Fisheries of the York River System

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ABSTRACT

The York River system supports a diverse fish fauna represented by members of the shad and herring family, drums, flatfishes, temperate basses, catfishes, sharks, skates, rays, and numerous smaller fishes that serve as forage such as bay anchovy, Atlantic menhaden, and killifish. Historically, fisheries for blue crabs, American shad, striped bass, and Atlantic sturgeon thrived in the Chesapeake Bay region but in recent times, and with the exception of striped bass, these fisheries have declined. Fishes of the York River exhibit divergent life history patterns, from fast growing, highly fecund species such as alewife, to slow growing, late-maturing species with low fecundity such as Atlantic sturgeon. The young of many species use the York River system as a nursery area and depend on the high productivity of this estuary for conferring fast growth and high survival during the first year of life. Habitat alterations that result in loss of water quality or quantity may deleteriously affect recruitment of young fishes through direct effects on young-of-the-year fish survival, or through disruption of spawning activity (e.g., dam construction, and water withdrawals that affect salinity and flow). Continued monitoring of recruitment success is crucial to understanding population-level responses to environmental and human-induced perturbations, especially in light of the projected growth of the human population in this watershed. Other important areas of continued research include assessment of habitat use and delineation of trophic interactions.

INTRODUCTION

The York River system is home to a diversity of fish species, some are year-round residents and others use the river during a particular season or life stage. Year-round residents, such as hogchoker and gizzard shad, move within areas of the river to make short spawning migrations or to find optimal water temperatures. Anadromous fish, such as American shad and striped bass, enter the York River system to spawn in spring, and the larval and juvenile stages use the shorelines of the fresh and brackish waters of the system as nursery grounds. Summer visitors to the York River (e.g., Atlantic croaker, spot, and weakfish) use the estuary as a nursery for juveniles and as foraging grounds for adults.

The Chesapeake Bay, positioned at the intersection of boreal and tropical regimes, serves as temporary and permanent habitat to a diversity of fish species. The York River's location near the mouth of the Chesapeake Bay allows for a number of marine species to use the system, in addition to the freshwater inhabitants found upstream. The VIMS Juvenile Fish Survey has been assessing fish populations in the York River since 1955, and has observed more than 130 fish species in the York River. These species include top predators such as sharks, as well as plankton feeders such as bay anchovies. The following sections describe many important fishes of the York River system and includes a description of the blue crab and its fishery because of the historical importance of this invertebrate fishery to Chesapeake Bay.

FISH GROUPS COMMON TO THE YORK RIVER SYSTEM

Shads and Herrings

The York River is home to several species in the shad and herring family (Clupeidae). Many of these species are anadromous, migrating into the York River and its tributaries to spawn in the freshwater reaches each spring. Several members of this family are important to commercial, recreational, and subsistence fishers.

American shad, *Alosa sapidissima*, have been harvested in Virginia for their meat and roe for centuries. Native Americans caught shad with seines made from bushes, as well as spears (ASMFC, 2007); European colonials also discovered and harvested this resource. Modern gears used to capture shad include pound nets, haul seines, fyke nets, staked gill nets, drift gill nets, and hook and line. Gill nets (Figure 1) are the preferred gear and have historically yielded the highest catches of American shad (Nichols and Massman, 1963). Because of the magnitude of the harvest, the shad stock has plummeted since its colonial heyday. Catches in 1897 were 11.5 million pounds compared with less than 1 million pounds in 1982 (ASMFC, 1999). To halt further declines of the American shad population in Virginia, a fishing moratorium on recreational and commercial harvest of American shad in the Chesapeake Bay and its tributaries was imposed in 1994. During the same year, the United States Fish and Wildlife Service (USFWS) and the Virginia Department of Game and Inland Fisheries (VDGIF) initiated a hatchery-restocking effort in the James and Pamunkey rivers using shad

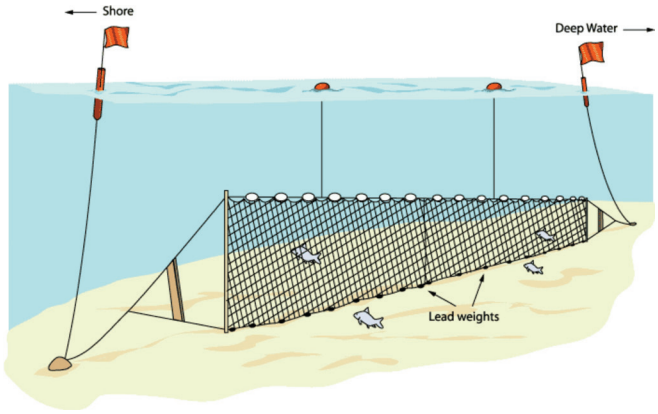

Figure 1. Gill net commonly used to catch shad and other fishes in the York River. (Figure courtesy of Michigan Sea Grant. http://www.miseagrant.umich.edu/nets/largegill.html)

broodstock taken from the Pamunkey River (Olney *et al.*, 2003). Current fish stocking efforts are conducted by VDGIF/USFWS and the Pamunkey and Mattaponi tribal governments. The Pamunkey and Mattaponi tribes, who have retained their rights to harvest this resource, stock 3-6 million fry to their respective rivers each year. This stocking of shad supplements the million (or more) shad fry stocked in the Pamunkey River by the VDGIF (T. Gunter, pers. comm.) The coastal fishery for American shad has been closed in Virginia waters since 2004 (ASMFC).

Current research efforts in the York River system seek to monitor abundance of both adult and juvenile American shad. VIMS has conducted staked gillnet monitoring of adult American shad each spring (during the spawning season) since 1998. Formerly, juvenile abundance was monitored using push-nets (1979-1986, 1991-2002), but now such data are collected from the VIMS Juvenile Striped Bass Seine Survey (Wilhite *et al.*, 2003). Results from these surveys show that the York River system has the highest index of abundance for juvenile shad compared with the James and Rappahannock rivers, thus highlighting the importance of the York River's shad runs to the Virginia Chesapeake Bay stock.

Adult American shad enter the York River in the spring to spawn in the fresh waters of the tributaries. Most of these spawners return to their natal stream, spend approximately 30 days in the area (Aunins, 2005, Olney *et al.*, 2006), then migrate to waters off the Gulf of Maine where they are found in summer and fall. Eggs have been collected between Mattaponi River km 81 and 124 and Pamunkey River km 98 and 150 (upstream of Sweet Hall Marsh). American shad larvae have been collected at the Sweet Hall Marsh area and upriver (Bilkovic *et al.*, 2002). The young of the year reside in fresh or brackish waters until fall when they leave the rivers. Most juvenile (Figure 2A) and adult shad overwinter in offshore waters, but some young of the year overwinter near the bay mouth.

American shad are filter feeders, eating planktonic shrimp and copepods, as well as fish larvae (Walter and Olney, 2003, Hoffman *et al.*, 2007). In the York estuary, mysid shrimp (*Neomysis americana*) are the primary food item of the adult spawners (Walter and Olney, 2003).

Hickory shad, *Alosa mediocris*, also spawn in freshwater during the spring. Adults return to the ocean in mid-summer after spawning, whereas juveniles move downstream into brackish or salt water and may remain there until autumn when they migrate offshore. Hickory shad are repeat spawners, with a smaller autumn spawning run. They eat crustaceans, fish eggs, squids, and small fishes (Murdy *et al.*, 1997).

Alewife (*Alosa pseudoharengus;* Figure 2B) and blueback herring (*Alosa aestivalis*) sometimes school together, and are thus collectively known as "river herring." Like American and hickory shad, these herrings spawn in spring in the freshwater reaches of the York River system. Alewives spawn in shallow, sluggish waters in late March and April, whereas blueback herring spawn in swifter waters later in the spring (April and May); adults move offshore after spawning. Juveniles of both species migrate from fresh or brackish waters to the ocean in early fall. Some remain in bay waters over winter. These herrings prey on planktonic organisms, such as diatoms, copepods, ostracods, shrimps, amphipods, as well as insects, small fishes, squids, and fish eggs (Murdy *et al.*,1997).

