Chapter 10

THREATS TO DIADROMOUS SPECIES

Please Note: Due to broad geographic ranges, diadromous species are susceptible to varied threats throughout different life stages. The threats identified under this section occur during the freshwater and/or estuarine portion of species life histories.

PART I. IDENTIFICATION OF THREATS

THREAT #1: BARRIERS TO UPSTREAM AND DOWNSTREAM MIGRATION

Section 1.1A: Dams and Hydropower Facilities

Issue 1.1A.1: Blocked or restricted upstream access

There has been considerable loss of historic spawning habitat for shad and river herring due to the dams and spillways impeding rivers along the East Coast of the United States. Permanent man-made structures pose an ongoing barrier to fish passage unless fishways are installed or structures are removed. Low-head dams can also pose a problem, as fish are unable to pass over them except when tides or river discharges are exceptionally high (Loesch and Atran 1994). Historically, major dams were often constructed at the site of natural formations conducive to water power, such as natural falls. Diversion of water away from rapids at the base of falls can reduce fish habitat, and in some cases cause rivers to run dry at the base for much of the summer (MEOEA 2005).

<u>Example: American shad</u>

Many dams have facilities that are designed to provide upstream passage to spawning habitat for migratory species. However, dams without adequate upstream fish passage facilities prevent, or significantly reduce, the numbers of migratory fish that return to available habitat (Quinn 1994). Suboptimal fish passage at a low-head dam on the Neuse River, North Carolina, resulted in limited production of American shad in that system (Beasley and Hightower 2000). Subsequent removal of the dam in 1998 facilitated the return of American shad and striped bass to historic spawning habitats above the dam (Burdick 2005).

American shad likely spawned in most, if not all, rivers and tributaries in their range prior to dam construction along the Atlantic coast (Colette and Klein-MacPhee 2002). Precise estimates are not possible, but scientists speculate that at least 130 rivers supported historical runs; now there are fewer than 70 spawning systems for American shad. Furthermore, individual spawning runs at one time may have numbered in the hundreds of thousands, but current runs may provide less than 10% of historic spawning habitat (Limburg et al. 2003). Dams built from the 19th century through the mid-20th century on several major tributaries to the Chesapeake Bay have substantially reduced the amount of spawning habitat available to American shad (Atran et al. 1983; CEC 1988), and likely contributed to long-term stock declines (Mansueti and Kolb 1953).

Example: American eel

Aside from presence/absence studies of American eel, no other methods are currently used to determine anthropogenic impacts on American eel populations. Since American eel randomly disperse throughout Atlantic coastal tributaries, it is assumed that they will colonize all available inland areas. Thus, an absence of American eel is often attributed to anthropogenic impacts. However, this theory is complicated by the fact that this speciesnaturally decreases in density as individuals migrate upriver from the sea, making it difficult to quantify the true impact that dams are having on American eel populations (Smogor et al. 1995; Richkus and Whalen 1999; Wiley et al. 2004). Using GIS analysis, Busch et al. (1998) found that 84% of Atlantic coastal tributary access has been lost or restricted from use by American eel. Habitat loss was greatest from Maine to Connecticut (91%), with a reduction in stream access from 111,482 km to 10,349 km. In the mid-Atlantic region (New York through Virginia), stream habitat has been reduced (88%) from 199,312 km to 24,534 km. From North Carolina to Florida, stream habitat has been reduced (77%) from 246,007 km to 55,872 km (Busch et al. 1998). In the St. Lawrence watershed, Verreault et al. (2004) identified 151 hydrodams greater than 2.5 m equipped with turbines and 8260 dams greater than 2.5 m without turbines. They estimate that these dams block 12,140 km^2 of suitable habitat within the St. Lawrence watershed, and that this loss of habitat represents 836,545 fecund females (Verreault et al. 2004).

Most fishways, particularly those designed for salmonids, are not adequate for American eel (Verdon et al. 2003) because they do not accommodate the unique swimming mode of anguillid eels (Knights and White 1998). Because American eel can climb damp substrates, they are sometimes able to ascend dams without passage structures (Legault 1988; Haro et al. 2000). Unfortunately, many coastal rivers do not have provisions for the upstream passage of American eel (Haro et al. 2000).

Barriers that impede or restrict upstream passage for American eel may cause a significant decrease in recruitment to upstream habitats. Because phenotypic sex in American eel may be determined by environmental factors, such as population density (Krueger and Oliveira 1999), a decline in recruitment could ultimately reduce the numbers of females that migrate out to sea to spawn (Verdon et al. 2003). River impoundments that lack fish passage structures could contribute to imbalanced sex ratios dominated by males, if high concentrations of American eel become trapped below the barriers (Richkus and Whalen 1999; Haro et al. 2000). Wiley et al. (2004) found that in Maryland, stream sites within 5 km of impassable or semi-passable structures had a mean American eel density twice that of sites located further away, demonstrating that American eel congregate in areas below artificial structures. American eel densities below taller structures were some of the highest recorded throughout the study (Wiley et al. 2004). American eel trapped below barriers could also incur mortality by increased predation, competition for food, and the spread of disease (Haro et al. 2000).

Machut (2006) found that an increase in the number of barriers on the Hudson River significantly lowered American eel condition (measure of fat content). American eel condition may be affected when their natural migratory behavior is altered. This can occur because dams may hamper movements between different habitat types (Cairns et al. 2004), and American eel have been documented moving between freshwater and estuarine habitats (Morrison et al. 2003). As brackish waters tend to lead to increased productivity and growth

(Helfman et al. 1987; Morrison and Secor 2003), a decreased ability to migrate back and forth into this type of habitat may lead to decrease in fat content. Svedäng and Wickstrum (1997) found that eels with a lower fat content (lower condition) might stall their migrations downstream in order to increase fat content to a level that will sustain them.

Example: Atlantic sturgeon

The most significant threat to Atlantic sturgeon is the loss of upstream spawning habitat from dams (Hill 1996; NRC 1996; Secor et al. 2002). The construction of dams is considered to be a factor in the reduction and elimination of Atlantic sturgeon in New England (ASMFC 1998; USFWS-NMFS 1998). Atkins (1887) noted a large decrease in the abundance of Atlantic sturgeon after a dam was built on the Kennebec River in Augusta, Maine. Before construction of the dam, the fish spawned between Augusta and Waterville, Maine (Atkins 1887; Colette and Klein-MacPhee 2002). The Roanoke River, North Carolina, historically a spawning ground of the Atlantic sturgeon, now restricts migration of Atlantic sturgeon with a 22 m high dam (Armstrong and Hightower 2002). Armstrong and Hightower (2002) estimate that 58% to 73% of the historic Atlantic sturgeon spawning habitat in the Roanoke River is now located above this dam. Additionally, the Wilson Dam in the Santee River Basin, South Carolina, eliminated almost all spawning habitat along this river (P. Brownell, NOAA Fisheries, Southeast Regional Office, personal communication).

Issue 1.1A.2: Impacts during downstream migration

Another impact of dams on diadromous species migration is their potential to cause mortality to young fish that pass over sluices and spillways during out-migration. Potential effects to fish passing through spillways or sluices may include injury from turbulence, rapid deceleration, terminal velocity, impact against the base of the spillway, scraping against the rough concrete face of the spillbay, and rapid pressure changes (Ferguson 1992; Heisey et al. 1996).

Example: Shad and river herring

Prior to the early 1990s, it was thought that migrating shad and river herring suffered significant mortality going through turbines during downstream passage (Mathur and Heisey 1992). One study estimated that mortality of adult American shad passing through a Kaplan turbine was approximately 21.5% (Bell and Kynard 1985).

Juvenile shad emigrating from rivers have been found to accumulate in larger numbers near the forebay of hydroelectric facilities, where they become entrained in intake flow areas (Martin et al. 1994). Relatively high mortality rates were reported (62% to 82%) at a hydroelectric dam for juvenile American shad and blueback herring, depending on the power generation levels tested (Taylor and Kynard 1984). In contrast, Mathur and Heisey (1992) reported a mortality rate of 0% to 3% for juvenile American shad (55 to 140 mm fork length), and 4% for juvenile blueback herring (77 to 105 mm fork length) through Kaplan turbines. Mortality rate increased to 11% in passage through a low-head Francis turbine (Mathur and Heisey 1992). Other studies reported less than 5% mortality when large Kaplan and fixed-blade, mixed-flow turbines were used at a facility along the Susquehanna River

(RMC 1991, 1994). At the same site, using small Kaplan and Francis runners, the mortality rate was as high as 22% (NA 2001). At another site, mortality rate was about 15% where higher revolution, Francis-type runners were used (RMC 1992).

