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AMERICAN SHAD AND HICKORY SHAD
Alosa sapidissima and *Alosa mediocris*

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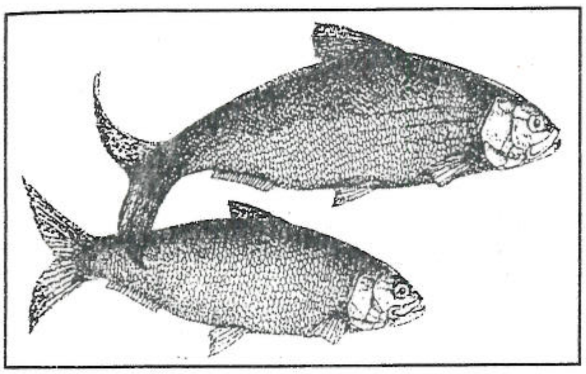

American shad and hickory shad are anadromous fish of the clupeid family. American shad are the largest anadromous clupeids of the U.S; hickory shad are medium-sized members of the family. Natural shad spawning habitats include non-tidal reaches of virtually all Chesapeake Bay tributaries. American shad juveniles leave the estuary in late fall, mature in the ocean, and return to the tributaries to spawn after two to five years. The life history of hickory shad is similar, but poorly known.

American shad historically supported important recreational and commercial fisheries in Chesapeake Bay tributaries, whereas hickory shad, because of their naturally lower abundance in the region, were a much less important fishery species. Severe stock declines of both species in the latter half of the 20th century led to drastically lower harvests, and a fishing moratorium in the Maryland portion of Chesapeake Bay which has been in effect since 1980. The causes of the declines apparently include overfishing in earlier decades, blockage of spawning rivers by dams and other impediments, and degradation of water quality and physical habitat in spawning reaches.

The critical life stages of shad are the eggs, larvae, and early juveniles. Water temperatures > 13°C, pH > 6.0, and dissolved oxygen > 5.0 mgL^{-1} are important requirements for American shad eggs. Larvae require water temperatures of 15.5-26.1°C, pH > 6.7, dissolved oxygen > 5.0 mgL^{-1} and suspended solids < 100 mgL^{-1}. Requirements of juvenile American shad are similar to those of larvae. Insufficient information is available to make definitive statements about the habitat requirements of hickory shad, but they probably are similar to those of American shad. Major habitat concerns for shad are stream acidification and interaction with dissolved metals, stream blockages, and land disturbance with associated sedimentation and turbidity.

Although American shad have shown some signs of recovery in recent years, stocks must continue to be protected, both from excessive harvest and from degradation of their spawning and nursery habitats. Continuing removal and mitigation of stream blockages, stocking programs, and harvest restrictions are positive steps toward recovery of these threatened populations.

INTRODUCTION

The American shad is the largest anadromous fish of the clupeid family in the United States. Maximum length is about 760 mm.[64] American shad have a deep and laterally compressed body, single soft-rayed dorsal and anal fins, and large easily-shed scales that come together to form saw-toothed scutes along the ventral margin of the belly.

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Adults are silvery white on the sides, with greenish or bluish coloration above that fades to brown as they migrate through freshwater to spawn. The large black spot located just behind the gill cover is followed by several (4-27) smaller dark spots.[131]

The hickory shad is a medium-sized anadromous clupeid that is smaller than the American shad but larger than the alewife and blueback herring. Maximum length is about 600 mm. The hickory shad is distinguished from the other anadromous clupeids by a strongly projecting lower jaw and small number of gill rakers, usually 19-21, on the lower limb of the first pharyngeal arch.[56,97] Hickory shad are gray-green along the back, with iridescent silver sides and belly. The dark shoulder spot commonly is followed by several obscure spots.[64,96]

DISTRIBUTION

The American shad is native to the Atlantic seaboard of North America, distributed from southeastern Labrador to the St. Johns River, Florida.[64,131] Along the east coast of the United States, American shad are most abundant from Connecticut to North Carolina.[99] In the mid-Atlantic region, American shad historically spawned in New Jersey, Delaware, and virtually all major tributaries to Chesapeake Bay. The presence of spawning populations in several Maryland tributaries has been difficult to document in recent years.[73]

In 1871, American shad fry were transported successfully by rail from the Atlantic Coast to the Pacific Coast and introduced into the Sacramento River, California.[124] Other Pacific Coast introductions followed in the Columbia, Snake, and Willamette rivers in 1885 and 1886.[120] From these introductions, American shad dispersed and populations are now established from Baja, California, northward to Cook Inlet, Alaska, and the Kamchatka Peninsula, Asia.[53,131] Attempts to introduce American shad into the Mississippi River drainage and streams in Florida were apparently unsuccessful.[11]

Historically, the hickory shad occurred along the east coast of North America from the Bay of Fundy, Canada, to the Tomoka River, Florida; but now the species probably is restricted to waters from New York southward[5,55,97,124] and is viewed as a more southern species than American shad.[73] Their current presence in Canadian waters is uncertain; they are not listed in a recent book on Atlantic fishes of Canada.[131] Overview documents prepared by state fisheries agencies along the east coast of the United States suggest that hickory shad currently do not spawn north of Maryland.[122] In Chesapeake Bay, hickory shad are near the northern limits of their spawning range and probably never have been abundant,[135] although they were harvested throughout the Bay prior to the 1970's.[97] Stable or declining stocks are present in the majority of coastal river systems in North Carolina, South Carolina, Georgia, and Florida.[124]

LIFE HISTORY

AMERICAN SHAD

The American shad is anadromous, lives at sea, and only enters freshwater in the spring to spawn. It is a schooling species and highly migratory. Each major shad-producing river along the Atlantic seaboard appears to have a discrete spawning stock.[12] Homing to the natal stream is relatively well documented in northern stocks[131] such as those of the Connecticut and Hudson rivers, and involves both olfaction and rheotaxis.[41] However, there is evidence of extensive straying, particularly on the West Coast of the U.S.[73] Straying and mixing also may occur among American shad stocks which use a large and diversified estuarine system such as the Chesapeake Bay.

Spawning Activity

American shad migrate from the sea to coastal rivers in the spring for spawning when water temperatures range from about 16-19°C.[79] Some adults enter the mouths of their natal rivers when temperatures are as low as 4°C or less.[64] The prespawning adults spend one or two days meandering near the saltwater-freshwater interface during a necessary period of adaptation before proceeding upstream to spawn.[41]

American shad can spawn as early as mid-November in Florida (typically not before February) to as late as July in some Canadian rivers.[95] If possible, the adults migrate far upstream and typically spawn in freshwater areas dominated by extensive flats and over sandy or rocky shallows,[64] including the mouths of larger tributary streams.[39] Males generally precede the females to the spawning grounds.[25]

Water temperature is the primary factor that triggers spawning, but photoperiod, current velocity, and turbidity also exert some influence.[79] In Chesapeake Bay, spawning runs typically begin in mid-February to early March, peak during April, and are over by early June.[55,64] Egg deposition has been observed at water temperatures between 8 and 26°C, but most spawning in Chesapeake Bay rivers occurs between 12 and 21°C.[64,148]

Most spawning activity occurs between sunset and midnight, with the time of onset related to light intensity.[110,131] In turbid rivers, spawning also may occur during daylight hours.[64] American shad are broadcast, open water spawners. During the spawning act, a single female is accompanied by several males as the eggs are released into the water column and fertilized.[100,108] Adults return to the sea soon after spawning.[26]

Egg and Larval Development

Fertilized eggs are spherical, semi-demersal to pelagic, non-adhesive, from 2.5-3.5 mm in diameter when water-hardened, and transparent pale amber or pink.[64] As American shad eggs water-harden and increase in diameter, they are carried by river currents along the bottom and may lodge in substrate rubble.

Egg incubation time can range from two days at 27°C, from three to nine days at 22-17°C, to 17 days at 12°C.[64] Optimum conditions reported for American shad egg development are 17°C, 7.5 ppt salinity, and darkness.[80] Maximum egg survival and hatching success is in the temperature range of 15.5-26.5°C.[79] Egg development can be prolonged and mortality increased when incubation temperatures fall below 16°C.[100] No viable eggs developed at temperatures below 10°C or above 29°C.[80,8] American shad eggs incubated at temperatures between 20.0 and 23.4°C hatched in three to five days, but the resulting yolk-sac larvae were deformed.[80]

Yolk-sac larvae are 6-10 mm total length (TL) at hatching and 9-12 mm TL when the yolk is absorbed at four to seven days old and the larvae begin to feed exogenously.[101,152] The larvae are photopositive,[61] most abundant near the surface in fresh and brackish waters up to about 7 ppt salinity,[101,97] and generally drift downstream and disperse as they develop.[49]

Natural mortality rates during the egg and larval stages of American shad are very high. Leggett[76] reported that, on average, only 0.00083% of the eggs spawned produce sexually mature adults. Most of this high mortality occurs between egg deposition and the juvenile stage. Survival from the yolk-sac larva through the juvenile stage is about 1 to 2%. Year class strength for cohorts in American shad populations is apparently established during the first 20 days after hatching and before the larvae reach the juvenile stage.[32] Availability of food is critical to the survival of first feeding larvae, but other environmental factors also are important. Recent studies suggested a relationship between water temperature, flow, food production, food density, and the survival of American shad larvae.[73]

Juveniles

Metamorphosis or transformation to the juvenile stage is completed in about 21-28 days when the young American shad reach 25-28 mm TL.[30] They form schools at 20-30 mm TL and prefer deep pools away from the shoreline in non-tidal areas, although they occasionally move into shallow riffles.[20] In the Chesapeake Bay system, juveniles spend their first summer in tidal freshwater reaches of the spawning rivers.

Juvenile American shad undergo diel vertical migrations in the summer nursery areas. Loesch *et al.*[90] observed that catches of juveniles in bottom trawls were significantly higher during the day than at night. Conversely, catches of juveniles in surface trawls were greater at night than during the day.

Autumn decreases in water temperatures below 19 or 20°C, increases in river flow, or combinations of both factors trigger downstream movements of juvenile American shad through brackish water and on to the sea.[21,148] Peaks in the seaward migration of juveniles in the Chesapeake Bay region occur from late October to late November[95] when water temperatures are below 15°C. Decreasing water temperatures may curtail the behavioral tendency of juveniles to maintain position against the current in low light or at night, and consequently, they drift downstream.[118]

Several investigators have reported that larger juveniles appear to move downstream earlier in the fall.[20,101,127] Juvenile American shad grow to average lengths ranging from about 80-110 mm prior to the fall seaward emigrations.[101,124,127] Growth of juveniles appears to be slower in more southerly rivers along the U.S. east coast.[101]

Estimates of juvenile American shad mortality rates in the nursery areas range from 1.8-2.0% per day.[32] Thus, if the juveniles remain in the nursery areas for three months before emigrating seaward, their survival rate would be about 30%. Conversely, 70% of the juveniles would perish before reaching the ocean,[122] assuming constant mortality rates during the larval and juvenile stages. Longer residence times in freshwater and brackish areas would further reduce first year survival of American shad cohorts.

