ECOSYSTEM BASED FISHERIES MANAGEMENT FOR CHESAPEAKE BAY

Striped Bass Species Team Background and Issue Briefs

The Ecosystem-Based Fisheries Management (EBFM) Project for Chesapeake Bay has been developed and coordinated by Maryland Sea Grant, working in partnership with the scientific community and the region's state and federal agencies (the Virginia Marine Resources Commission, Maryland Department of Natural Resources, Potomac River Fisheries Commission, Atlantic States Marine Fisheries Commission, District of Columbia Department of the Environment, NOAA, and EPA). The EBFM Project targets five key species identified in the Ecosystem Planning for Chesapeake Bay document, including striped bass, menhaden, blue crab, alosines, and oysters. The goals of the EBFM project are to build a sustainable mechanism for addressing ecosystem issues for fisheries within Chesapeake Bay and to develop ecosystem tools for use in ecosystem-based fishery management plans for the five key species (or group of species in the case of alosines). Currently the project involves 85 scientists, managers, and stakeholders from within and beyond the Chesapeake Bay region. For more information on Maryland Sea Grant's Ecosystem-Based Fishery Management Project please visit: www.mdsg.umd.edu/ebfm.

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Ecosystem Based Fisheries Management for Chesapeake Bay: Striped Bass Background and Issues Briefs

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Introduction

Jim Uphoff, Chair, Striped Bass Species Team

Few management plans have included ecological information that reach beyond a descriptive level. To be predictive or prescriptive — to actually put ecological information to use in managing fisheries — requires dedicated analysis of data, targeted research and monitoring, and a broader management process and perspective than is currently encompassed in single-species management. In theory, it is possible to prevent or replace unpopular restrictions on harvest with increased production by protecting, enhancing, or restoring critical habitats or ecological functions. It should also be possible to quantify the additional restrictions needed to offset losses from unfavorable environmental conditions so that the cost of these losses (reduced fishing mortality, yield, and spawning potential) is readily understood (Boreman et al. 1993). It would be useful to decision-makers to have quantitative estimates of the effect of alternative habitat or watershed management regimes on production when considering harvest reductions.

Fisheries management agencies have relied on single species fisheries management to sustain yield. This strategy has become less favored in light of the realization that the dynamics of predation, competition, environmental regime shifts, and habitat alteration or deterioration may take over once overharvesting has been controlled (Link 2002). Simply presuming that ceasing exploitation of an overfished stock will result in recovery ignores the uncertainty imposed by ecological systems (Link 2002). Locally, concerns about disease and forage-base collapse have risen in the Bay following efforts to restore striped bass (Uphoff 2003). Looming development pressure is prompting managers to explore methods to prevent or incorporate habitat loss into management decisions.

Implementation of broader ecological considerations in fisheries management has not become widespread even though it has been emphatically advocated. On a national level, both the Pew Oceans Commission and U.S. Commission on Ocean Policy advocated ecosystem-based management of ocean resources (Dayton et al. 2002; U.S. Commission on Ocean Policy 2004). A federal panel recommended each regional fisheries management council develop fisheries ecosystem plans (FEPs) as part of the Magnuson-Stevens Act reauthorization (NOAA Chesapeake Bay Fisheries Ecosystem Advisory Panel or CBFEAP 2006). This panel report spurred the NOAA Chesapeake Bay Office (NBO) to advocate and sponsor a FEP for Chesapeake Bay. The CBFEAP has completed a FEP umbrella document to support ecosystem-based management within the Bay (CBFEAP 2006).

As a step towards ecosystem-based fisheries management, a team of experts was assembled to develop background documents for a broad array of issues that will confront current and future managers of one of the Chesapeake Bay's most cherished resources: Striped bass. These briefs form a conceptual outline of the array of ecological problems that managers may face as fisheries management's focus moves beyond managing fishers as its fundamental response to nearly all issues. Quantitative Ecosystem Teams are expected to take these concepts and develop them into quantitative indicators, targets, and thresholds so that managers and stakeholders can readily understand how effective future policies are being implemented.

Issue Statements (Alphabetical Order)

Contaminants and Pollution. Contaminants were implicated in the decline of Chesapeake Bay striped bass recruitment in the 1970s, but their effects were indistinguishable at the population level from high fishing rates, an unfavorable climate regime, or a combination of these factors. Contaminants could depress productivity, requiring overly conservative fishing regulations to compensate. Risk management strategies will need to be developed in the future to deal with suspected contaminant-related problems because it is unlikely that causative factors will be well understood. Consumption-related advisories may lower desirability of striped bass as table-fare, impacting both commercial sales and recreational participation.

Disease. Striped bass are known to be susceptible to a variety of common fish pathogens and mortality events have occurred in Chesapeake Bay. Recent attention to striped bass disease in Chesapeake Bay, however, has largely centered on disease caused by bacteria in the genus *Mycobacterium.* Recent stock assessments in Chesapeake Bay indicate that non-fishing mortality in striped bass has increased since 1999. Recent modeling with newly developed epidemiological techniques has indicated that disease is associated with increased mortality in Chesapeake Bay striped bass. In addition to their impacts on fishes, aquatic mycobacteria may be human pathogens, producing lesions in skin and peripheral tissues.

Exploitation. Fishing removes biomass and can affect the structure and function of the Chesapeake Bay ecosystem. Traditional biological reference points do not account directly for dynamics in trophic interactions between the top predator, such as striped bass, and prey species. Changes in exploitation rates of striped bass, designed to achieve a certain management goal from single species prospective, will lead to a change in predatory pressure on prey species and may affect their population dynamics as well.

Flow. Consumptive use and hydropower operations in Chesapeake Bay tributaries can alter natural flow regimes thereby impacting striped bass spawning and nursery habitats.

Forage and Predation. Low fishing mortality and high size limits have led to more abundant and larger striped bass. Consumption by this population has been potentially high enough to seriously impact the fisheries and abundance of forage fishes. High demand has been concurrent with deterioration of indicators of striped bass nutritional state, an outbreak of lesions and mycobacterium, and rising natural mortality rate estimates.

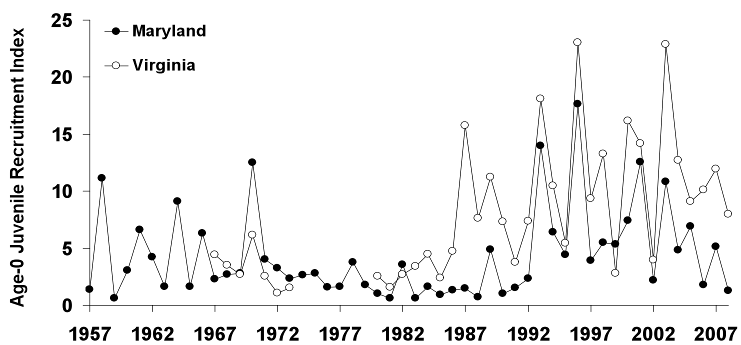
Global Warming. Future warming during winter and spring could disrupt the match between the timing of spawning and those conditions favorable to recruitment. Similarly, a mismatch between seasonal fisheries regulations and migration/distributions can occur due to warming. Winter warming could promote year-round residency, and reduce overwinter juvenile mortality. On the other hand, warming summers could substantially depress habitat suitability for older resident striped bass. Future management should maintain diverse spawning behaviors that promote stability in recruitment against future winter and spring climate conditions, which are likely to be warmer, increasingly variable, and unfavorable to striped bass recruitment.

Hypoxia. Hypoxic volume has expanded in Chesapeake Bay over the past 50 years and represents an increasing loss of summer habitat for adult and juvenile striped bass.

Invasive and Introduced Species. Blue and flathead catfish in tidal fresh and mesohaline tributaries of Chesapeake Bay are likely to compete with young of the year (YOY) to early age-1 striped bass for invertebrate prey and age-1 to adult striped bass for clupeid forage species. Predation of YOY striped bass by flathead catfish, blue catfish, or northern snakehead has not been documented, but predation of YOY striped bass is possible and should be monitored as the non-native invasive species populations expand.

Population Structure and Biodiversity. Yield, stability, resilience, and persistence of the Chesapeake Bay striped bass metapopulation depends upon (1) conservation of spawning units attached to each major Chesapeake sub-estuary; (2) sustained functioning of nurseries associated with those spawning units; and (3) some degree of connectivity between spawning units and their associated nurseries. Exploitation, habitat degradation, and climate will differentially affect spawning units and nurseries in unknown ways, but surveys can efficiently monitor their individual productivity and variances.

Recruitment Variability. Striped bass recruitments in the Maryland and Virginia portions of Chesapeake Bay vary more than 20-fold among years. Age-0 juvenile recruitments were low when the Atlantic coast fishery collapsed in the 1970s, and recruitment levels increased as the population recovered in the early 1990s. High interannual variability in recruitment is still a conspicuous characteristic of post-recovery striped bass population dynamics.



Watershed Development. Increasing urban sprawl associated with population growth has been identified as a threat to the Chesapeake Bay watershed. Sprawl may negatively impact water supply and water quality, affecting striped bass larvae, juveniles, and adults through sedimentation, flow alteration, nutrient enrichment, contaminants, and thermal pollution.

Socioeconomic Briefs. In addition, at the time this introduction is being written, we are awaiting receipt of four briefs addressing socio-economic concerns for striped bass in the Chesapeake Bay: Livelihoods, Economic Implications of Management, Valuation of Water Quality, and Consumption and Demand. These issue briefs will highlight the essential human component that is critical to successful Ecosystem Based Fisheries Management.

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STRIPED BASS BACKGROUND AND ECOSYSTEM ISSUE BRIEFS

STRIPED BASS BACKGROUND BRIEFS

Section	Authors
1. Early Life History	Fabrizio, Martino
2. Late Life History	Cimino, Johnson
3. Socioeconomics	Lipton
4. Management	Meserve, Cimino

BASS ECOSYSTEM ISSUE BRIEFS

QET	Authors	Issue Brief	Issues	Metric/Indicator Needed	Reference Points Needed
Habitat Suitability	Martino, Secor	5. Warming	Degraded Nursery	Habitat Suitability	% Carrying Capacity
			Increased Forage Demand	Trophic Demand/Supply	% Carrying Capacity
			Habitat Squeeze	Habitat Suitability	% Carrying Capacity
			Larval Survival	Ichthyoplank. Pres/Abs	% max (e.g. Uphoff, Secor)
			Increased Predation	Predator Demand	Conditional Mortality Rate
			Increased Emigration	Fall v. Spring Abundances	% Residency (spatially exp VPA)
	Uphoff, Topolski	6. Flow	Larval Survival	Ichthyoplank. Pres/Abs	% max (e.g. Uphoff, Secor)
	Uphoff, Secor	7. Hypoxia	Degraded Nursery	Habitat Suitability	% Carrying Capacity
				DO Level	DO level (EPA standard)
			Decreased Adult Growth	Habitat Suitability	% Carrying Capacity
			Increased Emigration	Fall v. Spring Abundances	% Residency (spatially exp VPA)
	Uphoff, Secor	8. Contaminants	Human Health	PCB Level	MD/VA Advisory Level
				Hg Level	MD/VA Advisory Level
	Uphoff, Fabrizio	9. Watershed Dev.	Degraded/Lost Nurseries	% Impervious Surface	Statistical Reference (uphoff)
				DO Level	DO level (EPA standard)
Foodweb	Uphoff, Jacobs, Gartland, LaTour	10. Forage and Predation	Depletion of prey	Forage Fish Index	% Bench Mark
				Forage demand	% Carrying Capacity
				Diet Composition	% Piscivory, % Optimum prey spp.
			Increased Emigration	Fall v. Spring Abundances	% Residency (spatially exp VPA)
			Decreased Condition	Fulton condition Index, others	% Bench Mark
			Invasive Species		
	Topolski, Fabrizio, Klauda	11. Invasive Species			
Stock Assessment	Fabrizio, Martino, Secor	12. Recruitment Variability	Yield	SSB Index	SSB Ref Points
			Stability	Age Structure Indices	Age Structure Ref Points
			Resiliency	Age Structure Indices	Age Structure Ref Points
				Habitat Diversity Indices	Portfolio Effect Ref Points
	Sharov, Johnson, Cimino	13. Exploitation	Overfishing	SSB Index, Opt Yield, etc	% Opt Yield, % EPR, various
	Gautier, Vogelbein, Jacobs	14. Disease	Human Consumption	Infection intensity	MD/VA Advisory Level
			Decreased Condition	Fulton Condition Index, others	% Bench Mark
			Increased Mortality	Disease Mortality	Conditional Mortality
	Secor, Gautier	15. Connectivity	Regional Depressed	Distribution of juvenile Prod	Portfolio Effect Ref Points
			Production/Isolation		
			Loss of Habitat		
Socio-economics	Paolisso	16. Livelihoods			
	Culzoni	17. Econ Implication of Mgmt			
	Lipton	18. Valuation of Water Quality			
	Lipton	19. Consumption/Demand			

Background

Early Life History

Mary Fabrizio and Ed Martino

Introduction

The early life history of Atlantic coast striped bass has been the focus of many studies due to the high recruitment variability that characterizes the dynamics of this mixed-stock population (Ulanowicz and Polgar 1980, Goodyear 1985). Contributions of the Chesapeake Bay stock to the Atlantic coast fisheries varies through time: during years of high production in the Bay, this Chesapeake Bay stock is a major contributor to the coastal fisheries (Berggren and Lieberman 1978, Fabrizio 1987). Not surprisingly, a majority of the research on early life processes was conducted in Chesapeake Bay.

The Atlantic coast striped bass fishery collapsed in the 1970s and early 1980s and striped bass populations did not recover until 1995. The recovery was likely a result of both successful management and environmental conditions favorable for early life survival (Richards and Rago 1999). The most likely explanation for recovery was that sufficient numbers of spawning females were protected and allowed to reproduce during environmental conditions favorable for the survival of their offspring (Secor 2000). As a result of differences in egg and larval survival during the first few weeks of life, annual recruitment variability since the recovery in 1995 remains high (Chesapeake Bay ≥ 20-fold). These differences in survival rates of the early life stages are believed to result from stochastic environmental factors (Ulanowicz and Polgar 1980), particularly temperature and freshwater flow.

Eggs and Yolk-sac Larvae

Anadromous striped bass spawn in tidal freshwater reaches of Chesapeake Bay tributaries (Figure 1) that are characterized by relatively warm temperatures in the early spring (>12 degrees C; Uphoff 1989). Eggs and larvae are retained in the area just above the salt front as a result of tidal circulation and minimal residual current velocities at this front. Field-based estimates of egg survival rates are highly variable (range: 9-90% per day), but average about 32% per day (Pamunkey River, VA; Olney et al. 1991).

The location of spawning and nursery areas used by Chesapeake Bay striped bass can vary markedly from year to year due to variations in freshwater flow and salt front dynamics in the estuarine turbidity maximum or ETM (North and Houde 2001, North and Houde 2003, Martino and Houde 2004, Martino et al. 2006, North and Houde 2006). Striped bass usually spawn within 40 km upriver of the salt front (Rathjen and Miller 1957). During years of high spring flow in upper Chesapeake Bay, most (75%) striped bass eggs were found up-estuary of the salt front (North and Houde 2001). Striped bass eggs and larvae may be retained in the salt front and ETM where their survival is enhanced. A larval mark-recapture study in the Patuxent River in Maryland revealed very high loss rates for larvae released below the salt front (Secor et al. 1995). Further, high freshwater flows may foster increased retention of eggs and larvae through enhanced estuarine gravitational circulation (North and Houde 2003).

Like other teleosts that broadcast eggs, striped bass egg size is determined by maternal size (Zastrow et al. 1989; Monteleone and Houde 1990; Secor et al. 1992). Larger eggs produce larger larvae, which exhibit higher subsequent larval growth rates than small egg broods (Monteleone and Houde 1990). Researchers have not yet detected higher survival or reduced predation rates due to larger initial egg size (Monteleone and Houde 1992), although such relationships have been proposed (Miller et al. 1988).

Survival to the larval stage is density independent, and negatively affected by low (11-12 degrees C) and high (21 C) water temperatures (Uphoff 1989; Secor and Houde 1995), and possibly poor water quality (Hall et al. 1987). In general, survival of larvae to first feeding (7 days post-hatch) is low; estimates range from 0.2 to 5.2% of eggs spawned (Secor and Houde 1998).

Feeding (Post Yolk-sac) Larvae

Factors affecting larval survival are critical to understanding recruitment success of striped bass because year-class strength appears to be determined in the larval stage. Previous studies (Uphoff 1989, Rutherford et al. 1997) based on correlation analyses between recruit abundance and the abundance of different early-life stages support the contention that recruitment is fixed before the early postlarval stage (8-10 mm SL). Further, a synthesis of larval striped bass mortality rates from several locations reveals a decrease in instantaneous mortality rates from 0.25 to 0.15 across larval sizes of 5 to 10 mm TL (Logan 1985).

Although larvae are tolerant of a wide range of water quality conditions [12-27 degrees C; 0-15 ppt salinity; pH of 7-8.5; hardness levels >150 mg/l $CaCO_3$; and dissolved oxygen concentrations >5.0 mg/l], mortality rates of larvae are strongly temperature dependent (Secor and Houde 1995). In addition, temperature was positively correlated with larval growth and the production of 8-mm SL larvae (i.e., larvae in the postlarval stage) (Rutherford and Houde 1995). Episodic events including sudden drops in temperature that occur during storm fronts can be lethal (Secor and Houde 1995). Field observations indicate that the highest survival of the 1991 year class from the Patuxent River occurred among cohorts experiencing average temperatures between 15 and 20 degrees C (Secor and Houde 1995).

The abundance and spatiotemporal variability of zooplankton prey also appears to be important for larval survival. High levels of freshwater flow may exert indirect positive effects on larval survival by enhancing production of mesozooplankton prey for striped bass larvae (Kimmel and Roman 2004, Kimmel et al. 2006). For example, recruitments in the upper Bay and Potomac during 1987 through 1989 were highest in 1989 when freshwater flows and zooplankton concentrations were highest (Rutherford et al. 1997). Similarly, upper Chesapeake Bay juvenile recruitments for the years 1968 through 1999 were positively correlated with mean Susquehanna River discharge. In the Chesapeake Bay, a combination of high spring flows and cooler temperatures extend or delay spring bloom conditions such that peak concentrations of mesozooplankton prey occur during May when most feeding larvae are present in the Bay (Wood 2000; Martino et al. 2006). Similarly, larval cohorts in the Hudson River that co-occurred with the spring bloom of cladoceran zooplankton exhibited relatively high survival compared with larvae hatching at other times (Limburg et al. 1999). Freshwater flow also controls the spatial distribution of larval striped bass and zooplankton prey, and high springtime flows are associated with increased spatial overlap of larvae and prey at the salt front and turbidity maximum (Martino et al. 2006).

The availability of zooplankton prey may affect larval striped bass nutritional condition, growth, size, and survival. Striped bass larval survival is positively related to larval size and growth (Uphoff 1989, Houde 1997, Rutherford et al. 1997). Simulation models predict poor survival of cohorts produced early in the season when zooplankton concentrations are low (Chesney 1989). Larvae from the Potomac River in 1985 exhibited poor nutritional state early in the season, and this condition was significantly correlated with copepod and cladoceran densities (Martin et al. 1985). Poor nutritional condition of larvae may have been the cause for poor recruitments during a field study in the Potomac River and upper Chesapeake Bay (Setzler-Hamilton et al. 1987). A model simulation of Potomac River striped bass supported the hypothesis that variability in larval prey alone could generate 10-fold variability in recruitment through effects on larval growth- and size-specific mortality (Cowan et al. 1993). Larval growth and the ratio of growth to mortality was significantly and positively related to recruitment in upper Chesapeake Bay (Rutherford et al. 1997).

Based on results from a simulated individual-based model, the high variability observed in striped bass recruitment cannot be achieved by varying a single factor (such as the size distribution of female spawners) (Cowan et al. 1993). Instead, two or more factors must act in concert; in particular, variations in the size distribution of females, and density of zooplankton prey during the larval stage were important in modeling variations in recruitment success. Modeling results also confirmed that large fluctuations in (simulated) recruitment could result from relatively small changes in the mortality rates of feeding larvae and younger stages (Cowan et al. 1993). Indeed, field observations indicate that larval mortality rates are highly variable (1991 year class, Patuxent River; Secor and Houde 1995; 1988 and 1989 year classes, upper Bay and Potomac River; Rutherford et al. 1997).

Juveniles (Age 0)

Like larvae, juveniles are also tolerant of a wide range of water quality conditions (Hall 1991). The results of one study revealed that salinity variations between 0 and 10 ppt have no effect on growth or condition of striped bass aged up to 133 days post-hatch (Overton and Van Den Ayvle 2005). Although, a different study found that juvenile growth rates were 40% higher at 7 psu when compared to growth at 0.5 and 15 psu (Secor et al. 2000). Regional patterns in striped bass young-of-the-year growth among East Coast estuaries exhibit counter-gradient variation where growth rates are inversely related to latitude (Conover et al. 1997).

Juvenile striped bass feed opportunistically: diets tend to reflect the annual and spatial variability of prey in the estuary (Jordan et al. 2003). Ontogeny and intra-season variation are only weakly associated with variation in juvenile diets (Jordan et al. 2003).

The relative abundance of juvenile striped bass is used to calculate juvenile recruitment indices. Juvenile indices are used to monitor the level of recruitment into the population and as a basis for management decisions (Goodyear 1985). Abundance of age-0 fish during the first summer of life was positively related to an aggregate measure of recruits in commercial landing at ages 2 through 5 years old (Goodyear 1985).

Year-class strength is largely determined at the egg and larval stages but recent research suggests that density-dependent growth and mortality is important during the juvenile stage in Chesapeake Bay (Martino and Houde 2004), an observation consistent with findings in the Hudson River (Buckel et al. 1999) and San Francisco Bay (Kimmerer et al. 2000). Density-dependent growth and mortality of juveniles between their first and second year of life may further reduce abundance of moderate and strong year classes. Although the mechanism responsible for density-dependence is uncertain, intra- and inter-specific competition for benthic prey appears likely. Bioenergetics modeling of age-0 juvenile striped bass consumption demand in Chesapeake Bay revealed that demand exceeded prey supply during the years 1990 through 1992 (Hartman and Brandt, 1995). A different study extended this analysis and found that during years when abundance is low, age-0 juvenile growth rates are highest, and consumption levels are on par with metabolic demands (Martino and Houde 2004). Juveniles may also exhibit increased dispersal and movement between nursery areas in strong recruitment years — a behavior reported for sympatric white perch (Kraus and Secor 2004, Kraus and Secor 2005). Our understanding of the role of both density-dependent mortality and dispersal in age-0 and age-1 juvenile striped bass is limited, and future research in this area is warranted.

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Adult Life History

Joseph Cimino and Michael Johnson

Introduction

The Chesapeake Bay hosts a year-round adult striped bass population that is predominantly male. The majority of females age 3+ leave the Bay and become a part of the coastal migratory stock. This emigration may take place as early as three years of age, although there is some indication that the emigration by age is gradual (Secor and Piccoli 2007), with successively greater numbers of emigrants with each succeeding age (Rugolo and Jones 1989). Striped bass that migrate out of the Bay return to spawn each spring, though not every fish will spawn annually. Some fish return to the mouth of the Bay during the winter migration, overwintering around the Chesapeake Bay Bridge Tunnel.

Environmental Parameters

Striped bass generally require water temperatures less than 25 degrees Celsius and dissolved oxygen above 2 to 3 mg/L. Concentrations of DO 5.0 mg/L or greater were considered desirable for many Chesapeake Bay living resources, including striped bass (Funderburk et al. 1991; US EPA 2003). When environmental factors are outside of these requirements, striped bass may display altered behaviors such as decreased feeding, increased disease transmission and susceptibility that reduce growth and reproductive success (Coutant 1985; Coutant 1987; Zale et al. 1990).

Growth

Striped bass are long lived, with specimens reaching ages of 30 plus years (Secor 2000), and weights in excess of 100 pounds. As fish near maturity, the growth rate for females typically outpaces males. Females also reach a larger maximum size and age than males, and striped bass that exceed 30 pounds or larger are almost exclusively female (Bigelow and Schroeder 1953). Growth rates of individual fish, as well as year classes are highly variable and can depend on many factors.

Diet

The diet of striped bass tends to change as striped bass grow larger, with smaller individuals relying more on invertebrate prey and larger fish consuming small pelagic finfish. By the time striped bass reach 2 years of age, they are almost exclusively piscivorous, with fish such as Atlantic menhaden and bay anchovies comprising a large portion of their diet (Rudershausen et al. 2005). Small juvenile blue crabs can also be an important food item for striped bass during the summer months (Walter 1999; see Food Web brief).

Spawning/ Migration

Sexually mature striped bass move upriver, typically above the salt front, to spawn in early spring. Areas and time of peak spawn are temperature and current velocity dependent, but are similar throughout the Bay (Grant and Olney 1991). Males mature earlier than females, although they grow slower (ASMFC 1990, Secor and Piccoli 2007). Males begin to mature at 2 years old and all are mature by age 3 (Hollis 1967). Estimates of maturity for females have varied among studies and stock assessments. Hollis (1967) reported that Chesapeake Bay females in the 1950s matured between ages 4 and 6. A similar age-at-maturity schedule was reported for female striped bass on the Potomac River spawning grounds during 1974-1976, but a small fraction of mature females were age 3 (Setzler et al.1980). Berlinsky et al. (1995) estimated that age-3 females collected during 1985-1987 off Rhode Island were immature, 12% were mature at age 4, 34% at age 5, 77% at age 6, and all were mature at age 7 and older. Stock assessments of combined Chesapeake Bay, Hudson River, and Delaware Bay stocks conducted for ASMFC since 1998 have used fixed female maturity schedules derived from Maryland spawning ground gill net surveys during the 1980s (NEFSC 1998; Nelson 2007): age 4, 4% mature; age 5, 13%; age 6, 45%; age 7, 89%; age 8, 94%, and ages 9+, 100%. Spawning season gill net surveys of Maryland's two largest spawning areas have indicated that age-at-maturity of females has become progressively later since 1985 (Warner et al. 2008). Female striped bass between ages 3 and 5 years old appeared on these spawning grounds each year during 1985-1994. Females younger than age 6 became rare after the mid-1990s and 3-4 year-olds have no longer been detected on the spawning grounds. Mean length at age of female striped bass age 7 and older have been steady throughout the time-series, while it has been more variable for younger ages (Warner et al. 2008). Data from a long standing pound net survey on the spawning grounds in the Rappahannock river in Virginia (VIMS Striped bass Monitoring Program), show that there has been a fluctuation in the presence or absence of 3-year old females on the spawning grounds in this river over the past 17 years. The catch-per-unit of effort for females ages 4-6 does appear to be declining since 1997 (P. Sadler, VIMS personal communication).

