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A Chronicle of Striped Bass Population Restoration and Conservation in the Northwest Atlantic, 1979-2016

US DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
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Northeast Fisheries Science Center
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A Chronicle of Striped Bass Population Restoration and Conservation in the Northwest Atlantic, 1979-2016

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INTRODUCTION

Striped Bass (*Morone saxatilis*) in the northeastern United States have long held a position of near reverence among both fishermen and culinary enthusiasts alike, beginning with the arrival of the pilgrims to the New World. The fish were abundant, and their anadromous behavior made them easily available to fishermen. In 1634 colonist William Wood (Wood [1634] 1994) described catching striped bass with hook and line with lobster for bait, then subduing the caught fish with a “knock on the head with a stick.” The value of striped bass became evident in the 1600s as laws were established to prevent the waste of the prized fish for use as fertilizer, and several years later a tax was imposed by the Plymouth Colony on the sale of striped bass, which created funds for the first public school.

Populations of striped bass along the coast have experienced several periods of high and low abundances over the years since the colonists took their first management action. Comments at public meetings held by the US Fish Commission in 1871 (Baird 1873) suggested that striped bass numbers were “greatly diminished.” Fishermen observations as reported in scientific documents implied low abundance until a large year class appeared in the Chesapeake Bay in 1934. Subsequent recruitment events helped sustain the coastal fishery until the 1970s when a decline in abundance got the attention of the public, scientists, fishery managers, and ultimately state and federal legislators. Scientific papers and stories in the popular press regarding the striped bass stock recovery have been written, but details of the analytical basis for decisions have not been well documented. The compilation of papers in this Technical Memorandum describes the quantitative work by some of the scientists involved over the past 45 years with the restoration and conservation of striped bass.

SECTION I
THE ORIGIN AND EARLY ACCOMPLISHMENTS OF THE EMERGENCY STRIPED BASS STUDY: 1979-1984

John Boreman and C. Phillip Goodyear

Abstract

The fishery for striped bass (*Morone saxatilis*) along the Atlantic Coast from Maine to North Carolina collapsed during the late 1970s, a condition which stimulated congressional legislation to establish an Emergency Striped Bass Study (ESBS) in 1979 to assess the economic value of the fishery, investigate the cause or causes for the fishery collapse, and recommend management actions that should be taken to restore the fishery. In 1980, the net value of commercial and recreational harvest of striped bass along the Atlantic coast was US$11.5 million, and the value of fishing trips taken by recreational anglers seeking striped bass was $200 million. Initial research into causes for the collapse of the fishery focused on contaminants and other environmental and human-induced factors affecting first-year survival of striped bass, including overfishing. Early into the ESBS, it became readily apparent that a significant reduction in fishing mortality was necessary to rebuild the coastal fishery for striped bass, even if overfishing was not the primary cause for the fishery collapse. In response to scientific advice generated by the ESBS, state and federal fishery managers instituted a 55% reduction in the fishing mortality rate across all states beginning in 1984. Subsequent analysis of tag returns indicated that the actual reduction imposed by the states was over 70%, and the coastal fishery for striped bass was declared rebuilt in 1995.

Introduction

Saltwater anglers fishing along the northeast coast of the United States during the 1970s witnessed the then-highest recorded catch of striped bass (*Morone saxatilis*) followed by a precipitous decline. The phenomenon was attributed to the occurrence at that time of the largest year class of striped bass on record from the Chesapeake Bay in 1970, which appeared in the coastal fishery in the mid-1970s but had almost disappeared from the fishery by 1979 (ASMFC 1981). During the remainder of the decade only 1 average-sized year class was produced in Chesapeake waters (in 1978); young-of-the-year indices of abundance in the other years were below average. Blame for the apparent collapse of the Atlantic coastal fisheries for striped bass was spread among many environmental and human-induced factors.

The Anadromous Fish Conservation Act (1965) was amended in 1979 to add provisions for an Emergency Striped Bass Study (ESBS). The purpose of the ESBS was to ascertain the current status of the coastal migratory stocks of striped bass along the Atlantic Coast, the economic value of the fishery for those stocks, and the cause (or causes) for the collapse of the fishery. The National Marine Fisheries Service (NMFS) was directed to assess the status of the coastal migratory stocks, the US Fish and Wildlife Service (USFWS) was charged with determining the cause(s) for the decline in abundance of the stocks[1], and the National Oceanic and Atmospheric Administration's (NOAA's) Sea Grant Program was assigned the task of determining the economic significance of the fisheries that depend on those stocks. A single planning and coordinating committee, consisting of federal agency leaders from NMFS, USFWS, and the Environmental Protection Agency (EPA), as well as state and citizen advisory group representatives, oversaw execution of the ESBS.

This paper describes the situation we faced, as the first comanagers of the ESBS[1], and the approach that was taken to understand the reasons for the collapse of the coast-wide fishery for striped bass. The focus of our paper is the basis for scientific advice we provided to Congress, fishery managers, and the public in general in the early 1980s to support rebuilding of the coastal stocks. We cover the range in years that began with inception of the ESBS in 1979 through implementation of the interjurisdictional fishery management plan in 1984, a plan that started the stocks on their rebuilding trajectories.

Economic Value of the Coastal Fishery

The ESBS legislation assigned responsibility for valuation of the commercial and recreational fisheries for striped bass along the Atlantic Coast to the Sea Grant Program of the National Oceanic and Atmospheric Administration (NOAA). Fisheries economists at the University of Maryland, Cornell University, North Carolina State University, and the University of Connecticut contributed to the valuation study, which culminated in a publication by the University of Maryland Sea Grant Program (Norton et al. 1983). By using 1980 as a representative year, the investigators concluded that the net value of striped bass caught along the Atlantic Coast was US$11.5 million — $3.5 million for the commercial harvest and $8 million for the recreational harvest. Extrapolating from the net value of the recreational harvest, the value of fishing trips for striped bass in 1980 was close to $200 million.

Since the commercial and recreational harvest of striped bass had declined significantly by 1980, the value of the coastal fishery must have been considerably higher earlier in the decade. To show the economic benefits for a record harvest year, Norton et al. (1983) examined statistics obtained from the Baltimore striped bass market in 1974 and found that they were 25 times higher than the benefits in 1980. The estimate of $6.4 million in 1974 for the Baltimore market represented 50% of the commercial and recreational benefits estimated for the entire Atlantic Coast fishery for striped bass in 1980.

Status of the Coastal Migratory Stocks in 1979

Between 1958 and 1979, reported commercial landings of striped bass along the Atlantic Coast rose steadily to a record level in 1973 (Figure 1). Landings declined sharply thereafter and by 1979 (the year that the ESBS was authorized by Congress) reported commercial landings had declined to less than 25% of the record 1973 level. Estimated recreational harvest during that time period is more difficult to track since it was based on the National Survey of Fishing, Hunting, and Wildlife-Associated Recreation conducted at 5-year intervals by the US Census Bureau for the US Fish and Wildlife Service, but it appeared to follow a trend similar to the reported commercial landings (Boreman and Austin 1985; Table 1). The NOAA Fisheries

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[1] Boreman was comanager on behalf of the National Marine Fisheries Service and Goodyear was comanager on behalf of the US Fish and Wildlife Service.

Service’s annual Marine Recreational Fisheries Statistics Survey (MRFSS) was not instituted until 1979.

The decline in reported landings since 1973 may be attributed, at least in part, to changes in fishing regulations that added harvest restrictions. The Hudson River fishery for striped bass was closed in 1976 because of excessive levels of polychlorinated biphenyls (PCBs) in samples of striped bass tissue taken from the river, and the James River fishery was closed in 1976 because of kepone contamination. However, the effects of these closures on total harvest in the coastal fishery for striped bass was probably small, because the fisheries in the Hudson and James Rivers historically had been a minor portion of the total landings for New York and Virginia, respectively (Boreman and Austin 1985).

Historically, the fisheries for striped bass in Chesapeake Bay and along the northeast Atlantic Coast were supported primarily by production of young in the tributaries within the bay (Koo 1970). The increasing trend in reported commercial landings from 1958 to 1973 was attributed to a series of dominant year classes of striped bass produced in Chesapeake Bay. In 1957, the State of Maryland initiated an annual beach seine survey in its major tributaries of the Chesapeake Bay (Potomac, Choptank, and Nanticoke Rivers, and the upper Bay region) that tracked abundance of young-of-the-year striped bass. By the time the ESBS was instituted in 1979, the abundance index for young-of-the-year based on the survey suggested dominant year classes of striped bass occurred in 1958, 1961, 1964, 1966, and 1970, with 1970 having the highest index in the time series (Figure 2). From 1971 to 1979, no dominant year classes were detected in Maryland waters of the Chesapeake Bay. Goodyear et al. (1985) concluded that continuing declines in first-year survival, adult survival, or both, as suggested by the Maryland survey index, would eliminate the Maryland striped bass stock and the fishery it supports.

Reasons for the Stock Declines

A number of environmental and human-induced factors were blamed for the collapse of the coastal migratory stock of striped bass including overfishing, chemical pollution in spawning and nursery areas, eutrophication of the Chesapeake Bay, acid precipitation, widening and deepening of the Chesapeake and Delaware Canal, which began in the 1960s and was completed in the mid-1970s, and loss of submerged aquatic vegetation caused by Tropical Storm Agnes, which moved up Chesapeake Bay in 1973. Since it was not possible to examine all possible causes for the decline in striped bass production, priority for the ESBS research program was given to the most plausible factors: reduction in survival of striped bass eggs and larvae from contamination, reduction in survival of age 0 striped bass from factors other than contamination, and overfishing (USDOI and USDOC 1980). All 3 factors were given equal weight in setting the research agenda for the ESBS.

For contaminant-related research, the first step was to conduct a thorough literature search to determine current knowledge in conjunction with a survey of human activities and a broad screening of toxic substances in the habitats that serve as nurseries for striped bass eggs and larvae. Protocols were established for testing susceptibility of eggs and larvae to contaminants known to exist in their nurseries and for comparing findings among laboratories and between laboratory and field observations. For examination of factors other than contaminants that may be have been affecting first-year survival of striped bass, intensive egg and larval abundance surveys were conducted on a limited number of stocks aimed at relating environmental factors to abundance, including zooplankton densities and abiotic factors such as freshwater inflow, dissolved oxygen, and pH. Eggs, larvae, and juveniles were also examined for the presence of infectious disease and genetic anomalies, and analyses were conducted to correlate the occurrence of these anomalies with potential biotic and abiotic stressors. Predators on young-of-the-year striped bass were also identified.

To assess the possible impacts of fishing on the production of striped bass stocks, landings data were assimilated, along with related biological characteristics of the catch when possible (age, sex, and size). A series of coordinated juvenile abundance surveys were also initiated to complement the surveys that were currently ongoing in the Maryland and Virginia tributaries of Chesapeake Bay. Finally, a stock assessment was undertaken, combining information obtained from the published literature on striped bass biology with information collected from the commercial and recreational landings, juvenile surveys, and historical tagging studies. We used the stock assessment to examine the potential influence of fishing mortality on stock production and to evaluate the trade-off between fishing mortality and mortality induced by other factors, both natural and human-induced. The stock assessment formed the basis for advice we provided to managers for rebuilding the coastal migratory stocks and reporting back to US Congress on the reasons for the fishery collapse. The assessment also gave us a means for prioritizing future research and data collection efforts.

Stock Assessment Method

In the 1970s there was considerable skepticism that reductions in the size of the adult striped bass stock or juvenile survival would have any real influence on subsequent recruitment. The assumption was that changes in stock size would bring about compensatory increases in survival- or fecundity-at-age (see McFadden 1977). The issue of compensation was a major element in the debate over the importance of power-plant-induced mortality of striped bass during the Hudson River power case (see Barnthouse et al. 1988). It was argued that the impact of power plant operations on the Hudson River was having little influence on population size or stability in future generations of striped bass. This debate spurred research into the nature of the compensatory response and ways to quantify the effects of alternative sources of mortality on populations. Goodyear (1977, 1980) developed an index (the compensation ratio, CR) of the degree of the overall change in survival and fecundity that must occur for a population undergoing exploitation to stabilize at a new equilibrium:

$$CR = \frac{P_{unfished}}{P_{fished}} \qquad (1)$$

where $P_{unfished}$ = potential recruit fecundity in the absence of fishing mortality; and P_{fished} = potential recruit fecundity in the exploited stock. Potential recruit fecundity (P) is the number of eggs that could be produced by an average recruit in the absence of density dependence. It carries the designation "potential" to highlight the notion that it includes both the actual average lifetime production of eggs per recruit at equilibrium population densities plus those eggs that would have been produced by an average recruit in the absence of any density-dependent suppression of maturity- or fecundity-at-age or of survival in post-recruit ages:

$$P = \sum_{i=1}^{n} X_i L_i \prod_{j=0}^{i-1} S_j \qquad (2)$$

where S_j = density-independent annual survival probabilities of females of age i while they are at age j; X_i = maximum mean fecundity of mature females at age i; L_i = maximum fraction of age i females that are mature; and n = number of ages in the unfished population. Goodyear (1977) noted that in depleted, heavily-exploited stocks, the fecundity, maturity, and survival parameters may be at or near the maxima permitted by density-independent limitations on population growth. In such circumstances, the values for the parameters needed to estimate P may be well represented by the current values in the existing population. Such was certainly the case for striped bass at the beginning of the ESBS in the early 1980s. Given this assumption, the compensatory issues may be ignored, and current estimates of fecundity, maturity, and natural mortality may be used to estimate P. This assumption also means that a linear relationship exists between population fecundity and mean recruitment for any given exploitation pattern, which allows for predicting future short-term population trends based on changes in exploitation, as well as for partitioning the exploitation among contributing agents, including nonfishing sources. The relationship represented in Equation (2) was the basis for a number of subsequent ESBS analyses of the effects of fishing and other sources of mortality on striped bass (e.g., Goodyear 1985b).

The reciprocal of *CR*, termed the spawning potential ratio (*SPR*), has been widely applied in the management of many other species (Goodyear 1993). The acronym, *SPR*, has also been used in another context to refer to spawner-per-recruit methods used to estimate biological reference points related to fishing mortality (e.g., Mace and Sissenwine 1993), but the data requirements and objectives of the 2 methods differ. We also applied *P*-ratios to develop methods for establishing and evaluating management alternatives in the context of equilibrium and also nonequilibrium assumptions where the *P*-values were weighted by observed or predicted recruitments. These collectively became known as eggs-per-recruit (EPR) analyses and were applied by the Striped Bass Committee of the Atlantic States Marine Fisheries Commission (ASMFC) to develop management advice in the early 1980s. Example applications of the EPR methods we originally developed for striped bass can be found in Boreman and Goodyear (1984) and Prager et al. (1987).