Subadults and Adults

Juvenile American shad leave the nursery areas in late fall and presumably join other schools of young shad in the ocean, where they grow and develop for three to five years before returning to their natal streams to spawn.[112] Chesapeake Bay stocks remain at sea for about four or five years; however two-year old fish have been collected in the Bay.[73]

American shad are long-distance coastal migrants. During an average life span of five years at sea, an individual may migrate over 20,000 km.[35] Ocean migration rates estimated from tag returns averaged 21 km d^{-1} during the spring northward migrations of adults from Chesapeake Bay to the Bay of Fundy,[76] and about 9 km d^{-1} for spent adults during a more recent tagging study.[35] Subadults appear to migrate farther offshore than sexually mature adults.[112]

American shad in the Atlantic Ocean tend to follow preferred isotherms of 13-18°C as they move along the Atlantic coast between summer feeding grounds in the Gulf of Maine and coastal overwintering areas off the mid-Atlantic states.[79] Dadswell *et al.*[35] reviewed 50 years of tagging studies and concluded that oceanic migration patterns of American shad were more complicated than previously thought. They suggested that American shad stocks do not concentrate in relatively small geographic areas and do not migrate together at the same rate. They also argued that origin, life history characteristics, and chance may be more important in the control of coastal migrations than ocean temperatures.

American shad may grow about 100 mm per year until they reach sexual maturity; then their growth slows to about 50 mm per year through adult life.[95] Size at age is typically greater in females than males in Chesapeake Bay[73] and elsewhere, and greater in northern stocks than southern stocks. The north-south stock difference appears to be genetically controlled.[77,122] Adult American shad from northern stocks also live longer than adults from more southern stocks. Melvin *et al.*[109] caught a male and female in the Annapolis River, Nova Scotia, that were 12 and 13 years old. American shad from mid-Atlantic populations live for seven to nine years,[124] but most adults are ages six and seven.

There is a paucity of information on age at maturity for American shad, in general, and none for stocks in the Chesapeake Bay system.[73] The available data suggest that males reach maturity at four or five years old, about one year earlier than females.[93,148] American shad collected in the Susquehanna River and Flats region of Maryland are generally mature by age three (males) and age four (females), according to Weinrich *et al.*[150] Females from Canadian populations tend to mature at a younger age than females from mid-Atlantic stocks, but there is no clear latitudinal gradient in age at maturity along the Atlantic seaboard.[77]

For frequency of repeat spawning, there is a clear latitudinal gradient.[148,77] In southern stocks (Florida, Georgia, South Carolina), the adults die after their first spawning and repeat spawning does not occur. Repeat spawning occurs at very low frequencies (< 5%) in North Carolina stocks.[122] During the 1970's, repeat spawning (males and females combined) increased progressively along the Atlantic Coast to 20% in the Potomac River, Maryland; 23% in the York River, Virginia; 27% in the James River, Virginia; 37% in the Susquehanna River, Maryland and Pennsylvania; 57% in the Hudson River, New York; 63% in the Connecticut River; and 73% in the St. John River, New Brunswick.[77]

In recent years, the percentage of repeat American shad spawners in the Susquehanna River region of the Chesapeake Bay has been relatively low.[150] Repeat spawning for males and females combined, 1980-1984, ranged from 2.7% (1981) to 12.14% (1980). Because repeat spawning is so low in Maryland stocks, the size of the spawning run in one year is more a function of the spawning success in prior years than of the contribution of repeat spawners. This stock condition argues for limitations on fishing exploitation to allow an increase in repeat spawning.[73]

Fecundity in American shad is relatively high and typically ranges from about 100,000-600,000 eggs per female depending upon length, weight, age, and origin of the fish.[124] In the York River, Virginia, and the Potomac River, Maryland, fecundity ranged from 169,000-525,000 eggs per female during the 1950's.[148] A trend toward higher fecundity per unit body weight in southern American shad stocks compared to northern stocks has been observed. This latitudinal trend in fecundity can be viewed as an evolutionary adaptation which could compensate somewhat for the opposite latitudinal trend in frequency of repeat spawning.

HICKORY SHAD

The hickory shad is somewhat of a mystery to fishermen and ichthyologists because so little is known about its general life history. Most detailed information comes from studies in Maryland, Virginia, North Carolina, and Georgia.[1,36,47,49,73,97,103,119,122,124,126,138]

Spawning Activity

As recently as the early 1950's, some ichthyologists speculated that hickory shad spawned in salt water and did not ascend freshwater streams in the Chesapeake Bay system to spawn.[97] This perception, later disproved, was inspired by the relative scarcity of juveniles in freshwater and brackish habitats. We now understand that hickory shad are anadromous and begin to ascend freshwater streams for spawning in early spring when water temperatures reach 12 or 13°C. Spawning can occur between March and early June, depending upon latitude, over a water temperature range of 12 to 22°C.[124] Peak spawning occurs during April and May when water temperatures are between 15-19°C.[96,97,119,126,138] In Chesapeake Bay, hickory shad spawning runs may precede American shad runs and typically begin during March and April.[135] Peak spawning activity occurs between late April and early June[132] when water temperatures reach 22°C.[73]

Specific spawning sites in the Chesapeake Bay are not well documented.[122] Mansueti[97] concluded that hickory shad spawned about 6-10 km upriver from the major spawning sites for American shad in the mainstem of the Patuxent River, Maryland.

In Virginia, the major hickory shad spawning sites are in mainstem rivers at the fall line, but some appear to spawn further downstream and also in tributaries.[39] In 1967, gravid or ripe hickory shad were collected in the mainstem of the Mattaponi River, between river miles 35 and 54, and in the mainstem of the Pamunkey River, between river miles 45 and 67.[37] In 1968, gravid or ripe fish were collected in the mainstem and tributaries of the Rappahannock River, between river miles 31 and 95, during April and May.[40] The same report also listed a catch of two ripe male hickory shad in the mainstem Potomac River at river mile 99. The James River was surveyed in 1969.[38] Ripe or gravid hickory shad were collected in the mainstem, in tributaries between river mile 40 and 59, and also in the Appomatox River. Hickory shad have been observed spawning in the James River at the fall line near Richmond.

The major spawning sites for hickory shad in North Carolina are in the freshwater reaches of coastal rivers.[103] Pate[119] surveyed hickory shad spawning sites in the Neuse River, North Carolina, and collected eggs and larvae only in flooded swamps and sloughs off the channels of tributary creeks and not in the mainstem river. Hickory shad apparently spawn in flooded areas off the channel of the Altamaha River, Georgia, and not in the mainstem of the upper reaches.[1]

During peak spawning activity, probably between dusk and midnight, hickory shad eggs apparently are broadcast into the water column and fertilized by accompanying males.[97,64] We could find no other information on hickory shad spawning behavior.

Egg and Larval Development

The early development of hickory shad was described by Mansueti.[97] The eggs are slightly adhesive and semi-demersal in slow-moving waters, but partially buoyant under more turbulent conditions.[98] The fertilized and water-hardened eggs are transparent, spherical, and range from 0.96-1.64 mm in diameter.[97] Egg development is characterized by meroblastic cleavage and a pattern of embryonic differentiation similar to that found in other clupeid eggs. Incubation time ranges from 48-72 h at temperatures between 21 and 18°C.

Newly-hatched larvae are typically clupeid-form and slender, with a large granulated yolk-sac in the anterior quarter of the body, relatively large eyes, and a transparent body with sparse pigmentation. Size at hatching ranges from 5.2-6.5 mm TL. At four to five days old and 5.5-7.0 mm TL, the yolk is fully absorbed, and the postlarvae are ready to feed exogenously. Mansueti[97] observed high mortality in laboratory-reared larvae after yolk absorption; none of the larvae could be induced to feed. Postlarvae transform to juveniles when 10-35 mm long.[146,73]

Juveniles

Young hickory shad 9-20 mm TL are difficult to distinguish from the young of other anadromous alosids such as American shad, alewife, and blueback herring.[97] As hickory shad grow beyond 20 mm TL, the strongly projecting mandible, straight dorsal profile, and low number of gill rakers on the first arch serve as important diagnostic characters.

Collections of juvenile hickory shad are sparse.[97,124] The fragmentary records suggest that most young fish leave their freshwater and brackish habitats in early summer and migrate to estuarine nursery areas at an earlier age than other anadromous alosids.[1,97,104,133] This conclusion is supported by catches of juvenile hickory shad in a surf zone off Long Island, New York, from April to November.[125] Studies in the Neuse River, North Carolina[119] suggested that young hickory shad may migrate directly to saline areas and not use the oligohaline portion of the estuary as a nursery area. The freshwater zone which forms on the scales of anadromous clupeids is difficult to see on scales from adult hickory shad.

A hypothetical growth curve for hickory shad developed by Mansueti[97] suggested that juvenile growth during the first season in the Patuxent River, Maryland, exceeded that of the other three alosid species. Growth curves for male hickory shad collected during 1970 in Octoraro Creek, Maryland, showed rapid growth rates during the first three years of life, similar to growth rates for hickory shad in the Altamaha River, Georgia, and Neuse River, North Carolina.[126] By age III, 79% of the growth in length was completed for the Octoraro Creek males. Juvenile hickory shad collected during bottom trawl surveys conducted by the Virginia Institute of Marine Science (VIMS) in the Rappahannock River, Virginia, during 1968 and 1969, averaged 73 mm in July and August, and 118 mm in September.[2] One juvenile collected in October 1968 measured 138 mm. The larger size of juvenile hickory shad compared to the other alosid species may be due to the earlier spawning time for hickory shad and a faster growth rate. Juvenile hickory shad collected in the Altamaha River, Georgia,[1] averaged 81 to 90 mm fork length (FL) during July and August. Additional data on juvenile hickory shad growth in southeastern U.S. rivers is presented in Rulifson *et al.*[124]

We could find no information on mortality rates for juvenile hickory shad.