Historically, river herring, like shad, were targeted by both river and ocean fisheries. Coastwide commercial landings of river herring decreased from the early 1970s to the 1990s (Klauda *et al.*, 1991, ASMFC, 1999). Historically, Virginia landings accounted for a large portion of total Chesapeake Bay landings (Klauda *et al.*, 1991). River herring are sought by recreational netters who practice "dipping"—holding a large net on the bottom and lifting it sporadically—during the spawning runs. Juvenile abundance of these two species in the York River system has been generally low since the 1990s. Juvenile alewives are less abundant than juvenile blueback herring in both the Pamunkey and Mattaponi rivers (VIMS Juvenile Striped Bass Seine Survey).

Gizzard or mud shad, *Dorosoma cepedianum*, do not undergo extensive spawning migrations. Gizzard shad inhabiting the brackish waters of the estuary move to fresh water to spawn in late spring or early summer. In fall and winter, they live closer to the mouth of the river. As their name suggests, these fish are found in soft bottom habitats, as well as near sand, gravel and vegetation in fresh and brackish water. Gizzard shad eat algae, crustaceans, and other organisms found on the bottom (Murdy *et al.*, 1997).

Atlantic menhaden, or bunker (*Brevoortia tyrannus*), first enter the York River system as larvae in November and early spring. Young fish move to brackish and fresh waters in May and June. In fall, the young of the year leave the bay and move to deeper waters. Some juveniles (Figure 2C) overwinter in the bay. Spawning occurs in shelf waters in spring and fall. Atlantic menhaden swim in schools and feed on phytoplankton and zooplankton (Murdy *et al.*, 1997).

Figure 2. Juvenile clupeids. A-American shad, B-Alewife, C-Atlantic menhaden (Photos courtesy of VIMS Juvenile Fish Survey)

Atlantic menhaden have been harvested in Chesapeake Bay for hundreds of years. These protein-rich oily fish were used by Native Americans as fertilizer. In the 20th century, menhaden meal and oil were used in animal feeds and various manufactured goods such as soap and linoleum. The current Atlantic commercial fishery captures menhaden for reduction (or processing) and bait. In Virginia, these fisheries operate in the Chesapeake Bay and nearby coastal waters. Atlantic menhaden landings in Virginia account for a high percentage of Atlantic menhaden landings coast wide (ASMFC, 2001, ASMFC, 2005(b)).

Threats to shad, herring, and menhaden include overfishing, habitat degradation (particularly water quality changes due to nutrient and sediment loading), and pollution. The anadromous members of this family are threatened by the addition of dams, which can prevent them from reaching their spawning grounds. If positioned in key locations, water withdrawal facilities—such as reservoir intakes—may pose a threat to freshwater spawners in terms of egg and larval losses.

Drums

Members of the family Sciaenidae, collectively referred to as drums, are important members of the York River fish community and include Atlantic croaker, spot, weakfish, spotted seatrout, and silver perch. Drums are mainly found in coastal and estuarine areas, but may be found in a variety of habitats including freshwater. Most species migrate seasonally along the coast and use Chesapeake Bay and the York River for feeding and as a nursery area. Drums are best known for their ability to produce drumming or croaking sounds using their specialized swim bladder and associated musculature.

Adult Atlantic croaker, *Micropogonias undulatus*, spawn offshore in winter and move into the York River in the late spring. They remain in the river until fall when they migrate back offshore. Young-of-the-year croaker move into the York River estuary in summer and fall and inhabit low salinity waters and freshwater creeks. The young fish overwinter in the deeper portions of the river, where they remain until the following fall when they migrate to the ocean with the adults (Murdy *et al.*, 1997).

Atlantic croaker is one of Virginia's most important fishery resources. Adults (Figure 3A) are captured by a variety of fishing gear including gill nets, pound nets, and haul seines. The abundance of this species can vary dramatically from year to year and commercial catches reflect this variation. Since 1950, commercial landings in Virginia ranged from 6,200 pounds to over 14,000,000 pounds (http://www.st.nmfs.gov/st1/commercial/landings/annual_landings.html). Extremely cold winters with low water temperatures (<3°C) can cause high mortality of juveniles, and therefore recruitment to the adult stock is mainly determined by environmental conditions during the first winter (Norcross, 1983; Lankford and Targett, 2001). Management efforts focus on maintaining the stock biomass above a target level so that stock abundance can rebound after periods of low recruitment (ASMFC, 2005a).

Figure 3. A-Adult Atlantic croaker, B-Juvenile Atlantic croaker (Photos courtesy of VIMS Juvenile Fish Survey)

Atlantic croaker are demersal (bottom-dwelling) fish. Adults can be found over sandy or muddy substrate often associated with submerged aquatic vegetation (ASMFC, 2004). Juveniles (Figure 3B) use the upper portion of the York River estuary where salinities are more stable and where turbidity is higher and organic matter and associated prey are more available (ASMFC, 2005a). Adults feed opportunistically on many types of invertebrates, such as polycheate worms, and even small fishes (Parthree *et al.*, 2006).

Spot, *Leiostomus xanthurus*, (Figure 4) undertake seasonal migrations from estuarine and coastal waters to offshore spawning grounds in winter. In the spring, adults and juveniles enter the York River where they remain until fall when they migrate south along the coast to Cape Hatteras. Adult spot are mainly found in the lower York River where salinity is higher, but juveniles move upriver to lower salinity tidal creeks, such as Taskinas creek, as well as freshwater areas in the Mattaponi and Pamunkey rivers.


Figure 4. Spot (Photo courtesy of VIMS Juvenile Fish Survey)

Spot are harvested by both commercial and recreational fishers. Spot population abundance fluctuates annually in response to environmental factors that contribute to larval and juvenile mortality.

Spot are bottom feeders as adults and feed nocturnally on invertebrates such as small crustaceans and mollusks. Juvenile spot feed mainly on zooplankton before becoming bottom feeders (Murdy *et al.*, 1997, ASMFC, 2005a).

Weakfish or grey trout, *Cynoscion regalis*, migrate seasonally along the Atlantic coast, moving into Chesapeake Bay and the York River in the spring and migrating to coastal waters in the fall, when they can be found in large aggregations. The adults spawn near the Bay mouth and in nearshore areas beginning in the spring and continuing through the summer. Young-of-the-year grey trout (Figure 5) can be found in low-salinity habitats in the York River in summer. Growing rapidly, juvenile grey trout move to more saline waters by late fall and in early winter, these juveniles leave the York River. Weakfish feed on a variety of fish and crustaceans and become more piscivorous as they grow older (Murdy *et al.*, 1997, ASMFC, 2004).


Figure 5. Young-of-the-year weakfish (Photo courtesy of VIMS Juvenile Fish Survey)

Silver perch, *Bairdiella chrysou-*

ra, (Figure 6) are found in the Bay throughout the year, but are most abundant in the York River from April to November. They spawn in nearshore areas of the eastern shore, both bayside and seaside; juveniles are usually abundant in shallow sea grass beds. Silver perch in the York River eat bay anchovies, mysids, blue crabs and a variety of other animals including other fishes and invertebrates (Parthree *et al.*, 2006).

Figure 6. Young-of-the-year silver perch (Photo courtesy of VIMS Juvenile Fish Survey)

Adult spotted seatrout or speckled trout, *Cynoscion nebulosus*, are found in the York River from April to November. They spawn near the mouth of the Bay and in nearshore coastal waters from May to July. Juvenile spotted seatrout are found in the York River system from summer to fall in intertidal creeks and marshes near submerged aquatic vegetation. This species can withstand a large range of salinities and is a popular target for recreational anglers fishing near seagrass beds (Murdy *et al.*, 1997). Large areas of submerged aquatic vegetation are important habitat for adult spotted seatrout.