Development of Fishery Management Advice

When the ESBS was initiated in 1979, states along the Atlantic Coast from Maine to North Carolina had minimum size limits ranging from none (Maine) to 18 inches total length (TL) (New Jersey); some states also had a maximum size limit (32 inches TL in Maryland and 20 lbs in Delaware). Most states had no creel limit, and anglers in all states except Connecticut were allowed to sell their catch. Commercial licenses were required in Maryland and Rhode Island, and none of the states had a saltwater fishing license requirement for recreational anglers (ASMFC 1981).

Based on results of the stock assessment for striped bass done under the aegis of the ESBS, it became immediately apparent that fishing mortality was a significant factor controlling the abundance and reproductive potential of coastal migratory striped bass, primarily because of the extended number of years that a striped bass could be exposed to the risk of fishing mortality. With a 12-14 inch TL minimum size limit in Chesapeake Bay, striped bass were recruiting to the fishery around age 2 (prior to sexual maturity) and could remain exposed to the risk of being caught each year for 20 years or longer. As such, a small reduction in survival rate of striped bass adults from more restrictive fishing regulations could offset a much larger reduction in first-year survival caused by a change in environmental or human-induced conditions (Figure 3). An analysis by Goodyear et al. (1985) concluded that a modest increase in adult survival of striped bass (1.8 - 1.9 %) could offset the loss caused by the apparent decline in first-year survival that occurred in Chesapeake Bay from 1969 to 1983 (9-13% per year), assuming that the decline was solely caused by a reduction in first-year survival.

Based on the sensitivity of the reproductive potential of striped bass to relatively small changes in fishing mortality, the advice we provided to fishery managers was to reduce fishing pressure on the coastal stocks of striped bass immediately, even if overfishing was not the primary cause of the decline in production during the 1970s. The stock assessment approach we used was relatively easy to grasp conceptually, as it related the effects of changes in fishing mortality and first year survival to potential lifetime egg production of a female striped bass. By attending local meetings of fishing clubs, testifying at congressional and state hearings, and interacting with stock assessment scientists and fishery managers at the state and federal levels, we were able to build a convincing argument that reducing fishing mortality on striped bass would reverse the downward trajectory of striped bass production and allow managers to “buy time” while the true cause or causes of the fishery collapse was determined. The questions fishery managers asked us were: how could the coastal states reduce fishing mortality in a way that would not give any one state an unfair advantage, and how much of a reduction in fishing mortality was necessary to reverse the trajectory?

It became immediately obvious that an across-the-board, one-size-fits-all regulation to reduce fishing mortality in all coastal states was not feasible. Harvesting methods varied across states, and gear that was legal to use for harvesting striped bass in some states was illegal in others (e.g., gill netting was allowed in Maryland waters, but was banned in Massachusetts waters). A common currency needed to be established that allowed the states to maintain flexibility in regulations for their state’s waters. The common currency selected by the striped bass technical advisory committee to the Atlantic States Marine Fisheries Commission (ASMFC), the body charged with developing a coast wide fishery management plan for striped bass, was fishing mortality rate. If each state agreed to reduce the fishing mortality rate imposed on striped bass in its waters by an equivalent amount, then none of the states would incur an unfair burden. Each state would then be responsible for presenting scientifically defensible evidence that its plan for reducing the fishing mortality rate would achieve the ASMFC goal of rebuilding the coastal migratory stocks. Today, the term “conservation equivalency” is used to describe this scientifically based management strategy.

Once the question was resolved as to how the states would reduce fishing pressure on the coastal migratory stocks of striped bass, the ASMFC Technical Committee turned their attention to deciding how much of an across-the-board reduction in the fishing mortality rate imposed by each state was necessary to start rebuilding the stocks. At the time of the deliberations by the ASMFC Technical Committee on how much of a reduction in the fishing mortality was needed, both of us had recently faced an analogous situation during the settlement of the Hudson River power case (Barnthouse et al. 1988). In that case, where the impacts on striped bass of continued use of once-through cooling systems by power plants sited on the Hudson River was the issue of primary concern, the regulatory agencies were requiring closed-cycle cooling at the major power plants while the utility companies were arguing that the existing once-through systems were doing no harm. The case was settled when the regulatory agencies and utility companies agreed to meet halfway; the regulatory agencies would not require cooling towers if the utility companies would reduce the mortality on striped bass imposed by the power plants by 50% through changes in intake technology coupled with scheduled outages (Englert et al. 1988).

For the striped bass fishery along the Atlantic Coast in the early 1980s, some stakeholders were calling for a coast wide moratorium on striped bass fishing until the stocks were fully recovered, while other constituents were pushing to keep the striped bass fishery open. We were able to demonstrate that reducing the fishing mortality rate on the coastal migratory stocks of striped bass by 50%, a strategy analogous to the one that led to successful negotiations in the Hudson River power case, was sufficient to reverse the downward trend in production and start the stocks on a rebuilding trajectory. This was the strategy adopted by the ASMFC Technical Committee, which advised the ASMFC to reduce fishing mortality by 50% plus an additional 5% to account for scientific uncertainty. The 55% reduction in the fishing mortality rate was eventually incorporated into the coast wide fishery management plan for striped bass as an amendment through an action taken by the Striped Bass Management Board of ASMFC at their 1984 annual meeting (Robert Beal, ASMFC, personal communication). Bolstering the 55% reduction, Maryland and Virginia also declared moratoriums for striped bass fishing within the Chesapeake Bay, and its tributaries around the same time the fishery management plan was adopted by ASMFC.

Conclusion

Based on an analysis of tag returns from a volunteer tagging program sponsored by the American Littoral Society, Sprankle (1994) estimated that the fishing mortality on the coastal stocks of striped bass was reduced by 76% following the regulations imposed by the states under the striped bass fishery management plan in 1984. This reduction far exceeded the 55% required by the plan and led the way for a more rapid recovery in biomass of the stocks supporting the coastal fishery than anticipated. The ASMFC declared the striped bass stocks managed under its interstate plan fully rebuilt in 1995. Today, striped bass is used as an example for demonstrating that the combination of management based on sound science and cooperation from the fishing public can lead to successful rebuilding of overfished stocks.

The initial success of the ESBS in the early 1980s can be attributed to several factors. First, the study was comprehensive in scope, having research, monitoring, assessment, and economic elements under the purview of a single oversight committee. This approach allowed easier integration of the findings from one element into another, and allowed for a greater focus on those factors that appeared to have been driving the collapse in the fishery. For example, the stock assessment analysis revealed data gaps that factored in setting of research and monitoring priorities. One such priority was the establishment of and continued support for age 0 abundance surveys analogous to the Maryland survey in all major spawning areas for the coastal migratory stocks (Roanoke River and Albemarle Sound and tributaries of Chesapeake Bay, Delaware River, and Hudson River). In the early 1980s no age 0 striped bass were being collected in the beach survey established with ESBS funding for the Delaware River, but it was important to begin the time series in anticipation that the Delaware River stock would rebuild (which it did).

Our use of an analysis of the effects of fishing on lifetime eggs per average recruit as a stock assessment tool was also a factor in the early success of the ESBS. The analysis is relatively straightforward, and lawmakers, managers, and the fishing public easily grasped the underlying concepts. We were also fortunate that the Maryland juvenile abundance index for striped bass was closely linked to the amount of subsequent harvest along the Atlantic Coast, which enabled managers to use the index as a performance measure for rebuilding the coast wide fishery.

Another factor adding to the success of ESBS was cooperation from fishing clubs. The dispersed nature of marine recreational fisheries for a species like striped bass, which can be caught by using a variety of methods and in a variety of locations, makes enforcement difficult. When regulations are tightened to clamp down on fishing pressure, enforcement usually becomes more problematic because of the temptation by anglers to ignore the reduced catch and increased size limits. When we made the argument that reduction in fishing pressure was the quickest and most reliable means of rebuilding the striped bass fishery, fishing clubs helped communicate the message to their membership and applied peer pressure to make sure the new regulations were being obeyed.

The research program under the ESBS was hypothesis-driven, which enabled us to relate research findings directly to potential causes for the decline in striped bass production and collapse of the coast wide fishery for striped bass. We chose not to have a team of researchers from academia, state, and federal agencies serve as the decision body for setting research priorities because we discovered early in the ESBS planning process that researchers bring a certain degree of bias based on the particular aspect of striped bass biology they are engaged in studying. Although we sought advice from researchers knowledgeable about the influence of environmental and human-induced effects on striped bass growth, survival, and reproduction, we decided that decisions related to assigning priorities to the hypotheses, and thus setting the research agenda, would lie solely with us. We thought that such an arms-length approach would bring more objectivity to the ESBS research program.

Finally, we made a determined effort to steer clear of the political rhetoric ongoing during the early 1980s. Commercial fishermen, especially the watermen in Chesapeake Bay, were fighting hard to protect their way of life by keeping their fishery operating, while at the same time some members of the public were advocating for a recreational-only fishery throughout the range of the coastal migratory stocks of striped bass (see Russell 2005). We saw our role as ensuring that the best and most recent scientific information was available to all sides of the political issues and communicating our science-based argument that the coastal fishery for striped bass could only be restored if fishing pressure was greatly reduced.

Table 1. Estimated harvest of striped bass in the marine recreational fishery along the Atlantic Coast, 1960 – 1980 (from Boreman and Austin 1985).

Survey Year	Measure	Harvest
1960	000s fish	9,272
	000s kg	16,851
1965	000s fish	15,982
	000s kg	25,106
1970	000s fish	14,166
	000s kg	33,161
1979	000s fish	1,133
	000s kg	2,838
1980	000s fish	536
	000s kg	780

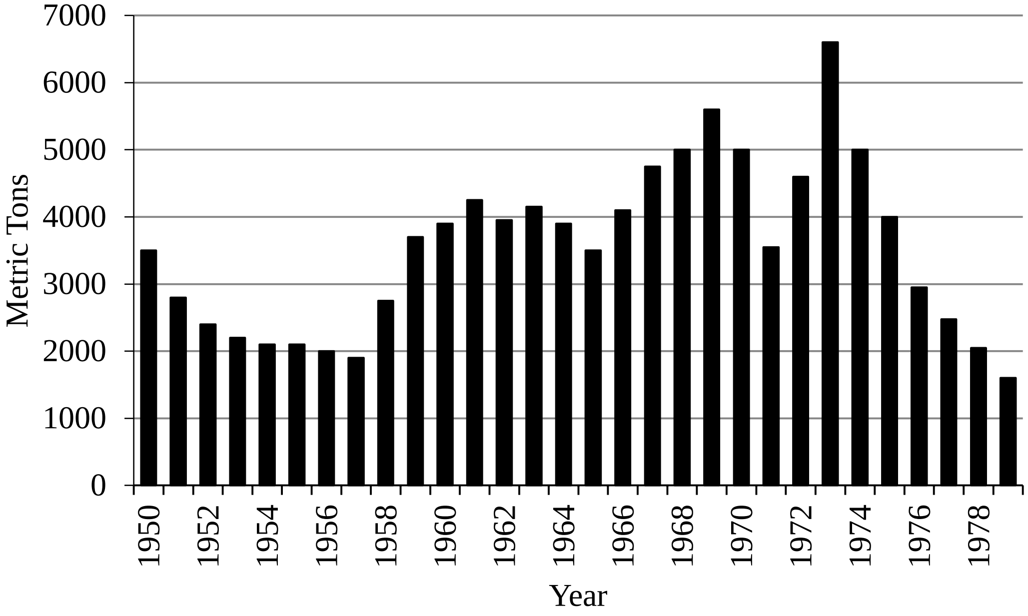

Figure 1. Reported commercial landings (in metric tons) of striped bass (*Morone saxatilis*) along the Atlantic Coast from 1950 to 1979.

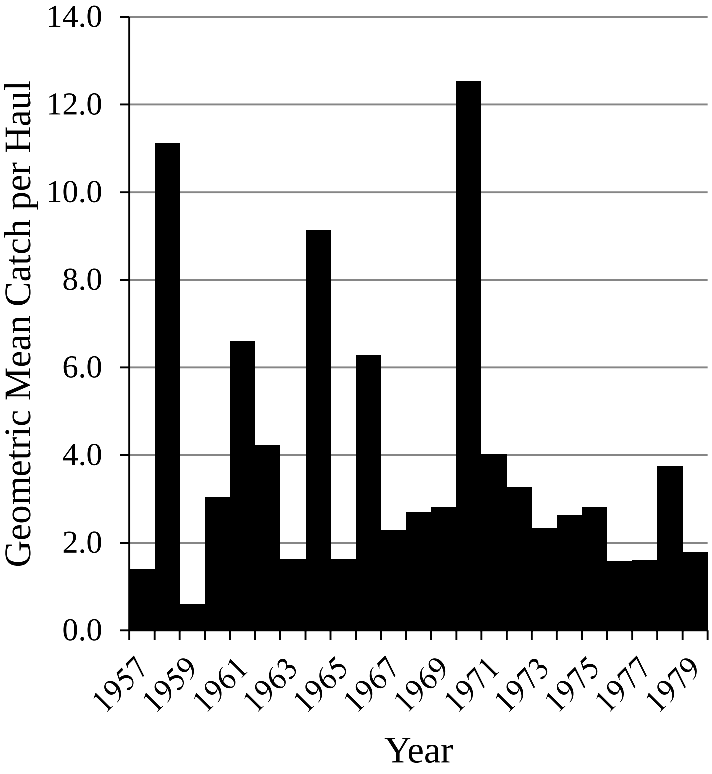

Figure 2. Juvenile abundance indices (geometric mean number per haul) of striped bass (*Morone saxatilis*) from Maryland Department of Natural Resources from 1957 to 1979 showing dominant year classes in 1958, 1961, 1964, 1966, and 1970.