Subadults and Adults

When young hickory shad leave the spawning areas and, presumably, move quickly through estuarine waters to the sea, their life history becomes very obscured. Hickory shad were mature by 287 mm TL (males), 320 mm TL (females), and at about age III in the Patuxent River, Maryland, in 1954.[97] Adults in this spawning run ranged from about 290-450 mm TL. From spawning checks, Schaeffer[126] concluded that about 80% of the male hickory shad collected in Octoraro Creek, Maryland, in 1976, matured at age II, with the rest maturing at age III. Females tended to begin spawning a year or so later than the males. The bimodal ages of males in Octoraro Creek were V and VI, 16% were VII, and one male was VIII. Females ranged from four to seven years old, with five and seven year olds each representing 43% of the sample population. The age and size distribution of hickory shad populations in U.S. east coast river systems from Florida to North Carolina ranged from two to eight years and 216-487 mm FL.[124] Females tend to be larger at age than males.[73]

In general, repeat spawning appears to be common in hickory shad runs; but it is also variable among river systems and can range from < 10% to over 80%.[63,93,122,124] Schaeffer's[126] sample of hickory shad from Octoraro Creek, Maryland, showed that all fish spawned every year. Most of the females he examined were on their third spawning run; the males were about evenly divided between their fourth and fifth runs. One female was on her fifth run and one male was on his seventh. In Georgia streams, individual hickory shad can make at least one and commonly up to three to four spawning runs. Pate[119] observed that hickory shad in the Neuse River, North Carolina, normally make three spawning runs per lifetime, but some males make up to five runs.

Limited fecundity data are available for hickory shad. Two estimates of fecundity for hickory shad populations in Octoraro Creek, Maryland, were 476,236 and 488,867 eggs per female. Numbers of eggs per female can range from 43,556 in three-year old fish (325 mm) to 347,610 eggs in six-year old fish of 434 mm.[119] Manooch[96] reported that a two-year old female can spawn 61,000 eggs, and a six-year old female more than 300,000. Street[138] estimated the fecundity of the Altamaha River, Georgia, population of hickory shad at 509,749 eggs per female.

Gonadal maturation in females is very rapid.[97] Adult collections were typically composed of all green (not ready for spawning) or all spent (fully spawned) females. The ovary of a single female collected during the spawning run contained groups of eggs in various stages of maturation. These observations suggest that ripe eggs are released in small numbers over a prolonged period rather than during a single brief spawning event.

After spawning, hickory shad return to oceanic waters where their distribution and movements are essentially unknown.[122,138] Hickory shad occasionally are harvested during summer and fall along the southern New England coast.[5] These observations suggest that hickory shad may migrate northward from the mid-Atlantic and southeast Atlantic spawning rivers in a pattern that is similar to the coastal migrations of American shad.[35]

ECOLOGICAL ROLE

AMERICAN SHAD

Food Habits

Young American shad are opportunistic and size selective plankton feeders. Copepods, other crustaceans, zooplankters, chironomid larvae, and terrestrial insects are important food items for the young fish in freshwater.[80,81,101,147] Juveniles occasionally consume small fish species such as striped anchovy, bay anchovy, and mosquitofish.[58,153] In the ocean, copeopods and mysids are primary foods for all size American shad.[130] Adults also consume ostracods, amphipods, isopods, insects, and small fishes.[58,79]

Competition

Juvenile American shad often coexist with young blueback herring and alewife in the same freshwater nursery areas. Hence, opportunities exist for interspecific competition among these three alosids. Competition between juvenile American shad and juvenile alewife may be minimized by differences in diel activity patterns.[127] Competition between juvenile American shad and juvenile blueback herring may be minimized by differences in feeding habits.[50,42]

Competition with gizzard shad in the Susquehanna River and upper Chesapeake Bay may have contributed to the decline of upper Bay stocks of American shad, or could be another factor that is delaying recovery of these stocks, but the meager evidence is circumstantial. The annual catch per effort of gizzard shad in the fish lift at Conowingo Dam on the Susquehanna River steadily increased from 1972 through at least 1981,[13] a period of rapid decline for American shad in Maryland.[135]

American eels prey upon American shad eggs and juveniles in freshwater, and striped bass prey on the juveniles.[99,148] Commercial landings of bluefish, a potential predator of young American shad, were relatively high from 1972 through 1986.[65] Large bluefish were also very abundant in the Bay from May through mid-October during 1988. Predation on juvenile American shad by bluefish and other large predators (e.g., weakfish) is perhaps a minor factor that could be delaying the recovery of American shad stocks in the Chesapeake Bay. Subadult American shad have been found in seal stomachs.[109] The adults appear to have few predators other than man.[131]

HICKORY SHAD

We could find no information on the food habits of larval or juvenile hickory shad. The adults are primarily piscivorous but also consume squid, fish eggs, small crabs, and pelagic crustaceans.[55,154] The adults apparently do not feed during their freshwater spawning migrations.[119]

We could find no information on competition or predation for hickory shad. Competition with gizzard shad in the Susquehanna River may have contributed to the decline of the hickory shad populations in the upper Chesapeake Bay, or is at least one factor that is delaying recovery of the stocks. The abundance of gizzard shad in the Conowingo Dam fish lift (Susquehanna River) steadily increased from 1972 through 1981,[13] coincident with a period of rapid decline for hickory shad in Maryland. The synchrony may be causative or coincidental - we do not know.

POPULATION STATUS AND TRENDS IN CHESAPEAKE BAY

AMERICAN SHAD

Historically, American shad was a major fishery resource all along the Atlantic seaboard. However, between 1897 and 1940, annual harvests declined from over 20×10^6 kg to about 5×10^6 kg.[99] Suspected causes of these coastwide declines include pollution and siltation of spawning rivers, overharvesting, and construction of dams which prevented access to several spawning areas.[148]

Records of Commercial and Recreational Landings

The American shad fishery in the Chesapeake Bay steadily increased throughout the 1800's and reached prominence toward the end of the century.[148] Commercial landings in Maryland peaked in 1890 at 3.2×10^6 kg. In 1896, the Maryland portion of the Bay was the fourth largest producer of American shad in the U.S.[99] The Susquehanna River and the upper Bay region once had the largest populations of spawning American shad in Maryland.[134,135] Commercial landings in Virginia peaked in 1897 at 5.2×10^6 kg.

Commercial landings and stock abundance have steadily declined in the Chesapeake Bay since the late 1890's. Maryland and Virginia continued intensive exploitation of American shad through the 1960's, even though the stocks were declining.[73] By 1979, commercial landings in Maryland and Virginia had decreased to 8.2×10^3 kg and 451.4×10^3 kg.[122]

The history of the recreational fishery for American shad began in the 1880's, but this source of exploitation is not well documented.[73] There were no survey data collected which described the extent of the recreational fishery when American shad were abundant in the Chesapeake Bay. Limited recreational surveys and creel censuses began in the late 1950's in the Conowingo Dam area of the Susquehanna River.[73] In 1958 and 1960, about 15,000 and 13,000 American shad (about 27,000 and 24,000 kg) were caught by anglers in the Conowingo Dam tailrace.

In 1980, the commercial and recreational fisheries for American shad were closed in Maryland,[135] but not in Virginia. Reported annual landings of American shad in Virginia from 1980 to 1985 stabilized at relatively low levels and have ranged from 0.2×10^6 kg to 0.7×10^6 kg.[7]

Commercial landings are only a rough index of American shad abundance in Chesapeake Bay, but nevertheless are the primary source of information. Little is known about the trends in effort either directed at or incidental to the commercial fishery for American shad.[73] If catchability increased as stock abundance declined, as Crecco and Savoy[30] observed, the American shad stock in the Chesapeake Bay actually may have been declining before the records of commercial landings declined.[135] Recreational catches of and fishing effort for American shad are not compiled in Maryland and Virginia, but both are probably small relative to commercial landings and effort. For additional information on the commercial and recreational fisheries for American shad in the Maryland portion of the Bay, see Krauthamer and Richkus.[73]

Juvenile Abundance Indices

The relationship between numbers of juvenile American shad produced each year and parental stock size has been studied intensively in the Connecticut River.[30,31] It was concluded that year-class strength was not related to stock size, but was regulated primarily by environmental factors, particularly river flow and temperature. Only recently have detailed life history and population dynamics studies been initiated in other Atlantic coast spawning rivers.[122]

If American shad populations in Maryland likewise are influenced strongly by environmental factors, the declining trend in juvenile abundance indices for 1958 through 1984 (juvenile finfish seine survey[135]) suggests that environmental conditions were periodically unfavorable through the early 1970's, and have been consistently unfavorable since. Unfortunately, the degree to which the seining sites, selected to provide striped bass monitoring information, are representative of the American shad nursery habitat has not been established.[73]

Current population levels of American shad are very low in Maryland, and perhaps near or below the critical threshold for a viable spawning stock size. Year class success should be most dependent upon environmental conditions when spawning stocks are large, and upon spawning stock size when spawning stocks are depressed. Therefore, parental stock size may be playing a much larger role in juvenile production in Maryland rivers, compared to Virginia rivers, the Connecticut River or the Hudson River, where American shad stocks are more abundant.[122]

Methods used in Virginia's juvenile American shad survey have changed over the years, so only a limited time series is comparable to the Maryland survey.[135] In two Virginia rivers, the Mattaponi and Pamunkey, juvenile abundance indices were relatively stable between 1980 and 1987.[6]

Current Status of Spawning Populations in Major Bay Tributaries

A qualitative assessment of the current status of American shad spawning populations in each of the major river systems in Chesapeake Bay is presented in this section.

Another recent assessment carried out independently by Richkus *et al.*[123] reached similar conclusions and generally confirmed our observations.

Our assessment was drawn from recent survey data, the observations of fisheries biologists associated with those surveys, and other informed individuals,[6,7,60,86,87,88,89,91,92,114,149,150] and personal communications (James Mowrer, Jay O'Dell, Harley Speir, and James Uphoff, Maryland Department of Natural Resources; Herb Benjamin, Northeast, Maryland; Joice Davis, Joseph Loesch, and James Owens, Virginia Institute of Marine Science). This assessment is relevant to the 1980's, especially the latter half of the decade, and represents a perspective on the current spawning populations compared to conditions in the late 1960's and early 1970's when Baywide American shad populations were much more abundant than they are today.

Susquehanna River and upper Chesapeake Bay
The population is at a very low level of abundance, but appeared to increase about 28-fold between 1980 (population estimate of 2,675 adults) and 1989 (population estimate of 75,329 adults). In 1989, catch per effort values for juvenile American shad in haul seines (0.17 fish per haul) and trawls (0.57 fish per trawl) in the upper Bay were the highest abundance indices recorded since 1980.

Patuxent River
A remnant population that is at a very low level of abundance and may be declining.