Changes in maturity at age could reflect sampling and aging differences, underlying assumptions among studies, or may be a consequence of a mix of factors having both compensatory and genetic origins (Trippel 1995). Changes in maturity schedule may reflect population size, exploitation, nutrition, and interspecific competition. Onset of maturation is sensitive to energy intake or growth during the juvenile phase. Fast-growing fish of exploited populations generally have relatively higher reproductive output than fish in unexploited fish, but this fecundity component of the compensatory response has not been widely documented (Trippel 1995). Shifts to younger spawners may have consequences for striped bass; eggs from 4-5 year olds had 21% less hatching success than eggs from 7-15 year olds (Zastrow et al. 1989).

Striped bass tagging has indicated that most, but not all, striped bass return to the same spawning area each year (Hollis 1967; Florence 1974). Examination of ovaries of large striped bass during 1954-1962 (Hollis 1967) and extensive hatchery experience since 1958 have not produced evidence of sexual senility of older striped bass (Hollis 1967; B. Richardson, MDDNR, personal communication). Secor (2008) described skipped (non-annual) spawning for a minority of

Chesapeake Bay striped bass, but concluded its effect on egg-per-recruit thresholds was minor given current management practices.

Coastal migration and spawning migration are separate phenomenon. Not all striped bass participate in coastal migration. Historically it was assumed most males do not leave the Bay at any part during their life cycle. Recent studies contradict this presumption. Dorazio et al. (1994) and Secor and Piccoli (2007) produced tagging data and otolith microchemical analysis, respectively, that suggests some striped bass, regardless of sex, will remain in the Bay for their entire lives. Migration estimates based on 1988-1991 spawning area and season tagging (40-100 cm TL) indicated that larger striped bass were more likely to migrate from spawning areas of the Chesapeake Bay to coastal areas north of Cape May, NJ than were smaller fish (Dorazio et al. 1994). Nearly all tagged fish larger than 100 cm TL migrated from the Chesapeake Bay to the northern region. Most of these larger fish were females. Fewer males participate in the northward migration, but this difference appeared to reflect differences in size of mature males and females (Dorazio et al. 1994). Kohlenstein (1981) determined that few young males leave the Chesapeake Bay. Migration studies conducted during the 1930s-1970s found that most striped bass (85%-90%) along the coast were females (Setzler et al. 1980).

More recent migration studies of Chesapeake Bay striped bass based on otolith microchemistry have generally confirmed oceanic movements of females, but have indicated more participation of males in oceanic migrations (Secor and Piccoli 2007). Contingent behaviors (fish that share migration patterns) have been identified for Chesapeake Bay striped bass. A small fraction were freshwater residents, while most exhibit periods of estuarine or marine residency after spawning (Secor and Piccoli 2007).

Studies of within-Bay movements appear to be confined to tagging in Maryland during 1954-1961 (Mansueti 1961; Hollis 1967). The majority of these striped bass were tagged from commercial gill nets, pound nets, and haul seines (1,103 tagged in Mansueti 1961 and 6,320 tagged in Hollis 1967) with a variety of tags. Nearly all were below size limits imposed on the current fishery (457 mm) for resident striped bass and 280-430 mm fish comprised the majority of fish tagged (Mansueti 1961; Hollis 1967). Most of these striped bass remained within Maryland's portion of Chesapeake Bay and very few were recaptured in Virginia. Generally, fish spawning in lower Bay rivers moved out of these systems during summer and then moved northwards in the Bay, while fish that spawned in the upper Bay shifted south. Many tagged fish that remained in the Bay were found between Poole's Island and Tilghman Island. Most fish tagged within the Potomac River were recaptured there, but some immigrated and emigrated (Mansueti 1961; Hollis 1967). Schools were concentrated along shoal areas during July-October (Lippson 1973). With the approach of cold weather, these aggregations move downriver or down-Bay towards deeper water and in February-March they disperse toward their respective spawning rivers (Lippson 1973).

Upper and mid-Bay regions occupied by most tagged striped bass in summer during the 1950s and 1960s (see Figure 7 in Mansueti 1961) are now considerably more hypoxic than at that time (see Figure 4 in Hagy et al. 2004) and the extent that movement to this area has been maintained is unknown. A tagging program has existed in Maryland and Virginia since the late 1980s for estimating mortality rates (Dorazio et al. 1994; NEFSC 2008), but these data might be useful for determining whether in-Bay migration patterns may have changed.

Mortality

Striped bass are recruited to the commercial and recreational fisheries at 18 inches total length. Estimates of fishing mortality are calculated annually for the Bay. Data used to estimate F on striped bass resident to the Chesapeake Bay are limited to male fish from 18 to 28 inches (total length). Recent F estimates, since 2000, have fluctuated between 0.11-0.14 and remain below the target value of 0.27 (NEFSC 2008). Current fisheries management practices actively manage the stock through a Bay-wide quota for the three jurisdictions in the Chesapeake Bay (Maryland, Potomac River, and Virginia waters), for both the recreational and commercial fisheries. Some of the fish that are overwintering off the Virginia coast, move into the Bay, and are encountered by the commercial and recreational fisheries.

The 2005-2006 commercial harvest in the Bay is composed mostly of ages 3-6, as opposed to the coastwide harvest which consists of primarily ages 4-10 (NEFSC 2008). Commercial harvest of striped bass from the Bay, measured in pounds and numbers of fish, account for a large portion of the total coastwide harvest. Commercial landings, Bay-wide, have been estimated to remove between half a million to over a million striped bass annually for the past decade. The average commercial harvest for the Bay, 2003-2007, is just over four million pounds annually. Recreational harvest, for 2005-2006, in the Bay is composed mostly of ages 4-8. It is estimated that well over half a million fish are landed each year recreationally from the Bay. For the five-year period 2003-2007, it is estimated that an average of five million pounds of striped bass per year are harvested from Maryland, Potomac River, and Virginia recreationally.

Size regulations, as well as daily trip limits (in the recreational fishery) lead to striped bass discards. Mortality on discarded fish from the commercial and recreational fisheries is estimated annually. In the recreational fishery, release estimates account for over 80% of the catch in recent years. Coastwide, recreational discards are the main source of fishing mortality on fish under three years of age, according to the 2007 stock assessment (data through 2006), and have accounted for roughly 30% of the total fishing mortality. Commercial discards have accounted for approximately 3.5% of all removals. Trends in discard mortality estimates for the Chesapeake Bay match those of the entire coast (NEFSC 2008).

Striped bass are often described as a long-lived species, with a maximum age around 30 years. Due to this considerable longevity, natural mortality has been assumed to be low (and constant around or at 0.15 annually). The most recent peer reviewed striped bass stock assessment for the Atlantic coast, referred to in this brief as NEFSC 2008, applied two methods to estimate M from tagging studies. One method is a modified version of Baranov's catch equations proposed by Pollock et al. (1991) and the second method used was an application of Jiang et al. (2007), Instantaneous Rates catch and release model, to obtain estimates of instantaneous mortality rates (NEFSC 2008). Mean M estimates for 2006, fish greater than or equal to 18 inches was estimated as 0.43 ± 0.13 (95% CI) for all producer areas, including the Hudson River and Delaware Bay, and the Chesapeake Bay data. Mean M estimates (for 2006) for fish greater than or equal to 28 inches for producer areas was $.028 \pm 0.20$(95% CI). Analyses of data from long standing tagging studies of Chesapeake Bay striped bass suggest natural mortality may have increased in magnitude since 1995 (NEFSC 2008; Jiang et al. 2007). This may be attributed to poor water quality, a loss of habitat, increased prevalence of disease (mycobacteriosis), or a combination of these factors. However, it is important to note assumptions on natural mortality can be confounded by systematic changes in reporting rate of tag returns.

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Insert Socioeconomics Background (S/3) here

Management

Nichola Meserve and Joseph Cimino

Overview

The Atlantic States Marine Fisheries Commission (ASMFC) is responsible for the oversight and management of Atlantic striped bass ranging from Maine through North Carolina. The ASMFC implemented the Interstate Fishery Management Plan (FMP) for Atlantic Striped Bass in October 1981 (ASMFC 1981). The Interstate FMP has been amended six times to incorporate additional information and address new needs. Amendment 6 to the Interstate FMP was adopted by the ASMFC in February 2003, replacing all previous plans (ASMFC 2003). It is enforceable through the Atlantic Striped Bass Conservation Act (1984) and the Atlantic Coastal Fisheries Cooperative Management Act (1993), as revised.

In addition to the Interstate FMP, a Chesapeake Bay FMP has been in place since 1989 for striped bass (USEPA 1989). Through the Chesapeake Bay Program, the state of Maryland, the commonwealths of Virginia and Pennsylvania, the District of Columbia, and the Potomac River Fisheries Commission (formed by a compact between Maryland and Virginia) coordinate striped bass management in the Chesapeake Bay. The primary objective of the Bay FMP and its amendment is to implement and follow the Interstate FMP's management program. Implementation of regulations consistent with the Interstate and Bay FMPs is performed by the Maryland Department of Natural Resources, the Virginia Marine Resources Commission, and the Potomac River Fisheries Commission for their jurisdictional waters.

Historical Management

Interjurisdictional management of striped bass was prompted by declining trends in landings and juvenile recruitment in the 1970s alongside findings from the 1980 Emergency Striped Bass Study report indicating a need for major reduction in fishing mortality for the species to recover (ASMFC 2003). The Interstate FMP recommended that states reduce fishing mortality with measures includeing minimum size limits (14" total length for producer areas, 24" total length for coastal areas). Several amendments recommended further fishing mortality reductions (e.g., 55% reduction in 1984 via Amendment 2). However, it was not until the passage of the Atlantic Striped Bass Conservation Act that the ASMFC was able to require state action (through Amendment 3), beginning with preventing directed fishing mortality on at least 95% of the 1982 year class females, and females of all subsequent year classes of Chesapeake Bay stock, until 95% of the females of these year classes had an opportunity to reproduce at least once (ASMFC 1985). In effect, the amendment required states to change their size limits each year (from 20" to 38" total length from 1985-1990) to account for growth of the 1982 year class, which had previously been found to be the last of near average recruitment (ASMFC 1990). Between 1985 and 1990, each jurisdiction from New York to North Carolina closed all or part of its fisheries for one to six years. In 1989, Chesapeake Bay recruitment hit a pre-determined trigger and states were allowed to reopen their fisheries the following year at a controlled rate, with an 18” minimum size limit for producer areas and 28” for coastal areas (ASMFC 1989). After five years, the coastal population was declared rebuilt (ASMFC 1995).

Current Management

The management program in Amendment 6 aims to provide a sustainable abundance of striped bass, quality and economically viable fisheries, coastwide management consistency while allowing state flexibility, cost-effective monitoring, and a long-term management regime (ASMFC 2003). Biological reference points form the basis of a control rule to maintain stock size and limit fishing mortality and guide future management changes. Fishery regulations are based on the control rule. The amendment requires specific fishery-independent and fishery-dependent monitoring programs for stock assessment purposes. Amendment 6 also addresses habitat considerations and management and research needs.

Control Rule

The control rule includes target and threshold levels of female spawning stock biomass (SSB) and rates of fishing mortality (F). The existing biological reference points include: a female SSB threshold equal to the 1995 level of female SSB, a female SSB target equal to 125 percent the threshold, a fishing mortality threshold equal to the fishing morality that achieves maximum sustainable yield (Fmsy), and a fishing mortality target set below the threshold based on management objectives. A separate F target exists for the Chesapeake Bay and Albemarle Sound-Roanoke River; however, no area-specific F threshold, SSB target, and SSB threshold exist. The estimates of SSB threshold, SSB target, and F threshold were updated in 2008, thus the values shown in the table below differ from those provided in Amendment 6 (ASMFC 2008).

	Female Spawning Stock Biomass	**Fishing Mortality Rate**
Threshold	30,000 metric tons	F=0.34
Target	37,500 metric tons	Coast: F=0.30 Chesapeake Bay & Albemarle Sound-Roanoke River: F=0.27

Overfishing occurs when the fishing mortality rate exceeds the fishing mortality threshold and would result in the ASMFC Striped Bass Management Board taking action to reduce fishing mortality. If the fishing mortality rate exceeds the fishing mortality target, the Management Board is not required to take steps to reduce fishing mortality, unless it is exceeded in two subsequent years and the female SSB falls below the target within either of those years. Rates of fishing mortality are estimated biennially for the coastwide population, as well as for the Chesapeake Bay and Albemarle Sound-Roanoke River segments of the population.

The stock is considered overfished if female SSB drops below the SSB threshold. If this occurs or if female SSB falls below the target for two subsequent years and the fishing mortality rate exceeds its target for one of those two years, the Management Board would take action to increase the female SSB. Female SSB is estimated biennially for the coastwide population.

Fishery Regulations

The striped bass fisheries are managed with regulations based on the fishing mortality targets (ASMFC 2003). In general, Amendment 6 requires a minimum size limit of no less than 28", a recreational creel limit of no more than two fish, and state-specific coastal commercial quotas[1]. However, variability exists between states because the plan allows for flexibility through management program equivalency[2]. Additionally, Amendment 6 defines a separate management program for the Chesapeake Bay Management Area[3] (as well as the Albemarle Sound-Roanoke River Management Area) based on the size availability of striped bass in these areas and the nature of striped bass migrations.

Amendment 6 permits an 18" minimum size limit for the Chesapeake Bay fisheries given the area's lower F target. The Bay's recreational creel limit and all commercial regulations are to be based on maintaining the target fishing mortality rate. Based on the target and the estimated Bay stock size, the three Chesapeake Bay regulatory agencies — Maryland Department of Natural Resources, Virginia Marine Resources Commission, and Potomac River Fisheries Commission — annually set a Baywide quota for the resident fish population. Resident fish are those that do not participate in coastal migrations; at 28", a striped bass is assumed highly likely to participate in coastal migrations (Dorazio et al. 1994). The Baywide quota is allocated among jurisdiction (Maryland: 53%, Virginia: 32%, Potomac River: 15%), and each jurisdiction allocates its share among fishing sectors. All striped bass caught in the Bay count towards the Baywide quota, with the exception of those greater than 28" caught during the spring spawning season (considered migratory). The governing bodies implement regulations, within the allowances of Amendment 6, to limit harvest to the quota.

Through the submission of proposals for alternative management, the Chesapeake Bay states have implemented and revised regulations for a spring "trophy" fishery in the Bay. Trophy sized striped bass are 28" or greater (32" or greater in Virginia waters and 33" or greater in Virginia tributaries of the Potomac River). Therefore, these trophy-sized fish are considered coastal migrants that have returned to the Bay to spawn. Maryland has also been permitted to implement an additional seasonal fishery in the Susquehanna Flats that was not written into Amendment 6 (see table below).

The FMP also includes several recommended measures, such as the use of circle hooks and the closure of directed fisheries on spawning grounds during the spawning season.

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[1] Each state implements additional coastal commercial regulations, such as seasons and trip limits, to keep coastal commercial harvest within the state coastal quota. Amendment 6 allocated a coastal commercial quota of 131,560 lbs to Maryland and 184,853 lbs to Virginia.

[2] A state may submit a proposal that, if found to include management measures that will not contribute to overfishing of the resource, may be approved by the Striped Bass Management Board for implementation.

[3] The Chesapeake Bay Management Area is defined as the area between the baseline from which the territorial sea is measured as it extends from Cape Henry to Cape Charles to the upstream boundary of the fall line (ASMFC 2003).

Atlantic Ocean waters beyond three nautical miles from shore are closed to the taking and possession of striped bass all year.

The following regulations applied in the Chesapeake Bay during 2008.

	Recreational	**Commercial**
Maryland	Susquehanna Flats Fishery: Open 5.16-5.31, 1 fish, 18-26" slot Spring Fishery: Open 4.21-5.15, 1 fish, 28" minimum, spawning areas closed Summer-Fall Fishery: Open 5.16-12.31[4] (spawning areas closed until 6.1), 2 fish, 18" minimum, and a 28" maximum for 1 fish, 2,795,611 lb. quota	18"-36" slot 2,254,831 lbs. quota Open Seasons: *Pound Net: 6.2-11.29* *Haul Seine: 6.9-11.28 (Mon.-Fri.)* *Hook and Line: 6.16-11.27 (Mon.-Thurs.)* *Drift Gill Net: 1.1-2.29, 12.1-12.31 (Mon.-Fri.)*
Potomac River	Spring Fishery: Open 4.19-5.13, 1 fish, 28" minimum Summer-Fall Fishery: Open 5.16-12.31, 2 fish, 18" minimum, and a 28" maximum for 1 fish, 575,414 lb. recreational quota, 71,927 lb. charter quota	18" minimum all year 36" maximum 2.15-3.25 647,341 lb. quota Open Seasons: Hook & line: 2.15-3.25, 6.1-12.31 Pound Net: 2.15-3.25, 6.1-12.15 Gill Net: 1.1-3.25 Other: 2.15-3.25, 6.1-12.15
Virginia	Spring Fishery: Open 5.1-5.15, 1 fish, 32" minimum (33" in Potomac River tributaries), spawning areas closed Open 5.16-6.15, 2 fish, 18-28" slot, with 1 fish >32" allowed (except in spawning areas) Fall Fishery: 10.4-12.31, 2 fish until 12.9, 1 fish after 12.9, 18-28" slot, with 1 fish >34" allowed 1,554,302 lb. quota	18" minimum all year 28" maximum 3.26-6.15 1,642,242 lb. quota Open: 2.1-12.31 Spring gill net restrictions: 4.1-5.31 No stake or anchored gill nets allowed within the spawning reaches of the James, Pamunkey, Mattaponi, and Rappahannock Rivers. Drift gill nets are allowed, but must be attended at all times, and no striped bass can be kept.

Monitoring

Within the Chesapeake Bay, the following fishery-independent monitoring is required by Amendment 6: a juvenile abundance index survey in Maryland's Chesapeake Bay Tributaries by

[4] The season closure date of December 31 is an exception for 2008 (approved by the Management Board); the season typically ends December 15.

the Maryland Department of Natural Resources (MDNR), a juvenile abundance index survey in Virginia's Chesapeake Bay Tributaries by the Virginia Marine Resources Commission (VMRC), a spawning stock biomass survey in the Upper Chesapeake Bay (Worton Pint to Elkton) and the Potomac River (Maryland Point to White Stone Point) by the MDNR, a spawning stock biomass survey in the Rappahannock River (Tappahannock to Fredericksburg) and the James River (Dancing Point to Tax Point) by the VMRC. Fishery-dependent monitoring is also required of MDNR, VMRC and the Potomac River Fisheries Commission (PRFC). Each jurisdiction must monitor and annually report commercial and recreational catch, effort, and catch composition.

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HABITAT

Warming and Climate Change

Ed Martino and Dave Secor

During the past 70 years the Chesapeake Bay has experienced nearly a 2°C rise in mean surface water temperature (Figure 1) and a rise of similar magnitude is expected during the next 70 years, setting the stage for management geared towards adapting to inevitable warming (Pyke et al. 2008). By the turn of the next century, current scenarios of warming indicate that summer-time water temperatures could be similar to those of southern Florida (Boesch et al. 2008). Other seasons are predicted to be more or less similar to conditions that now exist in North and South Carolina. The ability of striped bass and other important Chesapeake Bay living resources to adapt to global warming is unknown but specifies priority in managing for stability and resiliency for responses related to (1) spawning behavior and larval survival; (2) nursery habitat; (3) summer residency and foraging; and (4) enhanced overwintering habitat.

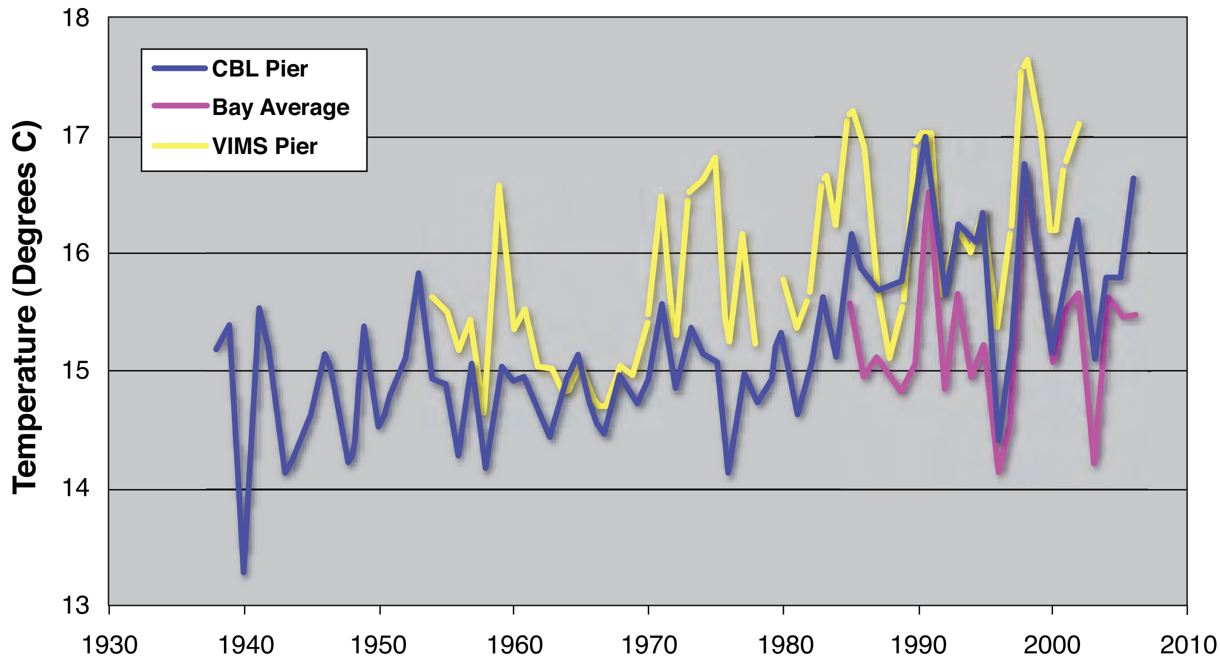

Figure 1. Annual Chesapeake Bay temperatures during the past 70 years (Pyke et al. 2008).

Issue 1: Spawning Behavior and Early Survival

Next only to Atlantic sturgeon, striped bass are the largest of the anadromous fishes that course up each spring from ocean waters to relatively small freshwater sub-estuaries to spawn. From March to June, individual females ranging from 4 to 40 kg undertake directed migrations up estuaries, resting just below the salt front (Hocutt et al. 1990), awaiting rising temperatures between 12 and 18 C, during which eggs will undergo final ripening (Secor 2000). Spawners movement into freshwater will end in liberation of hundreds of thousands to millions of buoyant eggs in relatively shallow surface waters (Olney et al. 1991; Rutherford and Houde 1995). The simultaneous spawning of females and males over one or several days can represent the progeny of a large portion of the overall population and thus represents a sweepstakes bet that conditions subsequent to spawning will favor offspring survival (Figure 2). Substantial research indicates that this is often a poor bet (e.g., Ulanowicz and Polgar 1980; Uphoff 1989; Secor 2000). For early female spawners, subsequent springtime cold fronts can plummet water temperatures to lethal and sublethal levels. For later spawning, rapidly warming late spring waters can result in high temperatures that result in greater offspring mortality (Figure 3). Thus, the dynamics of water temperature in these relatively small volatile nursery systems play a critical role in embryo and larval survival and subsequent recruitment.

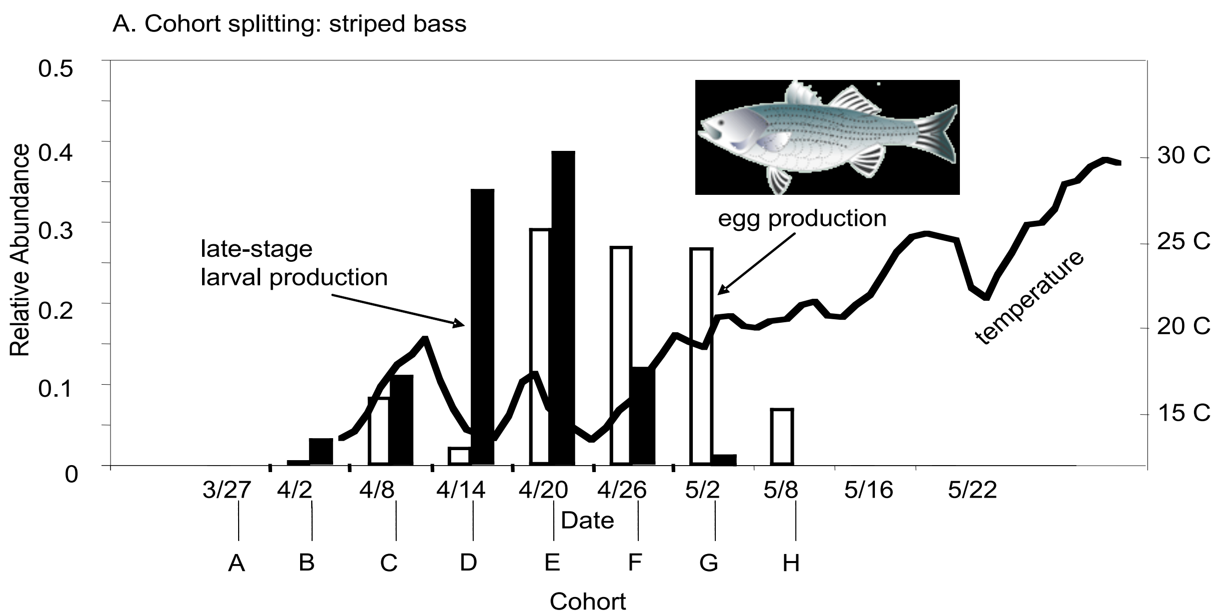

Figure 2. Relationship between weekly egg production, temperature and subsequent survival of striped bass larvae. Weekly cohorts denoted by letters. Data from Patuxent River estuary, 1991; Secor and Houde 1995.