Additional studies reported that changes in pressure had a more pronounced effect on juveniles with thinner and weaker tissues as they moved through turbines (Taylor and Kynard 1984). Furthermore, some fish may die later from stress, or become weakened and more susceptible to predation, so losses may not be immediately apparent to researchers (Gloss 1982).

Example: American eel

Risks to fish passing through turbines during downstream migration vary depending on the species. For American eel, greater mortality may be associated with the Kaplan turbine than with the Francis turbine (Desrochers 1994). Berg (1986) reported that 15% to 50% of European eel experienced lethal injuries in a Kaplan turbine. Monten (1985) reported injury rates of 9%, 65%, and 100% for European eel 50 to 52 cm in length from a Francis turbine operating under generator load conditions of 61%, 80%, and 100%. However, Hadderingh and Bakker (1998) reported disparate results for a Kaplan turbine. They found that European eel of comparable sizes had injury rates of 23%, 10%, and 6%, as flow increased. RMC (1995) reported that American eel (average size 86 cm) sustained a 9% injury rate in a small Francis turbine, but results may have been underestimated (McCleave 2001). At the Robert Moses Power Dam in New York, survival rates of American eel passing through the turbine were estimated at 84% for 1 hour and 73.5% for 88 hours. Seventy-six of 207 American eel had a visible injury after passage. Furthermore, 24.1% of the American eel had debilitating or fatal injuries, including severed bodies, hemorrhaging, lacerations, damaged eyes, scrapes, loss of equilibrium, and internal or vertebral damage (NA and Skalski 1998). American eel injured while passing through one turbine face a greater chance of mortality at the next facility downstream (McCleave 2001). Horizontal bulb turbines have the least impact on American eel due to the greater distance between bulb vanes and runner blades, and fewer blades than on vertical turbines (Hadderingh and Bakker 1998). Additionally, female American eel are generally longer than males of the species (Helfman et al. 1987; Krueger and Oliveira 1997; Oliveira and McCleave 2000), which may contribute to increased risk of mortality (Travade and Larinier 1992). Another potential threat of hydroelectric facilities is an alteration of natural lighting. Silver-phase American eel migrate downstream primarily at night and are strongly photophobic, so lighting may alter normal downstream migratory behavior (Haro and Castro-Santos 2000). Artificial lighting has also been found to impact yellow-phase American eel migrating upstream (Verdon et al. 2003).

Example: Atlantic sturgeon

For Atlantic sturgeon, larger fish may be more prone to mortality from hydroelectric dams. Dadswell and Rulifson (1994) found three dead Atlantic sturgeon (1.5 m to 2.0 m length) below the Annapolis River STRAFLO turbine in the Bay of Fundy. The cause of death was a mechanical strike, which is common for fish of larger sizes (Dadswell and Rulifson 1994).

Issue 1.1A.3: Delayed migration

Example: Alosines

When juvenile alosines delay outmigration, they may concentrate behind dams, making them more susceptible to actively feeding predators. They may also be more vulnerable to anglers that target alosines as a source of bait. Delayed outmigration can also make juvenile alosines more susceptible to marine predators that they may have avoided if they had followed their natural migration patterns (McCord 2005a). In open rivers, juvenile alosines gradually move seaward in groups that are likely spaced according to the spatial separation of spawning and nursery grounds (Limburg 1996; J. McCord, South Carolina Department of Natural Resources, personal observation).

Issue 1.1A.4: Changes to the river system

In addition to physically impeding fish migration, dams can have other impacts on anadromous fish habitat. Releasing water from dams and impoundments (or reservoirs) may lead to flow alterations, altered sediment transport, disruption of nutrient availability, changes in water quality downstream (including both reduced and increased changes in temperatures), streambank erosion, concentration of sediment and pollutants, changes in species composition, solubilization of iron and manganese and their absorbed or chelated ions, and hydrogen sulfide in hypolimnetic (release of water at low level outlets) releases (Yeager 1995; Erkan 2002). Many dams spill water over the top of the structure where water temperatures are the warmest, which essentially creates a series of warm water ponds rather than a natural stream channel (Erkan 2002). Conversely, water released from deep reservoirs may be poorly oxygenated, below normal seasonal water temperature, or both, thereby causing loss of suitable spawning or nursery habitat in otherwise habitable areas.

Reducing minimum flows can dehydrate otherwise productive habitats causing increased water temperature or reduced dissolved oxygen levels (ASMFC 1985, 1999; USFWS et al. 2001).

Pulsing or "hydropeaking" releases typically produce the most substantial environmental alterations (Yeager 1995), including reduced biotic productivity in tailwaters (Cushman 1985).

During low flow periods (typically summer and fall), gases, dissolved oxygen in particular, may be depleted (Yeager 1995). Storing water at hydropower facilities during times of diminished rainfall can also lead to low dissolved oxygen conditions downstream. Such conditions have occurred along the Susquehanna River at the Conowingo Dam, Maryland, from late spring through early fall, and have historically caused large fish kills below the dam (Krauthamer and Richkus 1987).

Example: Alosines

Disruption of seasonal flow rates in rivers has the potential to impact upstream and downstream migration patterns for adult and juvenile alosines (ASMFC 1985, 1999; Limburg 1996; USFWS et al. 2001). Changes to natural flows can also disrupt natural productivity and availability of zooplankton, which is nourishment for larval and early juvenile alosines (Crecco and Savoy 1987; Limburg 1996).

Although most dams that impact diadromous fish are located along the length of rivers, fish can also be affected by hydroelectric projects at the mouths of rivers, such as the large tidal hydroelectric project at the Annapolis River in the Bay of Fundy, Canada. Dadswell et al. (1983) found that this particular basin and other surrounding waters are used as foraging areas during summer months by American shad from all runs along the East Coast of the United States. Because the facilities are tidal hydroelectric projects, fish may move into and out of the impacted areas with each tidal cycle. Although turbine mortality is relatively minor with each passage, the repeated passage into and out of these facilities may cumulatively result in substantial overall mortalities (Scarratt and Dadswell 1983).

Example: American eel

River flow changes from dams may be especially stressful for poor swimming American eel elvers during their upstream migration. In fact, changes to the pattern and/or volume of discharge from a dam may delay or halt elver migration (Jessop and Harvie 2003). Jessop and Harvie (2003) found that flow changes at the Mactaquac hydroelectric dam on the St. Johns River, New Brunswick, may have caused a decrease in recruitment of American eel elvers through the dam. Prior to 1980, a large number of American eel elvers migrated through the Mactaquac dam. In 1980, two turbines were installed at the dam; following this change, migration of elvers ceased and has not since been documented. Researchers concluded that changes to hourly and daily discharge patterns could possibly account for the failure of elver migration (Jessop and Harvie 2003).

Example: Atlantic sturgeon

Atlantic sturgeon can be affected by altered dissolved oxygen concentrations, temperatures, water flow, destratification, water withdrawal, modified sediment load and channel morphology, and contaminated water as a result of dams that change the river system (Hill 1996; NRC 1996; Secor et al. 2002). Deepwater releases in late winter through early spring are often below habitable temperatures for Atlantic sturgeon (13.3 ^{o}C to 17.8^{o}C) (Borodin 1925). Dams can alter hard substrates that are utilized by Atlantic sturgeon for spawning habitat (Parsley et al. 1993; Beamesderfer and Farr 1997); impoundments can also be a limiting factor in Atlantic sturgeon recovery (Secor et al. 2000; Secor and Niklischek 2001). Furthermore, loss of access to substrate, as well as the degraded quality of substrate, may be the largest factors hampering the recovery of Atlantic sturgeon (P. Brownell, NOAA Fisheries, Southeast Regional Office, personal communication).

Issue 1.1A.5: Secondary impacts

Blocked migratory paths can reduce the diadromous species contribution of nutrients and carbon to riparian systems. Riverine habitats and communities may be strongly influenced by migratory fauna that provide a significant source of energy input (Polis et al. 1997). Furthermore, many freshwater mussels are dependent upon migratory fishes as hosts for their parasitic larvae (Neves et al. 1997; Vaughn and Taylor 1999); loss of upstream habitat for migratory fish is a major cause of mussel population declines (Williams et al. 1993; Watters 1996).

Example: Alosines

It is estimated that the annual biomass contribution of anadromous alosines to the nontidal James River, Virginia, was 155 kg/ha (assumes 3.6 million fish with 70% post-spawning mortality) in the 1870s, before dams blocked upstream migration (Garman 1992). Based on the estimated 90% reduction in alosine abundance in the Chesapeake Bay over the past 30 years, Garman and Macko (1998) concluded that, “the ecological roles hypothesized for anadromous *Alosa* spp. may now be greatly diminished compared to historical conditions.”

