Chapter 8

ATLANTIC STURGEON

(*Acipenser oxyrinchus oxyrinchus*)

Section I. Description of Atlantic Sturgeon Habitat

Atlantic Sturgeon General Habitat Description and Introduction

The Atlantic sturgeon (*Acipenser oxyrinchus oxyrinchus*) is an anadromous species found in Atlantic Coastal waters of the United States, and major river basins from Labrador (Churchill River, George River, and Ungava Bay), to Port Canaveral and Hutchinson Island, Florida (Van den Avyle 1984). Historically, Atlantic sturgeon once inhabited northern Europe as well, but since have become extinct (ASSRT 2007). According to historical records, important sturgeon fisheries existed in nearly all Piedmont river basins on the Atlantic Coast at some point in time (Goode 1887). Early accounts of sturgeon fishery landings did not distinguish between Atlantic sturgeon and the smaller shortnose sturgeon (*Acipenser brevirostrum*). However, it is likely that the accounts referred to the larger and more valuable Atlantic sturgeon. Following intense exploitation for food, and construction of mainstem river dams during the 19th and early 20th centuries, sturgeon populations were drastically reduced throughout their range and extirpated in some rivers (ASMFC 1998; USFWS-NMFS 1998; ASSRT 2007). Scientists believe that spawning populations of Atlantic sturgeon were extirpated from the St. Marys River in Georgia, the Housatonic River in Connecticut, the Connecticut River, the Taunton River in Massachusetts and Rhode Island, and all Maryland and Pennsylvania tributaries of the Chesapeake Bay (Burkett and Kynard 1993; Rogers and Weber 1995; ASMFC 1998; USFWS-NMFS 1998; ASSRT 2007).

Atlantic sturgeon are motile, long lived, and utilize a wide variety of habitats. Atlantic sturgeon require freshwater habitats for reproduction and early life stages, in addition to hard bottom substrate for spawning (Vladykov and Greeley 1963; Huff 1975; Smith 1985b). Coastal migrations and frequent movements between the estuarine and upstream riverine habitats are characteristic of this species (ASMFC 1998). Historical accounts describe captures of large sturgeon, most probably *A. oxyrinchus oxyrinchus*, during the summer and fall in fall-line habitats on the Savannah River (Lawson 1709). In some systems, Atlantic sturgeon may prefer extensive reaches of silt-free higher gradient boulder, bedrock, cobble-gravel, and coarse sand substrates for spawning habitat (Brownell et al. 2001). Juvenile and adult Atlantic sturgeon frequently congregate in upper estuary habitats around the saltwater interface, and may travel upstream and downstream throughout the summer and fall, and during late winter and spring spawning periods. Adult Atlantic sturgeon may spend many years between spawning periods in marine waters (Brundage and Meadows 1982; Bain 1997; ASMFC 1998; USFWS-NMFS 1998; Savoy and Pacileo 2003; ASSRT 2007).

Due to a variety of anthropogenic impacts, including river impoundments, water quality deterioration, and overfishing, only 20 of the 35 existing stocks of Atlantic sturgeon are reproducing, with many stocks likely at historically low levels (ASSRT 2007). In 1991, Atlantic sturgeon was listed as a candidate species (56 FR 26797) under the Endangered Species Act (ESA) and remained on the revised list in 1997 (62 FR 37560). In 1998, a status review of Atlantic sturgeon found that the continued existence of Atlantic sturgeon was not threatened by any of the five ESA listing factors. Therefore, Atlantic sturgeon was not listed as a threatened or endangered species (USFWS-NMFS 1998). In 2003, the National Marine Fisheries Service (NMFS) and U.S. Fish and Wildlife Service (USFWS) held a workshop on the “Status and Management of Atlantic Sturgeon” to discuss the current status along the Atlantic coast to determine what obstacles, if any, were impeding the recovery of Atlantic sturgeon. The results of the conference reported “mixed” reviews where some populations seemed to be recovering while others were declining. Bycatch and habitat degradation were noted as possible causes for some population declines (Kahnle et al. 2005). Based on the information gathered from the 2003 workshop on Atlantic sturgeon, NMFS initiated a second status review in 2006, and the results are currently under consideration by the Secretary of Commerce, as to whether the species warrants listing as threatened or endangered (W. Patrick, NOAA Fisheries Service, personal communication).

In 1990, the Atlantic States Marine Fisheries Commission wrote a Fisheries Management Plan (FMP) for Atlantic sturgeon, which was amended in 1998. In 1998, the ASMFC closed all Atlantic sturgeon fisheries coastwide in the United States, and recommended a 20 to 40 year moratorium so that the spawning stock of the slow-reproducing fish could be restored to a level where 20 year classes of adult females are present (ASMFC 1998). This action was followed by NMFS with a similar moratorium in Federal waters (K. Damon-Randall, NOAA Fisheries Service, personal communication).

Much of the habitat information on Atlantic sturgeon remains incomplete. Due to the relatively low numbers of fish in many river basins, habitat utilization patterns have been difficult to establish with certainty (Collins et al. 2000a). Life history, behavior, and movements have been most thoroughly documented in the Hudson River, New York, while many other river systems are lacking in vital life history information (Bain 1997; Bain et al. 2000; Gross et al. 2002). Below is a discussion of some of the general habitat requirements for the Atlantic sturgeon.

Part A. Atlantic Sturgeon Spawning Habitat

Since adult Atlantic sturgeon migrate through rivers and estuaries during their spawning migration, the discussion of adult Atlantic sturgeon estuarine and spawning habitat utilization patterns will be combined in this section. For the purposes of this report, female spawning adults are considered to be at least 15 years of age, and are a minimum of 1800 mm fork length (FL) or 2000 mm total length (TL). Male adult Atlantic sturgeon are 12 to 20 years of age, and between 1350 and 1900 mm FL or 1500 and 2100 mm TL (Bain 1997). See Table 8-1 for information on length-at-age.

Life Interval	Age Range (years)	Fork Length (mm)	Total Length (mm)
Larvae	<0.08		≤ 30
Juvenile	0.08-11	~20-1340	~30-1490
Non-spawning adults	≥ 12	≥ 1350	≥ 1500
Female spawners	≥ 15	≥ 1800	≥ 2000
Male spawners	12-20	≥ 1350-1900	≥ 1500-2100

Table 8-1. Age and size range of Atlantic sturgeon throughout their life cycle

Geographical and temporal patterns of migration

Atlantic sturgeon most often spawn in tidal freshwater regions of large estuaries (Hildebrand and Schroeder 1928; Bain 1997; Colette and Klein-MacPhee 2002; Moser and Ross 1995). This pattern is prevalent in New England and U.S. mid-Atlantic estuaries, where obstructions to migration at the fall line preclude upriver migration. In the South where many rivers remain unblocked, documentation shows that Atlantic sturgeon ascend hundreds of miles upstream into non-tidal rivers to spawn (M. Collins, South Carolina Department of Natural Resources, personal communication).

Spawning migrations are cued by temperature, which causes fish in U.S. South Atlantic estuaries to migrate earlier than those in mid-Atlantic and New England portions of their range (Smith 1985b). In Florida, Georgia, and South Carolina, spawning migrations begin in February. Collins et al. (2000b) found that in the Edisto River, South Carolina, ripe males were captured as early as March 2nd, and a single ripe female was captured on March 7th. Additionally, the researchers captured spent males as early as late March, and spent females as late as mid-May (Collins et al. 2000b). In contrast, researchers in the mid-Atlantic region report that spawning migrations for Atlantic sturgeon begin between April and May (Hildebrand and Schroeder 1928; Secor and Waldman 1999; Dovel and Berggren 1983; Bain et al. 2000). In New England and Canada, spawning migrations occur from May through July (Collette and Klein-MacPhee 2002). Furthermore, Hatin et al. (2002) reported that spawning occurred from early June to approximately July 20th, in the St. Lawrence River, Québec.

In addition to a spring migration, many studies document the occurrence of a fall migration (Smith et al. 1984; Smith 1985b; Collins et al. 2000b; Laney et al. 2007). Most fall migrations are movements out of the estuaries into marine habitats. Fall migrations occur from September through December, again, depending on the latitude (Smith 1985b). In addition, some researchers have proposed that an alternate fall migration into estuaries may be related to spawning (Smith et al. 1984; Rogers and Weber 1995; Weber and Jennings 1996, Moser et al. 1998; Collins et al. 2000b; Laney et al. 2007). Whether this fall migration results in fall spawning remains unknown. Smith et al. (1984) reported an upriver migration of fish in late August and September in South Carolina. Similarly, Collins et al. (2000b) noted the appearance of ripe males in South Carolina at the end of August and September; by October, 86% of the males were ripe. Furthermore, Collins et al. (2000b) tracked two sturgeon via radio and acoustic transmitters in the Edisto River, South Carolina. After spending the summer in the lower river, these fish migrated upriver to RKM 190 in October, which led the researchers to hypothesize that a fall spawning migration was occurring (Collins et al. 2000b). An alternative explanation is that the fall migration was comprised of fish that would reside in the upper river through the winter and spawn the following spring, as is reported to occur in Caspian Sea sturgeons (D. Secor, Chesapeake Biological Laboratory, University of Maryland Center for Environmental Science, personal communication). The general phenomenon of fall spawning remains uncertain and merits further study. Spring spawning, however, has been well documented in the literature (ASMFC 1998; USFWS-NMFS 1998; ASSRT 2007), and is most likely the dominant behavior of all North American sturgeon species.

Despite extensive mixing in coastal waters, Atlantic sturgeon return to their natal river to spawn as indicated from tagging records (Collins et al. 2000b; K. Hattala, New York State Department of Environmental Conservation, personal communication), and the relatively low rates of gene flow reported in population genetic studies (King et al. 2001; Waldman et al. 2002; from ASSRT 2007).

Spawning location (geographical)

The following information on Atlantic sturgeon spawning location (geographical) along the Atlantic coast was excerpted from ASSRT (2007):

<u>Maine Rivers</u>

The geomorphology of most small coastal rivers in Maine is not sufficient to support Atlantic sturgeon spawning populations, except for the Penobscot and the estuarial complex of the Kennebec, Androscoggin, and Sheepscot rivers. During the summer months, the salt wedge intrudes almost to the site of impassable falls in these systems: St. Croix River (rkm 16), Machias River (rkm 10), and the Saco River (rkm 10). Although surveys have not been conducted to document Atlantic sturgeon presence, subadults may use the estuaries of these smaller coastal drainages during the summer months (ASSRT 2007).

<u>St. Croix River – Maine/Nova Scotia</u>

The historic and current status of a St. Croix Atlantic sturgeon population is largely unknown. Mike Dadswell (Arcadia University, Canada) notes from personal communications with Nova Scotia Power (in 1993) that a small population of large sturgeon may be spawning annually below the hydropower dam on the St. Croix River (Dadswell 2006). Other than this personal communication, there is no additional information that an Atlantic sturgeon population exists on the St. Croix or regarding their status (ASSRT 2007).

<u>Penobscot River – Maine</u>

There have been two surveys conducted in the last 15 years to document the presence of shortnose and Atlantic sturgeon in the Penobscot River. The Maine Department of Marine Resources (MEDMR) conducted a limited sampling effort in 1994 and 1995 to assess whether shortnose sturgeon were present in the Penobscot River. The MEDMR made 55 sets of 90 meter experimental gill nets for a total fishing effort of 409 net hours (1 net hour = 100 yards fished for 1 hour). The majority of the fishing effort in the Penobscot River was in the upper estuary near head-of-tide. No shortnose or Atlantic sturgeon were captured. The sampling was determined to be inadequate to assess the presence of adult Atlantic sturgeon because the mesh sizes would have been selective only for subadult Atlantic sturgeon that are commonly found in the lower estuary of larger river systems. In 2006, a similar gill net survey was implemented in the lower river using both 15 cm and 30 cm stretched mesh sinking gill nets. As of January 2007, sixty-two shortnose and seven Atlantic sturgeon have been captured in 1004.39 net hours, 506.18 net hours using the smaller mesh and 498.21 net hours using the larger mesh (M.

Kinnison, University of Maine, personal communication). One of these Atlantic sturgeon, captured in July, may have been an adult based on its size (145 cm TL) and time of capture. Thus, it is probable that a small population of Atlantic sturgeon persists in the Penobscot River. This speculation is supported by archeological evidence that sturgeon were present, occasional observations by fishers, and at least one capture of an adult Atlantic sturgeon by a recreational fisherman (Bangor Daily News 2005; ASSRT 2007).

<u>Estuarial Complex of the Kennebec, Androscoggin, and Sheepscot Rivers – Maine</u>

Atlantic sturgeon were historically abundant in the Kennebec River and its tributaries, including the Androscoggin and Sheepscot rivers (Bigelow and Schroeder 1953; Vladykov and Greeley 1963; Kennebec River Resource Management Plan 1993). In 1849, a directed fishery for Atlantic sturgeon landed 160 mt. Population estimates based on the landings indicated that approximately 10,240 adult sturgeon were present prior to 1843 (Kennebec River Resource Management Plan 1993). Three hundred and thirty-six Atlantic sturgeon (nine adults and 327 subadults) have been captured in the Kennebec River in a multi-filament gill net survey conducted intermittently from 1977 through 2000 (Squiers 2004). During this period, the CPUE of Atlantic sturgeon has increased by a factor of 10 to 25% (CPUE from 1977 to 1981 was 0.30 versus CPUE from 1998 to 2000 at 7.43). The mean length of the 327 subadults was 86.7 cm TL with a range from 48 to 114.5 cm TL (a subadult was classified as being 40 to 130 cm TL). The majority of the adult captures were in July between Merrymeeting Bay and Gardiner. Additional insight concerning the timing of Atlantic sturgeon spawning season emerged from a small commercial fishery on the Kennebec River in South Gardiner near Rolling Dam from June 15 – July 26, 1980. Thirty-one adult Atlantic sturgeon (27 males, four of which were ripe, and four females, one of which was ripe) were captured. Two adults tagged in 1978 by the MEDMR in South Gardiner were recaptured in this fishery (ASSRT 2007).

On July 13, 1994, while sampling for sturgeon, the MEDMR captured seven adult Atlantic sturgeon just below the spillway of the Edwards Dam in Augusta. Five of the seven Atlantic sturgeon (56 to 195 cm TL) were males expressing milt. In 1997, a biweekly trawl survey conducted from April through November by Normandeau Associates in the lower Kennebec River, captured 31 subadults and one adult Atlantic sturgeon. Subadults were also captured by the MEDMR in September of 1997 in the Eastern River (n = 18) and the Cathance River (n = 5), which are freshwater tributaries to the Kennebec, in overnight sets of gill nets (T. Squiers, MEDMR, personal communication). Additional sampling from 2000 through 2003 of the MEDMR inshore groundfish trawl survey collected 13 subadults at the mouth of the Kennebec River, which had the greatest occurrences of Atlantic sturgeon among five regions sampled along the New Hampshire and Maine coasts (Squiers 2003). The most recent capture of an adult Atlantic sturgeon occurred in June of 2005, where a 178 cm TL sturgeon was captured in an American shad gill net (12.7 cm stretched mesh) in Ticonic Bay, just upstream of the confluence between Sebasticook and the Kennebec rivers (Squiers 2005; ASSRT 2007).

The presence of adult male Atlantic sturgeon in ripe condition near the head-of-tide during June and July of 1994, 1997, and possibly in 2005 presents strong evidence that a spawning population still exists in the Kennebec River. While no eggs, larvae, or YOY have been captured in the last 15 years, the presence of subadults (48 cm to over 100 cm TL) in tidal freshwater tributaries and the mid-estuary and mouth of the Kennebec River from at least April – November provides additional evidence that a spawning population of Atlantic sturgeon persists in the Kennebec River estuary (ASSRT 2007).

