the Baranov's catch equation method applied to tagging data was considered appropriate for estimating fishing mortality because natural mortality is allowed to change over time. This approach is used because of high and increasing estimates of F from the tag analysis when M was assumed constant. This conflicted with other estimates of exploitation and F in the bay from tag programs, and it coincided with the development of an epidemic of mycobacteriosis in the Bay. Also, estimates of abundance could be made.

A4.4 LIFE HISTORY AND BIOLOGY

A4.4.1 Geographic Range

Atlantic coast migratory striped bass live along the eastern coast of North America from the St. Lawrence River in Canada to the Roanoke River and other tributaries of Albemarle Sound in North Carolina (ASMFC 1990). Stocks which occupy coastal rivers from the Tar-Pamlico River in North Carolina south to the St. Johns River in Florida are believed primarily endemic and riverine and apparently do not presently undertake extensive Atlantic Ocean migrations as do stocks from the Roanoke River north (ASMFC 1990), although at least one individual tagged in the Cape Fear River recently did so, being recaptured at Montauk Lighthouse, New York.

Striped bass are also naturally found in the Gulf of Mexico from the western coast of Florida to Louisiana (Musick et al. 1997). Striped bass were introduced to the Pacific Coast using transplants from the Atlantic Coast in 1879. Striped bass also were introduced into rivers, lakes, and reservoirs throughout the US, and to foreign countries such as Russia, France and Portugal (Hill et al. 1989). The following life history information applies to the Atlantic coast migratory population.

A4.4.2 Age

The age of a fish is frequently used as a milestone in characterizing many aspects of the fish's life history such as age of maturity. Scales of striped bass collected in North Carolina show annulus formation taking place from late October through early January, with the peak occurring in early December. Annuli form on scales of striped bass caught in Virginia between April and June, or during the spawning season (Grant 1974).

Age data has also been fundamental to VPA-based stock assessments of striped bass. Since 1996, catch-at-age models have used scale age, principally because the time series of catch data extends back to 1982 and scales have been the only consistent collected age structure, even in more recent years. In the near future, the ASMFC plans an otolith collection program for 800 mm striped bass or larger as the state ageing programs have shown high precision in scale ageing striped bass up to age 10.

Generally, longevity of striped bass has been estimated as 30 years, although in recent years, a striped bass was aged as 31 years based on otoliths (Secor 2000). This longevity suggests that striped bass populations can persist during long periods of poor recruitment due to a long reproductive lifespan, and may have also conferred resiliency against an extended period of recruitment overfishing in the Chesapeake Bay (Secor 2000). Based on VPA estimates, young fish dominate the age composition of striped bass, but recent estimates of older striped bass (age-8 or older) indicate this grouping averaged 10% of striped bass age-1 or older, since 2000. This amount represents nearly a doubling of the proportion of age-8 and older striped bass during the decade of the 1990s.

A4.4.3 Growth

As a relatively long-lived species, striped bass are capable of attaining moderately large size, reaching as much as 125 lbs (Tresselt 1952). Fish weighing 50 or 60 lbs are not exceptional, and several fish harvested in North Carolina and Massachusetts, recorded in excess of 100 pounds, were estimated to have been at least 6 feet long (Smith and Wells 1977). Females do grow to a considerably larger size than males; striped bass over about 30 lbs are almost exclusively female (Bigelow and Schroeder 1953). Both sexes grow at the same rate until 3 years old; beginning at age 4, females grow faster and larger than males.

Growth occurs during the seven-month period between April and October. Within this time frame, striped bass stop feeding for a brief period just before and during spawning, but feeding continues during the upriver spawning migration and begins again soon after spawning (Trent and Hassler 1966). From November–March, growth is negligible.

Growth rates of striped bass are variable, depending on a combination of the season, location, age, sex, and competition. For example, a 35 inch striped bass can be anywhere from 7–15 years of age and a 10-lb striped bass can be from 6 to 16 years old (ODU CQFE 2006). Growth (in length) is more rapid during the second and third years of life, before reaching sexual maturity, than during later years. Merriman (1941) observed that striped bass of the 1934 year-class showed their greatest growth during the 3rd year, at which age migratory movements begin. Thereafter the rate dropped sharply at age 4 and remained nearly constant at 6.5–8.0 cm per year up to about age 8. The growth rate probably decreases even further after the 8th year.

Compensatory growth, in which the smaller fish in a year-class, growing at an accelerated pace, reduce or eliminate the size differences between themselves and other larger members of that age group, has been shown to occur in age 2 striped bass in Chesapeake Bay (Tiller 1942) and in age 2 and 3 fish from Albemarle Sound (Nicholson 1964).

A4.4.4 Reproduction

Striped bass are anadromous, ascending coastal streams in early spring to spawn, afterward returning to ocean waters. Spawning takes place in the shallow stretches of larger rivers and streams, generally within about the first 40 km of freshwater in rivers flowing into estuaries (Figures A4.2–A4.4) (Tresselt 1952). The actual distance upstream of the center of spawning varies from river to river and even within the same river from year to year. Striped bass spawning areas characteristically are turbid and fresh, with significant current velocities due to normal fluvial transport or tidal action. Tributaries of Chesapeake Bay, most notably the Potomac River, and also the James, York, and most of the smaller rivers on the eastern shore of Maryland, are collectively considered the major spawning grounds of striped bass, but other rivers (Hudson and Delaware) make substantial contributions to the population along the middle Atlantic coast. The spawning population is made up of males 2 years or older and females 4 or more years old.

The spawning season along the Atlantic coast usually extends from April to June, but it begins as early as January or February in Florida, and is governed largely by water temperature (Smith and Wells 1977). Striped bass spawn at temperatures between 10 and 23° C, but seldom at temperatures below 13–14°C. Peak spawning activity occurs at about 18° C and declines rapidly thereafter (Smith and Wells 1977).

The number of mature ova in female striped bass varies by age, weight, and fork length. Jackson and Tiller (1952) found that fish from Chesapeake Bay produced from 62,000–112,000 eggs/pound of body weight, with older fish producing more eggs than younger fish. Raney (1952) observed egg production varying with size, with a 3-pound female producing 14,000 eggs and a 50-pound specimen producing nearly 5,000,000. When ripe, the ovaries are greenish-yellow in color (Scofield 1931). After fertilization, the semi-buoyant eggs of striped bass are transported downstream or, if spawned in slightly brackish water, back and forth by tidal circulation. Hatching occurs in about 70–74h at 14–15°C, in 48h at 18–19°C, and in about 30h at 21–22°C (Bigelow and Schroeder 1953).

Newly hatched bass larvae remain in fresh or slightly brackish water until they are about 12–15mm long. At that time, they move in small schools toward shallow protected shorelines, where they remain until fall. Over the winter, the young concentrate in deep water of rivers. These nursery grounds appear to include that part of the estuarine zone with salinities less than $3.2^{0}/_{00}$ (Smith 1970).

Maryland data suggest that full maturity of females is not achieved until age 8. Maryland data were accepted as valid and were used to guide changes in size limits needed to meet the management requirements of Amendment 3 to the FMP (i.e., to protect 95% of females of the 1982 and subsequent year-classes until they had an opportunity to spawn at least once). Maryland maturity data were also incorporated into modeling work performed in order to develop management regimes specified in Amendment 4 to the FMP (ASMFC 1990).

There are indications that some older striped bass may not spawn every year (Raney 1952). Merriman (1941) reported that large, ripe females are regularly taken from Connecticut waters in late spring and early summer, during the regular spawning period. Jackson and Tiller (1952) reported curtailment of spawning in about 1/3 of the fish age 10 and older taken from Chesapeake Bay, though they also found striped bass up to age 14 in spawning condition.

A4.4.5 Movements and Migration

Migration of striped bass may occur at both juvenile and adult stages, although migratory patterns for all life stages vary by location. In general, juveniles migrate downstream in summer and fall, while adults migrate upriver to spawn in spring, afterwards returning to the ocean and moving north along the coast in summer and fall, and south during the winter (Shepherd 2007). As young and as adults, striped bass move in schools, except for larger fish, which either travel alone or with a few others of similar size.

Juvenile striped bass move down river in schools from their parent stream to low salinity bays or sounds when a year old (Richards and Rago 1999; Smith and Wells 1977). The timing of this juvenile migration varies by location. In Virginia, Setzler-Hamilton et al. (1980) observed the movement downstream during summer. In the Hudson River, striped bass begin migrating in July, as documented through an increase in the number of juvenile striped bass caught along the beaches and a subsequent decline in the numbers in the channel areas after mid-July. Downstream migration continues through late summer, and by the fall, juveniles start to move offshore into Long Island Sound (Raney 1952). Juveniles infrequently complete coastal migrations, but even though fish that are under the age of two are largely non-migratory, many do leave their birthplaces when they are two or more years old.

Most adult striped bass along the Atlantic coast are involved in two types of migrations: an upriver spawning migration from late winter to early spring, and coastal migrations that are apparently not associated with spawning activity. Not all fish take part in the coastal migrations. Otolith microchemical analysis of striped bass from the Hudson River and from the Roanoke River, indicate that individuals in these populations exhibited multiple life history strategies (Morris et al. 2003; Zlokovitz et al. 2003). In both populations, some individuals were permanent residents of the river, while others exhibited varying degrees of migratory behavior beginning at varying ages.

From Cape Hatteras NC to New England, striped bass coastal migrations are generally northward in summer and southward in winter. Results from tagging 6,679 fish from New Brunswick, Canada, to the Chesapeake Bay during 1959–1963, suggest that substantial numbers of striped bass leave their birthplaces when they are 3+ years old and thereafter migrate in groups along the open coast (Nichols and Miller 1967). These fish are often referred to collectively as the “coastal migratory stock,” suggesting they form one homogeneous group, but this group is probably, in itself, heterogeneous, consisting of many migratory contingents of diverse origin (Clark 1968).

Coastal migrations may be quite extensive; striped bass tagged in Chesapeake Bay have been recaptured in the Bay of Fundy. They are also quite variable, with the extent of the migration varying between sexes and populations (Hill et al. 1989). Larger bass, typically the females, tend to migrate farther distances. However, striped bass are not usually found more than 6–8 km offshore (Bain and Bain 1982). Recently, Welsh et al. (2007) determined from tag recovery locations that striped bass tagged off North Carolina and Virginia in winter migrated northward during summer as far as Maine, although the largest numbers were recovered from

New York to Massachusetts, as well as waters of Maryland. During spring months (April, May, and June), the largest numbers of tagged striped bass were caught within waters of Maryland (Chesapeake Bay) and New York (Hudson River). Although usually beginning in early spring, the time period of migration can be prolonged by the migration of bass that are late-spawning.

Some areas along the coast are used as wintering grounds for adult striped bass. The inshore zones between Cape Henry, Virginia, and Cape Lookout, North Carolina, serve as the wintering grounds for the migratory segment of the Atlantic coast striped bass population (Setzler-Hamilton et al. 1980). There are three groups of fish found in nearshore ocean waters of Virginia and North Carolina between the months of November and March, the wintering period. These three groups are bass from Albemarle and Pamlico Sounds, North Carolina, fish from the Chesapeake Bay, and large bass that spend the summer in New Jersey and north (Holland and Yelverton 1973). Based on tagging studies conducted under the auspices of the ASMFC and Southeast Area Monitoring and Assessment Program (SEAMAP; Welsh et al. 2007) each winter since 1988, striped bass wintering off Virginia and North Carolina range widely up and down the Atlantic Coast, at least as far north as Nova Scotia, and represent all major migratory stocks (Welsh et al. 2007, Appendix A1).

A4.4.6 Stock Definitions

The anadromous populations of the Atlantic coast are primarily the product of four distinct spawning stocks: a Roanoke River/Albemarle Sound stock, a Chesapeake Bay stock, a Delaware River stock, and a Hudson River stock (ASMFC 1998). The Atlantic coast fisheries, however, rely primarily on production from the spawning populations in the Hudson and Delaware rivers and in tributaries of Chesapeake Bay. Therefore, the inside fisheries of the Albemarle Sound and Roanoke River are managed separately from the Atlantic coastal migratory population, which includes all other migratory stocks occurring in coastal and estuarine areas of all states and jurisdictions from Maine through North Carolina. The Atlantic coast management unit, excluding the fisheries on the Roanoke River/Albemarle Sound stock, is the basis of this stock assessment.

The Chesapeake Bay stock of striped bass is widely regarded as the largest of the four major spawning stocks (Goodyear et al. 1985; Kohlenstein 1980; Fabrizio 1987). However, during most of the 1970s and 1980s, juvenile production in the Chesapeake Bay was extremely poor, causing a severe decline in commercial and recreational landings. The poor recruitment was probably due primarily to overfishing; but poor water quality in spawning and nursery habitats likely also contributed (Richards and Rago 1999).

Recent tag-recovery studies in the Rappahannock River and upper Chesapeake Bay show that larger and older (ages 7+) female striped bass, after spawning, move more extensively along the Atlantic coast than stripers from the Hudson River stock (ASMFC 2004). Tag recoveries of Chesapeake stripers from July–November have occurred as far south as Virginia to as far north as Nova Scotia, Canada. Like the Hudson River stock, nearly all tag recoveries from mature female stripers from the Chesapeake Bay stock have taken place during winter (December and February) off Virginia and North Carolina (Crecco 2005).

Following extensive pollution abatement during the mid 1980s, striped bass abundance in the Delaware River, as measured by juvenile seine surveys, rose steadily thereafter to peak abundance in 2003 and 2004.[3] Like the Chesapeake Bay and Hudson stocks, spawning migration in the Delaware River begins during early April and extends through mid June (ASMFC 1990).

[3] Tom Baum, NJ BMF, pers. comm.

Recent tagging studies in the Delaware River show that larger and older (ages 7+) female striped bass undergo extensive migration northward into New England from July to November that spatially overlap the migratory range of Chesapeake striped bass (ASMFC 2004). Like the Hudson River and Chesapeake Bay stocks, many tag recoveries from mature female stripers from the Delaware River have taken place between December and February off Virginia, North Carolina, New England, and Long Island (Crecco 2005). The Delaware River stock was officially declared restored in 1998 (Kahn et al. 1998).

A4.4.7 Disease

A rise in Mycobacterium disease in Chesapeake Bay could be causing increases in natural mortality (Pieper 2006; Ottinger and Jacobs 2006). Two primary hypotheses have emerged regarding the mechanism for increased natural mortality (Vogelbein et al. 2006). One is that elevated nutrient inputs to the Bay, with associated eutrophication, results in loss of thermal refugia for striped bass, forcing them into suboptimal and stressful habitat during the summer. A second is that alternations in trophic structure and starvation have resulted due to over-harvest of key prey species such as Atlantic menhaden (*Brevoortia tyrannus*) and reductions in the forage base in Chesapeake Bay. More studies are necessary in order to determine linkages between these factors and mortality of older juvenile and adult striped bass (Ottinger and Jacobs 2006).

A4.4.8 Predators and Prey

Bluefish, weakfish, and other piscivores prey on juvenile striped bass (Hartman and Brandt 1995b; Buckel et al. 1999). Adult striped bass consume of a variety of fish (e.g., *Brevoortia tyrannus*, *Anchoa mitchilli*, *Mendia* spp.) and invertebrates (e.g., *Callinectes sapidus*, *Cancer irroratus*, *Homarus americanus*), but the species consumed depends upon predator size, time of year, and foraging habitat (Schaefer 1970; Hartman and Brandt 1995a; Nelson et al. 2003).

A4.5 FISHERY DESCRIPTIONS

Commercial fisheries operate in eight of the 14 jurisdictions regulated by the Commission's FMP (Massachusetts, Rhode Island, New York, Delaware, Maryland, Virginia, Potomac River, and North Carolina; Table A4.1). Commercial fishing for striped bass is prohibited in New Jersey, Pennsylvania, Connecticut, New Hampshire, Maine and the District of Columbia. The predominant gear types in the commercial fisheries are gillnets, pound nets, and hook and line. In a few states, the trap gear is an important part of this fishery. Massachusetts allows commercial fishing with hook-and-line gear only, while other areas allow net fisheries. Most commercial fisheries are seasonal in nature because of bass movements and management regulations. Following the reopening of striped bass fisheries in 1990, a rebuilding management strategy remained in effect until 1995, when the stock was considered recovered. Subsequently, management constraints were relaxed to the extent that states were afforded increases in commercial quotas (Table A4.1)

Recreational fisheries operate in all 14 jurisdictions regulated by the Commission's FMP. The predominant gear type is hook and line (Table A4.1). Following the reopening of striped bass fisheries in 1990, state fisheries were limited to a 2-fish possession limit, 28-inch minimum size limit (except "producer" areas, such as the Chesapeake jurisdictions, were allowed to implement 18-inch minimum size limits) and modest open fishing seasons. By 1995, coincident with the recovered status of striped bass, open fishing seasons were extended, with some states establishing year-round open seasons (Table A4.1). In Chesapeake Bay, recreational caps have been established for specific seasonal fisheries.

A5.0 CHARACTERIZE COMMERCIAL AND RECREATIONAL CATCH INCLUDING LANDINGS AND DISCARDS. (TOR #1)

A5.1 COMMERCIAL DATA SOURCES

Strict quota monitoring is conducted by states through various state and federal dealer and fishermen reporting systems, and landings are compiled annually from those sources by state biologists (Appendix A2). Commercial harvest in some states is recorded in pounds and is converted to number of fish using conversion methods (Appendix A2). Biological data (e.g., length, weight, etc.) and age structures (scales) from commercial harvest are collected from a variety of gear types through state-specific port sampling programs (Appendix A2). Harvest numbers are apportioned to age classes using length frequencies and age-length keys derived from biological sampling. Sample sizes for lengths and age structures are summarized by state for 2000–2006 in Table A5.1.

A5.2 COMMERCIAL LANDINGS

A5.2.1 Commercial Total Landings

Historically, annual commercial harvest of striped bass peaked at almost 6,804 mt (15 million pounds) in 1973, but through management actions, it declined by 99 percent to 63 mt (140,000 pounds) in 1986. Commercial landings have increased from 313 mt (800,000 pounds) in 1990 to 3,073 mt (7.6 million pounds) in 2006 (Table A5.2) following liberalization of fishery regulations.

A5.2.2 Commercial Landings in Numbers

Commercial harvest of striped bass was over one million fish from 1997–2000 and near one million fish through 2006 (Table A5.2). In 2006, landings increased 8.4% in numbers (81 thousand fish) but decreased 5.1% in weight (167 MT) compared to 2005. The Chesapeake Bay jurisdictions (Maryland, Virginia, and the Potomac River Fisheries Commission) usually account for a major portion of the coastwide commercial harvest. In 2006, Chesapeake Bay jurisdictions accounted for 65% of the striped bass harvest, by weight, and 81.7% of the number of striped bass harvested (Table A5.3).

A5.2.3 Commercial Landings Age Composition

The age structure of commercial harvest varies by state due to size regulations and season of the fisheries. In 2005 and 2006, the commercial harvest was composed primarily of ages 4–10 striped bass (Table A5.4). Harvest in Chesapeake Bay fisheries (Maryland, Virginia, and the PRFC) was composed mostly of ages 3–6 (Table A5.4; Figure A5.1).

A5.3 COMMERCIAL DISCARDS

A5.3.1 Estimation of Discards

Few states collect reliable information on the discarding of striped bass in commercial fisheries. Direct measurements of commercial discards of striped bass are generally only available for fisheries in the Hudson River Estuary and were available from Delaware Bay during 2001–2003 (Clark and Kahn, MS). Discard estimates for fisheries in Chesapeake Bay, and coastal locations since 1982 are based on the ratio of tags reported from discarded fish in the commercial fishery to tags reported from discarded fish in the recreational fishery, scaled by total recreational discards:

CD = RD*(CT/RT)
where:
CD = unadjusted estimate of the number of fish discarded by commercial fishery,
RD = number of fish discarded by recreational fishery, estimates provided by the NOAA Marine Recreational Fisheries Survey (MRFSS),
CT = number of tags returned from discarded fish by commercial fishermen,
RT = number of tags returned from discarded fish by recreational fishermen.

Tag return data by gear for 2005 and 2006 are given in Table A5.5. Starting in 1998, the Technical Committee attempted to improve the estimate of commercial discards by calculating tag return ratios and discards separately for Chesapeake Bay and the coast. A separate estimate for Delaware Bay was added in 2004. The ratios of tags from fish discarded by commercial fishermen to tags returned from fish discarded by recreational fishermen are shown in Table A5.6 for 2005 and 2006.

Expanding recreational discards to commercial discards based on reported tag returns assumes equal reporting tag rates in commercial and recreational fisheries but in fact this is not true. To correct for this bias, a correction factor is calculated by dividing the three-year mean of ratios of commercial to recreational landings by the three-year mean of ratios of tags returned by the two fisheries (Tables A5.6 and A5.7). The adjusted correction factors and estimates of total discards for 2005 and 2006 are shown in Table A5.7. Total discards in 2005 and 2006 were estimated to be 6.0 million and 1.8 million fish, respectively.

A5.3.2 Estimation of Dead Discards

Total discards are allocated to fishing gears based on the relative number of tags recovered by each gear (Tables A5.5 and A5.8). Discards by fishing gear were multiplied by gear specific release mortalities and summed to estimate total number of dead discards in a given year (Table A5.8). The estimates of dead discards are 776,951 and 216,753 fish for 2005 and 2006, respectively. The highest discard losses occurred in anchor gill net, pound net, and hook-and-line fisheries (Table A5.8).

A5.3.3 Age Composition of Commercial Dead Discards

Commercial discard proportions at age were obtained by applying age distributions from fishery dependent sampling or independent surveys that used comparable gear types (Table A5.9). Gear specific proportions at age were applied to discard estimates by gear and expanded estimates summed across all gears. Most commercial discards since 2004 were fish of ages 3–7 (Table A5.10; Figure A5.2).

A5.4. TOTAL REMOVALS BY COMMERCIAL FISHERIES

Total commercial striped bass removals (harvest and discards) were 1.7 million and 1.2 million fish in 2005 and 2006, respectively (Figure A5.3). Removals in 2005 exceeded the peak observed in 2000 (Figure A5.3). Harvest has generally exceeded dead discards since the mid 1990s (Figure A5.3). Commercial losses in 2005 and 2006 were dominated by the 2001 year class (ages 4 and 5, respectively; Figure A5.4).

A5.5 RECREATIONAL DATA SOURCES

Data on harvest and release numbers, harvest weight, and sizes of harvested striped bass come from the National Marine Fisheries Service's Marine Recreational Fisheries Statistics Survey (MRFSS). The MRFSS data collection consists of a stratified intercept survey of anglers at fishing access sites that obtains numbers of fish harvested and released per angler trip, and a telephone survey that derives numbers of angler trips. Estimates of harvest and release numbers of striped bass for the Atlantic coast are derived on a bi-monthly basis beginning in March (wave 2). For detailed descriptions of the MRFSS program, see the MRFSS website (http://www.st.nmfs.gov/st1/recreational/overview/overview.html). Total number of interviews, total number of striped bass interviews, numbers of harvested striped bass measured, estimates of numbers harvested and released with proportional standard errors by state and years 2000–2006 are listed in Table A5.11.

Anecdotal evidence had suggested that North Carolina, Virginia, and possibly other states had sizeable wave-1 fisheries beginning in 1996 (wave-1 sampling that began in 2004 in North Carolina waters and large wave-1 tag return data for North Carolina and Virginia supported this contention). However, MRFSS did not sample in January and February (wave-1) prior to 2004; therefore, there was little information for the winter fishery (Jan, Feb) that had developed off of North Carolina and Virginia. Harvest in wave 1 for these fisheries was estimated back to 1996 using observed relationships between landings and tag returns (Appendix A3). For North Carolina, the ratio of estimated landings to tag returns in wave-1 of 2004 and annual tag returns in wave-1 were used to estimate annual landings from tag returns in January and February of 1996–2003. For Virginia waters, the 1996–2004 mean ratio of landings and tag returns in wave-6 and annual tag returns in wave-1 were used to estimate landings from tag returns in January and February of 1996–2004. Estimates of wave-1 harvest for both Virginia and North Carolina in 1996–2004 are listed in Appendix A3. For 2005 and 2006, MRFSS wave-1 estimates of harvest for the winter fishery in Virginia waters were still unavailable; therefore, they were estimated. The approach used to estimate wave-1 harvest in prior years was abandoned because correlation between wave 6 harvest and tag returns off Virginia weakened significantly. A new method was developed in which the ratio of wave-1 harvest to wave-1 tag returns from North Carolina were multiplied by the wave-1 tag returns in Virginia to estimate Virginia wave-1 harvest (Appendix A3). Dead releases for the winter recreational fishery in North Carolina or Virginia were not estimated.