The diet of juvenile spotted seatrout is comprised mainly of crustaceans, but as fish age, the diet shifts to penaeid shrimp and other fish species like mullet (Murdy *et al.*, 1997).

Flatfishes

Flatfishes in the order Pleuronectiformes are characterized by adults that lie flat on the bottom on one side of their body. At the beginning of their life, flatfish are bilaterally symmetrical and larvae live in the middle of the water column, but during development, larvae metamorphose to the compressed shape of the adult. During metamorphosis, the eyes and other sensory organs migrate to one side of the head and the fish becomes bottom dwelling. The dorsal side is usually pigmented and the ventral side (the blind side) is usually unpigmented. Flatfishes are referred to as either righteyed or lefteyed: lefteye flatfish lie on their right side and both eyes are on the left side of the head. The opposite is true for righteye flatfish. This character is consistent within a family (Helfman *et al.*, 1997). Representatives from five families of flatfishes can be found in the York River, and three of those families are represented by a member that is commonly encountered.

Summer flounder, *Paralichthys dentatus*, (Figure 7A) is a lefteye flounder and a popular sport fish in the lower York River. Adult summer flounder are migratory and spend the winter months offshore on the outer continental shelf. Summer flounder are found in the Bay and lower portion of the tributaries from spring to autumn. Spawning occurs during the offshore migration from late summer to mid-winter (Murdy *et al.*, 1997). Adults and juveniles in the York River prefer sandy habitats, but can also be found near eel grass beds or in marsh creeks. Adults spend most of their life burrowed in the substrate and can change their coloration to match the surrounding substrate (ASMFC, 2004, Murdy *et al.*, 1997). Summer flounder in the York River eat mostly fish (e.g., bay anchovy and spot) along with some invertebrates like mysids (Parthree *et al.*, 2006).

The hogchoker, *Trinectes maculatus*, (Figure 7B) is a small, ubiquitous righteye flatfish (maximum size 20 cm total length) that is a year-round resident of Chesapeake Bay and the York River. This species is the second most frequently captured in the VIMS Juvenile Fish Survey. Hogchokers can be found in all salinities from true freshwater to the marine environment and are often found on muddy substrates. Spawning takes place at night beginning in late spring and continues through late summer (Smith, 1986).

Hogchokers are exclusively bottom feeders, feeding on a wide range of invertebrates including amphipods, polycheates, dipteran larvae, and ostracods (Smith, 1986).

The blackcheek tonguefish, *Symphurus plagiusa*, a teardrop-shaped lefteye flatfish, is found in the York River and lower Chesapeake Bay throughout the year. It inhabits soft muddy bottoms and feeds on mollusks, worms, and small crustaceans (Murdy *et al.*, 1997). This species spawns in the Bay from late spring through summer.

Striped Bass and White Perch

Two species in the family Moronidae, known as temperate basses, inhabit the York River. White perch are year-round residents, whereas striped bass migrate into the river in spring as adults, but young striped bass (<4 years) are found in the estuary throughout the year.

White perch, *Morone americana*, (Figure 8A) tolerate a wide range of salinities and are found from the Bay to the upper reaches of the Pamunkey and Mattaponi rivers, though they prefer salinities around 18 ppt (parts per thousand). White perch undertake short migrations upstream to spawn from April to June. Juveniles use the shoreline areas of the Mattaponi, Pamunkey and upper York rivers as nursery habitat and their occurrence often overlaps with juvenile striped bass. White perch are a popular target for recreational anglers.

Adults feed on small fishes, crustaceans and shrimps, whereas juveniles feed mostly on aquatic insects and small crustaceans.

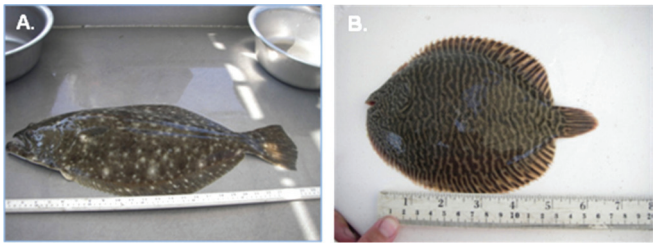

Figure 7. A-Summer flounder, B-Hogchoker (Photos courtesy of VIMS Juvenile Fish Survey)

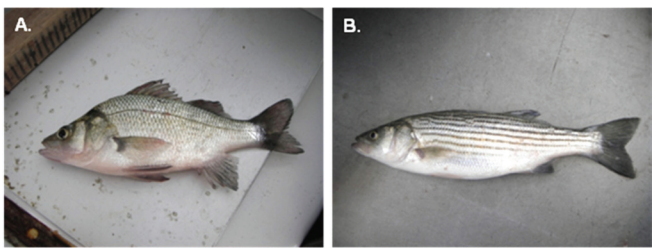

Figure 8. A-White perch, B-Striped bass (Photos courtesy of VIMS Juvenile Fish Survey)

Striped bass, *Morone saxatilis*, (Figure 8B) use the fresh waters of the Pamunkey and Mattaponi rivers as spawning grounds in early spring. After spawning, adults depart the bay and complete coastal migrations towards the north, returning in fall. Young-of-the-year striped bass inhabit brackish waters downstream from spawning grounds until fall when they migrate to deeper waters in the bay. The Virginia Institute of Marine Science's Juvenile Striped Bass Survey monitors the annual recruitment of striped bass in Virginia's tributaries to Chesapeake Bay, including the York, Pamunkey, and Mattaponi rivers. The Pamunkey River, including Sweet Hall Marsh, is an important spawning and nursery area for this species (Bilkovic *et al.*, 2002).

Young-of-the-year striped bass consume invertebrates such as copepods, shrimps, worms, insects, and insect larvae, as well as fish eggs and larvae (Muffelman, 2006). Adult and juvenile striped bass prey upon a variety of fishes, including anchovies, fishes in the drum family (croaker, spot, etc.), Atlantic menhaden, and invertebrates (Walter and Olney, 2003).

Catfishes

Several species of native and introduced catfish in the family Ictaluridae inhabit the York River and its tributaries (Figure 9). Catfish in this family can be easily identified due to several unique characteristics. Four pairs of barbels ("whiskers") around the mouth have given rise to the common name (Murdy *et al.*, 1997). Catfish lack scales and have a fleshy fin called an adipose fin that is just anterior to caudal fin. These fish are sought mostly by recreational anglers in the York River. Growth rates of the channel, white, and blue catfish are higher in the York River system than in other Chesapeake Bay tributaries in Virginia (Connelly, 2001).

Figure 9. Blue catfish (top panel), channel catfish (middle panel), white catfish (bottom panel) (Photos courtesy of VIMS Juvenile Fish Survey)

White catfish, *Ameiurus catus*, are native to all tributaries of Chesapeake Bay and are abundant in the York River system. They tolerate a wide range of salinities, although white catfish are most commonly found in freshwater. During spawning in early summer, eggs are deposited in a saucer-shaped nest that is constructed by the parents. One or both parents will guard the eggs and young in the nest. This species eats a variety of bottom-dwelling insects and crustaceans as well as fishes.

Channel catfish, *Ictalurus punctatus*, are not native to the York River. They were introduced to the major tributaries of Chesapeake Bay in the 1890s and are now common in the York, Pamunkey, and Mattaponi rivers (Connelly, 2001). The adults are found in deep pools near structure or cover such as submerged logs. Channel catfish spawn in fresh or low salinity waters in the late spring when water temperatures are near 24°C. Eggs are laid in a nest which can consist of an undercut stream bank, hollow log, crevice or even manmade containers (Murdy *et al.*, 1997). One or both parents guard the young while in the nest and upon hatching, the young stay together in tight aggregations near suitable cover. Channel catfish are opportunistic bottom feeders that will eat a variety of aquatic insects and insect larvae, fishes, and crabs.