The only documented occurrence of Atlantic sturgeon in the Androscoggin River was an adult captured and released approximately one km downstream of the Brunswick Dam in 1975. No studies have been conducted to assess whether Atlantic sturgeon are presently utilizing the Androscoggin River for spawning. Subadults have been captured in the Sheepscot River, which may function as a nursery area for Kennebec River Atlantic sturgeon (ASSRT 2007).

Piscataqua River/Great Bay Estuary System – New Hampshire

Few Atlantic sturgeon have been captured in the Piscataqua River (Hoff 1980). A subadult Atlantic sturgeon (57 cm; likely age-1) was captured by New Hampshire Fish and Game (NHFG) in June 1981 at the mouth of the Oyster River in Great Bay (NHFG 1981). Between July 1, 1987, and June 30, 1989, NHFG surveyed the deeper tributaries of the Great Bay Estuary, including the Piscataqua, Oyster, Little and Lamprey rivers, as well as the Great Bay for shortnose sturgeon, using 30.5 m nets (3 m deep, with 14 and 19 cm stretch mesh) that were fished for 146 net days. In 1988, sampling occurred in suspected spawning areas (salinities 0 to 10 ppt) in the spring and in suspected feeding areas (salinities around 24 ppt) in the summer. In 1989, nets were fished in May and June only (salinities 6 to 15 ppt). No Atlantic sturgeon were captured. However, a large gravid female Atlantic sturgeon (228 cm TL) weighing 98 kg (of which 15.9 kg were eggs) was captured by a commercial fisherman in a small mesh gill net at the head-of-tide in the Salmon Falls River in South Berwick, Maine, on June 18, 1990 (D. Grout, NHFG, personal communication). The Salmon Falls River is a shallow tributary of the Piscataqua and is the delineation between New Hampshire and Maine state lines. Since 1990, the NHFG has not observed or received reports of Atlantic sturgeon of any age-class being captured in the Great Bay Estuary and its tributaries (B. Smith, NHFG, personal communication). It is the conclusion of the Atlantic Sturgeon Status Review Team and NHFG biologists that the Great Bay Atlantic sturgeon population is likely extirpated (ASSRT 2007).

Merrimack River – New Hampshire and Massachusetts

Historical reports of Atlantic sturgeon in the Merrimack River include a 104 kg sturgeon taken at Newburyport on September 14, 1938, while netting for blueback herring (Hoover 1938). An intensive gill net survey was conducted in the Merrimack River from 1987 through 1990 to determine annual movements, spawning, summering, and wintering areas of shortnose and Atlantic sturgeon (Kieffer and Kynard 1993).

Thirty-six Atlantic sturgeon were captured (70 to 156 cm TL); most being under 100 cm TL. One dead Atlantic sturgeon was found on June 30, 1990 at the shortnose spawning area in Haverhill, Massachusetts (between rkm 31 and 32). Of 23 subadult Atlantic sturgeon sonically tracked in the river, 11 left the river within seven days, and the rest left by September or October of each year (Kieffer and Kynard 1993). Fish captured in one year were not observed in the river during subsequent years. On June 9, 1998, a 24 inch (estimated length) Atlantic sturgeon was captured and released in the Merrimack River by the United States Fish and Wildlife Service (USFWS) personnel who were conducting a contaminant study on the river (D. Major, USFWS, personal communication). This information provides no evidence of a spawning population of Atlantic sturgeon in the Merrimack River, although it seems that the estuary is used as a nursery area (B. Kynard, USGS Conte Anadromous Fish Research Center, personal communication; ASSRT 2007).

Taunton River – Massachusetts and Rhode Island

Historical records indicate that Atlantic sturgeon spawned in the Taunton River at least until the turn of the century (Tracy 1905). A gill net survey was conducted in the Taunton River during 1991 and 1992 to document the use of this system by sturgeon. Three subadult Atlantic sturgeon were captured but were determined to be non-natal fish (Burkett and Kynard 1993). In June 2004, a fisherman fishing in state waters noted that the first three fathoms of towed up gear held three juvenile Atlantic or shortnose sturgeon (Anoushian 2004). Trawlers fishing in state waters (less than three miles offshore) also occasionally report Atlantic sturgeon captures. Since 1997, only two sturgeon have been captured by the Rhode Island Department of Environmental Management Trawl Survey (RIDEM), one measuring 85 cm TL was captured in 1997 in Narragansett Bay, and another (130 cm TL) was captured in October 2005 in Rhode Island Sound (A. Libby, RIDEM, personal communication). The NMFS observer program has also documented Atlantic sturgeon bycatch off the coast of Rhode Island in Federal waters. Since spawning adults were not found during the expected spawning period of May and June, it is likely that a spawning population of Atlantic sturgeon does not occur in the Taunton River, though the system is used as a nursery area for Atlantic sturgeon (Burkett and Kynard 1993; ASSRT 2007).

Thames River – Connecticut

The Thames River is formed by the joining of the Yantic and Shetucket rivers in Norwich Harbor, Connecticut. Information on abundance of Atlantic sturgeon in the Thames River is scarce. Sturgeon scutes have been documented at an archeological site along the river, and historical reports note sturgeon use by Native Americans. Atlantic sturgeon were reportedly abundant in the system until the 1830s (reviewed in Minta 1992). Whitworth (1996) speculated that populations of both shortnose and Atlantic sturgeon in the Thames were always low because the fall line is located near the limit of saltwater intrusion, leaving little to no freshwater habitat for spawning. The construction of the Greenville Dam in 1825 further restricted available habitat and probably prevented sturgeon from spawning in the river. There have been some reports of low dissolved oxygen (DO) levels during the summer months. The mouth of the river is dredged to accommodate the shipyard, and the channel was recently improved to provide deeper depths to accommodate the Sea Wolf submarine. Subadult Atlantic sturgeon have been captured in the estuary (Whitworth 1996), but it is unlikely that a spawning population is present (ASSRT 2007).

Connecticut River – Massachusetts and Connecticut

Judd (1905) reports that sturgeon were speared at South Hadley Falls in the mid 1700s. There are historical reports of sturgeon migration as far as Hadley, Massachusetts, but regular migration of Atlantic sturgeon beyond Enfield, Connecticut, is doubtful due to presence of significant rapids (Judd 1905). A dam constructed at Enfield in 1827 effectively blocked any migration beyond this point, until 1977 when the dam was breached. Until recently, there has been no evidence that Atlantic sturgeon currently use the Massachusetts portion of the Connecticut River. On August 31, 2006, a 152.4 cm TL Atlantic sturgeon was observed in the Holyoke Dam spillway lift (around rkm 143). The Atlantic sturgeon was not sexed and was described as a subadult (R. Murray, Holyoke Gas and Electric, personal communication). However, based on the size of the Atlantic sturgeon it is possible that the fish was a mature adult. This is the first time an Atlantic sturgeon has been reported at the Holyoke Dam fish lift (ASSRT 2007).

Six juvenile fish (9 to 11 kg) were reportedly taken opposite Haddam Meadows in 1959, but it is unclear if these were Atlantic or shortnose sturgeon. As late as the 1980s, the Connecticut Department of Environmental Protection (CTDEP) fisheries staff reported occasional visual observations of Atlantic sturgeon below the Enfield Dam during May and June. From 1984 to 2000, the CTDEP studied the abundance, locations, and seasonal movement patterns of shortnose sturgeon in the lower Connecticut River and Long Island Sound (Savoy and Pacileo 2003). Sampling was conducted using gill nets ranging from 10 to 18 cm stretched mesh in the lower Connecticut River (1988 to 2005) and a stratified random-block designed trawl survey (12.8 m from 1984 to 1990, and 15.2 m from 1990 to 2005) in the Long Island Sound (also referred to as the LIS Trawl Survey). One hundred and thirty-one Atlantic sturgeon were collected from the lower Connecticut River gill net survey, and average lengths of fish reported from 1988 to 2000 were 77 cm FL (51 to 107 cm FL). The majority of these subadult Atlantic sturgeon were captured in the lower river (between rkm 10 and 26) within the summer range of the salt wedge (Savoy and Shake 1993). A total of 347 fish were collected in the LIS Trawl Survey from 1984 through 2004, of these with reported lengths (1984 to 2000) the mean length was 105 cm FL (ranging from 63 to 191 cm FL). Data from 1984 through 2000, indicated that 68% of the Atlantic sturgeon captured in the trawl survey came from the Central Basin (off Faulkner Island), while 6% of catches occurred in northern portions of the LIS survey near the mouth of the Connecticut River (ASSRT 2007).

While research efforts have not specifically investigated the occurrence of Atlantic sturgeon in the upper Connecticut River, the species has never been collected incidentally in this region during extensive sampling for shortnose sturgeon. Occasional reports, sightings, and capture of large Atlantic sturgeon (150 to 300 cm) are made, but most Atlantic sturgeon captured within tidal waters or freshwater in Connecticut are consistent with the size and seasonal locations of immature Atlantic sturgeon from the Hudson River (Savoy 1996). Based on the lack of evidence of spawning adults, stocks of Atlantic sturgeon native to Connecticut waters are believed to be extirpated (Savoy 1996; ASSRT 2007).

Housatonic River – Connecticut

Coffin (1947) reports that Atlantic sturgeon were abundant in the Housatonic River and were captured by Native Americans. According to Whitworth (1996), there was a large fishing industry for sturgeon in this basin, and subadults have been captured in the estuary. Atlantic sturgeon likely spawned at a natural fall (Great Falls) at rkm 123 until 1870 when the Derby Dam was constructed at rkm 23.5. The Derby Dam restricted access to approximately 100 km, or 81%, of historical habitat. The Housatonic has not been systematically sampled for sturgeon in recent years (last 15 years), but it is unlikely that a spawning population is present (USFWS-NMFS 1998; ASSRT 2007).

Hudson River – New York

Atlantic sturgeon in the Hudson River have supported subsistence and commercial fishing since colonial times (Kahnle et al. 1998). No data on abundance of juveniles are available prior to the 1970s; however, catch depletion analysis estimated conservatively that 6,000 to 6,800 females contributed to the spawning stock during the late 1800s (Secor 2002, Kahnle et al. 2005). Two estimates of immature Atlantic sturgeon have been calculated for the Hudson River stock, one for the 1976 year class and one for the 1994 year class. Dovel and Berggren (1983) marked immature fish from 1976 to 1978. Estimates for the 1976 year class at age one ranged from 14,500 to 36,000 individuals (mean of 25,000). In October of 1994, the New York State Department of Environmental Conservation (NYSDEC) stocked 4,929 marked age-0 Atlantic sturgeon, provided by a USFWS hatchery, into the Hudson Estuary at Newburgh Bay. These fish were reared from Hudson River brood stock. In 1995, Cornell University sampling crews collected 15 stocked and 14 wild age-1 Atlantic sturgeon (Peterson et al. 2000). A Petersen mark-recapture population estimate from these data suggests that there were 9,529 (95% CI = 1,916 to 10,473) age-0 Atlantic sturgeon in the estuary in 1994. Since 4,929 were stocked, 4,600 fish were of wild origin, assuming equal survival for both hatchery and wild fish and that stocking mortality for hatchery fish was zero. Estimates of spawning adults were also calculated by dividing the mean annual harvest from 1985 to 1995 by the exploitation rate (u). The mean annual spawning stock size (spawning adults) was 870 (600 males and 270 females) (Kahnle et al. *In press*; ASSRT 2007).

Current abundance trends for Atlantic sturgeon in the Hudson River are available from a number of surveys. From July to November during 1982 to 1990 and 1993, the NYSDEC sampled the abundance of juvenile fish in Haverstraw Bay and the Tappan Zee Bay. The CPUE of immature Atlantic sturgeon was 0.269 in 1982 and declined to zero by 1990. The American shad gill net fishery in the Hudson River estuary, conducted from early April to late May, incidentally captures young Atlantic sturgeon (< 100 cm) and therefore, has been monitored by onboard observers since 1980. Annual CPUE data from the observer program were summarized as total observed catch/total observed effort. Catch-per-unit-of-effort of Atlantic sturgeon as bycatch was greatest in the early 1980s and decreased until the mid 1990s. It has gradually begun to increase since that time (ASSRT 2007).

Hudson River Valley utilities (Central Hudson Electric and Gas Corp., Consolidated Edison Company of New York, Inc., New York Power Authority, Niagara Mohawk Power Corporation, Orange and Rockland Utilities, Inc.) conduct extensive river-wide fishery surveys to obtain data for estimating impacts of power plant operations. Detailed survey descriptions are provided in the utilities' annual reports (CONED 1997). Two surveys regularly catch sturgeon, despite the fact that these surveys were not specifically designed to capture sturgeon. The Long River Survey (LRS) samples ichthyoplankton river-wide from the George Washington Bridge (rkm 19) to Troy (rkm 246) using a stratified random design (CONED 1997). These data, which are collected from May through July, provide an annual index of juvenile Atlantic sturgeon in the Hudson River estuary since 1974. The Fall Shoals Survey (FSS), conducted from July through October by the utilities, calculates an annual index of the number of fish captured per haul. Between 1974 and 1984, the shoals in the entire river (rkm 19 to 246) were sampled by epibenthic sled; in 1985 the gear was changed to a three-meter beam trawl. Length data are only available for the beam trawl survey from 1989 to the present; fish length ranged from 10 to 100 cm TL, with most fish less than 70 cm TL. Based on these length data, it seems that ages-0 (YOY), 1, and 2 sturgeon are present in the river. Indices from utility surveys conducted from 1974 to the present (LRS and FSS) indicate a trend consistent with NYSDEC American shad monitoring data. Abundance of young juvenile Atlantic sturgeon has been declining, with CPUE peaking at 12.29 in 1986 (peak in this survey) and declining to 0.47 in 1990. Since 1990, the CPUE has ranged from 0.47 to 3.17, increasing in recent years to 3.85 (2003). In 2000, the NYSDEC created a sturgeon juvenile survey program to supplement the utilities' survey; however, funds were cut in 2000, and the USFWS was contracted in 2003 to continue the program. In 2003 to 2005, 579 juveniles were collected (N = 122, 208, and 289, respectively) (Sweka et al. 2006). Pectoral spine analysis showed they ranged from one to eight years of age, with the majority being ages two and six. None of the captures were found to be young-of-the-year (YOY; smaller than 41 cm TL) (ASSRT 2007).

Indices for post-migrant Atlantic sturgeon are provided by the New Jersey Bureau of Marine Fisheries from surveys of the coastal waters along the entire state (Sandy Hook to Delaware Bay). Since 1988 when the survey was initiated, a total of 96 Atlantic sturgeon have been captured. Abundances of post-migrants seem to be declining as CPUE has decreased from a high of 8.75 in 1989 to 1.5 in 2003. This trend differs from Hudson River Fall Shoals Utility Survey, which indicated an increasing or stable trend over the last several years (ASSRT 2007).

All available data on abundance of juvenile Atlantic sturgeon in the Hudson River estuary (i.e., mark/recapture studies, bycatch data from commercial gill net fishery, and utilities sampling) indicate a substantial drop in production of young since the mid-1970s. The greatest decline seemed to occur in the middle to late 1970s, followed by a secondary drop in the late 1980s. Sturgeon are still present, and juveniles (age-0 (YOY), 1, and 2 years) were captured in recent years and a slight increasing trend in CPUE has been observed. The capture of YOY sturgeon in 1991, 1993 to 1996, and 2003, provides evidence of successful spawning (ASSRT 2007).