Most states use the length frequency distributions of harvested striped bass measured by the MRFSS. The MRFSS measurements are converted from fork length (inches) to total length (inches) using conversion equations. Proportions-at-length are calculated and multiplied by the MRFSS harvest numbers to obtain total number harvested-at-length. The sample sizes of harvested bass measured by MRFSS may be inadequate for estimation of length frequencies; therefore, some states use harvest length data collected from other sources (e.g., volunteer angler programs) to increase sample sizes (Table A5.11). Full descriptions of state-specific programs are presented in Appendix A4.

Data on sizes of released striped bass come mostly from state-specific sampling or volunteer angling programs (Table A5.11). Proportions-at-length are calculated and multiplied by the MRFSS dead releases numbers to obtain total number dead releases-at-length. For those programs that do not collect data on released fishes, the lengths of tagged fish released by anglers participating in the American Littoral Society's striped bass tagging program or from state-sponsored tagging programs are used. Details on calculations are given in Appendix A4.

Many states collect scale samples during state sampling programs designed to collect information on harvest and released striped bass from the recreational fishery (Table A5.11). Age-length keys are usually constructed and applied to harvest and dead release numbers-at-length. When sampling of the recreational fishery does not occur, age-length keys are constructed by using data on age-length from commercial sampling, fisheries-independent sampling or striped bass tagging programs. For those states that do not collect scale samples, age-length keys are usually borrowed from neighboring states. Detailed descriptions of how age samples are collected, processed, and aged are given in Appendix A4.

Age composition of the January/February recreational fishery in North Carolina and Virginia was estimated from length-frequency data collected by MRFSS and appropriate state age-length keys. Length-frequencies for the North Carolina winter harvest of 2004 came from data in wave-6 of 2003 and wave-1 of 2004. Length-frequencies for the winter harvests of 1996–2003 came from wave-6 of year t-1. Lengths were converted to age for North Carolina with a combined age-length key from New York and North Carolina. Length-frequencies for the Virginia winter harvest in 1996–2006 came from MRFSS data in wave-6 of year t-1. We converted the Virginia lengths to age with a Virginia age-length key. Estimates of wave-1 harvest at age for North Carolina and Virginia were added to the existing CAA matrix for 1996 through 2006.

A5.6 RECREATIONAL LANDINGS

A5.6.1 Recreational Total Landings

Figure A5.5 traces the impressive growth of the Atlantic coast recreational fisheries from 1982 through 2006. Harvest increased from 1,010 mt (2.2 million pounds) in 1990 to 13,814 mt (29.1 million pounds) in 2006 (Table A5.2).

A5.6.2 Recreational Landings in Numbers

In numbers of fish, recreational harvest of striped bass was greater than 1.4 million fish from 1997 through 2006, and more than two million striped bass during 2003–2006 (Table A5.2). Harvest was generally highest in Virginia, Maryland, New Jersey, and Massachusetts (Table A5.12). The annual Atlantic coast harvest (in numbers) has been a small fraction of the catch (harvest and releases, combined) since the 1980s because the releases (B2s) have accounted for 85 to 90% of the annual catch in most years (see Section A5.6).

A5.6.3 Age Composition of Recreational Landings

Coastwide recreational harvest was dominated by the 2000 (age 5) and 1996 (age 9) year-classes in 2005, and by the 2001 (age 5) and 1996 (age 10) year-classes in 2006 (Table A5.13; Figure A5.6). Ages 4–10 made up >77% of the coastwide harvest, and ages 8+ made up about 50% in both years (Table A5.13). Recreational harvest from the coast (includes Delaware Bay) was composed mostly of ages 5–11, while harvest in Chesapeake Bay was dominated by ages 4–8 (Figure A5.7).

A5.7 RECREATIONAL RELEASES

A5.7.1. Estimation of Releases

The number of striped bass that are caught and released (B2) is estimated by MRFSS (Table A5.14). The releases have accounted for 85 to 90% of the annual catch in most years (Figure A5.8).

A5.7.2 Estimation of Dead Releases

The number of releases that die due to the capture and release process is estimated by multiplying the total release numbers (B2) by an estimate of hooking mortality (0.08) derived by Diodati and Richards (1996) prior to publication. Estimates of the number of dead releases are presented in Table A5.15. The numbers of fish released dead increased from 132 thousand fish in 1990 to 1.2 million fish in 1997. Releases remained around 1.2 million through 2003, but have increased to the series maximum of 2 million fish in 2006. The numbers of fish released dead are generally highest in Massachusetts and Maryland (Table A5.15).

A5.7.3 Age Composition of Dead Releases

Ages of coastwide recreational dead releases ranged from 0 to 13+, but most dead releases were ages 2–6 (Table A5.16; Figure A5.6). The dead releases were dominated by the 2001 and 2003 year-classes in both years (Table A5.16; Figure A5.6). Recreational dead releases from the coast (includes Delaware Bay) were composed of fish ages 2–5 and ages 3–6 in 2005 and 2006, respectively, but the 2001 and 2003 year-classes dominated (Table A5.16; Figure A5.7). In Chesapeake Bay, dead releases were composed of ages 2–4 and were dominated by the 2003 year-class in both years (ages 2 and 3; Figure A5.7).

A5.8 TOTAL REMOVALS BY RECREATIONAL FISHERIES

Total recreational striped bass removals (harvest and dead discards) in 2005 and 2006 were 3.9 million and 4.8 million fish, respectively (Table A5.17; Figure A5.9). Total removals were highest in Massachusetts, New Jersey, Maryland, and Virginia (Table A5.17). The harvest and dead releases combined were dominated by ages 2, 4–6, and 9 in 2005, and ages 3, 5–6, and 10 in 2006 (Figure A5.10). Total recreational dead releases and harvest losses have generally increased since 1982, with intermittent declines in 1998–1999 and 2001–2002 (Figure A5.9). Recreational removals in 2006 were the highest of the time series (Figure A5.9).

A5.9 TOTAL REMOVALS BY COMMERCIAL AND RECREATIONAL FISHERIES

Combined losses showed that the recreational fishery removed the largest number of striped bass in 2005 and 2006 (Figure A5.11). Historically, the recreational fishery has been the dominant source of fishing removals since 1991 (Figure A5.12). The above components were totaled by year to produce the overall catch at age matrix (Table A5.18). The total removals of striped bass in 2006 (6.11 million fish) were the highest in the time series and reflect an 8% and a 14% increase from 2005 and 2004, respectively. More importantly, removals of fish age 8+ increased in 2006 by 7% compared to 2005 (Figure A5.13). Ages 3 (2003 year-class) and 5 (2001 year-class) sustained the highest losses in 2006 (Table A5.18).

A5.10 CATCH WEIGHT AT AGE

Catch mean-weight-at-age data, which is used to calculate total biomass and spawning stock biomass, was calculated for the period 1998–2002 using all available weight data from MA, NY, MD, VA, NH, and CT (1998–2001) and adding data from RI and DE in 2002 (Appendix A5). For 2003–2006, mean weights at age for the 2003–2006 striped bass catches were determined as a result of the expansion of catch and weight at age. Data came from Maine and New Hampshire recreational harvest and discards; Massachusetts recreational and commercial catch; Rhode Island recreational and commercial catch; Connecticut recreational catch; New York recreational catch and commercial landings; New Jersey recreational catch; and Delaware, Maryland, Virginia, and North Carolina recreational and commercial catch (Appendix A5). Weighted mean weights at age were calculated as the sum of weight at age multiplied by the catch at age in numbers, divided by the sum of catch at age in numbers. Details of developing weights at age for 1982–1996 can be found in the SAW-26 consensus summary (Northeast Fisheries Science Center 1998). Weights at age for 1982–2006 are presented in Table A5.19.

A6.0 CHARACTERIZE THE FISHERIES-INDEPENDENT AND -DEPENDENT INDICES OF RELATIVE ABUNDANCE. (TOR#2)

A6.1 DATA SOURCES

States provide age-specific and aggregate indices from fisheries-dependent and fisheries-independent sources that are assumed to reflect trends in striped bass relative abundance. A formal review of age-2+ abundance indices was conducted by ASMFC at a workshop in July of 2004 (Appendix A6). Young of-the-year and age-1 indices had been reviewed and validated (ASMFC 1996). The 2004 workshop developed a set of evaluation criteria and tasked states with a review of indices. Both the Striped Bass Technical Committee and the Management Board approved the criteria and the review. The resulting review led to revisions and elimination of some indices formerly used in ADAPT (Appendix A6).

Based on the review of survey programs and technical committee recommendations (see Section 6.0), major changes were made to the suite of indices used in the ADAPT model. The NEFSC spring inshore survey, originally age-specific, was reduced to an aggregate index (ages 2–9) and was truncated at 1991 due to missed sampling of inshore survey strata prior to 1991. The Massachusetts commercial CPUE, originally age-specific harvest-per-trip indices, were redeveloped as age-specific (ages 2–13+) total catch-per-hour indices. The New Jersey trawl, originally an aggregate index, was further apportioned into age-specific mean indices for ages 2–13+. The New York ocean haul seine survey indices for ages 8–13+ were aggregated into an 8+ index. Connecticut age-specific recreational catch indices for ages 10–13+ were aggregated to 10+. The Virginia pound net survey, a single fixed station, commercial pound net index, was eliminated from the input because few analyses conducted could support its continued use as an index that reflected striped bass abundance. Two new surveys were added: age-specific (ages 2–13+) Delaware River electrofishing spawning stock indices and the coastwide MRFSS aggregate (2–13+) total catch rate index.

Descriptions of the current survey indices are given below and reflect changes to surveys following the formal review. A summary of index information is provided in Table A6.1.

A6.1.1 Fisheries-Dependent Catch Rates

A.6.1.1.1 Massachusetts Commercial Total Rate Index (MACOMM)

Age-specific (2–13+) indices of relative abundance for 1991 to present are generated from commercial catch data. All fishermen who sell striped bass are required to report the total hours fished, number and pounds of fish caught by disposition category (i.e., released sub-legal, released legal, sold, and consumed), area fished, and the fishing method (Surf, Boat, Both) by month. A generalized linear model (GLM) is used to generate a standardized CPUE aggregate index (Hilborn and Walters 1992). Each record is the summarization of a fisher's monthly number and pounds of fish caught and hours fished by year, month, area fished (reduced to 4 regions: Cape Cod Canal, Southern MA, Cape Cod Bay, North MA), and fishing mode. The catch rate for each record is calculated by dividing the total numbers caught by the total number of hours fished. The catch rate is standardized using PROC GLM in SAS. To partition the annual aggregate index into age-specific indices, annual length frequencies of all fish caught reported by fishers on voluntary logsheets are applied to age-length keys derived for each year to estimate proportions-at-age. The proportions-at-age are then multiplied by the annual aggregate index to obtain age-specific indices.

A6.1.1.2 Connecticut Recreational CPUE (CTCPUE)

An aggregate Connecticut CPUE index (CPUE) for striped bass (1981–2006) is derived as a ratio of annual Connecticut recreational catches (A, B1, B2) from the MRFSS to annual directed fishing effort (DE in trips) on striped bass:

$$CPUE = C / DE$$

Directed fishing effort is estimated annually as the product of the total fishing trips made annually in Connecticut based on MRFSS times the fraction of positive striped bass intercepts (fracp) from MRFSS. This quantity (E*fracp) is then divided by the fraction of successful striped bass trips (fracs) recorded annually in logbooks from the Connecticut Volunteer Angler Survey (CVAS):

$$DE = (E*fracp)/ fracs)$$

To disaggregate the time series (1981–2006) of indices by age, the annual index (CPUE) is first apportioned into length frequencies reported from logbooks in the CVAS. Each year, between 70 and 95 volunteer anglers record a total of 2,800 to 4,000 length measurements (length range: 6 to 51 inches TL) of striped bass in their catches. Once the length frequencies is established, an age frequency of the annual index is derived as a product of the annual length frequency and an annual age-length key for Long Island Sound stripers derived by biologists from the NY DEC.

A6.1.1.3 MRFSS Total Catch Rate Index (MRFSS)

An aggregate index of relative abundance for 1988 to present is generated from MRFSS intercept data. Generalized linear modeling (McCullagh and Nelder 1989) is used to derive annual mean catch-per-hour estimates by adjusting the number of caught fish per trip for the classification variables of state, year, two-month sampling wave, number of days fished in the past 12 months (as a measure of avidity), and number of hours fished. In the analyses, only data from anglers who reported that they targeted striped bass is used to insure methods used among anglers are as consistent as possible and to identify those targeting anglers that did not catch striped bass (zero catches). Also, only data from private boats fishing in the Ocean during waves 3–6 is used.

A delta-lognormal model (Lo et al. 1992) was selected as the best approach to estimate year effects after examination of model dispersion (Terceiro 2003) and standardized residual deviance versus linear predictor plots (McCullagh and Nelder 1989). In the delta-lognormal model, catch data is decomposed into catch success/failure and positive catch components. Each component is analyzed separately using appropriate statistical techniques and then the statistical models are recombined to obtain estimates of the variable of interest. The catch success/failure was modeled as a binary response to the categorical variables using multiple logistic regression:

$$\log it(p) = \log(p/1-p) = \alpha + \sum_{i=1}^{n} \beta_i X_i + \varepsilon$$

where p is the probability of catching a fish, α is the intercept, β_i is the slope coefficient of the *i*th factor, X_i is the *i*th categorical variable (coded as 0 or 1), and ε is the error term. PROC LOGISTIC in SAS is used to estimate parameters, and goodness-of-fit was assessed using concordance measures and the Hosmer-Lemeshow test.

Positive catches, transformed using the natural logarithm, is modeled assuming a normal error distribution using PROC GLM:

$$\log(y) = \alpha + \sum_{i=1}^{n} \beta_i X_i + \varepsilon$$

where *y* is the observed positive catch, β_i ,and X_i are the same symbols as defined earlier, and ε is the normal error term. Any variable not significant at α=0.05 with type-III (partial) sum of squares is dropped from the initial GLM model and the analysis is repeated. First-order interactions were considered in the initial analyses but it was not always possible to generate annual means by the least-square methods with some interactions included (Searle et al. 1980); therefore, only main effects are considered.

The annual index of striped bass total catch is estimated by combining the two component models. The estimate in year *i* from the models is given by

$$\hat{I}_i = \hat{p}_i * \hat{y}_i$$

where p_i and y_i are the predicted annual responses from the logistic and GLM. p_i is calculated as

$$\hat{p}_i = \frac{\exp(\hat{\alpha} + \hat{\beta}_i)}{1 + \exp(\hat{\alpha} + \hat{\beta}_i)}$$

and y_i is calculated as

$$\hat{y}_i = \exp(LSM_i + \sigma^2 / 2)$$

where LSM_i is the least squares mean for year i and σ^2 is the mean square error.

A6.1.2 Fisheries-Independent Survey Data

A6.1.2.1 Connecticut Trawl Survey (CTTRL)

Connecticut provides an aggregate (ages 2–4) index of relative abundance from a bottom trawl survey. The Long Island Sound Trawl Survey (LISTS) began in 1984 to provide fishery independent monitoring of important recreational species in Long Island Sound. Length data for these species are collected from every tow. All species are identified and counted. No information on the sizes of striped bass released is collected. Sampling is conducted monthly from April through November to establish seasonal patterns of abundance and distribution. LISTS is conducted from longitude 72° 03' (New London, Connecticut) to longitude 73° 39' (Greenwich, Connecticut). The sampling area includes Connecticut and New York waters from 5 to 46 m in depth and over mud, sand, and transitional (mud/sand) sediment types. Sampling is divided into spring (April–June) and fall (September–October) periods, with 40 sites sampled monthly for a total of 200 sites annually. The sampling gear employed is a 14 m otter trawl with a 51 mm codend. To reduce the bias associated with day-night changes in catchability of some species, sampling is conducted during daylight hours (Sissenwine and Bowman 1978).

LISTS employs a stratified-random sampling design. The sampling area is divided into 1.85 x 3.7 km (1x2 nautical miles) sites, with each site assigned to one of 12 strata defined by depth interval (0–9.0 m, 9.1–18.2 m, 18.3–27.3 m or, 27.4+ m) and bottom type (mud, sand, or transitional). For each monthly sampling cruise, sites are selected randomly from within each stratum. The number of sites sampled in each stratum is determined by dividing the total stratum area by 68 km^2 (20 square nautical miles), with a minimum of two sites sampled per stratum. Discrete stratum areas smaller than a sample site are not sampled. The CTTRL index is computed as the stratified geometric mean number per tow.

A6.1.2.2 Northeast Fisheries Science Center Bottom Trawl Survey (NEFSC)

The Northeast Fisheries Science Center provides an aggregate (2–9) index of relative abundance from the spring stratified-random bottom trawl survey. The survey covers waters from the Gulf of Maine to Cape Hatteras, NC. Only data from inshore strata from 1991–2006 are used.

A6.1.2.3 New Jersey Bottom Trawl Survey (NJTRL)

New Jersey provides age-specific (2–9+) geometric mean indices of relative abundance for striped bass from a stratified-random bottom trawl initiated in 1989. The survey area consists of NJ coastal waters from Ambrose Channel, or the entrance to New York harbor, south to Cape Henlopen Channel, or the entrance to Delaware Bay, and from about the 3 fathom isobath inshore to approximately the 15 fathom isobath offshore. This area is divided into 15 sampling strata. Latitudinal boundaries are identical to those which define the sampling strata of the National Marine Fisheries Service (NMFS) Northwest Atlantic groundfish survey. Exceptions are those strata at the extreme northern and southern ends of NJ. Where NMFS strata are extended into NY or DE waters, truncated boundaries were drawn which included only waters adjacent to NJ, except for the ocean waters off the mouth of Delaware Bay, which are also included. Samples are collected with a three-in-one trawl, so named because all the tapers are three to one. The net is a two seam trawl with forward netting of 12 cm (4.7 inches) stretch mesh and rear netting of 8 cm (3.1 inches) stretch mesh. The codend is 7.6 cm stretch mesh (3.0 inches) and is lined with a 6.4 mm (0.25 inch) bar mesh liner. The headrope is 25 m (82 feet) long and the footrope is 30.5 m (100 feet) long. Trawl samples are collected by towing the net for 20 minutes. The total weight of each species is measured with hanging metric scales and the length of all individuals comprising each species caught, or a representative sample by weight for large catches, is measured to the nearest cm. Total length is measured and only data from April are used for striped bass.

A6.1.2.4 New York Ocean Haul Seine Survey (NYOHS)

New York provides age-specific geometric mean indices of relative abundance for striped bass generated from an ocean haul seine survey. Since 1987, NY DEC has been sampling the mixed coastal stocks of striped bass by ocean haul seine. Sampling is conducted annually during the Fall migration on the Atlantic Ocean facing beaches off the east end of Long Island. A crew of commercial haul seine fishermen is contracted to set and retrieve the gear, and assist department biologists in handling the catch. The survey seine measures approximately 1,800 feet long and is composed of two wings attached to a centrally located bunt and cod end. The area swept is approximately ten acres. The seine is fifteen feet deep in the wings and twenty feet deep in the bunt.

Under the original design, sampling dates were selected at random to create a schedule of thirty dates. For each date selected, two of ten fixed stations were chosen at random, without replacement, as the sampling locations for that day. Since this design was difficult to implement due to weather-related delays, the sampling design was altered in 1990. Instead of randomly selecting thirty days, sixty consecutive working days were identified during the fall. One station was randomly selected, without replacement, for each working day until six "rounds" of ten hauls had been scheduled. Hauls that were missed due to bad weather or equipment failure were added to the next scheduled sampling day. No more than three hauls were attempted for any given day so that sampling was evenly distributed over time. Sixty hauls were scheduled for each year.

Since 1995, the survey team has been prohibited from gaining access to several of the fixed stations. Instead of the original ten stations, two of the original stations plus three alternate sites have been used to complete the annual survey. These alternate stations occur within the geographic range of the original standard stations. Also since 1995, funding delays have resulted in a one-month delay in the commencement of field sampling activities. Between 1987 and 1994 field sampling began in early September. Since 1995, sampling has begun in late September to early October. In addition, decreases in funding have led to reductions in annual sampling effort from sixty seine hauls to forty-five seine hauls per season since 1997. The time series of catch and catch-at-age has been standardized by date for the entire time series.

A6.1.2.5 Maryland Spawning Stock Survey (MDSSN)

Maryland provides spawning stock age-specific (2–13+) mean indices of relative abundance for striped bass in Chesapeake Bay from a gillnet survey initiated in 1985. Multi-panel experimental drift gill nets are deployed in spawning areas in the Potomac River and in the

Upper Chesapeake Bay during the spring spawning season in April and May. There are generally 20–25 sampling days in a season. Ten mesh panels 150 feet long that range from 8 to 11.5 feet deep are used. The panels are constructed of multifilament nylon webbing in 3.00–10.00-inch stretch-mesh. In the Upper Bay, the entire suite of 10 meshes is fished simultaneously. In the Potomac River, two suites of 5 panels are fished simultaneously. Overall, soak times for each mesh panel range from 15 to 65 minutes. In both systems, all 10 meshes are fished twice daily (20 sets) unless weather or other circumstances prohibit a second soak. Sampling locations are assigned using a stratified random survey design. Each sampled spawning area is considered a stratum. One randomly chosen site per day is fished in each spawning area. The Potomac River sampling area consists of 40 0.5-square-mile quadrants and the Upper Bay sampling area consists of 31 1-square-mile quadrants. The Choptank River was also sampled between 1985–1996. A sub-sample of striped bass captured in the nets is aged. Scales are removed from two-three randomly chosen male striped bass per one cm length group, per week, for a maximum of ten scales per length group over the entire season. Scales are taken from all males over 700 mm TL and all females regardless of total length.

CPUEs for individual mesh sizes and length groups are calculated for each spawning area. Mesh-specific CPUEs ($CPUE_{i,j}$) are calculated by summing the catch in each length group across days and sets, and dividing the result by the total effort for each mesh. Sex-specific mesh selectivity coefficients are then used to correct the mesh-specific length group CPUE estimates. Sex-specific models are used to develop selectivity coefficients for fish sampled from the Potomac River and Upper Bay. Model building and hypothesis testing has determined that male and female striped bass possess unique selectivity characteristics, but no differences are evident between the Upper Bay and the Potomac River. Therefore, sex-specific selectivity coefficients for each mesh and length group are estimated by fitting a skew-normal model to spring data from 1990 to 2000 following the procedure presented in Helser et al. (1998). Model residuals are re-sampled 1,000 times to generate a population of 1,000 mesh- and size class-specific selectivity coefficients for each year, sample area, and sex. The CPUE for each size class and mesh are then divided by the appropriate selectivity coefficient to generate 1,000 replicate matrices of mesh- and length-specific corrected catch frequencies. A vector of selectivity-corrected length-group CPUEs for each spawning area and sex is then developed. The selectivity-corrected CPUEs are averaged across meshes, using a mean that is weighted by the capture efficiency of the mesh. Finally, area- and sex-specific estimates of relative abundance are pooled to develop bay-wide estimates of relative abundance.

A6.1.2.6 Delaware Spawning Stock Electrofishing Survey (DESSN)

Delaware provides spawning stock age-specific (2–13+) mean indices of relative abundance for striped bass in the Delaware River from an electroshock survey initiated in 1996. Striped bass are sampled in the Delaware River from the vicinity of Big Timber Creek and League Island near river kilometer 152 located between Central Philadelphia downstream to the Delaware Memorial Bridge below Wilmington, DE at river kilometer 110. A stratified-random sampling design is used and a Smith-Root model 18-E boat electrofisher is used to collect striped bass. Typically, sampling is conducted with the boat moving in the direction of the tidal flow and in a zigzag pattern. Only striped bass approximately >200 mm total length are collected. Sampling is conducted weekly during mid-April to May (two days per week) and seven 12-minute timed samples are made per day. Length, weight, and sex are recorded and scales are collected from each fish.

A6.1.2.7 New York Young-of-the-Year and Yearling Survey (NYYOY and NY Age 1)

New York provides an index of relative abundance for young-of-the year striped bass in the Hudson River for years 1980 to present. The beach seine survey samples fixed stations between Tappan Zee to Haverstraw Bay area using a 61-m, 5-mm stretched mesh bag and 6 mm stretched mesh wing. A total of 33 fixed stations are sampled. Twenty-five stations are sampled biweekly from mid-July through early November. The arithmetic mean is used as the relative index.

New York also provides an index of relative abundance for yearling striped bass in western Long Island sound. The beach seine (61-m) survey samples fixed stations during May–October. The arithmetic mean is used as the relative index.

A6.1.2.8 New Jersey Young-of-the-Year Survey (NJYOY)

New Jersey provides an index of relative abundance for young-of-the year striped bass in the Delaware River for years 1980 to present. A bagged beach seine is used at fixed and random stations, which are sampled biweekly from August–October. About 256 samples are taken per year. Relative abundance index for striped bass is calculated as the mean geometric number of young-of-the-year captured per seine haul.