Potomac River
A remnant population that is at a low level of abundance.

Rappahannock River
The population is at a very low level of abundance and appears to be declining.

York River
The population is at a low level of abundance and appears to be stable. Since 1980, annual juvenile densities were higher in the Mattaponi River than the Pamunkey River by an average factor of about four.

James River
The population is at a low level of abundance and appears to be declining.

Chickahominy River
Current status is not known, but the population is probably at a very low level of abundance. There has been no commercial fishery for American shad since the late 1960's.

Pocomoke River
A remnant population that is at a very low level of abundance but appears to be increasing.

Wicomico River
A remnant population that is at a very low level of abundance and appears to be declining.

Nanticoke River
The population is at a low level of abundance but appears to be stable.

Choptank River
A remnant population that is at a very low level of abundance.

Chester River
Probably no spawning run left.

Sassafras River
Probably no spawning run left.

Bohemia River
Probably no spawning run left.

Elk River - Chesapeake and Delaware Canal
A remnant population that is at a low level of abundance but may be increasing.

Northeast River
Probably no spawning run left.

HICKORY SHAD
Hickory shad never have been as abundant as other alosids in Chesapeake Bay,[65] probably because they are near the northern limits of their spawning range.[2,135] Hickory shad are of minor importance as a foodfish because the meat is bony and considered inferior to the larger American shad. However, hickory shad roe is considered by some to be superior to American shad roe.[2] Hickory shad are a desirable sport fish during the spawning run.[65,126]

Records of Commercial and Recreational Langings
Hickory shad frequently are misidentified and taken as by-catch in commercial fisheries directed at the larger American shad.[122] Therefore, records of commercial landings may underestimate actual landings and offer an inaccurate profile of hickory shad population status and trends. Little is known about trends in fishing effort in Maryland directed at or incidental to the commercial fishery for hickory shad.[73] In Maryland, records of commercial landings available from 1959 through 1979 ranged from a high of 20,955 kg in 1970 to a low of 368 kg in 1977.[122] In January 1981, the catch of hickory shad in

Maryland was prohibited and the commercial and recreational fisheries have remained closed.[65]

In Virginia, records of commercial landings for 1920 to 1981 ranged from a peak of 106,171 kg in 1925 to a low of 629 kg in 1977.[2] Since 1977, the reported landings of hickory shad in Virginia have remained fairly stable near the low catch of 1977.[65] Commercial and recreational fishing for hickory shad in Virginia currently is not prohibited.

Directed fisheries for hickory shad in Chesapeake Bay during the 1960's and 1970's were limited to a few early spring gill netters and pound netters, and spotty spring recreational fisheries in several streams prior to the spawning migrations of the more abundant American shad and river herrings.[2,13,135] Sport fishermen take hickory shad by casting shad darts, spoons, and spinners in non-tidal reaches near the spawning grounds.[74] Limited recreational surveys and creel censuses concentrated in the Conowingo Dam vicinity of the Susquehanna River, Maryland, began in the late 1950's.[73] In 1958, the recreational fishery in this area caught and reported 2,755 hickory shad (about 5,000 kg). In 1960, anglers caught about 4,000 hickory shad (about 5,400 kg) in Octoraro and Deer Creeks, both tributaries to the lower Susquehanna River in Maryland.

Collections of adult hickory shad during spring 1975 and 1976 in Octoraro Creek, Maryland[126] showed an abnormal age distribution skewed toward the older age groups: 91% of the collections were comprised of age V or older fish. Year class contributions showed evidence of a decline since 1970, with no recruitment to the population spawning in Octoraro Creek since 1972. Schaeffer[126] concluded that the hickory shad spawning runs into the Susquehanna River, Deer Creek, and Octoraro Creek noticeably declined beginning about 1973. Additional observations which supported the evidence for this period of decline were reported by Krauthamer and Richkus.[73] Numbers of hickory shad taken by hook and line in Deer Creek, Octoraro Creek, and Northeast Creek apparently increased from essentially none in the early 1980's to a few by the late 1980's (personal communication: Herb Benjamin, Herb's Tackle Shop, Northeast, Maryland).

Juvenile Abundance Indices

We could find no information on annual abundance trends for juvenile hickory shad in Maryland or Virginia tributaries to Chesapeake Bay. Very few juveniles were taken in Maryland's Baywide seine survey (e.g., 2 in 1961, 2 in 1969, and 1 in 1971).[73]

Current Status of Spawning Populations in Major Bay Tributaries

Hickory shad either have been collected or authoritatively reported to occur throughout the Maryland portion of Chesapeake Bay.[97] However, little information is available on the specific distributions of the early life stages in Maryland tributaries or in the James, Pamunkey, Mattaponi, York, Rappahannock, and Potomac Rivers of Virginia.[39] The available information indicates that hickory shad spawning populations in Chesapeake Bay are now at very low levels of abundance in a few tributaries and probably non-existent in most others.

A single running-ripe (or spawnable) female and several running-ripe males were collected on May 10, 1956 in a tidal fresh area of the upper Patuxent River near Queen Annes Bridge in Anne Arundel County, Maryland.[97] Adult hickory shad were collected at this spawning location from about mid-April (mean river temperature = 12°C) through early June (mean river temperature = 18°C). The same section of the Patuxent River was sampled with seines in spring 1975, but no hickory shad were collected.[126] Local residents and fishermen reported that hickory shad had been rare in that section of the Patuxent River since about 1970. In 1955, many adult hickory shad were examined from catches of anglers and netters in the Patuxent, Choptank, and Northeast rivers, Maryland; but only green roe (ova not yet ovulated) and spent (spawned-out) individuals were found.[97] In spring 1975 and 1976, Schaeffer[126] sampled Octoraro Creek, near the Rowlandsville Bridge, a tributary to the Susquehanna River in Cecil County, Maryland. He collected 71 adults (63 males and 8 females) for age and growth examinations. Octoraro Creek was a popular sport fishing area for hickory shad during the spawning run prior to closure of the fishery in Maryland in 1981.[73]

Transforming young hickory shad (9-20 mm TL) were tentatively identified by Mansueti[97] from plankton samples collected on May 7, 1954 in the upper Patuxent River estuary near Lower Marlboro, Maryland, in slightly brackish water, about 9 km downstream from a known spawning location. During an eight year seine survey of young fishes in the Patuxent River (1950-1958) from June through October, only a few dozen hickory shad juveniles were collected while several thousand of the other three alosid species were captured.[97] The sparse data suggest that most juvenile hickory shad emigrate from the spawning rivers and estuaries in early summer, before the juveniles of the other three species of alosids leave.

Lippson *et al.*[83] speculated that the distribution of hickory shad in the Potomac River approximates that of American shad. Their Folio Maps 7 and 8 show that hickory shad spawn from late April through May, mostly in the tidal freshwater mainstem of the Potomac River on open water shoals. Some spawning also may occur in slightly brackish areas (0-3 ppt salinity) and in the lower portions of some tributaries such as St. Clements Bay (St. Mary's County), Nanjemoy Creek (Charles County), and Broad Creek (Prince Georges County). Adult hickory shad may lag slightly behind adult American shad in leaving the Potomac River and returning to the Atlantic Ocean after spawning.

The current distribution of hickory shad spawning in Maryland waters of Chesapeake Bay is largely unknown, presumably due to their very low abundance and the relative lack of interest in hickory shad compared to the other alosids. Surveys of fish eggs and larvae in the Patuxent River (1963-1965) and in the upper Bay (1966 and 1967) failed to collect any hickory shad eggs or larvae.[44] One egg was collected in the Magothy River in 1965. O'Dell *et al.*[113] did not collect any hickory shad adults or eggs during a 1970-1971 survey of the Potomac River drainage system. They did collect a few hickory shad larvae in the Wicomico River, Charles County (at the mouth of Allen's Fresh Run) and in Broad Creek. They also described hickory shad larvae as "being of probable occurrence" in Nanjemoy, Mattawoman, Pamunkey, and Piscataway creeks.

No evidence of hickory shad spawning was documented in the mainstem Patuxent River and 58 tributaries between 1980 and 1983.[114] The section of the upper Patuxent River from Queen Anne Bridge upriver to U.S. Route 50 was the site of an active sport fishery for hickory shad until about 1970.

No hickory shad were collected during 1984 and 1985 in the mainstem Choptank River and 13 tributaries.[150] No hickory shad were collected during 1985 juvenile alosid surveys in the Chester, Choptank, Nanticoke, Pocomoke, and Patuxent rivers, and in the upper Bay region.[60] Hickory shad eggs were collected from one Maryland Department of Natural Resources (MDNR) sampling site in the Wicomico River (Eastern Shore) at river mile 13.3 in spring 1986.[149]

Juveniles were collected at Mill Pond (Chester River) and Middle River in the upper Bay region.[73] Anectodal information suggests that some adult hickory shad ocassionally still are being caught (and presumably released) by sport fishermen in a few upper Bay tributaries: Deer, Octoraro, and Northeast creeks (personal communications: Harley Speir, MDNR, and Herb Benjamin, Herb's Tackle Shop, Northeast, Maryland). The MDNR alosid surveys during the 1980's offer only a few insights into the distribution of hickory shad spawning populations in Maryland, and support the perspective that hickory shad stocks are at very low abundance levels.

The current distribution of hickory shad spawning populations in Virginia waters is not much more certain. Two recent reports described the results of surveys of tributaries in the lower James River[115] and the middle James River[116] for spawning use by striped bass and anadromous alosids. Barriers to upstream movements of migratory fish also were identified in each tributary. Hickory shad were not mentioned. The same survey approach was extended to 148 Virginia tributaries of the lower Potomac River downstream of Great Falls.[117] The report concluded that anadromous alosids do not spawn in any tributaries downstream from Popes Creek (river mile 38). The authors did not mention the current use of any surveyed tributary by hickory shad.

Our review of several annual reports of *Alosa* stock composition and year-class strength in Virginia compiled from 1976 to 1988[6,7,84,86,87,88,89,91,92,93,94] did not find mention of any adult juvenile hickory shad collections in the James, Appomatox, Chickahominy, York, Pamunkey, Mattaponi, Rappahannock, or Potomac rivers. The consensus among fisheries workers at the Virginia Institute of Marine Science (VIMS) is that remnant populations of hickory shad probably still spawn in the Rappahannock and York River systems, but in such low numbers that juveniles have not been collected in push net or trawl surveys conducted since the early to mid-1970's (personal communications: Joseph Loesch, Joice Davis and James Owens, VIMS). Their views are based on scattered reports of hickory shad catches during the 1980's by sport fishermen and commercial gill netters operating near Tappahannock, on the Rappahannock River, and by commercial gill netters operating near West Point, on the York River at the confluence of the Mattaponi and Pamunkey rivers.