Delaware River – New Jersey, Delaware, and Pennsylvania

The Delaware River, flowing through New Jersey, Delaware, Pennsylvania and into Delaware Bay, historically may have supported the largest stock of Atlantic sturgeon of any Atlantic coastal river system (Kahnle et al. 1998; Secor and Waldman 1999; Secor 2002). Prior to 1890, it is expected that more than 180,000 adult females were spawning in the Delaware River (Secor and Waldman 1999, Secor 2002). Juveniles were once abundant enough to be considered a nuisance bycatch of the American shad fishery. Very little is known about adult stock size and spawning of Atlantic sturgeon in the Delaware river; however, based on reported catches in gill nets and by harpoons during the 1830s, they may have spawned as far north as Bordentown, south of Trenton, New Jersey (Pennsylvania Commission of Fisheries 1897). A recent sonic tracking project, on-going in 2006, has reported at least one adult Atlantic sturgeon migrating to Bordentown during the spawning season (D. Fox, Delaware State University, personal communication). Borodin (1925) reported that running-ripe sturgeon were captured near Delaware City, Delaware adjacent to Pea Patch Island. Spawning grounds with appropriate substrate occurred near Chester, Pennsylvania. Ryder (1888) suggested that juvenile Atlantic sturgeon used the tidal freshwater reach of the estuary as a nursery area. Lazzari et al. (1986) reported that the Roebling-Trenton stretch of the river may be an important nursery area for the species (ASSRT 2007).

The current abundance of all Atlantic sturgeon life stages in the Delaware River has been greatly reduced from the historical level. Brundage and Meadows (1982) recorded 130 Atlantic sturgeon captures between the years of 1958 through 1980. The Delaware Division of Fish and Wildlife (DNREC) began sampling Delaware Bay in 1966 by bottom trawl and have rarely captured Atlantic sturgeon. During the period from 1990 to 2004, the trawl survey captured 17 Atlantic sturgeon (Murphy 2005). However, there are several areas within the estuary where juvenile sturgeon regularly occur. Lazzari et al. (1986) frequently captured juvenile Atlantic sturgeon from May to December in the upper tidal portion of the river below Trenton, New Jersey (N = 89, 1981 to 1984). In addition, directed gill net surveys by DNREC from 1991 through 1998 consistently took juvenile (N > 1,700 overall) Atlantic sturgeon in the lower Delaware River near Artificial Island and Cherry Island Flats from late spring to early fall (Shirey et al. 1999). The number of fish captured in the lower river annually has declined dramatically throughout this time period from 565 individuals in 1991 to 14 in 1998. Population estimates based on mark and recapture of juvenile Atlantic sturgeon declined from a high of 5,600 in 1991 to less than 1,000 in 1995; however, it is important to note that population estimates violated most tagging study assumptions and should not be used as unequivocal evidence that the population has declined dramatically. No population estimates are available from 1996 and 1997, given the low number of recaptures. Voluntary logbook reporting of Atlantic sturgeon bycatch in the spring gill net fishery indicate that abundance varies year to year with no indication of decline or increase mainly because the number of bycatch reports varies considerably by commercial fishers reporting. Bycatch data are represented as the average bycatch per fisher per year (total bycatch/number of fishers). An annual small mesh gill net survey began in 1991 until 1998 when sampling was restricted to every three years in the lower Delaware River. The results of this study indicated that CPUE (fish per gill net hour) estimates have declined from 32 fish per effort hour in 1991 to only 2 fish per effort hour in 2004 (ASSRT 2007).

Carcasses of large adult fish (> 150 cm TL) are commonly reported along the lower Delaware River and upper Delaware Bay during the historic spawning season (G. Murphy, Delaware Division of Fish and Wildlife, personal communication). Fifteen adult size fish have been documented since 1994, including several gravid females and males. A 2.4 m female Atlantic sturgeon was found dead on June 14, 1994, adjacent to Port Penn; ageing of a pectoral spine indicated it was approximately 25 years old (D. Secor, University of Maryland, personal communication). Three years later, a second female sturgeon was found in late spring/early summer of 1997 adjacent to Port Penn, just south of the eastern end of the Chesapeake/Delaware Canal. A male sturgeon carcass was found on May 19, 1997, just north of the mouth of the Cohansey River, on Beechwood Beach; it seemed that the fish was cut in half by the propeller of a large vessel. Gonadal tissue and a pectoral spine were collected and sent to USFWS-Northeast Fisheries Center (NEFC), Fish Technology Section, Lamar, Pennsylvania, for analysis, where it was confirmed to be a male (W. Andrews, New Jersey Division of Fish, Game, and Wildlife, personal communication). In 2005, DNREC began tracking reported sturgeon mortalities during the spawning season. During the first year, six adults were found dead washed ashore in May 2005, including two from Woodland Beach (approximately 250 cm and 170 cm TL), one from Artificial Island (larger than 180 cm TL), one from South Bowers Beach (205 cm TL), one from Conch Bar (160 cm TL), and one from Slaughter Beach (160 cm TL). Six additional carcasses, presumed adults, were found during April through May 2006, including a gravid female at Augustine Beach (144 cm), a gravid male at Sleusch Ditch (180 cm), one at South Bowers Beach (119 cm), one at Brockonbridge Gut (112 cm), one at Kitts Hummock (208 cm), and one at Little Tinicum Island, Pennsylvania (106 cm). The majority of adults documented had substantial external injuries and were severed (ASSRT 2007).

In addition to the carcasses reported annually during the spawning season, several males were captured by directed gill net efforts and a reward program conducted by Delaware State University during April and May 2006. These males were collected in the lower Delaware River and upper Delaware Bay and were implanted with sonic transmitters to assist in determining spawning locations in the Delaware River (D. Fox, Delaware State University, personal communication). Although catch rates declined throughout the mid 1990s, the mature adults documented within the Delaware System provide evidence that a reproducing population exists. It is speculated, however, that the abundance of subadults within the Delaware River during the 1980s and early 1990s was the result of a mixture of stocks including the Hudson River stock. However, genetic data indicate that the Delaware River has a distinct genetic signature of a remnant population (Waldman et al. 1996a; Wirgin 2006; King supplemental data 2006; ASSRT 2007).

Chesapeake Bay and Tributaries (Potomac, Rappahannock, York, James, Susquehanna, Nanticoke) – Pennsylvania, Maryland, and Virginia

Historically, Atlantic sturgeon were common throughout the Chesapeake Bay and its tributaries (Kahnle et al. 1998; Wharton 1957; Bushnoe et al. 2005). There are several newspaper accounts of large sturgeon in the lower reaches of the Susquehanna River from 1765 to 1895, indicating that at one time, Atlantic sturgeon may have spawned there. Commercial landings data during the 1880s are available for the Rappahannock (8 mt), York (23 mt), and James (49 mt) providing evidence that Atlantic sturgeon were historically present in these rivers as well (Bushnoe et al. 2005). Historical harvests were also reported in the Patuxent, Potomac, Choptank, Nanticoke, and Wicomico/Pocomoke rivers (S. Minkkinen, USFWS, personal communication). Prior to 1890, when a sturgeon fishery began, Secor (2002), using U.S. Fish Commission landings, estimated approximately 20,000 adult females inhabited the Chesapeake Bay and its tributaries (ASSRT 2007).

For the past several decades, state fishery agencies and research facilities operating in the Chesapeake Bay have conducted extensive finfish sampling surveys in the mainstem Bay and all major tributaries. These surveys occurred in all seasons and were conducted using many gear types, including trawls, seines, and gill nets. While no surveys were directed at sturgeon, incidental captures were recorded. These data supplement reports of sturgeon captures from commercial fishers using gill nets, pound nets, and fyke nets with occasional visual observations of large sturgeon, including carcasses found on beaches during the summer (ASSRT 2007).

A mixed stock analysis, performed from nDNA microsatellite markers, indicated that the Chesapeake Bay population was comprised of three main stocks: 1) Hudson River (23 to 30%), 2) Chesapeake Bay (0 to 35%), and 3) Delaware River (17 to 27%) (King et al. 2001). The contribution of fish with Chesapeake Bay origin fish, which had not been identified in previous genetic studies, indicates the likely existence of a reproducing population within the Bay. This is further supported and substantiated by the capture of young juveniles at the mouth of the James River and two YOY Atlantic sturgeon captured in the river in 2002 and 2004 (Florida Museum of Natural History 2004; A. Spells, USFWS, personal communication; ASSRT 2007).

Several sturgeon sightings were made by commercial fishers and researchers between 1978 and 1987 near the Susquehanna River mouth. A deep hole (19 m) on the Susquehanna River near Perryville, Maryland also supported a limited sturgeon fishery (R. St. Pierre, USFWS retired, personal communication). Maryland Department of Natural Resources (DNR) personnel reported a large mature female Atlantic sturgeon in the Potomac in 1970 and another in the Nanticoke River in 1972 (H. Speir, Maryland DNR, personal communication; ASSRT 2007).

A Virginia Institute of Marine Science (VIMS) trawl survey was initiated in 1955 to investigate finfish dynamics within the Chesapeake Bay; the survey was standardized in 1979. Since 1955, 40 Atlantic sturgeon have been captured, 16 of which were captured since 1990, and two of these collections may have been YOY based on size. No fish were captured between 1990 and 1996; however, seven were captured in 1998. In subsequent years, catch declined ranging between zero and three fish per year. Similarly, American shad monitoring programs (independent stake gill net survey) also recorded a spike in Atlantic sturgeon bycatch that peaked in 1998 (N = 34; 27 from James River) and declined dramatically in later years to only one to three sturgeon being captured in each year from 2002 to 2004. These observations could be biased by stocking 3,200 juveniles in the Nanticoke River in 1996; however, the capture of wild fish in the Maryland Reward Tagging program conducted from 1996 to present shows identical rates of capture for wild fish (ASSRT 2007).

The Maryland reward tagging has resulted in the capture of 1,700 Atlantic sturgeon. Five hundred and sixty seven of these fish were hatchery fish, of which 462 were first time captures (14% recapture rate), the remaining captures (1,133) were wild. However, none of these 1,700 Atlantic sturgeon were considered YOY based on length data (S. Minkkinen, USFWS, personal communication). Similarly, Virginia initiated a reward tagging program in 1996 through 1998. The majority of their recaptures were wild Atlantic sturgeon taken from the lower James and York rivers in the 20 to 40 cm size range and are believed to be YOY (A. Spells, USFWS, personal communication). Captures of YOY and age-1 sturgeon in the James River during 1996 and 1997 suggest spawning has occurred in that system. Since then, captures from the reward program have varied, declining from 1999 to 2002 and then increasing in 2005 to levels similar to that of 1998 and with record levels during 2006. Further evidence that spawning may have occurred recently is provided by three carcasses of large adults found in the James River in 2000 to 2003, the discovery of a 213 cm carcass of an adult found in the Appomattox River in 2005, as well as the release of a 2.4 m Atlantic sturgeon near Hoopers Island (Chesapeake Bay) in April, 1998 (S. Minkkinen, USFWS, personal communication; ASSRT 2007).

These data indicate that some of the Chesapeake Bay tributaries may continue to support spawning populations as evidenced by YOY captures (James River) and carcasses of mature adults being found occasionally within the Bay during the spawning season. Commercial fishers have regularly reported observations of YOY or age-1 juveniles in the York River over the past few years (K. Place, commercial fisherman, personal communication). In 2006, tissue samples from 38 juvenile Atlantic sturgeon measuring between 500 to 600 mm TL (around age-1) were haplotyped and genotyped by researchers (I. Wirgin – NIEM, and T. King – USGS, supplemental data 2006). These 38 juveniles from the York River were significantly different ($P < 0.01$) from neighboring subpopulations including the James River subpopulation, based on frequency differences in mtDNA and nDNA markers. However, the York River does not contain unique mtDNA haplotypes differentiating it directly from other sturgeon populations, and the population could not be differentiated from the James River population using classification techniques. Additionally, a review of spawning habitat availability in the Chesapeake Bay and its tributaries indicated that spawning habitat is available in the James, York, and Appomattox rivers (Bushnoe et al. 2005). Therefore, the above information provides some evidence that a spawning population may exist in the York River, as the population exhibits significantly different haplotype frequencies from its neighboring subpopulations, and spawning habitat appears to be available. However, there is a possibility that samples taken from the York River were of a mixed stock since they measured 500 to 600 mm in total length (the size range of migratory subadults) and many of the collections were taken from the mouth of the river (ASSRT 2007).

North Carolina Rivers

Historically, Atlantic sturgeon were abundant in most North Carolina coastal rivers and estuaries; the largest fishery occurring in the Roanoke River/Albemarle Sound system and in the Cape Fear River (Kahnle et al. 1998). Historic landing records from the late 1800s indicated that Atlantic sturgeon were very abundant within the Albemarle Sound (around 61.5 mt/yr); however, these landings are relatively small compared to the Delaware fishery (around 2,700 mt/yr) (Secor 2002). Abundance estimates derived from these historical landings records indicated that between 7,200 and 10,500 adult females were present within North Carolina prior to 1890 (Armstrong and Hightower 2002; Secor 2002).

Albemarle Sound (Roanoke and Chowan/Nottoway Rivers) – North Carolina

Historic and current survey data indicate that spawning occurs in the Roanoke River/Albemarle Sound system, where both adults and small juveniles have been captured. Since 1990, the NC Division of Marine Fisheries (NCDMF) has conducted the Albemarle Sound Independent Gill Net Survey (IGNS), initially designed to target striped bass. The survey is conducted from November to May, using a randomized block sampling design and employing 439 m of gill net, both sinking and floating, with stretched mesh sizes ranges from 63.5 mm (2.5 in) to 254 mm (10 in). Since 1990, 842 sturgeon have been captured ranging from 15.3 to 100 cm FL, averaging 47.2 cm FL. One hundred and thirty-three (16%) of the 842 sturgeon captured could be classified as YOY (≤ 41 cm TL, ≤ 35 cm FL); the others were subadults. Incidental take of Atlantic sturgeon in the IGNS indicate that the subpopulation has been increasing in recent years (1990 to 2000), but since then recruitment has dramatically declined. Similarly, the North Carolina Division of Marine Fisheries (NCDMF) Observer Program documented the capture of 30 Atlantic sturgeon in large and small mesh gill nets; two of these individuals being YOY (less than 410 mm TL) (Blake Price, NCDMF, personal communication; ASSRT 2007).

In 1997 and 1998, North Carolina State University (NCSU) researchers characterized the habitat use, growth, and movement of juvenile Atlantic sturgeon (Armstrong and Hightower 2002). Their survey collected 107 Atlantic sturgeon, of which 15 (14%) could be considered YOY (≤ 41 cm TL or 35 cm FL). Young juveniles were observed more often over organic rich mud bottoms and at depths of 3.6 to 5.4 meters. Adult running ripe sturgeon have not been collected in the Roanoke River even though the North Carolina Wildlife Resources Commission (NCWRC) has sampled the spawning grounds since the 1990s during their annual striped bass electrofishing survey. However, in 2005, an angler captured a YOY (39 cm TL) Atlantic sturgeon in the Roanoke River, near the city of Jamesville, North Carolina. These multiple observations of YOY from the Albemarle Sound and Roanoke River provide evidence that spawning continues, and catch records indicate that this population seemed to be increasing until 2000, when recruitment began to decline (ASSRT 2007).