A6.1.2.9 Virginia Young-of-the-Year Survey (VAYOY)

Virginia provides an index of relative abundance for young-of-the-year bass in the Virginia portion of Chesapeake Bay. Begun in 1980, the fixed station survey is conducted in the James, York, and Rappahannock river systems. Eighteen index stations are sampled five times a year on a biweekly basis from mid-July through September. Twenty auxiliary stations provide geographically expanded coverage during years of unusual precipitation or drought when the normal index stations do not yield samples. A bagged beach seine (30.5 m long) is set by hand with one end fixed on the beach and the other fully extended perpendicular to the beach. The seine is swept with the current. Two hauls are made at each site. Abundance indices are computed as the geometric mean number of young-of-the-year or yearling bass per haul.

A6.1.2.10 Maryland Young-of-the-Year and Yearlings Surveys (MDYOY and MD Age1)

Maryland provides an index of relative abundance for young-of-the-year and yearling striped bass in the Maryland portion of Chesapeake Bay. Begun in 1954, the fixed station survey is conducted in the Upper Bay, Choptank, Nanticoke, and Potomac Rivers. Each station is sampled once during each monthly round performed during July, August, and September. A bagless beach seine (30.5 m long) is set by hand with one end fixed on the beach and the other fully extended perpendicular to the beach. The seine is swept with the current. Two hauls are made at each site. Abundance indices are computed as the geometric mean number of young-of-the-year or yearling bass per haul.

A6.2 COMPARISON OF FISHERIES-DEPENDENT AND FISHERIES-INDEPENDENT INDICES

Time series of each index used in 2005 and current assessments before aggregating and tuning adjustments were done are shown in Table A6.2. The original indices are a mixture of geometric and arithmetic mean estimates. For comparative purposes, the indices of presented in both forms where possible.

Among the fisheries-dependent indices, trends in the aggregated MA Commercial index suggests a steady abundance since the mid 90s, the CT Recreational CPUE suggests steady population levels from 1996 to 2004, but abundance increased in 2005 and 2006, while the coastwide MRFSS index suggests a decline in abundance from 1998 to 2003 and a steady rise through 2006 (Figure A6.1).

The fishery-independent indices for combined ages generally indicate an increase in population abundance from the early 1990s through the mid 1990s, and relatively stable levels thereafter (Figure A6.2). The exception is the Maryland gillnet survey which shows a relatively stable population since the mid 1980s (Figure A6.2).

Indices of young-of-the-year abundance show some pattern of decline since 2003. Recruitment in 2006 was close to lows of the time series since 1990 in Chesapeake Bay (Maryland index), Delaware Bay, and the Hudson River in 2006 (Figure A6.3). Strong year-classes were evident in 1993, 1996, 2001, and 2003 in Chesapeake Bay (Maryland and Virginia), and in 1993, 1995, 1999, and 2003 in Delaware Bay, in 1997, 1999, and 2001 in Hudson River (Figure A6.3).

A7.0 EVALUATE THE STATISTICAL CATCH AT AGE (SCA) MODEL AND ITS ESTIMATES OF F, SPAWNING STOCK BIOMASS, AND TOTAL ABUNDANCE OF ATLANTIC STRIPED BASS, ALONG WITH THE UNCERTAINTY OF THOSE ESTIMATES. (TOR #3)

A7.1 SCA MODEL

A forward-projecting age-structured statistical catch-at-age (SCA) model for the Atlantic coast migratory stocks of striped bass was constructed and is used to estimate fishing mortality, abundance, and spawning stock biomass during 1982–2006 from total removals-at-age and fisheries-dependent and fisheries-independent survey indices.

A7.2 MODEL STRUCTURE

The structure of the population model is aged-based and projects the population numbers-at-age forward through time given model estimates of recruitment and age-specific total mortality. The population numbers-at-age matrix has dimensions Y x A, where Y is the number of years and A is the oldest age group. The time horizon for striped bass is 1982–2006 since complete catch data are only available back to 1982. However, there are relative abundance data (Maryland young-of-the-year indices) available for earlier years. To use those earlier data, the dimensions of population numbers-at-age are expanded to (Y+A-1) x (A) matrix (Figure A7.1). The number of year classes in the model was 13, representing ages 1 through 13+.

Population numbers-at-age ($a<A$) are calculated through time by using the exponential cohort survival model

$$\hat{N}_{y,a} = \hat{N}_{y-1,a-1}\, exp^{-\hat{F}_{y-1,a-1} - M} \qquad (1)$$

where $\hat{N}_{y,a}$ is abundance of age a in year y, $\hat{N}_{y-1,a-1}$ is abundance of age $a-1$ in year $y-1$, $F_{y-1,a-1}$ is the instantaneous fishing mortality rate for age $a-1$ in year $y-1$, and M is the instantaneous natural mortality (assumed constant across years and ages). For the plus group (A), numbers-at-age are the sum of survivors of A-1 in year y-1 and survivors from the plus group in year y-1:

$$\hat{N}_{y,A} = \hat{N}_{y-1,A-1}\, exp^{-\hat{F}_{y-1,A-1} - M} + \hat{N}_{y-1,A}\, exp^{-\hat{F}_{y-1,A} - M} \quad (2)$$

Recruitment (numbers of age-1 bass) in year y ($N_{y,1}$) is estimated and it is modeled as a log-normal deviation from average recruitment:

$$\hat{N}_{y,1} = \hat{\bar{N}}_1 \cdot exp^{\hat{e}_y} \quad (3)$$

where $N_{y,1}$ is the number of age 1 fish in year y, $\hat{N}_1$ is the average recruitment parameter, and e_y are independent and identically distributed normal random variables with zero mean and constant variance and are constrained to sum to zero over all years. A penalty function is used to help constrain the recruitment deviations and is included in the total likelihood:

$$P_{rdev} = \lambda_R \sum_y e_y^2 \quad (4)$$

where λ_R is a user-specified weight. The initial population abundance-at-age for 2-13+ in 1970 is calculated by using $\hat{N}_{1970,1}$ and assuming $F_{1982,a-1}$:

$$\hat{N}_{1970,a} = \hat{N}_{1970,a-1}\, exp^{-\hat{F}_{1982,a-1} - M} \quad (5)$$

Estimation of fishing mortality-at-age is accomplished by assuming that fishing mortality can be decomposed into yearly and age-specific components (separability):

$$\hat{F}_{y,a} = \hat{F}_y \cdot \hat{s}_a \quad (6)$$

where F_y is the fully-recruited fishing mortality in year y and s_a is the average selectivity value of fish of age a. The dimensions of the F-at-age matrix are Y x A. Similar to recruitment, F_y is modeled as a log-normal deviation from average fishing mortality:

$$\hat{F}_y = \hat{\bar{F}} \cdot exp^{d_y} \quad (7)$$

where F_y is the fishing mortality in year y, $\hat{F}$ is the average recruitment parameter, and d_y are independent and identically distributed normal random variables with zero mean and constant variance and are constrained to sum to zero over all years. For years earlier than 1982, the fishing mortality-at-age is assumed equal to the values for 1982. A penalty function is used to help constrain the fishing mortality deviations and is included in the likelihood function:

$$P_{fdev} = \lambda_F \sum_y d_y^2 \quad (8)$$

where λ is a user-specified weight. Following Brodziak (2002), a fishing mortality penalty is imposed to ensure that extremely small Fs are not produced during the early phases of the estimation process:

$$P_{f_{add}} = \begin{cases} \text{phase} < 3, & \lambda_F \cdot 10 \cdot \sum_y (F_y - 0.15)^2 \\ \text{phase} \geq 3, & \lambda_F \cdot 0.001 \cdot \sum_y (F_y - 0.15)^2 \end{cases} \quad (9)$$

Selectivity for ages $a<A$ is modeled by using the Gompertz equation, and to ensure at least one age had a maximum selectivity of 1, s_a is calculated as

$$s_a = \frac{exp^{\left(-exp^{-\hat{\beta}(a-\hat{\alpha})}\right)}}{max_a\left(exp^{\left(-exp^{-\hat{\beta}(a-\hat{\alpha})}\right)}\right)} \quad (10)$$

where α and β are estimates. Based on historical changes in size and catch regulations and model comparisons (see *Exploratory Analyses* below), selectivity patterns are estimated for 4 periods: 1982–1984, 1985–1989, 1990–1995, and 1996–2006. s_a for the plus group (A) is assumed equal to s_a of age A-1.

For ease of computation, total mortality-at-age (Z) is calculated as

$$Z_{y,a} = F_{y,a} + M \quad (11)$$

and fills a matrix of dimension Yx A. For years earlier than 1982, Z is assumed equal to the Z values of 1982.

For total catch and survey indices data, lognormal errors are assumed throughout and the concentrated likelihood, weighted for variation in each observation, was calculated. The generalized concentrated negative log-likelihood ($-L_l$) (Parma 2002; Deriso et al. 2007) is

$$-L_l = 0.5 * \sum_i n_i * \ln\left(\frac{\sum_i RSS_i}{\sum_i n_i}\right) \quad (12)$$

where n_i is the total number of observations and RSS_i is the weighted residual sum-of-squares from dataset i. Equations for the weighted residual sum-of-squares are shown following the description (given below) of each dataset.

For the catch and survey age compositions, multinomial error distributions are assumed throughout and the negative log-likelihoods are calculated using the general equation

$$-L = \sum_y -n_y \sum_a P_{y,a} \cdot \ln\left(\hat{P}_{y,a}\right) \quad (13)$$

Specific equations for each dataset are shown following the description of each dataset.

Total catch (recreational and commercial harvest numbers plus number of discards that die due to handling and release) and the proportions of catch-at-age of striped bass fisheries are the primary data from which fishing mortalities, selectivities, and recruitment numbers are estimated. Given estimates of F, M, and population numbers, predicted catch-at-age is computed from Baranov's catch equation (Ricker 1975):

$$\hat{C}_{y,a} = \frac{\hat{F}_{y,a}}{\hat{F}_{y,a} + M} \cdot (1 - exp^{-\hat{F}_{y,a} - M}) \cdot \hat{N}_{y,a} \tag{14}$$

where $\hat{C}_{y,a}$ is the predicted removals of age a during year y and other variables are as defined above. All predictions are stored in a matrix of dimension Y x A. Predicted catch-at-age data are then compared to the observed total catch and proportions of catch-at-age through the equations:

Predicted Total Catch

$$\hat{C}_y = \sum_a \hat{C}_{y,a} \tag{15}$$

Predicted Proportions of Catch-At-Age

$$\hat{P}_{y,a} = \frac{\hat{C}_{y,a}}{\sum_a \hat{C}_{y,a}} \tag{16}$$

where $\hat{C}_y$ is the predicted total catch in year y and $P_{y,a}$ is the predicted proportions of age a in the catch during year y.

The weighted lognormal residual sum-of-squares (RSS_c) for total catch is calculated as

$$RSS_c = \lambda_c \sum_y \left(\frac{\ln\left(C_y + 1e^{-5}\right) - \ln\left(\hat{C}_y + 1e^{-5}\right)}{CV_y} \right)^2 \tag{17}$$

where C_y is the observed catch in year y, $\hat{C}_y$ is the predicted catch in year y, CV_y is the CV for observed catch in year y, and λ_c is the relative weight (Parma 2002; Deriso et al. 2007). Total catch CVs are assumed equal to the PSEs of MRFSS total catch estimates for the entire Atlantic coast (less South Carolina, Georgia and East Florida records) since it is assumed that only the estimates of recreational kill and dead discards have error.

In addition, the predicted proportions of catch-at-age are compared to the observed proportions of catch-at-age through a multinomial probability model. The proportions of catch-at-age negative log-likelihood (L_p) is

$$-L_p = \lambda_p \sum_y - n_y \sum_a P_{y,a} \cdot \ln\left(\hat{P}_{y,a} + 1e - 7\right) \tag{18}$$

where n_y is the effective number of fish aged in year y and $P_{y,a}$ is the observed proportion of catch-at-age. The multinomial probability assumes that the number of aged fish used to apportion the catch into age classes are sampled randomly and independently of each other. This is truly not the case because gear and fishing practices collect fish in groups or clusters; thus, the effective sample size is much smaller than the actual number of fish aged. Therefore, the effective sample size was estimated by using the manual, iterative method of McAllister and Ianelli (1997). The effective sample size for each year is the average over all years and it is set to 380 fish in this model.

The observed total catch and catch age compositions were generated from all state reported landings-at-age, recreational dead discards-at-age, and commercial dead discards-at-age. Total catch by year was calculated by summing catch across age classes. The catch age composition was calculated by dividing the catch-at-age for a given year by yearly total catch.

Young-of-the-year (YOY) and yearlings indices from New York (Hudson River YOY: 1980–2006; West Long Island Sound Age 1: 1986–2006), New Jersey (Delaware Bay YOY: 1981–2006), Maryland (Chesapeake Bay YOY and Age 1: 1970–2006), and Virginia (Chesapeake Bay YOY: 1983–2006) were incorporated into the model by linking them to corresponding age abundances and time of year:

$$\hat{I}_{t,y,\mathrm{a}} = \hat{q}_t \cdot \hat{N}_{y,a} \cdot \exp^{-p_t \cdot Z_{y,a}} \qquad (19)$$

where $\hat{I}_{t,y,a}$ is the predicted index of survey t for age a in year y, q_t is the catchability coefficient of index t, $N_{y,a}$ is the abundance of age a in year y, p is the fraction of total mortality that occurs prior to the survey, and $Z_{y,a}$ is the total instantaneous mortality rate. All qs are estimated as free parameters. Because age 0 striped bass are not modeled, the YOY and yearling indices were advanced one year and are linked to age 1 and age 2 abundances, respectively, and are tuned to January 1[st] (p=0;Table A7.1). All YOY and yearling indices are arithmetic means and corresponding CVs. More information on these surveys can be found in ASMFC (1996).

The aggregate indices (no or borrowed age data or other reasons) from the Marine Recreational Fisheries Statistics Survey (MRFSS: 1988–2006), Connecticut (Recreational CPUE: 1982–2006; bottom trawl survey: 1984–2006), Northeast Fisheries Science Center (NEFSC spring bottom trawl survey: 1991–2006) and Massachusetts (commercial total catch rates: 1991–2006) are incorporated into the model by linking them to aggregate age abundances and the time of year (Table A7.1):

$$\hat{I}_{t,y,\Sigma a} = \hat{q}_t \cdot \sum_a \hat{N}_{y,a} \cdot \exp^{-p_t \cdot Z_{y,a}} \qquad (20)$$

All aggregate indices are arithmetic means of the survey estimate. The annual CVs for the MRFSS index were calculated by dividing model estimates of standard errors by the index. The CVs for the Connecticut Recreational CPUE index were assumed equal to the CVs of the total recreational catch values for Connecticut generated by MRFSS. CVs for the remaining surveys were estimated from survey data.

The age-aggregated indices and age composition data from New York (ocean haul seine: 1987–2006), New Jersey (bottom trawl: 1989–2006), Maryland (gillnet: 1985–2006), and Delaware (electrofishing: 1996–2006) surveys are incorporated into the model by linking them to age abundances and the time of year:

$$\hat{I}_{t,y} = \hat{q}_t \sum_a \hat{s}_{t,a} \cdot \hat{N}_{y,a} \cdot \exp^{-p_t \cdot \hat{Z}_{y,a}} \tag{21}$$

where $s_{t,a}$ is the selectivity coefficient for age a in survey t. The fraction of the year and ages to which each survey is linked is listed in Table A7.1. The weighted residual sum of squares for survey t is given by:

$$RSS_t = \lambda_t \sum_y \left(\frac{\ln\left(I_{t,y} + 1e^{-5}\right) - \ln\left(\hat{I}_{t,y} + 1e^{-5}\right)}{CV_{t,y}} \right)^2 \tag{22}$$

The Gompertz equation is used to estimate the selectivity pattern for the Delaware spawning stock survey because theory indicates that vulnerability to electric fields increases with surface area of the fish (Reynolds 1983). Because MD survey estimates are corrected for mesh-size selectivity, it was determined by trial-and-error that only the selectivity value for age 2 had to be estimated; for ages ≥ 3, selectivity was set to 1. For the New York ocean haul survey, the Thompson's exponential-logistic model (Thompson 1994) is used to estimate the selectivity pattern

$$\hat{s}_a = \frac{1}{1-\gamma} \cdot \left(\frac{1-\gamma}{\gamma}\right)^{\gamma} \frac{\exp^{\alpha\gamma(\beta-a)}}{1+\exp^{\alpha(\beta-a)}} \tag{23}$$

For the New Jersey survey, a gamma function is used to estimate the selectivity pattern:

$$\hat{s}_a = \frac{a^{\alpha} \exp^{\beta \cdot a}}{\max_a (a^{\alpha} \exp^{\beta \cdot a})} \tag{24}$$

Total aggregate index by year is calculated by summing age-specific indices across age classes. The survey age composition is calculated by dividing the age-specific indices by the total aggregate index for a given year. The predicted age composition (proportions-at-age) of each survey is modeled and compared to the observed proportions-at-age through a multinomial probability model. The predicted survey indices-at-age are calculated as

$$\hat{I}_{t,y,a} = \hat{q}_t \cdot \hat{s}_{t,a} \cdot \hat{N}_{y,a} \cdot \exp^{-p_t \cdot \hat{Z}_{y,a}} \tag{25}$$

and predicted age composition is calculated as

$$\hat{U}_{t,y,a} = \frac{\hat{I}_{t,y,a}}{\sum_a \hat{I}_{t,y,a}} \tag{26}$$

The age composition negative log-likelihood for survey t is

$$-L_t^U = \lambda_t \sum_y -n_{t,y} \sum_a U_{t,y,a} \cdot \ln\left(\hat{U}_{t,y,a} + 1e^{-7}\right) \qquad (27)$$

where $n_{t,y}$ is the effective sample size of fish aged in year y from survey t, and $U_{t,y,a}$ and $U_{t,y,a}$ are the observed and predicted proportions of age a in year y from survey t. Used as starting values, the average effective sample size for each survey was calculated by using methods in Pennington and Volstad (1994) and Pennington et al. (2002). In essence, effective sample size was estimated by first calculating the length sample variance using the simple random sampling equation and dividing into it the cluster sampling variance of mean length derived through bootstrapping, assuming each seine/trawl haul, gillnet set, or electrofishing run was the sampling unit. The average of the annual effective sample sizes was used as starting values in each survey multinomial error distribution (Table A7.2).

Model fit for all components was checked by using residual plots. In addition, predicted average effective sample size for the catch and survey age composition data were compared to the observed starting values used in the model. Predicted average effective sample size ($\hat{\bar{t}}$) is calculated following McAllister and Ianelli (1997):

$$\hat{\bar{t}} = \frac{\sum_y \hat{t}_y}{d_y} \qquad (28)$$

and $\hat{t}_y$ is defined as

$$\hat{t}_y = \frac{\sum_a \hat{c}_{a,y}(1-\hat{c}_{a,y})}{\sum_a (o_{a,y} - c_{a,y})^2}$$

where $\hat{c}_{a,y}$ is the predicted proportion-at-age a in year y from the catch or survey, $o_{a,y}$ is the observed proportion-at-age, and d_y is the number of years of data for catch or survey series. The effective sample sizes for catch and survey proportions were repeatedly adjusted until the predicted sample sizes stabilized under equal weighting of all components. The effective sample sizes for NJ trawl and NY ocean haul survey did not change from the starting values, but those for the MD gillet and DE electrofishing surveys increased from 68 to 77, and 68 to 87, respectively. The average effective sample size for the catch proportions was estimated to be 380.

The total log-likelihood of the model is

$$f = -L_l - L_p - L_{NYOHS}^U - L_{NTrawl}^U - L_{NYOHS}^U - L_{MDSSN}^U + P_{rdev} + P_{fdev} + P_{fadd} \qquad (29)$$

The total log-likelihood is used by the autodifferentiation routine in AD Model Builder to search for the "best" selectivity parameters, average recruitment, recruitment deviations, average F, fishing mortality deviations, and catchability coefficients that minimize the total log-likelihood. AD Model Builder allows the minimization process to occur in phases. During each phase, a subset of parameters is held fixed and minimization is done over another subset of parameters until eventually all parameters have been included. In this model, the following parameters were solved over ten phases:

Phase
1 average recruitment
2 average fishing mortality and fishing mortality deviations
3 recruitment deviations
4 catch selectivity parameters
5 catchability coefficients of YOY/Yearling and aggregate survey indices
6 catchability coefficients of survey indices with age composition data
7 NY survey selectivity parameters
8 NJ survey selectivity parameters
9 DE survey selectivity parameters
10 MD survey selectivity parameters

The estimation proceeds by first calculating $F_{a,y}$ using initial starting values for F_y and s_a (initial parameters estimates are used for the selectivity equations) and, with M (which is fixed at 0.15) and initial values of average recruitment by year, the abundance matrix is filled (Figure A7.1). Note that recruitment is actually estimated back to 1970 in order to provide more realistic estimates of N in the first year of data (1982). Also, this allowed the incorporation of indices (e.g., Maryland young-of-the-year index) back to 1970 unlike the ADAPT model. All predicted values were calculated using the equations described above. Initial starting values for all parameters are given in Table A7.3 and were selected based on trial-and-error.

A7.2.1 Code Checking

To check accuracy of model code (Appendix A7), a virtual population of striped bass was simulated in EXCEL and catch numbers, catch age composition, one age-1 index, one aggregate index and one survey index with age composition data were generated using the above model equations and known values of fishing mortality, natural mortality, recruitment, catch and survey selectivities, and catchability coefficients. The catch and survey data and known parameters were then input into the model and the model was run without minimization to check if the code produced the exact values of the simulated population. The model was then run with minimization to check estimation. Both trials showed that the model duplicated the simulated population quantities.

A7.3 EXPLORATORY ANALYSES

A7.3.1 Catch Selectivity Functions

In the initial development of the model, four catch selectivity functions were examined: logistic (flat-top), Gompertz (flat-top), double logistic (dome-shaped), and gamma (dome-shaped). Through run comparisons, the Gompertz and gamma functions were shown to produce better predictions of catch age composition than the remaining two functions. Also, the model was slightly unstable using the double logistic (because four-parameters are estimated instead of two). To evaluate the "best" number of periods and most appropriate function to use, the number and type of function was varied over model runs with the striped bass data through 2006 and equal weighting across all components. Periods were >1982 (1 selectivity equation); 1982–1984 and ≥1985 (2 equations); 1982–1984, 1985–1989, and ≥1990 (3 equations); 1982–1984, 1985–1989, 1990–1995, and ≥1996 (4 equations); 1982–1984, 1985–1989, 1990–1995, 1996–2002, >2003 (5 equations). Each period designates a major change in management regulations. The

Akaike's Information Criterion (AIC; Burnham and Anderson 2002) for each run was calculated and the likelihood ratio test (LRT) was used to determine if the addition of a selectivity period significantly accounted for more variation than the previous run. Under equal weighting of all components, the values for AIC and LRT indicated that the best configuration was the model with 4 catch selectivity periods using the Gompertz function (Figure A7.2).

A7.3.2 Total Catch Lambda Weights

The model runs under the variable selectivity periods (see above) showed that the total catch was not predicted well in early years of the time series and large, unreasonable estimates of fully-recruited fishing mortality resulted (Figure A7.3). When the lambda weight of total catch was increased to 5 or 10, improved fit between observed and predicted and more reasonable estimates of fully-recruited fishing mortality occurred (Figure A7.4). However, as the lambda weight increased, the AIC values and fully-recruited F in 2006 estimates increased (Figure A7.5); regardless, the improved fit near the start of the time series warranted the use of the total catch lambda weight = 10.

A7.3.3 Component Contribution

The sensitivity of each data source under equal weighting of all components and the four period selectivity configuration was investigated by de-emphasizing each index one-at-a-time using a lambda of 0.5 and re-running the model. Relative changes between the base 2006 F and the 2006 F of de-emphasized cases were minor (<5% change), indicating that no single component had a major influence on model results (Table A7.4).

A7.3.4 Retrospective Analysis

Additional model runs were made to examine the effect of changing the number of selectivity periods (Gompertz functions) and total catch lambda weights on the retrospective pattern of the model. A retrospective index (the average of the differences between the 2004 and 2005 terminal F estimates and the same yearly estimate from the 2006 run) was calculated to compare retrospective patterns across levels. Retrospective plots (Figure A7.6) and comparison of the retrospective index (Figure A7.7) among model runs indicated that the retrospective bias was lowest at equal weights across all components and when 4 or less selectivity periods were used. Retrospective bias increased when larger total catch lambda weights were used and five selectivity periods were assumed (Figure A7.7).