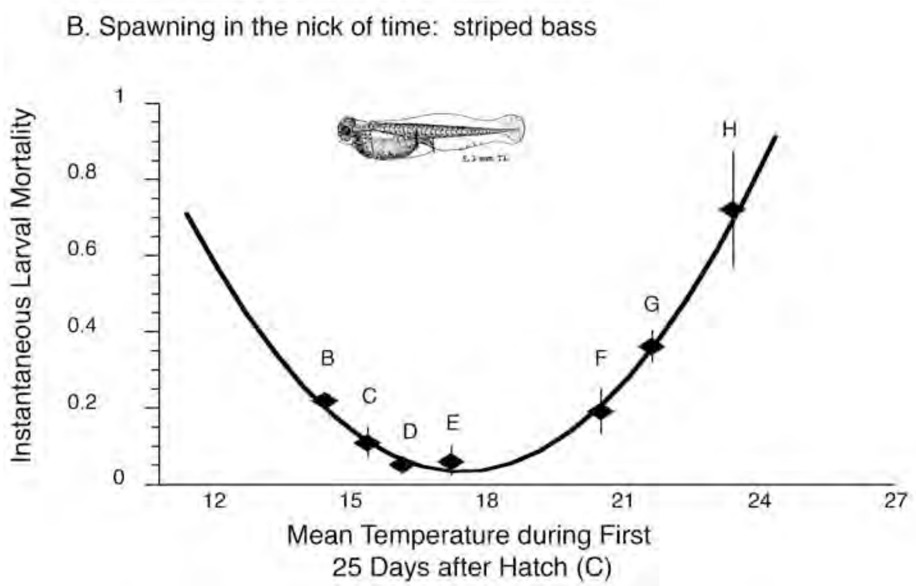

Figure 3. Relationship larval mortality and temperature experienced during the first 25 days after life. Weekly cohorts denoted by letters. Note that optimal larval survival conditions occur in the midst of the larval production season for cohorts C, D, and E. Data from Patuxent River estuary, 1991; Secor and Houde 1995.

Winter and spring temperature and precipitation are dominant influences affecting spring surface water temperature dynamics in Chesapeake Bay, all of which will be influenced by future warming. In general cooler and wetter winters favor striped bass early survival and recruitment (Figure 4). Historically higher winter precipitation resulted in snow pack and subsequent large spring freshets, which have been associated with strong striped bass recruitments. Although not related to strong spring freshets, recent strong year-classes also tend to be favored by cooler and higher flow winter-spring conditions. Proposed mechanisms include (1) increased productivity of waters following snow-melt (Heinle 1976); (2) increased nursery volume resulting in buffering against spring weather variability (Secor et al. 1996); and conditions that favor increased retention of offspring in the maximum turbidity zone, resulting in improved larval fish foraging (North and Houde 2001). Regardless of which of these mechanisms predominates, a strong statistical association between cooler and wetter winters and springs (e.g., Figure 4) indicates that long-term warming could disrupt the timing of spawning and subsequent early survival of offspring.

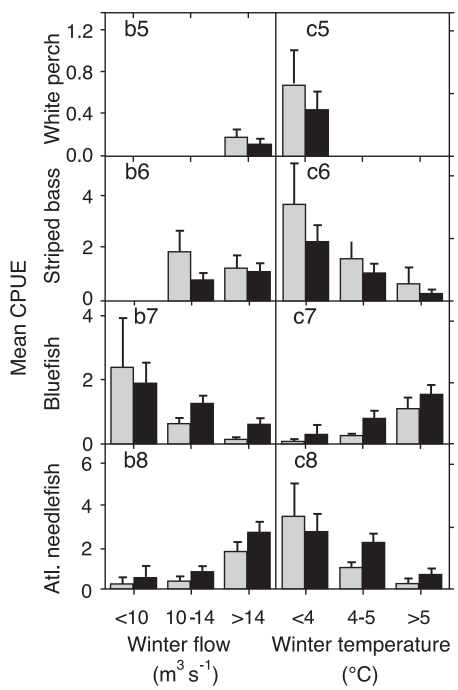

Figure 4. Declining YOY abundance of striped bass, white perch and Atlantic needlefish at CBL with changes in winter temperature and flow (Wingate and Secor 2008).

Issue 2: Degraded Nursery Habitat

Nursery habitats of larval and juvenile striped bass are particularly vulnerable to climate change and global warming. Striped bass is an anadromous species that spawns in tidal freshwaters above the salt front (Setzler-Hamilton et al. 1981). Surface water warming will likely be more severe in the shallow upper reaches of estuaries compared to locations further down-estuary where water depths, location-specific volumes, and the capacity to buffer environmental change is greater. Over the past century temperatures in estuaries and other shallow-water environments have increased more conspicuously compared to deeper continental shelf waters (Kerr et al. in press). Surface water temperatures have been increasing at the Patuxent River, Chesapeake Bay, USA (Chesapeake Biological Laboratory) over the period between 1938-2006. During this 69-year temperature record, a 1.5°C increase was observed when temperatures were averaged across all seasons (Secor and Wingate 2008). Higher rates of increasing temperature occurred during winter and spring months for the most recent twenty years.

Higher temperatures during spring will likely have negative effects on larval survival. Survival of striped bass larvae is highest at 18°C (Secor and Houde 1995). Average springtime temperatures in Chesapeake Bay typically fall near 18°C for approximately 2 to 3 weeks during April and May before consistently remaining above 20°C at the onset of summer. Warming of Chesapeake Bay will likely result in a more rapid spring to summer transition, and a reduction of the temporal period when temperatures are most favorable for larval survival. Mismatches between the occurrence of larvae and environmental conditions favorable for their survival are likely under projected warming scenarios (Figure 3).

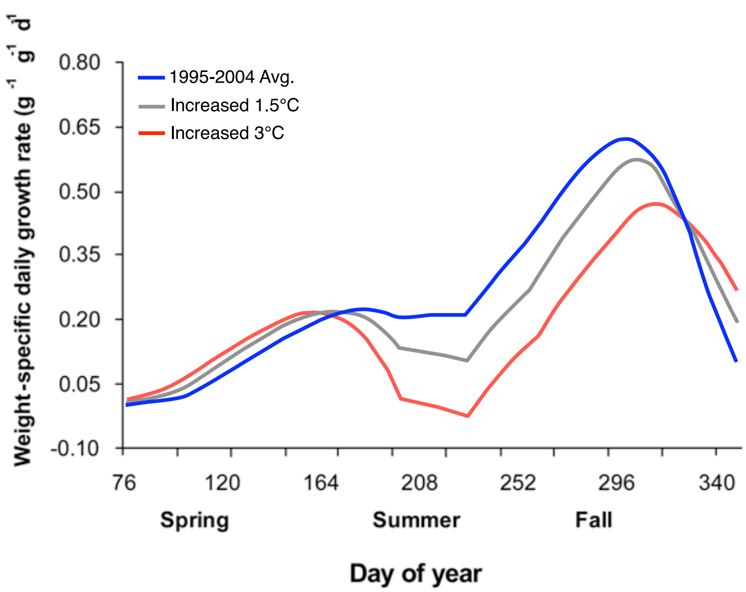

Figure 5. The effect of different seasonal temperature regimes on juvenile striped bass growth rates during the first year of life. Simulations were run using the Wisconsin bioenergetics model for three different seasonal temperature trends including (1) the average daily temperatures in upper Chesapeake Bay for the years 1995-2004, (2) an increase of 1.5°C above average temperatures, and (3) an increase of 3°C Celsius above the average.

Higher temperatures during summer and fall will have negative effects on the growth and possibly survival of age-0 juvenile striped bass. The relationship between temperature and maximum weight-specific consumption of juveniles is unimodal and peak consumption occurs between 20°C and 25°C. In contrast, metabolic costs increase monotonically between 5°C to >30°C. Thus, the scope for juvenile growth is highest at moderate temperatures that typically occur during fall months in Chesapeake Bay. Results from bioenergetics modeling reveal that potential juvenile growth will decline under projected warming scenarios at 1.5°C and 3.0°C above current average temperatures (Figure 5).

Reduced juvenile striped bass growth and smaller juvenile sizes could result in higher mortality during the first year of life (Sogard 1997). Smaller striped bass juveniles are likely to be more vulnerable to size-selective predation and overwintering mortality. Smaller juvenile sizes-at-age may increase their vulnerability to predators. For instance, bluefish predation is a major source of juvenile striped bass mortality in the Hudson River (Buckel et al. 1999). Similarly, size-dependent winter mortality is an important source of juvenile mortality and a regulator of recruitment in the Hudson River (Hurst and Conover 1998).

Issue 3: Degraded Foraging Habitat

Warming will interact with dissolved oxygen to further reduce summer time habitat suitability for striped bass in the Chesapeake Bay (Constantini et al. 2008; see Hypoxia Brief). Although the degree that a temperature oxygen squeeze will affect striped bass juvenile and adult foraging and production is difficult to predict, projections for summer temperatures under current carbon emission rates, indicate that the thermal regime could be similar to that of southern Florida by 2100 (Boesch et al. 2008). Such a thermal regime would virtually eliminate suitable habitats for adult striped bass during summer months.

Issue 4: Enhanced Winter Habitat

Overwintering mortality can act as a significant regulator of year-class strength in temperature-dependent fish populations (Hurst and Conover 1998; Post et al. 1998). Warmer and less frequent severe winters in Chesapeake Bay will extend the seasonal period when juvenile striped bass can feed and grow, and may enhance juvenile survival through winter. Many temperature and boreal fish cease feeding at low temperatures, and rely on lipid and other sources of intrinsic energy reserves to survive through winter. Survival of age-0 juveniles through severe winters depends on the quantity and quality of energy reserves rather than prey availability. Warmer winter conditions will result in increased juvenile feeding during winter, reduce the length of time when intrinsic energy reserves are required, and will likely enhance juvenile survival.

Milder winter conditions in Chesapeake Bay may diminish the significance of juvenile overwintering mortality and regulation of variability in year-class strength. A recent study on age-0 juvenile striped bass growth and mortality in Chesapeake Bay reported both density-dependent growth and mortality in the upper Bay (Martino and Houde 2004). In this study, growth of age-0 juveniles was density dependent, leading to diminished juvenile survival in years of high abundance through size-selective overwinter mortality. Through this mechanism, age-0 abundance levels that vary >10-fold are reduced to 3-4-fold variability at age-3 (Martino 2008). Warmer winter conditions may diminish the importance of both density-dependent growth and survival through winter. The result of reduced density-dependent juvenile mortality would be increased occurrences of strong yearling recruitments and increased variability in year class strength at age 1.

Migration timing influences the efficacy of fishing regulations. If changes in the timing of migration due to warming are sufficiently large, they may impact the timing and duration of a fishing season. For example, the Maryland "trophy" striped bass recreational season targets post-spawning individuals. Here, early spawning could effectively reduce the fishing season if the season has a fixed start date**.** In response to increasing temperatures, management agencies may need to explore temperature-specific regulations, rather than fixed fishing seasons.

Issue Statement

Future warming during winter and spring could disrupt the match between the timing of spawning and those conditions favorable to recruitment. Similarly a mismatch between seasonal fisheries regulations and migration/distributions can occur due to warming. Winter warming could promote year-round residency, and reduce overwinter juvenile mortality. On the other hand, warming summers could substantially depress habitat suitability for older resident striped bass. Future management should maintain diverse spawning behaviors that promote stability in recruitment against future winter and spring climate conditions, which are likely to be warmer, increasingly variable, and unfavorable to striped bass recruitment.

Indicators

Larger and older striped bass tend to spawn larger offspring, which may have survival advantages dependant upon temperature and foraging conditions. Thus, by maintaining a diverse age structure, an increased range of spawn dates may occur as a hedge against variability in spring-time water temperatures. Age structure diversity can be indexed according to expected contributions of individual age-classes to egg production under a condition of no exploitation (Secor 2007).

Age Structure

Striped bass are moderately long-lived, ranging over 30 years longevity (Merriman 1941; Secor et al. 1995). In several species, including striped bass, larger and older females tend to spawn earlier than younger females (Secor 2000). Further, larger and older striped bass tend to spawn larger offspring, which may have survival advantages dependant upon temperature and foraging conditions. Thus, by maintaining a diverse age structure, an increased range of spawn dates may occur as a hedge against variability in springtime water temperatures. Age structure diversity can be indexed according to expected contributions of individual age-classes to egg production under a condition of no exploitation (Secor 2007) by the formula indicated in Figure 6.

In past research Secor found a weak association between age structure diversity and recruitment. Houde (pers. comm.) using a similar approach found that age structure diversity (this time not indexed by expected egg production) was a significant predictor of Chesapeake Bay striped bass recruitment variability.

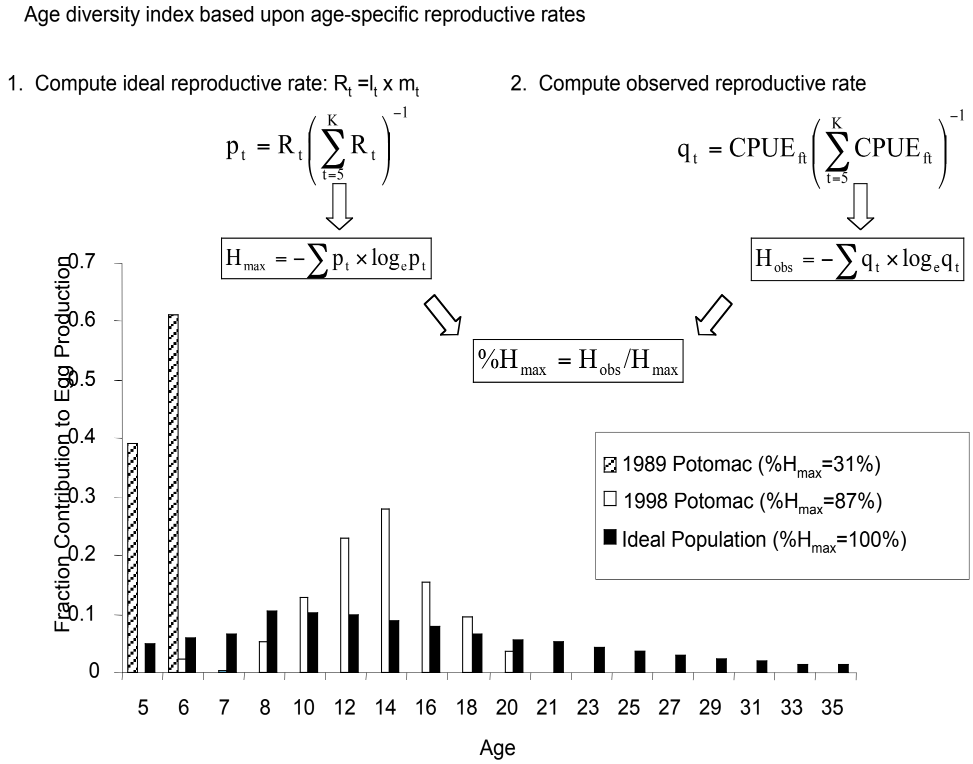

Figure 6. Age diversity index based upon age-specific reproductive rates.

Egg Presence: Absence Ratio

Based upon ichthyoplankton surveys, Uphoff (1993) computed an egg presence ration (E_p), which is the fraction of plankton tows containing >0 eggs, and uses this as a surrogate for egg production to make predictions on stock-recruitment relations. He demonstrated positive correlations between E_p and recruitment for several Chesapeake Bay spawning tributaries. Uphoff (pers. comm.) also established benchmarks for E_p based upon historical spawning stock biomass targets. E_p can also serve as an index of spawning dispersion in time and space (Secor 2000). The domain E_p represents the number of cells in a matrix of rows (dates) and columns (sampling stations). The greater the number of cells occupied by positive tows, the greater the spatial and temporal frequency of spawning in a given year.

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Flow

Jim Uphoff and Marek Topolski

Natural flow regimes of Chesapeake Bay striped bass spawning and nursery tributaries may be altered as a result of consumptive use and hydropower operations (M. Bryer, Nature Conservancy, personal communication). A river's flow regime structures physical and biotic components of aquatic ecosystems (Power et al. 1995b; Poff et al. 1997). Patterns of river flow determine physical habitat in rivers and on floodplains and influence organic matter, nutrient availability, water temperature, and water quality (Stanford et al. 1996, Bunn and Arthington 2002; Whiting 2002). Magnitude and frequency of occurrence of discharge, as well as duration, timing, and rate of change of flows, are critical components of a natural flow regime (Poff et al. 1997; Arthington et al. 2006). Changes in components of the natural flow regime, including both low and high flows, may result in loss of aquatic biodiversity, changes in aquatic food webs, and reductions in fish species and abundance (Power et al. 1995a; Power et al. 1995b; Wootton et al. 1996).

Variations in river flows to the Chesapeake Bay set up stratification, drive estuarine circulation, and cause fluctuations in inputs of freshwater, sediments, and nutrients (Kemp et al. 2005). These processes greatly influence hypoxia (Hagy et al. 2004; Kemp et al. 2005), which in turn impacts availability of habitat for striped bass juveniles and adults (see Hypoxia section). Associations of Chesapeake Bay tributary flow to striped bass year-class success have been explored and both positive and negative associations were detected (Kernehan et al. 1981; Uphoff 1989; Uphoff 1993; Rutherford et al. 1997). Striped bass spawning and larval nursery areas in Chesapeake Bay are located in the fresh-low salinity tidal reaches within the coastal plain and the estuarine turbidity maximum (ETM) is particularly important (North and Houde 2003). The ETM is a zone of high turbidity and suspended sediment associated with the landward margin of saltwater intrusion that is associated with conditions important for striped bass egg and larval survival (high zooplankton production, reduced predation, and optimum salinity and temperature conditions; North and Houde 2001). Differences in freshwater flow may influence survival of eggs and larvae by controlling retention in the ETM region and by affecting the overlap of temperature/salinity zones preferred by later-stage larvae with elevated productivity in the ETM (North and Houde 2001). Year-class success of striped bass is largely determined by survival of eggs and larvae (Uphoff 1989; 1993; Houde 1996).

Alteration of natural river flow due to dam operation, water withdrawal, and harbor maintenance have been implicated in declines of striped bass spawning success in Roanoke River (Rulifson and Manooch 1990), the Santee-Cooper System (Bulak et al. 1997), Savannah River (Reinert et al. 2005); and the Sacramento-San Joaquin Estuary (Stevens et al. 1985; Setzler-Hamilton et al. 1988). Restoration of "natural" salinity in Savannah River spawning habitat was followed by increased captures of wild larvae and juveniles (Reinert et al. 2005). Implementation of a natural flow regime and restrictions on fishing were followed by rebounding year-class success in Roanoke River (R. Rulifson, East Carolina University, personal communication; NCDENR 2004). The North Carolina Estuarine Striped Bass Fishery Management Plan specifically lists flow as a management issue (NCDENR 2004).

Construction of dams along the Susquehanna River and the Chesapeake and Delaware Canal may have altered spawning in the Head-of-Bay region (Dovel and Edmunds 1971). Completion of Conowingo Dam and reopening of the Chesapeake and Delaware (C and D) Canal as a sea level waterway in the late 1920s may have shifted most spawning from lower Susquehanna River to the east (Elk River and C and D Canal; Dovel and Edmunds 1971). Kernehan et al. (1981) believed it was more plausible that the upper Bay south of Turkey Point, rather than Susquehanna River, was the primary source of striped bass that spawned in the vicinity of the Elk River and C and D Canal.

Impacts from water withdrawal for consumptive uses such as agriculture, power generation, public utilities, and manufacturing during drought conditions in the Susquehanna River basin have been mitigated since 1973 (Susquehanna River Basin Commission 2008). Consumptive use mitigation is intended to maintain inflow to Chesapeake Bay above the 1 in 20 year monthly flow during August-October. Variance from the Federal Energy Regulatory Commission-mandated minimum flow at Conowingo Dam has been requested in the low flow years of 1999, 2001, 2002, 2005, 2007, indicating increased demand for Susquehanna River water. Late summer - fall mitigation would not influence flow-related processes associated with egg-larval dynamics that dominate striped bass year-class dynamics, but it does influence juvenile-adult habitat.

In the future, human population growth, energy development, conversion of rural areas to residential, increased agricultural withdrawal, and climate change will challenge water supply and quality (Wolman 2008). Human activities impact water supply by affecting its quantity and quality, and its management will need to be linked to human population growth (Wolman 2008). Cities such as Newport News and Baltimore have been looking to striped bass spawning rivers or their tributaries (Newport News, Mattaponi River and Baltimore, Susquehanna River) as sources of additional water to offset rising demand (www.kwreservoir.com; Brubaker and Brubaker 2002). Current water supply data in Maryland has not been completely analyzed to ensure that current and proposed water uses do not exceed supply (Wolman 2008).

Issue Statement

Consumptive use and hydropower operations in Chesapeake Bay tributaries can alter natural flow regimes thereby impacting striped bass spawning and nursery habitats.

Indicators

Egg Presence-absence and Juvenile Indices

Indices of juvenile and egg relative abundance were combined in a tabular stock-recruitment analysis to derive 1955-2008 larval survival history (see Figure 3 of Watershed Development brief; Uphoff 2008) that is not dependent on extensive larval surveys. Essentially, this analysis standardizes juvenile indices to a category of egg production. Exploratory analysis with 1957-2005 annual mean Susquehanna River flow at Harrisburg, PA and estimated Head-of-Bay larval survival, indicates a positive relationship ($r^2 = 0.12$, P = 0.01; Figure 1; J. Uphoff, MD DNR, unpublished). Strong year-classes occurred over the whole range of Susquehanna River flows, but years of good larval survival (ranked in the top 20%) were more frequent in the top 40% of annual flows. Poor larval survival (bottom 20%) was more likely when flows were in the bottom 40% of the distribution. This analysis illustrates potential for developing flow criteria linked to larval survival.

Seasonal Minimum Flow Requirement

Annual flow thresholds do not account for seasonal variability. Seasonal, monthly, and running thresholds are options to be explored. Winter-spring flows may be a better indicator of timing of that impact larval survival and year-class success, while summer-fall conditions could structure juvenile-adult habitat conditions.

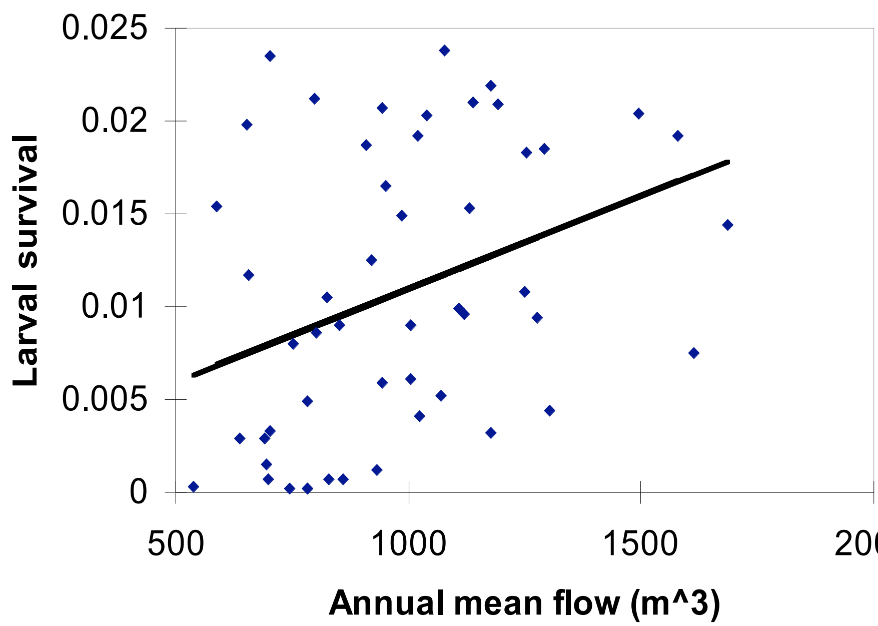

Figure 1. Plot of 1957-2005 observed and predicted Head-of-Bay annual striped bass egg-larval survival estimates and USGS annual mean Susquehanna River flow at Harrisburg, PA ($r^2 = 0.12$, P *= 0.01).*

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Hypoxia

Jim Uphoff and Dave Secor

There is general recognition that hypoxia (DO < 2 mg / L) impacts a substantial portion of Chesapeake Bay in summer, has increased in extent during the past 50 years, causes significant ecological harm, and is the target of substantial nutrient management efforts (Breitburg 2002; Hagy et al. 2004). Hypoxia's greatest impact on striped bass habitat occurs during summer when it is greatest in extent, but hypoxic conditions are present at lesser levels during spring and fall (Hagy et al. 2004; Constantini et al. 2008). Volume of hypoxic water in Chesapeake Bay increased dramatically during 1950-2001, demonstrating a strong role for cultural eutrophication (Hagy et al. 2004). This increased volume occurred concurrently with a long-term increase in NO_3- from fertilizers and other sources, and chlorophyll *a* concentrations (Hagy et al. 2004). Hypoxic volume in Chesapeake Bay estimated by Hagy et al. (2004) averaged about $4.4 \bullet 10^9$ m^3 during 1950-1984 and $8.2 \bullet 10^9$ m^3 during 1985-2001 (Figure 1). The spatial distribution of hypoxia expanded southward from a small area at the upstream limit of the mesohaline Bay in the late 1950s to encompass the entire mesohaline Bay and a portion of the polyhaline Bay in Virginia by the early 1990s. Mean depth of hypoxic waters did not change over the long-term (Hagy et al. 2004).

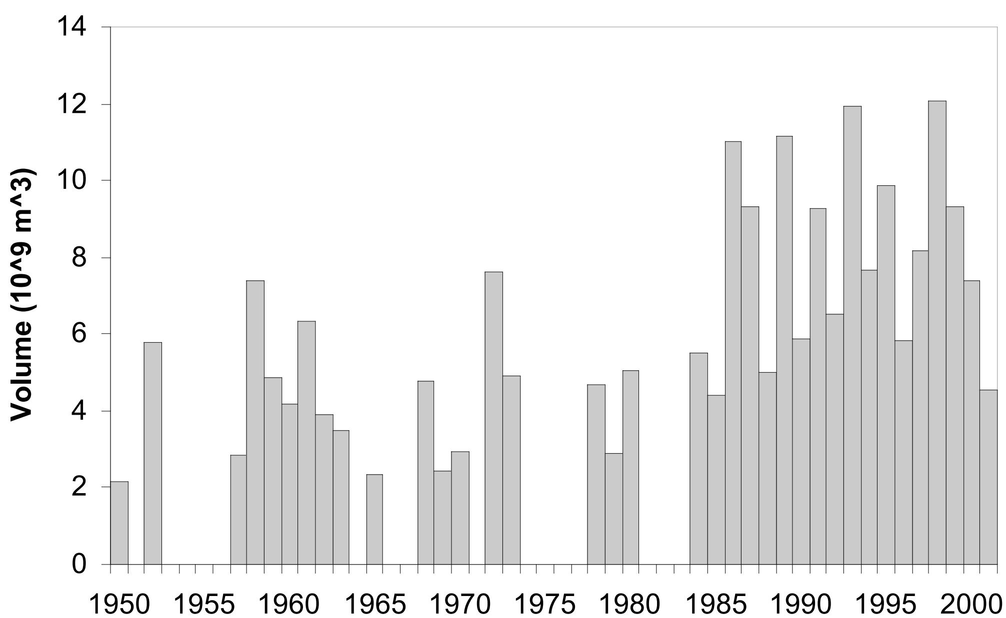

Figure 1. Estimates of Chesapeake Bay hypoxic volume during 1949-2001 (Hagy et al. 2004). Blanks are missing values.