Pamlico Sound (Tar and Neuse Rivers) – North Carolina

Evidence of spawning was reported by Hoff (1980), who noted captures of very young juveniles in the Tar and Neuse rivers. More recently, two juveniles (approximately 45 and 60 cm TL) were observed dead on the bank of Banjo Creek, a tributary to the Pamlico system (B. Brun, USFWS and U.S. Army Corps of Engineers (retired), personal communication). An independent gill net survey, following the Albemarle Sound IGNS methodology, was initiated in 2001. Collections were low during the periods of 2001 to 2003, ranging from zero to one fish per year. However, in 2004, this survey collected 14 Atlantic sturgeon ranging from 460 to 802 mm FL, and averaging 575 mm FL. During the same time period (2002 to 2003), four Atlantic sturgeon (561 – 992 mm FL) were captured by NCSU personnel sampling in the Neuse River (Oakley 2003). Similarly, the NCDMF Observer Program documented the capture of 12 Atlantic sturgeon in the Pamlico Sound from April 2004 to December 2005; none of these were YOY or spawning adults, averaging approximately 600 mm TL (Blake Price, NCDMF, personal communication).

The incidental capture of two juvenile Atlantic sturgeon in the Tar (1) and Neuse rivers (1) in 2005 also provides evidence that spawning may be occurring within those rivers. The Tar River juvenile was captured near Greenville, North Carolina, by an angler and reported to be less than 40 cm TL (P. Kornegay, NCWRC, personal communication). The other juvenile was captured in an illegal gill net set upstream of New Bern, North Carolina, and measured 46 cm TL. Although not confirmed as YOY, these two captures are important in that they represent the only evidence of possible spawning activities within the Pamlico Sound Drainage for at least the last 15 years (ASSRT 2007).

Cape Fear River – North Carolina

A gill net survey for adult shortnose and juvenile Atlantic sturgeon was conducted in the Cape Fear River drainage from 1990 to 1992, and replicated 1997 to 2005. Each sampling period included two overnight sets (checked every 24 hours). The 1990 to 1992 survey captured 100 Atlantic sturgeon below Lock and Dam #1 (rkm 95) for a CPUE of 0.11 fish/net-day. No sturgeon were collected during intensive sampling above Lock and Dam #1. In 1997, 16 Atlantic sturgeon were captured below Lock and Dam #1, an additional 60 Atlantic sturgeon were caught in the Brunswick (a tributary of the Cape Fear River), and 12 were caught in the Northeast Cape River (Moser et al. 1998). Relative abundance of Atlantic sturgeon below Lock and Dam #1 seemed to have increased dramatically since the survey was conducted in 1990 to 1992 (Moser et al. 1998) as the CPUE of Atlantic sturgeon was two to eight times greater during 1997 than in the earlier survey. Since 1997, Atlantic sturgeon CPUE has been gradually increasing; a regression analysis revealed that CPUE doubled between the years of 1997 (around 0.25 CPUE) and 2003 (0.50 CPUE) (Williams and Lankford 2003). This increase may reflect the effects of North Carolina's ban on Atlantic sturgeon fishing that began in 1991; however, the increase in CPUE may also be artificial as these estimates are similar among years except in 2002 (large increase) that likely skewed the regression analysis.

In 2003, the NCDMF continued the sampling program (Cape Fear River Survey) and have collected 91 Atlantic sturgeon (427 to 1473 mm FL) (ASSRT 2007).

Adult Atlantic sturgeon have been observed migrating upstream in the fall within the Cape Fear River, indicating that there may be two spawning seasons or some upstream overwintering may be occurring (M. Williams, formerly of University of North Carolina at Wilmongton, personal communcation). One large Atlantic sturgeon was tracked moving upstream in the Black River, which is a tributary of the Cape Fear River, in early October. Moreover, all of the largest sturgeon collected by University of North Carolina at Wilmington personnel were later captured only during September and October in both the Cape Fear and Northeast Cape Fear rivers. Finally, a carcass of an adult female Atlantic sturgeon with fully developed ovaries was discovered in an area well upstream of the saltwater-freshwater interface in mid-September. Studies in other river systems have also demonstrated that some sturgeon will participate in upstream spawning migrations in the fall (Rogers and Weber 1995; Weber and Jennings 1996; Moser et al. 1998; ASSRT 2007).

South Carolina Rivers

Historically, Atlantic sturgeon were likely present in many South Carolina river/estuary systems, but it is not known where spawning occurred. Secor (2002) estimated that 8,000 spawning females were likely present prior to 1890, based on US Fish Commission landing records. Since the 1800s, however, populations have declined dramatically (Collins and Smith 1997). During the last two decades, Atlantic sturgeon have been observed in most South Carolina coastal rivers, although it is not known if all rivers support a spawning subpopulation (Collins and Smith 1997; ASSRT 2007).

Winyah Bay (Waccamaw, Great Pee Dee, and Sampit Rivers) – South Carolina

Recent shortnose sturgeon sampling (using 5, 5.5, 7, and 9 inch stretched mesh experimental gill nets; 16’ otter trawl) conducted in Winyah Bay captured two sub-adult Atlantic sturgeon during 4.2 hrs of effort in 2004. Captures of age-1 juveniles from the Waccamaw River during the early 1980s suggest that a reproducing population of Atlantic sturgeon may persist in that river, although the fish could have been from the nearby Great Pee Dee River (Collins and Smith 1997). In 2003 and 2004, nine Atlantic sturgeon (48.4 to 112.2 cm FL) were captured in the Waccamaw River during the South Carolina Department of Natural Resources (SCDNR) annual American shad gill net survey, although none were considered spawning adults or YOY. However, Collins et al. (1996) note that unlike northern populations, in South Carolina, YOY are considered to be less than 50 cm TL or 42.5 cm FL, as growth rates are greater in the warmer southern waters compared to cooler northern waters. Therefore, the capture of a 48.4 cm FL sturgeon provides some evidence that YOY may be present in the Waccamaw River and some evidence of a spawning subpopulation. Lastly, watermen on the lower Waccamaw and Pee Dee rivers have observed jumping sturgeon, which suggest that rivers either serve as a nursery/feeding habitat or support an extant subpopulation(s) (W. Laney, USFWS, personal communication; ASSRT 2007).

Until recently, there was no evidence that Atlantic sturgeon spawned in the Great Pee Dee River, although subadults were frequently captured and large adults were often observed by fishers. However, a fishery survey conducted by Progress Energy Carolinas Incorporated captured a running ripe male in October of 2003 and observed other large sturgeon, perhaps revealing a fall spawning run (ASSRT 2007).

There are no data available regarding the presence of YOY or spawning adult Atlantic sturgeon in the Sampit River, although it did historically support a subpopulation and is thought to serve as a nursery ground for local stocks (ASSRT 2007).

Santee and Cooper Rivers – South Carolina

The capture of 151 subadults, including age-1 juveniles, in the Santee River in 1997 suggests that an Atlantic sturgeon population exists in this river (Collins and Smith 1997). This is supported by three adult Atlantic sturgeon carcasses found above the Wilson and Pinopolis dams in Lakes Moultrie (Santee-Cooper reservoirs) during the 1990s (M. Collins, SCDNR, personal communication). Although shortnose sturgeon spawning above the dam has been documented, there is scant information to support existence of a land-locked subpopulation of Atlantic sturgeon. In 2004, 15 subadult Atlantic sturgeon were captured in shortnose sturgeon surveys during 156.6 hours of effort conducted in the Santee estuary. The previous winter, four juvenile (YOY and subadults) Atlantic sturgeon were captured (360 to 657 mm FL) from the Santee (N = 221) and Cooper (N = 3) rivers. These data support previous hypotheses that a fall spawning run occurs within this system, similar to that observed in other southern river systems. However, SCDNR biologists are skeptical as to whether these smaller sturgeon (360 and 378 mm FL) from the Santee-Cooper are resident YOY as flood waters from the Pee Dee or Waccamaw River could have transported these YOY to the Santee-Cooper system via Winyah Bay and the Intercoastal Waterway (ICW) (McCord 2004; ASSRT 2007).

Ashley River – South Carolina

The Ashley River, along with the Cooper River, drains into Charleston Bay; only shortnose sturgeon have been sampled in these rivers. While the Ashley River historically supported an Atlantic sturgeon spawning subpopulation, it is unknown whether the subpopulation still exists (ASSRT 2007).

ACE Basin (Ashepoo, Combahee, and Edisto Rivers) – South Carolina

From 1994 through 2001, over 3,000 juveniles have been collected in the ACE Basin including 1,331 YOY sturgeon (Collins and Smith 1997; M. Collins, SCDNR, personal communication). Sampling for adults began in 1997, with two adult sturgeon captured in the first year of the survey, including one gravid female (234 cm TL) captured in the Edisto River and one running ripe male (193 cm TL) captured in the Combahee River. The running ripe male in the Combahee River was recaptured one week later in the Edisto River, which suggests that the three rivers that make up the ACE basin may support a single subpopulation that spawns in at least two of the rivers. In 1998, an additional 39 spawning adults were captured (M. Collins, SCDNR, personal communication). These captures show that a current spawning subpopulation exists in the ACE Basin as both YOY and spawning adults are regularly captured (ASSRT 2007).

Broad/Coosawatchie River – South Carolina

There has been little or no scientific sampling for Atlantic sturgeon in the Broad/Coosawatchie River. One fish of unknown size was reported from a small directed fishery during 1981 to 1982 (Smith and Dingley 1984; ASSRT 2007).

Savannah River – South Carolina and Georgia

The Savannah River supports a reproducing subpopulation of Atlantic sturgeon (Collins and Smith 1997). According to the NOAA-National Ocean Service, 70 Atlantic sturgeon have been captured since 1999 (J. Carter, National Ocean Service, supplemental data 2006). Twenty-two of these fish have been YOY (less than 410 mm TL). A running ripe male was captured at the base of the dam at Augusta during the late summer of 1997, which supports the hypothesis that spawning occurs there in the fall (ASSRT 2007).

Georgia Rivers

Prior to the collapse of the fishery in the late 1800s, the sturgeon fishery was the third largest fishery in Georgia. Secor (2002) estimated from U.S. Fish Commission landing reports that approximately 11,000 spawning females were likely present prior to 1890. The sturgeon fishery was mainly centered on the Altamaha River, and in more recent years, peak landings were recorded in 1982 (13,000 lbs). Based on juvenile presence and abundance, the Altamaha seems to currently support one of the healthiest Atlantic sturgeon subpopulations in the southeast (D. Petersen, University of Georgia, personal communication). Atlantic sturgeon are also present in the Ogeechee River; however, the absence of age-1 fish during some years and the unbalanced age structure suggests that the subpopulation is highly stressed (Rogers and Weber 1995). Spawning adults have been collected in recent years from the Satilla River (Waldman et al. 1996b). Recent sampling of the St. Mary's River failed to locate any sturgeon, which suggests that the subpopulation may be extirpated (Rogers et al. 1994). In Georgia, Atlantic sturgeon are believed to spawn in the Savannah, Ogeechee, Altamaha, and Satilla rivers (ASSRT 2007).

Ogeechee River – Georgia

Previous studies have shown the continued persistence of Atlantic sturgeon in this river, as indicated by the capture of age +1 fish. Sampling efforts (including 1991 to 1994, 1997, and 1998) to collect age-1 sturgeon as part of the Savannah River genetics study suggest that juvenile abundance is rare with high inter-annual variability, indicating spawning or recruitment failure. However, the Army's Environmental and Natural

Resources Division (AENRD) at Fort Stewart, Georgia, collected 17 sturgeon in 2003 considered to be YOY (less than 30 cm TL) and an additional 137 fish in 2004, using a 30 m x 2 m experimental gill net (3.8, 7.7, 12.7, 15.2, 17.8 cm stretched mesh). Most of these fish were juveniles; however, nine of these fish measured less than 41 cm TL and were considered YOY. In 2003, 17 sturgeon captured in this survey were also considered YOY (reported as less than 30 cm TL). The AENRD survey provides the most recent captures of YOY in the Ogeechee (ASSRT 2007).

Altamaha River – Georgia

The Altamaha River supports one of the healthiest Atlantic sturgeon subpopulations in the Southeast, with over 2,000 subadults captured in trammel nets, 800 of which were nominally age-1 as indicated by size. Independent monitoring of the American shad fishery also documents the incidental take of Atlantic sturgeon within the river. Using these data, the subpopulation does not seem to be increasing or decreasing, as catch trends are variable (ASSRT 2007).

A survey targeting Atlantic sturgeon was initiated in 2003 by the University of Georgia. Trammel nets (91 m x 3 m) and gill nets were set in the lower 27 rkm of the Altamaha River, and were fished for 20 to 40 minutes during slack tides only. Sampling for adults was conducted using large mesh-gill nets set by local commercial fishermen during the months of April through May 2003. During 2005, similar gill nets were drift set during slack tides to supplement catches. As of October 2005, 1,022 Atlantic sturgeon have been captured using these gear types (trammel and large gill nets). Two hundred and sixty seven of these fish were collected during the spring spawning run in 2004 (N = 74 adults) and 2005 (N = 139 adults). From these captures, 308 (2004) and 378 (2005) adults were estimated to have participated in the spring spawning run, which is 1.5% of Georgia's historical spawning stock (females) that were estimated from U.S. Fish Commission landing records (Schuller and Peterson 2006; Secor 2002; ASSRT 2007).

Satilla River – Georgia

Sampling results indicate that the Atlantic sturgeon subpopulation in the Satilla River is highly stressed (Rogers and Weber 1995). Only four spawning adults or YOY, which were used for genetic analysis (Ong et al. 1996), have been collected from this river since 1995 (ASSRT 2007).

St. Mary's River – Georgia and Florida

The lack of Atlantic sturgeon captures (in either scientific sampling and/or as bycatch in other fisheries) in the St. Mary's River indicates that the river neither supports a spawning subpopulation nor serves as a nursery ground for Atlantic sturgeon (Rogers and Weber 1995; Kahnle et al. 1998). However, no directed sampling surveys have been conducted in recent Years (ASSRT 2007).

St. Johns River – Florida

In the 1970s and 1980s, there were several reports of Atlantic sturgeon being captured by commercial fishermen, although these fish were considered juveniles measuring 69 to 84 cm in length (J. Holder, Florida Fish and Wildlife Commission, personal communication). There have been reports of Atlantic sturgeon tagged in the Edisto River (South Carolina) having been recaptured in the St. Johns River, indicating this river may serve as a nursery ground; however, there are no data to support the existence of a spawning subpopulation (i.e., YOY or running ripe adults) (Rogers and Weber 1995; Kahnle et al. 1998; ASSRT 2007).

Spawning location (ecological)

A study by Collins et al. (2000b) indicated that adult Atlantic sturgeon in South Carolina utilize a wide variety of habitats during the summer. They found sturgeon in the upper fresh/brackish interface zone, the lower interface zone, and in the high salinity portions of the estuary in the Edisto River, South Carolina. Atlantic sturgeon were present in this river from March to October. During the winter, southern Atlantic sturgeon resided in the ocean (Collins et al. 2000b). Adult Atlantic sturgeon in southern rivers exhibit behavior much like gulf sturgeon (*Acipenser oxyrinxhus desotoi*) in that they spend 9 months within the river system and 3 winter months in marine waters (M. Collins, South Carolina Department of Natural Resources, personal communication).

Most studies indicate that after spawning, Atlantic sturgeon migrate to salt water (Vladykov and Greeley 1963); these down-estuary migrations may occur over several months (Bain 1997). In the St. Lawrence River, migrations downstream have been reported from September through November (Scott and Crossman 1973). Hatin et al. (2002) found that the majority of Atlantic sturgeon were gone from the upper St. Lawrence River by late September in some years, while in other years, the sturgeon remained in the upper river through early December. In the Hudson River, females migrate back to salt water immediately following spawning, while males remain until the onset of cold temperatures in the fall (Smith 1985a). Additionally, Bain et al. (2000) reported post-spawn adult sturgeon and older juveniles congregating in deep water habitat during the summer in the Hudson River, New York.