Section 1.1B: Avoiding, Minimizing, and Mitigating Impacts of Dams and Hydropower Facilities

Approach 1.1B.1: Removing dams

Not all projects are detrimental to fish populations, so each site should be evaluated separately to determine if fish populations will be (or are being) negatively impacted (Yeager 1995). Wherever practicable, tributary blockages should be removed, dams should be notched, and bypassing dams or installing fish lifts, fish locks, fishways, or navigation locks should be considered. Full dam removal will likely provide the best chance for restoration; however, it is not always practicable to remove large dams along mainstem rivers. Removing dams on smaller, high-order tributaries is more likely to benefit ascending river herring than shad, which spawn in the larger mainstem portions of rivers (Waldman and Limburg 2003).

Example: Successful Dam Removals

Along the large, lower-river tributaries of the Susquehanna River, Pennsylvania, at least 25 dams have either been removed or fitted with fishways, which has provided a total of 350 additional stream kilometers for anadromous fish (St. Pierre 2003). In addition, some dams within the Atlantic sturgeon’s range have been removed, including the Treat Falls Dam on the Penobscot River, Maine, and the Enfield Dam on the Connecticut River, Connecticut. In 1999, the Edwards Dam at the head-of-tide on the Kennebec River was removed, which restored 18 miles of Atlantic sturgeon spawning and nursery habitat and resulted in numerous sightings of large Atlantic sturgeon from Augusta to Waterville (Squires 2001).

Unfortunately, many waterways along the Atlantic coast host impoundments constructed during the Industrial Revolution that originally were a source of inexpensive power; many of these structures are no longer in use and should be removed (Erkan 2002).

Approach 1.1B.2: Installing or modifying fish passage facilities

Approach 1.1B.2A: For upstream passage

Approach 1.1B.2A.1: Fishways

Fish passage facilities, or fishways, allow fish to pass around an impoundment they would otherwise be unable to negotiate. Vertical slot fishways are commonly used to provide upstream access around dam structures. They are designed to draw fish away from the turbulent waters at the base of the dam toward the smooth flowing waters at the entrance of the fishway. Once fish enter the fishway, they negotiate openings, or vertical slots, in the baffle walls. Fish move from pool to pool as they advance up the fishway, using the pools as rest areas (VA DGIF 2006).

Another type of fishway is the fish ladder. Fish ladders consist of a series of baffles, or weirs, that interrupt the flow of water through the passage structure. As with vertical slot fishways, a series of ascending pools is created.

A third type of fishway, the Denil fishway, is the most common type in the northeast and reliably passes shad and river herring. In fact, construction of fish ladders in coastal streams of Maine resulted in rapid and noticeable increases in the number of adult alewife returning to these streams (Rounsefell and Stringer 1943).

It is important to note that although fish passage facilities are instrumental in restoring fish to historical habitat, they are not 100% efficient because some percentage of target fish will not find and successfully use the fishway (Weaver et al. 2003). At sites where bypass facilities are in place, but are inadequate, efficiency of upstream and downstream fish passage should be improved. Furthermore, passage facilities should be designed specifically for passing target species; some facilities constructed for species such as Atlantic salmon, have proven unsuitable for passing shad (Aprahamian et al. 2003).

<u>Example: American shad</u>

In 1999, a vertical slot fishway was opened at Boshers Dam on the James River, Virginia, ending nearly 200 years of blocked access to upstream areas. As a result, 221.4 km of historical spawning habitat on the main stem of the river and 321.9 km on tributaries was restored. By 2001, an increasing trend of relative abundance of American shad in the fall zone was strongly correlated with an increasing trend of American shad passage (Weaver et al. 2003).

<u>Example: American eel</u>

For American eel, upstream passage is facilitated with the use of ramps and substrates to take advantage of the anguillid's natural climbing abilities. A channel or ramp is provided with low water flow and substrate (gravel or nylon brushes or mesh) to assist the American eel elvers and yellow-phase individuals in passing an obstruction (Richkus and Whalen 1999; Solomon and Beach 2004).). In New Zealand, 250 m gravel-lined pipes have been used to pass anguillid eels over dams as high as 68 m (Clay 1995). Portable elver passages may also be an option in some areas (Boubee and Barrier 1996; Wippelhauser et al. 1998). While the effectiveness of most designs has not been evaluated, there are several accounts of increased American eel biomass moving upstream after passes have been installed (Liew 1982; Clay 1995; Laffaille et al. 2005).

American eel passage is complicated by the fact that yellow-phase American eel require different substrates than elvers. Desrochers (1996) demonstrated an 85% efficiency rate of passage for migrating yellow-phase American eel, when approximately 450 mm of rods and tubes were placed on a ladder. The installation of tubes along the 58 m eel ladder at the Beauharnois Station on the St. Lawrence River resulted in a 77% ascent rate. Vegetation and matricial substrates proved ineffective for yellow-phase American eel (Desrochers 1996). Because the efficiency of passage of upstream migrants depends partly on the substrate size used in the ladder, it is important to determine the size and age of the American eel that are most likely to use the upstream passage for each river, as it will vary on a river-to-river basis (Richkus and Whalen 1999).

The stalling of fish at the exitways of ladders could potentially lower a ladder’s efficiency (Verdon 1998; Richkus and Whalen 1999). Suitable exit passageways should be designed to assist with the exit and upstream migration of American eel, as well as to decrease the likelihood of fall-back entrainment (Verdon 1998; Richkus and Whalen 1999; Richkus and Dixon 2003).

Approach 1.1B.2A.2: Pipe passes

Pipe passes consist of a pipe below the water level that passes through a barrier. Substrate is provided in the pipe to decrease water velocity and to allow American eel to crawl through the pipe. Although this design creates a direct passage, it is flawed because the pipe often becomes blocked with debris, rendering it ineffective. Pipe passes are most efficient at the outflow of large impoundments that act as a sediment trap for debris so that water entering the pipe is clear of material that might cause a blockage (Solomon and Beach 2004).

Approach 1.1B.2A.3: Locks and lifts

For locks, fish swim into a lock chamber with an open lower gate. The gate periodically closes and the chamber is filled with water, bringing it up to level with the headpond. The upper gate is then opened and the fish swim out. This type of fish passage involves a great deal of engineering and can be expensive. This solution is ideal for very high head situations where conventional passes are impractical (Solomon and Beach 2004).

Alternatively, a lift involves a chamber that fish swim into. The chamber is lifted up to or above the head pond level and the fish swim out. The amount of lifts may also be important. At the Conowingo Dam on the Susquehanna River, a second fish lift has contributed to successfully restoring American shad to that system. Over 200,000 fish passed at both lifts in 2001, compared to 1990, when only 15,000 fish returned (St. Pierre 2003). Moffitt et al. (1982) noted that blueback herring responded quite favorably to improved lift facilities at the Holyoke Dam on the Connecticut River, with passage increasing tremendously. Despite these improvements, stocks have declined considerably in recent years (R. St. Pierre, United States Fish and Wildlife Service retired, personal communication).

Approach 1.1B.2A.4: Easements

American eel often pass obstructions using irregularities in flow caused by edge effects, growth of algae and other plants, or features such as cracks and rubble. Providing these types of features is beneficial to areas where a full-scale engineering solution is not a viable option. Additionally, this enhancement is beneficial for sites with non-vertical barriers (weirs). It is both effective and inexpensive to maintain (Solomon and Beach 2004).

Approach 1.1B.2B: For downstream passage

Fish migrating downstream may pass through turbines, spillage, bypass facilities, or a combination of the three. One comparison between spillways and efficiently operated turbines found that the two systems were comparable in reducing fish mortality (Heisey et al. 1996).

Downstream passage of spent adult American shad through large turbines at the Safe Harbor project along the Susquehanna River, Pennsylvania, found that survival rate was 86% (NA and Skalski 1998). Survival rates would likely not be as favorable at facilities that employ smaller, high-speed turbines. Additional measures to help facilitate survival rates include controlled spills during peak migration months (St. Pierre 2003).

At some sites it is not desirable to move fish through turbines, so fish can be moved through a bypass facility. Creating a strong attraction flow helps guide fish to the bypass system and away from the intake flow areas of the turbines (Knights and White 1998; Verdon et al. 2003). Additionally, barrier devices can help deter fish away from flow intake areas. Barrier devices used to deter fish include lights, high-frequency sound, air bubble curtains, electrical screens, water jet curtains, and chemicals. Mechanical barrier devices include hanging chains, louvers, angled bars, and screens (Martin et al. 1994; Richkus and Whalen 1999; Richkus and Dixon 2003). Submerged strobe lights were found to be quite effective at directing fish away from turbines through a sluiceway (Martin et al. 1994).