A7.4 FINAL MODEL CONFIGURATION AND RESULTS

Based on the above analyses and recommendations from the ASMFC's striped bass stock assessment and technical committees, the final model contained four catch selectivity periods (using the Gompertz function), the total catch lambda weight=10, and all indices (except Massachusetts commercial index) and all survey selectivity functions. In addition, the aggregate age values for the Connecticut trawl survey were changed from ages 4–6 to ages 2–4 to reflect current opinion on the ages of trawl-caught striped bass, and aggregate age values for the MRFSS index were changed from ages 2–13 to ages 3–13 to reflect the age structure of larger fish found in offshore waters. The data used for the final model run configuration were updated and are different from those used in Section A7.3 because changes in the 2004 MRFSS harvest and release numbers occurred, and estimates of wave 1 harvest from Virginia waters in 2005 and

2006 were added. Initial starting values for all parameters are given in Table A7.3; there were 94 parameters estimated in the model.

A7.4.1 Results

Resulting contributions to total likelihood are listed in Table A7.5. The converged total likelihood was 28,809.5 (Table A7.5). Estimates of fully-recruited fishing mortality, recruitment, parameters of the Gompertz functions for the four selectivity periods, catchability coefficients for all surveys, and parameters of the survey selectivity functions are given in Table A7.6 and are shown graphically in Figure A7.8. Graphs depicting the observed and predicted values, as well as residuals for the catch age composition, survey indices, and survey compositions are given in Appendix A8. The model fit the observed total catch (Figure A7.8) and catch age composition well (Appendix A8), and the YOY, age 1, MRFSS, CTCPUE, CTTrawl, NEFSC indices reasonably well (Appendix A8). Except for MD SSN, the predicted trends matched the observed trends in survey indices, and predicted the survey age composition reasonably well (Appendix A8). The predicted values of effective sample size for the catch and survey age compositions using total catch lambda=10 were close to values derived under equal weighting of all components (Figure A7.9).

A7.4.1.1 Fishing Mortality

Fully-recruited fishing mortality in 2006 was 0.32 (ages 10–12; Table A7.6). The 2006 average fishing mortality rate (F) for ages 8 through 11 equaled 0.31 (95% CI: 0.233-0.404) and is slightly above the current target (0.30) but is not over the threshold (0.41)(Table A7.7; Figures A7.10 and A7.11). Average fishing mortality on ages 3–8, which are generally targeted in producer areas, was 0.22 (Table A7.7; Figure A7.10). Among the individual age groups, the highest values of F in 2006 (0.31–0.32) were estimated for ages 9–13+ (Table A7.8). An average F weighted by N was calculated for comparison to tagging results since the tag releases and recaptures are weighted by abundance as part of the experimental design. The 2006 F weighted by N for ages 7–11 (age 7 to compare with tagged fish ≥28”) was 0.31 (Table A7.7; Figure A7.10). An F weighted by N for ages 3–8, comparable to the direct enumeration estimate for Chesapeake Bay, was equal to 0.16 (Table A7.7; Figure A7.10).

Fishing mortality-at-age in 2005 and 2006 was partitioned into various components of the recreational and commercial fisheries using ratios of component catch-at-age to total catch-at-age. Results showed that, although the recreational fishery induced the highest mortality, the contribution of the recreational release and harvest components to the total fishing mortality changed with fish age (Figure A7.11).

A7.4.1.2 Population Abundance (January 1)

Striped bass abundance (1+) increased steadily from 1982 through 1997, when it had around 65 million fish (Table A7.9, Figure A7.8). Total abundance declined thereafter and has average around 57 million fish since 2000. Total abundance in 2006 was 55.8 million (95% CI: 44,339,600–68,642,300; Figure A7.12). The 2003 cohort remained strong at 16 million fish in 2006 (ages 3) and exceeded the sizes of the strong 1993, 1996, and 2001 year classes at the same age (Table A7.9). Abundance of striped bass age 8+ increased steadily through 2004 to 8.5 million, but has since declined to 6.2 million fish (95% CI: 4,587,450–7,932,800) in 2006 (Table A7.9, Figures A7.8 and A7.12).

A7.4.1.3 Spawning Stock Biomass

Weights-at-age used to calculate spawning stock biomass were generated from catch weights-at-age and the Rivard algorithm described in the NEFSC's VPA/ADAPT program. Sex ratio at age was assumed 50:50. Female SSB grew steadily from 1982 through 2003 when it peaked at about 33 thousand mt (Table A7.10, Figure A7.13). Female SSB has declined since then and was estimated at 25 thousand metric tons (95% CI: 18,563–32,169) in 2006 (Table A7.10; Figure A7.12). The estimated SSB in 2006 remained above the threshold level of 14 thousand metric tons and indicates that the striped bass are not overfished.

A7.4.1.4 Retrospective Analysis

Retrospective bias was evident in the estimates of fully-recruited F, SSB, and age 8+ abundance of SCA (Figure A7.14). The retrospective pattern suggests that fishing mortality is likely over-estimated and could decrease with the addition of future years of data. Similar retrospective trends have been observed in the previous assessment of striped bass using the ADAPT VPA (ASMFC 2005) and in the supporting ASAP and ADAPT models presented in the current assessment. Experiences from other assessments indicate that it is possible for the magnitude and direction of the retrospective pattern to change in subsequent assessments. For example, the retrospective analysis from the 2003 assessment of striped bass showed an underestimation of the terminal year estimation of fully recruited F while the retrospective analysis from the 2005 assessment showed an over estimation of F (ASMFC 2003b; ASMFC 2005).

A7.4.2 Sensitivity Analyses

A7.4.2.1 Starting Values

Starting values for the minimization routine are important to achieve proper convergence at the global minimum. The starting values were selected based on trial-and-error. Many runs were conducted to find values that appeared to be reliable and for which the global minimum was reached consistently. To further check the convergence properties of the model, 100 model runs using total catch lambda weight=10 were made, and for each run, starting values were randomly permuted by ±50%. A plot of fully-recruited Fs in 2006 and corresponding total log-likelihoods assessed convergence stability. The model demonstrated excellent convergence properties because 100 out of 100 trials converged at the same likelihood and estimated the same 2006 fishing mortality rate (Figure A7.15). Examples of randomized ±50% starting values are shown in Table A7.11.

A7.4.2.2 Natural Mortality

The effects of varying M above or below the assumed M of 0.15 are shown in Figure A7.16. Higher fully-recruited fishing mortality estimates were generated when M was decreased, and lower fully-recruited fishing mortality estimates were generated when M was increased.

The effects of increasing M to 1.0, 0.5, and 0.35 for ages 1–3, respectively, were also investigated. The time series of fully-recruited F estimates changed little when the higher natural mortality rates were used, but the recruit abundance estimates quadrupled in magnitude (Figure A7.17).

The effects of increasing M for all ages after 1996 was also investigated to determine if the retrospective pattern observed in fully-recruited F may be attributed to changes in M (due to the

Mycobacterium outbreak in Chesapeake Bay). M was set to 0.30 for years 1997–2006. Increasing M had a negative impact on the retrospective pattern because the retrospective bias increased (Figure A7.18) compared to the retrospective pattern assuming constant M=0.15 across all ages (Figure A7.14).

A7.4.2.3 Effects of Deleting Survey Datasets

The contribution of each survey data source to the results of the final model configuration was investigated by removing each dataset one-at-a-time and re-running the model. Changes in the time series of F estimates for 1982–2006 between base run (all indices) and each one removed one-at-a-time were minor (Figure A7.19). The removal of the NY YOY survey index had the largest impact on F estimates near the terminal year, and the removal of the MD gillnet survey had the largest impact on F estimates at the beginning of the time series (Figure A7.19)

A7.4.2.4 Effects of Changing Estimation Phases

The influence of the assigned estimation phases on the results (fishing mortality and total log-likelihood) of the final model configuration was investigated by changing the phase during which each parameter set was estimated. There were no differences between fully-recruited fishing mortality and total log-likelihoods of the three runs made (Table A7.12).

A7.4.2.5 Effects of Decreasing Effective Sample Sizes of Catch and Survey Multinomials

The influence of the magnitude of average effective sample sizes of the catch and survey multinomial likelihoods on the estimates of fully-recruited fishing mortality were investigated. When the average effective sample sizes were decreased to 10% of the original values, fully-recruited F estimates for years 1982–1989 varied from the original estimates but F estimates after 1989 changed little (Figure A7.20). In addition, when data from selected surveys were also deleted one-at-a-time, only slight differences in fully-recruited fishing mortality from 1990 to 2006 occurred (Figure A7.20).

A7.5 COMPARISON OF SCA MODEL RESULTS TO ADAPT AND ASAP MODELS RESULTS

The ADAPT Virtual Population (Appendix A9) and the ASAP statistical catch-at-age (Appendix A10) models were applied to the catch-at-age data and relative abundance indices (the same complement of indices used in 2005) and estimates of F were compared to the SCA model estimates. The ADAPT model produced the highest Fs for 1986–1999, while the SCA produced the highest Fs for 2001–2005 (Figure A7.21). All estimates of F were $\leq$0.34 in 2006. Although the SCA model did show slightly more retrospective bias in the estimates of fishing mortality and abundance than the ADAPT and ASAP models, the SCA was selected as the primary analytical model for several reasons. For the ADAPT model to get realistic fishing mortality estimates, many indices had to be removed (Appendix A9); therefore, the results may not be best at capturing all the information among all stock components. In the SCA model, all indices (except MA COMM) were used and the estimates of F were robust to the inclusion/exclusion of indices. Although the ASAP works well in predicting catch at age in recent years, it was necessary to fix the selectivity pattern (Appendix A10) based on the selectivity pattern from ADAPT which may perpetuate any errors from that model. Also, the indices in the ASAP were not fit well in many cases. In the SCA model, the number and form of the selectivity patterns were chosen based on analytical methods and were estimated in the model. Although the SCA model did not predict every index well, the results were not affected by the deletion of an index.

A7.6 COMPARISON OF SCA RESULTS TO CATCH CURVE ANALYSIS AND RELATIVE F ESTIMATES

Cohort catch curves and a year specific total mortality estimate derived from the cohort specific catch curve data were calculated by using the total catch-at-age matrix and linear regression (Appendix A11). In addition, relative F (Sinclair 1998) was derived as a ratio of landings to several selected tuning indices that were considered informative about changes in fully recruited (ages 8+) stock size (Appendix 12). The trend in relative F was similar (except for the decline in 2005 and 2006) to the trend in the average F for ages 8–11 from the SCA, ASAP and ADAPT (Figure A7.21). However, average total mortality (Z) from the catch curve analysis showed a declining trend after 2000 while Z from the SCA, ADAPT, and ASAP models showed increasing trend. Note that if M of 0.15 was subtracted from the catch curve Z, most estimate of F would be below 0.10 after 2002.

A7.7 SOURCES OF UNCERTAINTY IN SCA

Accurate estimates of catch at age require that we know the total loss in numbers and that we apportion this loss correctly to age. The best data on loss comes from the directed recreational and commercial fisheries. In this year's assessment, we had to estimate wave 1 recreational harvest of the winter fishery off Virginia by using North Carolina harvest and tag returns, along with Virginia tag returns, because MRFSS sampling is not conducted during this time. There is less confidence in estimates of discards in commercial and recreational fisheries because little of the data is measured directly. Moreover, gear specific discard/release mortalities are assumed to be constant even though mortalities may vary with season and with changes in gear specifics such as increased use of circle hooks. The quality of data on age composition varies among fisheries and region. In most cases, fish in catches or discards are measured and length frequencies are converted to age frequencies with age length keys. States with large harvests usually sample fisheries directly and develop age length keys from the fishery and time of year of the fishery. However, states with small fisheries must often rely on length data from small samples or fishery independent collections or use age length keys developed by neighboring jurisdictions. Finally, the assignment of age to scales samples becomes less certain with increasing fish age ($\geq$ age 10).

The abundance indices used in the SCA models were the suite of available indices approved through a reasoned and objective evaluation process. The review reduced the number of indices and the number of indices at age, especially for fish age eight and older. The CTCPUE indices were aggregated into separate indices because age-length data from New York were used to partition the CTCPUE into age-specific indices.

Estimates of F and population size from the catch at age analyses at the beginning of the time series, not the terminal year, are the most uncertain estimates. However, retrospective analysis indicated that the terminal year estimates are positively biased and may decrease somewhat with an additional year of data.

A8.0 EVALUATE THE BARANOV'S CATCH EQUATION METHOD AND ASSOCIATED MODEL COMPONENTS APPLIED TO THE ATLANTIC STRIPED BASS TAGGING DATA. EVALUATE ESTIMATES OF F AND ABUNDANCE FROM COASTWIDE AND CHESAPEAKE BAY SPECIFIC PROGRAMS ALONG WITH THE UNCERTAINTY OF THOSE ESTIMATES. (TOR #4)

A8.1 INTRODUCTION

This report summarizes the results of the United States Fish and Wildlife Service's (USFWS) Atlantic coastwide cooperative striped bass tagging program through the 2006 tagging year. The Striped Bass Tagging Subcommittee (SBTS) of the Striped Bass Technical Committee of ASMFC analyzes the data gathered by the tagging program. The subcommittee is composed of members from participating state agencies and USFWS.

Two modeling approaches were used for the 2006 assessment. Previously, the SBTS had used Program MARK to estimate a time series of annual survival rates (S) (Smith et al. 2000). Post modeling, instantaneous total mortality (Z as $-\log_e$ S) was partitioned into instantaneous fishing (F) and natural (M) mortalities using a biologically-based constant value of M (0.15). The use of this method produced estimates of F that were sometimes nonsensical and conflicted with other indicators of stock status. In an attempt to move away from an assumed M, the SBTS changed to a method based on estimates of survival estimates produced by Program MARK (White and Burnham 1999) and subsequent use of Baranov's catch equation (Ricker 1975) proposed by Pollock et al. (1991), to parse Z into F and M. Additionally, the SBTS is also presenting a new approach for the 2006 assessment – a formulation of Jiang et al. (2007) instantaneous (mortality) rates model. While additional assessment of this method needs to be performed, the committee would like to move towards this as the primary tag-based model in the future.

A8.2 DESCRIPTION OF ATLANTIC COASTWIDE STRIPED BASS TAGGING PROGRAM

Eight tagging programs participate in the USFWS Atlantic coastwide striped bass tagging program, and have been in progress for at least 14 years. As striped bass are a highly migratory anadromous species, the tagging programs are divided into two categories, producer area programs and coastal programs. Most programs tag striped bass (primarily fish $\geq$ 18 inches total length (TL)) during routine state monitoring programs.

Producer area tagging programs primarily operate during spring spawning on the spawning grounds. Several capture methods are used, such as pound nets, gill nets, seines and electroshocking. The producer area programs are:

- Delaware and Pennsylvania (DE/PA) - fish tagged in the Delaware River primarily in April and May;
- Hudson River (HUDSON) - fish tagged in May;
- Maryland (MDCB) - fish tagged in the Potomac River and the upper Chesapeake Bay primarily in April and May; and
- Virginia spawning stock program (VARAP) - fish tagged in the Rappahannock River during April and May.

Coastal programs tag striped bass from mixed stocks during fall, winter, or early spring. Gears include hook and line, seine, gill net, and otter trawl. The coastal tagging programs are:

- Massachusetts (MADFW) - fish tagged during September–October months;
- North Carolina winter trawl survey (NCCOOP) - fish tagged primarily in January;
- New Jersey Delaware Bay (NJDEL) - fish tagged in March and April; and
- New York ocean haul seine survey (NYOHS) - fish tagged during October–November months.

Tag recovery matrices for each program used in the current assessment are presented in Appendix A13.

A8.3 ASSUMPTIONS AND STRUCTURE OF THE MODEL

Survival estimates are generated from Program MARK using analysis protocol based on assumptions described in Brownie et al. (1985) and elaborated for striped bass in Smith et al. (2000). Important assumptions (Brownie et al. 1985) are:

1. the sample is representative of the target population;
2. there is no tag loss;
3. survival rates are not affected by the tagging itself;
4. the year of tag recoveries is correctly tabulated;
5. the fate of each tagged fish is independent of the fate of other tagged fish;
6. the fate of a given tagged fish is a multinomial random variable; and
7. all tagged individuals of an identifiable class (age, sex) in the sample have the same annual survival and recovery rates.

In this method, Program MARK (White and Burnham 1999) was used to develop estimates of survival. Program MARK is based on Kullback-Leibler information theory and Akaike's information criterion (AICc; Akaike 1973; Burnham and Anderson 1992, 2003). Maximum likelihood estimates of the multinomial parameters of survival and recovery are calculated based on the observed matrix of recaptures. Candidate models are fit to the tag recovery data and arranged in order of goodness-of-fit by a second-order adjustment to the Akaike's information criterion.

Candidate models were selected before analysis and were based on biologically-reasonable hypotheses. Parameters of the models define various patterns of survival and recovery as follows (model formulas are explained more fully in Table A8.1):

- the global model {S(t) r(t), i.e., fully parameterized model} is a time-saturated model and was used to estimate over-dispersion and model fit statistics (*see Model Diagnostics*);
- models {S(p)r(p), S(p)r(t), S(d)r(p) and S(v)r(p)} parameterize survival as constant within time periods that are based on regulatory changes between 1987 and 2006 (regulatory periods are explained in Table A8.2);
- one model estimates the terminal year separately {S(d)r(p)} and another estimates the most recent two years separately {S(v)r(p)} in order to provide more exact estimates of recent years for management; and
- constant models {S(.)r(.), S(.)r(p), S(.)r(t)} that hold survival and/or recovery constant over time are also reasonable and was included. Selection of a constant model does not

mean *"no"* variation in survival across the time series, but suggests that year-to-year variation in annual survival is "...relatively small in relation to the information contained in the sample data" (Burnham and Anderson 2003).

Models with time as a covariate within regulatory periods {S(Tp)r(Tp), S(Tp)r(t), S(Tp)r(p)}, designed to indicate increasing or decreasing monotonic trends in survival within regulatory periods, were removed from the suite of models this year. Analyses of simulated data showed trend models tended to underestimate the terminal year estimate of survival (overestimate F) by forcing a monotonic trend, when the true trend may not be linear through the entire period (Welsh 2004). Given that fisheries management emphasizes terminal year estimates, along with the use of a more comprehensive suite of models that can evaluate changes in latter years, the SBTS concluded there was no biological reason to continue using the trend models.

A8.4 MODEL DIAGNOSTICS

Model adequacy is a major concern when deriving inference from a model or a suite of models. Over-dispersion, inadequate data (such as low sample size) or poor model structure may cause a lack of model fit. Over-dispersion is expected in striped bass tagging data, given that a lack of independence may result from schooling behavior.

After running the suite of models in Program MARK, an estimate of the variance inflation factor ("c-hat") was used to adjust for over-dispersion, if detected (Anderson et al. 1994). Over-dispersion was examined through the goodness-of-fit of the global model. The goodness-of-fit probability of the global model was quantified as a bootstrap-derived p-value based on model deviance (Burnham and Anderson 2003). A low p-value (<0.15) and a large estimate of c-hat (> 4) imply inappropriate model structure (Burnham and Anderson 2003). A low bootstrap-derived p-value (<0.15) and a moderate estimate of c-hat (>1 and <4) support over-dispersion, with appropriate model structure. C-hat was estimated by dividing the observed Pearson chi-square value (goodness-of-fit statistic of the global model) by the expected Pearson chi-square value (derived from a bootstrap analysis of the global model).

A8.5 MODEL AVERAGING

After model diagnostics were performed, model averaging was performed to estimate program-specific annual survival rates. Survival rates were estimated for two size groups (fish ≥ 18 inches TL and fish ≥ 28 inches TL). These estimates were calculated as weighted averages across all models, where weight was a function of model fit (Buckland et al. 1997). Model averaging eliminated the need to select the single "best" model, and allowed the uncertainty of model selection to be incorporated into the variance of parameter estimates (Burnham and Anderson 2003). Survival is inestimable for the terminal year in the fully time-saturated {S(t)r(t)} model, so this model was excluded from the model-averaged survival estimate for the terminal year. A weighted average of unconditional variances was estimated for the model-averaged estimates of survival (Buckland et al. 1997).

A8.6 BIAS ADJUSTMENT

Because only harvested recoveries are modeled in Program MARK, the practice of catch-and-release fishing causes bias in the survival estimates. Therefore, an adjustment was made to the survival estimates according to the method of Smith et al. (2000).

Live release bias is defined as:

$$bias = -\left[\frac{\theta \cdot P_L \cdot \frac{f}{\lambda}}{(1-(1-\theta \cdot P_L)\frac{f}{\lambda}}\right] \qquad \textit{Eqn. 1}$$

where:

θ = release survival rate (0.92), based on the 8% hook-and-release mortality rate estimated by Diodati and Richards (1996);

P_L = annual proportion of tagged striped bass released alive;

f = annual recovery rate, estimated by a separate MARK run, using a Brownie recovery model (Brownie et al. 1985); and

λ = reporting rate.

Bias-corrected estimates of survival are then obtained by:

bias-corrected S = uncorrected S/(1+*bias*) *Eqn.2*

Accurate adjustment for live-release bias should also include estimates of tagging mortality and tag loss. Gear-specific tagging mortality was not included in bias adjustment because estimates were unavailable for most gear types. However, reported rates of general tag-induced mortality are low (0%, Goshorn et al. 1998; 1.3% Rugolo and Lange 1993), so tag-induced mortality was excluded from the bias adjustment. Reported rates of tag loss are also quite low (0% by Goshorn et al. 1998, 2% by Dunning et al. 1987, and 2.6% by Sprankle et al. 1996), so tag loss was also excluded from the bias adjustment.

A8.7 COASTWIDE TAGGING ASSESSMENT

A8.7.1 Methods for Estimation of F and M

In prior years' assessments, F was estimated by converting the adjusted survival (S) to Z as follows:

$$Z = -\log_e(S) \qquad \textit{Eqn. 3}$$

and parsing Z into F and M by subtracting a constant value for M. A value of M = 0.15 was assumed (ASMFC 1987). Using this technique, natural mortality was held fixed, and any change in Z resulted in an equal change in F.

There is general agreement among the SBTS that the use of an assumed constant value for M to estimate F is a weakness. Unreasonably high estimates of F seemed to contradict stable high harvests and continued high reproduction. Additionally, there has been concern that

Chesapeake Bay may have been experiencing higher natural mortality during the past decade due to an increase in the prevalence of mycobacteriosis.

Therefore, beginning in 2004, the bias-adjusted value of S has been used with a form of Baranov's catch equation to estimate program-specific values of F and M. Ricker (1975, p. 11) presented a formulation to solve for the exploitation rate (μ). He cautioned that it is applicable only for Type 2 fisheries, in which fishing and natural mortalities occur concurrently. This is the case for striped bass, where the fishery operates over much of the year. Pollock et al. (1991) used the same formula to solve for F as follows:

$$F = \mu / A * Z \qquad \textit{Eqn. 4}$$

where:

μ = exploitation rate;
A = annual total mortality rate (1 – S); and
Z = $-\log_e(S)$

and μ is calculated as follows:

$$\mu = ((R_k + R_L(1 - \theta)) / \lambda) / M \qquad \textit{Eqn. 5}$$

where:

R_k = the number of killed recaptures;
R_L = the number of recaptures released alive;
θ = release survival rate (0.92)
M = the number of fish tagged or marked at the beginning of the year; and
λ = reporting rate (0.43).

Once F is estimated, M is estimated by subtracting F from Z (Crecco 2003).

Variances associated with the estimates of F were calculated using the formulas in Pollock et al. (1991). These estimates were developed without inclusion of the covariance terms (because covariance terms could not be estimated from these data, they were assumed to be negligible). 95% confidence intervals were subsequently developed for each program's F.

Area fishing mortalities were calculated as mean values among the coastal and producer areas. Coastal F was calculated as the arithmetic mean of the coastal programs' values. The producer area F was calculated as a weighted mean of the producer area programs' values. The weights were based on each program area's proportional contribution to the coastwide stock. The values are:

- Hudson (0.13);
- Delaware (0.09); and
- Chesapeake Bay (0.78), with MD (0.67) and VA (0.33).

Variance associated with the area mean F estimates was calculated as additive variances. The additive variance for the unweighted coastal mean F was calculated as:

$$\operatorname{var}(\bar{x}_{coast}) = \sum w_i^2 \operatorname{var}(\bar{x}_{state}) \qquad \textit{Eqn. 6}$$

where:

w_i = (1 / number of coastal programs; will be equal);

var($\bar{x}_{state}$) = individual state's variance of mean F.