Maturation and spawning periodicity

Atlantic sturgeon mature at different times along the Atlantic coast, with maturity occurring earlier in the Southern regions (Vladykov and Greeley 1963). Females in South Carolina first spawn between the ages of 7 and 19, and males first spawn between 5 and 13 years. In the Hudson River, New York, females first spawn between the ages of 15 and 30 years, and males between 8 and 20 years (Dovel 1979; Smith et al. 1982; Smith 1985a; Smith 1985b; Young et al. 1988; Stevenson and Secor 1999). Scott and Crossman (1973) report that in the St. Lawrence River, Canada, female Atlantic sturgeon mature at approximately 27 years, and males mature between 22 and 34 years. Although most researchers have not verified age determination methods, Stevenson and Secor (2000) used marginal increment analysis and rearing studies to confirm the seasonality of annulus formation; they reported an aging precision of $\pm$ 5 years for Hudson River Atlantic sturgeon.

Sexually mature Atlantic sturgeon do not usually spawn every year (Van Eenennaam et al. 1996; Caron et al. 2002). However, some fish participate in spawning migrations even when they do not spawn (Smith 1985b). There remains a high degree of uncertainty on the frequency of spawning due in part to imprecision in methods, but also due to large natural variability expected in this parameter. In South Carolina, females are thought to spawn every 3 to 5 years, while males spawn at 1 to 5 year intervals (Smith 1985b). Additionally, Smith et al. (1982) found that an average interval of 5.4 years occurred between first and second spawnings, and 3.5 years between second and third spawnings. Vladykov and Greeley (1963) concluded that females spawn once every 2 to 3 years. Results from recent research on gonad histology and hard part analysis of Hudson River Atlantic sturgeon suggest a spawning frequency of 3-5 years (Van Eenennaam et al. 1996; Stevenson and Secor 2000). Interestingly, Collins et al. (2000b) caught and then recaptured a male sturgeon (in 1998 and 1999, respectively) that was in spawning condition for two successive spawning seasons. Similarly, Scott and Crossman (1973) indicated that spawning might occur every year in some females.

Spawning and the saltwater interface

Atlantic sturgeon generally spawn in tidal freshwater regions of estuaries, but may spawn in nontidal freshwater rivers in the southeastern part of their range. Most studies report that Atlantic sturgeon spawn in freshwater above the salt wedge in estuaries (Dovel 1978, 1979; Smith 1985b; Van Eenennaam et al. 1996; Bain et al. 2000). For instance, Dovel (1978, 1979) reported that Atlantic sturgeon in the Hudson River, New York, spawn in freshwater above the salt wedge. Smith (1985a) suggested that spawning fish may migrate seasonally, following the salt front upriver as the season progresses. Dovel and Berggren (1983) reported that the majority of spawning occurred between RKM 56 and 132 in the Hudson River. However, Van Eenennaam et al. (1996) suggest that these results might be questionable because the salt wedge extends to RKM 98. Atlantic sturgeon eggs cannot tolerate high salinity, thus it is more likely that sturgeon spawn above the salt wedge, and not in brackish waters (Van Eenennaam et al. 1996). In addition, Van Eenennaam et al. (1996) found ovulating sturgeon around RKM 136 in the Hudson River system.

Spawning substrate associations

Substrate is a key habitat parameter for Atlantic sturgeon, because a hard bottom substrate is required for successful egg attachment and incubation (Vladykov and Greeley 1963; Huff 1975; Smith 1985b; Gilbert 1989; Smith and Clugston 1997; Secor et al. 2002; Bushnoe et al. 2005). Within rivers, the areas of cobble-gravel, coarse sand, and bedrock outcrops, which occur in the rapids complex, may be considered prime habitat (Table 8-2). In northern rivers, these areas are nearer to the salt-wedge than in southern rivers. South of the Chesapeake Bay, nearly all rivers have extensive rapid-complex habitats in and/or near the fall line zone; these areas are generally at least 100 km upstream from the saltwater interface (P. Brownell, NOAA Fisheries, Southeast Regional Office, personal communication). This habitat provides Atlantic sturgeon with well-oxygenated water, clean substrates for egg adhesion, crevices that serve as shelter for post-hatch larvae, and macroinvertebrates for food (P. Brownell, NOAA Fisheries, Southeast Regional Office, personal communication).

Substrate	Activity	Location	Citation
Rock and bedrock	spawning	St. Lawrence River, Québec	Hatin et al. 2002
Rock, clay, & sand	spawning	St. Lawrence River, Québec	Caron et al. 2002
Irregular bedrock, silt, & clay	spawning	Hudson River, NY	Bain et al. 2000
Clay/silt with rocky shoreline	post-spawning	Hudson River, NY	Bain et al. 2000
Hard clay	spawning	Delaware River	Borodin 1925
Small rubble & gravel	spawning	Delaware River	Dees 1961
Clay	spawning	Delaware River	Scott & Crossman 1973
Limestone	spawning	Edisto River, SC	Collins et al. 2000b
Fine mud, sand, pebbles, & shell	post-spawning	Edisto River, SC	Collins et al. 2000b
Cobble/gravel	spawning	HSI Model	Brownell et al. 2001

Table 8-2. Spawning (and post-spawn) substrate type for Atlantic sturgeon along the Atlantic coast

Some researchers have attempted to identify likely spawning areas for Atlantic sturgeon using modeling techniques. Brownell et al. (2001) developed a Habitat Suitability Index (HSI) model for spawning Atlantic sturgeon and early egg development, and found that cobble/gravel (64 mm to 250 mm) was the optimal spawning substrate for Atlantic sturgeon. Boulder (250 mm to 4000 mm) scored the second highest in the model, and silt/sand (<2.0mm) and mud/soft clay/fines scored the lowest. The curve and the data values were based on the shortnose sturgeon model, and factors such as oxygenation, substrate embeddedness, available egg attachment sites, protection of eggs from predators, light intensity, and solar warming were all hypothesized to be available in cobble/gravel and boulder substrates (Brownell et al. 2001).

Bushnoe et al. (2005) identified potential spawning areas for Atlantic sturgeon in Virginia based on the location of suitable hard substrate and a variety of other water quality parameters, including temperature, dissolved oxygen, pH, salinity, hardness, and conductivity. They concluded that Turkey Island oxbow and the James Neck oxbow in the James River, the Appomattox River, the Mattaponi, and Pamunkey River in the York River system, and the Rappahannock River, all represented potential spawning habitat (Bushnoe et al. 2005).

Spawning depth associations

Atlantic sturgeon have been documented spawning in water from 3 m to 27 m in depth (Table 8-3) (Borodin 1925; Dees 1961; Scott and Crossman 1973; Shirey et al. 1999; Bain et al. 2000; Collins et al. 2000b; Caron et al. 2002; Hatin et al. 2002). Spawning depth seems to vary greatly depending upon the available depth range.

Depth Range (m)	Status	Location	Citation
10 - 22	Spawning	St. Lawrence River, Québec	Caron et al. 2002
17 - 21	Non-spawning	St. Lawrence River, Québec	Caron et al. 2002
15 - 27 (mean)	All	St. Lawrence River, Québec	Hatin et al. 2002
6 - 60	Spawning	St. Lawrence River, Québec	Hatin et al. 2002
>7.6	Migrating	Hudson River, NY	Dovel and Berggren 1983
12 - 27	Spawning	Hudson River, NY	Bain et al. 2000
11 - 13	Spawning	Delaware River	Borodin 1925; Scott & Crossman 1973
1.5 - 13	All	Edisto River, SC	Collins et al. 2000b
2.4 - 8	Spawning	HSI Model	Brownell et al. 2001

Table 8-3. Spawning (and non-spawn) depth ranges for Atlantic sturgeon along the Atlantic coast

A recent HSI model developed by Brownell et al. (2001) showed that the optimal depth range in the South for spawning Atlantic sturgeon and egg incubation ranged from 2.4 m to 8 m. It should be noted that depth in this model had a maximum range of 8 m because areas where spawning is likely to occur (areas above the fall zone) in the South are not much deeper than 8 m (P. Brownell, NOAA Fisheries, Southeast Regional Office, personal communication).

Spawning water temperature

Atlantic sturgeon reportedly spawn in waters where temperatures range from 13^{o}C to 26°C (Table 8-4) (Borodin 1925; Huff 1975; Smith 1985b; Bain et al. 2000; Caron et al. 2002; Hatin et al. 2002). Temperature appears to be a universal determining factor in spawning migration times. Migration temperatures seem to be fairly uniform across the Atlantic Coast, with southern fish migrating earlier in the spring, and northern fish following a few weeks later once the waters reach the appropriate temperature. Generally, male Atlantic sturgeon commence upstream migration when waters reach around 6^{o}C (Smith et al. 1982; Dovel and Berggren 1983; Smith 1985a). Females usually follow a few weeks later when temperatures are closer to 12^{o}C or 13^{o}C (Dovel and Berggren 1983; Smith 1985a; Smith 1985b; Collins et al. 2000b). Spawning has been found to occur most often in waters 13^{o}C to 21^{o}C (Ryder 1888; Scott and Crossman 1973; Bain et al. 2000; Caron et al. 2002). In addition, Mohler (2003) stated in the "Culture Manual for Atlantic Sturgeon" that the preferred temperature for induced spawning in cultured sturgeons is between 20^{o}C and 21°C.

Sex	Activity	Month	Temperature Range (°C)	Location	Citation
M/F	Spawning	N/A	14.5 - 23.4	St. Lawrence River, Québec	Caron et al. 2002; Hatin et al. 2002
M	Migration Up	N/A	5.6 - 6.1	Hudson River, NY	Smith 1985a
F	Migration Up	♂ + few weeks	12.2 - 12.8	Hudson River, NY	Smith 1985a
M	Migration Up	April	6	Hudson River, NY	Dovel and Berggren 1983
F	Migration Up	♂+ few weeks	13	Hudson River, NY	Dovel and Berggren 1983
M/F	Spawning	N/A	14 - 26	Hudson River, NY	Bain et al. 2000
M/F	Spawning	April - June	12.8 - 18.3	Delaware River	Ryder 1888
M/F	Spawning	N/A	13.3 - 17.8	Delaware River	Scott and Crossman 1973
M	Migration Up	N/A	13 - 19	South Carolina	Smith 1985b
F	Spent	Sept. - Oct.	17 - 18	Edisto River, SC	Collins et al. 2000b
M/F	Migration Up	March	13.6	Edisto River, SC	Collins et al. 2000b
M/F	Present	Summer	up to 33.1	Edisto & Combahee Rivers, SC	Collins et al. 2000b
M/F	Spawning	N/A	20 - 21	Aquaculture facility	Mohler 2003
M/F	Spawning	N/A	16 - 21	HSI Model	Brownell et al. 2001

Table 8-4. Spawning and migration temperatures for Atlantic sturgeon along the Atlantic coast

Spawning water velocity/flow

Atlantic sturgeon lay their eggs in flowing water (Vladykov and Greeley 1963; Van den Avyle 1983). Modeling studies suggest that the optimal water velocities for Atlantic sturgeon spawning range from 0.46 m/s to 0.76 m/s. Furthermore, velocities lower than 0.06 m/s and higher than 1.07 cm/s are unsuitable for spawning (Crance 1987). A recent HSI developed for spawning Atlantic sturgeon showed that optimal water velocity for spawning and egg incubation ranged from 0.2 m/s to 0.76 m/s (Brownell et al. 2001).

Spawning and other water parameters

Reports of gulf sturgeon (*Acipenser oxyrinchus desotoi*) indicate that other important habitat factors include hardness and conductivity. Sulak and Clugston (1999) and Fox et al. (2000) describe the spawning sites of gulf sturgeon on the Suwannee River, Florida, as having a moderate Ca++ ion concentration and conductivity ranging from 10 µS to 110µS. Bushnoe et al. (2005) used these criteria to identify Atlantic sturgeon spawning habitat in rivers in Virginia. More research will be needed to clarify the importance of these parameters.

Spawning feeding behavior

It has been hypothesized that Atlantic sturgeon do not feed during spawning migrations. Research is currently being conducted in South Carolina to test this hypothesis (M. Collins, South Carolina Department of Natural Resources, personal communication). Post-spawning adults that remain in freshwater systems have been documented feeding on gastropods and other benthic organisms (Scott and Crossman 1973). In general, adult Atlantic sturgeon feed indiscriminately throughout their lives and are considered to be opportunistic feeders (Vladykov and Greeley 1963; Murawski and Pacheco 1977; Van den Avyle 1983; Haley and Bain 1997; Colette and Klein-MacPhee 2002). They feed on mollusks, polychaetes, gastropods, shrimps, isopods, and benthic fish in estuarine areas (Dadswell et al. 1984; Secor et al. 2000b; Colette and Klein-MacPhee 2002). In freshwater, their prey includes aquatic insects, nematodes, amphipods, and oligochaetes (Colette and Klein-MacPhee 2002; Hain et al. 2002).

Spawning competition and predation

Adult Atlantic sturgeon appear to have few ecological competitors. They spawn later in the season and in different areas than shortnose sturgeon, thus avoiding competition for egg deposition space in areas where their habitat overlaps (Bath et al. 1981; Gilbert 1989; Kynard and Horgan 2002). Other species that might utilize the same spawning habitat include anadromous species, such as white perch, striped bass, and American shad (D. Secor, Chesapeake Biological Laboratory, University of Maryland Center for Environmental Science, personal communication).

The ASSRT (2007) notes the following information on competition and predation in Atlantic and shortnose sturgeon:

> Atlantic sturgeon are benthic predators and may compete for food with other bottom-feeding fishes and invertebrates including suckers (*Moxotoma* sp.), winter flounder (*Pleuronectes americanus*), tautog (*Tautoga onitis*), cunner (*Tautagolabrus adspersus*), porgies (Sparidae), croakers (Sciaenidae), and stingrays (*Dasyatis* sp.) (Gilbert 1989). Specific information concerning competition between Atlantic sturgeon and other species over habitat and food resources is scarce. There are no known exotic or non-native species that compete directly with Atlantic sturgeon. There is a chance that species such as suckers or other bottom forage fish would compete with Atlantic sturgeon, but these interactions have not been elucidated (from ASSRT 2007).
>
> The relationship between the Federally endangered shortnose sturgeon and the Atlantic sturgeon has recently been explored. Shortnose sturgeon are sympatric with Atlantic sturgeon throughout most of their range. Larger, adult shortnose are suspected to compete for food and space with juvenile Atlantic sturgeon in rivers of co-occurrence (Pottle and Dadswell 1979; Bain 1997). Haley and Bain (1997) found that while shortnose and Atlantic sturgeon overlap in their use of the lower estuary, the overall distribution of the two species differed by river kilometers, providing evidence that Atlantic and shortnose sturgeon partition space within the Hudson River despite co-occurrence in channel habitats. This finding is consistent with Kieffer and Kynard (1993) who found that subadult Atlantic and adult shortnose sturgeon in the Merrimack River, MA were spatially separate except for brief use of the same saline reach in the spring.

Kahnle and Hattala (1988) conducted late summer-fall bottom trawl collections in the lower Hudson River Estuary from 1981-1986 and found that most shortnose sturgeon occupied rkm 55-60 in water depths of greater than six meters. Even though there was overlap in river miles, there was separation by water depth. In Georgia, the distributions of adult shortnose and juvenile Atlantic sturgeons overlap somewhat, but Atlantic sturgeon tend to use more saline habitats than shortnose sturgeon (G. Roger, formerly Georgia Department of Natural Resources, personal communication; from ASSRT 2007).