Habitat loss due to hypoxia in coastal waters is often associated with fish avoiding DO that reduces growth and requires greater energy expenditures, as well as lethal conditions (Breitburg 2002). Fish strongly avoided hypoxic conditions, particularly chronic hypoxia, in the brackish Neuse River Estuary, North Carolina (Bell and Eggleston 2004). Spot, Atlantic croaker, and blue crab generally used the entire Neuse River Estuary when it was well oxygenated, but were restricted to oxygenated shallows when hypoxia was extensive (Eby and Crowder 2002). Hypoxic zones altered habitat use by fish and blue crabs — potentially increasing bioenergetic costs, sublethal effects such as reduced growth and condition, and overlap with competitors and predators (Breitburg 2002; Eby and Crowder 2002). Crowding in nearshore habitat, if accompanied by decreased growth due to competition, could lead to later losses due to size-based processes such as predation and starvation (Breitburg 2002; Eby and Crowder 2002; Bell and Eggleston 2004).

Once severe hypoxia becomes established, fish yields and abundances plummet (Breitburg 2002). Hypoxia in the Gulf of Mexico has been implicated in reduced food resources, reduced abundance of fishes and panaied shrimp, declining shrimp harvest efficiency, and has possibly blocked shrimp migration (Zimmerman and Nance 2000; Stanley and Wilson 2004). Hypoxia in Chesapeake Bay degrades benthic communities and may kill fish if wind- and tide-driven tilting of the pyncnocline brings hypoxic waters into shallow areas (Breitburg 2002; Hagy et al. 2004). There is evidence of cascading effects of low DO on demersal fish production in marine coastal systems through loss of invertebrate populations on the seafloor (Breitburg et al. 2002; Baird et al. 2004). Exposure to low DO appears to impede immune suppression in fish and blue crabs, leading to outbreaks of lesions, infections, and disease (Haeseker et al. 1996; Engel and Thayer 1998; Breitburg 2002; Evans et al. 2003). Exposure of adult common carp, *Cyprinus carpio*, to 1 mg/L oxygen for 12 weeks depressed reproductive processes such as gametogenesis, gonad maturation, gonad size, gamete quality, egg fertilization and hatching, and larval survival through endocrine disruption even though they were allowed to spawn under normoxic conditions (Rudolph et al. 2003).

Constantini et al. (2008) examined the impact of hypoxia on striped bass 2 years-old or older in Chesapeake Bay during 1996 and 2000 (hypoxic volumes = 5.4 and 7.4 • 109 m3, respectively; Hagy et al. 2004) through bioenergetics modeling and concluded that a temperature-oxygen squeeze had not limited growth potential of striped bass in the past. Hypoxia could have had opposing short-term effects. In years when summer water temperatures exceed 28 °C, hypoxia could reduce the quality and quantity of habitat through a temperature-oxygen squeeze. In cooler summers, hypoxia may benefit striped bass by concentrating prey and increasing encounter rates with prey in oxygenated waters. Hypoxia could become important if climate warming continues along its current trajectory (Constantini et al. 2008). Increased susceptibility to disease due to hypoxia was not addressed in this modeling study, although hypoxia is one of two dominant hypotheses explaining high prevalence of disease in the Bay (see Disease brief).

Bioenergetics approaches generally assess spatial heterogeneity of Chesapeake Bay habitat (Brandt et al. 1992; Constantini et al. 2008), but appear to consider the whole Bay available to striped bass. In-Bay migratory behavior and aggregation of striped bass may magnify consequences of hypoxia within Chesapeake Bay. Descriptions of movements of striped bass within Chesapeake Bay largely based on conventional tagging within Maryland's portion of

Chesapeake Bay during the 1950s-1960s, indicated high spatial aggregation in particular areas (Mansueti 1961; Hollis 1967; see Adult Background). In the main-Bay during summer, most were found between Poole's Island and Tilghman Island — an area now encompassed by expanded hypoxic volume (Mansueti 1961; Hollis 1967; Hagy et al. 1984). If aggregation in this area was maintained after recovery of the stock in the 1990s, then more abundant and larger striped bass had less well-oxygenated habitat to occupy.

Hypoxia is also associated with transition from rural to suburban landscapes in brackish Chesapeake Bay subestuaries. Bottom DO in channel waters was strongly and negatively associated with levels of impervious surface (a measure of intensity of human development; see Watershed Development brief; Figure 2; Uphoff et al., submitted). The chance of bottom waters becoming hypoxic was about 3-times greater when IS was 10% or more than when it was 5% or less. Impervious surface had a significant, negative influence on the odds of YOY striped bass being present in mid-channel bottom habitat, but did not negatively influence occupation of shore-zone habitat of brackish Chesapeake Bay tributaries (Uphoff et al., submitted). Loss of nursery habitat due to hypoxia may have implications beyond Chesapeake Bay because of the region's large contribution to Atlantic Coast fisheries (Richards and Rago 1999).

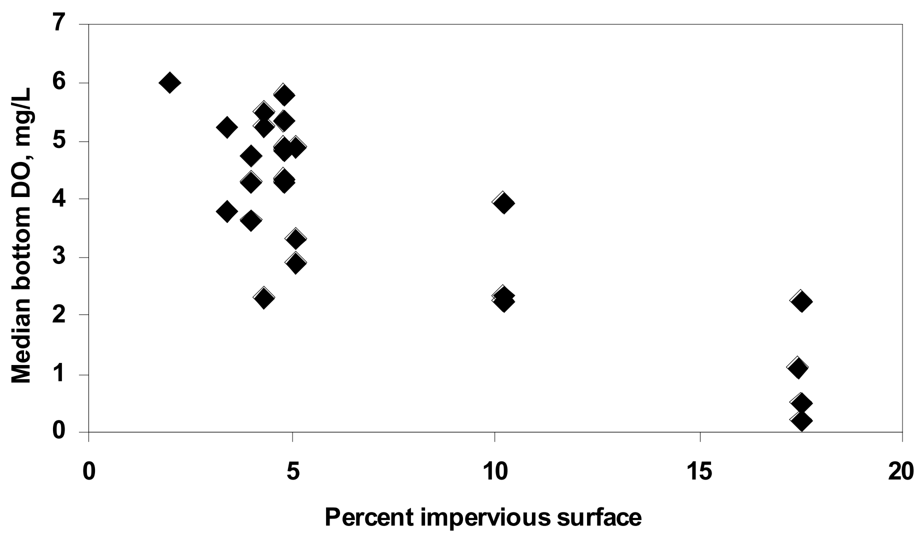

Figure 2. Plot of annual median dissolved oxygen during July-September and percent impervious surface for Chesapeake Bay tributaries sampled during 2003-2005 (Uphoff et al. submitted).

Issue Statement

Hypoxic volume has expanded in Chesapeake Bay over the past 50 years and represents an increasing loss of summer habitat for adult and juvenile striped bass.

Indicator

Volume, Location, and Extent of Hypoxia

Annual estimates of volume, location, and extent of hypoxia in Chesapeake Bay exist for 1984-2006 and for some years back to 1949 (Hagy et al. 2004; Scavia 2008). Current (2007-2008) estimates are being made as well (Ecocheck 2008).

Growth Rate Potential

Potential effects of hypoxia on habitat quality for striped bass can be examined by modeling spatially explicit bioenergetics-based growth rate potential (Constanti et al. 2008). NOAA's Chesapeake Bay Office has been developing this approach (H. Townsend, NOAA, personal communication).

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Contaminants

Jim Uphoff and Dave Secor

Differences in egg and larval survival during the first few weeks of life result in large annual recruitment variability of Chesapeake Bay striped bass. Generally, these differences in survival rates of the early life stages are believed to result from stochastic environmental factors, particularly temperature and freshwater flow (See Early Life History Brief). However, extended life cycle tests with several species of fish found that early life stages were most sensitive and larvae were extremely sensitive to a variety of toxicants (McKim 1977; Peterson et al. 1982; Bengtson et al. 1993). Larvae were more sensitive than eggs to contaminants within the water column (usually metals) (Peterson et al. 1982).

Between 1954 and 1970, strong year-classes were produced in Chesapeake Bay every 2-4 years (Richards and Rago 1999). Strong year-classes failed to appear after 1970 and year-class success declined steadily into the early 1980s and generally remained depressed until after 1988 (Richards and Rago 1999). Simulations indicated that decreased survival of Chesapeake Bay striped bass due to excessive larval mortality or overfishing could have reduced the population in the 1970s (Goodyear 1985). In either case, reduction of fishing mortality was a viable management strategy for restoring the stock and recovery has largely been attributed to reducing fishing mortality (Richards and Rago 1999). After 1988, the pattern of strong year- classes appearing every few years returned.

Synthesis of years of striped bass-related contaminants and water quality studies conducted in the 1980s suggested that problems existed in some Chesapeake Bay spawning rivers, but were not the sole problem (Richards and Rago 1999). Toxic water quality conditions (low conductivity, alkalinity, hardness, and pH and high levels of trace metals) and low water temperatures (< 12 °C) encountered by striped bass larvae were implicated in episodic mortalities in some tributaries in the 1980s (Uphoff 1989; 1992; Hall et al. 1993; Richards and Rago 1999). Toxicity of inorganic contaminants to striped bass larvae and juveniles decreased with age (Buckler et al. 1987). Uphoff (1989; 1992) concluded that temperature and water quality operated independently in Choptank River; egg-prolarval survival (prolarvae = yolk sac larvae) was reflective of water temperature and postlarval mortality (postlarvae = post yolk sac larvae) was associated with water quality conditions. Poor conditions at either or both stages produced a poor year-class, while optimal conditions were needed at both stages for a strong year-class. Acidic deposition, pesticides, and phosphate ores in fertilizers could have been sources of toxic inorganic metals (Brady 1974; May and McKinney 1981; Peterson et al. 1982) implicated in episodic mortalities of postlarvae in Choptank River (Uphoff 1992).

Retrospective analysis of postlarval survival estimates in Choptank River and records of agricultural best management practices (BMPs; Chesapeake Bay Program 2008a) implemented to reduce nutrient and pesticide use as part of the Chesapeake Bay Program lend some support to the notion that toxicity of the nursery grounds may have been reduced (Uphoff 2008). Agricultural pesticides and fertilizers were thought to be potential sources of toxic metals implicated in some episodic mortalities of striped bass larvae in Bay spawning tributaries (Uphoff 1989; 1992; Richards and Rago 1999). Human-related land use in the Bay watershed is dominated by agriculture (22% of watershed; Chesapeake Bay Program 2008b) and striped bass spawning areas are typically on the receiving end of large amounts of agricultural drainage because of their location at the junction of large fluvial systems and brackish estuaries (Uphoff 2008). An increasing trend in survival of postlarvae in Choptank River during 1980-1990 coincided with growth of BMPs. A correlation analysis of Choptank River watershed BMPs with estimates of postlarval survival indicated that as many as four BMPs were positively associated with survival and two measures that accounted for the greatest acreage, conservation tillage and cover crops, were the most strongly associated with increased postlarval survival (Figure 1). This correlation analysis cannot explain whether toxicity was lowered by BMPs, but it is possible that reduced contaminant runoff was a positive byproduct of agricultural BMPs aimed at reducing nutrients (Uphoff 2008).

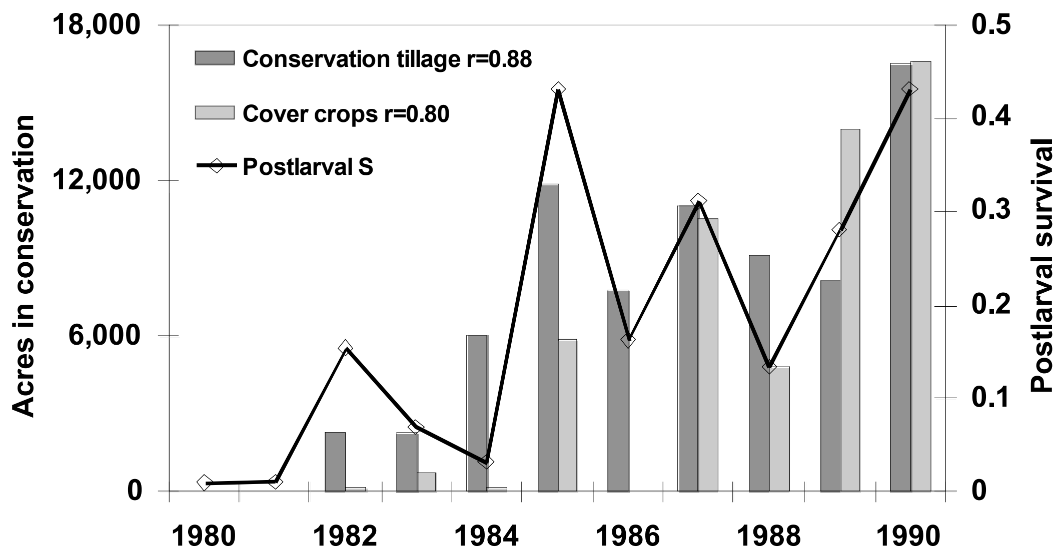

Figure 1. Trends in Choptank River striped bass postlarval survival and acreage of agricultural best management practices (BMP) implemented in Caroline County, Maryland. Correlation coefficients of BMPs and larval survival are reported next to BMP keys.

During egg development (oogenesis), diverse lipophilic contaminants are transferred from maternal tissues of fish to their eggs (Longwell et al. 1996). Contaminant-laden yolk material of the egg is then used during development of the embryo and larva. Maternal transfer of anthropogenic chemicals such as organochlorine pesticides (DDT, mirex) and industrial chemicals (PCBs) disrupt endocrine function associated with reproduction and are associated with inhibition of oocyte development, inhibition of spawning, reduced egg weight, depressed survival, malformation, and abnormal chromosome division of eggs and larvae (Westin et al. 1985; Longwell et al. 1992; Varanasi 1992; Longwell et al. 1996; Colborn and Thayer 2000). Maternal effects may be biomagnified by contaminants in the water column in some environments (Longwell et al. 1992). Experiments with Atlantic croaker indicated maternal transfer of PCBs to eggs and larvae would result in reduced growth rates and impair behaviors associated with avoidance of predators (McCarthy et al. 2003).

Westin et al. (1985) observed slightly better survival of striped bass larvae from eggs with lower concentrations of organochlorine compounds (including PCBs). Hudson River has been severely contaminated with PCBs for decades (Schneider et al. 2007), yet indices of striped bass year-class success have not deteriorated noticeably (NEFSC 2008). Human consumption advisories have been issued for striped bass in Chesapeake Bay due to excessive concentrations of PCBs and methyl-mercury (Maryland Department of Environment 2008; Virginia Department of Health 2008).

Improved sewage treatment (removal of P and N) since the 1970s has led to improved ecosystem responses (increased oxygen levels, clarity, and aquatic vegetation; reduced phytoplankton biomass) in regions of the Bay, but regional responses have varied considerably (Kemp et al. 2005). In general, these improvements would have recovered lost fresh-tidal nursery habitat for striped bass in some Chesapeake Bay tributaries.

For instance, installation of secondary wastewater treatment in the Philadelphia area improved water quality and allowed striped bass spawning to become re-established in Delaware River after decades of poor water quality (Weisberg and Burton 1993).

In recent years, endocrine disrupting compounds (pharmaceuticals, industrial compounds, and pesticides) have been detected in treated sewage effluent. These compounds have been associated with intersex in fishes and discovery of intersex in smallmouth bass and concurrent, unexplained fish kills in the fluvial Potomac River and its tributaries have received considerable attention (Blazer et al. 2007). These compounds are not limited to sewage and may be found in agricultural and industrial effluent as well. Endocrine disruption can produce an animal that is superficially healthy that experiences alterations in sexual development; however, reproductive impairment may not result from endrocrine disruption (Oberdörster and Oliver 2001). Other effects such as immunomodulation and an associated increase in disease susceptibility are possible (Blazer et al. 2007). Impact of these compounds on striped bass has not been described, but this emerging issue should be considered.

Issue Statement

Contaminants were implicated in the decline of Chesapeake Bay striped bass recruitment in the 1970s, but their effects were indistinguishable at the population level from high fishing rates, an unfavorable climate regime, or a combination of these factors. Contaminants could depress productivity, requiring overly conservative fishing regulations to compensate. Risk management strategies will need to be developed in the future to deal with suspected contaminant-related problems because it is unlikely that causative factors will be well understood. Consumption-related advisories may lower desirability of striped bass as table-fare, impacting both commercial sales and recreational participation.

Indicators

Indexing Egg-Larval Survival

Retrospective analysis of egg-larval survival indicated that 2-3 year depressions in larval survival have not been uncommon throughout the time-series, but sustained periods of four or more years may indicate deterioration of nursery habitat of striped bass (See Figure 3 of Watershed Development brief; Uphoff 2008). Juvenile and egg presence-absence indices were combined in a tabular stock-recruitment analysis to derive 1955-2008 larval survival history (Uphoff 2008) that is not dependent on extensive larval surveys. Essentially, this analysis standardizes juvenile indices to a category of egg production to index survival (relative measure of juveniles per egg).

Judging Impact of Contaminants on Fishing Strategies

Egg per recruit (EPR) models provide a basis for judging costs of contaminants on fishery yields (Boreman 1997). These equilibrium models can be easily modified to evaluate the effects of different mean levels of larval survival associated with contaminants and efforts to control contaminants on levels of fishing mortality (F) needed to maintain EPR. For example, effective eggs (EE) would be calculated as the sum of products of fecundity, abundance (a function of F, selectivity, and M), maturity, and mean larval survival (see *Indexing Egg-Larval Survival*, above). EE would be summed across age classes and divided by initial recruits in the calculations (EEPR). Baseline EEPR calculated from preferred F and larval survival would define target conditions. Reduced or enhanced larval survival estimates would be substituted into EEPR calculations to solve for F needed to maintain the baseline. In the case of reduced larval survival, an F reduction would be estimated, while improved larval survival would result in an F credit that might allow for additional harvest to reward habitat stewardship.

Contaminant-Related Consumption Advisories

Changes in contaminant-related striped bass consumption-advisories allows for tracking of some persistent bioaccumulating contaminants.

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Watershed Development

Jim Uphoff and Mary Fabrizio

Increasing urban sprawl associated with population growth has been identified as a threat to the Chesapeake Bay watershed (CBP 1999). As human populations grow, open land is converted to impervious surface (IS) in the form of paved surfaces, buildings, and compacted soils (Beach 2002). A variety of studies have documented a deterioration of freshwater aquatic ecosystems as IS occupies more than 10% of a watershed (Cappiella and Brown 2001; Beach 2002) and similar impacts have been noted in Chesapeake Bay estuaries (King et al. 2004; Uphoff et al. submitted). Lower levels of IS (2% IS) may eliminate sensitive species such as brook trout from streams (Broward et al. 1999). Impervious surfaces increase runoff volume and intensity in streams, leading to physical instability, increased erosion, and sedimentation (Beach 2002). This surface runoff is warmer than water draining forests or other porous lands, and represents a source of thermal pollution to the estuary. In addition, IS runoff may transport excess nutrients which are known to contribute to algal blooms, hypoxia, and anoxia. Heavy metals and organic compounds that are toxic to aquatic organisms may also be carried in IS runoff (Beach 2002).

Impaired reproductive success of several anadromous species has been associated with watershed development. Densities of alewife and white perch eggs in the Hudson River exhibited a strong negative threshold response to urbanization (Limburg and Schmidt 1990). Siltation, impoundment, removal of substrate, physical alterations, toxic or organic pollution, and increased acidification were cited as possible mechanisms that depressed anadromous fish spawning as urbanization of the Hudson River watershed progressed (Limburg and Schmidt 1990).

As IS progressed from approximately 9% to 13% during 1972-2006 in Bush River (a tributary of Chesapeake Bay) white perch and yellow perch adults, eggs, and larvae were far less likely to be in found in streams (Uphoff et al. 2007). Anadromous fish spawning was detected more frequently in streams in the adjacent, less developed Aberdeen Proving Ground region (≈3% IS in 1973 and 2006) than in the Bush River watershed (Uphoff et al. 2007). Yellow perch egg and larval viability was much lower in the Severn River watershed (≈ 17% IS) during 2001-2003 when compared with Severn River yellow perch hatchery records for 1901-1955 (largely prior to suburban development) and yellow perch larval presence-absence indices during 1965-2008 from other, less developed Chesapeake Bay watersheds (Uphoff et al. 2005; Uphoff et al. 2008).

In Chesapeake Bay tributaries, PCB concentrations in white perch were closely related to the amount of IS in a watershed (King et al. 2004). Organic contaminants such as PCBs accumulate in fishes, can disrupt endocrine function associated with reproduction, and have been associated with depressed survival, malformation, and abnormal chromosome division of eggs and larvae (Longwell et al. 1992, 1996; Colborn and Thayer 2000).

Hypoxia, associated with the transition from rural to suburban landscapes in Chesapeake Bay estuaries, had a significant negative influence on the odds that young-of-the-year striped bass were present in mid-channel bottom habitat (Uphoff et al., submitted). However, hypoxia did not negatively influence occupation of shore-zone habitat by YOY striped bass in brackish tributaries of Chesapeake Bay (Uphoff et al., submitted). Hypoxic conditions in deeper waters of the tributaries could lead to a loss of nursery habitat for striped bass, a condition that could have implications for the population of striped bass outside of Chesapeake Bay because of the Bay's large contribution to Atlantic coastal fisheries (Richards and Rago 1999). Experiments have indicated that hypoxia could act as an endocrine disruptor that depresses reproductive success of fish (Rudolph et al. 2003).

Striped bass spawning areas were overlaid onto the a U.S. Geological Survey map of estimated development pressure and, visually, all spawning area watersheds appeared to be under moderate to very high development pressure (Figure 1). Projections of the extent of impervious surface in 2020 in Chesapeake Bay indicated that urbanized areas in the Patuxent, Potomac, and James rivers (all critical spawning areas for striped bass) will experience the greatest proportional gains in IS, whereas development in watersheds around other striped bass spawning areas would remain just below 5% IS (Figure 2; Uphoff 2008). Patuxent River was projected to cross beyond 10% IS, while Potomac and James Rivers would develop between 5% and 10% IS. Potomac and James rivers are among the largest spawning areas in the Bay and their watersheds should be a priority area for urban best management practices (Uphoff 2008).

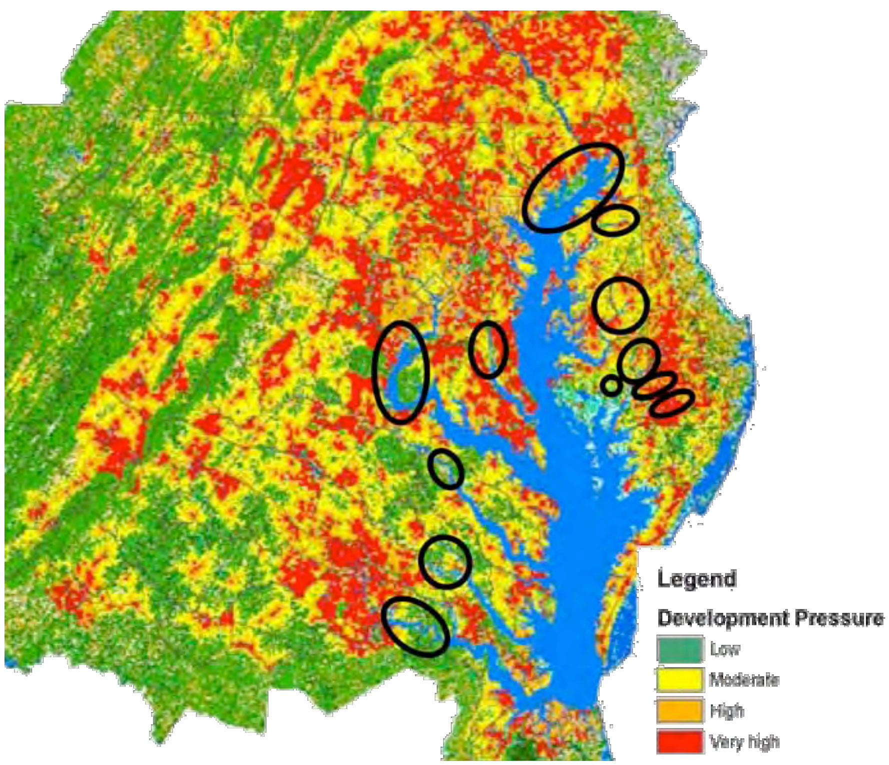

Figure 1. U.S. Geological Survey Projections of development pressure (prepared for the Chesapeake Bay Program) with ovals indicating striped bass spawning areas. Two lower Eastern Shore ovals may contain multiple spawning areas.

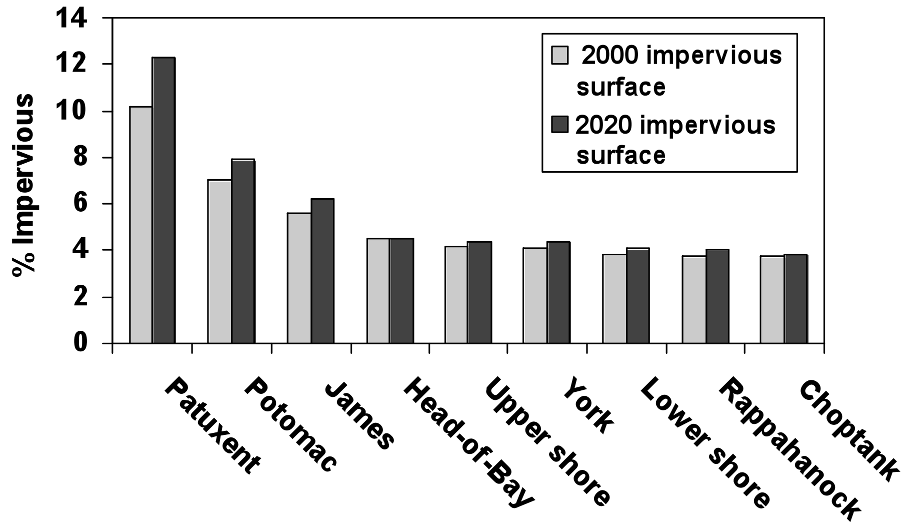

Figure 2. Projected levels of impervious surface for Chesapeake Bay striped bass spawning area watersheds (Uphoff 2008). Eastern Shore spawning areas are grouped into regions. Upper shore = Chester River; Lower shore = Nanticoke, Wicomico, Manokin, Blackwater, Chicamicomico, Transquaking, and Pocomoke rivers.

Issue Statement

Increasing urban sprawl associated with population growth has been identified as a threat to the Chesapeake Bay watershed. Sprawl may negatively impact water supply and water quality needed for striped bass larvae, juveniles, and adults through sedimentation, flow alteration, nutrient enrichment, contaminants, and thermal pollution.