HABITAT REQUIREMENTS

AMERICAN SHAD

Temperature

Suitable water temperatures for the development and survival of American shad eggs range from 13-26°C.[137,95] The optimum temperature for egg development is about 17°C.[80] Temperatures below 8-10°C and above 27°C are unsuitable because embryo development either ceases or abnormalities appear in the resulting larvae. No viable larvae developed from eggs incubated in water temperatures above 29°C.[8] Abnormalities also may occur if egg incubation temperatures rise to 22°C.[80]

American shad eggs can tolerate extreme temperature changes if exposure durations are relatively short. Schubel and Auld[129] simulated the time-temperature exposure conditions associated with cooling water condenser systems of steam-electric generating stations. Eggs were exposed to temperatures from 22.5-24°C for 5-25 minutes, and then cooled to ambient temperatures over 1-3 h. Eggs acclimated at 18.5°C exhibited no significant hatching differences between the control and treatment groups. A similar experiment exposed eggs to temperatures from 22.5-26.5°C for 2.5-60 minutes.[128] Eggs acclimated at 16.5°C showed no significant differences in hatching success among the various time-temperature treatments.

American shad eggs were acclimated at 17-24°C and then exposed to temperature increases of 10-14.5°C for 2.5-60 minutes.[69] Temperatures ≥ 34.0°C were lethal to eggs; lower temperatures produced variable results. Similar results were reported for eggs acclimated to 20.5°C and exposed to temperatures in excess of 35°C.[130] American shad eggs acclimated at 20.5°C could tolerate a 30 minute exposure to 30.5°C. However, the eggs could tolerate only a five minute exposure at 35.2°C. Koo *et al.*[72] and Koo[70] also reported an upper incipient lethal temperature of 32.5°C for American shad eggs after a 15 minute exposure. Sensitivity to temperature decreased as egg development increased.[71] Younger eggs (gastrula stage) were significantly more sensitive to 29.5°C than the older stages (tail-free embryo), which could tolerate 31.5°C.

Maximum survival of American shad larvae occurs between 15.5-26.5°C.[64] Koo *et al.*[71] and Koo[70] reported that larvae acclimated to 20.5°C survived a brief (15 minute) exposure to 31.5°C, but suffered significantly greater mortality when exposed to 33.5°C.

A habitat suitability index for American shad indicated that the optimum temperature range for juveniles is 15.6-23.9°C.[28] Larvae and juveniles were collected when temperatures were between 10-25°C in the upper Chesapeake Bay; 93% were collected at 21°C.[44] Juvenile American shad can detect and avoid rapid temperature increases in excess of 4°C above ambient (24-28°C).[111] Juveniles should be able to avoid potentially upper lethal temperatures during migration from nursery areas. Young American shad avoided effluent temperatures greater than 30°C by swimming below the power plant outflow.[101] The natural upper temperature limit for juveniles is near 30°C. A 96 h TL_{50} (lethal temperature that killed 50% of the test organisms) of 31.6°C was reported for young American shad acclimated to 24°C.[45]

A series of temperature avoidance studies with juvenile American shad was summarized in a power plant annual operating report.[121] Individuals acclimated to 28°C avoided temperatures ranging from 32-34°C. A critical thermal maximum of 34-35°C was reported for juvenile American shad in the Neuse River, North Carolina.[59]

The effects of decreasing temperatures on juvenile American shad, acclimated to 24°C, was examined by Chittenden.[21] He concluded that the lower lethal temperature was 2.2°C. Survival was limited after extended exposure to 4-6°C. In other studies of the effects of temperature decreases,[121] juveniles acclimated to 25°C suffered 100% mortality when the temperature was decreased to 15°C. No survival was recorded for juveniles acclimated to 15°C and exposed to temperatures ≤ 5°C. Individuals acclimated to 5°C and then exposed to 1°C also experienced 100% mortality.

The effects of heated effluents on juvenile American shad were examined by Marcy *et al.*[102] in an in-situ experiment. A live-box containing the test organisms was drifted through the heated effluent of a power plant on the Connecticut River. The following behavioral changes in response to heated effluent were observed: (a) schooling was not observed at ambient temperatures (19°C); (b) the juveniles formed a tight school immediately upon entering the heated effluent; (c) the juveniles began swimming rapidly in a circular pattern and then dispersed into smaller schools after one minute of exposure to 30°C; (d) disorientation and small school disintegration occurred after two minutes of exposure to 31.2°C; (e) no evidence of schooling and continued disorientation associated with loss of equilibrium occurred after 3-4 minutes of exposure to 31.8°C; and (f) total mortality occurred within 4-6 minutes of exposure to 32.2°C. This upper lethal temperature is similar to that reported in laboratory studies[111,121]. Underwater observations during submerged cage tests indicated that the juveniles avoided effluent temperatures greater than 30°C. The investigators concluded that 30°C was the upper natural temperature limit.

Salinity

American shad eggs were collected in areas of the upper Chesapeake Bay with 0-1 ppt salinity.[44] Eggs and larvae can survive exposures to salinities ranging from 7.5-15 ppt at 12 and 17°C.[80] Survival at 15 ppt was greater at 17 than at 12°C. Young American shad appear to be very tolerant of a wide range of salinities, and this tolerance begins early in life.[20]

Larval and juvenile American shad were collected only in freshwater areas in the upper Chesapeake Bay.[44] Chittenden[23] examined the effects of rapid and gradual (six day) changes between salt water and fresh water on juveniles held at 17°C. No mortality was observed when juveniles were abruptly or gradually transferred from fresh water or 5 ppt to 30 ppt. These results are similar to those Chittenden[22] reported for salinity transfer experiments conducted with blueback herring. Conversely, 100% mortality occurred within 9-19 h when juvenile American shad were transferred directly from 30 ppt salinity to fresh water. No mortality was observed when juveniles were moved directly from 5 ppt to fresh water.[23] Ions in salt water apparently act as buffers to reduce the Bohr effect, thereby increasing the handling success with American shad in salt water compared to fresh water.

Given their anadromous life history, adult American shad should also exhibit a wide range of salinity tolerance. Dodson *et al.*[41] examined the effects of salinity on adults by observing their movements with ultrasonic tracking techniques. They reported that a 24-53 h period within the saltwater-freshwater interface zone was necessary for the adults to make physiological adjustments successfully during spawning runs from salt water to fresh water.

Significant mortality of adult American shad that began five hours after a transfer from salt water (28 ppt) to fresh water, accompanied by a 5-6°C temperature increase, was reported by Leggett and O'Boyle.[78] Changes in several blood chemistry parameters were also noted.

Temperature and Salinity

The tolerance of juvenile and adult American shad to rapid temperature and salinity changes was examined by Tagatz.[142] The juveniles generally could cope with abrupt transfers from salt water to fresh water, but had difficulty adapting to transfers from fresh water to salt water. No mortality was observed when juveniles were abruptly transferred from salt water (15 and 33 ppt salinity) to fresh water, in association with temperature increases < 14 °C. Conversely, 100% mortality (no survival) was observed when juveniles were transferred from fresh water (at 21.1°C) to salt water (33 ppt) at 7.2-12.8°C. Survival varied from 30-50% after two days when juveniles were transferred from fresh water to 15 ppt in association with a temperature decrease <4 °C. Mortality was 60% after 48 h when juveniles were transferred directly from fresh water to 33 ppt at 21.1°C.

A discrepancy in juvenile survival was noted between the data of Tagatz[142] and Chittenden.[23] Chittenden[23] reported no mortality after 16 days when juveniles were transferred abruptly from 0 to 30 ppt at 17°C, whereas Tagatz[142] reported 60% mortality after two days when juveniles were abruptly transferred from 0 to 30 ppt at 21.1°C.

Adult American shad were tolerant of rapid changes from fresh water to salt water (23-24 ppt) during a temperature change ≤ 9°C, but they did not survive rapid changes from salt water (27 ppt) to fresh water during a 14°C temperature increase. Mortality of adults varied from 0-40% during direct transfers from salt water (13-25 ppt) to fresh water in association with temperature increases ≤ 5.6°C.

Dissolved Oxygen

Lethal dose (LD_{50}) values for dissolved oxygen (DO) ranged from 2.0-2.5 mgL^{-1} for Connecticut River American shad eggs, and were close to 3.5 mgL^{-1} for Columbia River eggs.[8] The LD_{50} values were based on the percentage of crippled or abnormal larvae that hatched from eggs incubated at several DO concentrations. A good hatch with a high percentage of normal larvae required DO levels during egg incubation of at least 4.0 mgL^{-1}. No eggs survived DO levels of 1.0 mgL^{-1}. No American shad eggs were collected in the Connecticut River when DO concentrations were less than 5 mgL^{-1}.[101] Eggs were collected in the Neuse River, North Carolina, within a DO range of 6-10 mgL^{-1}.[54] I could find no information on DO optima or tolerances for American shad larvae.

Juvenile and adult American shad require relatively well-oxygenated waters. Dissolved oxygen concentrations less than 5.0 mgL^{-1} should be considered sublethal to juveniles and adults.[110] Concentrations of DO less than 3.0 mgL^{-1} blocked adult and juvenile migrations, and concentrations less than 2.0 mgL^{-1} were lethal. For migrating adults and juveniles, DO must be at least 4 to 5 mgL^{-1} in headponds above hydroelectric dams on the St. John River, New Brunswick.[62] Healthy-appearing juveniles were collected in the Hudson River, New York, where DO was 4 to 5 mgL^{-1}.[10]

In the laboratory, DO less than 5 mgL^{-1} was lethal to juvenile American shad;[46] however, Chittenden[24] believed these findings were biased by handling stress. Chittenden's studies[20,24] showed that juvenile American shad did not lose equilibrium until DO decreased to 2.5-3.5 mgL^{-1}; mortality increased at DO below 2 mgL^{-1}, and all fish died when DO declined to 0.6 mgL^{-1}. Minimum daily DO levels of 2.5-3.0 mgL^{-1} should permit American shad to migrate through polluted areas, but 4.0 mgL^{-1} appears to be needed in spawning areas.[24] These conclusions are supported by recent observations of increased spawning of American shad in the Delaware River coincident with improved DO concentrations in the tidal portion.[105]

No mortality was observed when juvenile American shad were exposed for 96 h to DO concentrations between 2-4 mgL^{-1}, but respiratory movements increased when DO fell below 4 mgL^{-1}.[143] Dorfman and Westman[43] reported that juveniles could survive brief (5 minute) exposures to DO concentrations as low as 0.5 mgL^{-1} (at 17.8°C), if DO greater than 3 mgL^{-1} was readily available to the test organisms. The juveniles apparently could not detect and quickly avoid the low DO concentrations.

pH

A paucity of information exists concerning the effects of pH on various life stages of American shad.[66] In a laboratory study, Bradford *et al.*[8] reported that fertilized eggs developed successfully between pH 5.5 and 9.5 at 18 to 19°C, but most eggs succumbed to pH below 5.2 (0-32% hatch). The calculated lethal dose to 50% of the eggs (LD_{50}) exposed to pH 3.0-6.0 treatments was about pH 5.5; however, many of the larvae that hatched at pH 5.5 were deformed. A suitable pH for American shad eggs was ≥ pH 6.0. In another laboratory study, Klauda and Palmer[67] reported that advanced embryos (24 h post-fertilization) could tolerate pH 5.7, 6.7 and 7.5 treatments, but not pH 5.0 treatments, with no aluminum present. Simultaneous exposure to acidic pH and a range of dissolved aluminum concentrations (50-400 μgL^{-1}) increased egg mortality rates in the pH 5.7 treatment to 84%.