Juvenile shortnose sturgeon apparently avoid competition for food with Atlantic sturgeon in the Saint John River, Canada by spatial separation, but adult shortnose may compete for space with similar-sized juvenile Atlantic sturgeon (Dadswell et al. 1984). Haley and Bain (1997) analyzed stomach contents of Atlantic and shortnose sturgeon in the Hudson River using gastric lavage and found clear differences in their diets. Polychaetes and isopods were primary foods retrieved from Atlantic sturgeon while amphipods were the dominant prey obtained from shortnose sturgeon (Haley and Bain 1997; from ASSRT 2007).

Very little is known about natural predators of Atlantic sturgeon. The presence of bony scutes are likely effective adaptations for minimizing predation of sturgeon greater than 25 mm TL (Gadomski and Parsley 2005). Documented predators of sturgeon (*Acipenser* sp.) include sea lampreys (*Petromyzon marinus*), gar (*Lepisosteus* sp.), striped bass, common carp (*Cyprinus carpio*), northern pikeminnow (*Ptychocheilus oregonensis*), channel catfish (*Ictalurus punctatus*), smallmouth bass (*Micropterus dolomieu*), walleye (*Sander vitreus*), grey seal (*Halichoerus grypus*), fallfish (*Semotilus corporalis*) and sea lion (*Zalophus californianus*) (Scott and Crossman 1973; Dadswell et al. 1984; Miller and Beckman 1996; Kynard and Horgan 2002; Gadomski and Parsley 2005; Fernandes 2006; Wurfel and Norman 2006). In contrast to these findings, Moser et al. 2000 tested whether flathead catfish (*Pylodictus olivaris*) preyed on shortnose sturgeon (30 cm) in a controlled system, and despite sturgeon being the only prey available none were consumed. However, Gadomksi and Parsely (2005) tested at what size white sturgeon were preyed upon by channel catfish, northern pikeminnow, walleyes, and prickly sculpins (*Cottus asper*). Their results found that channel catfish (mean TL = 472 mm), northern pikeminnow (mean TL = 464 mm), and prickly sculpin (mean TL = 126 mm) fed on juvenile sturgeon of an average size of 121 mm TL, 134 mm TL, and 50 mm TL, respectively. Oddly, similar size walleye (~470 mm TL) rarely fed on white sturgeon, but juvenile walleye (mean TL = 184 mm) consumed sturgeon with a mean size of 59 mm TL. Gadomski and Parsley (2005) suggest that these findings indicate that predation could play an important role in sturgeon recovery (from ASSRT 2007).

Similarly, Brown et al. (2005) concluded that the "…introduction of [flathead catfish] has the potential to adversely affect ongoing anadromous fish restoration programs and native fish conservation efforts in the Delaware and Susquehanna basins." The same concern has been stated by fishery management agencies for south Atlantic river basins where flathead catfish are firmly established and have reached significant biomass, significantly altering native fish assemblages and biomass in the process. There is, however, no current evidence that predation rates on Atlantic sturgeon are elevated above "natural" levels (from ASSRT 2007).

Part B. Atlantic Sturgeon Egg and Larval Habitat

Geographical and temporal movement patterns

Due to a low tolerance for saline environments, Atlantic sturgeon eggs must be spawned upstream of the salt front (Van Eenennaam et al. 1996). On the other hand, research on the conspecific *A. o. desotoi* (Gulf sturgeon) indicates that Atlantic sturgeon probably select regions with high conductivity, above the salt wedge, but below fall line regions containing freshwater with low conductivity (Sulak and Clugston 1999; Fox et al. 2000).

Eggs are deposited into flowing water and disperse following fertilization. After approximately twenty minutes, the demersal eggs become strongly adhesive and attach to hard substrates (Murawski and Pacheco 1977; Van den Avyle 1983). The eggs hatch after 94 to 140 hours; subsequent to a pelagic yolksac larval period of about 10 days, late-stage larvae settle in the demersal habitat. This will be the principal type of habitat for the remainder of the sturgeon's life (USFWS-NMFS 1998).

Little is known about the habitat of larval Atlantic sturgeon. Larval Atlantic sturgeon are less than 4 weeks old, with lengths less than 30 mm (TL) (Van Eenennaam et al. 1996); they are assumed to inhabit the same riverine or estuarine areas where they were spawned (Bain et al. 2000; Kynard and Horgan 2002). Newly hatched larvae are active swimmers and leave the bottom to swim in the water column. Once the yolk sac is absorbed, the larvae exhibit benthic behavior (Smith et al. 1980, 1981). Bath et al. (1981) caught free embryos by actively netting the bottom near the spawning area, demonstrating that early life stages are benthic.

For a more controlled experiment, Kynard and Horgan (2002) raised captive Atlantic sturgeon in chambers. They found that upon hatching, the embryos sought cover where they remained for a few days. The fish left cover and began to migrate around day 8. Following the passage of a few more days, the larvae stopped migrating and exhibited foraging behavior. Downstream migration resumed again during the juvenile period when the temperature dropped. Atlantic sturgeon larvae are capable of dispersing long distances. Movement occurs at night during the first half of the larval migration; eventually, the fish become active during both the day and night (Kynard and Horgan 2002). Kynard and Horgan (2002) hypothesize that this foraging behavior is a way to reduce daytime predation while the larvae are still developing, yet still enable them to forage when there is daylight to aid in the visual detection of prey.

Mohler (2003) found similar results. Cultured Atlantic sturgeon were mostly pelagic after hatching and exhibited a "swim up and drift down" behavior. After three to four days, fry began to exhibit benthic clumping behavior and swam against the direction of water flow in the tank. Fry remained benthic for approximately four days, before moving around the tank in search of food. At this stage, the larval Atlantic sturgeon were noted to be pelagic, until live brine shrimp were thrown into the tank and the fry moved to the bottom of the tank to feed. Atlantic sturgeon fry did not actively seek out a food source, but rather waited until the currents brought food to them (Mohler 2003).

The ASSRT (2007) notes that downstream dispersal patterns may be different among watersheds:

> Differences in the innate dispersal patterns of sturgeon species in early life stages also suggest that there are markedly separated differences in behavior between

subpopulations of sturgeon (B. Kynard, USGS Conte Anadromous Fish Research Center, personal communication). Boyd Kynard, a researcher at the USGS Conte Anadromous Fish Research Center (Turner Falls, Massachusetts), has noted major differences in innate dispersal patterns of early life stage sturgeon species including *Acipenser fulvescens* (Wolf and Menominee rivers), *A. brevirostrum* (Connecticut and Savannah rivers), *A. transmontanus* (Sacremento and Kootenai rivers), and Atlantic/Gulf sturgeon subpopulations (Hudson and Suwannee rivers). This research suggests that Atlantic sturgeon are likely adapted to unique features of their watershed, considering their genetic discreteness and differing migration behaviors. These findings are similar to research conducted on striped bass (*Morone saxatilis*), an anadromous fish like Atlantic sturgeon, which correlated egg characteristics (e.g., egg diameter, egg density, etc.) with watershed type (e.g., low, medium, high energy) (Bergey et al. 2003). Differences in egg characteristics likely are the result of subpopulation adaptations to the watershed, but the manner in which these adaptations were produced were not determined. The ASSRT concluded that unique behavioral and physiological traits likely exist for each extant subpopulation of Atlantic sturgeon – except those that share a drainage basin (similar adaptations) (from ASSRT 2007).

Eggs, larvae, and the saltwater interface

Salinity is very important to the survival of sturgeon eggs (McEnroe and Chech 1985; Jenkins et al. 1993; Van Eenennaam et al. 1996). Eggs are spawned in regions between the salt front and the fall-line of large rivers or estuarine tributaries (Borodin 1925; Leland 1968; Scott and Crossman 1973; Crance 1987; Bain et al. 2000). Bath et al. (1981) collected larval sturgeon in salinities of 0 ppt to 22 ppt in the Hudson River, New York. Dovel and Berggren (1983) recorded sturgeon embryos from RKM 60 to RKM 148, which includes some brackish water. However, Van Eenennaam et al. (1996) report that Atlantic sturgeon embryo habitat must be well above the salt wedge, due to their low tolerance to salinity. Other species of sturgeon show this same salt intolerance. For example, free embryos, larvae, and age-0 juveniles of white sturgeon and shortnose sturgeon also exhibit low salt tolerance. Mortality has been documented at salinities as low as 5 ppt to 10 ppt (McEnroe and Chech 1985; Jenkins et al. 1993).

Egg and larval substrate associations

Atlantic sturgeon deposit their eggs on benthic hard substrate (Gilbert 1989; Smith and Clugston 1997). The eggs contain adhesive strings that attach to stones, shells, sticks, and weeds (Vladykov and Greeley 1963; Colette and MacPhee 2002). Hard substrate is also important to larval Atlantic sturgeon, as it provides refuge from predators (Kieffer and Kynard 1996; Fox et al. 2000). A study by Kynard and Horgan (2002) showed that after hatching, embryos immediately sought cover. Some scientists hypothesize that rapid-complex habitats might serve as hatcheries for Atlantic sturgeon because they provide cover, well-oxygenated hiding places, and a food source of microinvertebrates (P. Brownell, NOAA Fisheries, Southeast Regional Office, personal communication).

Egg and larval depth associations

The importance of depth to embryonic and larval Atlantic sturgeon has not been thoroughly discussed in the literature, but it is likely not as important to this species as benthic substrate characteristics (P. Brownell, NOAA Fisheries, Southeast Regional Office, personal communication). However, depth of migrating larvae would be an important issue to address for a project inserting intake structures into a river near nursery grounds (W. Patrick, NOAA Fisheries Service, personal communication). Additionally, Bain (1997) found that embryos remain on the bottom of deep channel habitats, and Bath et al. (1981) collected larval samples from 9.1 m to 19.8 m.

Egg and larval water temperature

Smith et al. (1980) found that Atlantic sturgeon eggs optimally hatch at temperatures ranging from 18°C to 20°C. Hatching occurs approximately 94 to 140 hours after egg deposition at temperatures of 20°C and 18°C, respectively, and larvae assume a demersal existence (Smith et al. 1980). Similarly, Mohler (2003) states that in a culture setting, a temperature range of 20°C to 21°C is favorable for the incubation of Atlantic sturgeon eggs. Temperatures below 18°C prolong hatching and increase the risk of fungal infestation to dead eggs, which in turn can kill the viable individuals. Hatching occurs in 60 hours at this temperature range (Mohler 2003).

Bath et al. (1981) collected larval sturgeon in the Hudson Bay, New York, in temperatures of 15.0°C to 24.5°C. Researchers recommend that first-feeding cultured Atlantic sturgeon fry be kept in water temperatures of 15^{o}C to 19°C, and that a temperature of 19°C yields higher growth rates (Kelly and Arnold 1999; Mohler 2003).

Egg and larval feeding behavior

There are no studies to indicate what larval Atlantic sturgeon prey upon in the wild. However, it is assumed that after they absorb the yolk sac, they feed on small bottom dwelling organisms (Gilbert 1989). Studies of other sturgeon species indicate that larvae in rivers feed on small mobile invertebrates, including cladocerans and copepods (Baranova and Miroshnichenko 1969; Miller et al. 1991). Miller et al. (1991) found that white sturgeon larvae primarily fed on amphipods.

During their lab test, Kynard and Horgan (2002) found that Atlantic sturgeon larvae (30 to 50 days old) preferred illumination and a white substrate. They hypothesize that an illuminated bright substrate may make it easier for young sturgeon to locate moving prey. Laboratory rearing of larvae depends principally on *Artemia* sp. as prey, which the Atlantic sturgeon can readily consume (Kynard and Horgan 2002).

Egg and larval competition and predation

Kynard and Horgan (2002) hypothesize that larval and juvenile Atlantic sturgeon have a low predation risk. This hypothesis is based on the theory that migration upon hatching is stimulated by predation risk to embryos. Species that undergo high predation tend to migrate from the area immediately after hatching (Kynard and Horgan 2002). While this hypothesis has not been fully tested, Kynard and Horgan (2002) have determined that shortnose sturgeon embryos have few predators. After sampling predators in a spawning area, they found that only one fish, the fallfish (*Semotilus corporalis*), had sturgeon eggs in its stomach (Kynard and Horgan 2002).

Part C. Atlantic Sturgeon Juvenile Estuarine Habitat

Geographical and temporal movement patterns

For the purposes of this report, a sturgeon will be considered juvenile according to the guidelines found in the ASSRT (2007), which broke juveniles down as such:

1) YOY (AGE-0): Thought to be natal to the river they were captured in and used as evidence in identifying extant populations
2) Juveniles or subadults (AGE-1 to AGE-15): Considered possible migrants from other systems though the older individuals could be reproducing (maybe in more northern waters)
3) Mature adults (AGE-15) or 150 cm TL: Generally considered mature, and if they were captured in a river during the spawning season it was assumed that they were going to spawn in that river (used to identify extant populations) (ASSRT 2007)

Most researchers have found that growth rates and sizes of Atlantic sturgeon vary by latitude, with rapid growth occurring in the southern latitudes and larger maximum sizes occurring in the north (Vladykov and Greeley 1963; Smith 1985a; Smith 1985b; Dovel and Berggren 1983; Collins et al. 1996; Stevenson and Secor 1999). However, Johnson et al. (2005), working off the New Jersey coast, found that their data did not fit this pattern. They suggested that this might have been due to a mixed sample composed of Atlantic sturgeon from different populations that had different growth rates (Johnson et al. 2005). These findings are partially supported by genetic studies performed by Waldman et al. (1996a) who showed that approximately 90% of the Atlantic sturgeon catch in the New York Bight was of Hudson River origin.

The ASSRT (2007) notes the following information on juvenile Atlantic sturgeon migrations:

> Upon reaching a size of approximately 76 to 92 cm, the sub-adults may move to coastal waters (Murawski and Pacheco 1977; Smith 1985b), where populations may undertake long-range migrations (Dovel and Berggren 1983; Bain 1997; T. King, USGS Leetown Science Center, Aquatic Ecology Laboratory, Kearneysville, West Virginia, supplemental data). Tagging and genetic data indicate that sub-adult and adult Atlantic sturgeon may travel widely once they emigrate from rivers. Sub-adult Atlantic sturgeon wander among coastal and estuarine habitats, undergoing rapid growth (Dovel and Berggren 1983; Stevenson 1997). These migratory sub-adults, as well as adult sturgeon, are normally captured in shallow (10 to 50m) near shore areas dominated by gravel and sand substrate (Stein et al. 2004; from ASSRT 2007).

Juvenile Atlantic sturgeon are thought to remain close to their natal habitats within the freshwater portion of the estuary for at least one year before commencing migration out to sea (Secor et al. 2000b). Migrations out to coastal areas occur between two and six years of age (Smith 1985b), and are seasonal, with movement occurring north in the late winter, and south in fall and early winter (Dovel 1978; Smith 1985b; USFWS-NMFS 1998). Seasonal migrations of juveniles are regulated by changes in temperature gradients between fresh and brackish waters (Van Den Avyle 1984). For example, hatchery-reared juveniles released in the Chesapeake Bay used brackish waters close to the estuary mouth during colder months, and moved upriver during warmer months (Secor et al. 2000b).