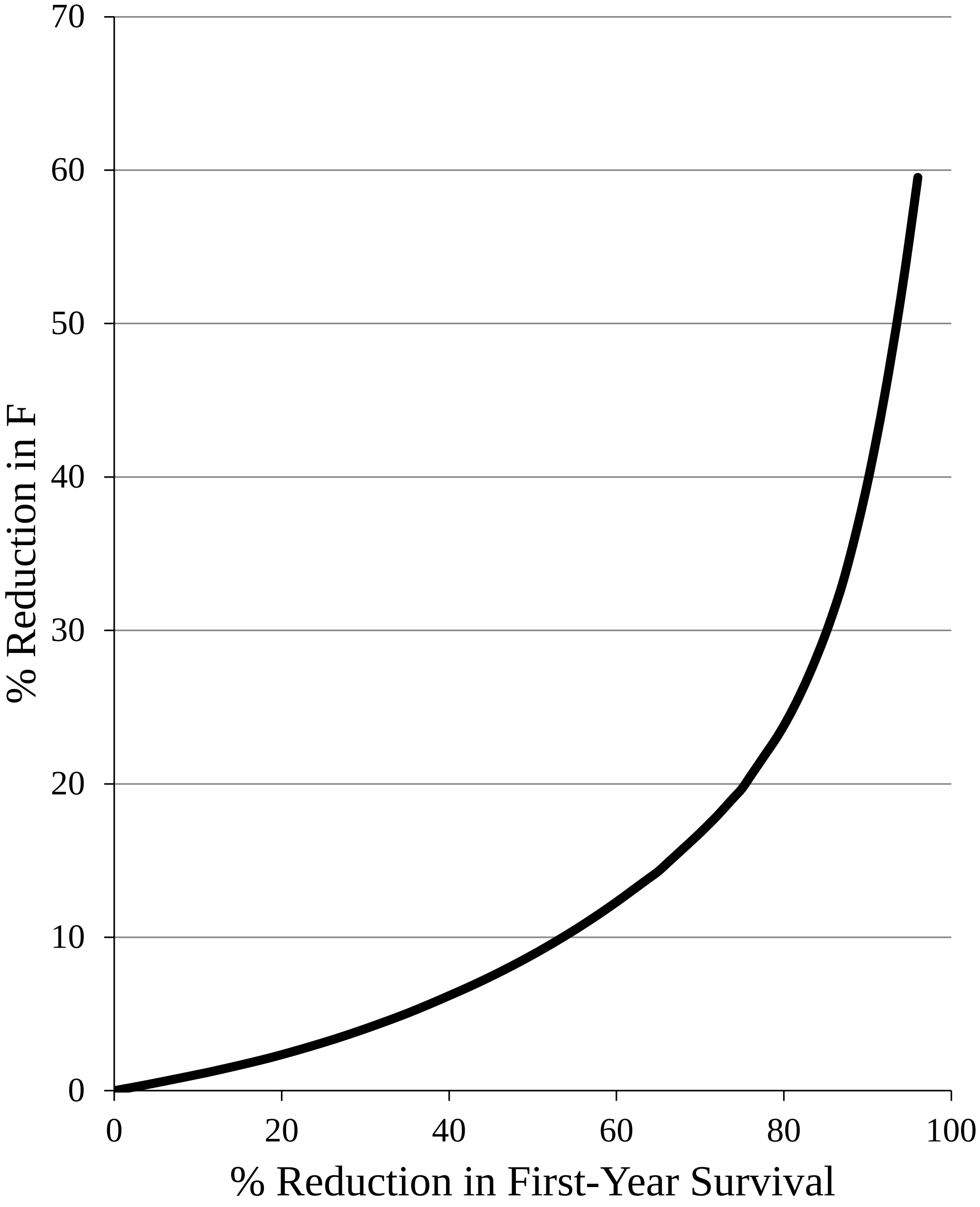

Figure 3. An illustration of the impact of changes in the first year survival of striped bass (*Morone saxatilis*) compared to a reduction in fishing mortality (F).

SECTION II
RESTORATION OF ATLANTIC STRIPED BASS POPULATIONS: 1985-1989

Paul J. Rago, R. Anne Richards and Gary R. Shepherd

Abstract

By the mid-1980s, fishery managers were recognizing that reducing fishing mortality on striped bass (*Morone saxatilis*) would be critical to restoring the Chesapeake Bay (Bay) stock. An average juvenile index had been produced in the Bay in 1982, and efforts focused on developing measures to protect the year-class until most of the females could reach maturity. Population models were developed that provided projections of population growth under different scenarios of migration, growth and stock-recruitment relationships, and predicted probabilities of recovery. During the same time, population monitoring programs were established, efforts to supplement natural reproduction by stocking hatchery striped bass reached a peak, a coast-wide tagging study was initiated, and intensive research efforts to identify causes for the decline continued. Fishery moratoria were established by some jurisdictions, and others adopted regulations that increased size limits each year to stay ahead of the growth of females of the 1982 year-class. A trigger for relaxing regulations was agreed upon by managers. In 1989, that trigger was reached with a juvenile index that exceeded the target value. Regulations began to be cautiously relaxed in 1990, only 5 years after stringent management measures were initiated. The response of the striped bass population to the management measures of 1985-1989 was dramatic and illustrates the potential for recovery of a severely depleted population given sufficient protection from exploitation.

Introduction

During the 1970s and early 1980s, critical groundwork was laid to convince managers and fishermen that action was needed to rebuild the Chesapeake Bay stock of striped bass, which had been in steady decline during the 1970s (Boreman and Austin 1985). Modeling efforts had clearly demonstrated that reducing fishing mortality would provide significant benefits (Goodyear 1984), and conservation measures were enacted with the goal of reducing fishing mortality by 55%. In 1979, US Congress passed legislation that funded an "Emergency Striped Bass Research Study" [ESBS] to be jointly administered by the US Fish and Wildlife Service and the National Marine Fisheries Service. Funds were used primarily to establish monitoring programs, investigate causes for the decline, and develop recommendations for management measures to rebuild the stocks.

A key indicator of condition of the Chesapeake Bay stock was the Maryland juvenile striped bass index, estimated from an annual survey in striped bass nursery areas that was initiated in 1954. This index was a good predictor of landings along the Atlantic Coast (Goodyear 1985a) and became a focal point for management actions. Goodyear et al. (1985) used the Maryland juvenile index to demonstrate that the Chesapeake Bay stock was failing to replace itself and that reducing fishing mortality would benefit recovery efforts regardless of the causes of the decline. This juvenile index also became the focal point for research and management efforts during the mid to late 1980s. This paper summarizes the research results, modeling efforts, and management actions of the mid to late 1980s that led to the eventual recovery of the Chesapeake Bay striped bass stock.

1982 Year-class: The Great Hope

An average Maryland juvenile abundance index in 1982 was cause for celebration after 11 years of poor recruitment in Chesapeake Bay. Managers had an opportunity to increase the chances for striped bass restoration if they could shepherd females of the 1982 cohort until they were able to reproduce. After more than a decade of poor recruitment, there was a strong sense of urgency to protect this average year-class. In order to protect the 1982 cohort, conservation measures needed to be enacted quickly. Striped bass females do not begin to mature until age 5; however, they would be susceptible to the Chesapeake Bay fishery by age 2. If decisive measures were not taken, the opportunity for rebuilding would be lost. Maryland's governor and legislatures made the bold decision to impose a moratorium on commercial striped bass fishing in the state starting January 1, 1985. Other states eventually followed suit, and by 1989 all states except North Carolina and Massachusetts had closed their commercial fisheries. In addition, the federal government imposed a closure in 1989 of commercial and recreational striped bass fishing in the US Exclusive Economic Zone (EEZ) (greater than 3 miles from Atlantic Coast shoreline).

Although many of the commercial fisheries were closed, recreational harvest continued and was thought to far exceed commercial harvest in most states (Richards and Deuel 1987). A straightforward approach was taken to reduce recreational fishing mortality on future spawners: increase size limits to stay ahead of the growth of females of the 1982 and subsequent cohorts until they could spawn at least once. Simple growth models based on historic length at age data were used to craft regulations that ratcheted up size limits annually to allow 95% of females to reach the size of first maturity (ASMFC 1989). Operationally, this meant that size limits were set at the predicted 95th percentile of predicted average length-at-age. With the passage of Amendment 3 to the Interstate Fisheries Management Plan (ISFMP) (ASMFC 1985), the minimum landing size along the coast increased from 18" to 33" total length (TL) over the course of 3 years, ultimately reaching a minimum size of 38" TL. These were draconian measures but were strongly supported by recreational fishermen for several reasons: (1) the resource was highly valued but clearly in deep trouble, (2) the management measures were equitable across states, and (3) the objective of protecting the 1982 year class until it could reproduce made intuitive sense. Hook and release morality was estimated to be relatively low (RMC 1990; Diodati and Richards 1996), and the striped bass recreational fishery became essentially a catch and release fishery.

The management actions that were promulgated to protect the 1982 year-class were enabled by passage of the Atlantic Striped Bass Conservation Act (SBCA, P.L. 98-613) in 1984 and its extension in 1986 (P.L99-432). This legislation bolstered the authority of the Atlantic States Marine Fisheries Commission's (ASMFC) ISFMP (Plan) because it provided for enactment of a Federal moratorium on striped bass fishing in any state that did not comply with the Plan. Prior to passage of the SBCA, the management initiatives in the ASMFC Plan were merely recommendations that states were asked to adopt voluntarily. The SBCA extension in 1986 received objection from the US Department of Justice on grounds that it was unconstitutional; however, the bill had bipartisan support from the US House and Senate and was signed into law by President Reagan. Federal moratoria were threatened several times in the District of Columbia and New Jersey and implemented once in New Jersey for a period of 5 days (March 1-5, 1990) before regulations were brought into line.

The new regulations for protecting the 1982 year-class were not without critics (Cronan 1986). The commercial fishing industry was generally opposed to the increasing size limits while recreational fishermen voiced concern that the commercial industry might not be held to the same standards. Despite the criticisms, the management changes were adopted by all ASMFC member jurisdictions, applied to both fishery sectors, and were viewed as generally equitable. Rebuilding was expected to be a slow process given the depressed state of the stock and life history characteristics of striped bass; however, there was a general sense that the stage was set and nothing more could be done except wait and hope.

Other Restoration Efforts

To supplement natural production, the US Fish and Wildlife Service (FWS) in cooperation with the states of Maryland and Virginia began to raise and stock fingerling striped bass in Chesapeake Bay. During 1985-1993 over 7.5 million hatchery-reared striped bass were released throughout the Chesapeake Bay (Dorazio et al. 1991). All fish were tagged with coded wire tags (CWT), and over 93,000 fish also received an anchor tag with external streamer. The tag recoveries provided information on the movements and mortality of hatchery striped bass and helped determine their contribution to natural stocks. An evaluation of the stocking program in 1994 found that the hatchery program made little contribution to the coastal migratory stocks and merely served to supplement local recruitment. The hatchery program was terminated when natural production increased to historically average levels. Despite the overall low survival of hatchery fish, some survived to become part of the migratory coastal stock. Striped bass up to age 12 tagged with CWTs were recovered in the New York haul seine survey. These fish proved useful for validation of ageing methods since the fish were of a known age (ASMFC 1999).

Causes for the Decline

The decline in juvenile production in Chesapeake Bay was hypothesized to have resulted from changes of 3 possible types (USDOI and USDOC 1989): (1) pollution or other human-induced disturbances, including acid rain, increases in toxic contaminants, reduced organic pollutants (causing declines in overall productivity), changes in water flow and spawning ground access from dams and canals; (2) ecological conditions such as availability of food during the larval stage, increased predation on early life stages, competition from other species, or climatic changes; (3) overexploitation due to commercial and/or recreational fishing. It was hypothesized that removals from fishing had reduced the spawning biomass to levels too low to sustain the stock.

Extensive studies were funded under the ESBS to investigate the potential impacts of pollution and other anthropogenic effects. In situ and on-site toxicity testing identified water quality problems in some Chesapeake Bay tributaries, although not consistently across years (Hall 1991). Striped bass eggs and larvae are extremely sensitive to pH levels below 7.0. Some rivers were poorly buffered and experienced episodic pH depressions with major rainfall events. Such events, coupled with high ambient levels of aluminum and other inorganic pollutants, could result in highly toxic conditions. Whether these events were sufficient to reduce recruitment would have depended not only on their severity but on the spatial and temporal overlap of toxic conditions with the period of spawning and larval development. Analyses of historical data on pH levels in major striped bass spawning areas revealed no systematic difference in the frequency or magnitude of low pH events before and after 1970 (Janicki et al. 1986). However, simulations indicated that historical monitoring programs would have been capable of detecting only major changes in the frequency or magnitude of such events (Richards and Rago 1999). It was concluded that anthropogenic effects may have contributed to the decline, but none of these appeared to have been the most significant factor.

Analyses of the effects of fishing on the stock demonstrated that striped bass had been subjected to growth overfishing, a condition in which fish are harvested before achieving their maximum potential for growth (Goodyear et al. 1985b). Historically, the striped bass fishery was sustained by frequent strong year classes, which had not been produced since the 1970 cohort. Tag returns from state and federal programs showed that over 40% of the coastal migratory stock was caught each year, a rate that likely resulted in recruitment overfishing.

Population Modeling Studies

Despite the high-profile concern over striped bass and extensive efforts to determine the causes of its decline in Chesapeake Bay, surprisingly little information was available regarding dynamics of the stocks. Population models were needed to estimate sustainable exploitation levels and evaluate production potential of the stock. Two models were developed by using different approaches, although both accounted for Bay/coast differences, migration, biological characteristics, etc. (ASMFC 1990).

The first model was developed by Drs. Paul Rago and Robert Dorazio of the US Fish and Wildlife Service (FWS). This simulation model with 2 areas (bay and coast), incorporated a Leslie matrix model of 2 interacting subpopulations. Age composition in the simulated population was ages 1 – 15, and growth occurred in annual time steps. Growth in weight was defined by length-at-age data collected by the Maryland Department of Natural Resources (MD DNR) and a length-weight regression published by Mansueti (1961). Length distributions within a year were assumed normally distributed, and growth occurred exponentially within a year and between adjacent age classes. Hence, differences in size limits could affect fishing mortality rates on more than 1 age class. The model was calibrated by maximizing agreement with the 1973-1979 population decline and the relative allocation of yield between the bay and the coastal stock. Density independent regulation was assumed, and the stock was considered collapsed (i.e., more specifically, begin a monotonic decline) when the finite rate of population growth fell below 1.0 (or equivalently, the annual instantaneous rate of population growth was less than 0).

An alternative model put forward by Dr. Vic Crecco from CT Department of Energy and Environmental Protection used a Thompson-Bell yield-per-recruit model (Thompson and Bell 1934) coupled with a Shepherd stock-recruitment model (Shepherd 1982). The model incorporated fish of ages 2-20 and 2 areas representing the Chesapeake Bay and the coastal stock. Time steps were half year periods, and the model assumed density-dependent population regulation. Growth was modeled by using a von Bertalanffy equation, and the simulation involved discrete annual growth and uniform length at age, resulting in no overlap among cohorts. The Shepherd stock-recruitment function was calibrated based on data from the Roanoke-Albermarle stock in North Carolina. Stock collapse in the simulated population occurred when the recruit to biomass ratio fell below that required to sustain equilibrium at low stock biomass. This point was equivalent to the slope of the stock/recruitment (S/R) function at the origin.