Yolk-sac larvae also were exposed to four pH levels (5.7, 6.2, 6.7, 7.5) and four dissolved aluminum concentrations (50, 100, 200, 400 μgL^{-1}) in the same laboratory study.[67] The larvae could tolerate acid-only treatments of pH 6.7

and 7.5, but mortality was 100% in the pH 5.7 and 6.2 treatments after only a 55 h exposure. Simultaneous exposure to the lowest concentration of aluminum (50 μgL^{-1}) reduced survival of the larvae in each pH treatment.

The effects of acid pulses on pre-feeding and feeding American shad larvae also were examined in the laboratory.[68] Feeding larvae were more sensitive than pre-feeding larvae to single acidic pulses (pH 7.6-6.2; pH 7.6-5.2), with or without a concomitant aluminum pulse (32-104 μgL^{-1}). A conservative critical acidity condition for American shad reproduction in the Chesapeake Bay was defined by Klauda[66] as an acidic pulse from circumneutral to pH between 6.2-6.7 associated with a total monomeric aluminum peak of at least 30 μgL^{-1} that lasted for at least 48 hours.

We could find no information on pH optima or tolerances for juvenile, subadult, or adult American shad.

Hardness and Alkalinity

We could find no information on water hardness optima or tolerances for any life history stage of American shad. Their wide salinity tolerance range (see **Salinity** section above) suggests that hardness is not likely to be a critical habitat requirement.

We could find no information on alkalinity optima or tolerances for any life history stage of American shad. However, since the larvae appear to be quite sensitive to moderate acidity (see **pH** section above), reproductive success in poorly buffered (low alkalinity) spawning and nursery areas that are subjected to episodic or chronic acidity inputs may be reduced compared to success in river systems with higher alkalinities that are less vulnerable to acidification.

Suspended Solids

American shad larvae appear to be more sensitive to elevated levels of suspended solids than other early life history stages. Suspended solids concentrations $\leq$ 1000 mgL^{-1} did not significantly reduce the hatching success of eggs.[4] However, four-day exposures of yolk-sac larvae to suspended solids concentrations $\geq$ 100 mgL^{-1} significantly reduced larval survival relative to the controls.

Extensive dredging of the Hudson River produced no measurable adverse effects on American shad abundance compared to other population stressors such as commercial fishing.[144] Adults readily migrate into the Shuebenacadie River, Nova Scotia, where suspended solids concentrations were sometimes as high as 1000 mgL^{-1}.[80] High turbidity (Secchi disk mean = 0.30 m) in the inner Bay of Fundy, Canada, may restrict light penetration and provide the filter-feeding and planktivorous American shad with a competitive advantage over other large pelagic fishes that apparently cannot feed effectively in these turbid conditions.[34]

Current Velocity and Turbulence

Optimal water velocities for American shad spawning habitats and egg incubation success range from about 30-90 cm s^{-1}.[137] This velocity range was based on field observations reported by Walburg and Nichols[148] and Kuzmekus.[75] Optimal current velocities for larvae and juveniles probably range from about 6-30 cm s^{-1} and from about 6-75 cm s^{-1}, respectively.

We could find no information on current velocity or turbulence tolerances for any life history stage of American shad. Velocity and turbulence-related stresses encountered by American shad that pass through turbines at hydroelectric stations could provide some insights to their responses to these extreme conditions.[48]

Physical Habitat

Substrate type should be relatively unimportant to successful American shad spawning since the eggs are broadcast into the water column over a range of substrates and most are carried downstream.[95,99] Only in areas where the eggs settled to the bottom, were covered by silt or sand and then smothered would substrate become a critical habitat problem. American shad also show little depth preference for egg deposition and spawn at depths ranging from 0.45-7 m.[95] Stier and Crance[137] suggested that at least 50% of the estuarine habitat used by American shad should be subtidal.

Hickory Shad

Our review of the literature revealed that information on the habitat requirements for hickory shad is sparse and limited to the material presented below. Hickory shad are closely related to American shad and the two river herrings; therefore it is reasonable, given current data limitations, to assume that hickory shad requirements are similar to the other three alosids.[65,16]

Temperature

Hickory shad eggs have been collected in water temperatures ranging from 9.5-22°C.[9,54,103,119,138,139] Eggs hatch in 48-72 hours when incubated in the laboratory at temperatures between 21-18°C.[97] We could find no information on temperature optima or tolerances for any life history stage of hickory shad.

Dissolved Oxygen

Live hickory shad eggs were collected in areas of the Neuse River, North Carolina, where DO ranged from 5-10 mgL^{-1}.[54] We could find no information on dissolved oxygen optima or tolerances for any life history stage of hickory shad.

Salinity

Juvenile hickory shad were collected during summer in estuarine sections of the Altamaha River, Georgia, where salinities reached 10 ppt.[138] In August and December, they were captured in salinities ranging from 10-20 ppt. Adults were collected in salinities ranging from 2.0-10.7 ppt in the St. Johns River, Florida.[106] We could find no information on salinity optima or tolerances for any life history stage of hickory shad. Since hickory shad are anadromous and spawn in mostly freshwater areas, salinity tolerance data for eggs and larvae would be most useful for evaluating habitat requirements.

pH

Live hickory shad eggs were collected in areas of the Neuse River, North Carolina, where pH ranged from 6.4-6.5.[54] We could find no information on pH optima or tolerances for any life history stage of hickory shad. Because the older juveniles, subadults and adults occur primarily in well-buffered estuarine and marine habitats, pH tolerance data for the eggs and larvae would be most useful for evaluating habitat requirements.

Hardness and Alkalinity

We could find no information on hardness or alkalinity optima or tolerance for any life history stage of hickory shad.

Suspended Solids

We could find no information on suspended solids optima or tolerances for any life history stage of hickory shad.

Current Velocity and Turbulence

We could find no information on swimming ability and current velocity or turbulence optima or tolerances for any life history stage of hickory shad.

Physical Habitat

Adult hickory shad appear to spawn in a diversity of physical habitats ranging from backwaters and sloughs, to tributaries, to mainstem portions of large rivers in tidal and non-tidal freshwater areas. We could find no information on specific physical habitat optima and tolerances for other life history stages of hickory shad.

SPECIAL PROBLEMS

AMERICAN SHAD

Contaminants

Relatively little information exists on the acute and chronic effects of contaminants on various life history stages of American shad.

The lethal dose (LD_{50}) for sulfates to eggs was > 1000 mgL^{-1} at 15.5°C.[8] The LD_{50} for iron to eggs was greater than 40 mgL^{-1} over a pH range from 5.5-7.2.[8] Eggs exposed to zinc and lead concentrations of 0.03 and 0.01 mgL^{-1} exhibited very high mortality within 36 h of exposure.[107] Low hardness of the test water (12 mgL^{-1}) apparently intensified the toxicity of these two metals to American shad eggs. Available information on aluminum toxicity to eggs and yolk-sac larvae was discussed above in the **pH** section.

Juvenile American shad avoided a total residual chlorine concentration of 0.07 mgL^{-1} when tested in 7 ppt salinity at 19°C.[121]

Tagatz[143] reported 48 h lethal concentrations (LC_{50}) for juveniles ranging from 2,417-91,167 mgL^{-1} for gasoline, No. 2 diesel fuel and bunker oil. The toxicity of gasoline and diesel fuel to juvenile American shad increased when DO was simultaneously reduced. Exposure of juveniles to gasoline concentrations of 68 mgL^{-1} at temperatures of 21-23°C resulted in a lethal time (LT_{50}) of 50 minutes when DO was reduced to 2.6-3.2 mgL^{-1}. An LT_{50} of 270 minutes was reported when juveniles were exposed to 84 mgL^{-1} of diesel fuel at temperatures of 21-23°C and DO between 1.9-3.1 mgL^{-1}.

Nutrients

We could find no information which would directly implicate high nutrient levels as a factor which has contributed to the Bay-wide decline of American shad populations in Chesapeake Bay. The rapid decline in American shad runs in the Delaware River during the early 1900's was attributed to severely depressed DO in the tidal river between Wilmington and Philadelphia.[20,46,110] The poor water quality apparently blocked a portion of the adult population during their spring upstream migration to spawning areas, and prevented most of the juvenile population from emigrating seaward in the fall. American shad spawning has increased in the Delaware River since 1981, presumably because of improved DO in the tidal areas.[105] Rulifson *et al.*[124] mentioned low DO, sewage outfalls, and poor water quality as nutrient-related factors that were "possibly important or very important in contributing to the decline of certain populations of American shad" in North Carolina, South Carolina, Georgia and Florida.

Nutrient inputs to Chesapeake Bay and its tributaries from point sources, stormwater runoff and atmospheric deposition are of concern to scientists and resource managers. Excessive nutrient enrichment stimulates heavy growth of phytoplankton. Decay of phytoplankton blooms involve high rates of oxygen consumption which can lead to low DO during the growing season in the bottom waters of the Bay's deeper channels, and to diurnally low DO in tidal tributaries.[27,145] These conditions can stimulate fish kills during hot summer months. Nutrient reduction is a major goal of the 1985 Chesapeake Bay Restoration and Protection Plan.[33,136]

Parasites and Diseases

American shad seem to be relatively free of parasites.[131] Parasites that have been reported include nematodes, trematodes, round worms, sea lice, acanthocephalans, sea lamprey, and freshwater lamprey.[148] A bacterium, *Aeromonas liquefaciens*, was the lethal agent in an American shad kill in California.[51] However, stress induced by low DO (< 3 mgL^{-1}) probably triggered the epidemic.