Similar behavior has been seen in a number of river systems, including the Delaware River, Hudson River, and the Winyah Bay system (South Carolina) (Brundage and Meadows 1982; Smith et al. 1982; Dovel and Berggren 1983; Gilbert 1989). Dovel and Berggren (1983) reported a mass down-estuary migration of juvenile Atlantic sturgeon in the Hudson Estuary, New York, when the temperature dropped below 20°C. Down-river/down-estuary migrations peak at the end of October in the Hudson system. At this time, many juveniles overwinter in deep holes, while others leave the Hudson River and move south along the Atlantic coast (Dovel and Berggren 1983). In contrast, Moser and Ross (1995) found that juvenile sturgeon in the Cape Fear River, North Carolina, kept the same center of distribution near the saltwater-freshwater interface year round. However, these fish were unable to move upriver because of the location of the Cape Fear Lock and Dam No. 1, just above the estuary (0.5 ppt interface) (P. Brownell, NOAA Fisheries, Southeast Regional Office, personal communication).

Coastal features or shorelines where migratory Atlantic sturgeon commonly aggregate include the Bay of Fundy, Massachusetts Bay, Rhode Island, New Jersey, Delaware, Delaware Bay, Chesapeake Bay, and North Carolina, which presumably provide better foraging opportunities (Dovel and Berggren 1983; Johnson et al. 1997; Rochard et al. 1997; Kynard et al. 2000; Eyler et al. 2004; Stein et al. 2004; Dadswell 2006). Smith (1985b) stated that fish tagged off South Carolina migrated as far north as Pamlico Sound and Chesapeake Bay. Most data indicate that Atlantic sturgeon in the northern rivers travel more extensively than those in the southern rivers (ASMFC 1998). However, research in the southern region has not adequately addressed inter-basin movements in the south (P. Brownell, NOAA Fisheries, Southeast Regional Office, personal communication).

Later-stage juveniles often enter and reside in non-natal rivers that lack active spawning sites (Bain 1997). Inter-estuarine migrations have been documented extensively in the literature (Dovel and Berggren 1983; Smith 1985b; Welsh et al. 2002; Savoy and Pacileo 2003). These non-natal estuarine habitats serve as nursery areas, providing abundant foraging opportunities and thermal and salinity refuges. Therefore, these areas are very important to the Atlantic sturgeon's survival (Moser and Ross 1995).

Juveniles and the saltwater interface

There is a large amount of variation in the salinity tolerance of juvenile Atlantic sturgeon (Table 8-5). Some Atlantic sturgeon may occupy freshwater habitats for two or more years, while others move downstream to brackish waters when the water temperature drops (Scott and Crossman 1973; Dovel 1978; Hoff 1980; Lazzari et al. 1986). Additionally, bioenergetic studies on YOY juveniles indicate poor survival at salinities greater than 8 ppt, but euryhaline behaviors are exhibited by juveniles age-1 and 2 (Niklitschek 2001).

Salinity Range (ppt)	Location	Citation
>3	Hudson River, New York	Appy and Dadswell 1978
3 - 16	Hudson River, New York	Dadswell 1979
3 - 16	Hudson River, New York	Brundage and Meadows 1982
0 - 6	Hudson River, New York	Dovel and Berggren 1983
3 - 16	Hudson River, New York	Smith 1985b
3 - 16	Hudson River, New York	Haley et al. 1996
>3	Hudson River, New York	Bain et al. 2000
0 - 12	Delaware River	Shirey et al. 1999
<10	Brunswick River, North Carolina	Moser and Ross 1995

Table 8-5. Salinity tolerance ranges for young juvenile Atlantic sturgeon along the Atlantic coast

Juvenile substrate associations

Kynard et al. (2000) reported that juvenile Atlantic sturgeon in Massachusetts were found mostly over sand substrates, but other associated substrates included rock, cobble, and mud (Kynard et al. 2000). Savoy and Pacileo (2003) found that 85% of the juvenile Atlantic sturgeon caught in Long Island Sound were in mud or transitional bottom habitats. Correspondingly, Bain et al. (2000) found juveniles off Long Island Sound over mud substrates. In the Hudson River, Haley et al. (1996) collected juvenile Atlantic sturgeon at sites that had silt substrates. However, the researchers state that it is unclear whether this represents habitat preference or habitat use, as the majority of sites sampled was composed of this substrate (Haley et al. 1996). In the same system, Bain et al. (2000) documented juveniles over clay, silt, and sand substrates. Stein et al. (2004) found migratory sub-adults, as well as adult Atlantic sturgeon, generally in areas dominated by gravel and sand substrate.

Juvenile depth associations

Many researchers have found that juvenile Atlantic sturgeon tend to congregate in deep waters (Table 8-6) (Moser and Ross 1995; Bain et al. 2000; Savoy and Pacileo 2003). Moser and Ross (1995) report that juvenile Atlantic sturgeon in North Carolina use deep and cool areas as thermal refuges, particularly in the summertime.

Depth Range (m)	Location	Citation
2 - 12	Massachusetts	Kynard et al. 2000
30 - 40	Long Island Sound, Connecticut	Bain et al. 2000
27 - 37	Long Island Sound, Connecticut	Savoy and Pacileo 2003
Mean = 22.7	Hudson River, New York	Haley et al. 1996
10 – 25 (<700 mm TL)	Hudson River, New York	Bain et al. 2000
16 – 26 (>700 mm TL)	Hudson River, New York	Bain et al. 2000
7 - 16	Delaware River, Pennsylvania	Lazzari et al. 1986
5.5 - 11	Delaware River, Delaware	Shirey et al. 1999
<20	Chesapeake Bay, Virginia	Musick et al. 1994
<7	Brunswick River, North Carolina	Moser and Ross 1995
>10	Cape Fear River, North Carolina	Moser and Ross 1995
1.8 - 5.4	Albemarle Sound, North Carolina	Armstrong and Hightower 2002

Table 8-6. Depth ranges for young juvenile Atlantic sturgeon along the Atlantic coast

Juvenile Atlantic sturgeon farther north also seem to prefer deeper areas. Bain et al. (2000) stated that those juveniles that did not migrate out to sea during the winter occupied deep-water habitat in the Hudson River, New York. Further north, Savoy and Pacileo (2003) found that juvenile Atlantic sturgeon in Long Island Sound preferred the deep-water areas within the central basin of the Sound. They reported that 71% of the Atlantic sturgeon were caught in areas of the deepest stratum (deeper than 27 m). This area comprised only 26% of the available habitat (Savoy and Pacileo 2003). Savoy and Pacileo (2003) also reported that Atlantic sturgeon were rarely caught in the shallow areas (5 m to 9 m), and that the 20 fish caught in the shallow stratum were fish migrating in and out of Long Island Sound.

While the majority of juvenile Atlantic sturgeon have been collected at the deepest depths available, some have also been collected in shallower waters (Table 8-6). A telemetry study on hatchery-released age-1 juveniles showed that most Atlantic sturgeon utilized depths less than 6 m (Secor et al. 2000b).

Juvenile water temperature

Temperature Range (^{o}C)	Location	Citation
13.2 – 26.7	Merrimack River, Massachusetts	Kieffer and Kynard 1993
24.2 – 24.7	Hudson River, New York	Dovel and Berggren 1983
27	Hudson River, New York	Haley et al. 1996
24 – 28	Hudson River, New York	Bain et al. 2000

Table 8-7. Summer temperature ranges for juvenile Atlantic sturgeon along the Atlantic coast

Temperature is a key habitat parameter for the structuring of juvenile Atlantic sturgeon summer habitat (Table 8-7) (Niklitschek and Secor 2005). Temperatures in excess of 28ºC are judged to have sublethal effects on Atlantic sturgeon. An increase in temperature coupled with low dissolved oxygen and high salinity can cause loss of juvenile Atlantic sturgeon nursery habitat. Their low tolerance to temperature and low oxygen is of particular concern during the first two summers of life when juveniles are restricted to lower saline waters, and are unable to seek out thermal refuge in deeper waters (Secor and Gunderson 1998; Niklitschek 2001; Niklitschek and Secor 2005).

Temperature may also be an important habitat parameter with regard to migration patterns, since juvenile Atlantic sturgeon appear to migrate in response to certain temperature thresholds. Dovel and Berggren (1983) stated that downstream migrations in the Hudson River began when temperatures reached 20°C, and peaked between 12°C and 18°C. By the time the temperature was 9°C, juvenile Atlantic sturgeon had congregated for the winter in deep holes (Dovel and Berggren 1983) where water temperatures can approach 0°C (Bain et al. 2000). Similar migration patterns were noted by Dovel (1979) in the Hudson River and by Brundage and Meadows (1982) in the Delaware River. However, Lazzari et al. (1986) reported that juvenile Atlantic sturgeon in the Delaware River used the tidal portion of the bay for a longer period of time and at lower temperatures than reported by other researchers. T hey found Atlantic sturgeon in these areas through December when temperatures approached 0.5°C.

Kieffer and Kynard (1993) found during their biotelemetry studies that juvenile Atlantic sturgeon in the Connecticut and Merrimack Rivers, Massachusetts, did not enter the river until mid-May when the temperatures were 14.8°C to 19.0°C. The fish left the river by September or October when river temperatures were 13°C to 18.4°C (Kieffer and Kynard 1993).

Temperature may also affect juvenile Atlantic sturgeon feeding behavior. Mohler (2003) found that in cultured juvenile Atlantic sturgeons, a noticeable decrease in feeding occurred when temperatures dropped to 10°C. However, minimum weight gains were noticed at temperatures as low as 5.4°C, with weight loss occurring at lower water temperatures (Mohler 2003).

Juvenile dissolved oxygen associations

Dissolved oxygen is a very important habitat parameter for juvenile Atlantic sturgeon. A large proportion of Atlantic sturgeon nursery habitat has been degraded as a result of persistent low levels of dissolved oxygen. Secor and Niklitschek (2001) report that in habitats with less than 60% oxygen saturation (4.3 mg/L to 4.7 mg/L at 22°C to 27°C), YOY fish aged 30 to 200 days, will experience a loss in growth. Mortality of juvenile Atlantic sturgeon has been observed for summer temperatures at levels of less than or equal to 3.3 mg/L (Secor and Niklitschek 2001). Recently, the Chesapeake Bay Program adopted dissolved oxygen guidelines based upon levels that would protect Atlantic and shortnose sturgeon, which show unusually high sensitivity to low oxygen concentrations among estuarine living resources (Secor and Niklitschek 2002; EPA 2003).

Juvenile feeding behavior

Pottle and Dadswell (1982) examined the gut contents of juvenile Atlantic sturgeon in the St. Johns River, Florida. They found that juvenile Atlantic sturgeon fed on diptera and trichoptera, in addition to amphipods. Secor et al. (2000b) found that juvenile Atlantic sturgeon in the Chesapeake Bay preyed upon annelid worms, isopods, amphipods, chironomid larvae, and mysids. Moser and Ross (1995) found polycheate worms, isopods, and mollusk shell fragments in the stomachs of juvenile sturgeon in North Carolina. An examination of 12 juvenile Atlantic sturgeon in the Connecticut and Merrimack Rivers showed a mix of amphipods and polychaetes (Kynard et al. 2000). In freshwater, juvenile Atlantic sturgeon ate plant and animal matter, sludgeworms, chironomid larvae, mayfly larvae, isopods, amphipods, and small bivalve mollusks (Scott and Crossman 1973). Scott and Crossman (1973) also noted that sturgeon consumed mud while foraging on the bottom.

Secor et al. (2000b) analyzed the gut content of 12 juvenile Atlantic sturgeon in the Chesapeake Bay and found that sand, silt, and detritus accounted for 34% of the gut contents. Annelid worms made up 61% of the prey items, followed by isopods (*Cyathura polita* and *Cyathura* sp.; 23%), amphipods (*Leptocheirus plumulosus* and *Gammarus* sp.; 10%), chironomid larvae (1.6%), and mysids (*Neomysis americana*; 1.5%). One-third of the Atlantic sturgeon had empty guts (Secor et al. 2000b). In this small study, Secor et al. (2000b) did not find that juvenile Atlantic sturgeon preyed upon mollusks, despite their high biomass in the Chesapeake Bay.

Juvenile competition and predation

Both juvenile Atlantic sturgeon and shortnose sturgeon occupy the same freshwater/saltwater interface nursery habitat, although shortnose sturgeon tend to be located in freshwater, while Atlantic sturgeon utilize more saline areas (Dadswell 1979; Dovel and Berggren 1983; Dovel et al. 1992; Kieffer and Kynard 1993; Haley et al. 1996; Bain 1997). Haley et al. (1996) collected the majority of juvenile Atlantic sturgeon in the Hudson River in deeper, mesohaline (3.0 ppt to 16.0 ppt) regions, while juvenile shortnose sturgeon were found most often in the shallower, freshwater (<0.5 ppt) zones of the estuary. Furthermore, bioenergetic comparisons showed that age-1 Atlantic sturgeon demonstrated better growth in brackish water (1 ppt to 10 ppt), than sympatric shortnose sturgeon juveniles (Niklitschek 2001).

In contrast, Bain (1997) found that early juvenile Atlantic sturgeon had the same distribution as juvenile shortnose sturgeon in the Hudson River estuary during all seasons. Both species were similar in size, grew at about the same rate, had similar diets, and shared deep channel habitats early in life (Bain 1997). Additionally, Bain (1997) found that the distribution of adult shortnose sturgeon overlapped with the distribution of juvenile Atlantic sturgeon.

Haley et al. (1996) hypothesized that the freshwater/saltwater interface where both sturgeon species concentrate, may serve as a foraging ground, and that Atlantic and shortnose sturgeon may compete for food in this area. However, Pottle and Dadswell (1982) found that juvenile Atlantic and shortnose sturgeon in the St. Johns River preyed on different species. They found that Atlantic sturgeon preyed upon diptera, trichoptera, and some amphipods, while shortnose sturgeon preyed mostly upon cladocerans, amphipods, mollusks, and insect larvae (Pottle and Dadswell 1982). When reared in large outdoor tanks and fed an artificial diet, shortnose sturgeon juveniles fed at higher rates and grew more rapidly than similar sized Atlantic sturgeon (Niklitschek 2001).

In more southern rivers, juvenile Atlantic sturgeon and adult shortnose sturgeon may share parts of the river with similar salinity levels. This has been documented in the Savannah River during the fall and winter, and in the Altamaha River during warm summers (Kieffer and Kynard 1993).

Atlantic sturgeon juveniles would be expected to compete with other demersal feeding fishes in estuaries. In mid-Atlantic estuaries these demersal feeders include catfishes, white perch, carp, spot, croaker, and hogchoker (Murdy et al. 1997).

Part D. Atlantic Sturgeon Late Stage Juvenile and Adult Marine Habitat

All estuarine habitats for adult and juvenile Atlantic sturgeon are discussed under previous sections. This section focuses entirely on juvenile and adult Atlantic sturgeon habitat in marine waters.

Geographical and temporal patterns at sea

Juvenile Atlantic sturgeon are known to emigrate out of their natal estuarine habitats and migrate long distances in the marine environment (Murawski and Pacheco 1977); the longest oceanic journey recorded was 1,450 km (Magnin and Beaulieu 1963). Tag returns (n = 120) of juvenile Atlantic sturgeon that were originally tagged in the Delaware River provide insight into the coastal migration of this life stage that encompasses a broad size range (C. Shirey, Delaware Department of Fish and Wildlife, unpublished data). After leaving the Delaware River estuary during the fall, juvenile Atlantic sturgeon were recaptured by commercial fishermen in nearshore waters along the Atlantic coast as far south as Cape Hatteras, North Carolina, where they were recaptured from November through early March. Juvenile Atlantic sturgeon repeatedly crossed the mouth of the Chesapeake Bay and traveled around the Delmarva Peninsula in March and April, with a portion of the tagged fish re-entering the Delaware River estuary. However, many fish continued this northerly coastal migration through the mid-Atlantic and into southern New England waters where they were recovered throughout the summer months, primarily in the waters of Massachusetts, Rhode Island, and Long Island, New York. Movements as far north as Maine were documented. A southerly coastal migration was apparent from tag returns reported in the fall. The majority of these tag returns were reported from relatively shallow nearshore fisheries with few fish reported from waters in excess of 25 m (C. Shirey, Delaware Department of Fish and Wildlife, unpublished data).