The models differed in many operational details although both accounted for the basic dynamic processes of reproduction, growth, mortality, and migration. The assumed migration rates between the Bay and coastal stocks were critical model inputs that affected the estimated potential for population recovery and implications for management. Consequently, differences between migration rates and how they were implemented in the models were a major reason for differences in output of the models. The Crecco model (ASMFC 1990) assumed all fish migrate on July 1 whereas FWS assumed October 1, resulting in about a 6% difference in allocation of yield between the bay and coast. However, differing assumptions about the age-specific timing of migration had far greater effects. In the Crecco model, fish remained in the Bay 1 year longer than in the FWS model. This delay resulted in greater yield to Bay fisheries and increased the fishing mortality of younger fish because of lower size limits in the Bay. In contrast, recruits in the FWS model were afforded an extra year of protection by higher size limits on the coast. In the FWS model, allocation to the Bay increased as the finite growth rate above 1.0 rose. Under those conditions, the population had a higher proportion of recruits, which counteracted the decreased residency period of the FWS model.

In the Crecco model, spawning closures caused 25% of the coast's yield to be transferred to the Bay. The 25% figure rested on the assumption of a 4 month fishery during which 75% of the coastal population was available to the Bay fishery and assuming 75% of the coastal population was mature. This increased the Bay's yield more than the FWS model which used a six week closure period under the base F in the Bay. When length limits on the coast were low, differences between the models' predictions increased, and there was increased yield to the coast. When 25% of this increased yield was added to the Bay yield, the relative allocation to the Bay increased. As the coastal length limit increased, the relative differences in the allocation patterns between the 2 models tended to decrease. Thus, the allocation to the Bay in the Crecco model would have increased if Fs were low, and it would likely underestimate the fraction of coastal yield transferred to the Bay under low base Fs.

Another key difference between the approaches was characterization of recruitment relative to spawning adult biomass. The Shepherd stock-recruitment relation used in the Crecco model implies density-dependence, whereas the FWS model assumed density-independence. One of the consequences of this difference, when coupled with the migration rates, was that it further increased discrepancies in yield allocation between the Bay and coast. If fishing mortality allowed an increase in population growth, recruits entering the system would increase, and consequently the age distribution would shift to a lower average age. With more recruits contributing to Bay fisheries with small size limits, allocation in yield would shift to the Bay. The debate over population regulation was less a matter of philosophy than application. A key concern was the adequacy of historical data to parameterize a stock recruitment function. Such debates continue to this day to influence management of striped bass and many other species.

Neither model fully captured the temporal dynamics of the striped bass population. Both assumed a stable age distribution; however, variation in cohort success would have implications about population variation from equilibrium conditions. Early in 1988, the Rago and Dorazio model was modified to forecast future recruitment under alternative rates of exploitation. By explicitly considering the protection afforded to the 1982 year class, the model suggested that the Maryland Juvenile Index (MDJI) could increase rapidly between 1988 and 1990, even when fished at historically high exploitation rates. However, the predicted boom would be short-lived if high rates of mortality were not curbed.

Monitoring Programs

The modeling efforts of the 1980s were critical for focusing efforts to restore striped bass and provided a foundation for management once the Chesapeake Bay stock was declared recovered. Also invaluable were the monitoring programs that were established during this time period. For example, monitoring of juvenile striped bass abundance by the New York State Department of Environmental Conservation in western Long Island bays began in 1984, and adult stock surveys were initiated in the Hudson River in 1985 and in coastal Long Island in 1987. Maryland DNR also began a stock survey in 1985 that sampled the spawning grounds on several rivers. A coast-wide tagging program for wild striped bass was started with the objective of monitoring exploitation rates of adult fish. The tagging program involved state fishery agencies in Massachusetts, Rhode Island, New York, New Jersey, Maryland, Virginia, and North Carolina and was coordinated by the US Fish and Wildlife Service. Many of these programs remain in operation and continue to provide important contributions to stock assessments of striped bass.

Restoration of the Fishery

The participating states had agreed to use the long term average of the Maryland juvenile striped bass survey as a trigger point to indicate when recovery of the Chesapeake Bay stock had been achieved. Achieving a 3-year average juvenile index above the trigger point would allow states to lift moratoria, reduce minimum size limits, and enact other regulations to reopen fisheries. The trigger point was exceeded in 1989, but its arrival was a cause for anxiety as well as celebration. The 1989 index had been preceded by very low 1987 and 1988 juvenile indices, but the 1989 index was sufficiently high to bring the 3 year average over the trigger. The interannual variability was worrisome, but the variability within the 1989 index was cause for even greater concern. The high 1989 index was strongly influenced by large tows at 1 sampling site. An extreme weather event between 1988 and 1989 had changed the depth and current conditions at that site and may have resulted in an unusual aggregation of juvenile striped bass. However there was additional evidence that the 1989 year class was above average. The juvenile survey traditionally sampled auxiliary sites that were not included in the index calculation. These sites had numbers of striped bass above average as did other individual stations regularly sampled for the index. News of the high index quickly spread, and in 1990 a congressional hearing was held to discuss the survey result, illustrating the degree of scrutiny that had been focused on the recovery efforts for Atlantic striped bass.

Despite the influence of the single sampling site, the management bargain was kept, and the fisheries were reopened. Because of the uncertainty in the trigger, managers took a cautious approach to relaxing regulations. In retrospect, the simple control rules for striped bass restoration can be viewed as an early example of management strategy evaluation. The results of the FWS striped bass population-simulation model concluded that the stock could sustain a fishing mortality (F) of 0.5 but noted that the combination of alternative size limits in the bay and on the coast would result in only a small fraction of the population being vulnerable to this maximum F. Given the strong influence of the age-specific migration rate from the bay to the coast on the FWS model and the uncertainty of these estimates, managers adopted a more conservative target F = 0.25. In addition, the ASMFC Technical Committee immediately instituted changes in the calculation of the index by using the geometric mean in order to reduce the potential influence of anomalous stations in calculating the annual juvenile index.

Other Stocks

Although the initial impetus for management actions of the 1980s was to reduce fishing mortality on the Chesapeake Bay stock, the reductions benefited the migratory Hudson and Delaware River stocks as well. The Delaware River stock had experienced a decline even before the decline in Chesapeake Bay. This decline was blamed largely on pollution, which caused low dissolved oxygen near Philadelphia and effectively blocked the striped bass upriver spawning migration (Chittenden 1971). Consequently, there had been little productivity from the Delaware River, and for many years the stock had been considered inconsequential. However pollution remediation efforts in the Delaware River, coupled with a release from fishing pressure, resulted in the restoration of the Delaware stock by 1995. In contrast, the Hudson River stock did not experience a decline in the 1970s. High levels of polychlorinated biphenyl (PCBs) had led to a closure of the fishery in the Hudson River in 1976, and productivity of the stock remained strong. Measures aimed at protecting the Chesapeake Bay stock would have also protected the Hudson River stock during its coastal migrations, and juvenile abundance indices in the Hudson River in 1987 and 1988 were among the highest since the beach seine survey began in 1976 (USDOI and USDOC 1989,1992).

Conclusion

The ASMFC Interstate Fisheries Management Plan for Striped Bass was developed in 1981 (ASMFC 1981) with a focus on strategies to restore and maintain striped bass, minimizing the likelihood of recruitment failure. This initiative was followed by an amendment in 1989 with 3 objectives for managing a recovered resource: (1) maintain self-sustaining spawning stocks, minimizing the possibility of recruitment failure;(2) promote fair allocation of any allowable harvest among the various components of the fishery; and (3) adopt standards of environmental quality necessary for the maximum natural reproduction of striped bass and the utilization of allowable harvest. The amended plan used a strategy of adaptive management to allow as much flexibility as possible among states with changes in stock status. In 1990 the moratorium in all the states was lifted, and the fishery reopened with restrictive commercial quotas and recreational size and bag limits. The moratorium in the EEZ remained and is still in effect to this day. When the fishery moratorium began in Maryland in 1985, the expectation was that the recovery of the striped bass stock in Chesapeake Bay would be a long process. Yet within 5 years, plans for reopening the fishery were put in place and soon thereafter the fishery was operating on a fully recovered stock.

The story of the striped bass recovery has been often used to illustrate the product of good fishery management in rebuilding a collapsed stock. The 1985-1989 period built on the concepts developed by Goodyear and Boreman by initiating monitoring and tagging programs to understand key population parameters and developing models to help guide management. Collectively, these actions allowed managers to make informed decisions and enabled the political mandate to carry them out.

Striped Bass was one of the first instances where a management strategy evaluation (MSE) approach was used to evaluate the prospects for a stock recovery. The simulation modeling gave quantifiable justification for simple, basic arguments that could be understood by managers, politicians, and the general public: reduce fishing, give them a chance to spawn, improve the habitat, and the fish will have a chance to recover. Add to that a well-defined trigger for resumption of fishing and the result was public support for the program. Although good fortune always plays an element in resource conservation, striped bass ultimately showed that control of exploitation, coupled with improved habitat, could in fact result in stock recovery.

SECTION III
ADVANCES IN THE EVALUATION OF ATLANTIC STRIPED BASS STOCK STATUS – 1990-2009

Gary R. Shepherd

Abstract

Following the reopening of Atlantic striped bass fisheries in 1990, the Atlantic States Marine Fisheries Commission Technical Committee was faced with the task of quantifying the efficacy of recovery efforts. In the early 1990s, a time series of Chesapeake Bay juvenile striped bass abundance indices were used to support a population model which concluded that spawning stock biomass had rebounded to levels observed in the early 1970s, prior to collapse of the stock. Consequently, in 1995 striped bass stocks were declared recovered. With the collection of additional fishery dependent and independent information, an age-based stock assessment was developed in 1998. A virtual population analysis (VPA) was used to calculate stock status information (e.g., abundance-at-age, spawning stock biomass, fishing mortality, and recruitment) and documented the continued increase in striped bass abundance through 2004. When the population growth stabilized, a forward-projecting, catch-at-age model was found to be superior to the VPA for evaluating stock status. Biological reference points were developed as changes occurred in both management and stock assessment methods. Both the VPA and catch-at-age models were initially supplemented with simple tag models by using the annual ratio of recovered tags to number released, but these simple models have been replaced over time with more complex Brownie-type tag models. Tag recoveries continue to provide information about exploitation of both individual and combined coastal stocks in addition to migration patterns.

Introduction

In the 1970s fishermen witnessed the well-documented collapse of striped bass in the Chesapeake Bay (Russell 2006), yet this environmental tragedy was actually preceded by a more extensive collapse of migratory striped bass from the Delaware River stock (Chittenden 1971). By 1980, the disappearance of striped bass on the Atlantic Coast was evident to all concerned. In response to these failures, fishery managers imposed strict regulations on commercial and recreational fishermen in an attempt to rebuild depleted stocks in the Chesapeake Bay and Delaware River. The approach included strict size and bag limits in the recreational fishery, size restrictions and quotas in commercial fisheries, and moratoria on striped bass fisheries in several states. These strict regulations also applied to the more abundant Hudson River stock, since there was no way to distinguish Hudson fish from Chesapeake fish in the ocean. However, a closure of Hudson River commercial striped bass fishing was previously implemented in 1976 to control consumption of striped bass contaminated with polychlorinated biphenyls (PCBs) (ASMFC 1990).

In 1989 the principal index of juvenile abundance from the Maryland young of the year seine survey increased significantly, resulting in a 3 year average index greater than 8.0 striped bass juveniles per tow that triggered a conservative reopening of striped bass fisheries in state waters. Although the closure remained in Federal waters (beyond 3 miles), the lifting of the moratorium in effect reopened the striped bass fisheries along the Atlantic Coast. However, it was clear from the age distribution of the stock that the striped bass population in Chesapeake Bay was not yet fully recovered from the collapse. Rather than allowing the reopening to proceed at an exploitation rate associated with maximum yield, managers took the more conservative approach of setting fishing mortality (F) to a target necessary for rebuilding rather than one that promotes long-term sustainability. The Atlantic States Marine Fisheries Commission (ASMFC) Striped Bass Technical Committee (SBTC) was charged with finding quantitative measures to determine when the Chesapeake and Delaware striped bass stocks were fully recovered. This would require an assessment of current stock abundance and exploitation rate relative to a target, as well as identifying a measure of biomass which defines a fully recovered stock.

The analytical approach for assessing the striped bass population has evolved over the past several decades. The changes can be partitioned into 3 distinct phases as additional data and more sophisticated models became available. The objective of this paper is to document the development of the analytical methods used to evaluate the status of the striped bass resource since 1990.

Population Analysis – Phase I

In response to the reopening of the striped bass fishery, the ASMFC implemented Amendment 4 to the Interstate Fisheries Management Plan (FMP) for striped bass (ASMFC 1989). The objective of the plan was to allow sustainable harvest while preventing overfishing. Striped bass presented several technical difficulties in developing quantitative metrics of population dynamics. The species was managed as a single stock, but in fact fisheries targeted a mixture of the Hudson River stock, the Delaware River stock, and the Chesapeake Bay stock (Richards and Rago 1999). Juvenile production occurs independently within each system, but following emigration all 3 stocks are exploited together in a coastal fishery. Information regarding the stock composition of the coastal mixture was limited and prevented any stock specific compilation of removals. Although abundance of each stock was indexed in its respective natal estuary at premigratory and spawning ages, annual stock status evaluation required information on the entire mixed stock.

Indices of relative population abundance generally result from a well-designed, fishery-independent survey. Striped bass north of Cape Hatteras, NC, are managed as 1 unit stock, yet there has never been a singular targeted survey to collect information on relative abundance of the mixed stocks throughout its range. Each state with striped bass spawning areas was required under Amendment 4 to develop surveys to measure relative juvenile abundance. These juvenile indices are based on seine surveys and are done independently with a survey design best suited for each particular spawning area. There are also state requirements to monitor removals from commercial and recreational fisheries and, in some cases, to conduct tag and release programs. Although some states had multispecies coastal surveys, quantitative information on striped bass stock abundance was relatively limited and in some cases fragmented by individual stock component within the overall management unit.

It is generally accepted that the Chesapeake Bay stock contributes the largest proportion of coast-wide striped bass production and that the collapse of that stock was the catalyst for management action. The dynamics of the Chesapeake stock were reflected in the collapse of juvenile recruitment, documented with changes in the relative abundance index of age 0 fish. The time series of relative juvenile abundance was developed from a seine survey begun in 1954 by

Maryland DNR within the Maryland portion of Chesapeake Bay. Goodyear (1985a) showed that the index was a strong predictor of commercial landings 2 years later. Consequently, this index became critical not only as a predictor of future abundance but also as a source of information for past recruitment to the adult stock. The concept of hindcasting striped bass relative abundance by using the juvenile indices was explored by Rago and Dorazio (1988) and further developed by Rugulo et al. (1994). Applying this concept for reconstructing past relative abundances of striped bass in Chesapeake Bay, a simulation model known as the spawning stock biomass model (SSB) was developed. In this simulation model, each year class (cohort) represented by the annual, relative juvenile-abundance index with an assumed starting sex ratio of 50:50, was advanced through time and allowed to grow in length and weight according to sex specific parameters. As each cohort advanced, they were subjected to estimated instantaneous natural and fishing mortalities (modified by selectivity for a given age) as well as emigration to coastal fisheries. Each cohort at age was partitioned by maturity (divided into immature and mature components) then converted to weight, resulting in a measure of spawning stock biomass per cohort. By summing across cohorts within a year, an annual relative index of spawning stock biomass was calculated. Because juvenile indices have been available in Maryland since the early 1950s, a time series of relative spawning biomass was developed which overlapped the period when the Chesapeake stocks of striped bass were considered stable. The average relative spawning stock biomass for the stable period of abundance from 1960 to 1972 became the standard by which striped bass recovery would be judged (Figure 1).