Blue catfish, *Ictalurus furcatus*, are not native to Virginia. They were introduced to the Mattaponi River in 1985 and are now established in both the Mattaponi and Pamunkey rivers (VIMS Juvenile Fish Survey, unpublished data). This species inhabits brackish waters, but is mainly found in the main channels of large rivers where salinities are below 12 ppt. Blue catfish spawn during the late spring when water temperatures are at least 21°C. Males build nests in cavities of submerged logs or undercut banks and guard the eggs and newly hatched young until the young leave the nest.

This species is a popular sport fish for recreational anglers and will strike at a variety of live and artificial baits. Blue catfish are scavenging carnivores and in the York River system they eat benthic crustaceans, such as crabs and amphipods; clams; and fishes, such as Atlantic menhaden and gizzard shad (Parthree *et al*., 2006).

Other Important Fishes

The fish community of the York River is diverse and some of the common species are not well known by the public, but they play an important role in the ecosystem.

Bay anchovy, *Anchoa mitchilli*, (Figure 10) are an abundant year-round resident of the lower York River. Bay anchovy are a schooling species that are found in deeper water in the winter and in shallow areas along shorelines in the summer. They spawn at night in estuaries from spring to late summer with peak spawning occurring in July. Bay anchovy feed mainly on zooplankton, such as copepods and other crustaceans.

Figure 10. Bay anchovy (Photo courtesy of VIMS Juvenile Fish Survey)

Bay anchovy have no commercial or recreational value; however, they are an important food resource for numerous other fish species (e.g., striped bass and summer flounder)

that inhabit the York River, thus making them an important component of the food web. Bay anchovy abundance and recruitment are highly variable from year to year and are controlled by complex environmental and biological processes (Jung and Houde, 2004).

The oyster toadfish, *Opsanus tau*, is commonly found yearround in the lower to middle reaches of the York River. It is easily identified because of its broad head and wide mouth with fleshy protrusions, and slimy, scaleless skin. The male produces vocalizations during the spawning season (April to October) to attract females to a nest (usually shells or even old cans or jars), where the female deposits large eggs and then leaves the male to fertilize and guard them.

Both juvenile and adult oyster toadfish are bottom dwelling and feed on a variety of crustaceans, mollusks, and fish. They are often caught by hook and line and are safe to eat but are not consumed due to the sharp teeth and perceived difficulty in handling.

The spotted hake, *Urophycis regia*, is a member of the cod family. Juveniles inhabit the lower bay and its estuaries, including the York River, from March to June. As water temperatures warm, spotted hake move offshore. Adults spawn offshore from late summer to winter. Spotted hake consume crustaceans, fishes, and squids.

The American eel, *Anguilla rostrata*, is a catadromous species with a complex life cycle (Figure 11); eels spend their adult life in freshwater ponds, streams, and brackish water. Adult

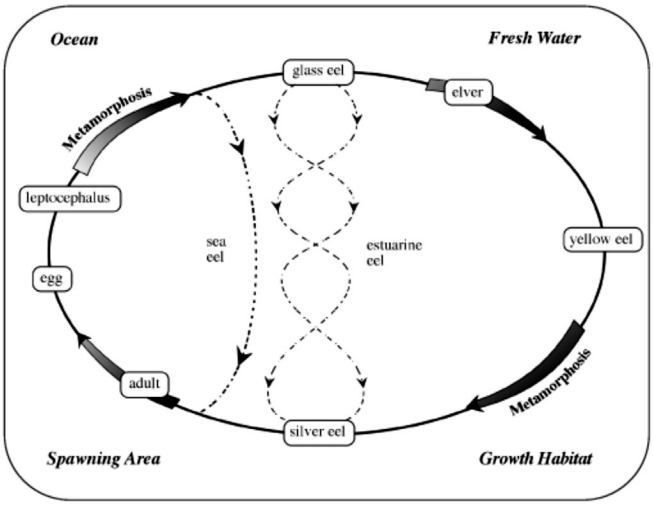

Figure 11. American eel life cycle. (Figure courtesy of Department of Fisheries and Oceans Canada, Underwater World factsheet)

eels leave these habitats to migrate to the Sargasso Sea to spawn in late winter to early spring. Young eels begin their life as leptocephalus larvae and drift on ocean currents for up to one year before entering Chesapeake Bay and the York River. Just before they enter the estuary, the larvae metamorphose into the "glass eel" stage, called such because they are transparent. The glass eels become pigmented as they migrate upstream and are then called elvers. Elvers and later stage adult eels called yellow eels inhabit a diversity of habitats in the York River system from brackish marshes to freshwater ponds.

Eels play an important role in the York River ecosystem. Adults feed nocturnally on a diet of insects, worms, crustaceans and fish, and eels of all sizes are preyed upon by other fish and fish-eating birds and mammals. They are harvested commercially for bait and for export to Asia and Europe, and recreational anglers catch them to use as bait for popular game fish such as striped bass and cobia. Recent declines in the commercial harvest of American eels throughout their range have raised concerns about the status of the population. State and federal agencies are now closely monitoring commercial landings and the recruitment of juvenile eels to help assess the status of the stock and establish sustainable harvest limits.

Striped killifish, *Fundulus majalis*, are very common and abundant in the lower York River throughout the year. They inhabit sandy-bottom shallow habitats with relatively high salinities and are not found in freshwater. Males and females of this species differ in their coloration. Males have 15 to 20 black vertical bars on their sides, whereas females have 2 or 3 black horizontal stripes and a few vertical bars near the caudal fin. Striped killifish feed on invertebrates such as polycheate worms and insects, and serve as food for other fishes and wading birds (Murdy *et al.*, 1997).

Mummichogs, *Fundulus heteroclitus*, are an abundant yearround resident of the marshes and creeks of the York River system. They prefer salinities lower than the striped killifish, but the two species are often collected together where their distributions overlap. The mummichog diet is varied and includes many types of mollusks, insects, plants, and occasionally other fishes (Murdy *et al.*, 1997). They are sold as bait (minnows) for recreational anglers and are food for other fishes and wading birds.

The Atlantic sturgeon is a member of an ancient family of fishes (Acipenseridae) thought to have been on Earth for more than 120 million years. The Atlantic sturgeon consists of two subspecies (Ong *et al.*, 1996): *Acipenser oxyrinchus oxyrinchus*, the subspecies that spawns in the Chesapeake Bay and ranges from Labrador to northern Florida, and *Acipenser oxyrinchus desotoi*, also known as the gulf sturgeon, which inhabits the Gulf of Mexico. All populations of Atlantic sturgeon are anadromous, thus they are dependent on freshwater tributaries for spawning and nursery habitats. In mid-Atlantic latitudes, spawning occurs between May and July over hard bottom in regions of adequate flow. Hard substrates provide good adhesion for the sticky eggs and sufficient flow keeps the eggs well oxygenated and prevents them from burial by settling sediments. The exact location of spawning grounds in the Chesapeake's tributaries is unknown. Currently, there is an effort to locate, protect and restore these areas in the James River where historic populations were very large, but this effort has not yet expanded into the York River watershed.

The Atlantic sturgeon (Figure 12) was once abundant throughout the Atlantic coast of North America (Colligan *et al.*, 1998). In the early 20th century, Virginia landed over half a million pounds for flesh and highly prized caviar for several consecutive years (Hildebrand and Schroeder, 1928). However, sturgeon populations were unable to support these high

Figure 12. Atlantic sturgeon (VIMS Fisheries Science Department Photo)

levels of exploitation. Their rapid growth, predictable seasonal migration patterns with distinct seasonal concentration areas (Bain, 1997), and unusual morphology (Boreman, 1997) made the species highly susceptible to capture. Late maturation and inconsistent spawning intervals combined to make the species biologically sensitive to overfishing (Boreman, 1997). Once the population was severely reduced, relatively small bycatch mortalities may have significantly hindered their reproductive potential, thus resulting in continued recruitment failure (Boreman, 1997). In addition to direct harvest, anthropogenic habitat alterations in the Chesapeake Bay watershed reduced the extent of, destroyed, or restricted access to many of the species' essential habitats. The Atlantic sturgeon depends on channel habitats for all life stages and on healthy freshwater habitats for reproduction; such biological needs are in direct conflict with human activities, such as dredging and dam construction, which alter habitats or reduce water quality (Secor *et al.*, 2000). Additional studies are necessary to identify the effects of these alterations and develop means of restoring essential habitats. The effectiveness of artificial spawning reefs has been demonstrated in other regions and such approaches could be evaluated for Chesapeake Bay tributaries. Stocking programs could be developed and pilot stocking studies may be used to evaluate habitat use.