Indicators

Impervious Surface

Uphoff et al. (submitted) proposed a fisheries management framework for Maryland's Chesapeake Bay tributaries based on the amount of IS in the watershed. In systems with less than 5% IS, fish habitat is generally considered unimpaired and harvest management actions should be effective in ensuring sustainability of the harvested population. Preservation of the watershed at this level of IS would also be desirable. Five percent might be considered a target level of IS representing a compromise between maintaining spawning area productivity while accommodating population growth by allowing for some development. As IS increases from 5% to 10%, aquatic habitat loss has an increasingly negative effect on the dynamics of the harvested resource. At these levels of IS, fisheries managers could compensate for additional habitat-related losses by increasing adjustments to harvest while land-use and environmental managers impose growth, stormwater, and pollution controls. At or above the 10% IS threshold, successful preservation or restoration of resident stocks by traditional harvest adjustments becomes unlikely and habitat restoration would be the key to maintaining sustainable fisheries (Uphoff et al. submitted).

Indexing Egg-Larval Survival

Development could affect survival of eggs and larvae, but detecting changes in first year survival of striped bass in response to urbanization may be exceedingly difficult because of high natural variability in reproduction (Schaaf et al. 1987; Rago 1991). Juvenile and egg presence-absence indices can be combined in a tabular stock-recruitment analysis to derive 1955-2008 larval survival history (Uphoff 2008) that is not dependent on extensive larval surveys. Essentially, this analysis standardizes juvenile indices to a category of egg production to index survival (relative measure of juveniles per egg). Retrospective analysis of egg-larval survival indicated that two to three year depressions in larval survival have not been uncommon throughout the time series, but sustained periods of four or more years may indicate deterioration of nursery habitat of striped bass (Figure 3; Uphoff 2008). Negative influence of development would be suspected if low survival were sustained for four or more years within developed tributaries (based on IS, percent urban, or other measures), but not in less developed ones.

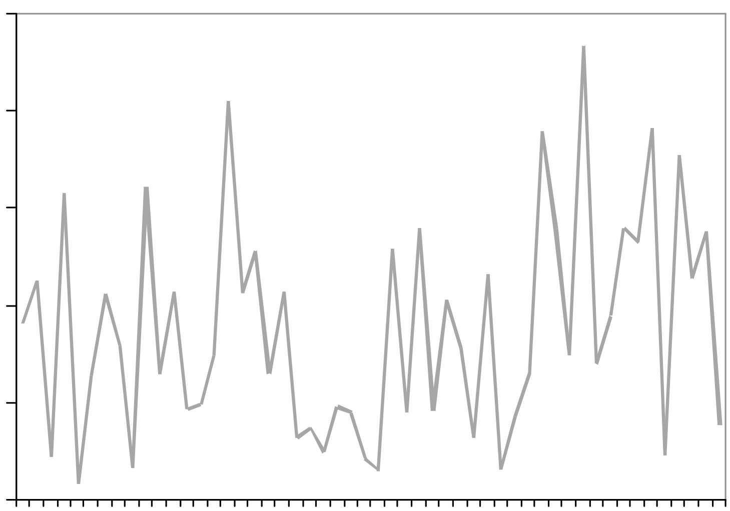

Figure 3. Averaged striped bass egg-larval survival for four major Maryland striped bass spawning areas (Uphoff 2008). Note the extended depression of survival in the mid-1970s to early 1980s. Estimates made for each of the major tributaries have been averaged here.

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FOODWEB

Forage and Predation

Jim Uphoff, John Jacobs, Jim Gartland, and Rob Latour

Striped bass are omnivores and feed at various trophic levels throughout their life history. Feeding generally begins at 5 days post hatch (dph), with larvae targeting copepods, copepodites, and cladocerans, and gradually moving onto mysids by 30 dph (Setzler-Hamilton and Hall 1991). Juvenile striped bass are non-selective, feeding on insect larvae, polychaetes, larval fish, mysids, and amphipods. (Setlzer-Hamilton and Hall 1991). Age-1 striped bass undergo an ontogenetic shift in foraging from primarily invertebrate sources to fish (Hartman and Brant 1995; Hartman 2003; Walter et al. 2003).

Striped bass switch to a fish diet as one-year-olds (Hartman and Brandt 1995; Hartman 2003; Walter et al. 2003). Early switching requires high growth rate, which implies high densities of proper forage and safe foraging opportunities (Persson and Brönmark 2002). Species undergoing ontogenetic diet shifts face a risk of delayed transitions among feeding stages if food resources are limited and competition is intense. Individuals not reaching size advantage over prey may become stunted at sizes where consumption balances metabolic requirements and, if these conditions prevail, recruitment to adult stages may be reduced by size-dependent processes such as predation or starvation (Bax 1998; Persson and Brönmark 2002).

Striped bass in Chesapeake Bay increasingly use the pelagic food web as they age (Hartman and Brandt 1995). In the Chesapeake Bay region, bay anchovy represented the prey most consumed by one-year-old striped bass as they initiated piscivory, but within a year larger clupeids, primarily Atlantic menhaden, predominated (Hartman and Brandt 1995; Walter et al. 2003). Diets vary substantially among seasons, regions, and ages or sizes of striped bass in Chesapeake Bay (Hartman and Brandt 1995; Griffin and Margraf 2003; Overton 2003; Walter et al. 2003; Walter and Austin 2003). In the Chesapeake-Delaware region, striped bass < 600 mm consumed greater quantities of mysids and blue crabs in spring and summer and greater quantities of white perch and gizzard shad in winter (Walter et al. 2003).

While past studies of striped bass diet composition in Chesapeake Bay found that Atlantic menhaden was the primary forage of age-2 and older striped bass, routine monitoring since 2002 (Chesapeake Bay Multispecies Monitoring and Assessment Program) has noted a smaller contribution (VIMS 2008). Atlantic menhaden were consumed by all sizes of striped bass examined, but did not become dominant prey until striped bass reached 560 mm TL. Mysid shrimp and bay anchovy were main prey of striped bass smaller than 465 mm and continued to account for appreciable portions of the diet of striped bass up to 660 mm (VIMS 2008). Departure of recent results from previous findings may reflect real changes in the diet of striped bass in this estuary or differences in approaches used to calculate diet composition (cluster versus random sample estimators; Bogstad et al. 1995; Buckel et al. 1999; R. Latour, Virginia Institute of Marine Science, personal communication).

Juvenile menhaden and spot were most relevant to younger, smaller striped bass making the transition through piscivory because piscivorous fishes are size selective and gape limited, and typically select prey that are 20-30% of their length (Stein et al. 1988; Juanes 1994; Uphoff 2003). Relative abundances of juvenile menhaden, spot, and bay anchovies in MD, VA, and NC have fallen from above average levels in the 1970s and 1980s to below average after the early 1990s (Uphoff 2003; Uphoff 2006; Figure 1). Minimum diet item size changes little as striped bass grow and is less than 50 mm (Walter and Austin 2003; Overton et al. 2008). The upper 99% quantile of prey fish length (mm) that can be eaten by striped bass (ETL) can be estimated as (1) ETL = (0.34 * STL) + 7.78 (F. Juanes, University of Massachusetts, personal communication); where STL is the length of striped bass in mm.

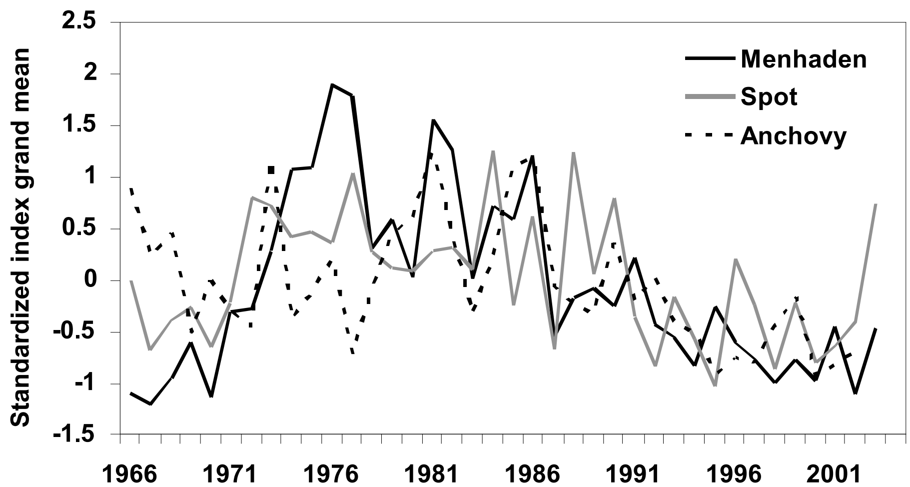

Figure 1. Grand means of standardized (z-transformed) indices of bay anchovy, Atlantic menhaden, and spot from surveys in Maryland, Virginia, and North Carolina during 1966-2003. Mean = 0; negative values indicate below average relative abundance; and positive values are above average.

Reduced fishing mortality and higher size limits that underpinned management to restore striped bass lead to more abundant and larger striped bass as the 1990s progressed (Uphoff 2003). Consumption of menhaden and anadromous herrings by a recovered striped bass population was potentially high enough to seriously impact the fisheries and abundance of these forage fishes (Hartman 2003; Uphoff 2003; Crecco and Benway 2008). Potential consumption estimates of age 0-2 Atlantic menhaden by striped bass increased steadily from a small fraction of commercial harvest in 1982 until it exceeded harvest after 1994 and exceeded estimated abundance after 1997 (Uphoff 2003).

Striped bass actively select for Atlantic menhaden, but will feed on other species when menhaden are not sufficiently abundant (Overton 2003; ASMFC 2004; Ruderhausen et al. 2005). Stable isotope analysis of striped bass scales collected during 1982-1997 from Chesapeake Bay indicated striped bass increased their use of the benthic food web as menhaden abundance decreased (Pruell et al. 2003). Switching to alternate prey may have serious implications for other prey items that are not tightly linked to striped bass. Depensatory mortality may exist when a fish population is faced with a predator that spends much of its time feeding on one prey species, but also has secondary prey (Hilborn and Walters 1992). Predator abundance may be independent of the secondary prey and, if the predators are efficient at finding and capturing secondary prey, then the number eaten will be more or less constant. As primary prey abundance declines, the mortality rate caused by the predators on the secondary prey increases (Hilborn and Walters 1992). Fish stocks that are subject to moderate to severe depensatory mortality often undergo sudden and persistent drops in surplus production over time, even when fishing mortality rates have remained low (Spencer and Collie 1997). A statistical-empirical-production modeling approach has indicated potentially large negative effects in recent years of high striped bass abundance on alternate prey or competitors such as Atlantic coast weakfish (Kahn et al. 2006; Uphoff 2006), summer flounder (Crecco 2008), Long Island Sound winter flounder (Crecco and Howell 2006), and Connecticut River American shad (Savoy and Crecco 2004; Crecco et al. 2006).

The menhaden fishery, centered in Chesapeake Bay, generally harvests 1-3 year-old menhaden (ASMFC 2006). Competition with striped bass is likely since 400+ mm striped bass were predicted (based on equation 1) to be capable of eating fish of the size menhaden attain at age 1 and 600+ mm striped bass would eat fish of the size menhaden attain at age 2. Diet studies by Walter and Austin (2003) and Overton et al. (2008) found that striped bass 900+ mm were capable of eating fish in excess of 400 mm, near the largest size attained by Atlantic menhaden (Ahrenholz 1991).

Generalizations of functional response suggest that the fishery would outcompete striped bass at low menhaden densities (Uphoff 2003). Catchability (a fishery's functional response) of purse seine-based menhaden fisheries is inversely related to abundance (a greater fraction of the menhaden stock is caught on a per set basis at low stock size; Schaaf 1975). A predator's functional response (number of prey consumed per unit area, per unit time by an individual predator; Yodzis 1994) is both a function of attack success and prey handling time. Handling time varies little for a given predator so predator feeding efficiency should be a function of prey per predator (Ney 1990; Yodzis 1994). The ratio of biomass of ages 1+ menhaden (ASMFC 2006) to age 2+ striped bass (NEFSC 2008) biomass fell from an average of 73 during 1982-1987 to asymptotic low of about 6 after 1996 (Figure 2) and attack success of striped bass on Atlantic menhaden along the Atlantic Coast should be indexed by this ratio.

A prey-size cascade could be precipitated in Chesapeake Bay by competition between large striped bass and the fishery. Large striped bass would rely more on small pelagic prey (bay anchovy and juvenile clupeids) needed by small striped bass, while diets of these smaller piscivores shift to benthic invertebrates (Hartman and Brandt 1995; Griffin and Margraf 2003; Overton 2003). These changes in striped bass diets have been noted by Griffin and Margraf (2003) and Overton (2003).

Hartman (2003) suggested that seasonal food shortages limited striped bass production as early as 1993. Indicators of change in the nutritional state of striped bass have subsequently been reported, including increased variation in weight-at-length, declining length- and weight-at-age, low tissue lipids and elevated moisture content (Uphoff 2003; Jacobs et al. 2004). In the late 1990s, a chronic, progressive bacterial disease (mycobacterioisis) was first reported from Chesapeake Bay striped bass (Heckert et al. 2001; Rhodes et al. 2001); a condition that currently persists at elevated prevalence (Rhodes et al. 2004; Ottinger and Jacobs 2006; see Stock Assessment-Disease Brief). The temporal association of these findings led to hypotheses linking food limitation to disease state (Hartman and Margraf 2003, Uphoff 2003). Field evaluations of the association between measures of fitness or nutritional state and disease status have yielded inconsistent results (Overton et al. 2003; Jacobs et al. 2004; Gauthier et al. 2006; Ottinger et al. 2006). However, it is difficult to prove direction of the response from field studies where prior history of the animal is unknown. In laboratory studies, Jacobs (2007) demonstrated the capability of a reduced ration to severely impact the progression and severity of the disease as caused by Mycobacterium marinum. Fish receiving a reduced ration were 37 times more likely to perish from the disease than those fed an adequate ration diet. Epidemiological modeling indicated that survival of striped bass diseased with Mycobacterium was about 69% of non-diseased fish (Gauthier et al. 2008).

Issue Statement

Low fishing mortality and high size limits have lead to more abundant and larger striped bass. Consumption by this population has been potentially high enough to seriously impact the fisheries and abundance of forage fishes. High demand has been concurrent with deterioration of indicators of striped bass nutritional state, an outbreak of lesions and *Mycobacterium*, and rising natural mortality rate estimates.

Indicators

Prey-Predator Ratios

Prey-predator ratios index attack success of predators. Striped bass: prey ratios may be based on assessment estimates of biomass or abundance or on ratios of relative abundance indices (Figure 2). Attack success of striped bass on Atlantic menhaden along the Atlantic Coast was indexed by the ratio of biomass of age 2+ striped bass (NEFSC 2008) to biomass of ages 1+ menhaden (ASMFC 2006) during 1982-2005 (the time-span in common in both assessments. Striped bass egg presence-absence from Maryland's striped bass spawning areas an index of mature female biomass (Uphoff 1997) and presence-absence of menhaden in the Maryland seine survey (E. Durell, MD DNR, personal communication) provide the most extensive view (1959-2008) of relative attack success. Trends in both sets of ratios tracked each other closely, falling from their highest levels in the early 1980s to asymptotic lows in the mid-1990s (Figure 2). Index-based menhaden:bass ratios indicated low attack success in the 1960s and a sudden rise in 1971. Higher ratios were maintained until the early 1990s (Figure 2).

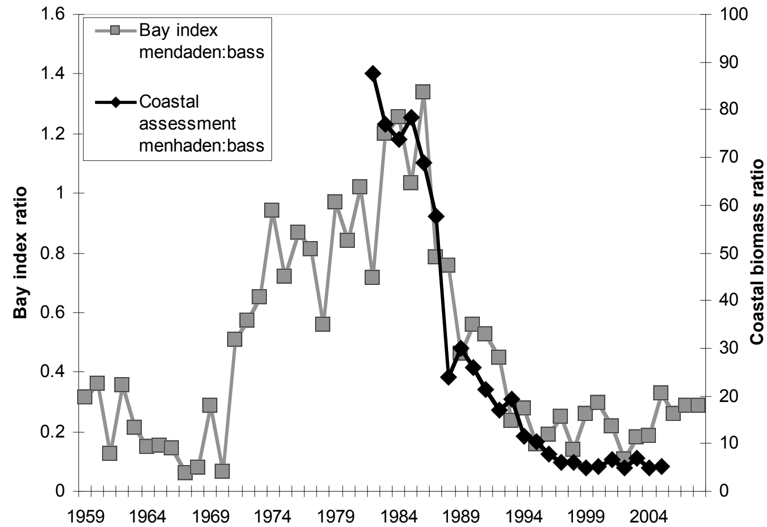

Figure 2. Ratio of ages 1+ menhaden biomass: ages 2+ striped bass biomass derived from coastal stock assessments and from Chesapeake Bay indices.

Condition Indices and Length-Weight Relationships

Fulton-type condition factors, relative weight indices, and length-weight regression slopes, intercepts, and regression coefficients provide means for comparing "well-being " of fish populations (Anderson and Gutreuter 1983). These comparisons should be standardized to common sizes and seasons (Anderson and Gutreuter 1983).

Diet Sampling

Widespread, year-round, low-frequency striped bass diet monitoring could provide information on prey-abundance and striped bass consumption. These data could be applied to bioenergetics based growth potential analyses (see Hypoxia brief).

Prey Consumption per Striped Bass Recruit Analysis

Dynamic pool models (yield or spawner biomass per recruit) can be adapted to address the effect of management changes (size limits and F) on relative consumption of prey by striped bass (Uphoff 2003). Striped bass bioenergetics analyses by Hartman and Brandt (1995) and Overton (2003) provide weight-specific estimates of menhaden and bay anchovy (respectively) consumption-at-age. Multiplying these estimates of equilibrium consumption by striped bass juvenile indices (Durell and Weedon 2008) provide an index of lifetime demand by a striped bass year-class for these prey fish. Smoothing with a running average and projecting the lifetime demand indices forward several years roughly translates future into contemporary relative demand that can be compared to indices of forage relative abundance in Chesapeake Bay (Figure 3).

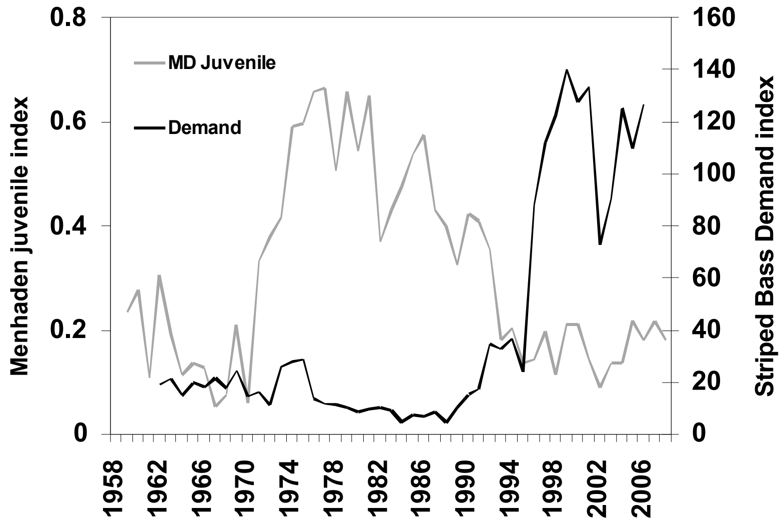

*Figure 3. Index of relative demand for menhaden by striped bass and the Maryland menhaden juvenile index. Relative demand index is based on menhaden consumption per recruit * recruitment index (recruitment index = Maryland striped bass juvenile indices; demand index smoothed three years and projected three years forward). Menhaden juvenile index is proportion of seine hauls with menhaden.*

Bass-Prey Biomass Dynamic Models

Surplus production models that include predation functions (Steele and Henderson 1984; Collie and Spencer 1993; Spencer and Collie 1997) can be used to examine relative effects of fishing and striped bass predation and competition on preyfish dynamics. When applied generally, adding a sigmoidal type III predation function to a biomass dynamic model has reproduced the types of rapid shifts in abundance exhibited by marine populations (Steele and Henderson 1984). When a striped bass predation term is successfully added, these models provide estimates of non-equilibrium striped bass related deaths and M, F, and non-equilibrium or equilibrium reference points. Annual consumption of prey per striped bass can be estimated and compared with bioenergetics-based results. This approach has indicated potentially large effects of striped bass predation and competition in recent years of high on weakfish, summer flounder, winter flounder, American shad, and blueback herring (noted previously). This type of model was useful for producing biomass estimates for some species in the development of an Ecopath with Ecosim model for Chesapeake Bay (Christensen et al., in press). The predator-prey production model provides a bridge between single-species (constant M) and more expansive multispecies or ecosystem models.

As an example of the potential of this approach, a logistic production model of Atlantic coast menhaden biomass with a Type-III striped bass predation function fit a menhaden index time-series better ($AIC_c = 45$) than a single species Schaefer model ($AIC_c = 83$, F-test $P < 0.001$; J. Uphoff, MD DNR, unpublished). Striped bass consumption of menhaden varied from 10-120% of harvest (Figure 4). Total mortality (Z = F + M from bass) exceeded levels for MSY (Z_{msy}) during 1964-1971 (mostly due to F) and since 1994 (≈ equal F and M). Losses in excess of Z_{msy}

were associated with low menhaden biomass (≈ 2-3 • 10^5 mt) while an extended period in excess of 8 • 10^5 mt was associated with Z below 70% of $Z_{msy.}$ Estimated per capita consumption of menhaden (1-8 kg menhaden per kg striped bass) generated from the Type-III function compared favorably with estimates striped bass bioenergetics models (J. Uphoff, MD DNR, unpublished).

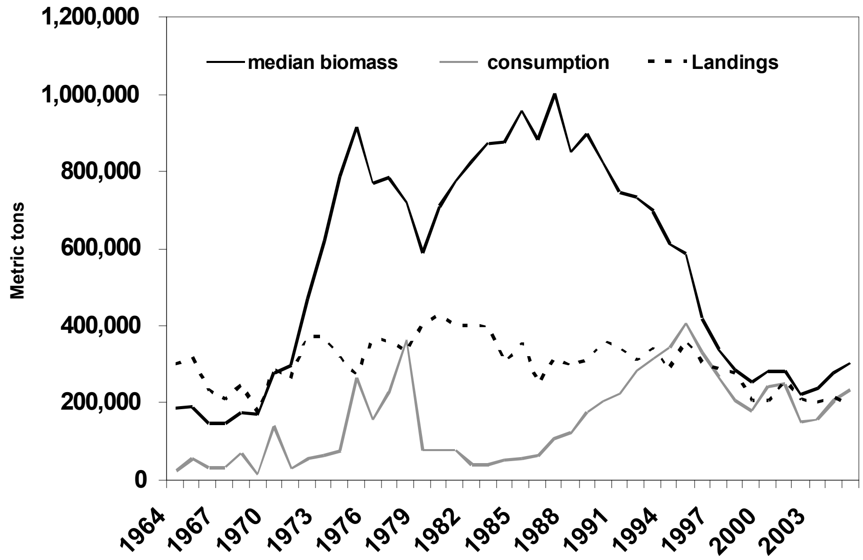

Figure 4. Estimated menhaden biomass and estimated biomass of menhaden consumed by striped bass from a logistic surplus production model that included a Type III striped bass predation function. Landings were an input into the model.

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Invasive Species

Marek Topolski, Mary Fabrizio, and Ron Klauda

Introduction

At least 18 (U.S. Department of Agriculture) of the estimated 200 non-native invasive species in the Chesapeake Bay Basin (Chesapeake Bay Program 2008) are aquatic. Invasive species can alter food webs and habitats, displace native species, and disrupt economic systems (Parker et al. 1999; Mack et al. 2000). Three non-native piscivorous fish have recently become abundant in Chesapeake Bay waters: flathead catfish (*Pylodictis olivaris*), blue catfish (*Ictalurus furcatus*), and northern snakehead (*Channa argus*). These introductions of potential predators to spawning and nursery habitats pose likely challenges to striped bass populations in Chesapeake Bay.

Blue and Flathead Catfish

Flathead catfish were introduced to the Potomac River in 1965 and the James River between 1965 and 1977 (Jenkins and Burkhead 1994). The first flathead catfish report from the Susquehanna River Basin was in 1991, and several were collected from the West fish lift at Conowingo Dam in 2004 (Brown et al. 2005). The salinity LC50 for flathead catfish is 14.5-15.8 ppt in synthetic seawater (Bringolf et al. 2005) suggesting that dispersal among the Rappahannock River and tributaries north is plausible including the Chesapeake and Delaware Canal and Delaware Basin (Brown et al. 2005).

Blue catfish were introduced into the Mattaponi River (York River drainage), James River, Rappahannock River and impoundments in the Mattaponi River and Potomac River watersheds (Higgins 2006; Jenkins and Burkhead 1994) during the 1970s and 1980s with the intent to establish a recreational fishery. Graham (1999) reported blue catfish introductions to the Potomac River in Maryland as early as 1898 to 1905. Microsatellite genetic analysis indicates that presence of blue catfish in the Pamunkey, Potomac and Piankatank Rivers are a result of range expansion from populations in the James, Rappahannock, and Mattaponi Rivers rather than discrete incidences of new introductions (Higgins 2006). Escapees from impoundments may also have contributed to range expansion in the Pamunkey and Potomac Rivers. Blue catfish salinity tolerance is 11.4 ppt indicating that its potential range expansion would be comparable to that of flathead catfish (Perry 1968 in Jenkins and Burkhead 1994). However, the Virginia Institute of Marine Science (VIMS) juvenile trawl survey has collected blue catfish in 13.7 ppt water, a 2.3 ppt increase in salinity tolerance (Mary Fabrizio, VIMS, personal communication).