Although the fishery was reopened in 1990, exploitation was tightly controlled to foster a continued recovery of the stock (Richards and Rago 1999). Changes in spawning stock biomass reflected this increase, and by 1995 the SSB index crossed the historic threshold (Rugolo et. al 1994) necessary to declare the stock restored (Figure 1). The recovery of striped bass was hailed as a success (Field 1998). Regulations were relaxed to some degree, but managers still understood the need for caution. Minimum sizes remained restrictive at 28” or greater in coastal fisheries and 20” in producer areas (reduced to 18” with a penalty of a quota reduction) along with catch restrictions in both commercial and recreational fisheries. With the reopening of the fishery, the challenge was to effectively monitor the stocks response to annual exploitation based on the established criteria of acceptable fishing mortality.

The appropriate fishing mortality for the stock was developed as part of Amendment 4 to the FMP (Table 1). However, since only a measure of relative SSB was available at that time, biological reference points were limited to fishing mortality thresholds and targets. To produce long term sustainability, the accepted threshold was a fishing mortality (F) of 0.5, assuming a natural mortality of 0.2 (ASMFC 1990). Since there was uncertainty associated with the calculation of optimal F, the target F was chosen to remain at a rebuilding F = 0.25 in order to reduce the risk of inadvertently exceeding the threshold.

With the establishment of target and threshold exploitation rates, it became necessary to evaluate mortality annually in order to determine stock status. Catch curve analysis became the primary method for this evaluation. States collected yearly landings information and associated biological data which, in combination with recreational landings and discard data collected in the Marine Recreational Fisheries Statistics Survey (MRFSS), were used to develop annual catch-at-age vectors. In turn, these catch curves were used to estimate total mortality (Z) from each state fishery. Annual fishing mortality (F) for comparison to the target F was calculated by subtracting the estimate of M (0.2) from each Z and averaging across all state estimates. Although this method involves the assumption of constant annual recruitment, it nevertheless provided some indication of exploitation rate.

Another means of estimating exploitation rate was analysis of tag recapture data. Tagging programs run by state agencies and coordinated by the US Fish and Wildlife Service began in 1987 in coastal New York and the Chesapeake Bay, in 1988 in the Hudson River, in 1989 in coastal North Carolina, and in 1991 in Delaware Bay and Massachusetts. Annual estimates of exploitation and subsequently fishing mortality were developed for each system and for both sexes, when possible. During the first few years of tag data analysis, exploitation rates were calculated as a simple ratio of the number recovered divided by the number marked and released (Ricker 1975). As more return data became available and additional tagging programs came on-line, tag modeling evolved to estimation of survival with the use of Brownie models (Brownie et al. 1985) implemented in the program SURVIV (White 1992). Brownie models evaluate a series of probabilities that the tags survive (S) and are recovered (f). The probability of recovery is a function of both exploitation and tag reporting rate. A suite of possible models were evaluated, and the final survival estimate represented the average among models, weighted by the value of Akaike's Information Criteria (AIC). The Brownie model estimates of survival for each tag program were converted to fishing mortality and then averaged across comparable programs (coastal areas or producer areas) (Table 2). Despite variability among estimates (e.g., an extreme example was the NC program where values ranged from 0.08 in 1988-89 to 0.68 the following year), the overall results demonstrated that exploitation was within the bounds dictated by the FMP.

Population Analysis – Phase II

In 1995 striped bass were declared restored which allowed an expansion of the commercial and recreational fisheries. With the increased fishing effort targeting bass, and consequently the increased risk of overfishing, regulators were requesting additional information on which to base management decisions. Although the available analyzes proved adequate for monitoring exploitation and the SSB model successfully tracked changes in the Chesapeake spawning stock biomass, there were several shortcomings. The tag models required 2 years of release/recovery data to produce a survival estimate, so an exploitation rate estimate could not be made for the current year. In addition, the SSB model was applicable only to the Chesapeake stock, therefore it could not be used to fully assess the mixed stock coastal complex. An absolute estimate of spawning stock biomass was desired for development of a biomass-based reference point applicable to the entire stock, and a model also was desired which could accommodate expected changes in fishery selectivities. In response to those concerns, the Technical Committee developed a virtual population analysis model (VPA) that would produce annual estimates of fishing mortality, biomass, and recruitment by using the available catch-at-age data and state/federal indices of abundance (ASMFC 1998).

The new analytical age-based assessment model was a significant improvement because it allowed an integration of all the indices and produced results that could be evaluated in a statistical framework. The model was implemented using the program ADAPT (http://nft.nefsc.noaa.gov/VPA.html). The VPA model estimates population abundance and fishing mortality backward though time by solving the Baranov catch equation by year and age:

$$C_{t,a} = F_{t,a}\ (N_{t+1,a+1}\exp(F_{t,a}+M))(1-\exp-(F_{t,a}+M))(F_{t,a}+M)^{-1} \quad (1)$$

Where $C_{t,a}$ = catch at year t and age a, $N_{t,a+1}$ is abundance at year t for age +1, $F_{t,a}$ is fishing mortality at year t, and age a and M is natural mortality, assumed constant over time and ages. Since catch is known and M is held constant, F and N at age and year can be solved. However, because there is no unique solution for the 2 parameters solved simultaneously, additional information from indices at age can be used to calibrate the model. For striped bass, fishery independent indices were available from seine surveys for Maryland ages 0 and 1, Virginia age 0, Hudson River age 0, western Long Island Sound age 1, and Delaware River age 0. Maryland adult spawning indices from a gillnet survey and indices from ages 2 and above from a New York haul seine survey in eastern Long Island. Fishery dependent indices were also available from Massachusetts (commercial catch per unit effort [CPUE] at age), Connecticut (recreational CPUE at age) and Hudson River (commercial CPUE at age from bycatch in the American shad [*Alosa sapidissima*] and hickory shad [*Alosa mediocris*] fishery). Since coast-wide catches could not be partitioned into individual stock components, the VPA results applied to all stocks combined. However, some effort was made to weight the indices according to how well they characterized the abundance estimates, which essentially produced results that were weighted according to stock abundance. The time series of catch-at-age data included commercial harvest and discards to age 15+, as well as recreational landings and discards spanning the same age range. The series began in 1982 which was the first year MRFSS catch estimates were available. A 50:50 sex ratio was assumed in estimating female spawning biomass (the currency used in the biomass reference point), full selectivity was assumed to occur at age 4, and natural mortality (M) was assumed to be 0.15 (a change from 0.2 previously used). Striped bass in Chesapeake Bay were assumed to be fully selected to the fishery by age 3 because of the smaller minimum size in the areas designated as “producer” areas. Therefore, F in the Chesapeake Bay was represented by F at ages 3 to 8 in the VPA. The resulting VPA estimates of spawning stock biomass compared favorably to the SSB model and showed that abundance was increasing (Figure 3). Fishing mortality, although higher in magnitude, followed a trend similar to that derived from analysis of the tagging data. However, fishing mortality still remained below the F threshold (Figure 3).

Independent of the catch-at-age modeling, the tag analysis continued to evolve toward more comprehensive model development with the advent of the software MARK (White and Burnham 1999). The MARK software incorporated the Brownie model approach but used a redefined parameter for recovery rate (f) and allowed an opportunity to explore more alternative model configurations than SURVIV. Brownie models were originally developed for analysis of bird banding data where a returned tag represented a dead bird (Brownie et al. 1985). Violation of the assumption that a “dead” tag equaled a dead fish caused biased estimates in catch and release fisheries. Smith et al. (2000) developed an approach to account for situations when a tag was removed but the fish was released alive. Final survival estimates from MARK followed the same model-averaging approach with the addition of bias adjustment for live releases. As with the VPA results, the models’ results showed an increasing fishing mortality trend but remained below the threshold F (Figure 4).

The development of an analytical age-based model resulted in population parameters that could consequently be used to develop updated biological reference points. The original threshold F values (0.5) developed for Amendment 4 (1989) relied on 2 primary models: a Leslie matrix projection model (Rago and Dorazio 1988) and an equilibrium yield model using Thompson-Bell yield per recruit with a Shepherd stock/recruitment model (Crecco 1988). With Amendment 5 (ASMFC 1995), the reference point was based solely on the Crecco approach, and when modified with the newly adopted M of 0.15, F_{MSY} equaled 0.38. In both cases the stock/recruitment model was based on theoretical parameters representing anadromous species. The VPA results provided stock and recruitment estimates necessary to develop new reference points for F_{MSY} and a threshold SSB. The new estimate of F_{MSY}, following the procedure of Sissenwine and Shepherd (1987), was based on model results applied to a Shepherd stock/recruitment model (Shepherd 1982). With the new information, F_{MSY} was revised to be 0.41 (Table 1). An $SSB_{Threshold}$ was chosen to reflect the spawning biomass in 1995, the year striped bass were declared fully recovered. These new values were approved in Amendment 6 to the striped bass FMP (ASMFC 2003). Managers now had an SSB reference point and the requisite tools to evaluate the fishing mortality and biomass resulting from the previous year's fishery.

Population Analysis – Phase III

Following the declaration of a restored population, striped bass experienced a decade of increasing population growth, variable recruitment with the occasional large year classes reminiscent of the 1960s, and modest but increasing exploitation rates. By 2004 striped bass abundance was well above the target and population growth stabilized (ASMFC 2005). However, the change from a growing population to a stable one had implications in the catch-at-age modeling (Shepherd 2001). During the decade of population growth, trends in both the Chesapeake and Delaware stocks provided such strong signals to the ADAPT model that performance of the model remained relatively consistent year to year. Development of the analytical catch-at-age and tag models, along with improvements in the associated software, simplified the annual estimation of fishing mortality or survival, spawning biomass, and recruitment. Nevertheless, the SBTC modified several points such as a reduction of the plus group in the catch-at-age to 13+ and a revision of ages for estimating F to age 8-11. The success of the VPA model was predicated on the strong signal of a growing population in all 3 striped bass stocks modeled as a single entity. However as the population growth plateaued, the signal to noise ratio in the data changed, resulting in a disruption in the model performance. Consequently the ADAPT model results became erratic (Figure 5). A reevaluation of the modeling approach was made in 2007, and a new statistical catch-at-age model (SCA) was adopted (NEFSC 2008).

Statistical catch-at-age models use the same basic information as a VPA but take a different approach to parameter estimation. The ADAPT model uses nonlinear least squares estimation and begins with the most recent year in the time series to reconstruct the past population abundance, based on catch-at-age data and indices at age. A statistical catch-at-age model such as SCA takes the opposite approach and begins the estimation of abundance and F from the first year in the time series while fitting the model to data by using maximum likelihood methods. The SCA model also has more flexibility in defining the selectivity at age in the fishery and the option of weighting indices differentially during the fitting process. As with the model selection, the indices selected for tuning also changed in the new approach. Following evaluation of each index, the SBTC included young of the year indices from NY, NJ, MD, and VA; age 1 indices from MD and NY surveys; age specific indices from the NY ocean haul seine (through 2007), NJ trawl survey, and MD spawning stock survey; DE spawning stock survey; and age aggregated indices from MRFSS catch per angler, CT catch per angler, NEFSC trawl survey, and the CT trawl survey. The new SCA estimates of fishing mortality, using ages 1 to 13+, were lower than ADAPT results, although with comparable trends (Figure 6). Similarly, the trend in SSB, now calculated with sex ratio input to the model, showed the same upward trend followed by a recent stable period (Figure 7).

A change in modeling approach benefits from additional review to ensure it conforms to accepted scientific methods. The new catch-at-age model developed in 2007 underwent peer review (NEFSC 2008) and was accepted as an appropriate tool for assessing the status of striped bass stocks. The model continued to show a general increase in population biomass although, with catches increasing steadily since the reopening in 1995, fishing mortality steadily increased towards the F threshold. By 2004, population abundance and biomass reached their highest values since 1982. The SCA model was able to capture the population dynamics that seemed to make the VPA model unstable. However, as the time series of data increased beyond 2004, there was an increasing model retrospective bias where F was overestimated and abundance and biomass underestimated. Such retrospective bias can result from: errors in the catch-at-age, changes in natural mortality, and/or changes in catchability (or selectivity) in the fisheries or survey gear (Legault 2009). Consequently, with the addition of a new year of data, the estimate of F declined to 0.21 in 2008, and SSB estimates increased substantially (note: in addition, the estimate of SSB was altered when the sex ratio was no longer assumed constant at 50:50 but was instead based on empirical data). Meanwhile as the catch-at-age model was modified to account for changes in the population dynamics, the tag analysis approach was modified as well.

Advances in modeling to analyze tagging data focused on alternative model configurations and selection criteria. However, as with the catch-at-age model, natural mortality was assumed to be 0.15 and constant across time and age. Field observations from Chesapeake Bay striped bass showed an increasing incidence of the disease mycobacteriosis, which is a potentially lethal condition for fish (Gauthier et al. 2008). Estimates of the proportion of sampled fish showing signs of the disease ran as high as 68% (Ottinger 2006). Consequently, there was some concern among biologists that natural mortality of striped bass in the Bay was increasing well above the assumed rate of 0.15. Models were developed to examine tagging data in such a way that both natural mortality and fishing mortality could be determined. Jiang et. al (2007) approached the problem with a variation of the Brownie model, while Kahn and Crecco (NEFSC 2008) adopted a form of the Baranov catch equation for estimating both F and M parameters. Both concluded that natural mortality in Chesapeake Bay striped bass had increased since the late 1990s. Incorporating higher M into the tag recapture models meant that the resulting F estimates were substantially lower than previous values or SCA model estimates. However, alternative estimates of natural mortality have not been fully incorporated in the models used for management.

Changes to the catch-at-age model prompted a reevaluation of input parameters for the biological reference points. In 2008 the SBTC revised the F_{MSY} and $SSB_{Threshold}$ values based on the new estimates of SSB and recruitment from the SCA model. After much discussion, the SBTC adopted a compromise approach for the stock-recruitment input as the average of model configurations using the Shepherd (1982) and Ricker (1975) stock/recruitment models with normal and log-normal error assumptions (Figure 8). The F_{MSY} estimate using the Shepherd models equaled 0.28, while the over-compensation assumption in the Ricker models resulted in an F_{MSY} equal to 0.37. The resulting reference points became an F_{MSY} of 0.34 and target F of 0.30. The $SSB_{Threshold}$ remained as the biomass in 1995, which was now estimated at 30,000 mt.