The additive variance for the weighted producer area mean F was calculated as:

$$\text{var}(\bar{x}_{producer}) = \sum w_i^2 \ \text{var}(\bar{x}_{state}) \qquad \textit{Eqn. 7}$$

where:

w_i = 0.09 for Delaware;

w_i = 0.13 for Hudson;

w_i = 0.78 for Chesapeake Bay; with 0.67 for Maryland and 0.33 for Virginia;

var($\bar{x}_{state}$) = individual state's variance of the mean F.

95% confidence intervals were subsequently developed for each area's F.

The annual coastwide fishing mortality was calculated as the arithmetic mean of the coastal and producer area means. No associated variance was calculated.

A8.7.2 Methods for Estimation of Stock Size

Stock size was estimated for fish $\geq$ 18 inches TL, corresponding roughly to 3-year-old and older striped bass, and for fish $\geq$ 28 inches TL, corresponding to 7-year-old and older fish. A form of Baranov's catch equation was used:

$$\text{average stock size} = \text{catch} / \text{F} \qquad \textit{Eqn. 8}$$

Since F was based on an exploitation rate that included discard mortality from released fish, total catch was used.

A8.7.3 Reporting Rate

The reporting rate used throughout these calculations is the proportion of recaptured fish whose tags are reported to the USFWS. Currently, a constant value of 0.43 is used, based on a high-reward tag study conducted on the Delaware River stock but employing tag returns from the whole Atlantic coast (Kahn and Shirey 2000). This estimate was substantiated by Smith et al. (2000). However, the subcommittee recognizes that a constant reporting rate is unlikely.

A sensitivity analysis was performed to quantify the effect of inaccuracy in reporting rate on estimates of exploitation rate and fishing mortality. Four values of reporting rate were used with Program MARK, the catch equation and the IRCR model to estimate a time series of values for exploitation rate and fishing mortality. The values of reporting rate used in the sensitivity analysis were:

0.23 (a lower bound to show significant effect);

0.43 (the estimate currently used in the assessment);

0.63 (a middle value); and

0.83 (an upper bound from the 2006 Maryland pilot study using recreational returns, see section A8.7.4.7).

A8.7.4 Coastwide Results and Discussion

A8.7.4.1 Model Diagnostics

The Akaike weights assigned to the candidate models are presented in Table A8.3 (fish ≥ 28 inches) and Table A8.4 (fish ≥ 18 inches). For fish ≥ 28 inches, multiple models are used by all programs. The period models received the majority of the weight for the producer area programs. For fish ≥ 18 inches, one model received essentially all weight for all programs except DE/PA. For the coastal programs, all but MADFW use the global model.

Retrospective analyses of catch equation fishing mortality results are presented in Figure A8.1 (fish ≥ 28 inches) and Figure A8.2 (fish ≥ 18 inches). Because this method has only been in use for the last two stock assessments, the analysis was limited to 2 years of results. Retrospective bias was evident for some programs, while others showed no change.

As each year of data is added to the time series, Program MARK is run again on the entire matrix. For many of the tagging programs, MARK selects and assigns different weights to a different group of models every year. The cause of this is not clearly understood, but raises questions about the legitimacy of comparing results among years.

The catch equation method uses both the recovery matrix for the entire time series (calculation of S) and the most recent year's recovery vector (calculation of exploitation). Some concern has been expressed about the use of two different time scales of the recovery data in the same equation, but the effect has not been investigated.

A8.7.4.2 Exploitation Rates

The exploitation rates for fish ≥ 28 inches are presented by program and as an unweighted coastwide mean (Table A8.5). 2006 estimates of exploitation ranged from a maximum of 0.21 (DE/PA) to 0.10 (MADFW). The 2006 overall coastwide mean exploitation rate was 0.14, which continued a decline since a peak value of 0.26 in 1997.

The exploitation rates for fish ≥ 18 inches (Table A8.6) were lower than those for fish ≥ 28 inches. The 2006 mean exploitation rate of 0.09 was a continuation of a decline similar to that seen for the larger fish.

As input to the catch equation, estimates of exploitation impact the estimates of fishing mortality. Most programs have had relatively low exploitation rates in recent years, resulting in low fishing mortality estimates. The mean exploitation rates for both size groups of fish peaked in the late 1990s and have been declining since.

A8.7.4.3 Survival Rates

Program MARK produces estimates of survival that are biased low due to the practice of catch-and-release fishing (uncorrected S). These uncorrected and the bias-corrected estimates of survival are presented by program in Table A8.7 (fish ≥ 28 inches) and Table A8.8 (fish ≥ 18 inches). The 2006 bias-corrected estimates of S for fish ≥ 28 inches ranged from 0.54 (NJDEL) to 0.77 (MADFW). The Chesapeake Bay states of MD and VA had estimates in the middle of this range (0.63 and 0.66, respectively).

The 2006 bias-corrected estimates of S for fish ≥ 18 inches ranged from 0.55 (MDCB and VARAP) to 0.77 (MADFW). The Chesapeake Bay states of MD and VA, NYOHS and DE/PA had estimates in the lower part of this range.

A8.7.4.4 Fishing Mortality

Results for each program are presented in Table A8.9 (fish $\geq$ 28 inches) and Table A8.10 (fish $\geq$ 18 inches), which provide the catch equation input values of A, Z and u, as well as estimates of F and M. Figure A8.3 presents the coastal and producer area mean fishing mortality estimates and their 95% confidence intervals.

The 2006 estimates of F for the fully-recruited fish were lower than the target value of 0.30 for all programs, and produced a coastwide mean of 0.16 (Table A8.11). The 2006 catch equation estimates of F for fish $\geq$ 28 inches among the producer area programs were 0.18 for HUDSON, 0.16 for MDDNR, 0.17 for VARAP, and 0.26 for DE/PA, producing a mean value of 0.17 $\pm$ 0.08 (95% CI, Table A8.12). The 2006 estimates of F for fish $\geq$ 28 inches among the coastal programs were 0.11 for MADFW, 0.17 for NYOHS, 0.19 for NJDEL, and 0.15 for NCCOOP, producing a low mean coastal area F of 0.15 $\pm$ 0.06 (95% CI, Table A8.12).

The 2006 estimates of F for fish $\geq$ 18 inches were also lower than the target value of 0.30 for all programs, and produced a coastwide mean of 0.12, the lowest in a continuing decline since the peak estimate of 0.18 in 1997 (Table A8.11). The 2006 mean fishing mortalities for fish $\geq$ 18 inches for the producer area programs was 0.16 $\pm$ 0.07 (95% CI) and was 0.09 $\pm$ 0.03 (95% CI) for the coastal programs (Table A8.13).

In general, use of the catch equation produces biologically reasonable F estimates. Because M is not held constant, there is not a set amount partitioned into natural mortality. F estimates reflect exploitation rate, which is generally low for fish between 18 and 28 inches (Tables A8.5 and A8.6).

A8.7.4.5 Natural Mortality

The mean natural mortality values for fish $\geq$ 28 inches were not significantly different between the producer area programs and coastal programs, and these mean values were approximately twice that of the previously assumed value of 0.15 (Table A8.14). The 2006 catch equation estimates of M for fish $\geq$ 28 inches among the producer area programs were 0.16 for HUDSON, 0.19 for DE/PA, and slightly higher for the Chesapeake Bay states (0.25 for VARAP and 0.33 for MDDNR), resulting in a producer area mean of 0.28 $\pm$ 0.20 (95% CI). The 2006 estimates of M for fish $\geq$ 28 inches among the coastal programs were 0.16 for MADFW, 0.42 for NYOHS, 0.43 for NJDEL, and 0.22 for NCCOOP, producing a coastal mean of 0.31 $\pm$ 0.12 (95% CI) (Table A8.14).

The 2006 mean natural mortality estimates for fish $\geq$ 18 inches followed the same pattern (Table A8.15). The 2006 estimates of natural mortality for fish $\geq$ 18 inches in the producer areas were 0.21 for HUDSON, 0.42 for DE/PA, 0.46 for VARAP and 0.48 for MDCB, resulting in a producer area mean of 0.43 $\pm$ 0.13 (95% CI). Estimates of M in the coastal programs covered a wide range, from 0.17 for MADFW to 0.52 for NYOHS, resulting in a coastal mean of 0.34 $\pm$ 0.08 (95% CI).

While the catch equation produced reasonable estimates of fishing mortality, natural mortality estimates were fairly high for most programs and lacked precision (Figure A8.4). Nonsensical, negative values appear throughout the time series for several programs in both size groups. The highest estimates were observed for fish $\geq$ 18 inches in DE/PA, MDCB and VARAP. The recent increases in estimates of M from these tagging programs are consistent with the increased incidence of mycobacteria in Chesapeake Bay and Delaware Bay which likely is resulting an increase in natural mortality of striped bass in these areas (Kahn and Crecco

2006). High values were also observed in NYOHS, and values in that program were very erratic over the time series.

A8.7.4.6 Stock Size

The time series of stock size estimates based on the catch equation are presented in Table A8.11 and Figure A8.5 (fish ≥ 28 inches approximating age 7+, and fish ≥ 18 inches approximating age 3+). The stock size estimates for fish ≥ 28 inches exhibit fair stability with a period of rapid stock growth around 2000. The 2006 estimate for fish ≥ 28 inches (13 million fish) has been approximately stable since 2002. Stock size estimates for fish ≥ 18 inches show fairly consistent growth and the 2006 value is the highest in the time series at 47.9 million fish.

A8.7.4.7 Reporting Rate

The results of the sensitivity analysis of reporting rate on the estimates of exploitation and fishing mortality are shown in Figure A8.6. Results from Program MARK, the catch equation and the IRCR model are similar. Reporting rate acts as a non-linear scalar, with lesser effect on F estimates at higher values. For the catch equation and IRCR methods, an increase in reporting rate results in a decrease in F. However, for the constant M method, the opposite effect is seen. This is because an increase in reporting rate causes an increase in bias (Equation 1), with a consequent decrease in S.

A constant reporting rate of 0.43 is used throughout these calculations, based on a high-reward tag study conducted on the Delaware River stock in 1999. The Delaware Division of Fish and Wildlife and the Pennsylvania Fish and Boat Commission conduct a cooperative survey of the Delaware River spawning stock of striped bass every spring (Kahn and Shirey 2000). Both agencies tag fish at that time as part of the USFWS cooperative striped bass tagging program. In 1999, a high reward tagging study was conducted in conjunction with the standard tagging program releasing 159 high reward tags on fish greater than 20 inches in length and 411 standard tags on fish greater than 18 inches in length. The reward for reporting a high reward tag was $100, a monetary reward believed to be high enough to precipitate a reporting rate response of 100% (Nichols et al. 1991). Total recoveries from the 1999 recovery year were 27 high reward tags and 37 standard tags. Only one high reward tag and 6 standard tags were recovered from the commercial fishery, so the 0.43 estimate of tag reporting rate was based on only the recreational fishery.

However, there is evidence that this estimate may be low. The most recent information for reporting rate is from a high reward tagging study implemented by Maryland Department of Natural Resources in the spring of 2006. In April and May of 2006 tagging efforts were increased to include marking striped bass with high reward tags concurrently with standard tags from the USFWS Cooperative Coastal Striped Bass Tagging Program. Fish were tagged in the upper Chesapeake Bay and the upper Potomac River. High reward tags were applied to every sixth fish resulting in approximately 20% of all fish tagged having high reward tags. Returns of tags with a $125 reward were used to estimate the tag-reporting rate. This value represented a 25% increase over the $100 high reward used by Nichols et al. (1991) and a considerable increase from their estimate of $70 to elicit 100% reporting. All tags reported within the 13-month period following tag deployment were included in analysis, so the reporting period was April 2006 through May 2007. A total of 772 striped bass were tagged with standard tags and 153 with high reward tags. Recoveries were used from both Chesapeake Bay and Atlantic coast fisheries for a total of 61 standard tag recoveries and 16 high reward tag recoveries. Tag reporting rate was estimated to be 0.756 (±0.045 SE) from all fisheries dependent sources and all areas of recovery. The recreational reporting rate was 0.826 (±0.070) and the commercial reporting rate was 0.545 (±0.101).

The Maryland results are from one release area, and will complement expanded high reward tagging studies initiated in 2007. The expansion of the high reward study to additionally include the Delaware and Hudson Rivers for tagging in 2007 will help address further precision and accuracy of tag reporting rates, both from an increased sample size perspective, and an assessment of possible geographic differences. Results from the first year of this study will be available in 2008 for use in assessment of the 2007 data.

For the 2006 assessment, the SBTS chose to continue with current convention and use the 0.43 reporting rate estimate from Kahn and Shirey (2000) for several reasons. Primarily, the work conducted by Maryland DNR in 2006 is considered a pilot study and will be complemented in subsequent years with the addition of Virginia's Chesapeake Bay, Delaware and Hudson River's high reward tagging projects. Additionally, the 43% reporting rate is considered conservative in terms of producing F estimates. Finally, use of the 43% reporting rate in the current assessment provided continuity with previous assessments.

A8.8 CHESAPEAKE BAY TAGGING ASSESSMENT

Amendment 6 implemented a separate management program for the Chesapeake Bay due to the size availability of striped bass in this area. It also specified a separate fishing mortality target of 0.27 (ASMFC 2003). Therefore, a separate estimate of fishing mortality is produced. The striped bass fishery in Chesapeake Bay exploits the pre-migratory/resident striped bass population that consists of smaller fish (TL < 28 inches), mostly ages 3 through 6. Fishing mortality in Chesapeake Bay was calculated using data from the same Maryland and Virginia tagging programs described above. The migratory rates reported by Dorazio et al. (1994) suggest that striped bass between 18 and 28 inches TL are predominantly resident fish. MDDNR data have shown that males make up 80–90% of the resident fish population. Therefore, the data were limited to male striped bass in this size range to estimate fishing mortality on resident fish.

A8.8.1 Methods for Estimation of F and M

Fishing mortality for resident striped bass in Chesapeake Bay was estimated using the catch equation method described in section A8.5.1.

A8.8.2 Reporting Rate

Two high-reward tagging studies have been conducted in the Chesapeake Bay to determine a Bay-specific reporting rate. In 1993, a rate of 0.75 was estimated by Rugolo et al. (1994). The study was repeated in 1999 and resulted in a slightly lower estimate of 0.64 (Hornick et al. 2000). Although the current coastwide assessment uses a value of 0.43 (section A8.7.4.7), a value of 0.64 is used for the Chesapeake Bay analysis because it is the most recent area-specific value. A current Chesapeake-Bay-specific value is anticipated to be available in 2008.

A8.8.3 Chesapeake Bay Results and Discussion

A8.8.3.1 Model Diagnostics

The Akaike weights assigned to the candidate models from Program MARK for Maryland and Virginia are presented in Table A8.16. For Maryland, model S(t) r(p), in which survival varies over time and reporting varies by regulatory period, received the majority of weight. The global model received all the weight for Virginia fish.

A8.8.3.2 Exploitation Rates

Exploitation rates estimated for the Chesapeake Bay resident fish are presented in Table A8.17.

A8.8.3.3 Survival Rates

Program MARK produces estimates of survival that are biased low due to the practice of catch-and-release fishing (uncorrected S). These uncorrected and the bias-corrected estimates of Chesapeake Bay survival are presented in Table A8.18. Maryland estimates of survival show a general decline over the time series, but have been fairly stable since 2000. The 2006 bias-corrected estimate of S for Maryland fish was 0.43. The Virginia estimates also show an overall decline, but mimic the erratic values observed in the coastwide analysis for the VARAP $\geq$ 18 inch fish. The 2006 bias-corrected estimate of S for Virginia fish is biologically unreasonable at 0.05.

A8.8.3.4 Fishing Mortality

Estimates of F for both states and bay-wide were all below the target value of 0.27. Results are presented in Table A8.19 (catch equation input values of A, Z and u, and estimates of F and M for the programs). Fishing mortality in MD steadily increased from near zero values in the early 1990s (when the fishery reopened) to a peak in 1998 (0.19 year^{-1}), then declined and have fluctuated between 0.11 – 0.14 year^{-1} without trend since that time (Figure A8.7). The 2006 estimate for MD was 0.14 year^{-1}. In general, estimates of F from VA data vary without trend between 0.06 and 0.16 year^{-1}, with a few higher values in 1991, 1992 and 1994. These values are likely the consequence of few fish in the size range of 18–28 inches tagged in these years. When these years are removed from the VA data set, the overall range of estimated Fs for MD and VA are very similar. The 2006 F estimate for VA was 0.16 year^{-1}. The bay-wide F, calculated as a weighted mean, shows a trend similar to MD with a 2006 value of 0.14 (Table A8.20).

A8.8.3.5 Natural Mortality

Estimates of natural mortality for VA varied from near-zero values to 2.8 year $^{-1}$. (Figure A8.8, Table A8.19). Very large inter-annual variation and large estimates of M are not biologically reasonable and should be viewed with caution. The natural mortality estimates for MD seem to be steadily increasing from 0.15 – 0.2 in the early 1990s to 0.4 by the middle of the 1990s to between 0.6–1.0 year $^{-1}$ since 1998 (Figure A8.8, Table A8.19). Although the values of M for recent years seem excessively high (between 0.8–1.0), the overall trend of increasing M is supported by some field observations. A number of studies in recent years have indicated a development of mycobacteriosis, a bacterial disease in Chesapeake Bay striped bass beginning around 1997 (Ottinger 2006, Panek and Bobo 2006, Pieper 2006). The disease is believed to have spread significantly thereafter. It has been suggested that mycobacteriosis might lead to an increase in striped bass mortality. Kahn and Crecco (2006) analyzed MD and VA spring tagging data for two groups of fish (fish $\geq$ 18 inches TL and fish $\geq$ 28 inches TL) using Program MARK and the catch equation. They reported high natural mortality rates similar to those estimated in the present analysis and suggested that their high estimates of natural mortality were related to mycobacteriosis.

A8.9 SOURCES OF UNCERTAINTY IN CATCH EQUATION METHOD

- The reporting rate is used in the bias adjustment and in the calculation of exploitation rate, which is used to estimate F in the catch equation method. Based on the most recent information, 0.43 is low. A current estimate is needed, and will be available in 2008.
- Potential violations of Program MARK assumptions. There is a general consensus in the SBTC that effects are minor.
    - The sample is representative of the target population;
        - Geographic distributions of recaptures, by tagging program, indicate most tagged fish follow the same movement patterns and are exposed to the same fisheries.
    - There is no tag loss;
        - Dunning et al. (1987) and Sprankle et al. (1996) report tag loss to be low.
    - Survival rates are not affected by the tagging itself;
        - Goshorn et al. (1998) and Rugolo and Lange (1993) found tag-induced mortality to be low, however, it can vary with experience of the tagger.
    - The year of tag recoveries is correctly tabulated;
        - Quality control checks are performed on the data, and vary by each individual program.
    - The fate of each tagged fish is independent of the fate of other tagged fish;
        - Striped bass are a schooling fish, but the overdispersion adjustment of c-hat is an attempt to correct for a violation of this assumption.
        - Examination of the spatial and temporal distributions of recaptures has shown that tagged fish from each program exhibit the same basic patterns (Appendix 14).
    - The fate of a given tagged fish is a multinomial random variable; and
    - All tagged individuals of an identifiable class (age, sex) in the sample have the same annual survival and recovery rates.
- Model averaging incorporates the uncertainty of model selection into the variance of parameter estimates (Burnham and Anderson 2003).
- Bias adjustment is affected by release survival rate. A constant value of 0.92 is used, but studies have shown that survival varies by age, type of hook, and temperature.
- 95% confidence intervals for the area F estimates were calculated without inclusion of the covariance terms (because covariance terms could not be estimated from these data, they were assumed to be negligible). The magnitude of those terms is unknown.
- The catch equation method uses both the recovery matrix for the entire time series (calculation of S) and the most recent year's recovery vector (calculation of exploitation). Some concern has been expressed about the use of two different time scales of the recovery data in the same equation.
- Program MARK may choose and weight the models differently each year as that year's data are added to the recovery matrix.
- While the catch equation provides reasonable estimates of F, there is considerable variation and some nonsensical values in the estimates of M.

A9.0 REVIEW THE INSTANTANEOUS RATES TAG RETURN MODEL INCORPORATING CATCH-RELEASE DATA (IRCR) AND ESTIMATES OF F ON ATLANTIC STRIPED BASS. PROVIDE SUGGESTIONS FOR FURTHER DEVELOPMENT OF THIS MODEL FOR FUTURE USE IN STRIPED BASS STOCK ASSESSMENTS (TOR #5)

A9.1 INSTANTANEOUS RATES MODEL

Use of the catch equation with Program MARK was intended to provide more reasonable estimates of instantaneous mortality than were seen with the use of Program MARK and a pre-determined value for M. However, like the use of a constant M, the catch equation method uses the survival estimate produced by MARK and parses Z into its component parts. Therefore, the values of F and M are not independent. Several tagging programs have continued to produce occasional unreasonable values (negative values for M) with the use of the catch equation.

The committee is now exploring the use of an instantaneous rates model. Hoenig et al. published a basic instantaneous rates model in 1998. In this model, observed recovery matrices from harvested fish were compared to expected recovery matrices to estimate model parameters. Jiang et al. published an expanded version of the instantaneous rates model in 2007 that accounts for the release of caught, tagged fish. Since many of the tagging programs do not age all tagged fish, the subcommittee elected to use an age-independent form of the "instantaneous rates – catch and release" (IRCR) model by Jiang et al. (2007). The model was programmed in AD Model Builder by Gary Nelson (MA DFW) and tested using data provided in Jiang (2005). Details of model algorithms are provided in Jiang et al. (2007) and can be found in Appendix A15. Tag return data for each program used in the IRCR model are presented in Appendix A14. Like Program MARK, several biologically-reasonable candidate models were formulated based on historical changes in striped bass management (Table A9.1). These models are analogous in structure to the models used in program MARK, but estimate instantaneous mortality rates instead of S. The output from the IRCR model consists of estimates of S, F, F' (tag mortality), M and associated standard errors for each of the candidate models.

A9.2 ASSUMPTIONS AND STRUCTURE OF THE MODEL

Similar to Hoenig et al. (1998), observed recovery matrices from the harvested and caught and released fish with tags removed before release are compared to expected recovery matrices to estimate model parameters. The expected number of tag returns from harvested fish ($R_{i,y}$) and caught-and-released fish (R'_{iy}) follow a multinomial distribution so that the full likelihood is the product multinomial of the cells (Hoenig et al. 1998). Tagged fish are assumed to be fully recruited to the fishery.

The expected number of tag returns from fish tagged and released in year *i* and harvested in year *y* is:

$$\hat{R}_{i,y} = N_i \hat{P}_{i,y} \qquad \textit{Eqn. 1}$$

where:

- N = the number of fish tagged and released in year *i*; and
- $P_{i,y}$ = the probability that a fish tagged and released in year *i* will be harvested and its tag reported in year *y*.

$P_{i,y}$ is defined as:

$$\hat{P}_{i,y} = \begin{cases} \left(\prod_{v=i}^{y-1} \hat{S}_v\right)\left(1-\hat{S}_y\right)\dfrac{\hat{F}_y}{\hat{F}_y + \hat{F}_y^{'} + M}\hat{\lambda} & (when\ y > i) \\ \left(1-\hat{S}_y\right)\dfrac{\hat{F}_y}{\hat{F}_y + \hat{F}_y^{'} + M}\hat{\lambda} & (when\ y = i) \end{cases}$$

Eqn. 2

where: *Eqn. 3*

$$S_y = e^{-\hat{F}_y - \hat{F}_y^{'} - M},$$

and:

F_j = instantaneous rate of fishing mortality on fish in year;
M = instantaneous rate of natural mortality;
λ = tag reporting given that a tagged fish is harvested; and
S_y = annual survival rate in year y for tags on fish alive at the beginning of year y.

The expected number of tag returns from fish tagged and released in year *i* and recaptured and released without a tag in year *y* is:

$$\hat{R}'_{i,y} = N_i \hat{P}'_{i,y}$$

Eqn. 4

where N_i = number of fish tagged and released in year *i*; and
$P'_{i,y}$ = probability that a fish tagged and released in year *i* will be caught and released and its tag reported in year *y*.

$P'_{i,y}$ is defined as:

$$\hat{P}'_{i,y} = \begin{cases} \left(\prod_{v=i}^{y-1} \hat{S}_v\right)\left(1-\hat{S}_y\right)\dfrac{\hat{F}'_y}{\hat{F}_y + \hat{F}_y^{'} + M}\hat{\lambda}' & (when\ y > i) \\ \left(1-\hat{S}_y\right)\dfrac{\hat{F}'_y}{\hat{F}_y + \hat{F}_y^{'} + M}\hat{\lambda}' & (when\ y = i) \end{cases}$$

Eqn.5

where: $$\hat{S}_y = e^{-\hat{F}_y - \hat{F}_y^{'} - M}$$ *Eqn. 6*

and:

F'_j = instantaneous rate of fishing mortality in year *y* on the tags taken from fish that are caught and released and
λ' = tag reporting given that a tagged fish is recaptured, the tag is clipped off, and the fish is released alive.