The Atlantic sturgeon has been protected from harvest in Virginia since 1973, and along the coast by the Atlantic States Marine Fisheries Commission since 1998. A lack of stock recovery, however, has recently resulted in the recommendation by the NMFS Status Review Team to list the species by distinct population segments under the Endangered Species Act. These segments include the New York Bight, Chesapeake Bay, and Carolina populations of Atlantic sturgeon. In the York River system, potential spawning habitats are considered to be located above the upper limits of saltwater intrusion in the Mattaponi and Pamunkey rivers (Bushnoe *et al*., 2005). In the late 1960s to early 1970s, a single pound-net in the Pamunkey River was landing approximately 1000 lbs. of sturgeon per year. Today, we know that the Chesapeake Bay contains a genetically distinct stock and that reproduction occurs in the James River, however, geneticists do not agree as to whether the population in the York River is genetically unique (Wirgin, 2006), thus, there is no unequivocal evidence for reproduction in the York River watershed. Despite this, numerous juvenile Atlantic sturgeon have been collected at upriver sites since 2005, and a large group of juveniles were actively using soft-bottom habitats in and around beds of submerged aquatic vegetation at the mouth of the river in 2006. Interestingly, these young fish (presumably 2-3 years old) did not return to the York River in 2007. It is suspected that these fish may have left the Bay to start their coastal wandering pattern, a typical pattern for 2-3 year-old fish. Perhaps when these fish return in 8 to 10 years, the research needed to identify, preserve, and restore this magnificent fish's essential spawning and nursery habitats will have been completed.

The longnose gar (*Lepisosteus osseus*) (Figure 13) is part of an ancient family of fishes, Lepisosteidae, that has remained relatively unchanged for 100 million years. The longnose gar is a year-round resident in Virginia and is common in the upper York, Mattaponi, and Pamunkey rivers. This is the only species of gar found here. Longnose gar is considered a freshwater fish, but often inhabits oligohaline and mesohaline water and is occasionally captured at the mouth of the York River

Figure 13. Longnose gar (Photo courtesy of Pat McGrath)

in salinities greater than 20 psu (Hildebrand and Schroeder, 1928, McGrath, unpublished). Scientific accounts of longnose gar in Virginia are sparse; those that exist mention only their presence, larval development, or individuals with abnormal coloration (Hildebrand and Schroeder, 1928, Pearson, 1942, Massman *et al.*, 1952, Mansuetti and Hardy, 1967, Woolcott and Kirk, 1976, Jenkins and Burkhead, 1993, Murdy *et al.*, 1997). The longnose gar spawns in the spring along the banks of the Mattaponi and Pamunkey rivers, with females releasing approximately 30,000 eggs. Juvenile longnose gar grow quickly, attaining 500 mm before the end of their first year. They have been reported to attain a maximum size of 1200 mm and live to 22 years of age (Netsch and Witt, 1962, Ferrara, 2001, McGrath, unpublished). The longnose gar is almost exclusively piscivorous in other riverine and lacustrine systems (Goodyear, 1967, Crumpton, 1970, Seidensticker, 1987, Tyler *et al.*, 1994). McGrath (unpublished) examined the stomach contents of 51 longnose gar from the York, Pamunkey, and Mattaponi rivers and found that the dominant prey items by weight and number were juvenile croaker (*Micropogonias undulatus*), menhaden (*Brevoortia tyrannus*), and spot (*Leistomus xanthurus*).

SHARKS, SKATES AND RAYS

Sharks, skates, and rays are seasonal visitors to the York River. These fish generally migrate from offshore waters or from south of Cape Hatteras and inhabit the bay between May and November. Most species prefer the higher salinity areas and beds of submerged aquatic vegetation in the lower bay and lower tributaries, such as the York River, but some are known to penetrate into fresh water.

Sharks

The family Carcharhinidae, or ground sharks, is represented in the York River system by the sandbar shark (*Carcharhinus plumbeus*; Figure 14) and the bull shark (*Carcharhinus leucas*). The sandbar shark is by far the most numerous shark found in the York River (Murdy *et al*.,1997; unpublished data,

Figure 14. Sandbar shark (Photo courtesy of Dean Grubbs)

VIMS Trawl Survey). Adult females use this area as a nursery for their young. Sandbar sharks as large as one meter in length have been taken in mesohaline waters. Primarily a bottom feeder, this shark is known to feed on crustaceans and its principal prey is soft adult female blue crabs. Although historically very common in the York River and the Chesapeake Bay, the abundance of sandbar sharks has declined in recent years (Figure 15). This shark has been the most valuable commercial shark species fished on the east coast since the late 1940s.

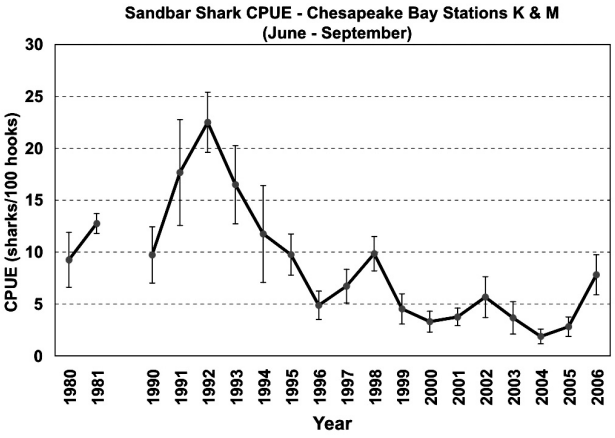

Figure 15. Sandbar shark CPUE (catch per unit effort) from two long-line stations in lower Chesapeake Bay (VIMS long-line survey).

Bull sharks are extremely rare in the York River (VIMS Trawl Survey, unpublished data). Bull sharks are one of the very few sharks known to penetrate into fresh water and have been captured as far as one thousand miles up river in the Mississippi River (Murdy *et al.*,1997). Bull sharks frequent the Chesapeake Bay and have been known to feed on sandbar shark pups. Adult bull sharks are extremely dangerous and are considered to be the second or third most likely shark to be implicated in attacks on humans. The numbers of bull sharks have been severely reduced due to commercial fishing (Murdy *et al.*,1997).

The smooth dogfish (*Mustelus canis),* a member of the family Triakidae (smoothhounds), is a frequent visitor to the York River. Smooth dogfish are a small, thin shark reaching a maximum size of 1.5 meters. Animals have been taken in the Chesapeake Bay as far north as the mouth of the Patuxent River, Maryland (Murdy *et al.*,1997). Smooth dogfish may be found in small schools and are active feeders on small invertebrates. They are often captured incidentally by anglers, haul seines, and pound nets and are also thought to survive short intervals in fresh water (Murdy *et al.*,1997, VIMS Trawl Survey, unpublished data).

Skates

Skates (family Rajidae) are distinguished from rays by not having a barbed tail. The clearnose skate (*Raja eglanteria;* Figure 16) is the most common skate in the bay; its name aptly describes the appearance of this species. The tail is covered with three rows of thorns. Clearnose skates are often taken by commercial and recreational fishers and are considered a nuisance. Like most skates and rays, this species feeds on bottom-dwelling organisms, taking mainly small invertebrates (Murdy *et al.*,1997).