Regardless of the changes to the catch-at-age modeling approaches and revised reference points, the striped bass stock complex remained above $SSB_{Threshold}$, and fishing mortality on the stock complex remained below F_{MSY}.

Conclusion

Over the past 2 decades, major advances have occurred in the striped bass stock assessment process. Current population models can now account for changes in the fishery, changes in survey data, and changes in stock dynamics. The use of both tag models and catch-at-age models to evaluate exploitation is highly valuable and a rare commodity in stock assessments. Yet despite the advancements in the modeling, the basic information gathered remains the same. As with many fisheries, there are components of the catch data that remain uncertain (e.g., commercial discards). Recent comparisons of age determinations among age readers, together with comparisons to fish with known ages, have raised the question of the accuracy of striped bass age readings using scales (Secor et al. 1995; Liao et al. 2013). There is no single fishery-independent survey of the mixed stock coastal fishery that is equally effective for both small and large fish. The difficulty of assessing a mixed stock complex remains and has become more acute, as abundance trends among the 3 stocks have diverged under different exploitation and environmental conditions. As the assessment process continues to evolve, there will be a need to further address problems related to: (a) time and age varying natural mortalities, (b) different migratory patterns of each stock and area-specific exploitation rates, and (c) new approaches to developing indices of abundance. The ultimate demonstration of the advances made in the assessment of striped bass populations will be the continuation of reliable scientific advice leading to successful management of the resource.

Table 1. Sequence of striped bass (*Morone saxatilis*) biological reference points since the 1990 reopening of the fishery. M refers to natural mortality, F is fishing mortality, SSB is spawning stock biomass, $F_{rebuild}$ is the fishing mortality necessary to rebuild stock biomass to target levels, F_{MSY} is fishing mortality necessary to achieve maximum sustainable yield, $F_{interim}$ is a fishing mortality between $F_{rebuild}$ and F_{MSY}, F_{target} is a fishing mortality that minimizes the probability of exceeding F_{MSY}, $SSB_{threshold}$ is an SSB below which requires management action to rebuild the stock, and SSB_{target} is the SSB which reduces the likelihood of dropping to $SSB_{threshold}$.

1990 Amendment 4 (M = 0.2)

- sustainable F = 0.5, $F_{rebuild} = 0.25$
- no SSB target or threshold

1995 Amendment 5 (M = 0.2)

- $F_{MSY} = 0.4$, $F_{interim} = 0.33$
- no SSB target or threshold

M adjusted to 0.15

- $F_{MSY} = 0.38$, $F_{target} = 0.31$
- no SSB target or threshold

2003 Amendment 6 (M=0.15)

- $F_{MSY} = 0.41$, $F_{target} = 0.30$
- $SSB_{threshold} = 14{,}000$ mt
- $SSB_{target} = 17{,}500$ mt

2008 Amendment 6 (revised)

- $F_{MSY} = 0.34$, Ftarget = 0.30
- $SSB_{threshold} = 30{,}000$ mt
- $SSB_{target} = 37{,}500$ mt

Table 2. Estimates of striped bass (*Morone saxatilis*) fishing mortality developed by using Brownie models applied to tag recapture results.

Location	Month Tagged	Years of Inference	Fishing Mortality male	female
Chesapeake	March	1988-1989	0.31	0.35
		1989-1990	0.08	0.11
		1990-1991	0.37	0.41
Hudson	April	1988-1989	0.08	0.11
		1989-1990	0.58	0.63
		1990-1991	0.49	0.53
			sexes combined	
North Carolina	January	1988-1989	0.08	
		1989-1990	0.68	
		1990-1991	0.38	
New York	September	1987-1988	0.27	
		1988-1989	0.23	
		1989-1990	0.20	

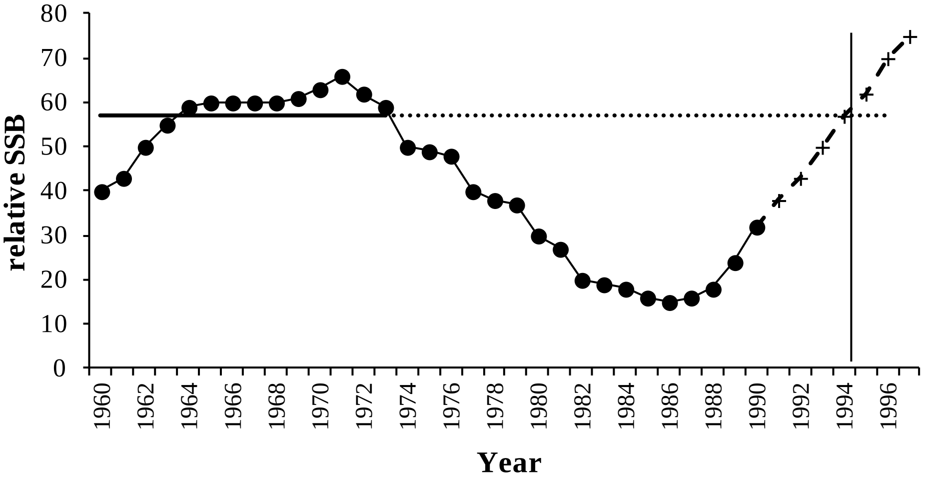

Figure 1. The spawning stock biomass (SSB) model formed the basis for evaluating striped bass (*Morone saxatilis*) rebuilding success. The average from 1960-1972 was the standard for restoration. In 1995 the SSB index exceeded the 1960-1972 average, and the Chesapeake striped bass stock was declared restored.

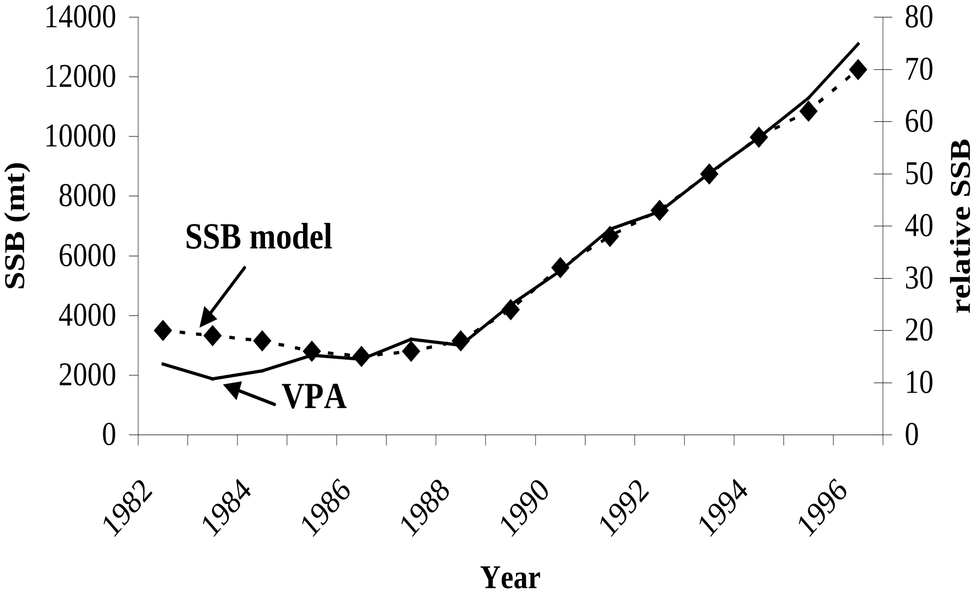

Figure 2. Results of a virtual population analysis (VPA) model estimates of striped bass (*Morone saxatilis*) spawning stock biomass (SSB) compared to results from SSB model.

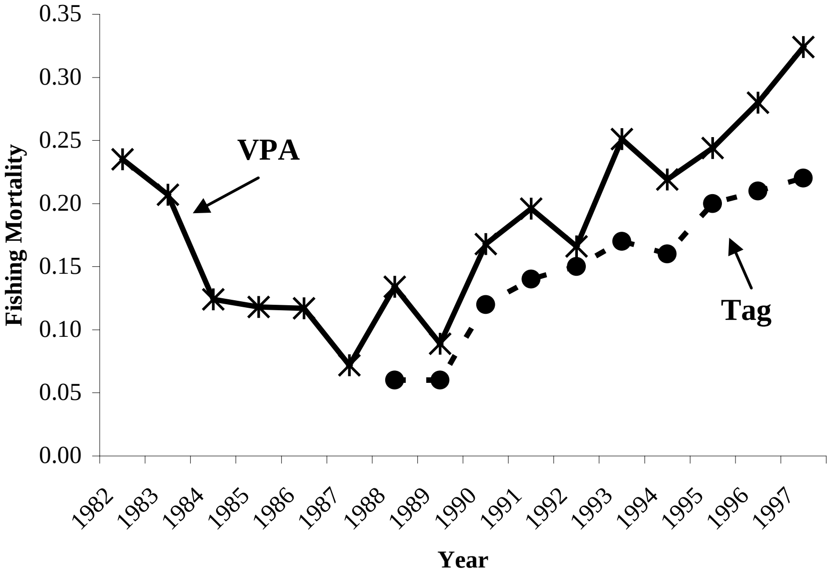

Figure 3. Initial 1997 time series of striped bass (*Morone saxatilis*) fishing mortality (ages 4-13) from the virtual population analysis model (VPA) compared to average tag results for coastal stock complex (≥ 28”).

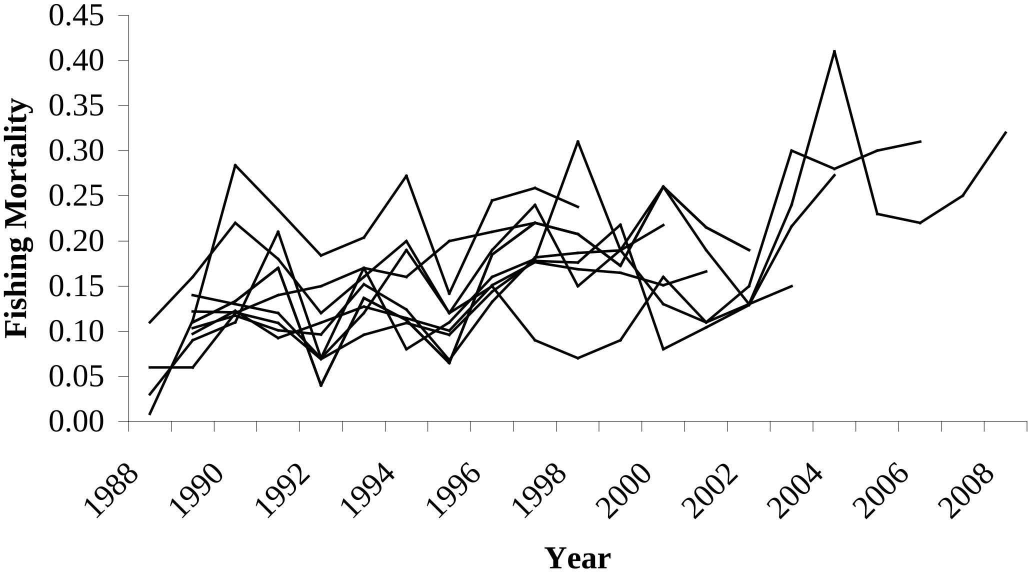

Figure 4. Bias corrected average tag model estimates of striped bass (*Morone saxatilis*) fishing mortality for coastal stocks ≥ 28” for a series of years, developed using MARK software. No evidence that average fishing mortality (F) exceeded the threshold.

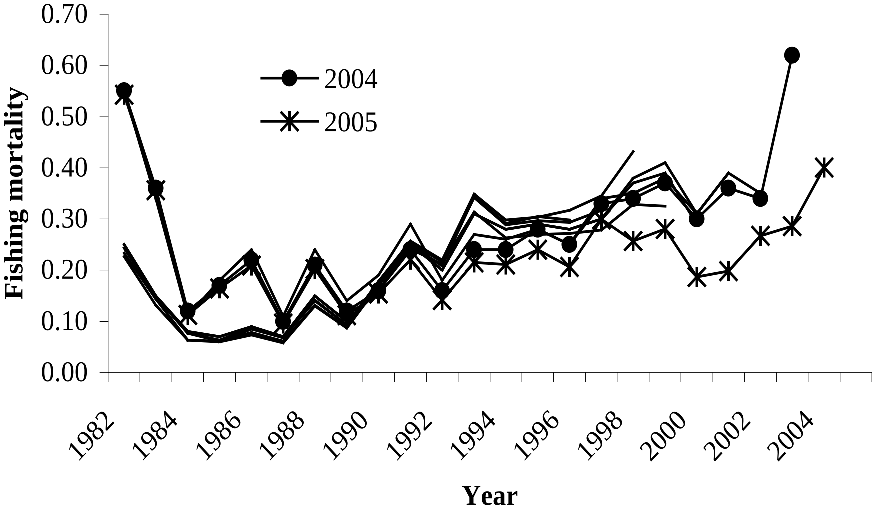

Figure 5. Trends in striped bass (*Morone saxatilis*) fishing mortality from the virtual population analysis model (VPA) among years showing divergence in 2004 and 2005.

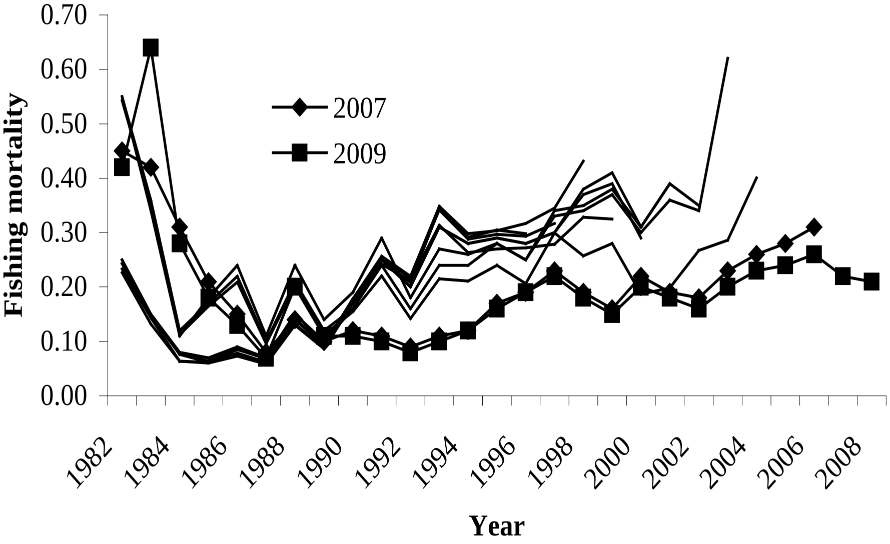

Figure 6. Estimates of striped bass (*Morone saxatilis*) fishing mortality from the statistical catch at age (SCA) model in 2007 and 2009 compared to earlier annual estimates from the virtual population analysis model (VPA).