<u>Example: American eel</u>

Studies of anguillid eels have stressed the importance of installing deterrents near the turbines and attraction mechanisms to direct the fish to the bypass facility (Hadderingh et al. 1992; Knights and White 1998; Verdon et al. 2003). Research suggests that light may be the best deterrent for American and European eels, with several studies demonstrating strong avoidance reactions to high intensity light

(Patrick et al. 1982; Hadderingh et al. 1992). One facility using underwater and overwater high intensity lights had a 51% deflection rate of yellow-phase anguillid eels and a 25% deflection rate of silver-phase anguillid eels (Hadderingh et al. 1992). Another facility on the St. Lawrence River created a “wall of light” by suspending 90 m long, surface to bottom 84 1000W halogen lamps in an area where the depth was 10 m. It was estimated that 85% of the downstream migrant American eel avoided the light (McGrath et al. 2003). Other researchers have found that silver-phase European eel showed no reaction to strobe lights (Adams and Schwevers 1997). Additional research is needed to find effective methods for deterring American eel from turbine entries (Richkus and Whalen 1999).

Example: Atlantic sturgeon

Atlantic sturgeon are not known to successfully use existing fish passageways (USFWS-NMFS 1998; Secor et al. 2002), but a lot of work has been done recently to identify promising upstream and downstream passage engineering designs for Atlantic sturgeon (P. Brownell, NOAA Fisheries, Southeast Regional Office, personal communication).

Approach 1.1B.3: Operational modifications

Hydroprojects operate more closely to the natural flow patterns of a stream when water moves through them with a fairly constant flow. Consequently, storage-release projects are more likely to alter both daily and seasonal flow patterns (Yeager 1995). Adjusting instream flows to more closely reflect natural flow regimes may help increase productivity of alosines, especially during summer to early fall when large, deep reservoirs stratify, and anoxic water releases are possible (McCord 2003).

Power generation can also be reduced, or ceased altogether, during prime downstream migration periods. This option might be cost-effective if migratory behavior coincides with off-peak rate schedules (Gilbert and Wenger 1996). Flows can be re-regulated at dams downstream of the primary dam to stabilize flows further downstream (Cushman 1985). Additionally, some studies have found that the most efficient operating flows for small turbines may not result in the best fish survival rates, but that operation at higher flows may pass fish more safely (Fisher et al. 1997).

Where hydrological conditions have been modified, additional measures can be implemented to help mitigate impacts on the river. For example, operational changes can be made to accomplish a number of improvements, such as reducing the upper limit of variability of one or more of the physical or chemical characteristics of the river. For example, incorporating turbine venting into major dams has proven useful for increasing dissolved oxygen concentrations. Alternatively, aerating reservoirs upstream of hydroelectric plants (Mobley and Brock 1996), as well as aerating flows downstream from the plants using labyrinth weirs and infuser weirs have also proven reliable for increasing the dissolved oxygen concentration in the water (Hauser and Brock 1994).

Example: Alosines

For alosines that migrate downstream during early evening hours, maintaining peak efficiency flows through selected turbines during these hours, as well as employing turbines that reduce mortality, may be effective (St. Pierre 2003).

Example: American eel

In simulation studies, Haro et al. (2003) showed that turbine mortality decreased significantly for American eel during days when there was substantial rainfall. Furthermore, the simulations showed that if power generation were suspended on days when eel catch was 25% to 75% of the total catch for all days, eel mortality was reduced by two-thirds to one-half relative to normal operations**.** Mortality was further halved when limits were set on generation using a combination of rainfall events and eel run timing factors (Haro et al. 2003).

Approach 1.1B.4: Streambank stabilization

States that have significant problems with streambank erosion have turned to stabilization to help further prevent erosion. Projects should maintain vegetated riparian buffers, making use of native vegetation wherever possible (MEOEA 2005). Habitat modification, including manipulating the cross-sectional geometry of the stream channel, may also serve to mitigate effects (Cushman 1985).

Example: Blueback herring

Loesch (1987) found that blueback herring responded favorably to changes in physical and hydrological conditions, becoming re-established and even increasing in abundance once favorable conditions were established or restored.

Approach 1.1B.5: Fish transfers

When populations have been extirpated from their habitat due to dam blockage, it may be necessary to transfer sexually mature pre-spawning adults or hatchery-reared fry and fingerlings above obstructed areas.

Example: American eel

Transplanting American eel may lead to a decrease in predation because the eels can disperse in the river instead of concentrating below the obstruction (Soloman and Beach 2004). Anguillid eels have also been successfully trapped upstream of a dam in New Zealand and released on the downstream side (Charles and Mitchell Associates 1995; Richkus and Whalen 1999).

Example: Alosines

Transplanting of fertilized alosine eggs has had limited success; eggs are now collected mostly for use in culture operations. Culture operations have focused primarily on American shad, and to a lesser degree blueback herring, alewife, and hickory shad (Hendricks 2003). Transplanting adult American shad, blueback herring, and alewife has been highly successful. Adult gravid shad can be trapped in the river where they originate, or other rivers, and trucked to upstream sites where they can be expected to spawn in areas that are otherwise not accessible. This may be an effective means for supplementing the river population until fish passage facilities are improved (both in the upstream and downstream direction), or fish passage facilities are constructed where they currently do not exist. As the return populations grow, further modifications may be necessary to accommodate larger runs (St. Pierre 1994).

For example, the release of hatchery-reared American shad in the James River, Virginia, in the mid-1990's, resulted in greater than 40% of hatchery-reared fish spawning several years later. This percentage greatly exceeded the percentage of the hatchery contribution (3 to 8%). If the offspring of hatchery-reared fish survive to reproduce, this should provide a significant boost to this severely depressed population (Olney et al. 2003).

At the Conowingo Dam on the Susquehanna River, Pennsylvania, 70 to 85% of the adult American shad returning from 1991 through 1995 were hatchery-reared. By 2003, the hatchery-to-wild ratio had been reversed, and naturally produced adults comprised 40 to 60% of returning fish (St. Pierre 2003).

Additionally, Maryland reported that over 80% of the 142 adults captured in the Patuxent and Choptank rivers in 2000 were of hatchery origin. It appears that shad stock enhancement, through the release of hatchery-reared fish, has proven to be beneficial when accompanied by other management measures including habitat restoration and water quality protection (Hendricks 2003).

Finally, pre-spawning adult American shad were taken from the Connecticut River and transplanted in the Pawcatuck River, Rhode Island, where they had been absent for 100 years. Six years later, in 1985, a population of over 4,000 fish existed (Gibson 1987).

Section 1.2: Road Culverts and Other Sources of Blockage

Issue 1.2A: Road culverts

While dams are the most common obstructions to fish migration, road culverts are also a significant source of blockage. Culverts are popular, low-cost alternatives to bridges when roads must cross small streams and creeks. Although the amount of habitat affected by an individual culvert may be small, the cumulative impact of multiple culverts within a watershed can be substantial (Collier and Odom 1989).

Roads and culverts can also impose significant changes in water quality. Winter runoff in some states includes high concentrations of road salt, while stormwater flows in the summer cause thermal stress and bring high concentrations of other pollutants (MEOEA 2005).

Example: Alosines

Sampled sites in North Carolina revealed river herring upstream and downstream of bridge crossings, but no herring were found in upstream sections of streams with culverts. Additional study is underway to determine if culverts are the cause for the absence of river herring in these areas (NCDENR 2000). Even structures only 20 to 30 cm above the water can block shad and river herring migration (ASMFC 1999).

Issue 1.2B: Other man-made structures

Additional man-made structures that may obstruct upstream passage include: tidal and amenity barrages; tidal flaps; mill, gauging, amenity, navigation, diversion, and water intake weirs; fish counting structures; and earthen berms (Durkas 1992; Solomon and Beach 2004). The impact of these structures is site-specific and will vary with a number of conditions including head drop, form of the structure, hydrodynamic conditions upstream and downstream, condition of the structure, and presence of edge effects (Solomon and Beach 2004).

Issue 1.2C: Natural barriers

Rivers can also be blocked by non-anthropogenic barriers, such as beaver dams, waterfalls, log piles, and vegetative debris. These blockages may be a hindrance to migration, but they can also be beneficial since they provide adhesion sites for eggs, protective cover, and feeding sites (Klauda et al. 1991). Successful passage at these natural barriers is often dependent on individual stream flow characteristics during the fish migration season.