Figure 16. Clearnose skate (Photo courtesy of Virginia Tech University)

Rays

The smooth butterfly ray (*Gymnura micrura*; family Gymnuridae) lacks a tail barb and is, therefore, harmless. The shape of the body of this species resembles a butterfly and the skin is smooth without thorns. The disk width of this species can be as large as 1.2 m (Murdy *et al.*,1997, Smith and Merriner, 1978, VIMS Trawl Survey, unpublished data).

Members of the family Dasyatidae have diamond-shaped bodies with long slender tails (Smith and Merriner, 1978). The bluntnose stingray, *(Dasyatis say)* is gray to brown above and white underneath, and grows to a width of 1m. It is generally considered a nuisance species by commercial and recreational fishers. As with all members of the family, this species can deliver an extremely painful sting from the venom in the barbed tail.

The Atlantic stingray *(Dasyatis sabina)* is a small sting ray usually not exceeding 0.4 m in disk width, with an obviously triangular, pointed snout. It is rarely captured at depths greater than 3 m (Smith and Merriner, 1978). Atlantic stingrays are usually captured in mesohaline waters; they are rarely found north of the York River, which appears to be the northernmost extent of their range (Murdy *et al.*,1997, Smith and Merriner, 1978).

The southern stingray (*Dasyatis americana*; Figure 17) is a rare visitor to the lower York River. Original descriptions were made from an animal taken in Crisfield, Maryland (Hildebrand and Schroeder, 1928). The snout is barely projecting and the disk is wider than it is long, with a finlike fold along the underside of the tail (Murdy *et al.*, 1997). Disk width has been reported to reach 1.5 m (Smith and Merriner, 1978).

Figure 17. Southern stingray (Photo courtesy of Dean Grubbs)

Cownose rays (*Rhinoptera bonasus*; family Rhinopteridae), common visitors to the York

River, are strong swimmers that can cover long distances. A single school, estimated at 5 million adults and covering 1,100 acres, was observed in the 1980s in lower Chesapeake Bay (Murdy *et al*., 1997, Virginia Marine Resource Bulletin, 2007 Vol. 39, No 2.). These rays are often seen swimming in small schools on the surface, with the tips of both wings projecting from the surface of the water. Cownose rays may be identified by their somewhat pointed wings and two small lobes on the snout. Both adults and pups are found in the York River with adults captured as far upriver as Goff Point (river km 45). This species feeds on bivalves, including oysters and clams, and cownose rays are known to destroy portions of beds of submerged aquatic vegetation while feeding. Currently, efforts are underway to develop a commercial fishery, as this species is readily taken incidentally by pound nets (Figure 18). Cownose rays are slow to mature, reaching maturity at age eight, and producing few young (females have only one pup every year). Great care should be exercised in ensuring this species is not overfished.

Figure 18. Pound net fishers take a large haul of cownose rays. (Photo courtesy of Bob Fisher)

BLUE CRABS

The blue crab (*Callinectes sapidus*; Figure 19) is the most widely distributed species in the genus *Callinectes*, a genus of swimming crabs (Williams, 2007). Primarily because of the cold winters, the life history of the blue crab in Chesapeake Bay differs in some respects from its life history in lower latitudes (Hines, 2007). Crabs enter a state of low to no activity in the winter when temperatures drop below about 10 degrees Celsius, and they often bury in muddy sediments in deeper water during this period. Crabs quickly become active again when the water temperature rises. Males and females mate during the spring in the shallow areas of the Bay's tributary creeks and rivers, often in low salinity areas. Inseminated females migrate to the lower, more saline portions of the Bay to develop broods, or sponges (Figure 19). When the eggs hatch, larvae (zoeae) are transported into the open waters of the continental shelf. The larvae develop through seven or eight zoeal stages into postlarvae (megalopa), which rely on advective transport to return them to the Bay in the fall. Postlarvae typically settle in structured habitats, such as areas of submerged aquatic vegetation, where they metamorphose into juvenile crabs. Growth rates of blue crab in Chesapeake Bay are highly variable (Ju *et al.*, 2001), but some crabs can reach a size that makes them available to the commercial fishery within their first year of life (about 75 mm, or 3 inches).

Figure 19. Adult female blue crab (left panel) (Photo courtesy of Kristie Erickson). A female blue crab with a newly extruded egg mass or sponge (right panel).

Blue crabs are often a numerically dominant component of the benthic assemblage in shallow areas throughout the Bay, and are especially abundant in the York River. Areas of submerged aquatic vegetation are important as settlement and nursery habitats for juvenile crabs. Such structured habitats provide protection from predators during molting and a rich source of food. Near the mouth of the York River, aquatic vegetation beds around Goodwin and Allens Islands and the Guinea marshes routinely host large numbers of small and large crabs. Unstructured habitats, such as the muddy, detrital areas along marshes and the lower reaches of tidal creeks, are also important as foraging areas for juvenile and adult crabs. Within the York River, crabs range upstream to the tidal freshwater sections of the Mattaponi and Pamunkey rivers.

The blue crab is woven into the culture and economy of the Chesapeake Bay region more intimately than perhaps any other aquatic species (Warner, 1976). The blue crab has supported an important commercial fishery in the Bay since the late 1800s. Unfortunately, similar to other Bay resources, the blue crab population in the Bay has declined significantly from its historic abundance. Fishery-independent monitoring indicates that the population may be reduced to as little as 50% of the abundance observed in the early 1990s (CBSAC, 2007). As a result, watermen that depend on the blue crab for their livelihood have been negatively affected; recent commercial harvests have been the lowest on record since reporting began in 1945 (Figure 20; Miller *et al.*, 2005, CBSAC,

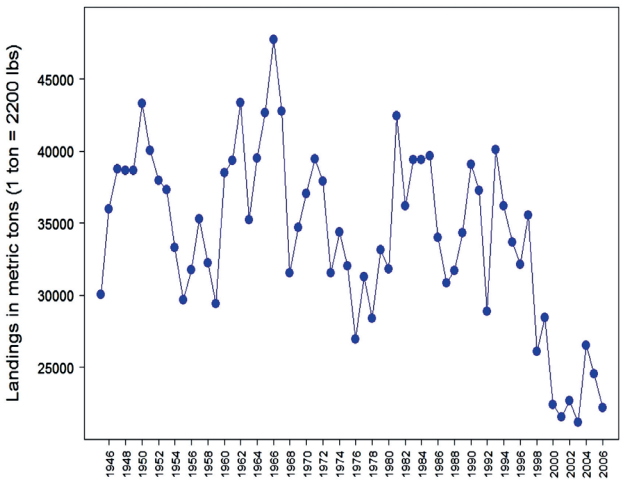

Figure 20. Chesapeake Bay commercial blue crab landings, 1945-2006 (Data from CBSAC 2007).

2007). Despite the decline, the blue crab fishery remains consistently one of the highest value fisheries in the Bay (NMFS, 2007), and is the leading contributor to the total U.S. landings of blue crab (Fogarty and Lipcius, 2007). The resilient nature of the blue crab's life history provides hope that the population can rebound, but management jurisdictions will need to define goals for the fishery and develop a more comprehensive management plan (CBSAC, 2007).

THREATS TO YORK RIVER FISHERIES

Threats to the fishes and fisheries of the York River system can be broadly categorized as habitat alteration and overfishing. Habitat alteration can take the form of water quality changes associated with increased levels of nutrients, sediments, and contaminants. Nutrient loading leads to algal blooms, which can decrease the concentration of dissolved oxygen (DO) in the water. Low DO can reduce the amount of suitable habitat for fish and can impair fish growth and reproduction. Air and water pollution can introduce harmful substances that affect the reproductive health of fishes. Changing the structure of the river by removing riparian (riverbank) habitat, eliminating vegetation, or dredging channels can change the amount and location of usable habitats for fishes. Structural changes to the York River system can affect the spawning habitats of anadromous species. Dams impede spawning migrations and water withdrawal facilities can pose a threat to the eggs and larvae of species that spawn in freshwater. Overharvesting leads to low number of reproductively viable adults, and consequently, fewer young are produced.