Little is known about the habitat use of adult Atlantic sturgeon during the non-spawning season, particularly when the sturgeon return to marine waters (Bain 1997; Collins et al. 2000b). While at sea, adult Atlantic sturgeon have been documented using relatively shallow nearshore habitats (10 m to 50 m) (Laney et al. 2007; Stein et al. 2004). It is possible that individual fish select habitats in the same areas, or even possibly school to some extent (Bain et al. 2000; Stein et al. 2004; Laney et al. 2007).

Substrate associations at sea

Stein et al. (2004) reported that Atlantic sturgeon were found mostly over sand and gravel substrate, and that they were associated with specific coastal features, such as the mouths of the Chesapeake Bay and Narragansett Bay, and inlets in the North Carolina Outer Banks. Laney et al. (2007) found similar results off the coasts of Virginia and North Carolina. The researchers used GIS layers to analyze data from the Cooperative Winter Tagging Cruise, and found that Atlantic sturgeon were located primarily in sandy substrates. However, the authors state that GIS does not depict small-scale sediment distribution, thus only a broad overview of sediment types was used. In addition, sediment sampling done along the North Carolina coast shows that gravel substrates are found a little farther offshore from where the sturgeon were found (Laney et al. 2007).

Depth associations at sea

The greatest depth in the ocean at which Atlantic sturgeon have been reported caught was 75 m (Colette and Klein-MacPhee 2002). Collins and Smith (1997) report that Atlantic sturgeon were captured at depths of 40 m in marine waters off South Carolina. Stein et al. (2004) investigated data collected by on-board fishery observers from 1989-2000 to determine habitat preferences of Atlantic sturgeon. They found that Atlantic sturgeon were caught in shallow (<60 m) inshore areas of the Continental Shelf. Sturgeon were captured in depths less than 25 m along the Mid-Atlantic Bight, and in deeper waters in the Gulf of Maine (Stein et al. 2004).

The Northeast Fisheries Science Center bottom trawl survey caught 139 Atlantic sturgeon from 1972-1996 in waters from Canada to South Carolina. They found the fish in depths of 7 m to 75 m, with a mean depth of 17.3 m. Of the fish caught, 40% were collected at 15 m, 13% at 13 m, and less than 5% at all the depth strata (NEFC, unpublished data, reviewed in Savoy and Pacileo 2003).

Upon entering the marine habitat, Atlantic sturgeon have been documented near the shore in shallow waters where the depths measure less than 20 m (Gilbert 1989; Johnson et al. 1997). During their tagging cruise off the coasts of Virginia and North Carolina, Laney et al. (2007) captured Atlantic sturgeon at depths up to approximately 6 m. Vladykov and Greeley (1963) record a maximum depth of at least 18 m. Additionally, Johnson et al. (2005) reported that Atlantic sturgeon were caught within 5 km of the coast of New Jersey in waters approximately 15 m deep.

Feeding behavior at sea

There is little information regarding the marine diet of Atlantic sturgeon. Johnson et al. (1997) suggest that this is because of the low population density of Atlantic sturgeon offshore, and the fact that most studies have focused on rivers and estuaries. A stomach content study by Johnson et al. (1997) found that Atlantic sturgeon off the coast of New Jersey preyed upon polychaetes, isopods, decapods, and amphipods. They also found that mollusks and fish contributed little to the diet, and that sand and organic debris were major components (Johnson et al. 1997). Scott and Crossman (1973) stated that in marine waters, Atlantic sturgeon fed on mollusks, polychaete worms, gastropods, shrimps, amphipods, isopods, and small fish (particularly sand lances).

Competition and predation at sea

Atlantic sturgeon compete with other bottom feeding fish and invertebrates. Gilbert (1989) lists winter flounder (*Pleuronectes americanus*), tautog (*Tautoa onitis*), cunner (*Tautogolabrus adspersus*), porgies (Sparidae), croakers (Sciaenidae), and stingrays (*Dasyatis* sp.) as possible competitors. Scott and Crossman (1973) report that Atlantic sturgeon are killed by sea lampreys, *Petromyzon marinus*; in South Carolina, long nose gar have been reported attacking sturgeon (Smith 1985b). Other predators can be found in Part A of this chapter.

Section II. Identification and Distribution of Habitat Areas of Particular Concern for Atlantic Sturgeon

Habitat types that qualify as Habitat Areas of Particular Concern for Atlantic sturgeon include spawning sites/hatching grounds, nursery areas, inlets, and wintering grounds.

Spawning sites/hatching grounds occur in freshwater portions of estuaries and large river tributaries along the Atlantic coast. These areas provide the habitat parameters essential for reproduction, including well oxygenated water, clean substrates for egg adhesion, and crevices that provide cover for post-hatch larvae and abundant macroinvertebrate prey items. This habitat type is very sensitive to anthropogenic impacts, including dams and other river impoundments, nutrient and sediment loading, pollution, navigational dredging, and other coastal developments (especially those with intake structures). Spawning sites are very limited and have been rendered inaccessible and/or degraded since coastal areas have become industrialized and developed.

Nursery areas are limited to freshwater/estuarine tributaries for Atlantic sturgeon age 0-2; nursery areas include bays, estuaries, and nearshore ocean environments for older juveniles (age >2). Freshwater and low salinity areas are important to larvae and age-0 juveniles, because they cannot tolerate high salinity (Secor and Niklitschek 2002). Nursery habitats for juvenile Atlantic sturgeon are essential for growth of this species. This habitat provides foraging grounds for juvenile Atlantic sturgeon, and in some cases, thermal refuge during the summer and winter months (Moser and Ross 1995). Nursery habitats are severely impacted by hypoxic conditions, particularly during summer months when high temperatures can combine with low oxygen levels to degrade and eliminate valuable habitat for juveniles (Secor and Niklitschek 2002; McBride 2004). Other anthropogenic impacts include navigational dredging and port development, sedimentation, nutrient loading (which leads to hypoxic conditions), and recreational and commercial vessel traffic. While nursery areas are less limited in extent than spawning areas, they are still scarce.

Estuarine inlets provide adult and intermediate/late juvenile Atlantic sturgeon with migration corridors to and from freshwater spawning habitat and estuarine nursery grounds. The importance of these areas to Atlantic sturgeon has not been researched; inlets are potentially more rare than spawning habitats. Inlets are impacted by channel alterations (deepening and stabilization) and commercial and recreational coastal development activities. Examples of inlets used by juvenile and adult Atlantic sturgeon include New York Harbor, Delaware Bay, Oregon Inlet, Hatteras Inlet, and Okracoke Inlet for Atlantic sturgeon entering/leaving the Cape Fear River, North Carolina. For movement into or out of the James River, Virginia, fish must migrate through the mouth of the Chesapeake Bay (W. Laney, U. S. Fish and Wildlife Service, personal communication).

Wintering Grounds for adult and late juvenile Atlantic sturgeon include the nearshore areas off the Atlantic coast from the Gulf of Maine south to at least Cape Lookout, North Carolina (Stein et al. 2004; Laney et al. 2007). These areas provide Atlantic sturgeon with foraging grounds and habitat for most of the year (Johnson et al. 1997). Anthropogenic impacts include habitat degradation due to fishing activities, commercial navigation, oil and gas exploration, and construction of offshore liquefied natural gas (LNG) facilities. Ghost fishing may result in sturgeon losses due to entanglement in lost gear. Winter habitat occurs in coastal nearshore waters, which is expected to not be as limited as spawning habitats and inlets.

Section III. Present Conditions of Habitat and Habitat Areas of Particular Concern for Atlantic Sturgeon

Habitat quantity

Although the amount has not been quantified, Atlantic sturgeon habitat has decreased or been degraded by clear-cutting, agricultural practices, dams, and other channel and watershed modifications since the eighteenth and nineteenth centuries (Hill 1996; Secor et al. 2002; Bushnoe et al. 2005). Historically, Atlantic sturgeon were documented in 38 rivers ranging from the Hamilton Inlet on the coast of Labrador to the St. Johns River in Florida. The ASSRT (2007) most recently reported that 35 of those historical rivers have Atlantic sturgeon present, and 20 are believed to be extant reproducing populations. Once abundant in every river and associated estuary within their range, Atlantic sturgeon have now either been extirpated, or are at historically low levels. Consequently, although Atlantic sturgeon still remain throughout much of their former range, their numbers have been severely reduced (ASSRT 2007).

Habitat quality

The quality of Atlantic sturgeon habitat has been seriously impacted by human actions. Since European settlement, overfishing, habitat loss, and poor water quality have all contributed to the decline of Atlantic sturgeon stocks. Most of these impacts have been gradual and are poorly understood (Smith 1985b; ASFMC 1998; USFWS-NMFS 1998; Secor and Gunderson 1998; Secor et al. 2000a; Secor and Niklitschek 2001; ASSRT 2007).

Section IV. Significant Environmental, Temporal, and Spatial Factors Affecting Distribution of Atlantic Sturgeon

Table 8-8. Significant environmental, temporal, and spatial factors affecting distribution of Atlantic sturgeon. This table summarizes the current literature on Atlantic sturgeon habitat associations. For most categories, optimal and tolerable ranges have not been identified, and the summarized habitat parameters are listed under the category reported. In some cases, unsuitable habitat parameters are defined. NIF = No Information Found. N/A = Not Applicable.

Life Stage	Time of Year and Location	Depth (m)	Temperature (°C)	Salinity (ppt)	Substrate	Current Velocity (m/sec)	Dissolved Oxygen (mg/L)
Adult (Spawning)	Freshwater rivers and possibly tidal freshwater regions of large estuaries (in the north) Feb – Southern states April-May – Mid-Atlantic May-July – Northern States and Canada Sept-Dec – Second spawning documented in Southern regions	**Tolerable:** NIF **Optimal:** 2.4-8+ (HSI model for Southern Regions) **Reported:** 3-27	**Tolerable:** NIF **Optimal:** 16-21 (HSI model for Southern Regions); 20-21 for cultured sturgeon **Reported:** Male migrations 5.6-6.1; Female migrations 12.2-13; Spawning 13-23.4	**Tolerable:** NIF **Optimal:** NIF **Reported:** Above the salt wedge in fresh water.	**Tolerable:** NIF **Optimal:** Cobble/gravel >64mm-250mm (HSI model for Southern Regions) **Reported:** Hard substrate, including rubble, gravel, clay, rock, bedrock, slag from old steel mills and limestone	**Tolerable:** NIF **Optimal:** 0.2 - 0.76 **Reported:** 0.46 – 0.76 okay; unsuitable if ≤0.06, or ≥ 1.07	**Tolerable:** NIF **Optimal:** NIF **Reported:** NIF
Adult (Estuarine)	Sturgeon do not spawn every year, yet may participate in an upstream migration. After spawning, some sturgeon remain in the rivers through the summer, while others migrate to sea. Downstream migrations occur Sept – Nov in Canada. Present in South March – Oct. Overwinter in the ocean.	**Tolerable:** NIF **Optimal:** NIF **Reported:** 1.5-60	**Tolerable:** NIF **Optimal:** NIF **Reported:** Adult sturgeon documented in waters with temperatures as high as 33.1 in SC.	**Tolerable:** NIF **Optimal:** NIF **Reported:** Documented summer habitat in upper/fresh/ brackish interface, lower interface, and high salinity portions of estuaries in SC. Salinity ranged from 0-28.6	**Tolerable:** NIF **Optimal:** NIF **Reported:** Found over fine mud, sand, pebbles, and shell substrate	**Tolerable:** NIF **Optimal:** NIF **Reported:** NIF	**Tolerable:** NIF **Optimal:** NIF **Reported:** NIF

Life Stage	Time of Year and Location	Depth (m)	Temperature (^{o}C)	Salinity (ppt)	Substrate	Current Velocity (m/sec)	Dissolved Oxygen (mg/L)
Egg and Larval	Eggs are laid in flowing water in rivers along the Atlantic coast. Larval sturgeon are found in same habitat where spawned and are benthic.	**Tolerable:** NIF **Optimal:** 2.4-8+ for egg incubation (HSI model for Southern Regions) **Reported:** Embryos remain in deep channels. Larval collected at 9.1-19.8	**Tolerable:** NIF **Optimal:** 20-21 Cultured sturgeon **Reported:** Eggs hatch in 94-140 hours ranging from 15.0 – 24.5	**Tolerable:** NIF **Optimal:** NIF **Reported:** Found upstream of salt front; have a low tolerance to salinity; mortality reported in 5-10 for some sturgeon species	**Tolerable:** NIF **Optimal:** Cobble/gravel >64mm-250mm (HSI model for Southern Regions) **Reported:** After 20 minutes, eggs become adhesive and attach to hard substrate. Larvae also use hard substrate as refuge	**Tolerable:** NIF **Optimal:** NIF **Reported:** NIF	**Tolerable:** NIF **Optimal:** NIF **Reported:** NIF
Juvenile (Estuarine)	Remain in natal habitats within estuary for up to a year before migrating out to sea. Migrations to other estuaries are common. Use brackish water near month of estuary during winter and move up-estuary during warmer months	**Tolerable:** NIF **Optimal:** Deep water and holes serve as thermal refuge **Reported:** 2-37	**Tolerable:** 3-28 **Optimal:** ~20 **Unsuitable:** Temperatures >28 are sub-lethal **Reported:** Downstream migration begins when water reaches 20°C and peaks between 12-18°C. Documented range of 0.5-27	**Tolerable:** NIF **Optimal:** ~10 **Reported:** Large juveniles found mostly where salinity is >3; found in 0-27.5	**Tolerable:** NIF **Optimal:** NIF **Reported:** Found mostly over sand substrate and mud or transitional habitats. Also found over rocks and cobble	**Tolerable:** NIF **Optimal:** NIF **Reported:** NIF	**Tolerable:** NIF **Optimal:** >5 mg/L **Reported:** Mortality at summer temperature s (26°C) observed at levels <3.3mg/L

Life Stage	Time of Year and Location	Depth (m)	Temperature (°C)	Salinity (ppt)	Substrate	Current Velocity (m/sec)	Dissolved Oxygen (mg/L)
Juvenile and adult (At-sea)	Utilize marine waters during non-spawning seasons. Nearshore areas off the Atlantic coast from the Gulf of Maine to at least Cape Lookout, NC. Little is known about this part of their lives	**Tolerable:** NIF **Optimal:** NIF **Reported:** Most found in shallow waters; greatest depth recorded = 75; depth range 7-43	**Tolerable:** NIF **Optimal:** NIF **Reported:** NIF	**Tolerable:** NIF **Optimal:** NIF **Reported:** Marine waters off the continental shelf	**Tolerable:** NIF **Optimal:** NIF **Reported:** Sand, gravel, silt and clay. Suggested that they will use any substrate that supports their food resource	**Tolerable:** NIF **Optimal:** NIF **Reported:** NIF	**Tolerable:** NIF **Optimal:** NIF **Reported:** NIF

Section V. Atlantic Sturgeon Literature Cited

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