A9.3 MODEL DIAGNOSTICS

The post-model calculations of F and M for each program followed the same procedures used in the MARK modeling. Over-dispersion was corrected with a c-hat adjustment. The pooled Pearson chi-square statistic was used in the c-hat estimate, and was calculated by pooling expected cells (observed cells were pooled to match the expected cells) until the value was $\geq$1.

A9.4 COASTWIDE TAGGING ASSESSMENT

A9.4.1 Methods for Estimation of S, F and M

Estimates of survival and fishing and natural mortality and associated standard errors from each IRCR run were imported into an EXCEL spreadsheet where the final estimates were calculated as weighted averages across all models. The corresponding variances were calculated as weighted averages of unconditional variances (conditional on the set of models).

A9.4.2 Methods for Estimation of Stock Size

Stock size was estimated using the IRCR model results for F and the same methodology used with Program MARK and the catch equation.

A9.4.3 Coastwide Results and Discussion

A9.4.3.1 Model Diagnostics

In general, the period models were weighted most heavily for both size groups of fish. For fish $\geq$28 inches, the period models received the majority of the weight for all programs. For fish $\geq$18 inches, the period models received the majority of the weight for all coastal programs, while various models were chosen in the producer areas. The Akaike weights assigned to the candidate models are presented in Table A9.2 (fish $\geq$ 28 inches) and Table A9.3 (fish $\geq$ 18 inches).

Model choice and weighting were fairly consistent among the majority of programs. For coastal programs, models in which F was constant during regulatory periods tended to receive the majority of weight in both size groups of fish. In the producer areas, the period models and models in which F varied each year tended to receive the majority of weight, with the exception of DE/PA where a constant F model received the most weight.

A9.4.3.2 Survival Rates

Model averaged estimates of S produced from the IRCR model are presented in Table A9.4 (fish $\geq$ 28 inches) and Table A9.5 (fish $\geq$ 18 inches). The 2006 estimates of S for fish $\geq$ 28 inches ranged from 0.65 (DE/PA) to 0.79 (MDCB) for the producer areas, and 0.74 (NCCOOP) to 0.81 (MADFW) for the coastal programs. The producer area weighted average for 2006 was 95% CI = 0.74 $\pm$ 0.03 and the coastal program mean was 95% CI = 0.79 $\pm$ 0.03 (Table A9.4).

The 2006 estimates of S for fish $\geq$ 18 inches ranged from 0.57 (VARAP) to 0.78 (HUDSON) in the producer areas and 0.70 (NCCOOP) to 0.80 (MADFW) in the coastal programs. The producer area weighted average for 2006 was 95% CI = 0.70 $\pm$ 0.02 and the coastal program mean was 95% CI = 0.76 $\pm$ 0.02 (Table A9.5).

A9.4.3.3 Fishing Mortality

The time series of program F estimates, along with the 2006 producer area and coastal area mean F's are presented in Table A9.6 (fish ≥ 28 inches) and Table A9.7 (fish ≥ 18 inches).

The 2006 IRCR estimates of F for fish ≥ 28 inches were quite low and were not significantly different between the producer and coastal areas. Producer area F estimates were all below the target value of 0.30 and were fairly evenly distributed throughout the range of values (0.18 for HUDSON, 0.26 for DE/PA, 0.10 for MDDNR and 0.11 for VARAP). The resulting 2006 producer area F was quite low (95% CI = 0.13 + 0.015). The 2006 estimates of F for fish ≥ 28 inches among the coastal programs showed a bimodal distribution, with very low values for three of the programs (0.10 for MADFW, 0.12 for NJDEL and 0.12 for NCCOOP) and 0.19 for NYOHS. The 2006 coastal mean F was therefore low (95% CI = 0.13 + 0.015) and was the same value as for the producer area programs.

The 2006 IRCR estimates of F for fish ≥ 18 inches were also low and were not significantly different between the producer and coastal areas. Producer area F estimates among the producer area programs were all low (0.12 for HUDSON, 0.16 for DE/PA, 0.08 for MDDNR and 0.09 for VARAP). The subsequent value for the 2006 weighted mean producer area F was also quite low (95% CI = 0.10 + 0.03). The 2006 estimates of F for fish ≥ 18 inches among the coastal programs were also very low (0.09 for MADFW, 0.05 for NYOHS, 0.12 for NJDEL, and 0.09 for NCCOOP). The 2006 coastal mean F was therefore low as well (95% CI = 0.09 + 0.015).

A9.4.3.4 Natural Mortality

Whereas there was considerable variation among programs, the combined M estimates based on the IRCR model were very close to the value of 0.15 used in the previous method (the IRCR model estimates one M value over the entire time series for each program). For fish > 28 inches, the natural mortality estimates for producer area programs were 0.09 for HUDSON, 0.16 for DE/PA, 0.14 for MDDNR and 0.28 for VARAP (Table A9.8). The weighted mean M for producer areas was 0.17 + 0.02 (95% CI). Coastal program M values for fish > 28 inches were 0.11 for MADFW, 0.09 for NYOHS, 0.09 for NJDEL, and 0.18 for NCCOOP. The mean M for coastal programs was 0.12 + 0.01 (95% CI).

IRCR estimates of natural mortality for both producer and coastal areas were higher for fish > 18 inches than for fish > 28 inches (Table A9.9). Producer area values were 0.12 for HUDSON, 0.25 for DE/PA, 0.20 for MDDNR and 0.47 for VARAP, producing a weighted mean M of 0.26 + 0.02 (95% CI). Coastal program M values for fish > 18 inches were 0.12 for MADFW, 0.24 for NYOHS, 0.15 for NJDEL, and 0.26 for NCCOOP, producing a mean of 0.19 + 0.01 (95% CI).

A9.4.3.5 Stock Size

The time series of stock size estimates from the IRCR model are also presented in Table A9.10 (fish ≥ 28 inches, approximating age 7+ and fish ≥ 18 inches, approximating age 3+). The stock size estimates for fish ≥ 28 inches also exhibit fair stability with a period of rapid stock growth around 2000. The 2006 estimate for fish ≥ 28 inches (16.6 million fish) has been approximately stable since 2003. Stock size estimates for fish ≥ 18 inches has shown fairly consistent growth and the 2006 value is the highest in the time series at 60.8 million fish.

A9.5 CHESAPEAKE BAY TAGGING ASSESSMENT

The instantaneous rates model can be structured to estimate natural mortality as a constant for the entire period of the study or estimate different natural mortality values within time periods. Some studies have suggested that natural mortality of striped bass in Chesapeake Bay has increased since 1997 due to disease (mycobacteriosis) and reduced forage base (Ottinger 2006, Panek and Bobo 2006, Pieper 2006). Following these assumptions, estimates of fishing mortality for both Maryland and Virginia data sets were calculated using the IRCR model for three natural mortality scenarios – constant natural mortality for the entire period, separate estimates of natural mortality for two periods (1987–1997 and 1998–2006), and for three periods (1987–1997, 1998–2000 and 2001– 2006).

A9.5.1 Methods for Estimation of F and M

The model and the software used in Chesapeake data analysis are identical to those described in section A9.2.

A9.5.2 Reporting Rate

See section A8.6.2

A9.5.3 Chesapeake Bay Results and Discussion

A9.5.3.1 Fishing Mortality

IRCR estimates of F for both states and bay-wide were all below the target value of 0.27 (Tables A9.11, 12 and 13).

Under the assumption of constant natural mortality, fishing mortality estimated from MD data increased from near-zero values during the moratorium period to 0.15 year^{-1} in 1992, fluctuated upward to a maximum of 0.17 year^{-1} in 1998, then declined to 0.05 year^{-1} in 2005–2006 (Table A9.11, Figure A9.1). When two and three different periods of M were considered, similar trends and values were observed up to 1997, but there was no declining trend for the 1998–2006 period (Tables A9.12, 13).

Analysis of Virginia data indicated that regardless of model structure for estimating M, fishing mortality was low and relatively stable, fluctuating between 0.04 and 0.09 year^{-1} (Tables A9.11, 12, 13 and Figure A9.2). A single peak in 1992 is likely to be an artifact caused by the very low number of fish marked in that year.

A9.5.3.2 Natural Mortality

Using MD data, the IRCR model estimated levels of natural mortality that were up to four times the previously assumed value of 0.15 year^{-1} and suggested that most of total mortality is due to natural causes (Figure A9.3). For the constant M scenario natural mortality was estimated at 0.33 year^{-1}, for two periods M was 0.27 year^{-1} for 1987–96 and 0.68 year^{-1} for 1997–2006, for three periods M was 0.28 year^{-1} for 1987–96, 0.65 year^{-1} for 1997–2000, and 0.74 year^{-1} for 2001–2006. When a constant M was considered, total mortality seemed to have two stable periods, with mortality around 0.45 year^{-1} during 1992–1998 and a slightly lower value (0.40 year^{-1}) in the more recent period (1999–2006). When two or three periods of M were assumed, there were also two periods of Z, but their values were drastically different. During 1990–1996 total mortality was 0.3–0.4 year^{-1} and from 1997–2006 it was 0.8 – 0.9 year^{-1}. These results suggest a substantial increase in natural mortality during the last decade.

Similar to the MD analysis, the estimated M values from VA data were very high in all scenarios. Natural mortality was estimated at 0.6 year^{-1} for constant M, for two periods M was 0.85 year^{-1} during 1988–1996 and 0.9 year^{-1} for 1997–2006, and for three periods M was 0.35 year^{-1} for 1988–96, 0.99 year^{-1} for 1997–2000, and 0.81 year^{-1} for 2001–2006 (Figure A9.4).

A significant advantage of the catch equation method and the IRCR model is the ability to estimate natural mortality in addition to fishing mortality, either through the use of external model results (the catch equation uses survival estimates from Program MARK) or internally (IRCR model). As reported above, estimated values of natural mortality from both methods were substantially higher than the life-history-based fixed level of natural mortality traditionally used in the analyses (0.15 year^{-1}). A significant increase in natural mortality of striped bass in Chesapeake Bay may have a significant effect on population dynamics and serious implications for management. An obvious effect of increase in M is a faster decay of individual cohort size (increase in the catch curve slope) and overall decline of population abundance. Using these levels of natural mortality, the IRCR model estimates total mortality for striped bass in the Bay of 0.9 – 1.1 year^{-1} since 1997. Such levels of mortality are not sustainable and a significant decline in population should have been observed. Figure A9.5 provides an illustration of the Chesapeake Bay striped bass exploitable biomass using constant M of 0.15 year^{-1} and the IRCR model with variable M. These calculations were completed with the Harvest Control Model (Rugolo and Jones 1989), which projects the age-0 index forward using year-specific estimates of fishing and natural mortality. A significant decline in population size should in turn affect fish availability and lead to a decline in CPUE and total harvest. However, the actual landings increased, reaching record harvest values in 2006. This lack of agreement between model results and observed fishery data suggests a need for careful evaluation of the tagging analysis assumptions (full mixing and equal probability of marked fish to be recovered) and interpretation of the results. What is currently interpreted in the model as total mortality can be more generally described as a rate of disappearance, where disappearance includes total mortality and emigration. Striped bass emigrate from Chesapeake Bay as they age and if the fish are moving to areas that are not fished or very lightly fished (for example, the EEZ) the probability of tagged fish being recovered becomes extremely low. In this case the decline in the number of recovered tags is interpreted in the model as a decline in survival and increase in natural mortality. A simulation analysis is recommended to investigate the ability of the instantaneous rates model to differentiate natural mortality from emigration to areas with different or no fishing activity / tag return.

A9.6 SOURCES OF UNCERTAINTY IN IRCR MODEL

- The reporting rate is used in the bias adjustment and in the calculation of exploitation rate, which is used to estimate F in the IRCR model. Based on the most recent information, 0.43 is low. A current estimate is needed, and will be available in 2008.

- Due to the relatively short time the committee has been working with the IRCR model, it is not presented as the primary model. Additional assessment of the suite of candidate models and diagnostic tests are recommended.

A9.7 COMPARISON OF IRCR MODEL AND CATCH EQUATION METHOD

A9.7.1 Coastwide

The two methods produced similar estimates of F for both size groups of fish, however the catch equation estimates were much less precise. Coastal and producer area mean F estimates generated from these methods are compared for fish $\geq$ 28 inches (Figure A9.6) and fish $\geq$ 18 inches (Figure A9.7). For fish $\geq$ 18 inches, the erratic values produced by the previous method assuming constant M are also shown for comparison.

In general the M estimates generated from the IRCR model were slightly lower than the catch equation estimates in the most recent years and more precise. Coastal and producer area mean M estimates generated from the IRCR model and catch equation method are compared for fish $\geq$ 28 inches (Figure A9.8) and fish $\geq$ 18 inches (Figure A9.9). The candidate models for the IRCR model held M constant over the time series. Additional candidate models will be explored which allow M to vary over time and/or regulatory periods.

The bias-corrected mean S estimates from Program MARK and the IRCR model are compared for fish $\geq$ 28 inches in Figure A9.10 and for fish$\geq$ 18 inches in Figure A9.11. For fish $\geq$ 28 inches, the IRCR model estimates were stable and similar to those from Program MARK until 2003, when the MARK estimates declined. For fish $\geq$ 18 inches, the IRCR estimates were fairly stable throughout the time series, whereas estimates from Program MARK were erratic throughout the time series and dropped in more recent years.

Stock size estimates from these methods are compared in Figure A9.12. Estimates for age 7+ fish are fairly similar for all methods through 2002. After 2002, the method assuming constant M shows decreasing stock size but the catch equation and IRCR model show continuing increase. Estimates for age 3+ fish from the method assuming constant M show stable abundance while estimates from the catch equation and IRCR show continued growth. Estimates of stock size for both groups of fish computed from the catch equation F's are lower than those obtained with the IRCR model (because estimates of F based on the catch equation are higher, lower stock size is estimated for the same harvest).

A9.7.2 Chesapeake Bay

All models showed the same trend for Maryland data – a stable increase in fishing mortality from near-zero values during the moratorium period to a peak of 0.15–0.2 $year^{-1}$ in 1998, followed by fluctuation without trend in a narrow range of 0.08 – 0.17 $year^{-1}$ thereafter. An instantaneous rates model formulation that estimated a constant M for the entire period of analysis differed slightly and showed a decline in F after 1998. This trend and the range of variation were similar to the fishing mortality estimates based on the summer-fall tagging study, which was an independent source of data (Figure A9.13). Despite slight differences in fishing mortality estimates among the models, all annual estimates of fishing mortality were below the Bay F target of 0.27 $year^{-1}$ (Figure A9.13).

The general trend of fishing mortality of fish tagged in Maryland is consistent with additional information on the status of the coastwide stock. Since the reopening of the fishery, landings have consistently risen both in Chesapeake Bay and coastwide. The stock has been increasing in size, based on the VPA assessment (ASMFC 2005). The F estimates in Maryland are also comparable to F's for ages 3–8, weighted by numbers from the 2005 VPA assessment (Figure A9.13). The weighted-by-numbers fishing mortality for ages 3–8 has been used by the

Technical Committee in the past to characterize F in producer areas, of which Chesapeake Bay is dominant.

Fishing mortality estimates for the Virginia component of the resident stock were generally flat and low in values. With the exception of the catch equation results, F ranged between 0.03 – 0.1 $year^{-1}$ (Figure A9.14). High values of F for 1992 and 1994 are most likely an artifact resulting from small sampling size (number of fish marked). Low fishing mortality for VA is somewhat surprising, considering the total striped bass harvest in Virginia's portion of Chesapeake Bay. Lack of spatial coverage could potentially explain VA's low estimated fishing mortality values. Tagging in Virginia is conducted in one location (the Rappahannock River) using one pound net. Consequently, tags could have been applied to the specific strain of fish from a Rappahannock spawning population, which are not necessarily representative of the entire group of resident striped bass in Virginia waters. This hypothesis is supported in part by the results presented in Hoenig et al. (2004), in which the Virginia tagging dataset showed a non-mixing effect. Although non-mixing can be accounted for by using a non-mixing model, this would not guarantee that corrected fishing mortality estimates would be representative of the Bay population and not of the Rappahannock River population itself. An expansion of geographical coverage would be the best solution for the problem.

The analyses of Maryland and Virginia data have been presented separately in this report to account for differences in tagging methodology and geographical coverage. A bay-wide average estimate of F weighted by the number of fish landed in each state shows no trend within the entire time series, varying between 0.05 and 0.15 $year^{-1}$ (Figure A9.15). The 1992 and 1994 estimates of F in VA are suspected to be due to low sampling size. Based on the results of the spring tagging data analysis, the fishing mortality in Chesapeake Bay has been low in general since the late 1980s and never exceeded the target threshold for Chesapeake Bay established by Amendment 6 (0.27 $year^{-1}$). These conclusions are corroborated by other sources such as the summer–fall tagging program and the age structured analysis (VPA) from the 2005 assessment.

The IRCR model and the catch equation method both indicated high levels of natural mortality for striped bass since 1997, ranging between 0.64 and 1.0 $year^{-1}$. These estimates are inconsistent with trends in harvest and projected population size. A careful review of the tagging model assumptions is recommended. A test of the IRCR model's ability to estimate natural mortality in the presence of emigration and refuge from the fishery is also recommended. Care should be exercised in interpreting natural mortality estimates until such analyses are completed.

A10.0 REVIEW THE FORWARD-PROJECTING STATISTICAL CATCH-AT-AGE MODEL INCORPORATING THE AGE-INDEPENDENT INSTANTANEOUS RATES TAG RETURN MODEL (SCATAG) AND ESTIMATES OF F, SPAWNING STOCK BIOMASS, AND TOTAL ABUNDANCE OF STRIPED BASS. PROVIDE SUGGESTIONS FOR FURTHER DEVELOPMENT OF THIS MODEL FOR FUTURE USE IN STRIPED BASS STOCK ASSESSMENTS (TOR #6)

A10.1 *SCATAG* MODEL

The 36th SARC reviewers recommended that an assessment model incorporating tag returns and catch-at-age data for striped bass should be constructed to provide only one estimate of fishing mortality. In response, the committee constructed a forward-projecting age-structured statistical catch-at-age model incorporating tag return data for the Atlantic coast migratory stocks of striped bass during 1982–2006.

A10.2 MODEL STRUCTURE

A10.2.1 Catch-at-Age Structure (same as SCA model)

The structure of the population model is aged-based and projects the population numbers-at-age forward through time given model estimates of recruitment and age-specific total mortality, and is the same structure as the SCA model. The population numbers-at-age matrix has dimensions Y x A, where Y is the number of years and A is the oldest age group. The time horizon for striped bass is 1982–2004 since complete catch data are only available back to 1982. However, there are relative abundance data (Maryland young-of-the-year indices) available for earlier years. To use those earlier data, the dimensions of population numbers-at-age were expanded to Y+A-1 x A matrix (Figure A10.1). The number of year classes in the model was 13, representing ages 1 through 13+.

Population numbers-at-age ($a<A$) are calculated through time by using the exponential cohort survival model

$$\hat{N}_{y,a} = \hat{N}_{y-1,a-1}\, exp^{-\hat{F}_{y-1,a-1} - M} \qquad (1)$$

where $\hat{N}_{y,a}$ is abundance of age a in year y, $\hat{N}_{y-1,a-1}$ is abundance of age $a-1$ in year $y-1$, $F_{y-1,a-1}$ is the instantaneous fishing mortality rate for age $a-1$ in year $y-1$, and M is the instantaneous natural mortality (assumed constant across years and ages). For the plus group (A), numbers-at-age are the sum of survivors of $A-1$ in year $y-1$ and survivors from the plus group in year $y-1$:

$$\hat{N}_{y,A} = \hat{N}_{y-1,A-1}\, exp^{-\hat{F}_{y-1,A-1} - M} + \hat{N}_{y-1,A}\, exp^{-\hat{F}_{y-1,A} - M} \qquad (2)$$

Recruitment (numbers of age-1 bass) in year y ($N_{y,1}$) is estimated and it is modeled as a log-normal deviation from average recruitment:

$$\hat{N}_{y,1} = \hat{\bar{N}}_1 \cdot exp^{\hat{e}_y} \qquad (3)$$

where $N_{y,1}$ is the number of age 1 fish in year y, $\hat{\bar{N}}_1$ is the average recruitment parameter, and e_y are independent and identically distributed normal random variables with zero mean and constant variance and are constrained to sum to zero over all years. A function is used to help constrain the recruitment deviations and is included in the total likelihood:

$$P_{rdev} = \lambda_R \sum_y e_y^2 \qquad (4)$$

where λ_R is a user-specified weight. The initial population abundance-at-age for 2–13+ in 1970 is calculated by using the $\hat{N}_{1970,1}$ and assuming $F_{1982,a-1}$:

$$\hat{N}_{1970,a} = \hat{N}_{1970,a-1}\, exp^{-\hat{F}_{1982,a-1} - M} \qquad (5)$$

Estimation of fishing mortality-at-age is accomplished by assuming that fishing mortality can be decomposed into yearly and age-specific components (separability):

$$\hat{F}_{y,a} = \hat{F}_y \cdot \hat{s}_a \qquad (6)$$

where F_y is the fully-recruited fishing mortality in year y and s_a is the average selectivity pattern of fish of age a. The dimensions of the F-at-age matrix are Y x A. Similar to recruitment, F_y is modeled as a log-normal deviation from average fishing mortality:

$$\hat{F}_y = \hat{\bar{F}} \cdot exp^{d_y} \qquad (7)$$

where F_y is the fishing mortality in year y, $\hat{F}$ is the average recruitment parameter, and d_y are independent and identically distributed normal random variables with zero mean and constant variance and are constrained to sum to zero over all years. For years earlier than 1982, the fishing mortality-at-age is assumed equal to the values for 1982. A function is used to help constrain the fishing mortality deviations and is included in the likelihood function:

$$P_{fdev} = \lambda_F \sum_y d_y^2 \qquad (8)$$

where λ is a user-specified weight. Following Brodziak (2002), a fishing mortality penalty is imposed to ensure that the observed catch could not produce extremely small Fs during the early phases of the estimation process:

$$P_{f_{add}} = \begin{cases} \text{phase} < 3, & \lambda_F \cdot 10 \cdot \sum_y (F_y - 0.15)^2 \\ \text{phase} \geq 3, & \lambda_F \cdot 0.001 \cdot \sum_y (F_y - 0.15)^2 \end{cases} \qquad (9)$$

Selectivity for $a<A$ is modeled by using the Gompertz equation, and to ensure at least one age had a maximum selectivity of 1, s_a is calculated as

$$s_a = \frac{exp^{(-exp^{-\hat{\beta}(a-\hat{\alpha})})}}{max_a(exp^{(-exp^{-\hat{\beta}(a-\hat{\alpha})})})} \qquad (10)$$

where α and β are estimates. Based on historical changes in size and catch regulations and model comparisons (see *Exploratory Analyses* below), selectivity patterns are estimated for 4 periods: 1982–1984, 1985–1989, 1990–1995, and 1996–2006. s_a for the plus group (A) is assumed equal to s_a for age $A-1$.

For ease of computation, total mortality-at-age (Z) is calculated as

$$Z_{y,a} = F_{y,a} + M \qquad (11)$$

and fills a matrix of dimension Y x A. For years earlier than 1982, Z is assumed equal to the values for 1982.

For total catch and survey indices data, lognormal errors were assumed throughout and the concentrated likelihood weighted for variation in each observation was calculated. The generalized concentrated negative log-likelihood (L_l) (Parma 2002; Deriso et al. 2007) is

$$L_l = 0.5 * \sum_i n_i * \ln\left(\frac{\sum_i RSS_i}{\sum_i n_i}\right) \qquad (12)$$

where n_i is the total number of observations and RSS_i is the weighted residual sum-of-squares from dataset *i*. Equations for the weighted residual sum-of-squares are shown following the description (given below) of the estimation of predicted values for each data type.

For the catch and survey age compositions, multinomial error distributions were assumed throughout and the negative log-likelihoods were calculated using the general equation,

$$L = \sum_y - n_y \sum_a P_{y,a} \cdot \ln\left(\hat{P}_{y,a}\right) \qquad (13)$$

Specific equations for each dataset are shown following the description of the estimation of predicted values.