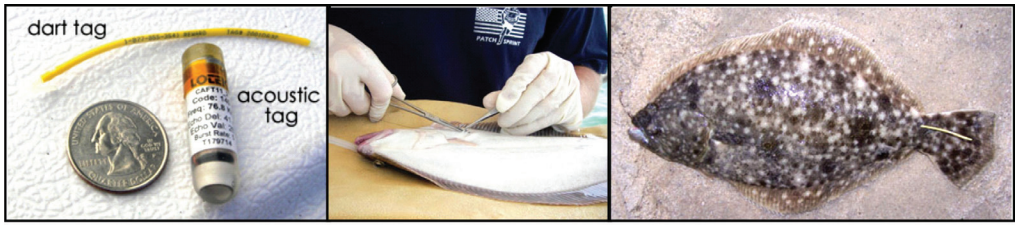

Figure 21. Acoustic and dart tags used for summer flounder and shad tracking research at VIMS (left panel). Surgically implanting summer flounder with an acoustic transmitter (middle panel). Summer flounder with an implanted acoustic transmitter and an external tag (right panel) (Photos courtesy of VIMS Department of Fisheries Science)

ONGOING AND FUTURE RESEARCH

The Virginia Institute of Marine Science has several programs to assess the relative abundance of fish species at the juvenile stage. The VIMS Juvenile Fish Survey collects monthly samples in the York River system, including three stations in the Pamunkey River. Data from the survey are used to develop abundance indices for several species, including Atlantic croaker and summer flounder. The VIMS Juvenile Striped Bass Seine Survey targets young-of-the-year striped bass and samples in the York system from Clay Bank to river km 96 in the Mattaponi River and river km 112 in the Pamunkey River. This survey also generates an index for juvenile American shad. Adult American shad abundance is monitored in the York River by VIMS researchers each spring. The abundance of juvenile American eels is monitored each spring in two creeks in the lower York River.

Using fish collected by these surveys, food web interactions are examined by the Chesapeake Bay Trophic Interactions Laboratory Services (CTILS) group at VIMS. These data are used to monitor changes in fish diets over time and location, as well as to model trophic linkages among species.

Acoustic tagging—attaching or implanting tags in fish that emit sonic "pings" —has been used to investigate fish behavior and movements (Figure 21) and VIMS researchers are studying summer flounder movements in the lower York River using this technology. The behavior of American shad has also been examined using acoustic telemetry. Additionally, the movements of striped bass and white perch have been examined in the Poropotank River (a York River tributary).

Ensuring the continued health of the York River system's fisheries will require continued monitoring and assessment of juvenile fish abundance, spawning stock abundance, and understanding of trophic linkages. Studies on movement and habitat use are pivotal to understanding and delineating habitats that are essential for fish survival and reproduction. Periodic research on ichthyoplankton (fish eggs and larvae) may be necessary to determine the potential effects of land use changes in the watershed.

ACKNOWLEDGMENTS

The authors acknowledge: Pat McGrath of VIMS for contributing the section on the gar; Chris Hager of VIMS for the section on the sturgeon; Paul Gerdes of VIMS for the section on sharks and rays; and David Hewitt of VIMS for the section on the blue crab. Thanks also to the VIMS Department of Fisheries Science for the numerous photos used throughout.

LITERATURE CITED

Atlantic States Marine Fisheries Commission (ASMFC), 1999. Amendment 1 to the Interstate Fishery Management Plan for Shad and River Herring. *Fishery Management Report,* 35, 76p.

ASMFC, 2001. Amendment 1 to the Interstate Fishery Management Plan for Atlantic Menhaden. *Fishery Management Report,* 37, 131p.

ASMFC, 2004. Species habitat fact sheets. (http://www.asmfc.org)

ASMFC, 2005(a). Amendment 1 to the Interstate Fishery Management Plan for Atlantic Croaker. *Fishery Management Report,* 44, 108p.

ASMFC, 2005(b). 2005 Review of the Fishery Management Plan for Atlantic Menhaden, 16p.

ASMFC, 2007. American shad stock assessment report for peer review. Vol III., Section 12: Status of American shad in Virginia. Contributors: J.E. Olney, K.A. Delano, R.J. Latour, T.P. Gunter, Jr. and L.A. Weaver. Stock Assessment Report No. 07-01 (Supplement), pp. 198-250.

Aunins, A.W., 2005. Migratory and spawning behavior of American shad in the James River, Virginia. Master's thesis. College of William and Mary, Gloucester Point, Virginia, 99pp.

Bain, M. B., 1997. Atlantic and shortnose sturgeons of the Hudson River: Common and Divergent Life History Attributes. *Environmental Biology of Fishes*, 48, 347-358.

Bilkovic, D.M., C.H. Hershner and J.E. Olney, 2002. Macroscale assessment of American shad spawning and nursery habitats in the Mattaponi and Pamunkey rivers. *North American Journal of Fisheries Management*, 22, 1176-1192.

Boreman, J., 1997. Sensitivity of North American sturgeons and paddlefish to fishing mortality. *Environmental Biology of Fishes*, 48, 399-405.

Bushnoe, T.M., J.A. Musick and D.S. Ha., 2005. Essential fish habitat of Atlantic sturgeon Acipenser oxyrinchus in the southern Chesapeake Bay. VIMS Special Scientific Report no. 145. Virginia Institute of Marine Science, College of William and Mary, Gloucester Point, Va., 47p.

Chesapeake Bay Stock Assessment Committee (CBSAC), 2007. 2007 Chesapeake Bay Blue Crab Advisory Report. National Oceanic and Atmospheric Administration, Chesapeake Bay Office. http://noaa.chesapeakebay.net/

Colligan, M., M.R. Collins, A. Hecht, M. Hendrix, A. Kahnle, W. Laney, R. St. Pierre, R. Santos and T. Squires, 1998. Status review of Atlantic Sturgeon *(Acipenser oxyrhinchus oxyrhinchus)*. Washington, D.C., National Marine Fisheries Service and U.S. Fish and Wildlife Service, 125p.

Connelly, W.J., 2001. Growth patterns of three species of catfish (Ictaluridae) from three Virginia tributaries to Chesapeake Bay. Master's thesis. College of William and Mary, Gloucester Point, Virginia, 153p.

Crumpton, J., 1970. Food habits of longnose gar (*Lepisosteus osseus*) and Florida gar (*Lepisosteus platyrhincus*) collected from five central Florida lakes. Proceedings of the Twenty-fourth Annual Conference, Southeastern Association of Game and Fish Commissioners. September 27-30. Atlanta, Georgia, pp. 419-424.

Ferrara, A.M., 2001. Life-history strategy of Lepisosteidae: Implications for the conservation and management of alligator gar. Ph.D. dissertation. Auburn University, Auburn, 129p.

Fogarty, M.J., and R.N. Lipcius, 2007. Population dynamics and fisheries. *In:* V. S. Kennedy and L. E. Cronin, editors. *The blue crab Callinectes sapidus*. (Chapter 16). Maryland Sea Grant College, College Park, pp. 711-755

Goodyear, C.P., 1967. Feeding habits of three species of gars, *Lepisosteus*, along the Mississippi gulf coast. *Transactions of the American Fisheries Society*, 95, 296-300.

Hines, A.H., 2007. Ecology of juvenile and adult blue crabs. *In:* V. S. Kennedy and L. E. Cronin, editors. *The blue crab Callinectes sapidus*. (Chapter 14). Maryland Sea Grant College, College Park, pp. 565-654.

Helfman, G.S., B.B. Collette, and D.E. Facey, 1997. *The Diversity of fishes*. Blackwell Science, Inc., Malden, Massachusettes, 507p.

Hildebrand, S.F. and W.C.Schroeder, 1928. Fishes of Chesapeake Bay. *Fishery Bulletin*, 43(1), 1-366.