Impediments to Spawning Migrations

Dams built during the 1800's and in the early to mid-1900's on several major tributaries to Chesapeake Bay have reduced substantially the amount of spawning habitat available to American shad[2,17] and likely contributed to long-term stock declines.[99] Construction of the Conowingo hydroelectric power dam at river mile 10 in 1928 blocked all but about 16 km of the Susquehanna River to American shad spawning migrations. The Conowingo Dam was the fourth in a series of dams that was constructed between 1901 and 1928.[11] The other three dams were built at river mile 55 (York Haven), at river mile 34 (Safe Harbor), and at river mile 26 (Holtwod). Before the York Haven and Holtwood Dams were constructed between 1904 and 1916, American shad could migrate upriver at least as far as Binghamton, New York (river mile 330) to spawn.[151]

A major program is underway in the Susquehanna River which involves the U.S. Fish and Wildlife Service, New York Department of Environmental Conservation, Pennsylvania Fish Commission, MDNR, and five electric utilities. The multi-year program began in 1980 and seeks to restore American shad to the river.[17,72,135,140,141] The goal of the restoration program is to establish a run of 2,000,000 American shad through use of hatcheries, transplanting gravid adults, and construction of fish passage facilities.

A second permanent fish passage facility designed for the Conowingo Dam began operation in spring 1991 at a cost of $12.5 million.[18] This facility will supplement the existing fish lift which has operated since 1972. Design planning for fishways at the Holtwood, Safe Harbor, and York Haven dams on the Susquehanna River is in progress.

The Conowingo Dam may have played two additional roles in the decline of the Susquehanna River American shad stock. The effect of flow alterations at the hydroelectric facility is one major issue that has been raised.[73] Another issue relates to the impoundment of water behind the dam during low flow periods in summer and fall, which leads to the discharge of water with very low DO to downstream areas.

The migration of American shad up the Potomac River essentially is blocked by Little Falls Dam at river mile 117, about 2 km upstream from Washington, D.C.[113] This dam has excluded American shad from about 15 km of potential spawning habitat since the early 1950's.[17] Discussions among officials from the District of Columbia, Virginia, Maryland, Army Corps of Engineers, and interested federal agencies have suggested several mitigative options: (a) a new fishway could be constructed on the Virginia side of the Potomac River; (b) the Corps could operate and maintain the presently non-functional Snake Island fishway located in the center of Little Falls Dam; and (c) the Corps could design and construct a new fishway with funds provided by the mitigation agreement with the Port America development.

In Virginia, American shad originally migrated about 465 km up the James River to spawn.[3] A series of five dams constructed in the Richmond area beginning in 1804 blocked adults from over 300 km of potential spawning habitat. Presently, three of the five dams (Manchester, Brown's Island, Belle Isle) are partially negotiable by adult American shad at most river levels. Fish passageways are planned for the two remaining dams: William's Island and Bosher's. Scott's Mill Dam, the first dam in the series of seven around Lynchburg (224 km upstream from Richmond) recently was granted a license for hydropower generation by the Federal Energy Regulatory Commission.[17] The license contains requirements for fish passage, if and when fish reach the dam and fishery agencies deem fish passage is needed. The first two of four dams on the Appomatox River near Petersburg also were recently issued hydropower licenses that contain provisions for fish passage. The Appomatox River is a major tributary that joins the James River downstream from Richmond.

On the Chickahominy River, another major tributary of the James River below Richmond, a low head dam was built about 30 km upstream from the confluence in 1943. The area below this structure (Walker's Dam) was once the downstream limit of American shad spawning in the Chickahominy River, but now it is the only spawning area. At present, there is no fishery for American shad in the Chickahominy River.[3] The city of Newport News supported the construction of two Denil-type fishways at Walker's Dam in 1988. River herrings were documented using the fish passage facilities in spring 1989.[15] No use of the passage fish facilities by American shad has yet been observed.

The Embrey Dam at Fredericksburg blocks about 110 km of the mainstem Rappahannock River to American shad spawning runs, and is the only obstruction to anadromous fish migration on this river. The dam, located just above the fall line, recently was licensed for hydropower generation.[17] The license includes requirements for fish passage.

Dams and impoundments also are viewed as factors that have contributed and are probably still contributing to the decline of American shad populations in North Carolina, South Carolina, Georgia and Florida.[124] Major restoration efforts focused on reopening historical spawning sites blocked by dams are also presently underway in Maine, New Hampshire, Massachusetts and Rhode Island.[122] A major program has been underway since the mid-1950's on the Connecticut River. The successes of these restoration programs have generally been encouraging but not yet conclusive.

Large tidal hydroelectric projects are being considered for construction in two or more basins of the Bay of Fundy, Canada.[34] These proposed projects, if implemented, pose a major threat to American shad populations from Chesapeake Bay and other east coast rivers. Extensive tagging studies carried out by Dadswell and his co-workers revealed that American shad from all east coast stocks migrate northward and use the basins in the Bay of Fundy as feeding areas during the summer.[34,35] Construction of these large tidal projects would pose a threat to the migrating fish from turbine mortality, since the fish would be exposed to turbine passage with each tidal cycle. Neither of the proposed tidal projects currently is being developed, but if demands for electrical power increase, supplies of fossil fuels decrease, or prices for fossil fuels increase, development of this new hydropower technology could proceed rapidly.[122]

Erosion

We could find no information which would directly implicate erosion as a factor which contributed to the Bay-wide decline of American shad populations. Severe floods, intensive agriculture, urban development, stream channelization, and roadway construction in the watersheds of Chesapeake Bay tributaries can accelerate the erosion of surface soils during stormwater runoff and increase levels of suspended solids and siltation rates in water courses. Periodic floods are normal occurrences in American shad spawning and nursery areas that should not affect stock abundance over the long run.

However, the turbid water and high flows associated with the severe flooding caused by Tropical Storm Agnes in June 1972 may have contributed to the failure of the 1972 year class in Virginia rivers.[2,85] In Maryland, the Bay-wide juvenile abundance index for American shad was about average in 1972, but the 1973 and 1974 indices were very low.[135] In 1972, the Potomac River index was relatively high, but the upper Bay index was very low.[1221] The effects of tropical storm Agnes on American shad reproduction in Maryland appeared to vary among river systems, but apparently was less severe overall than in Virginia. Refer to the section on **Suspended Solids** for sensitivities of American shad early life stages to erosion-related changes in habitat quality.

Fishing Pressure

Overharvesting has been suggested as one of the major factors involved in the dramatic decline in American shad stocks along the Atlantic seaboard between the late 1800's and the 1940's, and also may be a current deterrent to their recovery.[99,148] The specific role of fishing pressure on American shad stocks in Maryland and Virginia since the 1950's is unclear. As stocks declined in Virginia, so did fishing effort, because many fishermen switched to larger mesh gear and pursued the equally scarce but more valuable striped bass.[2] Information is spotty about trends in fishing effort directed at the commercial or recreational fisheries for American shad in Maryland prior to the closure of the fishery in 1980.[73] In 1975, 344 people were involved in the commercial harvest; but by 1980, this number decreased to 115.

Landings of American shad in the ocean fishery (termed coastal intercept fisheries) along the eastern seaboard of the U.S. increased more than five-fold between 1978 and 1988.[52] All Atlantic coast states have intercept fisheries for American shad, either directed or by-catch, that are conducted primarily with gill nets during late winter and early spring. These intercept fisheries harvest adults of various spawning river origins and capture fish that are en route from overwintering to spawning areas. Ocean harvest of American shad is dominated by four states: New Jersey, South Carolina, Virginia and Florida. In Maryland and Virginia, the ocean shad fisheries are directed rather than by-catch, usually begin in early February, and continue through early to late April.

About 20% of the fishing effort in Maryland occurs within about three miles of shore, in Assawoman and Chincoteague Bays and in National Marine Fisheries Service (NMFS) Sectors 621 and 622.[52] All fish are landed at Ocean City. Between 1978 and 1990, the reported annual landings of American shad in Maryland's ocean fishery ranged from only 15 kg in 1981 to 222×10^3 kg in 1989 (personal communication: H. Speir, MDNR). About 93% of the harvest occurred during March and April.

In Virginia, the ocean fishery directed at American shad is distributed along the entire coast, with most of the catch harvested by gill nets, haul seines and bottom trawls within three miles of shore.[52] Most of the fish are caught in NMFS Sectors 625, 631 and 621, and landed at several ports. Between 1978 and 1990, reported annual landings of American shad in Virginia's ocean fishery (including seaside bays) ranged from 6×10^3 kg in 1978 to 293×10^3 kg in 1984.

The recent Alosid Management Plan for Chesapeake Bay[18] recommended that coastal tagging programs be implemented to determine which American shad stocks are exploited in the ocean fishery. Given the location of a major overwintering area for Atlantic coast stocks (off

North Carolina) and the distribution of fishing effort (north of the entrance to Chesapeake Bay), it is unlikely that Maryland's ocean fishery for American shad harvests any Chesapeake Bay stocks. Rather, the fishery probably intercepts mostly Delaware and other more northern stocks as the adults migrate from overwintering areas to their spawning rivers. The ocean fisheries in Virginia and North Carolina almost certainly exploit American shad stocks that spawn in Chesapeake Bay tributaries and more northern rivers.[52]

Early studies of American shad population dynamics reported that the number of juveniles produced is directly related to the number of adults that spawned.[144,147] More recent studies found deficiencies in some of the earlier work, and concluded that year class strength may be related to spawning stock abundance, but appears to be most heavily influenced by environmental variables.[78] Studies of American shad in the Connecticut River[29,31] showed that stock size had almost no influence on the number of recruits that returned to spawn. The determining factors that appeared to control year class in this population were environmental and focused on the pre-juvenile stages.

These findings for the Connecticut River, where American shad landings have remained relatively stable over the past 20 years,[122] may not be completely relevant to Chesapeake Bay where American shad stocks declined to very low levels in the mid-1970's. Fisheries researchers acknowledge that at relatively low spawner population levels, near the critical threshold, total run size and fecundity should play a greater role in determining the number of young produced than when the stock is relatively abundant. What the critical stock size thresholds are for American shad spawning stocks in Maryland and Virginia is not known. Therefore, the decision to prohibit commercial and recreational harvests of American shad in Maryland waters of Chesapeake Bay in 1980 was wise, given the currently low stock abundance in all Maryland rivers.

HICKORY SHAD

Contaminants

We could find no information on the effects of contaminants on any life stage of hickory shad.