THREAT #2: WATER WITHDRAWAL FACILITIES

Section 2.1A: Hydropower, Drinking Water, Irrigation, and Snow-making Facilities

Issue 2.1A.1: Impingement and entrainment

Large volume water withdrawals (e.g., drinking water, pumped-storage hydroelectric projects, irrigation, and snow-making), especially at pumped-storage facilities, can drastically alter local current characteristics (e.g., reverse river flow). Withdrawals may also alter other physical characteristics of the river channel, including stream width, depth, current velocity, substrate and temperature. This can cause delayed movement past the facility, or entrainment where the intakes occur (Layzer and O'Leary 1978). Planktonic eggs and larvae entrained at water withdrawal projects experience high mortality rates due to pressure changes, shear and mechanical stresses, and heat shock (Carlson and McCann 1969; Marcy 1973; Morgan et al. 1976). Well-screened facilities are unlikely to cause serious mortality to juveniles; however, large volume withdrawals can entrain significant numbers (Hauck and Edson 1976; Robbins and Mathur 1976).

Impingement of fish can trap them against water filtration screens, leading to asphyxiation, exhaustion, removal from the water for prolonged periods of time, or removal of protective mucous and descaling (DBC 1980).

For Example: American eel

Impingement and entrainment in water intakes and turbines have been identified as sources of mortality of seaward-migrating American eel at facilities in South Carolina (McCord 2005b).

Example: Alosines

Studies conducted along the Connecticut River found that larvae and early juveniles of alewife, blueback herring, and American shad suffered 100% mortality when temperatures in the cooling system of a power plant were elevated above 28°C; 80% of the total mortality was caused by mechanical damage and 20% was due to heat shock (Marcy 1976b). Ninety-five percent of the fish near the intake were not captured by the screen, and Marcy (1976b) concluded that it did not seem possible to screen fish larvae effectively. Results from earlier years led Marcy (1976a) to conclude that although mortality rates for eggs and larvae entrained in the intake system were very high, given the high natural mortality rate and the number of eggs produced by one adult shad, the equivalent of only one adult shad was lost during that study year as a result of egg and larval entrainment. Furthermore, there was no evidence that adult shad had changed the location of their spawning areas in the river as a result of plant operation (Marcy 1976a).

Another study of juvenile American shad emigrating from the Hudson River found that impingement at power plants was an inconsequential source of mortality; however, when added to other more serious stresses, it may possibly contribute to increased mortality rates (Barnthouse and Van Winkle 1988).

Example: Striped bass

Withdrawals or diversions of water can cause direct mortality of egg, larval, and juvenile striped bass due to entrainment (eggs, larvae, juveniles) or impingement (eggs, larvae, or juveniles depending upon the size of screen openings). Striped bass eggs may be able to survive impingement velocities up to 24 cm/s (0.8 ft/s) for 6 min, but test results have been highly variable (Skinner 1974). Survival of juvenile striped bass less than 40 mm was significantly affected at impingement velocities over 15 cm/s (0.5 ft/s) (Skinner 1974). Juveniles 40 to 50 mm long could withstand 6 minute periods at 24 cm/s (0.8 ft/s), but not 49 cm/s (1.6 ft/s). Skinner (1974) concluded that water velocity was a more important factor than time of exposure, but both were related to survival.

Kerr (1953) showed that 80% of striped bass 19 to 38 mm could avoid an impingement velocity of 30.5 cm/s (1 ft/s). However, only 5% of this size class could avoid 43 cm/s (1.4 ft/s). For juveniles 26 to 76 mm, 95% were able to avoid an impingement velocity of 61 cm/s (2 ft/s), and all juveniles 127 to 178 mm avoided 84 cm/s (2.7 ft/s) (Kerr 1953).

Issue 2.1A.2: Alteration of stream physical characteristics

Water withdrawals can also alter physical characteristics of streams, including: decreased stream width, depth, and current velocity; altered substrate; and temperature fluctuations (Zale et al. 1993). In rivers that are drawn upon for water supply, water is often released downstream during times of decreased river flow (usually summer). Additionally, failure to release water during times of low river flow and higher than normal water temperatures can cause thermal stress, leading to fish mortality. Consequently, water flow disruption can result in less freshwater input to estuaries (Rulifson 1994), which are important nursery areas for many anadromous species.

<u>For Example: American shad</u>

Cold water releases often decrease the water temperature of the river downstream, which has been shown to cause juvenile American shad to abandon their nursery areas (Chittenden 1969; 1972). At the Cannonsville Reservoir on the West Branch of the Delaware River, cold water releases from the dam resulted in the elimination of nursery grounds below the dam for American shad (DBC 1980).

Section 2.1B: Avoiding, Minimizing, and Mitigating Impacts of Water Withdrawal Facilities

Approach 2.1B.1: Use of technology and water velocity modification

Impacts resulting from entrainment can be mitigated to some degree through the use of the best available intake screen technology (ASMFC 1999), or through modifying water withdrawal rates or water intake velocities (Lofton 1978; Miller et al. 1982). Devices have also been used at hydroelectric projects to deter fish from intake flows, including: electrical screens, air bubble curtains, hanging chains, lights, high-frequency sound, water jet curtains, chemicals, visual keys, or a combination of these approaches (Martin et al. 1994). Promoting measures among industry that use reclaimed water, instead of freshwater from natural areas, can help reduce the amount of freshwater needed (FFWCC 2005). Location along the river was also found to be a significant factor affecting impingement rates in the Delaware River (Lofton 1978).

<u>THREAT #3: TOXIC AND THERMAL DISCHARGES</u>

Section 3.1A: Industrial Discharge Contamination

Issue 3.1A.1: Chemical effects on fish

Industrial discharges may contain toxic chemicals, such as heavy metals and various organic chemicals (e.g., insecticides, solvents, herbicides) that are harmful to aquatic life (ASMFC 1999). Many contaminants have been identified as having deleterious effects on fish, particularly reproductive impairment (Safe 1990; Longwell et al. 1992; Mac and Edsall 1991). Chemicals and heavy metals can be assimilated through the food chain, producing sub-lethal effects such as behavioral and reproductive abnormalities (Matthews et al. 1980). In fish, exposure to polychlorinated biphenyls (PCBs) can cause fin erosion, epidermal lesions, blood anemia, altered immune response, and egg mortality (Post 1987; Kennish et al. 1992). Furthermore, PCBs are known to have health effects in humans and are considered to be human carcinogens (Budavari et al. 1989).

A number of common pollutants have been found to disturb the thyroid gland in fish, which plays a role in the maturation of oocytes. These chemicals include: lindane (organochlorine) (Yadav and Singh 1987); malathion (organophosphorus compound) (Lal and Singh 1987; Singh 1992); endosulfan (organochlorine) (Murty and Devi 1982); 2,3,7,8-PCDD and –PCDF (dioxin and halogenated furane); some PCBs (particularly 2,3,7,8-TCDD *para* and *meta* forms) (Safe 1990); and PAHs (polycyclic aromatic hydrocarbons) (Leatherland and Sunstegard 1977, 1978, 1980).

Steam power plants that use chlorine to prevent bacterial, fungal, and algal growth present a hazard to all aquatic life in the receiving stream, even at low concentrations (Miller et al. 1982). Pulp mill effluent and other oxygen-consuming wastes are discharged into a number of streams.

Example: Alosines

Lack of dissolved oxygen from industrial pollution and sewage discharge can greatly affect abundance of shad and prevent migration upriver or prevent adults from emigrating to sea and returning again to spawn. Everett (1983) found that during times of low water flow when pulp mill effluent comprised a large percentage of the flow, river herring avoided the effluent. Pollution may be diluted in the fall when water flow increases, but fish that reach the polluted waters downriver before the water has flushed the area will typically succumb to suffocation (Miller et al. 1982).

Effluent may also pose a greater threat during times of drought. Such conditions were suspected of interfering with the herring migration along the Chowan River, North Carolina, in 1981. In past years, the effluent from the pulp mill had passed prior to the river herring run, but drought conditions caused the effluent to remain in the system longer. Toxic effects were indicated, and researchers suggested that growth and reproduction may have been disrupted as a result of eutrophication and other factors (Winslow et al. 1983).

Even thermal effluent from power plants can have a profound effect on fish, causing disruption of schooling behavior, disorientation, and death. Researchers concluded that 30°C was the upper natural temperature limit for juvenile alosines (Marcy et al. 1972).