Total catch (recreational and commercial harvest numbers plus number of discards that die due to handling and release) and the proportions of catch-at-age of striped bass fisheries are primary data from which fishing mortalities, selectivities, and recruitment numbers are estimated. Given estimates of F, M, and population numbers, predicted catch-at-age is computed from Baranov's catch equation (Ricker, 1975):

$$\hat{C}_{y,a} = \frac{\hat{F}_{y,a}}{\hat{F}_{y,a} + M} \cdot (1 - exp^{-\hat{F}_{y,a} - M}) \cdot \hat{N}_{y,a} \qquad (14)$$

where $\hat{C}_{y,a}$ is the predicted removals of age *a* during year *y* and other variables are as defined above. All predictions are stored in a matrix of dimension *Y* x *A*. Predicted catch-at-age data are then compared to the observed total catch and proportions of catch-at-age through the equations:

Predicted Total Catch

$$\hat{C}_y = \sum_a \hat{C}_{y,a} \qquad (15)$$

Predicted Proportions of Catch-At-Age

$$\hat{P}_{y,a} = \frac{\hat{C}_{y,a}}{\sum_a \hat{C}_{y,a}} \qquad (16)$$

where $\hat{C}_{y,a}$ is the predicted total catch in year y and $P_{y,a}$ is the predicted proportions of age a in the catch during year y. The weighted lognormal residual sum-of-squares (RSS_c) is calculated as

$$RSS_c = \lambda_c \sum_y \left(\frac{\ln\left(C_y + 1e^{-5}\right) - \ln\left(\hat{C}_y + 1e^{-5}\right)}{CV_y} \right)^2 \qquad (17)$$

where C_y is the observed catch in year y, $\hat{C}_{y,a}$ is the predicted catch in year y, CV_y is the CV for observed catch in year y, and λ_c is the relative weight (Parma 2002; Deriso et al. 2007). Total catch CVs were assumed equal to the PSEs of the MRFSS total catch estimates for the entire Atlantic coast (less South Carolina, Georgia and East Florida records) since it is assumed that only the estimates of recreational kill and dead discards have error.

In addition, the predicted proportions of catch-at-age are compared to the observed proportions of catch-at-age through a multinomial probability model. The proportions of catch-at-age negative log-likelihood (L_p) is

$$L_p = \lambda_p \sum_y - n_y \sum_a P_{y,a} \cdot \ln\left(\hat{P}_{y,a} + 1e-7\right) \qquad (18)$$

where n_y is the effective number of fish aged in year y and $P_{y,a}$ is the observed proportion of catch-at-age. The multinomial probability assumes that the numbers of aged fish used to apportion the catch into age classes are sampled randomly and independently of each other. This is truly not the case because gear and fishing practices collected fish in groups or clusters, so the effective sample size is much smaller than the actual number of fish aged. Therefore, the effective sample size was estimated by using the manual, iterative method of McAllister and Ianelli (1997). The effective sample size for each year is the average over all years and it is set to 380 fish in this model.

The observed total catch and catch age composition data were generated from all state reported landings-at-age, recreational dead discards-at-age, and commercial dead discards-at-age. Total catch by year was calculated by summing catch across age classes. The catch age composition was calculated by dividing the catch-at-age for a given year by yearly total catch.

Young-of-the-year (YOY) and yearlings indices from New York (Hudson River), New Jersey (Delaware Bay), Maryland (Chesapeake Bay), and Virginia (Chesapeake Bay) were incorporated into the model by linking them to corresponding age abundances depending on the time of year the survey was conducted:

$$\hat{I}_{t,y,a} = \hat{q}_t \cdot \hat{N}_{y,a} \cdot \exp^{-p_t \cdot Z_{y,a}} \qquad (19)$$

where $\hat{I}_{t,y,a}$ is the predicted index of survey t for age a in year y, q_t is the catchability coefficient of index t, $N_{y,a}$ is the abundance of age a in year y, p is the fraction of total mortality that occurs prior to the survey, and $Z_{y,a}$ is the total instantaneous mortality rate. All qs were estimated as free parameters. The YOY and yearling indices were advanced one year and were linked to age 1 and age 2 abundances, respectively and were tuned to January 1st (p=0;Table A10.1). All YOY and yearling indices are arithmetic means and corresponding CVs. More information on these surveys can be found in ASMFC (1995).

The aggregate indices (no or borrowed age data or other reasons) from the Marine Recreational Fisheries Statistics Survey (MRFSS), Connecticut (Recreational CPUE and bottom trawl survey), Northeast Fisheries Science Center (NEFSC: spring bottom trawl survey) and Massachusetts (commercial total catch rates) were incorporated into the model by linking them to summed age abundances depending on the time of year of the survey and the ages included in the index (Table A10.1). The predicted index equation is:

$$\hat{I}_{t,y,\Sigma a} = \hat{q}_t \cdot \sum_a \hat{N}_{y,a} \cdot \exp^{-p_t \cdot Z_{y,a}} \qquad (20)$$

All aggregate indices are arithmetic means of the survey estimate. The CVs for the MRFSS index were calculated by dividing model estimates of standard errors by the index. The CVs for the Connecticut Recreational CPUE index were assumed equal to the CVs of the total recreational catch values for Connecticut generated by MRFSS.

The age-aggregated indices and age composition data from New York (ocean haul seine), New Jersey (bottom trawl), Maryland (gillnet spawning stock survey), and Delaware (electrofishing spawning stock survey) surveys are incorporated into the model by linking them to age abundances depending on the time of year the survey and the ages included in the index:

$$\hat{I}_{t,y} = \hat{q}_t \sum_a \hat{s}_{t,a} \cdot \hat{N}_{y,a} \cdot \exp^{-p_t \cdot \hat{Z}_{y,a}} \qquad (21)$$

where $s_{t,a}$ is the selectivity coefficient for age a in survey t. The fraction of the year and ages to which each survey is linked is listed in Table A10.1. The weighted residual sum of squares for survey index t is given by:

$$RSS_t^I = \lambda_t \sum_y \left(\frac{\ln\left(I_{t,y} + 1e^{-5}\right) - \ln\left(\hat{I}_{t,y} + 1e^{-5}\right)}{CV_{t,y}} \right)^2 \qquad (22)$$

The Gompertz equation is used to estimate the selectivity pattern for the Delaware spawning stock surveys because the survey is an electrofishing survey and theory indicates that vulnerability increases with surface area of the fish. Because MD survey estimates are corrected mesh-size selection, by trial-and-error, it was determined that only the selectivity value for age 2 had to be estimated; for ages ≥ 3, selectivity was set to 1. For the New York ocean haul survey, the Thompson's exponential-logistic model (Thompson 1994) is used to estimate the selectivity pattern

$$\hat{s}_a = \frac{1}{1-\gamma} \cdot \left(\frac{1-\gamma}{\gamma}\right)^{\gamma} \frac{\exp^{\alpha\gamma(\beta-a)}}{1+\exp^{\alpha(\beta-a)}} \qquad (23)$$

For the New Jersey survey, a gamma function is used to estimate the selectivity pattern:

$$\hat{s}_a = \frac{a^{\alpha} \exp^{\beta \cdot a}}{\max_a (a^{\alpha} \exp^{\beta \cdot a})} \quad (24)$$

The predicted age composition (proportions-at-age) of each survey is modeled and compared to the observed proportions-at-age through a multinomial probability model. The survey indices-at-age are calculated as

$$\hat{I}_{t,a,y} = \hat{q}_t \cdot \hat{s}_{t,a} \cdot \hat{N}_{y,a} \cdot \exp^{-p_t \cdot \hat{Z}_{y,a}} \quad (25)$$

and predicted age composition is calculated as

$$\hat{U}_{t,y,a} = \frac{\hat{I}_{t,y,a}}{\sum_a \hat{I}_{t,y,a}} \quad (26)$$

The age composition negative log-likelihood for survey t is

$$L_t^U = \lambda_t \sum_y -n_{t,y} \sum_a U_{t,y,a} \cdot \ln\left(\hat{U}_{t,y,a} + 1e^{-7}\right) \quad (27)$$

where $n_{t,y}$ is the effective sample size of fish aged in year y from survey t, and $U_{t,y,a}$ and $U_{t,y,a}$ are the observed and predicted proportions of age a in year y from survey t. Used as starting values, the average effective sample size for each survey was calculated by using methods in Pennington and Volstad (1994) and Pennington et al. (2002). In essence, effective sample size was estimated by first calculating the length sample variance using the simple random sampling equation and dividing into it the cluster sampling variance of mean length derived through bootstrapping, assuming each seine/trawl haul, gillnet set, or electrofishing run was the sampling unit. The average over the years of data received was used as the effective sample size for all years (Table A10.2).

Model fit for all components was checked by using residual plots. In addition, predicted average effective sample size for the catch and survey age composition data were compared to the observed average values used in the model. Predicted average effective sample size ($\hat{\bar{t}}$) is calculated following McAllister and Ianelli (1997):

$$\hat{\bar{t}} = \frac{\sum_y \hat{t}_y}{d_y} \quad (28)$$

and $\hat{t}$ is defined as

$$\hat{t}_y = \frac{\sum_a \hat{c}_{a,y}(1 - \hat{c}_{a,y})}{\sum_a (o_{a,y} - c_{a,y})^2}$$

where $\hat{c}_{a,y}$ is the predicted proportion-at-age a in year y from the catch or survey, $o_{a,y}$ is the observed proportion-at-age, and d_y is the number of years of data for catch or survey series.

A10.2.2 Tag Returns Model Structure

The age-independent model of Jiang et al. (2007) is used to bridge the catch-at-age and tag return data. The benefits of this instantaneous rates model are that data from tagged fish that are recaptured and released alive are directly incorporated in the estimation of fishing mortality. This model assumes that tagged fish are fully-recruited to the fishery. Similar to Hoenig et al. (1998), observed recovery matrices from the harvest and catch/release fish with removed tags are compared to expected recovery matrices to estimate model parameters.

The expected number of tag returns ($R_{i,y}$)from fish tagged and released in year i and harvested in year y is

$$\hat{R}_{i,y} = N_i \hat{P}_{i,y} \qquad (29)$$

where N_i is the number of fish tagged and released in year i, $P_{i,y}$ is the probability that a fish tagged and released in year i will be harvested and its tag reported in year y and is defined as

where F_y is the instantaneous rate of fishing mortality on fish in year y, F'_y is the instantaneous rate of fishing mortality in year y on the tags taken from fish that are caught and released, λ is the tag reporting given that a tagged fish is harvested, and S_y is the annual survival rate in year y for tags on fish alive at the beginning of year y,

The expected number of tag returns ($R'_{i,y}$)from fish tagged and released in year i and recaptured and released without a tag in year y is

$$\hat{R}'_{i,y} = N_i \hat{P}'_{i,y} \qquad (30)$$

$$\hat{P}_{i,y} = \begin{cases} \left(\prod_{v=i}^{y-1} \hat{S}_v\right)\left(1-\hat{S}_y\right)\dfrac{\hat{F}_y}{\hat{F}_y + \hat{F}'_y + M}\hat{\lambda} & (when\ y > i) \\ \left(1-\hat{S}_y\right)\dfrac{\hat{F}_y}{\hat{F}_y + \hat{F}'_y + M}\hat{\lambda} & (when\ y = i) \end{cases}$$

$$\hat{S}_y = e^{-\hat{F}_y - \hat{F}'_y - M},$$

where N_i is the number of fish tagged and released in year i, $P'_{i,y}$ is the probability that a fish tagged and released in year i will be caught and released and its tag reported in year y and is defined as

$$\hat{P}'_{i,y} = \begin{cases} \left(\prod_{v=i}^{y-1} \hat{S}_v\right)\left(1-\hat{S}_y\right)\dfrac{\hat{F}'_y}{\hat{F}_y + \hat{F}'_y + M}\hat{\lambda}' & (when\ y > i) \\ \left(1-\hat{S}_y\right)\dfrac{\hat{F}'_y}{\hat{F}_y + \hat{F}'_y + M}\hat{\lambda}' & (when\ y = i) \end{cases}$$

$$\hat{S}_y = e^{-\hat{F}_y - \hat{F}'_y - M}$$

where F'_y is the instantaneous rate of fishing mortality in year y on the tags taken from fish that are caught and released and λ' is the tag reporting given that a tagged fish is recaptured, the tag is clipped off, and the fish is released alive. R_{iy} and R'_{iy} follow a multinomial distribution so that the full likelihood is the product multinomial of the cells (see Hoenig et al. 1998). See Jiang et al. (2007) for more details of the model.

A10.2.3 Link Between Catch-at-Age and Tag Return Models

The link between the two models is fully-recruited fishing mortality (F_y). Both component models assume a Type 2 fishery (Ricker, 1975). Only data from tagged striped bass ≥28 inches were used to represent fish that are fully-recruited to the fisheries. There are eight tagging programs along the Atlantic coast and they are described in the "Tagging Data Analyses". Data from all programs are used in this model.

The log-likelihood for tagging program r is:

$$-L_r = \lambda_r \sum_{a=1}^{A}\sum_{i=1}^{I}(N_{i,a} - \sum_{v=i}^{Y} R_{i,v,a} + R'_{i,v,a}) \cdot \ln(1 - \sum_{v=i}^{Y} \hat{P}_{i,v,a} + \hat{P}'_{i,v,a}) + \sum_{y=1}^{Y} R_{i,y,a} \ln(\hat{P}_{i,y,a}) + R'_{i,y,a} \ln(\hat{P}'_{i,y,a}) \qquad (31)$$

The current total log-likelihood of the full model is

$$f = -L_l - L_p - L^U_{NYOHS} - L^U_{NTrawl} - L^U_{NYOHS} - L^U_{MDSSN} - MAtag - NYtag - Hudsontag - NJtag - MDtag - VAtag - NCtag - DEtag + P_{rdev} + P_{fdev} + P_{fadd}$$

The total log-likelihood is used by the autodifferentiation routine in AD Model Builder to search for the "best" selectivity parameters, average recruitment, recruitment deviations, average F, fishing mortality deviations, annual tag mortality, and catchability coefficients that minimize the total log-likelihood. AD Model Builder allows the minimization process to occur in phases. During each phase, a subset of parameters is held fixed and minimization is done over another subset over parameter until eventually all parameters are included in the estimation. In this model, the following parameters were solved over eleven phases:

Phase	
1	average recruitment
2	average fishing mortality and fishing mortality deviations
3	recruitment deviations
4	catch selectivity parameters
5	catchability coefficients of YOY/Yearling and aggregate survey indices
6	catchability coefficients of survey indices with age composition data
7	NY survey selectivity parameters
8	NJ survey selectivity parameters
9	DE survey selectivity parameters
10	MD survey selectivity parameters
11	fishing mortality on tags for each year

The estimation procedure proceeds by first calculating $F_{a,y}$ using initial starting values for average F, F'_y, average R, and parameters estimates for the selectivity equations, and M (which is fixed at 0.15), and then the abundance matrix is filled (Figure A10.1). Note that in this model recruitment is actually estimated back to 1970 in order to provide more realistic estimates of N in the first year of data (1982). Also, this allowed the incorporation of data (e.g., Maryland young-of-the-year index) back to 1970 which cannot done in the ADAPT model. All predicted values were calculated using the equations described above. A constant reporting rate of 0.43 and a constant phi of 1 were used for all harvest and released tag returns.

A10.2.4 Code Checking

As described in the SCA document, the SCA code was checked for accuracy by inputting catch and survey index data from a simulated population with known parameters and the model estimated the parameters exactly (see SCA document). The tag model code was checked using data provided in Jiang (2005) and Hoenig et al. (1998).

A10.3 RESULTS

A10.3.1 Initial Analyses

The initial model run was based on all current data, aforementioned model equations, initial starting values (Table A10.3), equal weighting of all components in the total log-likelihood, and the final model configuration of the SCA. Equal weighting of all components provided poor estimates of total catch at the beginning and end of the time series, but provided reasonably precise estimates of fully-recruited Fs (Figure A10.2). Fishing mortality on the tags (F') had moderate variances (Figure A10.2).

A10.3.2 Final Model Configuration

To improve the fit of total catch, the total catch lambda was increased to 50 (Figure A10.3). Comparisons of the equal and 50 weight for total catch suggested that the higher lambda weight had little effect on fishing mortality estimates post-1985 (Figure A10.4). Therefore, the remaining analyses were completed with total catch lambda weight=50. Resulting contributions to total likelihood are listed in Table A10.4. Estimates of fully-recruited fishing mortality, recruitment, parameters of the Gompertz functions for the four selectivity periods, catchability coefficients for all surveys, and parameters of the survey selectivity functions are given in Table A10.5 and are shown graphically in Figure A10.3. Graphs depicting the observed and predicted values, and residuals for the catch age composition, survey indices, survey compositions and tag return residuals are given in Appendix A16.

The model fit the observed total catch (Figure A10.3), catch age composition, and the YOY and age 1 indices reasonable well (Appendix A16). The model did less well at predicting MRFSS, CTTrawl, and NEFSC, aggregate indices, and the survey indices with age composition data (NYOHS, NJ Trawl, MDSSN and DESSN). The observed age composition for each survey (NYOHS, NJ Trawl, MDSSN and DESSN) was predicted with some accuracy (Appendix A16). The patterns in residuals of the harvest and catch/release observed and predicted tag recoveries varied depending on the tagging program. In general, the model under-estimated tag returns from the Hudson River, NYOHS, and New Jersey programs (positive residuals) and it over-estimated tag returns from Virginia, Massachusetts, and North Carolina (negative residuals), but results were mixed for Delaware and Maryland (Appendix A16).

A10.3.2.1 Fishing Mortality

The converged total likelihood was 77,162.7 and the fully-recruited fishing mortality in 2006 was 0.15 (Table A10.5). The 2006 average fishing mortality rate (F) for ages 8 through 11 equaled 0.14 and is below the current target (0.30) and threshold (0.41)(Table A10.6; Figure A10.5). Average fishing mortality on ages 3–8, which are generally targeted in producer areas, was 0.09 (Table A10.6; Figure A10.5). An average F weighted by N was calculated for comparison to tagging results since the tag releases and recaptures are weighted by abundance as part of the experimental design. The 2006 F weighted by N for ages 7–11 (age 7 to compare with tagged fish ≥28") was 0.14 (Table A10.6; Figure A10.5). An F weighted by N for ages 3–8, comparable to the direct enumeration estimate for Chesapeake Bay, was equal to 0.08 (Table A10.6; Figure A10.5). Among the individual age groups, the highest values of F in 2006 (0.14–0.15) were estimated for ages 9–12 (Table A10.7).

A10.3.2.2 Population Abundance (January 1)

Striped bass abundance (1+) increased steadily from 1982 through 2004 when it peaked around 131 million fish (Table A10.8; Figure A10.6). Total abundance declined to 115 million through 2006. The 2003 cohort remained strong at 38 million fish in 2006 and exceeded the size of the strong 1993 and 2001 year classes the same age (Table A10.8). Abundance of striped bass age 8+ increased steadily through 2004 and averaged around 11.9 million through 2006 (Table A10.8, Figure A10.6).

A10.3.2.3 Spawning Stock Biomass

Female spawning stock biomass (SSB) is higher than those produced by the SCA model because higher abundances were estimated in the SCATAG model. Female SSB grew steadily from 1982 through 2006 when it peaked at about 49 thousand metric tons (Table A10.9, Figure A10.7). The estimated SSB in 2006 remained above the threshold level of 14.6 metric tons and indicates the stock is not overfished.

A10.3.2.4 Retrospective Analysis

Only slight retrospective bias was evident in estimates of fully-recruited F and age 8+ abundance (Figure A10.8); therefore, the 2006 fishing mortality estimate may decrease slightly when another year of data in added in the future.

A10.3.2.5 Influence of Reporting Rate

The effects of varying reporting rate on estimates of fully-recruited fishing mortality above and below the assumed λ=0.43 were explored. Fishing mortality rates over the entire time series declined rapidly as reporting rate was increased from 0.23 to 0.73, particularly in the most recent years, indicating the results of the SCATAG model are highly dependent on the reporting rate (Figure A10.9).

A10.3.2.6 Tagging Program Influence

The influence that the tag return data from each program had on the estimation of fully-recruited fishing mortality was investigated by removing each dataset one-at-a-time and re-running the model. Changes in the time series of F estimates for 1982–2006 when each dataset was removed one-at-a-time were minor (Figure A10.10). No single tagging program had a major influence.

The effects of using tagging data from only coastal programs whose releases are believed to be subjected to the full coastwide fishing mortality was explored. Only minor changes in the time series of F estimates for 1982–2006 occurred when data from NYOHS, NJ, and NCCOOP programs were used (Figure A10.11).

A10.4 SOURCES OF UNCERTAINTY

The same sources of uncertainty discussed for the SCA model apply to the SCATAG model. The unique source of uncertainty that has a large impact on SCATAG results is the reporting rate. The current estimate of 0.43 is assumed constant across all years and is outdated; luckily, John Hoenig of VIMS is currently conducting a coastwide high reward tag return study which will provide a more up-to-date estimate. It is possible to estimate reporting rate in the model, but the estimate is not an independent one because it is very highly correlated with other parameters (natural mortality, some F deviations) in the model.

The model as implemented assumes that tagged fish 28 inches and greater are fully recruited to the fishery over time, but this may not have been entirely true during 1980s when large minimum size regulations were in place. A better model configuration would be the age-dependent model of Jiang et al. (2007), and when incorporated in SCA, common selectivity functions could be estimated for both the catch and tag data.

A10.5 FUTURE OF THE SCATAG MODEL

To date, the age-dependent tag return model of Jiang et al. (2007) has been incorporated into the SCATAG, but results can not be obtained because decisions have to be made on how to assign ages to tagged fish for which ages were not determined, what programs to use, and how to group data because sample sizes drop dramatically when two recapture matrices per age are produced. Although Jiang et al. (2007) assumes similar age selectivity patterns among harvest and released tag returns, selectivity functions can be estimated for each disposition separately by making slight changes to the code. These selectivity patterns can be linked to the catch data, but the proportions-at-age matrix and total catch will have to be split into harvest and dead releases matrices and it will take considerable work to do so.

A11.0 EVALUATE THE CURRENT BIOLOGICAL REFERENCE POINTS FOR ATLANTIC STRIPED BASS FROM AMENDMENT 6 AND DETERMINE STOCK STATUS BASED ON THOSE REFERENCE POINTS. (TOR #7)*

EDITOR'S NOTE: In this striped bass assessment report, the meaning of TOR 7 was clarified during the independent peer review. In addition to determining stock status, the purpose of TOR 7 was to review the methods used to determine the current biological reference points, and to get the reviewer's opinion on whether the BRPs were developed appropriately and whether those approached should be continued.

A11.1 HISTORY OF STRIPED BASS REFERENCE POINTS AND AGE AT FULL F

In the early 1990s, the status of Atlantic striped bass stocks was determined using annual tag based estimates of survival and the associated fishing mortality. Fishing mortalities that produced a sustainable population were estimated in simulation models developed by Rago and Dorazio, as well as Crecco, and described in the Amendment 4 source document (ASMFC 1990). Subsequent to Amendment 4, a relative index of spawning stock biomass was developed using a forward projecting model of age-0 recruits as determined by the time series of MD juvenile indices (ASMFC 1998). The SSB index served as the basis for developing a biomass threshold for evaluation of the stock rebuilding status. The SSB index increased to a level comparable to historic abundance in the 1960s and consequently, in 1995 striped bass was declared restored. The modeling approach used for the SSB index also served as the basis for the Crecco model for biological reference points, specifically F_{msy} (ASMFC 1998). The model applied a combination of minimum sizes (20" in producer areas and 28" on the coast) to define full recruitment to the fisheries. The biological reference point of $F_{msy} = 0.40$ was adopted in Amendment 5 and a target F of 0.31 was established with a subsequent addendum to the FMP. A lower target F of 0.28 for the producer areas was derived based on equivalent SSB/R when the jurisdictions requested a reduction in their minimum size limit from 20 to 18 inches. These values were compared against annual tag based estimates of F for determination of stock status.

In 1997, the ASMFC Technical Committee adopted the results of a VPA model as the method for determination of stock status. Average F was calculated for the ages at full recruitment with age at full F based on the distributions of ages in the catch. The fully recruited F was defined as ages 4–13. Comparisons were made to target F (and F_{msy}) which were products of the Crecco model.

In 2003, the ASMFC adopted Amendment 6 to the Striped Bass FMP. As part of the amendment, new biological reference points (SSB_{target}, $SSB_{threshold}$, F_{target}, and $F_{threshold}$) were established. F_{msy}, estimated using a Shepherd/Sissenwine model, was adopted as $F_{threshold}$. An exploitation rate of 24%, or F=0.30 was chosen as F_{target}. Target F for the producer area, Chesapeake Bay, was reduced proportionately to 0.27. $SSB_{threshold}$ (14,000 mt) was chosen to be slightly greater than the female spawning stock biomass in 1995 when the population was declared recovered. SSB_{target} (17,500 mt) was 25% greater than $SSB_{threshold.}$ No biomass targets were chosen specifically for Chesapeake Bay.