Observations from fish communities in North Carolina rivers indicate that flathead catfish and blue catfish may compete with juvenile and adult striped bass for Clupeid prey such as American shad, gizzard shad, and bay anchovy. Flathead catfish in the Neuse River and Northeast Cape

Fear River tributaries are known to consume juvenile American shad (Pine III et al. 2005). In the adjacent Albemarle Sound (NC) system, juvenile *Alosa* sp. are significant prey items for age-1 striped bass (Rudershausen et al. 2005; Tuomikoski et al. 2008). Ashley & Buff (1987) reported gizzard shad and adult American shad to be significant prey items of large flathead cat-fish (33-112 cm) in the Cape Fear River

Within the Mississippi River drainage, blue catfish exhibited greater diversity of prey selection than did flathead catfish, although both species consumed clupeids such as gizzard shad and non-clupeids (Eggleton and Schramm Jr. 2004; Eggleton and Schramm Jr. 2003). In Oklahoma reservoirs, blue catfish target gizzard shad wounded by striped bass (Graham 1999). Blue catfish (mean fork length = 246 mm) in Virginia river mainstems primarily foraged on invertebrates such as amphipods, bivalves, and mud crabs; however, Atlantic menhaden and to a lesser extent bay anchovy, Atlantic croaker and gizzard shad were observed prey (Debra Parthree, Virginia Institute of Marine Science, College of William and Mary, Chesapeake Bay Trophic Interaction Laboratory Services, unpublished data). Blue catfish feed on clupeid fish, non-clupeid fish, chironomids, and oligochaetes while in lower Mississippi River floodplain lakes and secondary channels where reduced currents and soft sediments are common (Eggleton and Schramm Jr. 2003). These invertebrates and others including mysids, amphipods, crabs, polychaetes, chirono-mids, and isopods are common prey of age-0 striped bass (Jordan et al. 2003; Howe et al. 2008; Hartman and Brandt 1995). Age-1 striped bass transition from invertebrate prey to piscivory, often feeding on Atlantic menhaden, bay anchovy (Hartman and Brandt 1995), and *Alosa* species (Rudershausen et al. 2005; Tuomikoski et al. 2008). Striped bass age-2+ forage on Atlantic menhaden and to a lesser extent on bay anchovy, spot, and polychaetes (Hartman and Brandt 1995; Rudershausen et al. 2005); although invertebrates and bay anchovy may constitute a greater proportion of striped bass diet in the Chesapeake Bay (Bonzek et al. 2007). Large (≥ 458 mm) striped bass consume mainly river herring (*Alosa pseudoharengus* and *Alosa aestivalis*) and gizzard shad (Walter III and Austin 2003) in the tidal freshwater regions of Chesapeake Bay, whereas in the mesohaline portion of the Bay, large striped bass feed primarily on Atlantic menhaden (Walter III and Austin 2003). A more comprehensive discussion of striped bass foraging is given in the Biological Background Brief and the Food Web: Forage and Predation Issue Brief.

Competitive foraging interactions may occur between striped bass and both flathead catfish and blue catfish. All age classes of striped bass could be affected. Modeling of the Neuse River (North Carolina) fish community using Ecopath and Ecosim consistently produced a negative relationship between the relative biomass of invasive flathead catfish and anadromous striped bass (Pine et al. 2007) suggesting a competitive interaction. An interaction is unlikely in poly-haline waters where striped bass, flathead catfish, and blue catfish do not co-occur.

Northern Snakehead

A self-sustaining northern snakehead population was detected in the tidal freshwater portion of the Potomac River in 2004 (Odenkirk and Owens 2005; Orrell and Weigt 2005). Northern snakehead are considered to be intolerant of salinities >0.6-1 ppt (Courtenay & Williams 2004), but northern snakehead have survived 10-12 days at 12 ppt (Steve Minkkinen, U.S. Fish and Wildlife, personal communication). The apparent salinity tolerance of northern snakehead indi-cates comparable distribution potential to that of both blue and flathead catfish. The diet of adult northern snakehead in the Potomac River is dominated by banded killifish (27%) and 5% each of bluegill, pumpkinseed, and adult white perch (Odenkirk2006 in Chaconas et al., unpublished manuscript; Odenkirk and Owens 2007; John Odenkirk, Virginia Department of Game and Inland Fish, personal communication; Nick Lapointe, Virginia Tech, Department of Fish and Wildlife Sciences, personal communication). Frequency of occurrence for clupeids in the diet did not exceed 1%. Diet studies to date do not support a competitive interaction between northern snakehead and striped bass, nor do they suggest potential for significant predation of young-of-year (YOY) striped bass. However, it would be premature to conclude that the entirety of northern snakehead impacts to Chesapeake Bay fisheries have occurred after only four years.

Issue Statement

Blue and flathead catfish in tidal fresh and mesohaline tributaries of Chesapeake Bay are likely to compete with YOY to early age-1 striped bass for invertebrate prey and age-1 to adult striped bass for clupeid forage species. Predation of YOY striped bass by flathead catfish, blue catfish, or northern snakehead has not been documented, but predation of YOY striped bass is possible and should be monitored as the non-native invasive species populations expand.

Indicator

Currently, there is insufficient characterization of blue catfish, flathead catfish, and northern snakehead populations and diet across their life history in Chesapeake Bay tributary waters for an indicator at this time. However, an understanding of ontogenetic shifts in diet composition, bioenergetic demand, stock characterization, and spatial distribution of these fish species would be a starting point for development of suitable metrics.

Catfish diet composition data is currently being collected by VIMS and Maryland Department of Natural Resources. The Virginia Department of Game and Inland Fish and VIMS are collaborating on a comprehensive blue catfish predation study that will also provide data for refining population estimates (Starke 2008). Northern snakehead diet composition data is being collected by the U.S. Fish and Wildlife Service, Virginia Department of Game and Inland Fish, and Virginia Tech.

Associated with efforts to characterize diets for these three species are efforts to determine population trends and spatial distribution. The blue catfish population in Virginia waters is estimated at between 10 and 50 million (Mary Fabrizio, VIMS, personal communication). Preliminary analysis of blue catfish distribution from 1990 to 2007, from VIMS trawl data, indicates an approximate minimum range expansion of 18 river km in the James River, 33 river km in the York River, and 37 river km in the Rappahannock River (Figure 1; Mary Fabrizio, VIMS, personal communication). As of 2004, northern snakeheads were distributed in the tidal freshwater portion of the Potomac River upstream to Wheaton Regional Park north of Washington DC (see Figure 2 in Chaconas et al., unpublished manuscript).

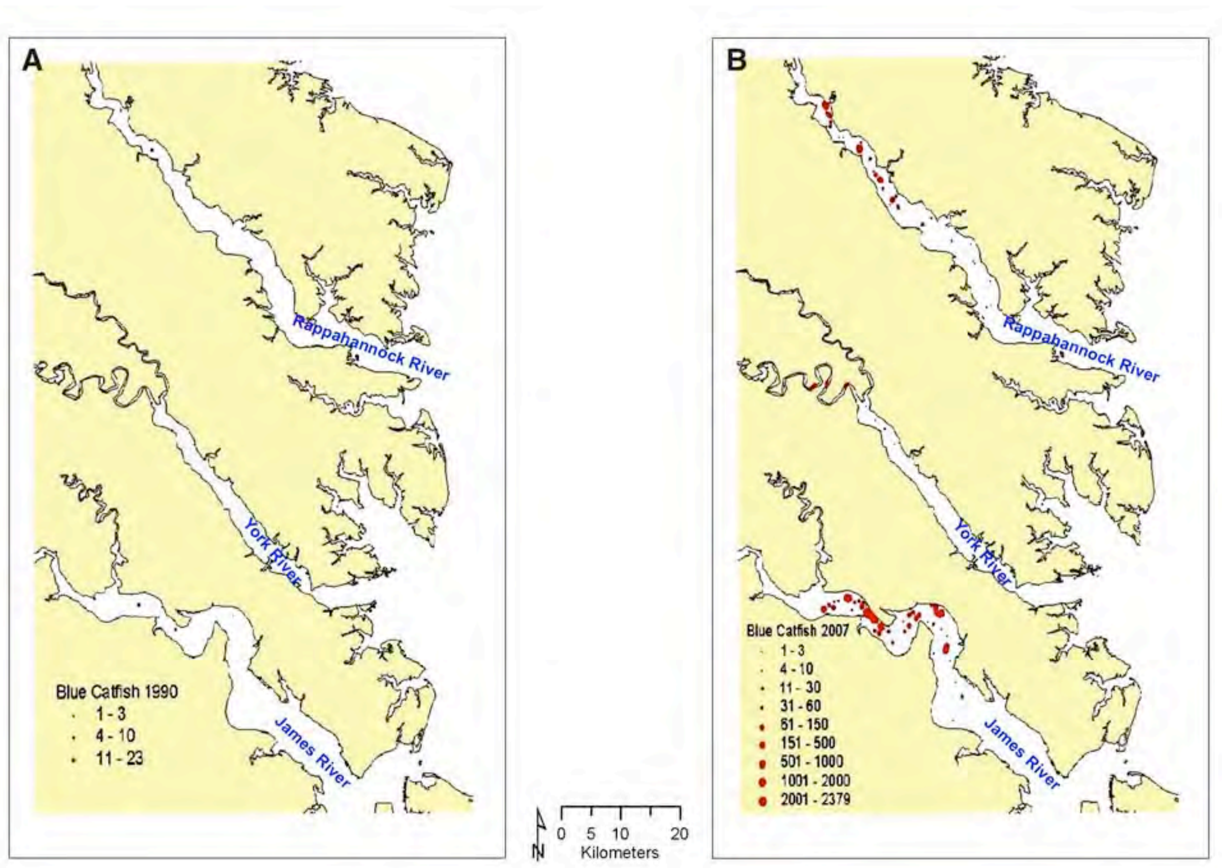

Figure 1. Distribution of blue catfish caught in Virginia tributaries during 1990 (A) and 2007 (B) by the VIMS juvenile trawl survey. Red dots indicate blue catfish collected. Maps have been modified from those provided by Mary Fabrizio (unpublished data).

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STOCK ASSESSMENT

Recruitment Variability

Mary Fabrizio, Ed Martino, and Dave Secor

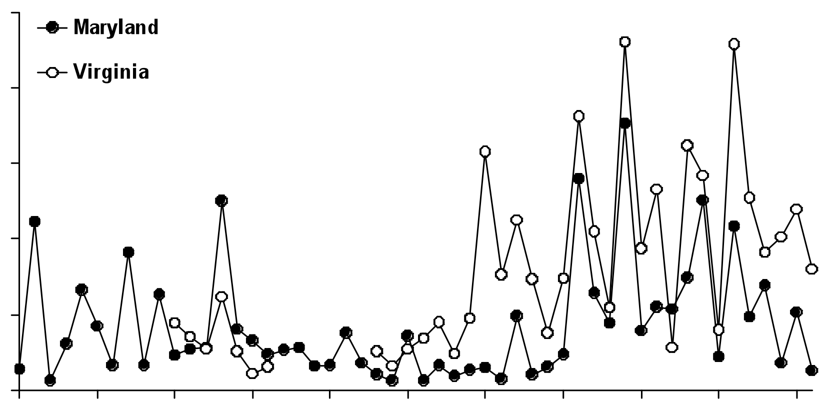

Figure 1.

Striped bass recruitments in the Maryland and Virginia portions of Chesapeake Bay vary more than 20-fold among years (Figure 1; Durrell and Weedon 2008). Age-0 juvenile recruitments were low when the Atlantic coast fishery collapsed in the 1970s, and recruitment levels increased as the population recovered in the early 1990s. High inter-annual variability in recruitment is still a conspicuous characteristic of post-recovery striped bass population dynamics.

Life history theory can be used to predict general patterns in the response of populations to environmental change and regime shifts and to explore the potential efficacy of select management measures (see Winemiller 2005a and 2005b). According to the Winemiller and Rose (1992) triangular model of life history strategies for freshwater and marine fishes, striped bass exhibit a periodic strategy due to their longevity, high fecundity, and high recruitment variation. Because stochastic environmental variation has a large effect on the recruitment dynamics of these species, simple stock-recruitment models provide poor descriptions of this relationship (Winemiller 2005a). Regime shifts and climate change are expected to lead to rapid demographic responses in periodic strategists, and these responses should be observable over broad spatial scales; specific predicted outcomes include genetic bottlenecks, local extirpations, and range shifts (Winemiller 2005b).

In this context, management actions that exacerbate variability in population processes such as recruitment and growth could also accelerate demographic response to environmental change. Population dynamics and recruitment of temperate marine fishes is controlled by both stochastic density-independent environmental processes and density-dependent biological constraints. Thus, the highly variable recruitment of Chesapeake Bay striped bass results from the interplay of environmental effects and biological attributes of the stock including spawning stock biomass, fecundity, and adult demographics. In this brief, we explore the effects of environmental processes and density-dependent constraints on the stability and resilience of striped bass stocks. *Stability* refers to the return of a population to equilibrium conditions following a perturbation, which may be small or large, frequent or infrequent. *Resilience* is a measure of stability that can be described as the ability of a population to recover from a perturbation (see Golinski et al. 2008).

The stock-recruitment relationship describes the number of progeny produced for a given level of spawners. This relationship can be useful for evaluating alternative harvesting strategies, and especially to determine the level of fishing beyond which a population is likely to collapse. However, the relationship is difficult to estimate quantitatively for most stocks due to the effects of environmental variability on spawner condition and early life survival, and striped bass is no exception. Age-0 juvenile recruitment and spawning stock abundance indices from upper Chesapeake Bay have been fit to Ricker stock-recruitment models both with and without freshwater discharge, which serves as a strong environmental predictor of recruitment (North and Houde 2003). The Ricker model fit without freshwater discharge explained only 3% of the variance in recruitment while the model incorporating freshwater discharge explained an additional 41% of the variance. These modeling results highlight the importance of hydrological conditions as a coarse control of striped bass recruitment variability (see Background Brief: Early Life History and Habitat Brief: Flow). The link between meteorological and hydrological conditions and striped bass recruitment variability has been recognized for several decades (Merriman 1941).

Environmental Processes

In Chesapeake Bay, synoptic climatology patterns exert strong controls on patterns of abundance of young-of-the-year anadromous fishes (Wood 2000). For example, most (71%) of the variation in abundance of juvenile striped bass in the upper Chesapeake Bay from 1986 to 2002 was explained by mean freshwater flow rates and number of pulsed freshwater flow events during the spawning season (North et al. 2005). High levels of freshwater flow and low temperatures during March through May are associated with high recruitment of striped bass (Boynton 1976; Rutherford et al. 1997; Wood 2000), and these two factors alone have been used to successfully forecast (+/- 30% error) striped bass recruitments in recent years (Martino et al. 2006).

A single year class of striped bass is typically composed of cohorts hatched at different times, reflecting the age composition of spawning females and episodic variations in temperature and flow that directly affect survival of early life stages (Secor and Houde 1995; North et al. 2005). Juveniles from strong and weak year classes may thus exhibit differences in the distribution of their hatch dates (McGovern and Olney 1996) (Cooper et al. 1998). For instance, in the Pamunkey River, juveniles from an average-size cohort were hatched late in the season, whereas juveniles from a larger size cohort were hatched over a longer period of time (McGovern and Olney 1996). Selection for survival of cohorts has been related to favorable temperatures: cohorts hatched later in the spawning season when temperatures consistently exceeded 17 degrees C in the Potomac River had better survival than early-hatching cohorts (Rutherford and Houde 1995). In another study, highest survival rates for the 1991 year class were observed among cohorts experiencing average temperatures between 15 and 20 degrees C during the 25-day period after hatching (Secor and Houde 1995). In 1991, these conditions occurred for cohorts spawned during the mid-season (Secor and Houde 1995). These observations suggest that hatch date distribution and year-class strength are related, but additional studies with multiple year classes are needed to determine if this is a general pattern, and if this pattern persists in the recovered population. In addition, these studies suggest that the protracted spawning tactic of striped bass helps to ensure appropriate conditions for the survival and growth of young fish. Spawning activity that is misaligned spatially and temporally with abiotic and biotic conditions necessary for high egg and larval survival leads to poor year classes (Ulanowicz and Polgar 1980). Changes in the distribution of spawning times are likely to increase recruitment variability and the risk of successive poor year classes.

Fish species for which density-independent processes (such as effects of water flow and temperature) play a large role in regulating population size tend to be less stable than those exhibiting a high degree of density-dependent regulation (Walsh et al. 2004).

Human activities (e.g., dredging, altered river flows, urbanization) and environmental changes (e.g., global warming) that alter temperature and freshwater flow regimes can have dramatic consequences on striped bass population dynamics and on the sustainability of the stocks. For instance, an increase in the percent of impervious surfaces in a watershed may expose eggs and larvae to higher variability in both temperature and flow with uncertain consequences to early life survival (see Background Brief: Early Life History; Habitat Brief: Flow; and Habitat Brief: Watershed Development).

Density-dependent Constraints

Population resilience is an important determinant of the time scales under which populations respond to management measures, but may be difficult to predict. In general, populations that exhibit density-dependent regulation are more resilient and thus more likely to recover from perturbations such as declines in abundance. A moratorium in response to overfishing of the yellowtail flounder and plaice fisheries in Canada allowed yellowtail flounder stocks to rebound, but plaice, which exhibited less density dependence and higher recruitment variability than yellowtail, failed to recover (Walsh et al. 2004).

The timing of density-dependent control may be as critical as the magnitude of the effect on population dynamics of fish. Stock-recruitment model simulations indicate that as the regulating effects of density-dependence are increasingly delayed, population stability decreases and cycles of boom and bust become more extreme (Golinski et al. 2008).

One indicator of the resilience of fish stocks that has been proposed is the maximum annual reproductive rate (the rate of recruitment at low spawning stock size; Fogarty et al. 2001). The maximum annual reproductive rate is the average number of replacement spawners produced per spawner per year (in the absence of density-dependent mortality; see Myers 2001). The maximum reproductive rate of Atlantic coast striped bass was reported to be 20 spawners per spawner, a value that indicates there is a high level of compensatory reserve in this stock (Myers 2002).

For Atlantic coast striped bass, the relative importance of density-independent control versus density-dependent regulation likely depends on spawner abundance and age structure. The 1990s recovery of Atlantic coast striped bass was characterized by a conspicuous increase in spawner biomass and age-0 juvenile recruitment (Richards and Rago 1999). The increase in recruitment success during this period was likely a result of both reduced fishing mortality on adults, and a shift toward environmental conditions that promoted larval survival (Richards and Rago 1999). Environmental controls appear to play a large role in explaining striped bass recruitment variability especially since the recovery of the population (Wood 2000; North and Houde 2001; Martino et al. 2006). However, mean age and age diversity may continue to increase as this recovered population matures (Secor 2000). Possible outcomes resulting from changes in spawner demography include a wider range of spawning behaviors (Secor, 2000), reduced recruitment variability, and a decoupling of reported links between recruitment and environmental variability (Secor 2007).

Spawner demography plays a critical role in determining the stability and resilience of striped bass populations because young and old spawners tend to spawn at different times during the spawning season. The age diversity of female striped bass was positively correlated with egg dispersion and juvenile recruitment success (Secor 2000), and suggests that higher age diversity increases a population's capacity to buffer the effects of variable environmental conditions (Secor 2007). Striped bass are long-lived fishes, capable of achieving a maximum age and size of approximately 35 years and 35 kg. Females can produce 200,000 eggs per kg, and fecundities for larger females can exceed 1 million eggs. Spawning behavior that permits egg deposition over a broad range of temperatures and dates ensures that some larval cohorts will encounter favorable conditions and survive to recruit to the adult population (Secor and Houde 1995). Differences in the timing of spawning between young and old striped bass spawners (older, larger females tend to spawn earlier in the spawning season; Hollis 1967) may ensure that some offspring co-occur with environmental conditions favorable for survival (Secor 2000).

In addition to maximizing the range of spawning dates, the presence of older and larger females in the spawning population may also have direct consequences for early life survival. Larval survival of several marine species is known to be affected by the age of spawners (e.g., Ottersen et al. 2004 and Spencer 2006), an association that obscures the stock-recruitment relationship for these species. Generally, older fish produce disproportionally more eggs than first-time spawners and eggs from older fish are of higher quality (Marshall et al. 2003). In such instances, egg production and SSB may not be the best measures of spawner output and may lead to overestimation of the resilience of stocks to fishing (Murawski et al. 2001). Instead, metrics such as hatched egg production and viable larval production may be better indicators of actual spawner output (Murawski et al., 2001). Stock-recruitment models can thus be modified to accommodate the effect of the age composition of the spawning stock (Murawski et al. 2001). In addition, younger, less diverse spawning stocks are less resilient to environmental (climatic) perturbations (Ottersen et al. 2004). In the Chesapeake Bay, larger striped bass females produce larger and better quality offspring that are more likely to survive (Zastrow et al. 1989; Monteleone and Houde 1990). Thus, a high diversity of ages among spawning females appears to contribute to reproductive success by maximizing temporal alignment with environmental conditions conducive to high survival and by producing more robust offspring. High biomass and diverse age characteristics of the spawning population are important prerequisites for recruitment success but do not necessarily guarantee production of strong or even moderate year classes.

Indicators

The demographics of the spawning population of Chesapeake Bay striped bass may be used as an indicator of the stability and resiliency of this population. Measures such as age diversity of the spawning stock, maximum age, mean age, and proportion of female spawners greater than 8 years old may be useful in tracking changes associated with recruitment variability. Recruitment indices, both juvenile (age 0) indices and indices of abundance of fish recruiting to the fishery, should continue to be used as measures of the annual contribution to production. Attention to the form of the juvenile index (geometric mean vs. arithmetic mean) and to the spatial representation of the index (separate indices for MD and VA vs. a baywide index) is warranted. For example, recent research at VIMS using fishery-independent data indicates that a baywide index for striped bass provides a better predictor of subsequent abundances of adult striped bass (ages 1-7) in the bay (J. Woodward, pers. comm.).

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Exploitation

Alexei Sharov, Michael Johnson, and Joseph Cimino

Striped bass have been exploited in the area since colonial times (Merriman, 1941; Boreman and Austin 1985). Chesapeake Bay stocks have made the highest contribution to coastal landings – up to 90% in the case of the 1970 dominant year-class. Atlantic coast commercial landings (including Chesapeake Bay) ranged from 800-6,700 mt between 1880 and 1983. Recreational landings estimates during 1960-1980 ranged from 780 mt in the 1980 to 33,000 mt in 1970 (Boreman and Austin 1985).

Early commercial fisheries in Chesapeake Bay targeted shad and herring with haul seines fished at stationary locations with elaborate shore installations for processing (Hollis 1967). Drift nets, which employed fewer people, came into widespread use later. Pound nets, anchor gill nets and stake gill nets were employed in the Bay before the 1900s. The introduction of gasoline engines in boats, synthetic netting, and outboard motors improved efficiency. During 1954-1964, there was a pronounced trend of more and more striped bass being caught commercially during spring months; most of these fish were taken from spawning rivers with gill nets. Fishermen targeted fish from 12-16 inches, but began employing larger mesh gill nets with higher breaking strength during the 1960s to target larger striped bass from the 1956-1958 year-classes. Chesapeake Bay striped bass fisheries operated with minimal regulations prior to 1990 (Tarnowski 2008). Size limits were low (< 14 inches), catch limits were negligible and technological innovations (depth finders, communications, nylon netting) increased efficiency (Hollis 1967; Richards and Rago 1999).

Exploitation of Chesapeake Bay striped bass was high prior to the moratorium in 1985, but fisheries and recruitment levels were maintained until the 1970s. Mean F derived from mark-recapture data base for Atlantic Coast striped bass equaled 0.78 during 1969-1983 and 0.18 during 1984-1992 (Sprankle 1994). During 1959-1968, estimates of F (separable VPA on market class catch data) ranged from 0.50-0.75; most estimates of F were less than 0.60; F rose to approximately 0.75 during 1969-1971 and then climbed above 0.75 through 1984 and exceeded 1.0 for greater than half of these years (Gibson 1993). In Maryland's portion of Chesapeake Bay, fishing mortality of the 1970 year-class was 36% for females of age 6 and 36-92% for males at ages 4-6 (Richards and Rago 1999). In coastal mixed-stock areas, annual fishing mortality ranged from 30-60% (Richards and Rago 1999). Failure of strong year-classes in Chesapeake Bay after 1970 and an alarming decline of landings provided the basis for harvest moratoria in the Bay region (starting with Maryland in 1985) and much more restrictive management elsewhere. The criterion for recovery and reopening fisheries was met in 1989 (a 3-year running average of the Maryland JI of 8) and a new era of much more conservative harvest management began in 1990 (Richards and Rago 1990).

In recent years the commercial fishery employs a variety of gear, including drift, anchor and stake gill nets, hook and line, pound net and haul seine. Recreational fishermen employ variable hook and line tackle. National Marine Fisheries Service (NMFS) records showed significant variations in commercial landings during the past fifty years, reflecting periods of variable productivity and exploitation (Figure 1). Recreational landings reported by the NMFS Marine Recreational Fisheries Statistics Survey (MRFSS) since 1982 also varied from low numbers in mid-1980s, which most likely resulted from overfishing, to high levels in late 1990s, following stock rebuilding (Richards and Rago 1999, see Figure 2). In most recent years annual landings in the Chesapeake Bay area stabilized around nine million pounds.

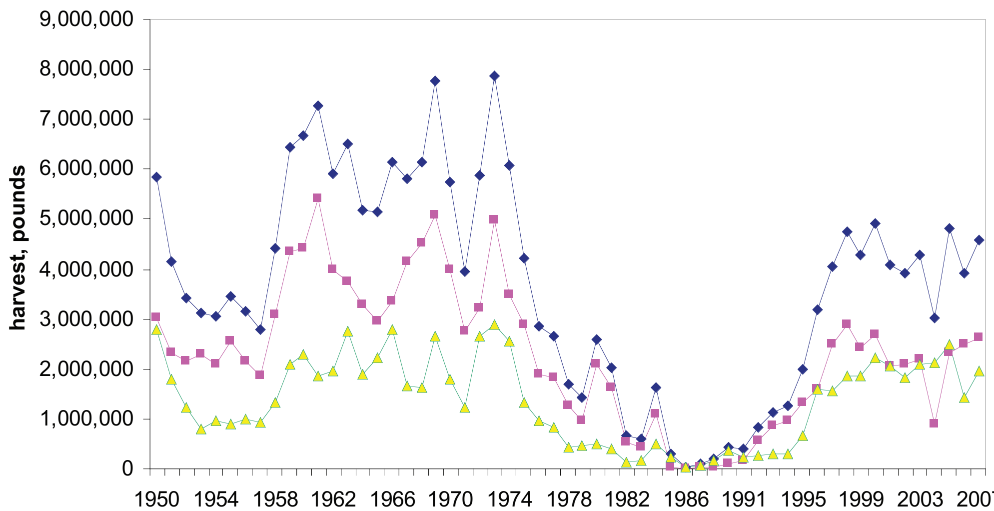

Figure 1. Striped bass commercial harvest in weight (pounds) in Maryland (squares), Virginia (triangles), and Baywide (diamonds).

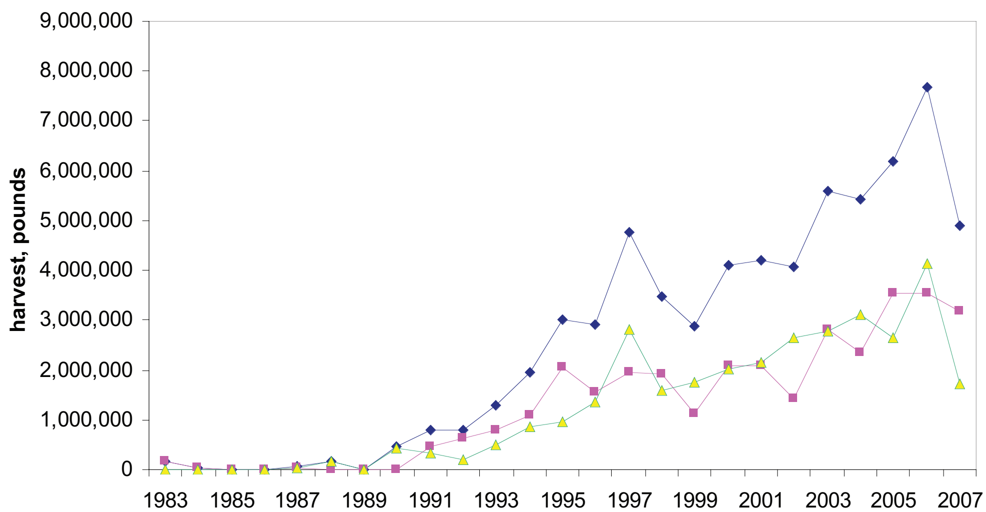

Figure 2. Striped bass recreational harvest in weight (pounds) in Maryland (squares), Virginia (triangles), and Baywide (diamonds).