Hoffman, J.C., K.E. Limburg, D.A. Bronk and J.E. Olney, 2007. Overwintering habitats of migratory juvenile American shad in Chesapeake Bay. Environmental Biology of Fishes. *Environmental Biology of Fishes*, 81 (3), 329-345.

Jenkins, R.E. and N.M. Burkhead, 1993. *Freshwater Fishes of Virginia*. American Fisheries Society, Bethesda, Maryland.

Ju, S.J., D.H. Secor, and H.R. Harvey, 2001. Growth rate variability and lipofuscin accumulation rates in the blue crab *Callinectes sapidus*. *Marine Ecology Progress Series*, 185, 171-179.

Jung, S. and E.D. Houde, 2004. Recruitment and spawning-stock biomass distribution of bay anchovy (*Anchoa mitchilli*) in Chesapeake Bay. *Fishery Bulletin*, 102 (1), 63-67.

Klauda, R.J., S.A. Fischer, L.W. Hall, Jr., and J.A. Sullivan, 1991. Alewife and blueback herring. *In: Habitat requirements for Chesapeake Bay living resources* (S.L. Funderburk, S.J. Jordan, J.A. Mihursky, and D. Riley, eds.), Chesapeake Research Consortium, Inc. Annapolis, Md., pp. 10-29.

Lankford, T.E. and T.E. Targett, 2001. Low-temperature tolerance of age-0 Atlantic croakers: recruitment implications for U.S. mid-Atlantic estuaries. *Transactions of the American Fisheries Society*, 130, 236–249

Mansuetti, A.J. and J.D. Hardy, 1967. *Development of fishes of the Chesapeake Bay region: An atlas of egg, larval, and juvenile stages, part 1*. University of Maryland, Natural Resources Institute, College Park, Md.

Massman, W.H., E.C. Ladd, and H.N. McCutcheon, 1952. A biological survey of the Rappahannock River, Virginia. Virginia Institute of Marine Science, Special Scientific Report No. 6. Gloucester, Va.

McGrath, P.E., 2007. Unpublished data on the life history of longnose gar in Virginia. Virginia Institute of Marine Science, Gloucester Point, Va.

Miller, T.J., S.J.D. Martell, D.B. Bunnell, G. Davis, L. Fegley, A. Sharov, C. Bonzek, D. Hewitt, J. Hoenig, and R.N. Lipcius, 2005. Stock assessment of the blue crab in Chesapeake Bay, 2005. University of Maryland Center for Environmental Science, Technical Report Series TS-487-05, Solomons. Available: http://hjort.cbl.umces.edu/crabs/Assessment05.html.

Muffelman, Sarah C., 2006. Diel and site-specific feeding of young striped bass in a heterogeneous nursery habitat. M.S. Thesis. The College of William and Mary. Gloucester Point, Va.

Murdy, E.O., R.S. Birdsong and J.A. Musick, 1997. *Fishes of Chesapeake Bay.* Smithsonian Institution Press. Washington, 324p.

National Marine Fisheries Service (NMFS), Fisheries Statistics Division, 2007. Commercial fishery landings. Available: *http://www.st.nmfs.noaa.gov/st1/*.

Nichols, P.R., and W.H. Massman, 1963. Abundance, age and fecundity of shad, York River, VA, 1953-59. *Fishery Bulletin*, 63, 179-187.

Norcross B. L., 1983. Climate scale environmental factors affecting year-class fluctuations of Atlantic croakers (*Micropogonias undulatus*) in the Chesapeake Bay. Doctoral dissertation. The College of William and Mary, Gloucester Point, Va.

Olney, J.E., D.A. Hopler Jr., T.P. Gunter Jr., K.L. Maki and J.M. Hoenig, 2003. Signs of recovery of American shad (*Alosa sapidissima*) in the James River, Virginia (USA). *American Fisheries Society Symposium*, 35, 323-329.

Olney, J.E., R.J. Latour, B.E. Wateekins and D.G. Capone, 2006. Migratory behavior of American shad in the York River, Virginia, with implications for estimating in-river exploitation from tag-recovery data. *Transactions of the American Fisheries Society*, 135, 889-896.

Ong, T.L., J. Stabile, I.I. Wirgin, and J.R. Waldman. 1996. Genetic divergence between *Acipenser oxyrinchus oxyrinchus* and *A. o. desotoi* as assessed by mitochondrial DNA sequencing analysis. *Copeia*, 1996 (2), 464-469.

Parthree, D.J., C.F. Bonzek, and R.J. Latour, 2006. Chesapeake Bay trophic interactions laboratory services. Project RF 05-12. Final Report. Submitted to Virginia Marine Resources Commission Marine Recreational Fishing Advisory Board, Newport News, Va.

Pearson, J.C., 1942. The fish and fisheries of colonial Virginia. William and Mary Quarterly Historical Magazine, 22(3), 213-220.

Netsch, N.F., LT., and A. Witt Jr., 1962. Contributions to the life history of the longnose gar, (*Lepisosteus osseus*) in Missouri. *Transactions of the American Fisheries Society*, 91, 251-262.

Secor, D. H., E. J. Niklitschek, J. T. Stevenson, T. E. Gunderson, S. P. Minkkinen, B.Richardson, B. Florence, M. Mangold, J. Skjeveland, and A. Henderson-Arzapalo, 2000. Dispersal and growth of yearling Atlantic sturgeon, *Acipenser oxyrinchus*, released into Chesapeake Bay. *Fishery Bulletin*, 98, 800-810.

Seidensticker, E.P., 1987. Food selection of alligator gar and longnose gar in a Texas reservoir. Proceedings of the Annual Conference of the Southeast Association of Fish and Wildlife Agencies, 41, 100-104.

Smith, S., 1986. Reproductive ecology, population dynamics and seasonal movement of the hogchoker in the Elizabeth River, Virginia. Master's thesis, College of William and Mary, Virginia Institute of Marine Science, Gloucester Point, Va.

Smith, J.W. and J.V. Merriner, 1978. Biology and identification of rays in the Chesapeake Bay. Virginia Institute of Marine Science, Educational Series Number 20. Gloucester Point, Va.

Tyler, J.D., J.R. Webb, T.R. Wright, J.D. Hargett, K.J. Mask, and D.R. Schucker, 1994. Food habits, sex ratios, and size of longnose gar in southwestern Oklahoma. *Proceedings of the Oklahoma Academy of Science*, 74, 41-42.

Virginia Marine Resource Bulletin, 2007 Vol. 39, No 2. Virginia Sea Grant Program, Virginia Institute of Marine Science, Gloucester Point, VA.

Walter, J.F., and J.E. Olney, 2003. Feeding behavior of American shad during spawning migration in the York River, Virginia. *American Fisheries Society Symposium*, 35, 201-209.

Warner, W.W., 1976. *Beautiful swimmers: Watermen, crabs and the Chesapeake Bay.* Little, Brown and Company, Boston, Mass.

Wilhite, M.L., K.L. Maki, J.M. Hoenig and J.E. Olney, 2003. Towards validation of a juvenile index of abundance for American shad (*Alosa sapidissima*) in the York River, Virginia (USA). *American Fisheries Society Symposium*, 35, 285-294.

Williams, A.B., 2007. Systematics and evolution. *In:* V. S. Kennedy and L. E. Cronin, editors. *The blue crab Callinectes sapidus*. (Chapter 1) Maryland Sea Grant College, College Park, Md. 1-2 pp.

Wirgin, I., 2006. Use of DNA approaches in the management of Atlantic sturgeon populations. Presentation given to the Atlantic States Marine Fisheries Commission Atlantic Sturgeon. Technical Committee By-catch Workshop, held February 1-3, 2006, Norfolk, Va.

Woolcott, W.S., and W.L. Kirk, 1976. Melanism in *Lepisosteus osseus* from the James River, Virginia. *Copeia*, 4, 815-817.