Example: Atlantic sturgeon

Due to their benthic feeding behavior and long life span, Atlantic sturgeon may be particularly sensitive to contaminants (USFWS-NMFS 1998). Although few studies have documented the impact of environmental contaminants on Atlantic sturgeon, PCBs have been detected in Atlantic sturgeon in the St. Lawrence and Hudson Rivers. Levels of PCBs in these fish were above the upper limit set by the U.S. Environmental Protection Agency (EPA) for edible fish (Spagnoli and Skinner 1977). Other contaminants reported in Atlantic sturgeon include cadmium, mercury, and lead (Rehwoldt et al. 1978).

Example: American eel

Impacts to American eel from contamination include: impaired osmoregulation, direct mortality, decreased growth rate, reduced fecundity, and impaired reproductive success (Dutil et al. 1987; Brusle 1991, 1994; Castonguay et al. 1994a, b; Hodson et al. 1994; Knights 1997; Casselman et al. 1998; Haro et al. 2000; Robinet and Feunteun 2002).

American eel are particularly vulnerable to contamination by lipophilic compounds (Robinet and Feunteun 2002). Due to their high lipid content and benthic habitat preference, American eel have a high bioaccumulation rate (Couillard et al. 1997; Richkus and Whalen 1999). American eel might be a good indicator species for bioaccumulation studies (Van der Oost et al. 1988) because they transfer most of their somatic lipid stores to the gonads and gametes making them particularly sensitive to water contamination (Robinet and Feunteun 2002; Ashley et al. 2003). For example, in the St. Lawrence River, the highest concentrations of contaminants were found in the gonads of migrating silver eels. These chemical levels could be toxic to larvae, and since migrating females do not feed, the chemical levels in the eggs could be toxic at hatching (Hodson et al. 1994). In another instance, American eel exposed to fenithrothion (an organophosphorus insecticide) were found to have significantly lower fat contents (Sancho et al. 1998). Calow (1991) estimated that energy costs resulting from chemical stress have some minor consequences on growth and reproduction. These pesticides disturb fat accumulation, and are likely to reduce migration efficiency and breeding success in American eel.

Other suspected impacts from pesticides and contaminants include changes in behavior and migratory orientation, and performance and successful mating of American eel. These suspected threats have not yet been documented in the literature (Haro et al. 2000).

There is also some evidence that the contamination of eels may have an impact on the food chain. Studies of dead beluga whales (*Delphinapterus leucas*) in the estuary and the Gulf of St. Lawrence show levels of PCBs, DDT, pesticides, and mirex far above those found in Beluga whales in the Arctic (Massé et al 1986; Martineau et al. 1987). Marine mammals are exposed to contaminants by the prey they consume over their lifetime. The mirex found in the beluga whales is thought to be unique to the fish in the upper St. Lawrence River and Lake Ontario (Kaiser 1978; Castonguay et al. 1989). American eel contain 10 times as much mirex as estuarine fish in these areas. Thus, the eels may be a source of toxic chemicals to the beluga whales (Hodson et al. 1994).

Issue 3.1.2: Sewage effects on fish

Sewage can have direct and indirect effects on anadromous fish. Minimally effective sewage treatment during the 1960s and early 1970s may have been responsible for major phytoplankton and algal blooms in tidal freshwater areas of the Chesapeake Bay, which reduced light penetration (Dixon 1996), and ultimately reduced SAV abundance (Orth et al. 1991). Some of Massachusetts' large to mid-sized rivers receive raw sewerage into their waters, and during summer low flows, are composed primarily of sewerage treatment effluent (MEOEA 2005).

Issue 3.1.3: Thermal effects on fish

<u>Example: Striped bass</u>

Reductions or increases in temperature as a function of industrial discharges or hydropower operations can affect spawning activity of striped bass. A sharp rise in temperature occurring during the spawning run may cause premature spawning in normally unsuitable areas (Farley 1966). Sudden drops in water temperature during the spawning run, or during the spawning act, have caused complete cessation of spawning activities (Calhoun et al. 1950; Mansueti and Hollis 1963; Boynton et al. 1977). Adult striped bass may overwinter in thermal discharge areas along the Atlantic coast, provided that they do not have to remain in the plume too long (Marcy and Galvin 1973).

Additionally, reductions or increases in temperature as a function of industrial discharges or hydropower operations can affect survival of eggs, larvae, and juveniles. Striped bass early life stages show significantly elevated mortality rates when exposed to rapid changes in water temperature (such as that in a thermal discharge plume) (Schubel et al. 1976). Eggs were able to sustain 15°C temperature elevation for 4 to 60 minutes, but an elevation of 20°C above acclimation temperature killed all eggs in 2 minutes. Yolk-sac larvae survival was significantly affected at a temperature elevation of 15°C. Furthermore, slightly lower temperature elevations, on the order of 10°C, significantly affected survival of 8 mm and 24 mm striped bass (Chadwick 1974). Mortality was not over 50% unless the absolute test temperature was 32.2°C or higher, regardless of the temperature elevation. Kelly and Chadwick (1971) presented 48 hour LC_{50} values from 30°C to 33°C for various acclimation temperatures.

Section 3.1B: Avoiding, Minimizing, and Mitigating Impacts of Toxic and Thermal Discharges

Approach 3.1B.1: Proper treatment of facility discharge

Although there has been a general degradation of water quality coastwide, the levels of sewage nutrients discharged into coastal waters during the past 30 years have decreased as a result of the Clean Water Act, passed in 1972. This has led to a decrease in organic enrichment, which has benefited water quality conditions. A reduction of other types of pollutant discharges into these waters, such as heavy metals and organic compounds, would not be expected (ASMFC 1999).

In many northern rivers, such as the Kennebec, Penobscot, Connecticut, Hudson, and Delaware Rivers, dissolved oxygen levels approached zero parts per million in the 1960s and 1970s. Since then, water quality has greatly improved as a result of better point-source treatment of municipal and industrial waste (USFWS-NMFS 1998). In 1974, secondary and tertiary sewage treatment was initiated in the Hudson River, which led to conditions where dissolved oxygen was greater than 60% saturation. There was a return of many fish species to this habitat (Leslie 1988), including a high abundance of juvenile shortnose sturgeon (Carlson and Simpson 1987; Dovel et al. 1992).

Additionally, although poor water quality is often identified as a barrier to fish migration, it should be noted that poor water quality can be caused by both point and non-point sources of pollution. In fact, it may be difficult, if not impossible, for water quality standards to be achieved in some regions due to the effects of non-point sources of pollution (Roseboom et al. 1982).

Example: American shad

The estimated lost spawning habitat for American shad in 1898 was 5.28 x 10^3 river km, and in 1960 it was estimated at 4.49 x 10^3 km. The most recent estimate is now 4.36 x 10^3 river km. This increase in available habitat has been largely attributed to restoration efforts and enforcement of pollutant abatement laws (Limburg et al. 2003).

In compliance with the Clean Water Act, proper treatment of large city domestic sewage at treatment plants has dramatically improved the poor water quality conditions that persisted in the Delaware River for many years. Water quality problems were dramatically manifested in a “pollution block,” including severely depressed levels of dissolved oxygen in the early 1900s in the Philadelphia/Camden area. There were very few repeat American shad spawners in this river, compared with other mid-Atlantic rivers (Miller et al. 1982). The situation had greatly improved by the late 1950s, due to a reduction in point-source pollution entering tidal waters, which led to an increase in dissolved oxygen by the 1980s (Maurice et al. 1987). This has led to a large enhancement of the American shad population in this river (Ellis et al. 1947; Chittenden 1969; Miller et al. 1982).

Similarly, improvements to water quality in the Potomac River in the 1970s led to increased water clarity and subsequently an increase in SAV abundance in 1983 (Dennison et al. 1993). In addition, pulp mill effluent was thought to have limited American shad survival in the Roanoke River (Walburg and Nichols 1967), but compliance with water quality standards in recent years has resulted in improved spawning habitat in this system (Hightower and Sparks 2003). Additional measures to improve habitat include reducing the amount of thermal effluent into rivers and streams, and discharging earlier in the year to reduce impacts to migrating fish (ASMFC 1999).

Example: American eel

While contaminated areas still exist in the United States, environmental toxin levels have decreased in many watersheds, which will potentially minimize the impacts on American eel. A decrease in American eel recruitment was not observed until well after the introduction of pollutants into watersheds, therefore contaminants cannot be the main cause of eel decline (Castonguay 1994a). Further research is needed to determine the impacts of these remaining contaminants on the eel population (Richkus and Whalen 1999).