Striped bass present a particularly difficult species for estimating biological reference points because of the differences in fisheries among areas and sexes. Under current management, striped bass fisheries are managed under one suite of regulations along the coast and alternative regulations within Chesapeake Bay. The Bay fisheries are generally understood to be primarily male bass which mature younger (age 2) and have a shorter life-span than females. Coastal fisheries with larger size limits target primarily females which mature at ages 5–8 and have a potential life span of 30+ years. Reference points were developed as a compromise between maximizing yield on males and conserving spawning biomass in females.

A Thompson-Bell yield per recruit model was fitted with natural mortality equal to 0.15 and a maximum age of 25 (Figure A11.1). A maturity ogive was developed for combined sexes: age 2 - 25%, age 3 - 38%, age 4 - 52%, age 5 – 57%, age 6 – 73%, age 7 – 95% and ages 8 to 25 at 100% mature. Weight at age were averages from VPA input for years 1982–2000 up to age 13, and ages 14–25 from growth equations developed from fishery independent and dependent sources. The same weights at age were applied to catch and stock weights. Partial recruitment values in the YPR model came from the VPA output average for the period 1995–2000. Full recruitment occurred at age 9 and remained flat-topped through age 25. Age specific partial recruitments are presented in Figure A11.2. Sex ratios at age were assumed 50:50.

Annual spawning stock biomass (male and female maturity ogives applied to a 50:50 split of total biomass) and age one abundance for 1982–2000 were fitted to a Shepherd stock-recruitment model with parameter estimates: a = 0.53, b = 1.87, and k = 41,500 (Figure A11.3). The S/R parameters were used in conjunction with the YPR results (Sissenwine and Shepherd 1987) to estimate an F_{msy} = 0.41.

A11.2 CURRENT STOCK STATUS IN RELATIONSHIP TO REFERENCE POINTS.

The existing reference points for striped bass, as defined in Amendment 6 to the FMP (ASMFC 2003) are:

Female Spawning Stock Biomass Threshold ($SSB_{Threshold}$) = 14,000 mt
Female Spawning Stock Biomass Target (SSB_{Target}) = 17,500 mt
Fishing Mortality Rate Threshold (F_{MSY}) = 0.41
**The target fishing mortality rate for Chesapeake Bay is* F_{Target} *= 0.27.*

The assessment covers the entire stock of the Atlantic coast migratory striped bass. The EEZ is managed under Federal authority and is closed to fishing for striped bass whereas fisheries in state waters are managed under the authority of the ASMFC. Although the EEZ is managed separately, striped bass present in these waters are still considered part of the coastal migratory stock. The estimates of F and biomass obtained from the stock assessment are intended to represent the status of the entire stock of striped bass.

Estimates of fully recruited F in 2006 from the CEM (F for fish ≥ 28 inches = 0.16) and the SCA model ($F_{age\ 8\text{-}11}$ = 0.31) are both below the Amendment 6 threshold (Tables A7.7 and A8.11). Therefore, overfishing is not occurring on the coastal migratory stocks of Atlantic striped bass.

Time series F estimates from the CEM and SCA model (as well as the IRCS, SCATAG and other supporting models) show similar trends through 2002 (Figure A11.4). After this point, the F estimates from SCA (and the supporting ASAP and ADAPT models) continued to increase while trends from the other models and methods were flat or declining. Only the terminal estimate of F from the SCA model (and the supporting ADAPT model) exceed the target F of 0.30. However, retrospective bias was evident in estimates of fully-recruited F from SCA (Figure A7.12). The pattern suggests that the 2006 F estimate is likely over-estimated and could decrease with the addition of future years' data. For example, the 2002 estimate of fully recruited F from the SCA base model run is 23% lower than the estimate from a run with 2002 as the terminal year. Similar retrospective trends have been observed in the previous assessment of striped bass using the ADAPT VPA (ASMFC 2005) and in the supporting ASAP and ADAPT models presented in the current assessment. However, experiences from other assessments indicate that it is possible for the magnitude and direction of the retrospective pattern to change in subsequent assessments.

A lower target F of 0.27 is used to assess the striped bass fishery on resident fish in Chesapeake Bay because of the 18 inch minimum size limit that is below the 20 inch standard in Amendment 6 for producer areas. F estimates from the CEM (as well as the IRCS model) are continuously below F_{Target} throughout the time series (Figure A9.15).

Estimates of female SSB from the SCA model show a steady increase through 2003 before declining somewhat to the 2006 estimate of 25,000 mt (Table A7.10). The 2006 estimate is above both the $SSB_{Threshold}$ and SSB_{Target} and therefore striped bass are not overfished. Retrospective bias was evident in estimates of SSB from SCA (Figure A7.12). This pattern suggests that the 2006 SSB estimate is likely under-estimated and could increase with the addition of future years of data. For example, the 2002 estimate of SSB from the SCA base model run is 33% higher than the estimate from a run with 2002 as the terminal year. Similar retrospective trends have been observed in the supporting ADAPT model presented in the current assessment and in previous assessments of striped bass using the ADAPT VPA (ASMFC 2005). However, experiences from other assessments indicate that it is possible for the magnitude and direction of the retrospective pattern to change in subsequent assessments.

Trends in SSB from the SCA, ADAPT, and SCATAG models show an increasing trend through 2002 or 2003 (Figures A7.11 & A10.7; Appendix 8). After this point, the SCATAG SSB continues to increase through 2006 while SCA and ADAPT show a modest decline.

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A13.0 REFERENCES

Akaike H. 1973. Information theory as an extension of the maximum likelihood principle. In: Petrov BN, Csaki F, editors. 2nd International Symposium on Information Theory. Budapest: Akademiai Kiado; p 267–281.

Anderson DR, Burnham KP, White GC. 1994. AIC model selection in overdispersed capture-recapture data. Ecology 75:1780–1793.

Atlantic States Marine Fisheries Commission (ASMFC). 1987. Interstate Fisheries Management Plan for the Striped Bass of the Atlantic Coast from Maine to North Carolina. Washington (DC): ASMFC Fish Manage Rep. #1.

ASMFC. 1990. Source document for the supplement to the Striped Bass FMP - Amendment #4. Washington (DC): ASMFC Fish Manage Rep No.16; 244 p.

ASMFC. 1996. Report of the Juvenile Abundance Indices Workshop. Washington (DC): ASMFC Spec Rep No.48; 83 p.

ASMFC. 1998. Amendment #5 to the Interstate Fishery Management Plan for Atlantic Striped Bass. Washington (DC): ASMFC Fish Manage Rep No. 24; 31 p.

ASMFC. 2003. Amendment #6 to the Interstate Fishery Management Plan for Atlantic Striped Bass. Washington (DC): ASMFC Fish Manage Rep No. 41; 63 p.

ASMFC 2003b. 2003 stock assessment report for Atlantic striped bass: catch-at-age based VPA & tag release/recovery based survival estimation. ASMFC Rep. SBTC-2003-3; 85 p.

ASMFC. 2004. Summary of the USFWS Cooperative Tagging Program Results. Washington (DC): ASMFC. Report by Striped Bass Tag WG to Striped Bass Techn Comm; 27 p.

ASMFC. 2005. 2005 stock assessment report for Atlantic striped bass: catch-at-age based VPA & tag release/recovery based survival estimation. Washington (DC): ASMFC. Report by Striped Bass Techn Comm for Atlantic Striped Bass Management Board; 131 p.

Bain MB, Bain JL. 1982. Habitat suitability index models: coastal stocks of striped bass. Washington (DC): USFWS, Div Biol Serv, Rep. FWS/OBS-82/10.1; 29 p.

Bigelow HB, Schroeder WC. 1953. Fishes of the Gulf of Maine. US Fish and Wildl Serv Fish Bull 74(53):1-577.
Brodziak JKT. 2002. An age-structured assessment model for Georges Bank winter flounder. Woods Hole (MA): NEFSC Ref Doc 02-03; 54 p.
Brownie C, Anderson DR, Burnham KP, Robson DR. 1985. Statistical inference from band recovery - a handbook. 2nd ed. Washington (DC): USFWS Res Publ No. 156; 305 p.
Burnham KP, Anderson DR. 1992. Data-based selection of an appropriate biological model: the key to modern data analysis. In: McCullogh DR, Barrett RH, eds. Wildlife 2001: Populations. London (UK): Elsevier Science Publications; p 16–30.
Burnham KP, Anderson DR. 2002. Model selection and multi-model inference: a practical information-theoretic approach. 2nd ed. New York (NY): Springer-Verlag; 488 p.
Burnham KP, Anderson DR. 2003. Model selection and multi-model inference: a practical information-theoretical approach. 3rd ed. New York (NY): Springer-Verlag; 496 p.
Buckland ST, Burnham KP, Augustin NH. 1997. Model selection: an integral part of inference. Biometrics 53:603–618.
Buckel JA, Fogarty MJ, Conover DO. 1999. Mutual prey of fish and humans: a comparison of biomass consumed by bluefish, *Pomatomus saltatrix*, with that harvested by fisheries. Fish Bull 97: 776–785.
Clark JH, Kahn DM. [in revision.] Amount and disposition of striped bass discarded in Delaware's spring striped bass gill net fishery during 2001 through 2003: effects of regulations and fishing strategies. Submitted to N Amer J Fish Manage.
Clark JR. 1968. Seasonal movements of striped bass contingents of Long Island Sound and the New York Bight. Trans Am Fish Soc. 97:320–343.
Crecco V. 2003. Method of estimating fishing (F) and natural (M) mortality rates from total mortality (Z) and exploitation (u) rates for striped bass. Old Lyme (CT): A Report to the ASMFC Striped Bass Technical Committee. 40 p.
Crecco V. 2004. Further analyses on the 2003 fishing mortality (F) on striped bass based on landings and effort data from Connecticut. Old Lyme (CT): A Report to the ASMFC Striped Bass Technical Committee; 23 p.
Deriso RB, Maunder MN, Skalski JR. 2007. Variance estimation in integrated assessment models and its importance for hypothesis test. Can J Fish Aquat Sci 64:187–197.
Diodati PJ, Richards AR. 1996. Mortality of striped bass hooked and released in salt water. Trans Amer Fish Soc. 125:300–307.
Dorazio RM, Hattala KA, McCollough CB, Skjeveland JE. 1994. Tag recovery estimates of migration of striped bass from spawning areas of the Chesapeake Bay. Trans Am Fish Soc 123(6):950–963.
Dunning DJ, Ross QE, Waldman JR, Mattson MT. 1987. Tag retention by, and tagging mortality of, Hudson River striped bass. N Am J Fish Manage. 7:535–538.
Fabrizio MC. 1987. Contribution of Chesapeake Bay and Hudson River stocks of striped bass to Rhode Island coastal waters as estimated by isoelectric focusing of eye lens protein. Trans Am Fish Soc 116:588–593.
Goodyear CP, Cohen JE, Christensen S. 1985. Maryland striped bass: recruitment declining below replacement. Trans Am Fish Soc 114:146–151.
Goshorn C, Smith D, Rodgers B, Warner L. 1998. Estimates of the 1996 striped bass rate of fishing mortality in Chesapeake Bay. Annapolis (MD) and Kearneysville (WV): Maryland Dep Nat Res. A report to the ASMFC Striped Bass Technical Committee; 31 p.

Grant GC. 1974. The Age Composition of Striped Bass Catches in Virginia Rivers, 1967–1971, and a Description of the Fishery. Fish Bull 72(1):193–199.

Hartman K, Brandt S. 1995a. Trophic resource partitioning, diets, and growth of sympatric estuarine predators. Trans Am Fish Soc. 124: 520–537

Hartman K, Brandt S. 1995b. Predatory demand and impact of striped bass, bluefish, and weakfish in the Chesapeake Bay: applications of bioenergetics models. Can J Fish Aquat Sci. 52: 1667–1687.

Helser TE, Geaghan JP, Condrey RE. 1998. Estimating gillnet selectivity using nonlinear response surface regression. Can J Fish Aquat Sci. 55:1328–1337.

Hill J, Evans JW, Van Den Avyle MJ. 1989. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (South Atlantic) – striped bass. Washington (DC), Vicksburg (MS): USFWS Div Biol Serv Biol Rep. 82(11.118), US Army Corps Engineers Waterways Exp Sta Coastal Ecol Group TR EL-82-4. 35 p.

Hilborn R, Walters CJ. 1992. Quantitative Fisheries Stock Assessment: Choice, Dynamics, and Uncertainty. New York (NY): Chapman and Hall, Inc. 570 p.

Hoenig JM, Barrowman NJ, Hearn WS, Pollock KH. 1998. Multiyear tagging studies incorporating fishing effort data. Can J Fish Aquat Sci. 55:1466–1476.

Hoenig JM, Hepworth D, Latour R, Sadler P. 2004. Fishing mortality in the Chesapeake. Gloucester Point (VA): Virginia Institute of Marine Science. A report to the ASMFC Striped Bass Technical Committee; 18 p.

Holland Jr BF, Yelverton GF. 1973. Distribution and biological studies of anadromous fishes offshore North Carolina. Morehead City (NC): NCDMF Div Commer Sportfish. NC Dep Nat Econ Resour Spec Sci Rep 24. 132p.

Hornick HT, Rodgers BA, Harris RE, Zhou JA. 2000. Estimate of the 1999 Striped Bass Rate of Fishing Mortality in Chesapeake Bay. Annapolis (MD), Gloucester Point (VA): MD MDR, VMRC; 11 p.

Jackson HW, Tiller RE. 1952. Preliminary observations on spawning potential in the striped bass. Solomons (MD): Chesapeake Bay Laboratory. CBL Pub No. 93; 16 p.

Jiang H. 2005. Age-dependent tag return models for estimating fishing mortality, natural mortality and selectivity [dissertation]. Raleigh (NC): NC State Univ.; 124 p.

Jiang H, Pollock KH, Brownie C, Hoenig JM, Latour RJ, Wells BK, Hightower JE. 2007. Tag return models allowing for harvest and catch and release: evidence of environmental and management impacts on striped bass fishing and natural mortality rates. N Amer J Fish Manage 27:387–396.

Kahn DM, Crecco V. 2006. Tag recapture data from Chesapeake Bay striped bass indicate that natural mortality has increased. In: Ottinger CA, Jacobs JM, editors. USGS/NOAA Workshop on Mycobacteriosis in Striped Bass, May 7–10, 2006, Annapolis, Maryland. Reston (VA): USGS. p 25–26.

Kahn DM, Miller RW, Shirey CA,Grabowski S. 1998. Restoration of the Delaware River Spawning Stock of Striped Bass. Dover (DE): Delaware Division of Fish and Wildlife.

Kahn DM, Shirey CA. 2000. Estimation of Reporting Rate for the USFWS Cooperative Striped Bass Tagging Program for 1999. Dover (DE): Division of Fish and Wildlife. A Report to the ASMFC Technical Committee; 5 p.

Kohlenstein LC. 1980. Aspects of the population dynamics of striped bass spawning in Maryland tributaries of the Chesapeake Bay [dissertation]. Laurel (MD): Johns Hopkins Univ; 143 p.

Lo NC, Jacobson LD, Squire JL. 1992. Indices of relative abundance from fish spotter data based on the delta-lognormal models. Can J Fish Aquat Sci 49:2525–2526.

McAllister MK, Ianelli JN. 1997. Bayesian stock assessment using catch-age and the sampling-importance resampling algorithm. Can J Fish Aquat Sci 54: 284–300.

McCullagh P, Nelder JA. 1989. Generalized linear models. London (UK): Chapman and Hall; 511 p.

Merriman D. 1941. Studies on the striped bass *Roccus saxatilis* of the Atlantic coast. USFWS Fish Bull 50(35):1–77.

Morris JA Jr, Rulifson RA, Toburen LH. 2003. Genetics, demographics, and life history strategies of striped bass, *Morone saxatilis*, inferred from otolith microchemistry. Fish Res. 62:53–63.

Musick JA, Murdy EO, Birdsong RS. 1997. Striped Bass. In: Fishes of Chesapeake Bay. Washington (DC): Smithsonian Institution Press; p 218–220.

Nelson GA, Chase BC, Stockwell J. 2003. Food habits of striped bass (*Morone saxatilis*) in coastal waters of Massachusetts. J Northw Atl Fish Sci. 32:1–25.

Nelson G. 2007. A forward-projecting Statistical Catch-at-Age model for striped bass. Gloucester (MA): MA Division of Marine Fisheries. A Report to the Striped Bass Stock Assessment Subcommittee; 45 p.

Nichols JD, Blohm RJ, Reynolds RE, Trost RE, Hines JE, Bladen JP. 1991. Band reporting rates for mallards with reward bands of different dollar values. J Wildlife Manage. 55:119–126.

Nichols PR, Miller RV. 1967. Seasonal movements of striped bass tagged and released in the Potomac River, Maryland, 1959–1961. Chesapeake Sci 8:102–124.

Nicholson WR. 1964. Growth compensation in four year classes of striped bass from Albemarle Sound, NC. Chesapeake Sci 5:145–149.

Northeast Fisheries Science Center (NEFSC). 1998. 26th Northeast Regional Stock Assessment Workshop (26th SAW): SARC Consensus Summary of Assessments. Northeast Fish Sci Cent Ref Doc. 98-03; 283 p.

Old Dominion University Center for Quantitative Fisheries Ecology (ODU CQFE). Striped Bass, *Morone Saxatilis* [Internet]. 2006 [cited 2007 June 6]. Available from: http://www.odu.edu/sci/cqfe/

Ottinger CA. 2006. Mycobacterial infections in striped bass (*Morone saxatilis*) from upper and lower Chesapeake Bay: 2002 and 2003 pound net studies. In: Ottinger CA, Jacobs JM, editors. USGS/NOAA Workshop on Mycobacteriosis in Striped Bass, May 7–10, 2006, Annapolis, Maryland. Reston (VA): USGS; p. 15–16.

Panek FM, Bobo T. 2006. Striped bass mycobacteriosis: a zoonotic disease of concern in Chesapeake Bay. In: Ottinger CA, Jacobs JM, editors. USGS/NOAA Workshop on Mycobacteriosis in Striped Bass, May 7–10, 2006, Annapolis, Maryland. Reston (VA): USGS; p 9–10.

Parma A. 2002. Bayesian approaches to the analysis of uncertainty in the stock assessment of Pacific halibut. Am Fish Soc Symp. 27:113–136.

Pennington M, Burmeister L, Hjellvik V. 2002. Assessing the precision of frequency distributions estimated from trawl-survey samples. Fish Bull 100: 74–80.

Pennington M, Volstad JH. 1994. Assessing the effect of intra-haul correlation and variable density on estimates of population characteristics from marine surveys. Biometrics 50:725–732.

Pieper L. 2006. Striped bass disease overview for the past ten year plus. In: Ottinger CA, Jacobs JM, editors. USGS/NOAA Workshop on Mycobacteriosis in Striped Bass, May 7–10, 2006, Annapolis, Maryland. Reston (VA): USGS; p. 10–11.

Pollock KH, Hoenig JM, Jones CM. 1991. Estimation of fishing and natural mortality when a tagging study is combined with a creel survey or port sampling. Am Fish Soc Symp 12:423–434.

Raney EC. 1952. The life history of the striped bass, *Roccus saxatilis* (Walbaum). Bull Bingham Oceanogr Collect 14(1):5–97.

Reynolds JB. 1983. Electrofishing. In: Nielsen LA, Johnson DL, editors. Fisheries Techniques. Bethesda (MD): Am Fish Soc.; 147–163.

Richards RA, Rago PJ. 1999. A Case History of Effective Fishery Management: Chesapeake Bay Striped Bass. N Am J Fish Manage 19(2): 356–375.

Ricker WE. 1975. Computation and interpretation of biological statistics of fish populations. Can J Fish Aquat Sci Bull 191: 382 p.

Rugolo LJ, Crecco VA, Gibson MR. 1994. Modeling stock status and the effectiveness of alternative management strategies for Atlantic coast striped bass. Washington (DC): ASMFC. A Report to the ASMFC Striped Bass Management Board. 30 p.

Rugolo LJ, Jones PW. 1989. A recruitment based interseason harvest control model for Chesapeake Bay striped bass. Annapolis (MD): Maryland Department of Natural Resources. A Report to the ASMFC Striped Bass Technical Committee. 51 p.

Rugolo LJ, Lange AM. 1993. Estimation of exploitation rate and population abundance for the 1993 striped bass stock. Annapolis (MD): Maryland Department of Natural Resources. A Report to the ASMFC Striped Bass Technical Committee. 38 p.

Scofield EC. 1931. The striped bass of California (*Roccus lineatus*). Sacramento (CA): Calif Dept Fish and Game. Fish Bull 29. 84 p.

Searle SR, Speed FM, Milliken GA. 1980. Population marginal means in the linear model: an alternative to least-squares means. Am Stat 34: 216–221.

Secor DH. 2000. Longevity and resilience of Chesapeake Bay striped bass. ICES J Mar Sci.: J Cons. 57(4): 808–815.

Setzler-Hamilton E, Boynton WR, Wood KV, Zion HH, Lubbers L, Mountford NK, Frere P, Tucker L, Mihursky JA. 1980. Synopsis of Biological Data on Striped Bass, *Morone saxatilis* (Walbaum). Washington (DC): NOAA Nat Mar Fish Serv. FAO Synopsis No. 121; 74 p.

Shepherd G. Striped bass (*Morone saxatilis*). Status of fishery resources off the Northeastern United States [Internet]. 2007 [cited 2007 Jun 6]. Available from: http://www.nefsc.noaa.gov/sos/spsyn/af/sbass/

Sinclair AF. 1998. Estimating trends in fishing mortality at age and length directly from research survey and commercial catch data. Can J Fish Aquat Sci 55:1248–1263.

Sissenwine MP, Bowman E. 1978. An analysis of some factors affecting the catchability of fish by bottom trawls. ICNAF Res Bull 13:81–87.

Sissenwine MP, Shepherd JG. 1987. An alternative perspective on recruitment overfishing and biological reference points. Can J Fish Aquat Sci. 44:913–918.

Smith DR, Burnham KP, Kahn DM, He X, Goshorn CJ, Hattala KA, Kahnle AW. 2000. Bias in survival estimates from tag recovery models where catch-and-release is common, with an example from Atlantic striped bass (*Morone saxatilis*). Can J Fish Aquat Sci 57:886–897.

Smith LD. 1970. Life history studies of striped bass. Brunswick (GA): GA Dept Nat Res Fish Sec. Final Report AFS-2; 134 p.

Smith WG, Wells A. 1977. Biological and fisheries data on striped bass, *Morone saxatilis*. Highlands (NJ): NOAA Northeast Fisheries Science Center. Sandy Hook Lab Tech Ser Rep No. 4; 42 p.

Sprankle K, Boreman J, Hestbeck JB. 1996. Loss rates for dorsal loop and internal anchor tags applied to striped bass. N Am J Fish Manage 16:461–464.

Terceiro M. 2003. The statistical properties of recreational catch rate data for some fish stocks off the northeast US coast. Fish Bull 101:653–672.

Thompson GG. 1994. Confounding of gear selectivity and natural mortality rates in cases where the former is a nonmonotone function of age. Can J Fish Aquat Sci 51:2654–2664.

Tiller RE. 1942. Indications of Compensatory Growth in the Striped Bass *Roccus saxatilis*, Walbaum, as Revealed by a Study of the Scales. Solomon Island (MD): Chesapeake Biological Laboratory. CBL Pub No. 57; 16 p.

Trent L, Hassler WH. 1966. Feeding behavior of adult striped bass in relation to stages of sexual maturity. Chesapeake Sci 7:189–192.

Tresselt EF. 1952. Spawning Grounds of the Striped Bass or Rock, *Roccus Saxatililis* (Walbaum), in Virginia. Bull Bingham Ocean Coll 14(1):98–110.

Vogelbein WK, Hoenig JM, Gauthier DT. 2006. Epizootic mycobacteriosis in Chesapeake Bay striped bass: What is the fate of infected fish? In: Ottinger CA, Jacobs JM, editors. USGS/NOAA Workshop on Mycobacteriosis in Striped Bass, May 7–10, 2006, Annapolis, Maryland. Reston (VA): USGS; p 26–27.

Welsh SA. 2004. Overestimation of tag-based fishing mortality rates by linear trend models: examples from simulated and real data. Morgantown (WV): USGS West Virginia University. Report submitted to the ASMFC Striped Bass Tagging Subcommittee; 28 p.

Welsh SA., Smith DR, Laney RW, Tipton RC. 2007. Tag-based estimates of annual fishing mortality of a mixed Atlantic coastal stock of striped bass. Tran Am Fish Soc 136:34–42.

White GC, Burnham KP. 1999. Program MARK - survival estimation from populations of marked animals. Bird Study 46:120–138.

Zlokovitz ER, Secor DH, Piccoli PM. 2003. Patterns of migration in Hudson River striped bass as determined by otolith microchemistry. Fish Res. 63:245–259.