Allocation

Atlantic coast striped bass is managed according to the Interstate Fisheries Management Plan (Amendment 6, ASMFC) with the goal "to allow commercial and recreational fisheries consistent with the long-term maintenance of a broad age structure, a self-sustaining spawning stock and to provide for the restoration and maintenance of their essential habitat." To achieve this goal, the target fishing mortality level is established (F=0.30) below the fishing mortality rate that allows for maximum sustainable yield (Fmsy=0.41). To compensate for the smaller minimum size limit, the target fishing mortality for striped bass in Chesapeake Bay is set a F=0.27. This fishing mortality rate is used to calculate the annual Chesapeake Bay quota. Bay-wide quota is further divided by three jurisdictions (Maryland, Virginia and Potomac River Fisheries Commission (PRFC) according to their historical proportions of Bay wide harvest. Currently Maryland's portion of the quota is 53%, Virginia's 32% and PRFC 15%. State quota is further subdivided into commercial and recreational quotas according to state preferences and historical allocation. Historical proportions of harvest by state and fisheries reflects regional socio-economical aspects such as number of watermen in the area, other employment opportunities, profitability of the fishery, availability of striped bass and other exploitable species. Changes in local economy, demography, ecological conditions may lead to decline / increase in regional removals and therefore, to changes in allocation. Shift of the removals towards Upper Bay (Maryland) or Lower Bay (Virginia) may lead to changes in the size and structure of the harvest (fish harvested in Maryland are on average smaller than in Virginia).

Age and Size of Harvested Fish

Due to migratory nature of striped bass and sex specific migration rates, resident striped bass population in Chesapeake Bay consists primarily of relatively small young fish. About 90% of the harvested fish are of age 3 to 6 years (Figure 3) and of 18 to 25 inches (Figure 4). Over 80% of these fish are males (MD DNR data). Specific features of age and size distribution impose certain restrictions on choice of regulatory measures. For example, to increase average size of fish in the recreational harvest, minimum legal size was raised to delay fishing mortality on smaller fish. This lead to a significant reduction in the number of fish harvested and substantial increases in the amount of discards. Such tradeoffs should be taken into consideration when developing management goal.

Removals

Landings

To maintain a removal rate at or below the target level, fishing mortality estimates must be generated on an annual basis. Survival and fishing mortality of resident striped bass in the Chesapeake Bay are currently measured through the suit of tagging models that include Mark and instantaneous rates models (NEFSC 2008). The accuracy of these estimates is dependent on meeting the tagging models assumptions. Violations of those assumptions may lead to biased estimates of fishing mortality. Natural mortality and migration can be significant confounding factors. Commercial harvest is tightly monitored by all jurisdictions on a nearly real time basis. Daily catches are reported to regulating agencies (MD DNR, PRFC and VMRC) and cumulative harvest is calculated daily. Consequently, commercial removals are stopped as soon as cumu-

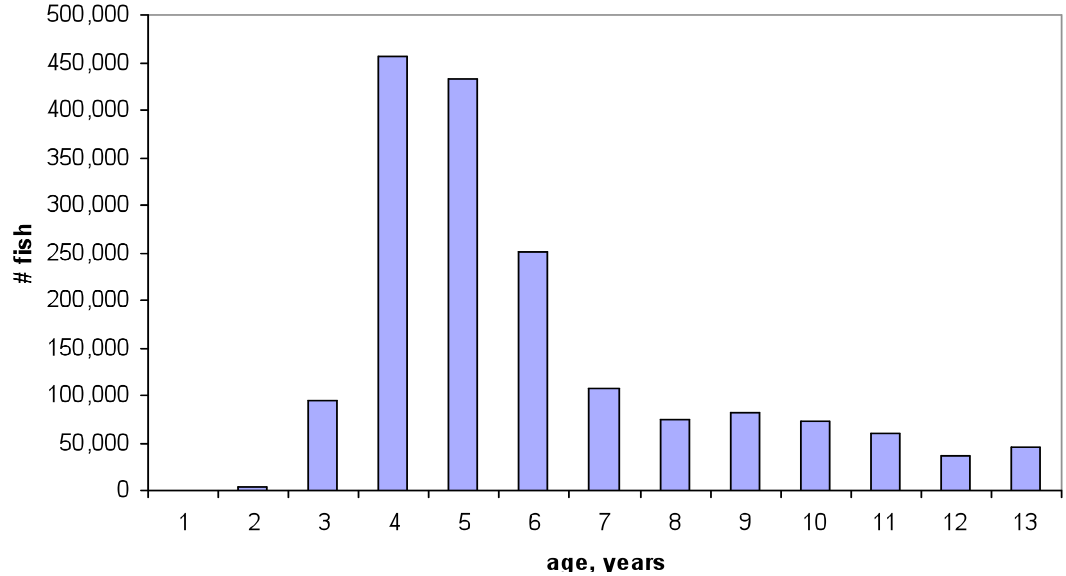

Figure 3. Age structure of striped bass harvest in Chesapeake Bay, 2005-2007 average.

lative harvest reaches the annual quota for a jurisdiction. While the commercial harvest monitoring system allows for effective control of removals, recreational harvest cannot be regulated in the same fashion. Recreational harvest estimates are produced by the MRFSS on a bimonthly basis and become available with a delay of several months. For this reason, recreational harvest is not effectively controlled by the quota and is prone to be over or under the target (quota). Inability to control recreational harvest in real time requires a precautionary approach in target setting and regulation development. A set of management tools such as setting a minimum size, creel limit, or fishing season length should be designed in a way that minimizes the risk of exceeding the limit of recreational removals. Stable regulations for a certain period of time (at least several years) are required to evaluate an average level of removals from the population for a given set of regulations.

Landings of Migratory Striped Bass

In addition to the resident stock (for management purposes, resident refers to fish 18 inches and under), migratory striped bass are harvested by a spring trophy recreational fishery in the second half of April and May. The number of migrant striped bass harvested between 1993 and 2007 varied from 2.7 to 67.7 *103 of fish. Until 2008 there was an annual quota on migrant striped bass harvest, but in practice, the spring fishery was regulated primarily by the length of the season, bag and size limits. The cap on the trophy fishery was based on the number of age 8+ fish in the coastwide population. Total catch of migrant striped bass in the spring fishery comprises about 1-4% of the total migrant striped bass annual harvest coast-wide (NEFSC 2008). However, estimates of total number of spawners in the Chesapeake Bay stock are not available and therefore the exploitation rate of the spawning stock is unknown. Possible boundaries for the Chesapeake Bay spawning stock can be derived from the estimates of the coastwide

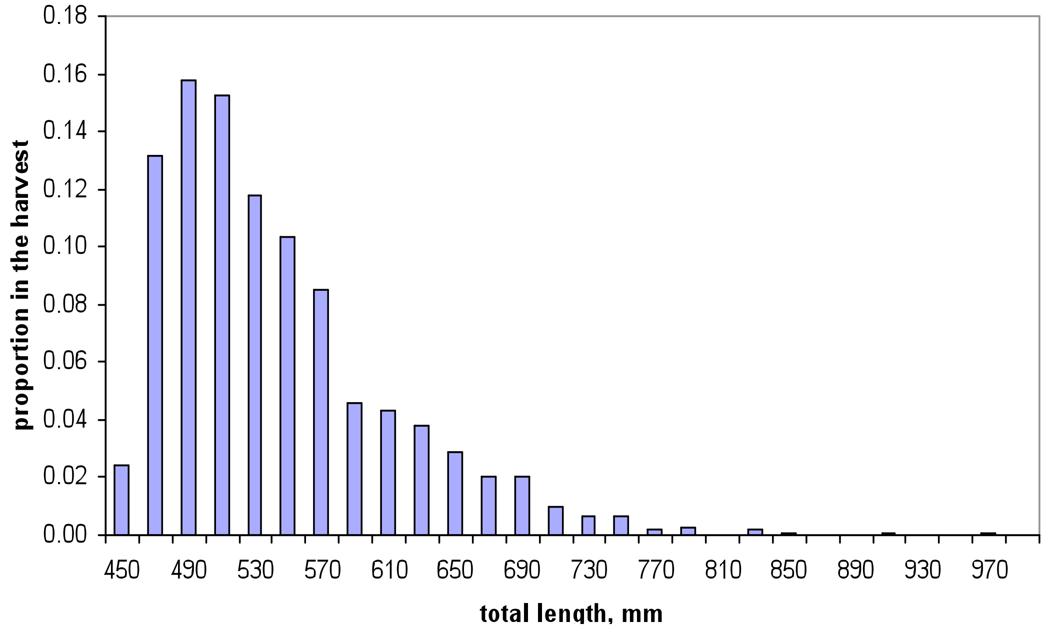

Figure 4a. Size frequency distribution of striped bass in pound net harvest in Maryland in 2007.

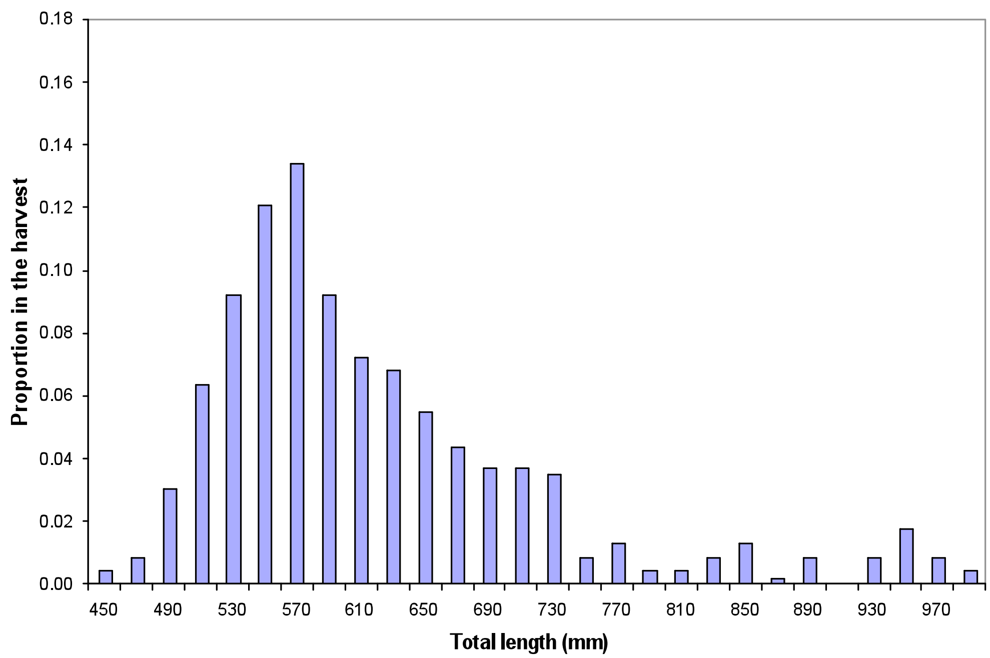

Figure 4b. Size frequency distribution of striped bass in pound net harvest in Virginia in 2007.

spawning stock reported in stock assessment documents based on the generally accepted fact that Chesapeake stock is the dominant stock on the Atlantic coast.

Discards

Discarding of undersized or otherwise unwanted striped bass takes place both in commercial and recreational fisheries. According to MRFSS data, the number of fish released alive by recreational anglers is 4 to 12 times higher than the number of fish harvested in recreational sector (NEFSC 2008). Because of the very high volume of fish releases, dead discards of striped bass in the recreational fisheries in the Bay are as high as 40 - 50% of the total recreational landings and 18 – 29 % of combined recreational and commercial landings (NEFSC 2008). A discard mortality rate of 8% estimated by Diodati and Richardson (1996) is currently used to estimate the total number of dead discards, this rate is applied to discards from all fisheries. However, studies by Lukacovic and Florence (1999) and Lukacovic and Uphoff (2007) found that discard mortality in the recreational fishery varies significantly with water temperature, salinity and hooking injury location. Since about one third of estimated numbers of striped bass killed are dead discards, precise and accurate estimation of discards is critical for the quality of stock assessment. Application of seasonal temperature dependent discard mortalities will lead to a substantial improvement in the estimation of total removal and population size.

Discards by the commercial fishery in the Chesapeake Bay are poorly estimated. Discard calculations are based on the ratio of tags reported from discarded fish in the commercial fishery to tags reported from discarded fish in the recreational fishery, scaled by total recreational discards. Total discards are allocated to fishing gears based on the relative number of tags recovered by each gear. Discards by fishing gear are multiplied by gear specific release mortalities and summed to estimate total number of dead discards in a given year. Estimated dead discards from the commercial fishery varies from less than 10 to 50% of the total commercial harvest, primarily due to the estimate's dependency on tag returns by commercial fishermen and recreational discard estimates (NEFSC 2008). Direct estimation of commercial discards by gear type can significantly reduce uncertainty and improve our knowledge of total removals.

Bycatch

Striped bass are harvested by a variety of gears, including pound nets, gillnets, hook and line. Pound nets are nonselective traps and catch a variety of species alive. Species caught include striped bass, white perch, menhaden, shads, croaker, weakfish, spot, and flounder. Mortality of discarded fish varies by species, temperature, salinity and density of the fish in poundnets, but specific estimates are rare. Unlike poundnets, drift or anchored gillnets are used to specifically catch striped bass. Drift gillnets are used in winter in Maryland and generate little bycatch due to reduced species representation in wintertime and relatively large mesh size. Stake and anchor gillnets fished in spring in Virginia encounter some other species, such as menhaden and alosines and their mortality is likely to be significant. In general, bycatch by all types of gears is poorly quantified and discard mortalities are unknown.

Natural Mortality Effects

Current limits of the removals are based on a target fishing mortality that was calculated based on the existing fishery structure (which is reflected in partial recruitment values) and the assumption of a constant natural mortality rate reflecting average long-term natural mortality corresponding to striped bass longevity. Any change in fishing mortality by age as a result of management actions or a change in natural mortality rate due to environmental conditions will result in different target fishing mortality and require a recalculation of target removals. Recent studies indicate that a significant increase in natural mortality of striped bass in Chesapeake Bay could have occurred as a result of Mycobacteriosis (Gauthier et al, 2008; Kahn and Crecco 2006). Increased natural mortality would lead to decreased abundance and may require adjustments to F, depending on the intensity of compensation.

Ecological Effects of the Removals

From an ecosystem perspective, fishing removes biomass and can affect the structure and function of the Chesapeake Bay ecosystem (Lipcius and Latour 2006). Striped bass exercise significant predatory pressure on a large number of species, including menhaden and blue crab (Walter et al. 2003). Traditional biological reference points do not account directly for dynamics in trophic interactions between the top predators, such as striped bass, and prey species. It is believed that the extensive growth of the striped bass population in Chesapeake Bay and on the Atlantic coast during past fifteen years resulted in depressed absolute abundance of pelagic prey species such as bay anchovy and menhaden due to a high level of striped bass trophic demand (Uphoff 2003). Changes in exploitation rates of striped bass, designed to achieve a certain management goal from the single species prospective, will lead to a change in predatory pressure on prey species and may affect their population dynamics as well. Such interactions should be taken into consideration and accounted for by using multi-species models such as multi-species VPA or others that are specifically designed to simulate trophic interactions (Chesapeake Bay Ecopath with Ecosim; Christensen et al. in press).

Issues

1. Maintaining fishing mortality rate at or below target level both in Chesapeake Bay and on the coast ensures sustainable fishery and robust spawning stock size reliably producing strong year classes.

2. Striped bass discards are substantial in recreational and sometimes in commercial fishery. Development of methods for discards quantification discard mortality evaluation is critical to reliable estimation of total removals.

3. Proper characterization of other species bycatch by gears and seasons is needed to develop approaches for bycatch reduction.

4. Available forage biomass should be taken into consideration when target fishing mortality and stock size are considered. Increased removals should be considered when population size is too large compared to the available forage base. This may require

exceeding target fishing mortality level that was calculated based on longterm yield optimization in single species context.

5. Removals characteristics may change according to evolution of societal preferences (equitable management among stakeholders).

Indicators

Indicators of removals may include:

1. Target and threshold fishing mortality (to control removal rate)
2. Natural mortality (to monitor overall abundance decay rate
3. Exploitable stock biomass
4. Spawning stock size
5. Eggs presence /absence in plankton survey
6. Juvenile index
7. Bycatch and discards
8. Ratio factor of forage demand and forage biomass available or similar indicators
9. Removals proportions by fishery and area (to monitor the limits and trends)

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Disease

David Gauthier, Wolfgang Vogelbein, and John Jacobs

Striped bass are known to be susceptible to a variety of common fish pathogens (Paperna & Zwerner 1976, Plumb 1991), and mortality events attributed to *Streptococcus* sp. and *Edwardsiella* sp. have occurred in Chesapeake Bay (Baya et al. 1990, Baya et al. 1997). Recent attention to striped bass disease issues in Chesapeake Bay, however, has largely centered on disease caused by bacteria in the genus *Mycobacterium.*

Mycobacteriosis is a chronic disease common in wild and captive fishes worldwide. Mortality is not typically associated with mycobacteriosis in wild fishes; however, this may be attributed to the difficulties in observing protracted mortalities in a field setting. High mortality is observed in aquaculture (Nigrelli & Vogel 1963, Hedrick et al. 1987, Bruno et al. 1998). Disease is usually visceral, with spleen (Fig. 1b), liver, and kidney as the primary target organs. Ulcerative dermal disease is also observed in aquaculture, often as an immediate precursor to mortality.

Mycobacteriosis in Chesapeake Bay striped bass was first described in 1997 (Vogelbein et al. 1998), and has since been found with very high prevalence, exceeding 70% in some samples (Cardinal 2001, Overton et al. 2003, Gauthier et al. 2008). Granulomatous inflammation in visceral organs (Fig. 1b) is the typical disease presentation; however, ulcerative skin lesions (Fig. 1a) are common. Heavily diseased fish are often emaciated, and external lesions make fish highly unattractive to anglers.

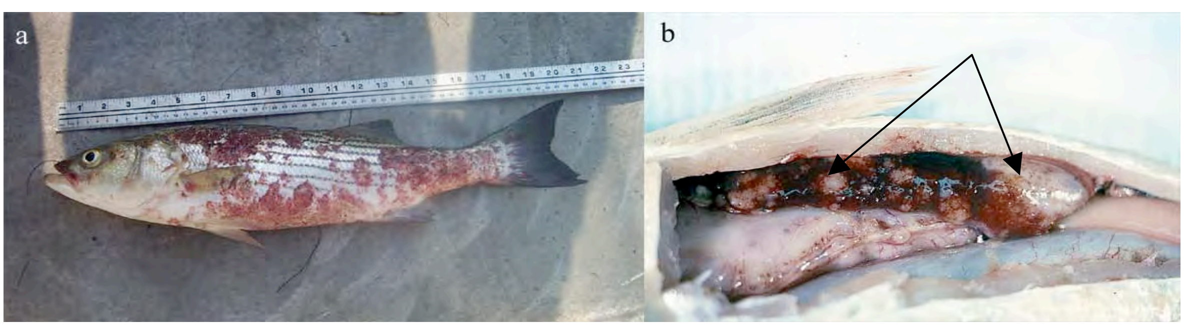

Figure 1. Gross signs of mycobacteriosis in Chesapeake Bay striped bass.(a) severe ulcerative dermatitis.(b) multi-focal gray nodules (arrows) within the spleen.

Mycobacterial infections of Chesapeake Bay striped bass involve *Mycobacterium* spp. other than those typically found in diseased fishes (i.e., *M. marinum*, *M. fortuitum*, *M.*

chelonae). A number of *Mycobacterium* spp. have been cultured from Bay striped bass, including the new species *M. shottsii* and *M. pseudoshottsii* (Rhodes et al. 2001, Rhodes et al. 2003, Rhodes et al. 2005), which are the dominant isolates (Rhodes et al. 2004) . Both *M. shottsii* and *M. pseudoshottsii* are closely related to *M. marinum* and *M. ulcerans*, important pathogens of fishes and humans, respectively. In addition to *M. pseudoshottsii* and *M. shottsii*, a variety of other slowly-growing mycobacteria have been isolated from both diseased and healthy striped bass (Rhodes et al. 2004). These isolates demonstrate considerable diversity in phenotype and 16S rRNA gene sequence (Gauthier & Rhodes In press), and their relative pathogenicity to striped bass remains unexplored.

In addition to their impacts on fishes, aquatic mycobacteria also pose significant zoonotic concerns. *M. marinum* is a human pathogen, producing lesions in skin and peripheral tissues ("fisherman's finger") (Lewis et al. 2003, Petrini 2006). Infection with *M. marinum* also produces falsely-positive *M. tuberculosis* PPD skin tests (Lewis et al. 2003). Considering the severity of disease caused by *M. ulcerans* infection in humans (Buruli ulcer), the discovery of closely related mycobacteria in fishes (i.e., *M. pseudoshottsii*) is of concern, although only one case of zoonosis by this group has been reported (Chemlal et al. 2002). It is not currently known whether *M. pseudoshottsii* or *M. shottsii* can infect humans.

Mycobacteria are typically generalist pathogens, although a number of *Mycobacterium* species are adapted to one or few host species (e.g., *M. tuberculosis* (tuberculosis), *M. leprae* (leprosy)). Therefore, it is not surprising that mycobacteria are found in finfish species other than striped bass within Chesapeake Bay (Kane et al. 2007). *M. pseudoshottsii* has recently been detected in Atlantic menhaden, as well as water and sediments of the mainstem Bay and Rappahannock River (Gauthier et al., unpublished data). *M. shottsii*, however, was not found in either prey items or environmental matrices, suggesting it may be adapted more specifically to the striped bass host.

Recent stock assessments in Chesapeake Bay indicate that non-fishing mortality in striped bass has increased since 1999 (ASMFC 2005, Kahn & Crecco 2006, Jiang et al. 2007, NEFSC 2008). Recent modeling with newly developed epidemiological techniques has indicated that disease is associated with increased mortality in Chesapeake Bay striped bass, especially in older female fish (Gauthier et al. 2008). Collaborative tag-recapture studies are currently underway at VIMS and through Maryland DNR to investigate skin disease progression and directly estimate relative survival of externally diseased and non-diseased fish. Hopefully, these studies will provide multiple lines of evidence about the magnitude of disease-associated mortality and its significance to the striped bass population in Chesapeake Bay.

Two dominant hypotheses have emerged to explain the cause(s) for the high prevalence of disease currently being observed. The first is the thermal-oxygen "squeeze" hypothesis presented to explain population declines of striped bass in various reservoirs and estuaries (Coutant 1985). Adult and sub-adult striped bass avoid water >25°C (Coutant 1985), and it is thought that deeper channels of the Bay and its tributaries are used as thermal refugia during summer months. These areas, however, are heavily impacted by summer hypoxia due to anthropogenic eutrophication. This may force striped bass to occupy suboptimal temperature regimes in which crowding, disease transmission, food limitation, respiratory stress, and other stressors may occur. The mainstem Chesapeake Bay and some of its tributaries are known to undergo seasonal hypoxia in bottom waters, and resident striped bass may thus be subject to thermal-oxygen "squeeze." This hypothesis is supported by research in inland reservoirs, and although it is widely presented as fact with regard to Chesapeake Bay (e.g., Boesch et al. 2007), studies addressing this issue in the Bay have been equivocal (Coutant & Benson 1990). A recent study indicated that thermal-oxygen habitat limitation has not negatively impacted striped bass with respect to growth potential (Constantini et al. 2008), however, disease was not addressed by this work. A second hypothesis advanced to explain the high prevalence of disease in striped bass is nutritional stress resulting from a reduced forage base. Numbers of forage-sized Atlantic menhaden (*Brevoortia tyrannus*), which form a major portion of the striped bass diet (Hartman & Brandt 1995, Walter & Austin 2003), declined to near historic lows during the mid 1990's (Uphoff 2004), while striped bass numbers have recovered to near historic highs (Field 1997), possibly leading to a trophic imbalance. Research on this hypothesis is ongoing (Jacobs et al. 2004, Jacobs et al. 2006), however, it will be difficult to unravel the causative relationship between disease and emaciation (i.e., which precedes the other?).

Research Needs

A workshop entitled "Mycobacteriosis in Striped Bass" was sponsored by USGS/NOAA in May 2006 (Ottinger & Jacobs 2006). The workshop documented the current state of knowledge and identified research priorities, which fall into three major categories:

1. ***Population-level impacts and distribution.*** A primary research priority is determination of mortality associated with disease in Chesapeake Bay striped bass, as well as potential for population impacts.

2. ***Mycobacterial ecology and routes of exposure.*** In order to identify potential actions that could remediate the disease situation in Chesapeake Bay striped bass, it is first necessary to better understand basic aspects of disease ecology and pathobiology. These aspects include mycobacterial distribution in the environment, transmission between environment, prey, and striped bass, and species and strain diversity among mycobacteria pathogenic to striped bass.

3. ***Impacts of environmental stressors.*** Chesapeake Bay will continue to experience environmental challenges such as eutrophication and habitat degradation for the foreseeable future. It is therefore probable that fish diseases such as mycobacteriosis will continue to plague Chesapeake Bay. Thus, it is necessary that we begin to lay the framework by which we may account for disease-associated population effects in fisheries modeling. Additionally, if management efforts are to be undertaken in order to reduce prevalence and severity of disease in Chesapeake Bay striped bass, the specific stressors linked to disease transmission and expression must be identified.