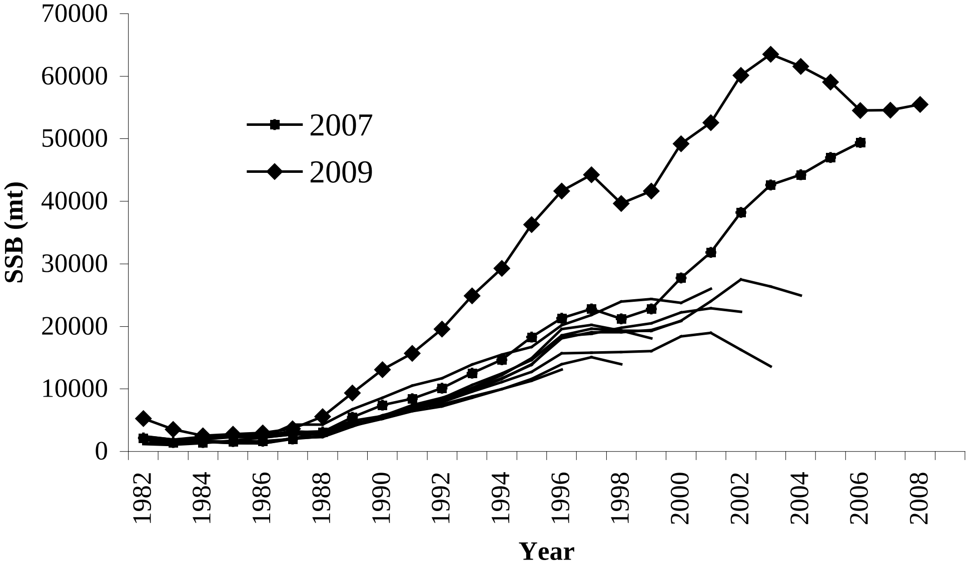

Figure 7. Striped bass (*Morone saxatilis*) spawning stock biomass (SSB) estimates from the virtual population analysis model (VPA) (solid lines) compared to the statistical catch at age (SCA) model from 2007 and 2009 (which also incorporated changes in the sex ratio).

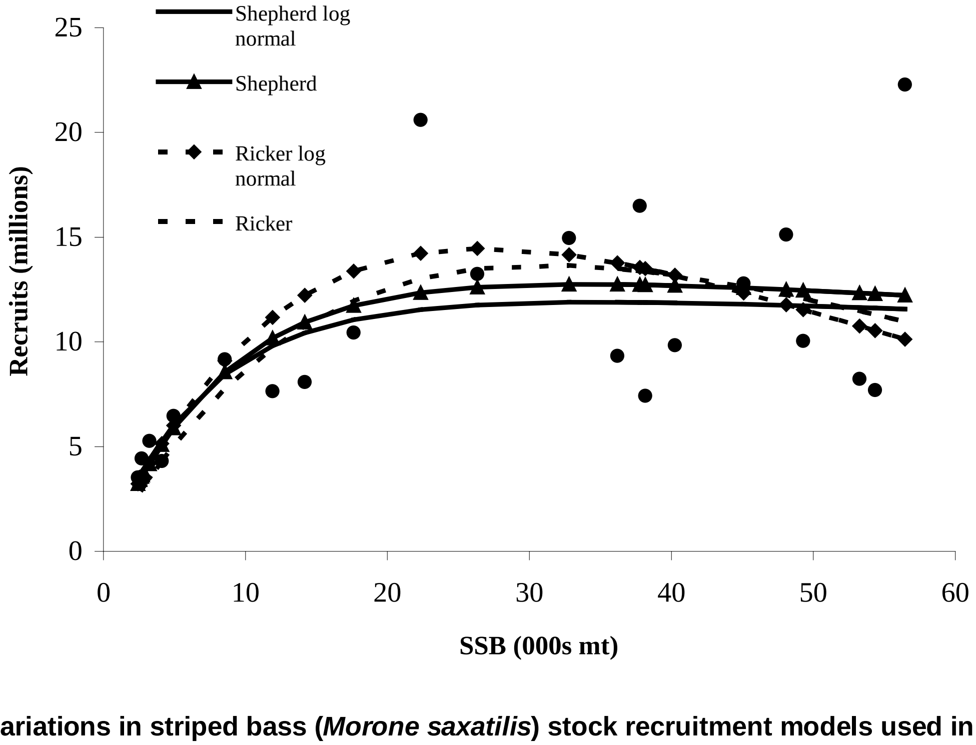

Figure 8. Variations in striped bass (*Morone saxatilis*) stock recruitment models used in 2008 biological reference point calculations.

SECTION IV
RECENT DEVELOPMENTS IN THE STATISTICAL CATCH-AT-AGE ASSESSMENT MODEL, REFERENCE POINTS, AND STOCK STATUS FOR ATLANTIC MIGRATORY STRIPED BASS

Gary A. Nelson

Introduction

The migratory striped bass (*Morone saxatilis*), has been an economically-important anadromous fish species on the east coast of the United States from Maine through North Carolina since colonial times (Setzler et al. 1980). Since the 1980s, the Atlantic States Marine Fisheries Commission (ASMFC) has been responsible for assessing the stock status of striped bass. Under auspices of the ASMFC, assessments are conducted by the ASMFC Striped Bass Technical Committee (SBTC) (Richards and Rago 1999). Since 2006, the striped bass assessment has been updated every 2 years by using models with consistent structure, and a benchmark assessment in which new models can be introduced is scheduled every 5 or 6 years.

Many technical approaches from tagging analyses to catch-at-age models have been used to determine the stock status of striped bass (see previous section entitled, “Advances in the Evaluation of Atlantic Striped Bass Stock Status – 1990 to 2009”). The use of a statistical catch-at-age model (SCA) is the most recent approach. The SCA framework is very flexible (Fournier and Archibald 1982) in that many types of fisheries data (e.g., catch, relative abundance indices, etc.) are integrated in the model, errors in point estimates of landings are accounted for, and incomplete time series of data are used. Since the SCA model is the primary striped bass assessment tool used by the ASMFC to provide management values such as reference points, discussion of the development of the model and its impact is warranted. In this paper, I present a historical perspective of the developments in the striped bass statistical catch-at-age model, reference points derived from the results, stock status determination, and actions taken by the Atlantic States Marine Fisheries Commission’s Striped Bass Management Board in response to recent results of the assessment.

Stock Assessments 2007-2015

The statistical catch-at-age model (SCA) has been used as the primary assessment tool for striped bass since 2007 (NEFSC 2008) because it provides management information, such as direct comparison to biological reference points, that the supplementary tagging analyses cannot provide. Unlike the Virtual Population Analysis (VPA) model used previously, the SCA model accounts for error in commercial catch and the recreational harvest and releases determined from the Marine Recreational Information Program (MRIP, previously known as MRFSS), fishery independent indices of relative abundance and age data, most of which are estimated by or collected from on-going state survey sampling programs (NEFSC 2008). Although SCA models like ASAP (http://nft.nefsc.noaa.gov/ASAP.html) are available in software packages, the 2007

SCA model was specifically developed to accommodate data from striped bass. Details of the 2007 model equations and structure are given in NEFSC (2008).

The 2007 SCA model population dynamics assumed a single unit stock. To that end, state removal (harvest plus dead discards) numbers and age composition data were combined for model input. Three fisheries-dependent and 9 fisheries-independent surveys provided age-specific and age-aggregated indices that were used to tune the model (Table 1). A constant natural mortality rate (M) of 0.15 was used for all ages to allow estimation of fishing mortality (F) and age-specific selectivity. Similarly, constant age-specific female to male ratios of 50:50 were assumed to calculate the female spawning stock biomass (SSB). The ASMFC Striped Bass Technical Committee (SBTC) agreed that the SCA model structure and resulting estimates of F and SSB (Figure 1) were improvements over the VPA model but noted that retrospective bias observed in the VPA model was still present. Nonetheless, the SBTC agreed that the model was useful for management purposes as did members of the Stock Assessment Review Committee (SARC) who scrutinized the model (NEFSC 2008). Comparison of the average F (ages 8-11) and SSB in the terminal year (2006) to previously determined biological reference points for F and the updated SSB (threshold: estimated 1995 value; target: 1.25 times the threshold) indicated that the striped bass stock was not overfished and that overfishing was not occurring (Table 2).

The same 2007 structure of the SCA model was used for the 2009 and 2011 stock assessment updates, but input data were updated. Some fishery independent indices were changed such as the New York ocean haul seine survey and the Northeast Fisheries Science Center trawl survey which were discontinued from model input in 2007 and 2009, respectively (Table 1). Based on a recommendation of the SARC review, age-specific empirical estimates of female to male sex ratios were used in the calculation of female spawning stock biomass starting in 2009 which significantly changed the magnitude of SSB (Figure 1). Therefore, recalculation of the F and SSB reference points using the 2009 model output was required. Annual recruitment was not estimated by using a predetermined stock recruitment function (e.g., McGilliard et al. 2015); therefore, the fishing mortality reference points (F_{MSY} and target F) were calculated by using a mixture of stock-recruitment functions fitted externally to the model estimates of recruitment and SSB (Table 2). Like previous assessments, the spawning stock biomass threshold remained as the SSB estimated in 1995, and the target was set at 1.25 times the threshold (Table 2). Comparison of the average F for ages 8-11 and SSB in the terminal years (2008 and 2010) of the 2009 and 2011 reference points updates indicated that striped bass were not overfished and that overfishing was not occurring (Table 2).

A benchmark assessment in 2013 allowed the SCA model structure to be altered. The SBTC decided to update it to take full advantage of the information content of the catch and age data beyond the current configuration. For example, there were suspected differences in fishing selectivities between Chesapeake Bay and the coastal fisheries because of major size differences observed in the catches, yet these differences had not been incorporated into the previous assessments. To that end, the striped bass SCA model was generalized to allow specification of multiple regional fleets, different stock-recruitment relationships, year- and age-specific natural mortality rates, different selectivity functions for fleets and surveys with age composition data, and ageing error matrices. Although finer resolution of the catch and age was incorporated, the base population dynamics model still assumed a single stock.

In the 2013 SCA model, the catch and age data were split into regional "fleets" as a way to account for suspected regional differences in selectivity. The 2 main fleets were Chesapeake Bay (Maryland and Virginia bay removals) and the "ocean" which included ocean catch from all states (including Maryland and Virginia) as well as catch from Delaware Bay and Hudson River. Unfortunately, the estimates of commercial discards in the catch estimate could not be split into regions, so these data were treated as a separate fleet. This “fleet” model allowed region-specific patterns in selectivity to be estimated. In addition, age-specific estimates of natural mortality derived from tagging analyses, and life history invariant methods (e.g., Lorenzen 1996) were incorporated as well. The 2013 SCA model was used to estimate fishing mortality for each fleet, abundance and spawning stock biomass of striped bass for 1982-2012 from updated total removals-at-age and fisheries-dependent and fisheries-independent survey indices used previously. An additional fisheries-dependent index (Virginia pound net) was also included (Table 1). The model and results were reviewed by a SARC panel in 2013, and members agree that the model represented the best available science and could be used for management purposes (NEFSC 2013).

The changes made in the 2013 SCA model required recalculation of the reference points because the new fleet selectivities, the switch to fully-recruited F as the management value, and incorporation of age-specific natural mortality again changed the magnitude of F and SSB (Figure 1). In previous assessments, the target and threshold reference points for F and SSB were not linked through a common model like spawning biomass per recruit analysis (Shepherd 1982), but were determined independently. Therefore, the SBTC decided to use a different approach which would link the F and SSB reference points. The definition of the female spawning stock biomass threshold (estimated 1995 SSB) and target (1.25 times the threshold) were retained, but the fishing mortality necessary to achieve the threshold and target SSB were estimated by using Monte Carlo simulation. By using a stochastic projection which drew recruitment from empirical estimates (the appropriate stock-recruit relationship for striped bass was unknown) and a distribution of starting population abundance-at-age from the SCA model output, fishing mortalities associated with the SSB target and threshold were determined by repeated projections of the population over a 50 year period. Selectivity was calculated as the geometric mean of the last 5 years of total F at age, scaled to the highest F at age. Estimates of recruitment were restricted to 1990 and later, when the stock was considered restored but not fully rebuilt. Based on the updated reference points, the stock status of the striped bass population in 2012 was not overfished and overfishing was not occurring (Table 2).

Although the stock status was positive, the 2013 assessment showed that SSB was declining (Figure 1) primarily because of average to below-average production of recruits in Chesapeake Bay during 2004-2010 (NEFSC 2013). Projections indicated the SSB would fall below the SSB threshold with near complete certainty by 2015 if fishing mortality remained at the current level (Figure 2). As a precautionary measure, the ASMFC Striped Bass Management Board initiated the development of Addendum IV of the striped bass management plan to reduce the decline in SSB by decreasing fishing mortality. Stochastic projections were used to determine the fishing mortality that would allow SSB to begin recovery after 2015, and the results indicated that coast-wide removals would have to be reduced by 25%.

To achieve the 25% reduction, Addendum IV restricted recreational and commercial fisheries to certain management options. The recreational fisheries in all coastal jurisdictions were constrained to a 1 fish bag limit and 28-inch minimum size limit, but any state could submit alternate measures that demonstrated conservation equivalency of at least a 25% reduction in removals. For the commercial fisheries, quotas had to be reduced by 25%, but states were also allowed to make size limit changes as long as conservation equivalency was met. An exception was made for the Chesapeake Bay jurisdictions. Reductions of only 20.5% were required in the recreational and commercial fisheries because harvest had been already reduced as part of their management measures to adjust quotas with changes in recruitment levels. All conservation equivalency proposals were subject to SBTC review, and board approval and regulations changes were implemented in 2015.

For the 2015 striped bass stock assessment, the 2013 model structure was used and data were updated through 2014 (ASMFC 2015a). The Atlantic striped bass stock remained not overfished, and overfishing was not occurring based on the point estimates of fully-recruited fishing mortality and female spawning stock biomass relative to the reference points (Table 2). However, estimates of SSB for the latter years of the time series showed less decline than did the estimates from the 2013 assessment (Figure 1), and the projections now suggested that the SSB will still decline, but the point estimates will be close to but will not fall below the SSB threshold (Figure 2).

In response to the 2015 updated assessment, members of the ASMFC Striped Bass Management Board from MD and VA made a motion during the November 2015 meeting to initiate an addendum to reconsider the reduction options in Addendum IV for the 2016 fishing season in the Chesapeake Bay. The motion was tabled but only after considerable discussion and rejection of the motion by other states. However, a compromise was reached to update the assessment with data from 2015 to show potential population changes associated with the 2015 regulations. However, only 1 year of data will be available to estimate selectivity in the terminal year; thus, the updated estimates of F and SSB in the terminal year may have considerable uncertainty.