Nutrients

We could find no information which would implicate high nutrient levels as a factor which directly contributed to the decline of hickory shad populations in Chesapeake Bay. Rulifson *et al.*[124] mentioned low DO, sewage outfalls, poor water quality, and non-point source pollutants as nutrient-related factors that were "possibly important or very important in contributing to the decline of certain populations of hickory shad" in North Carolina, South Carolina, Georgia, and Florida. Nutrient reduction is a major goal of the 1985 Chesapeake Bay Restoration and Protection Plan.[33,136]

Parasites and Diseases

We could find no information which would implicate parasites and diseases as factors which have contributed to the decline of hickory shad populations in Chesapeake Bay. Hickory shad can be afflicted with several parasites including nematodes (*Ascaris* spp.), larval cestodes, *Scolex polymorphus*, and trematodes.[82] Digenetic trematodes were identified in the stomachs of adult hickory shad collected in the St. Johns River, Florida.[154]

Impediments to Spawning Migrations

Man-made dams, impoundments, stream flow gauging weirs, roadway culverts, bridge aprons, and other impediments to upstream spawning migrations such as waterfalls, beaver dams, and log-debris piles have been implicated in Chesapeake Bay as factors which may be contributing to the delay in recovery of hickory shad populations. Other factors must have been involved in the drastic declines which occurred Bay-wide in the 1970's, because most major blockages were in place before the major stock declines began and some river systems do not have dams or other impediments to spawning migrations, yet these stocks have also declined.

Maryland DNR and the Chesapeake Bay Program are concerned that stream blockage is a factor which may be contributing to the delayed recovery of hickory shad and other alosid stocks.[17] In Virginia and several southeastern states, the construction of impoundments on coastal rivers also has resulted in a loss of spawning habitat and is viewed as a factor which likely contributed to the decline of hickory shad populations.[3,124]

Erosion

We could find no clear linkage between erosion and the Baywide declines in hickory shad stocks. Periodic floods are normal occurrences in hickory shad spawning and nursery areas that should not adversely affect stock abundance over the long run. However, the turbid water and high flows associated with the severe flooding caused by tropical storm Agnes in June 1972 probably contributed to the decimation of the 1972 year class of hickory shad in Maryland[126] and in Virginia,[2] significantly altered important spawning areas, may have contributed to reduced reproductive success for several years, and added another environmental stressor on an already stressed population.

Between June 21 and 23, 1972, the entire Bay watershed was subjected to measured rainfall in excess of 127 mm, with about a third of the region receiving more than 305 mm. Isolated locations recorded 457 mm during the three-day period.[19] Most rivers crested at levels higher than previously recorded. Hickory shad larvae and juveniles may have been destroyed through physical damage from high concentrations of suspended solids, by displacement downstream to areas of low food availability, and from osmotic stresses. Erosion stimulated by normal and intense rainfall events, flashy stormwater runoff episodes, and subsequent siltation in spawning areas, exacerbated by careless land use practices represents a habitat quality problem that is likely to be detrimental to hickory shad reproduction in many Bay tributaries.

Fishing Pressure

We could find no information which would implicate fishing pressure in Chesapeake Bay and its tributaries as a factor which contributed to the decline of hickory shad populations. Estimates of fishing mortality rates for hickory shad in the Bay do not exist.[73] Information on effort trends in the commercial or recreational fisheries prior to the 1980 Maryland closure is limited. Numbers of watermen who reported that they caught at least one pound of hickory shad declined from 150 in 1975 to 47 in 1980.[73] The recreational fishery for hickory shad in Maryland was concentrated in two tributaries of the lower Susquehanna River, Octoraro and Deer Creeks. We could find no information on the number of anglers that fished for hickory shad in these streams.

Some investigators have suggested that the offshore foreign fishery had a detrimental effect on all east coast alosid populations, including hickory shad, in the late 1960's and early 1970's.[56,57] Unfortunately, there are no data to support the view that this offshore fishery caught substantial numbers of hickory shad. The offshore foreign fishing fleets, primarily from the USSR, East Germany, Bulgaria, and Poland, began operating off the Delaware, Virginia and North Carolina coasts in 1967. This fishery harvested immature river herrings and other alosids that eventually would have matured and spawned in rivers of the mid-Atlantic states. Since 1977, alosid catches by offshore foreign fishing fleets have decreased to relatively low levels as a result of agreements between the U.S. and foreign countries and enactment of the 200-mile Fishery Conservation Zone.[2]

SUMMARY AND RECOMMENDATIONS

American Shad

The American shad is the largest anadromous clupeid in the United States. Native to the Atlantic seaboard of North America, they are distributed from southeastern Labrador to the St. Johns River, Florida. Along the east coast of the U.S., American shad are most abundant from Connecticut to North Carolina. In the mid-Atlantic region, American shad historically spawned in New Jersey, Delaware and virtually all major tributaries to the Chesapeake Bay.

American shad live at sea and only enter fresh water in mid-February to early March to spawn. Peak egg deposition in the upstream reaches of Chesapeake Bay rivers occurs during April. The juveniles move gradually downstream during the summer. Their seaward migrations accelerate from late October through late November when water temperatures fall below 15°C. The subadults and adults participate in extensive oceanic migrations from the Chesapeake Bay to summer feeding grounds as far north as the Bay of Fundy, Canada. Males and females reach sexual maturity at 4 and 5 years of age, and then return to their natal rivers to spawn. Repeat spawning ranges from about 20-37% in Chesapeake Bay populations.

Historically, American shad represented a major fishery resource all along the Atlantic seaboard. But between 1897 and 1940, annual harvests declined dramatically due to pollution and siltation of spawning rivers, overharvesting, and construction of dams which prevented access to spawning sites. Commercial landings of American shad in the Chesapeake Bay reached record lows in the late 1970's. In 1980, the commercial and recreational fisheries were closed in Maryland waters of Chesapeake Bay. American shad population levels in Virginia have been relatively low but stable since the late 1970's; therefore, fishing is still allowed.

Uncertainty surrounds any attempts to define the major factors responsible for the decline in American shad stocks throughout Chesapeake Bay. Gradual loss of spawning habitat quantity and quality and overharvesting during the 1800's and through the first half of the 1900's are the major explanations offered for the large population declines during this period. Fishing pressure has eased substantially since the mid-1950's. But until the 1980's, efforts to restore lost spawning habitat were limited and generally unsuccessful. Both Maryland and Virginia currently are engaged in restoration efforts designed to supplement natural reproduction with hatchery-reared young (Susquehanna River) and provide fish passage facilities at existing dams (in several rivers) to reopen lost spawning habitats. Current restoration programs focused on fish passage and designed to increase habitat quantity are encouraging, but their long-term achievements will take many years to be seen. These restoration efforts should continue and include sufficient intensive monitoring studies to evaluate their effects.

Other factors which also may be contributing to the depressed condition of the Bay stocks are receiving little attention. Concerns about the quality of American shad spawning and nursery habitats are clearly justified, but few studies are being directed at this topic. Acidic deposition and discharge of chlorinated sewage effluents are two of potentially many pollutant sources that may be slowing the recovery of depressed American shad stocks in Chesapeake Bay. Research should be directed at these issues.

Temptations to reopen the fishery for American shad in the Maryland portion of the Bay should be resisted until adequate stock recovery is documented. If stocks do not show clear signs of recovery or decline further in Virginia, management options that include a moratorium on fishing should be considered. Harvests of adults in the coastal intercept fishery should be closely monitored and evaluated.

This survey of the literature on American shad suggests that the critical life history stages are the egg, prolarva (yolk-sac or prefeeding larva), postlarva (feeding larva, and early juvenile (through the first month after transformation). The critical life history period is April through July. A matrix of habitat requirements for the critical life stages is presented in Table 1.

HICKORY SHAD

The hickory shad is a medium-sized anadromous clupeid that occurred historically along the east coast of North America from the Bay of Fundy, Canada, to the Tomoka River, Florida. This alosid species is now most abundant from New York southward, but hickory shad probably do not spawn north of Maryland. In Chesapeake Bay, hickory shad are near the northern limits of their spawning range and probably never have been abundant, although they were harvested throughout the Bay prior to the 1970's.

The hickory shad is somewhat of a mystery to both fishermen and ichthyologists because so little is known about its basic life history. In Chesapeake Bay, hickory shad spawning runs typically began during March and April, with spawning activity occurring between late April and early June. Specific spawning sites are not well documented, but they appear to be concentrated in mainstem reaches of rivers upstream from the major spawning sites for American shad. Juvenile hickory shad appear to migrate directly to saline areas during the summer and may not use oligohaline portions of Bay estuarines as nursery areas.

Records of commercial landings support the view that hickory shad populations throughout the Chesapeake Bay declined dramatically during the early to mid-1970's. Loss of spawning habitat quantity and quality, heavy exploitation in the offshore foreign fishing between 1967 and 1977, and decimation of the 1972 year class and alteration of many spawning areas by tropical storm Agnes are major factors that probably were involved in the population declines, or are acting to slow any stock recovery. Commercial and recreational fishing for hickory shad was closed effective January 1981 in Maryland waters, but not in Virginia. Given the currently low stock abundance levels, a Baywide moratorium on fishing for hickory shad should be implemented and continued until the stocks show clear signs of recovery.

Hickory shad populations in Maryland are at such low levels of abundance that natural stock recovery may be very slow in coming, if it can occur at all. Carefully designed restocking efforts may be needed if adult hickory shad can be transported from areas where they are relatively abundant or the eggs and larvae can be reared in fish hatcheries. In Virginia, the prognosis for stock recovery is somewhat more optimistic. Current programs and plans for fish passage facilities in both states should increase the quantity of spawning habitat available to remnant hickory shad populations. However, until we understand more about hickory shad life history and population dynamics, it will be difficult to determine what specific resource management actions, in addition to the current closure of the fisheries in Maryland, should be taken to rebuild Baywide stocks.

The critical life history stages of hickory shad are the egg, prolarva, postlarva and early juvenile. The critical life history period is March through July. Available information was not adequate to construct a matrix of life history requirement for any life history stage.

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Table 1. Summary of habitat requirements for American Shad.

Life Stage	Temp. °C	Salinity ppt.	pH	Dissolved Oxygen mgL^{-1}	Suspended Solids mgL^{-1}
Egg	13.0-26.0	0-15	> 6.0	> 5.0	< 1000
Larvae	15.5-26.1	NA	> 6.7	> 5.0	< 100
Juvenile	15.6-23.9	0-30	NA	> 5.0	< 100
Adult	10-30	0-30	NA	> 5.0	< 100