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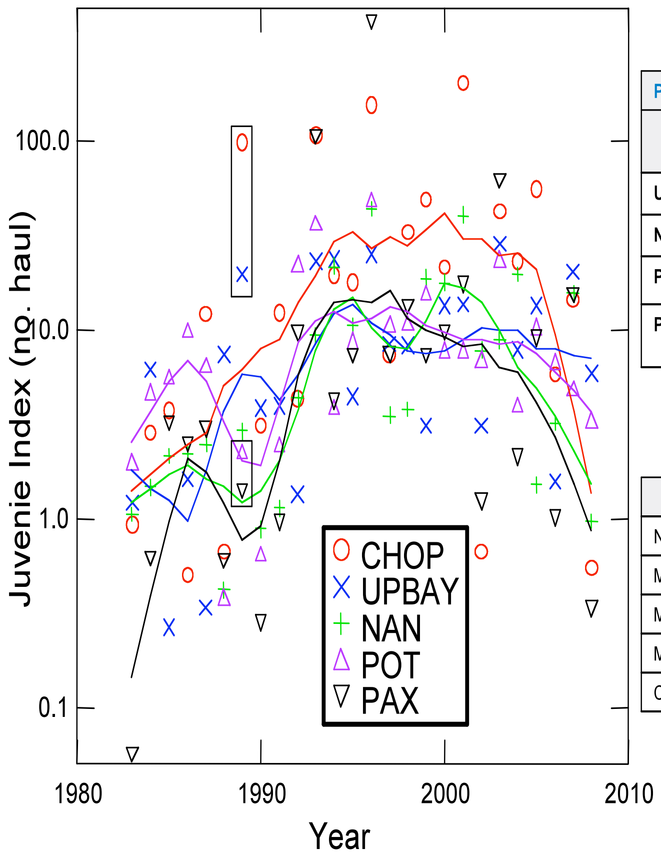
Connectivity

Dave Secor and David Gauthier

Long ago, scientists understood that fluctuations in Atlantic coastal landings of striped bass depended heavily on juvenile production from the Chesapeake Bay (Merriman 1941). Only striped bass north of Cape Hatteras undertake extensive coastal migrations, but of these, the Chesapeake, Hudson, and Delaware populations make principal contributions to coastal harvests (Richards and Rago 1999; ASMFC 2008). That dynamics of the coastal stocks can often mirror recruitment dynamics in the Chesapeake Bay indicates that the population the Bay harbors is indeed dominant, and perhaps just as importantly, that its dynamics are largely independent to other Mid-Atlantic/New England populations.

Breeding philopatry (inter-generational return to a natal region) is strongly indicated by genetic studies between the Chesapeake population and other major populations spawning in the Delaware, Roanoke, and Hudson River estuaries (Waldman et al. 1997). Population structure between major spawning tributaries within the Chesapeake Bay is less certain. Research based upon mitochondrial DNA supported sub-population structure between upper (Upper Bay and Choptank) and lower (Rappahannock and James) spawning tributaries (Wirgin et al. 1990), but nuclear micro-satellite markers have failed to show significant population structuring across spawning tributaries (Brown et al. 2005). Although the two approaches are expected to provide differing perspectives on lineage, comparisons of past genetic studies are confounded by inconsistency in sampling design. Further complicating comparison is asymmetric homing suggested by past tagging and genetic studies (Chapman 1989; Brown et al. 2005), where high rates of straying occur for males but not for females. Regardless of genetic differences, it is highly probable that the Chesapeake Bay harbors a metapopulation comprised of individual spawning units each of which utilizes a major sub-estuaries as spawning and nursery habitats. This view is supported by (1) ichthyoplankton and juvenile surveys and (2) tagging studies on adults (Setzler et al. 1980; Vladykov and Wallace 1952; Mansueti 1961; Massman and Pacheco 1961).

Spawning units among sub-estuaries contribute to biodiversity, persistence, and stability of the entire Chesapeake metapopulation. Although the degree of homing by females (and to a lesser extent males) may not be sufficient to lead to divergence of genetic markers, over several generations homing could select for life history traits and behaviors adaptive to local spawning and nursery conditions. For instance, recruitment is largely controlled during the first weeks of life and depends strongly on time of spawning (Rutherford and Houde 1995; Secor and Houde 1995). Because recruitments are not strongly correlated among sub-estuaries (Figure 1), conservation of spawning units is relevant to recruitment at the metapopulation level. Uncorrelated responses to the same regional conditions among spawning units will mean contribute to stability of recruitments at the metapopulation level (Harden Jones 1968; Secor et al. in press). For instance, poor juvenile production in 1989 by Potomac and Patuxent spawners are offset by high production by Choptank and Upper Bay spawners (Figure 1).



Pearson Correlation Matrix (r)

	CHOP	UPBAY	NAN	POT
UPBAY	0.562			
NAN	0.740	0.505		
POT	0.531	0.496	0.480	
PAX	0.565	0.507	0.614	0.836

	CHOP	UPBAY	NAN	POT	PAX
N	26	26	26	26	26
Minimum	0.500	0.262	0.417	0.381	0.056
Maximum	201.875	28.429	43.667	48.524	420.389
Mean	34.125	9.526	9.396	10.245	27.031
CV	1.500	0.908	1.237	1.095	3.082

Figure 1. Temporal patterns of covariance in juvenile abundance among Maryland sub-estuaries. Left panel shows smoothed Lowess trends in juvenile production by system. Rectangles highlight production in 1989 (see text). Also shown are correlations between system pairs and inter-annual statistics for each system. Note that systems that are most proximate (PAX v. POT; NAN v. CHOP) show highest synchrony. Smaller systems tend to have higher coefficient of variation (CV) than larger systems.

In tandem with conservation of spawning units, it is important to recognize that straying (aka population connectivity) also plays an important role. Straying is critical to metapopulation persistence, where it offsets severe depression and extirpation of local sub-populations (Cury 1994; Harden Jones 1968). Density-dependent straying reduces variance among sub-population dynamics and can contribute to overall metapopulation yield (Ware and Schweigert 2001; Secor et al. in press). Straying could occur during either juvenile or adult stages. In particularly wet years and/or years of high juvenile production, the upper Bay nursery merges with nurseries associated with spawning units in the Chester, Choptank, and Patuxent estuaries, permitting juvenile exchange (Kerr et al. in press). As stated previously, most straying during the adult stage depends upon male behaviors. Thus, actions designed to conserve spawning units, but also to permit some degree of straying, should take sex-specific natal homing behaviors into account.

As a hypothetical example, historical management focused on harvest of pan-sized striped bass (<15" total length) (Richards and Rago 1999). Fishing mortality on 1 and 2 year old males was extremely high (Gibson 1993). At the same time, a maximum size limit (36" total length) conserved a small number of large and old females (Secor 2000). Under this regime, spawning units might be conserved (albeit at a much reduced spawning stock biomass), but straying would be retarded as few males might escape their natal tributary to spawn elsewhere. A gauntlet of gillnets within spawning tributaries served as a barrier against connectivity by young straying males.

Conservation of spawning units was a principal goal of a large scale hatchery effort centered in Maryland to offset the risk of the potential loss of nursery function in some systems (Richards and Rago 1999). In the mid to late 1970s, ichthyoplankton surveys in the Potomac River detected very low numbers of first feeding larvae (Setzler-Hamilton, E.M., pers. comm.). Further, mobilization of monomeric aluminum and other lethally toxic metals due to acid rain was hypothesized to cause loss of nursery function to entire eastern shore larval nurseries (i.e, the Nanticoke estuary), which had low acid neutralizing capacities (Setzler-Hamilton and Hall 1991). Although recovery of striped bass recruitments by natural reproduction (rather than by hatchery enhancement) subsequently occurred for all these systems, the priority remains – to conserve essential elements of Chesapeake Bay's striped bass spawner and nursery yield and diversity.

Striped bass demonstrate large plasticity in migration patterns (Secor 1999). Striped bass in Chesapeake Bay are partial migrants; only a fraction of individuals will leave estuarine habitats for oceanic waters (Kohlenstein 1981). Rates of oceanic habitat vary by sex and increase with age (see Background Brief: Late Life History). It may be hypothesized that the fraction of migratory striped bass may be dependent upon environmental conditions that they encounter during their larval and juvenile periods. For congeneric and sympatric white perch, early spawning and lower larval growth rates were associated with juveniles and adults undertaking a more migratory life history, similar to some species of salmon (Kraus and Secor 2005; Kerr and Secor in press). Interestingly, wet conditions favored a larger fraction of migratory white perch, whereas drought conditions favored the more resident contingent. Opposing environmental dependencies by contingents indicates that partial migration in striped bass could be important in dampening population responses to climate variability (Kraus and Secor 2005; Kerr et al. in press). For sub-adult and adults, the fraction of migratory striped bass is also expected to be related to habitat suitability and forage conditions within the Chesapeake Bay. For instance, reduced habitat suitability due to increased summer time hypoxia, sub-optimal temperatures, and reduced forage would be expected to increase emigration out of the Chesapeake.

Issue Statement

Yield, stability, resilience, and persistence of the Chesapeake Bay striped bass metapopulation depends upon (1) conservation of spawning units attached to each major Chesapeake sub-estuary; (2) sustained functioning of nurseries associated with those spawning units; and (3) some degree of connectivity between spawning units and their associated nurseries. Exploitation, habitat degradation, and climate will differentially affect spawning units and nurseries in unknown ways, but surveys can efficiently monitor their individual productivity and variances.

Indicators

Persistence and relative abundance of spawning units is currently assessed in most major Chesapeake tributaries through spawning stock surveys. The contribution of yield and diversity among spawning units, nurseries, and migratory contingents to metapopulation dynamics can be represented by aggregate mean, variance, and portfolio indicators (Doak et al. 1998; Elmquist et al. 2003; Secor et al. in press). The portfolio indicator (developed by Secor et al. in press) compares population and metapopulation coefficient of variation estimates (CVs). Individual population CVs are weighted according to their respective abundances to estimate what the metapopulation CV would be if the constituent populations were responding in complete synchrony to environmental forcing. A comparison of the metapopulation CV with this weighted CV provides an estimate of what is termed the portfolio effect (PE; Doak et al. 1990), the degree of variance dampening due to independence between populations contributing to an aggregate metapopulation:

$$PE = 1 - \frac{CV_{Metap}}{\sum_{P=1}^{P=k} \left(\frac{N_P}{N_{Metap}} CV_P \right)}$$

Where Metap=metapopulation; N_P=spawning stock biomass (SSB) for each constituent population; CVp = coefficient of variation of SSB for each population, and k=number of populations.

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SOCIOECONOMICS

To be added to Socioeconomics as contributing authors submit:

Livelihoods (S/16)

Economic Impacts of Striped Bass Management in the Chesapeake Bay

Kate Culzoni

In 1990, the striped bass fishery was re-opened to commercial watermen after a moratorium was put in place to rebuild the depleted Chesapeake striped bass stocks. Since 2000, Maryland and Virginia have accounted for 62% of commercial landings (by weight), 33% and 29% respectively (ASMFC 2008b). Both states manage large Chesapeake Bay commercial quotas and smaller Atlantic Ocean quotas. While both Maryland and Virginia have modified striped bass commercial regulations, Virginia has made more dramatic changes since 1990. The evolution of striped bass regulations in the Chesapeake Bay affects the way fishermen fish for striped bass and in turn individual economics for fishermen.

Maryland Striped Bass Management

Maryland Department of Natural Resources (MD DNR) manages the striped bass fishery using various traditional and inventive approaches to maintain a sustainable fishery in the Bay. Many of Maryland's Bay striped bass are resident fish ages 10 and younger and therefore have unique guidelines from the Atlantic States Marine Fisheries Commission (ASMFC). The Chesapeake Bay Management Area (CBMA) receives the majority of the coastal striped bass quota. Based on landings history, Maryland receives 52% of the CBMA allocation (commercial and recreational). That percentage is then allocated between the recreational and commercial sectors, 52.5% and 47.5% respectively. To avoid considerable overcapitalization within the fishery, Maryland caps the amount of commercial permits for the striped bass fishery at 1231 permits. DNR reports that 169 of those permits have no reported harvest to date (Kennedy 2008). The Maryland commercial Chesapeake Bay quota is then allocated quotas for each gear sector. The gear quota is tracked and effort is further limited using monthly quotas (gillnet and hook and line sectors) and seasonal, weekly and/or daily limits (Figure 1) (Kennedy 2008). Gear sectors are

MD CBMA Gear Sector	MD CBMA Quota Allocation	2008 Participation	Effort Constraints
Gillnet	45%	808	Daily Limits and Monthly Quotas
Pound net	25%	152	Daily and Net Limits
Hook and Line	30%	169	Daily/Weekly Limits; Monthly Quotas
Haul Seine	No specific quota	Unknown	Daily and Seasonal Limits

Figure 1. 2008 Maryland Chesapeake Bay effort breakdown.

given specific seasons when they can fish while all Maryland striped bass fishermen in the Bay must fish using a slot limit of 18" to 36" (ASMFC 2008a). All these regulations are in place to limit effort and decrease the probability of quota overages each year.

Virginia Striped Bass Management

In the wake of the moratorium, Virginia fisheries managers faced a difficult challenge: too many fishermen for too few fish. ASMFC allowed the Virginia Marine Resource Commission (VMRC or the Commission) to open up the striped bass fishery at 20% of Virginia's 1972-79 striped bass landings, or 211,000 pounds; with 865 people permitted to fish striped bass, the season was four to five days long (O'Reilly 1997). By 1992, it became apparent that open access in the fishery was not working and fishermen requested stricter permitting criteria for commercial striped bass fishing. In response, the Commission created and convened a Fishermen Advisory Committee (FAC) comprised of fishermen in the region, to help guide the VMRC in developing stricter permitting criteria (O'Reilly 1997). The recommendations from this group were the starting point for a limited entry program in the striped bass fishery.

The Commission instituted the limited entry program in 1993 based on established criteria by the FAC; to receive a 1993 striped bass permit, a fisherman must have held a 1990 or 1991 striped bass permit and proved that at least 50% of his earned income had come from fishing activities. These requirements resulted in eligibility for a total of 287 fishermen. Less than 10% of commercial watermen in Virginia were eligible to fish for striped bass (O'Reilly 1997).

The limited access program for the striped bass fishery evolved from 1993 to 1997 and criteria were modified to allow more entry into the fishery under a lottery system developed by VMRC as the fishery recovered and became economically viable once again. The Commission continued to refine the striped bass management system; however some fundamental problems like short seasons, derby fishing, and market gluts remained (Travelstead 2008).

In 1998, the VMRC adopted an innovative approach to striped bass fisheries management, instituting an alternative management system. The system used tag-based individual transferrable fishing quotas (ITQ) for striped bass fishermen. A fisherman was eligible for striped bass quota if he had: (1) a valid commercial registration license, (2) the appropriate gear license, (3) and any historical landings in the striped bass fishery from the 70's until the current year (Travelstead 2008). With historical landings information dating back to the '70s and '80s, the VMRC was able to group data by five gear types (gillnet, hook and line, fyke net, pound net, and haul seine) allocating each gear type a percentage of the commercial catch based on landings (Travelstead 2008). Within each sector, eligible fisherman with historical landings in a specific gear sector received an equal share of the gear-type allocation. After initial allocation, shareholders were able to temporarily or permanently transfer tags to other fishermen. There were no limits on how many times shareholders could temporarily transfer tags, which is still the case today. After transfers occurred, 575 fishermen were left with individual quota in the fishery in 1998 (Figure 2). In 2007, ten years after implementation, there were 381 quota holders (VMRC, 2009). In 2008, the lowest share was 10 pounds and the highest share was approximately 35,000 pounds (Johnson, 2008). A maximum holding cap was set at two percent in order to allow fishermen to grow their businesses while not creating a monopoly in the fishery.

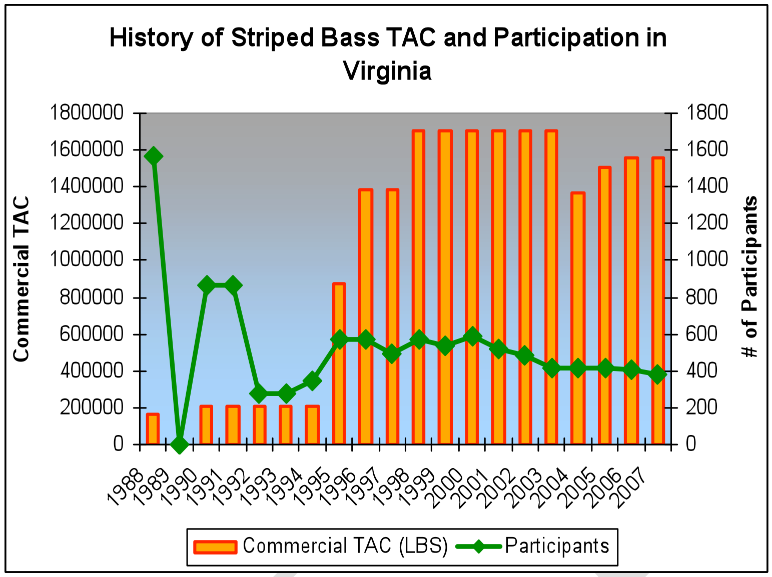

Figure 2. 1989-2007 TAC and participation levels in Virginia.

The initial striped bass system, a fish-based tag system, worked by having each tag represent one fish — determined by the previous year's average weight per fish. Each eligible Virginia fisherman was allocated a number of tags representing his allowable harvest which he would attach to harvested fish. Initial allocations were divided equally among fishermen in each gear sector (Figure 3) (VMRC 2009).

The fish-based tag system created a problem for both fisheries managers and the majority of fishermen. The average annual fish weight began to significantly increase resulting in fewer tags per quota holder each year. Some fishermen in the Bay were maximizing their catch by harvesting the largest fish possible, discarding smaller fish, and modifying gear to avoid smaller fish. Meanwhile, fishermen fishing in the rivers maintained their average fish weight of five to seven pounds but received less tags each year. As a result, the fishery was switched from a fish-based tag system to a weight-based tag system in 2007 (Travelstead, 2008). This system allowed fish of any size fish to be valuable. Tags are still distributed to fishermen based on projected catch but the accountability is measured by pounds instead of number of fish. This management measure has been effective at reducing the overall average weight of fish and reducing the number of discards by fishermen.

Gear Sector	% Share of Initial Quota
Gill Net	0.14%
Pound Net	0.52%
Haul Seine	0.35%
Fyke Net	0.39%
Hook Lime	0.04%

Figure 3. Initial quota by gear sectors.

Controlling Effort vs. Allocating Individual Shares

Maryland and Virginia have taken related but distinct approaches to manage striped bass in the Chesapeake Bay. Maryland uses a more traditional approach of management through limited entry and effort controls. In the pound net sector, fishermen essentially have a 4000 lb quota (allowance of four nets with 1000 lb limit/net) each year (ASMFC 2008a). In contrast, Virginia striped bass management has evolved into individual transferrable fishing quotas (ITQs), or catch shares, that grant individual fishermen a percentage of the overall allowable quota. Both states have implemented management systems targeted to improve the health of the fishery despite the fishery being deemed healthy, or "recovered", in 1995; although the striped bass stock itself was healthy, the fishery remained economically plagued by supply gluts, increasing costs, and hazardous fishing conditions.

For decades, regulators tried to limit the striped bass fishery by imposing a complicated array of "effort controls." These limits on when and how to fish are aimed at regulating fishing gear and method — without holding individual fishermen accountable for adhering to catch limits. Fishermen have generally complied with effort controls, but driven by their entrepreneurial spirit, have found innovative ways to catch more fish. For example, Maryland pound netters use temporary transfers to get around the 4000 lb season limit even though the transfer clause is in place for hardship only (Kennedy 2008). This cat-and-mouse game results in a "race for fish" as limited fishing seasons increase competition among fishermen to catch as much fish as they can as fast as they can (Babbitt and Greenwood 2008). This burns excessive fuel, raises fishermen's costs and often forces fishermen to fish in inclement weather. The result is often a glut of fish on the market for a short time with low earnings for fishermen.

Catch shares, or individual fishing quotas, allocate a secure, dedicate share of the stock to an individual in the form of a strong privilege to access a portion of the stock. Under catch shares, managers tell fishermen what their share of the overall catch is. This solution of designating access privileges provides clarity and security for fishermen about their role in the fishery, in return for individual accountability to remain within that designated amount of catch (Babbitt and Greenwood 2008). Incentives shift from maximizing the quantity of fish caught to maximizing the value of the catch. To work most effectively, a catch share program appropriately balances the management and responsibilities of the fishery resource between fishermen and fisheries managers, in the form of rights and duties.

In Virginia, the evolution of management from open access (1990 to 1993) to limited entry (1993 to 1997) to a fish-based ITQ (1998 to 2006) and finally weight-based individual quotas (2007 to current) provides an interesting case study for evaluating economic performance in a recovered fishery (O'Reilly 1997 and Travelstead 2008). This is interesting not only in comparison to Maryland's striped bass Bay fishery but also in comparison to other types of striped bass management previously explored by Virginia.

Economic Impact of Alternative Management Systems

Annual price means from 1990 to 2007 (ACCSP 2008) demonstrate that immediately post-moratorium, Maryland received higher striped bass prices ($/lb) than Virginia by eight percent, $2.40/lb to $2.20/lb respectively. However, from implementation of the Virginia ITQ to 2007, Virginia mean price was five percent more than Maryland price per pound. In 2007, Virginia received 33% more for striped bass then Maryland, $2.36/lb compared to $1.77/lb respectively. The fluctuation of price from the early to late '90s may be explained by the increased demand and market confidence for striped bass as the fishery recovers and the total allowable catch (TAC) increases (Figure 4).

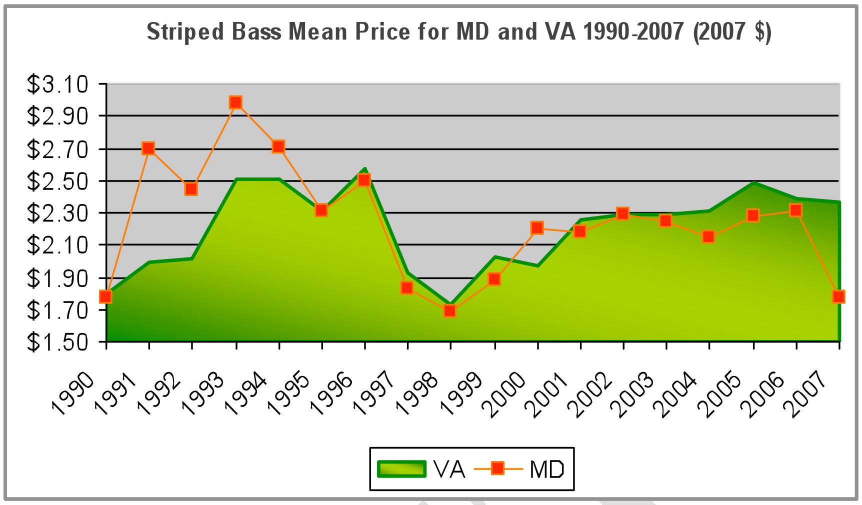

Figure 4. MD/VA price mean comparison: 1990-2007.

Current regulations in Maryland manage the details of how fishermen conduct their business — who, when, how, and how many. In Virginia, striped bass fishermen have the flexibility to be more targeted and efficient. This has resulted in increased compliance with management and higher revenues per boat. Fishermen can decrease the number of trips that need to be taken and save money on fuel, ice, bait, and other trip expenses. A combination of decreased costs and increased dockside prices provides fishermen with an opportunity to maximize profits and have something to leverage in the future.

Unlike Maryland striped bass fishermen, Virginia shareholders hold an asset whose value reflects the sustainability of the stock. This creates an incentive for fishermen to make the best decisions for the long-term sustainability of the striped bass fishery. Under current management, the options are either a government-backed buyout to reduce capacity or fishermen who are left with nothing. In contrast, under catch shares, those who wish to retire or leave the fishery can sell their shares to willing buyers. These transactions avoid the buyouts that frequently require remaining fishermen to fund the attrition of others, adding a considerable financial burden to an already economically constrained industry (Babbitt and Greenwood 2008). In Virginia, lease and purchase quota transactions have occurred since 1998. During the first year of implementation, purchase transactions outweighed lease transactions almost two to one. In 2008, the lease to purchase ratio was five to one (Figure 5) (VMRC 2008). According to preliminary results of a recent Virginia striped bass survey (Culzoni 2009), fishermen report that on average the purchase of quota is $7/lb, ranging from $3/lb to $9/lb, while lease price is half the market value price (1/2 $/lb).

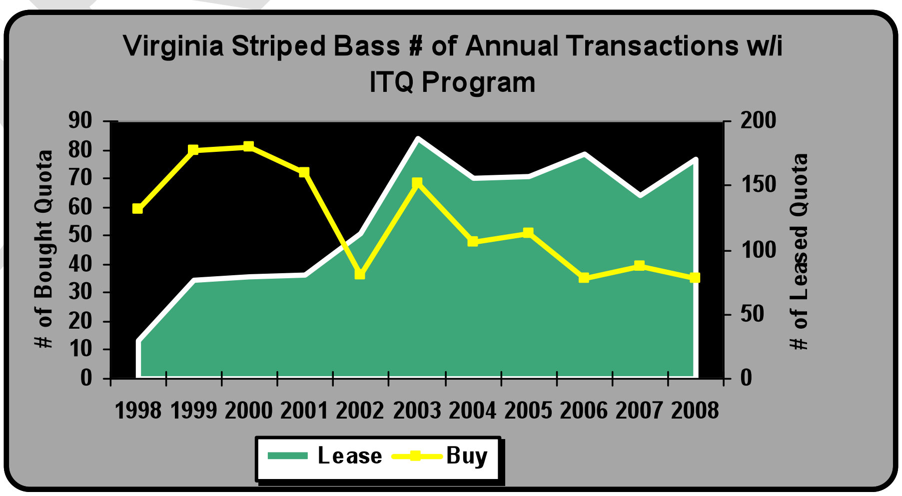

Figure 5. Virginia striped bass history of quota transactions: 1998-2008.

Indicators

Designing the appropriate management system depends on the priorities of fishermen and fisheries managers. Identifying a fishery's goals is the first and most important step of determining the appropriate alternative management. In absence of knowing the goals for a fishery, it will be impossible to identify the most appropriate design of a management program and will lead to arguments amongst stakeholders and confusion over how to proceed. Typically, there are three potential objectives: maximizing biological, economic, and social value. These objectives range from reducing by-catch to increasing the value of landing fish to promoting healthy fishing communities.

Fishing has been a vital, integral part of the Chesapeake Bay community, both economically and socially. Traditionally, under open access fisheries, the fish stock is viewed as a community asset rather than an individual asset with associated property rights. There is a concern that under a quota share system, many individuals will choose to move or sell their quota, thus abandoning communities. Quota shares have the potential to alter the distribution of fishing, landings and quota holders, however, there are design elements that may be instituted to maintain the fisheries social and/or historical structure. For example, maximum holding caps may be placed on quota in an effort to decrease the probability of any fishery becoming monopolized by a few participants. Additional measures, such as community quotas in vulnerable areas, or community partnerships that include resources to retrain fishermen and/or provide opportunities for fishermen to participate in cooperative research projects on the water may also alleviate the potential for monopolies in a quota based system. (Babbitt and Greenwood 2008).

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To be added to Socioeconomics as contributing authors submit:

Valuation of Water Quality (S/18)
Consumption and Demand (S/19)