THREAT #4: CHANNELIZATION AND DREDGING

Section 4.1A: Impacts of Dredging on Fish Habitat

Issue 4.1A.1: Primary environmental impacts of channelization

Channelization has the potential to cause significant environmental impacts (Simpson et al. 1982; Brookes 1988), including bank erosion, elevated water velocity, reduced habitat diversity, increased drainage, and poor water quality (Hubbard 1993). Dredging and disposal of spoils along the shoreline can also create spoil banks, which block access to sloughs, pools, adjacent vegetated areas, and backwater swamps (Frankensteen 1976). Dredging may also release contaminants resulting in bioaccumulation, direct toxicity to aquatic organisms, or reduced dissolved oxygen levels (Morton 1977). Furthermore, careless land use practices may lead to erosion, which can lead to high concentrations of suspended solids (turbidity) and substrate (siltation) in the water following normal and intense rainfall events. This can displace larvae and juveniles to less desirable areas downstream and cause osmotic stress (Klauda et al. 1991).

Spoil banks are often unsuitable habitat for fishes. Sand areas are an important nursery habitat to YOY striped bass. This habitat is often lost when dredge disposal material is placed on natural sand bars and/or point bars. The spoil is too unstable to provide good habitat for the food chain. Mesing and Ager (1987) found that electrofishing CPUE for gamefish was significantly greater on natural habitat than on “new (75%),” recent (66%),” or “old (50%)” disposal sites. Old sites that had not been disposed on for 5 to –10 or more years had not recovered to their natural state in terms of relative abundance of gamefish populations. The researchers also found that placement of rock material on degraded sand disposal sites had significantly greater electrofishing CPUE for sportfish than these sites had prior to placement of the rock material (Mesing and Ager 1987).

<u>Example: Alosines</u>

Draining and filling (or both) of wetlands adjacent to rivers and creeks in which alosines spawn, has eliminated spawning areas in North Carolina (NCDENR 2000).

<u>Example: Striped bass</u>

Reinert et al. (2005) published a case history documenting the impact of harbor modifications on striped bass in the Savannah River, Georgia, and South Carolina. During the 1980's, Savannah River striped bass suffered a population decline. The CPUE declined by 97% and egg production declined by 96%. Loss of freshwater spawning habitat through harbor modifications was identified as the primary cause (Reinert et al. 2005).

Spawning habitat deterioration in the St. Lawrence River was thought to be caused by construction of the St. Lawrence Seaway (1954-1959), island construction for the International World’s Fair of 1967 in Montreal (1963-1964), and creation of Sterns Island from dredged sediments in 1965 (Beaulieu 1985).

Issue 4.1A.2: Secondary environmental impacts of channelization

Secondary impacts from channel formation include loss of vegetation and debris, which can reduce habitat for invertebrates and result in reduced quantity and diversity of prey for juveniles (Frankensteen 1976). Additionally, stream channelization often leads to altered substrate in the riverbed and increased sedimentation (Hubbard 1993), which in turn can reduce the diversity, density, and species richness of aquatic insects (Chutter 1969; Gammon 1970; Taylor 1977). Suspended sediments can reduce feeding success in larval or juvenile fishes that rely on visual cues for plankton feeding (Kortschal et al. 1991). Fish species that rely on benthic invertebrates within sediments may also experience decreased food availability if prey numbers are reduced. Sediment re-suspension from dredging can also deplete dissolved oxygen, and increase bioavailability of any contaminants that may be bound to the sediments (Clark and Wilber 2000).

Issue 4.1A.3: Impacts of channelization on fish physiology and behavior

Example: Alosines

Migrating adult river herring have been found to avoid channelized areas with increased water velocities. Several channelized creeks in the Neuse River basin in North Carolina have reduced river herring distribution and spawning areas (Hawkins 1979). Frankensteen (1976) found that the channelization of Grindle Creek, North Carolina removed in-creek vegetation and woody debris, which served as substrate for fertilized eggs.

Channelization can also reduce the amount of pool and riffle habitat (Hubbard 1993), which is an important food-producing area for larvae (Keller 1978; Wesche 1985). American shad postlarvae have been found concentrated in riffle-pool habitat (Ross et al. 1993).

Dredging can negatively affect alosine populations by producing suspended sediments (Reine et al. 1998), and migrating alosines are known to avoid waters of high sediment load (ASMFC 1985; Reine et al. 1998). It is also possible that fish may avoid areas where there is ongoing dredging due to suspended sediment in the water column. This was believed to have been the cause of a diminished return of adult spawning shad in a Rhode Island river, although no causal mechanism could be established (Gibson 1987). Filter-feeding fishes, such as alosines, can be negatively impacted by suspended sediments on gill tissues (Cronin et al. 1970). Suspended sediments can clog gills that provide oxygen, resulting in lethal and sub-lethal effects to fish (Sherk et al. 1974, 1975).

Nursery areas along the shorelines of the rivers in North Carolina have been affected by dredging and filling, as well as by erection of bulkheads; however, the degree of impact has not been measured. In some areas, juvenile alosines were unable to enter channelized sections of a stream due to high water velocities caused by dredging (ASMFC 2000b). Despite findings by Miller et al. (1982) that the effects of river dredging on fish populations were insignificant, they suspected that migrating juvenile shad could potentially be impacted by increased suspended solids, lowered dissolved oxygen concentration, and release of toxic materials.

Example: American eel

Dredging can also entrain seaward-migrating adult American eel, increase turbidity or suspended sediments that may negatively affect migrating adults, glass eels, and elvers, and cause changes in salinity regimes that could impact eel distribution and prey availability (McCord 2005b; ASMFC 2000).

Example: Atlantic sturgeon

Some studies have noted that dredging and filling operations alter habitat characteristics important to Atlantic sturgeon, including: disturbance of benthic flora and fauna; elimination of deep holes through establishment of uniform depth profiles; alteration of the rock substrate; and increased sedimentation (Smith and Clugston 1997; IAN 1999; Stein et al. 2004). Indirect impacts include destruction of feeding areas, disruption of migrations, and re-suspension of sediments in the spawning habitat (USFWS-NMFS 1998; Bushnoe et al. 2005). Siltation from dredging can also reduce spawning success by smothering eggs and covering suitable substrates for adhesive eggs (USFWS-NMFS 1998).

Dredging, and the removal of a rock outcropping, in the Rocketts, James River, Virginia, may have destroyed historic Atlantic sturgeon spawning grounds. Before dredging occurred in this area, Rocketts had substrate that was the exact configuration of known spawning sites (Bushnoe et al. 2005). Other studies have found no direct link between dredging and impacts to Atlantic sturgeon habitat, but it has been cited as a potential threat to the recovery of the species (Beamesderfer and Farr 1997; USFWS-NMFS 1998; Caron and Tremblay 1999; Collins et al. 2000; Bushnoe et al. 2005).

In addition to altering habitat, mechanical and hydraulic dredging can cause physical harm to Atlantic sturgeon by entraining fish through the drag arms and impeller pumps. Mortalities of this nature have been documented in King's Bay (Georgia) and Charleston (South Carolina) (M. Collins, South Carolina Department of Natural Resources, personal communication), and in the Cape Fear River (North Carolina) (USFWS-NMFS 1998). Dredging operations can also potentially have an impact on larval sturgeon. Veshchev (1981) documented the impact of dredges on *Acipenser guldenstadti* and *A. stellatus* larvae in the Volga River, Russia. He found that dredging caused 68.0% to 76.8% mortality of the total larvae caught upstream of the suction unit. Veshchev (1981) reported that 1,000 larva were destroyed by the dredges. Khodorevskaya (1972) also recorded the entrainment of fingerling sturgeon by dredges.

Example: Striped bass

Larval striped bass consumed 40% less prey when suspended solids exceeded 200 mg/L (Breitburg 1988).

Issue 4.1A.4: Increase in boat strikes

<u>Example: Atlantic sturgeon</u>

Dredging creates areas of safe passage for ships and boats. Increased boating traffic is likely to occur in dredged areas, which in turn may increase the risk of Atlantic sturgeon propeller strikes. To date, there is only one documented case of propeller strike mortality to Atlantic sturgeon in the Delaware River (USFWS-NMFS 1998), however, Delaware Fish and Wildlife staff consistently find adult and juvenile Atlantic sturgeon that wash ashore in the Delaware River during the spring or historical spawning season with obvious propeller wounds (C. Shirey, Delaware Division of Fish and Wildlife, personal communication). In May 2005, there were six confirmed reports of dead Atlantic sturgeon in the Delaware River, three of which had obvious external injuries. Dead sturgeon ranged from juvenile to adult, with one fish aged at 45 to 49 years (G. Murphy, Delaware Division of Fish and Wildlife, personal communication). The Delaware River may pose a bigger collision threat than other areasdue to the high volume of ship traffic and the narrow, shallow nature of the port (D. Fox, Delaware State University, personal communication).