Future Assessments

The development of stock-specific assessment models for striped bass has been the ultimate goal of the SBTC. A recent initiative to produce Chesapeake Bay and ocean reference points from the current stock assessment model by using ad hoc methods (ASMFC, 2015b) has stressed the importance of developing stock-specific models. Separate stock assessment models would provide the management values and reference points needed to conserve each stock and to reduce the risk of over-exploitation of a single stock with use of the combined stock model.

Much of the data required to develop stock-specific models are lacking. Information on annual removals, age composition, and relative abundance is available for 3 main stocks (Chesapeake Bay, Delaware Bay, and Hudson River) in the production areas, but information on annual stock composition of ocean removals is not available. In addition, striped bass exhibit sex-specific growth, mortality, and spatial dynamics, so incorporating these differences will require data on sex composition of the removals, natural mortality rates, as well as stock-specific migration rates. Unfortunately, most data collection programs do not include sex composition. Determination of stock composition is possible through genetic analyses (Bulak et al. 2004) but would require annual sampling because of changes in year-class strength. Some information on emigration rates can be derived for the Chesapeake Bay and Delaware Bay stocks through the standard tagging programs (e.g., Dorazio et al. 1994), but estimation of immigration rates from the ocean to spawning areas would require additional studies. It may also be possible to estimate natural mortality and immigration rates with the use of acoustic telemetry (Hightower et al. 2001; Kneebone et al. 2014), and some ASMFC-funded studies are currently underway.

There are several additional hurdles that have to be addressed to develop stock-specific models. First, in a time of shrinking budgets, fewer staff and resources of fishery agencies are being dedicated to data collection beyond the standard baseline information (i.e., catch, age data, and abundance indices). Consequently, most state agencies cannot support additional efforts to collect the needed data for stock specific models. Second, there is no single sampling design among programs and limited coordination among programs that provide striped bass data. For instance, the tagging of striped bass by 8 separate programs occurs at different times of the year and in relatively few locations, and the resulting estimates of mortality among the programs are often quite different in magnitude (NEFSC 2008). Deriving stock-specific quantities such as immigration rates will require a coordinated coast-wide effort to sample over the entire distribution range of the migratory striped bass. Finally, development of the necessary studies, analysis of results, and modeling the complex dynamics of this species requires time and resources which are often limited, a factor which hinders timely development of required population estimates. Until these issues are resolved, managers may have to depend on the assessment results produced within the context of the SCA model and the inherent uncertainty associated with managing a mixed stock as a single entity.

Table 1. Summary of fisheries-dependent and fisheries-independent survey data used in the striped bass (*Morone saxatilis*) statistical catch at age (SCA) model for assessment years 2007, 2009, 2011, 2013, and 2015. Acronyms used in the table include catch per unit effort (CPUE), young of the year (YOY), National Marine Fisheries Service (NMFS), and Northeast Fisheries Science Center (NEFSC).

Surveys	Design	Data Availability	Time of Year	Stock	Linked Ages	Assessment Years
Fisheries-Dependent						
Massachusetts Commercial CPUE[1,2]	Commercial Trip Reports	1991-2010	June-Sept	Mixed	2-13+	2007-2011
Connecticut Recreational CPUE[3]	Volunteer Anglers	1981-2011	May-Dec	Mixed	1-13+	2007-2011
Coast-wide NMFS Recreational Survey[3,4,5]	Stratified Random	1988-present	May-Dec	Mixed	Aggregate (3-13+)	2007-2015
Virginia Pound Net Survey[6]	Fixed	1991-present	March-May	Chesapeake	1-13+	2013-2015
Fisheries-Independent [7,8]						
Connecticut Trawl Survey	Stratified Random	1984-present	April-June	Mixed	Aggregate (4-6)	2007-2015
NEFSC Trawl Survey[9]	Stratified Random	1991-2008	March-May	Mixed	Aggregate (2-9)	2007-2015
New York Ocean Haul Seine Survey	Random	1987-2006	Sept-Nov	Mixed	2-13+	2007-2015
New York YOY Seine Survey	Fixed	1980-present	July-Nov	Hudson	1	2007-2015
New York W. Long Island Seine Survey	Fixed	1980-present	May-Oct	Hudson	2	2007-2015
New Jersey YOY Seine Survey	Fixed/Random	1980-present	Aug-Oct	Delaware	1	2007-2015
New Jersey Trawl Survey	Stratified Random	1989-present	April	Mixed	2-13+	2007-2015
Delaware Electrofishing Survey	Lattice	1996-present	April-May	Delaware	2-13+	2007-2015
Virginia YOY Seine Survey	Fixed	1980-present	July-Sept	Chesapeake	1	2007-2015
Maryland YOY and Age 1 Seine Survey	Fixed	1954-present	July-Sept	Chesapeake	1 and 2	2007-2015
Maryland Spawning Stock Gillnet Survey	Stratified Random	1985-present	April-May	Chesapeake	2-13+	2007-2015

[1] Total catch rate (number per hour)

[2] Generalized linear model with normal errors

[3] Total catch rate (number per trip)

[4] Intercepts from boats and ocean only

[5] Delta-lognormal linear model

[6] Geometric mean number per set

[7] Geometric mean number per set (gill nets), tow(trawls), haul (seines), and hour (electrofishing)

[8] All YOY and age-1 seine surveys are advanced one year and age because age-0 numbers are not modeled.

[9] Ship change precludes use of data after 2008

Table 2. Summary of striped bass (*Morone saxatilis*) historical fishing mortality and female spawning stock biomass terminal year values and corresponding reference points.

	Terminal Year				
Management Value	2006	2008	2010	2012	2014
F	0.31	0.21	0.23	0.20	0.21
SSB (mt)	25,000	55,000	50,000	58,200	63,918
F threshold	0.41	0.34	0.34	0.22	0.22
F target	0.30	0.31	0.31	0.18	0.18
SSB threshold (mt)	14,000	30,000	30,000	57,626	57,626
SSB target (mt)	17,500	37,500	37,500	72,033	72,033

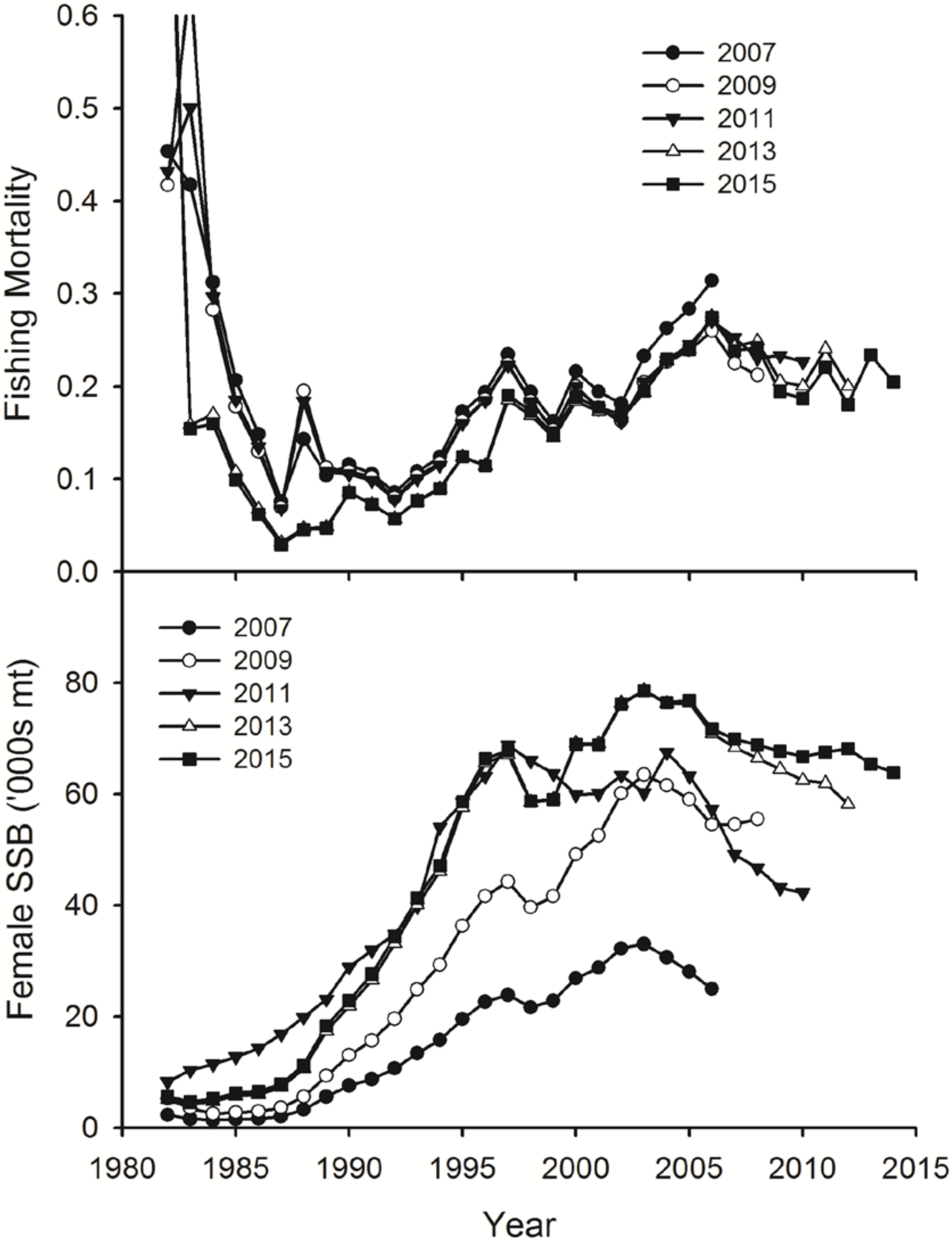

Figure 1. Estimates of fishing mortality and female spawning stock biomass of striped bass (*Morone saxatilis*) from the 2007-2015 statistical catch-at-age models.

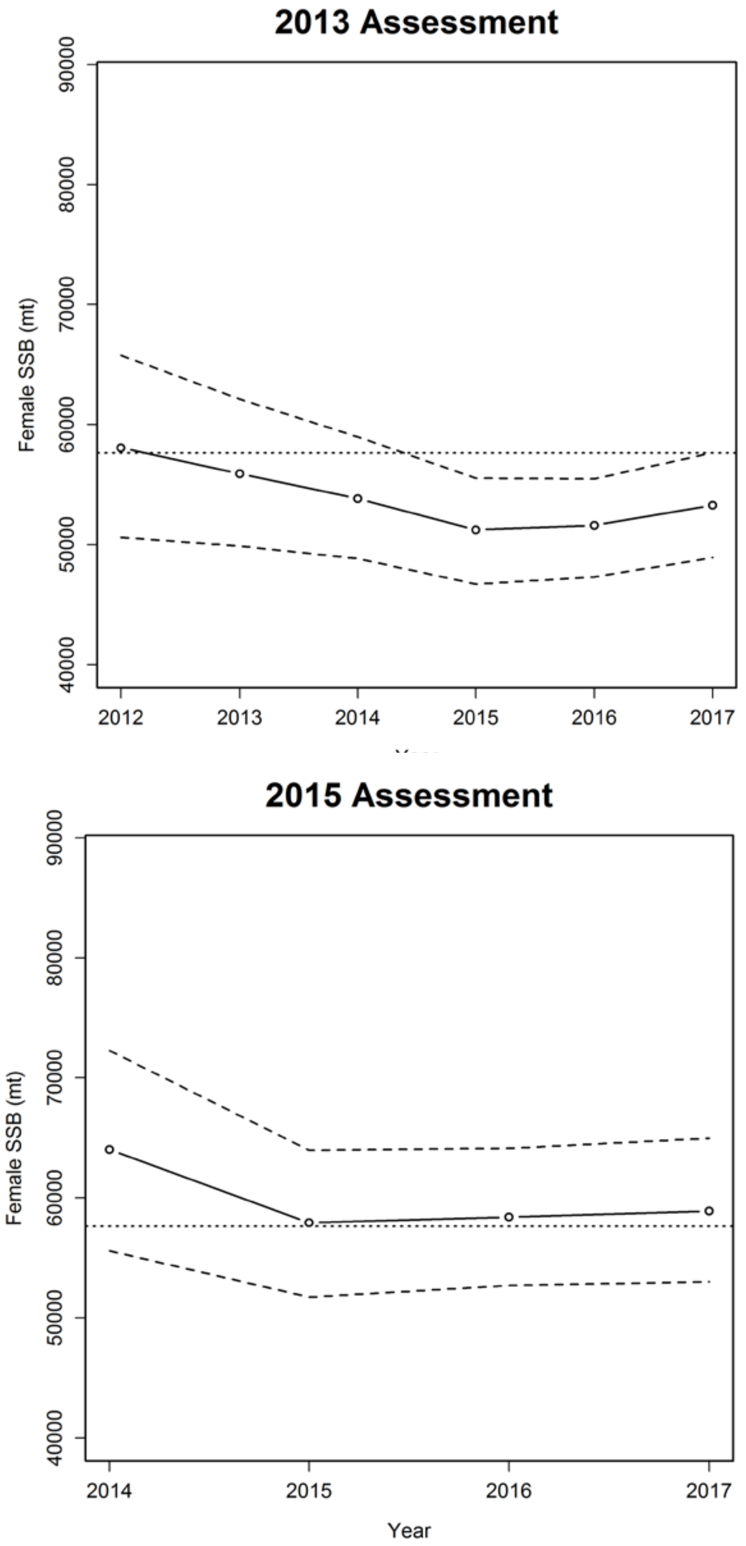

Figure 2. Stochastic projections of female striped bass (*Morone saxatilis*) spawning stock biomass from the 2013 and 2015 stock assessment results.

CONCLUSIONS

The story of the recovery of Atlantic striped bass from the collapse in the 1970s still resonates among fishery managers as a success story. Cooperation among fishermen, managers, scientists, and politicians who all contributed to the success was possible because of the common goal of restoring the fishery. Not to be lost in the success was the simple fact that striped bass as a species is very resilient. As pointed out by Pearson (1938), striped bass has perhaps the broadest range of any gamefish in America. Following transplantation of striped bass from New Jersey to California in 1879, the species has adapted to habitats along the west coast, from Washington to southern California, as well as the Gulf of Mexico up to the Gulf of Maine and the Gulf of St. Lawrence. Habitats range from deep freshwater lakes, brackish estuaries, and the marine environment. It should come as no surprise that once fishing pressure was reduced and the environmental conditions in the Chesapeake Bay and tributaries were appropriate for successful egg and larval survival, the stock responded favorably. Yet it serves as a reminder to all that participate in fisheries and fisheries management that with reasonable scientific information and a common objective, fisheries management success stories are possible.

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