Boat strikes do not appear to be an issue in the Hudson River because the channel is not routed through prime spawning habitat (J. Mohler, U.S. Fish and Wildlife Service, personal communication). Little is known about the extent of sturgeon mortalities in other areas due to ship strikes and more research is needed in this area.

Section 4.1B: Avoiding, Minimizing, and Mitigating Impacts of Channelization

Approach 4.1B.1: Seasonal restrictions and proper material disposal

Dredging restrictions are already in place in many rivers including the Kennebec, Connecticut, Cape Fear, Cooper, and Savannah Rivers (USFWS-NMFS 1998), to help curtail the impacts of dredging to anadromous fish. Seasonal restrictions on dredging in areas where anadromous fish are known to occur should be established until there is irrefutable evidence that dredging does not restrict the movement of fish (Gibson 1987). It is recommended that dredge material be disposed of in the most ecologically beneficial way possible that will prevent harm to existing natural habitats (FFWCC 2005).

<u>THREAT #5: LAND USE CHANGE</u>

The effects of land use and land cover on water quality, stream morphology, and flow regimes are numerous, and may be the most important factors determining quantity and quality of aquatic habitats (Boger 2002). Studies have shown that land use influences dissolved oxygen (Limburg and Schmidt 1990), sediments and turbidity (Basnyat et al. 1999; Comeleo et al. 1996), water temperature (Hartman et al. 1996; Mitchell 1999), pH (Osborne and Wiley 1988; Schofield 1992), nutrients (Basnyat et al. 1999; Osborne and Wiley 1988; Peterjohn and Correll 1984), and flow regime (Johnston et al. 1990; Webster et al. 1992).

Siltation, caused by erosion due to land use practices, can kill submerged aquatic vegetation (SAV). SAV can be adversely affected by suspended sediment concentrations of less than 15 mg/L (Funderburk et al. 1991) and by deposition of excessive sediments (Valdes-Murtha and Price 1998). SAV is important because it improves water quality (Rybicki and Hammerschlag 1991), and provides refuge habitat for migratory fish and planktonic prey items (Maldeis 1978; Killgore et al. 1989; Monk 1988).

Section 5.1A: Agriculture

Issue 5.1A.1: Sedimentation and irrigation

Decreased water quality from sedimentation became a problem with the advent of land-clearing agriculture in the late 18th century (McBride 2006). Agricultural practices can lead to sedimentation in streams, riparian vegetation loss, influx of nutrients (e.g., inorganic fertilizers and animal wastes), and flow modification (Fajen and Layzer 1993). Agriculture, silviculture, and other land use practices can lead to sedimentation, which reduces the ability of semi-buoyant eggs and adhesive eggs to adhere to substrates (Mansueti 1962).

In addition, excessive nutrient enrichment stimulates heavy growth of phytoplankton that consume large quantities of oxygen when they decay, which can lead to low dissolved oxygen during the growing season (Correll 1987; Tuttle et al. 1987). Such conditions can lead to fish kills during hot summer months (Klauda et al. 1991).

Another factor, chemical contamination from agricultural pesticides, has a significant potential to impact stream biota, especially aquatic insects, but is difficult to detect (Ramade et al. 1984).

Furthermore, irrigation can cause dewatering of freshwater streams, which can decrease the quantity of both spawning and nursery habitat for anadromous fish. Dewatering can cause reduced water quality as a result of more concentrated pollutants and/or increased water temperature (ASMFC 1985).

<u>Example: American eel</u>

American eel habitat may be further reduced in areas that already have poor water quality where dewatering only exacerbates the problem (McCord 2005b).

<u>Example: River herring</u>

Uzee (1993) found that in some Virginia streams, there was an inverse relationship between the proportion of a stream’s watershed that was agriculturally developed and the overall tendency of the stream to support river herring runs. In North Carolina, cropland alteration along several creeks and rivers has significantly reduced river herring distribution and spawning areas in the Neuse River basin (Hawkins 1979).

Issue 5.1A.2: Nutrient loading

Atmospheric nitrogen deposition in coastal estuaries of states such as North Carolina, has had an increasingly negative effect on coastal waters, leading to accelerated algal production (or eutrophication) and water quality declines (e.g., hypoxia, toxicity, and fish kills). The primary source of atmospheric nitrogen in these areas comes from livestock operations and their associated nitrogen-rich (ammonia) wastes, and to a lesser degree, urbanization, agriculture, and industrial sources (Paerl et al. 1999). Animal production farms have greatly contributed to deteriorating water quality in other areas, including the Savannah, Ogeechee, and Altamaha Rivers (Georgia), and the Chesapeake Bay (USFWS-NMFS 1998; Collins et al. 2000; McBride 2006).

From the 1950s to the present, increased nutrient loading has made hypoxic conditions more prevalent (Officer et al. 1984; Mackiernan 1987; Jordan et al. 1992; Kemp et al. 1992; Cooper and Brush 1993; Secor and Gunderson 1998). Hypoxia is most likely caused by eutrophication, due mostly to non-point source pollution (e.g., industrial fertilizers used in agriculture) and point source pollution (e.g., urban sewage).

<u>Example: Atlantic sturgeon</u>

Eutrophic conditions pose a serious threat to Atlantic sturgeon because the species does not have the physiological or behavioral ability to cope with hypoxic conditions (Niklitschek 2001; Secor and Niklitschek 2001), and oxygen squeezes can cause direct mortality. Reduced dissolved oxygen levels are thought to be the cause of extirpation of Atlantic sturgeon populations in the St. Mary’s River, Georgia (USFWS-NMFS 1998; Collins et al. 2000). Furthermore, degraded habitat in southern estuaries may have contributed to decreased spawning populations of juvenile shortnose sturgeon (Collins et al. 2000). Particularly, summer nursery habitats for juvenile Atlantic sturgeon are at risk from water quality deterioration, specifically hypoxic conditions (Secor and Gunderson 1998; Secor et al. 2000; Secor and Niklitschek 2002; Niklitschek and Secor 2005).

Issue 5.1A.3: Hypoxia

<u>Example: Atlantic sturgeon</u>

Niklitschek and Secor (2005) evaluated how temperature, dissolved oxygen, and salinity influence Atlantic sturgeon production in the Chesapeake Bay. They determined that summer was the most critical season for Atlantic sturgeon, and that low tolerance for high temperatures (greater than 28ºC) is a limiting factor during the first two summers of life. Using models, Niklitschek and Secor (2005) predicted that as temperatures increase to sub-lethal levels in the summer, YOY would utilize deeper and cooler waters as a thermal refuge. However, in the Chesapeake Bay, deeper and cooler areas are located down-estuary and do not have suitable salinities for early juvenile Atlantic sturgeon, which are restricted to lower salinity regions. This model also predicted that summer habitat would include 0 to 35% of the modeled bay area, but in drought years almost no summer habitat was available for juvenile sturgeon. Niklitschek (2001) found that summer hypoxic conditions and high temperatures in the mainstem and tidal sections of the tributaries of the Chesapeake Bay caused habitat fragmentation and restricted usable habitat to a small portion of the bay. The total area of suitable habitat under average July conditions corresponded to 1586 km^3 and 1076 km^3, which was only 8.5% and 5.8%, respectively, of the total surface area of the mainstem and tidal sections of the tributaries (Niklitschek 2001).

Hypoxic conditions in Narragansett Bay (Rhode Island), Chesapeake Bay (Virginia and Maryland); Cape Fear River, Neuse River estuary, and Pamlico Sound (North Carolina), and the Savannah and Cooper Rivers (Georgia) threaten juvenile sturgeon (Mallin et al. 1997; Leathery 1998; Collins et al. 2000; Secor and Niklitschek 2001; C. Powell, formerly Rhode Island Division of Fish and Wildlife, personal communication). A secondary threat is mortality to their benthic prey organisms (McBride 2006; W. Laney, U.S. Fish and Wildlife Service, personal communication). Evidence of the effects of hypoxia on sturgeon populations remains circumstantial, but trends show that hypoxia may affect populations, and spawning is absent in many estuaries where hypoxic conditions prevail (Collins et al. 2000).

Section 5.1B: Avoiding, Minimizing, and Mitigating Agricultural Impacts

Approach 5.1B.1: Erosion control and best management practices

Erosion control measures and best management practices (BMPs) can reduce sediment input into streams, which can reduce the impact on aquatic fauna (Lenat 1984; Quinn et al. 1992). Agricultural BMPs may include: vegetated buffer strips at the edge of crop fields, conservation tillage, strip cropping, diversion channels and grassed waterways, soil conservation and water quality planning, nutrient management planning, and installing stream bank fencing and forest buffers. Animal waste management includes: manure storage structures, runoff control for barnyards, guttering, and nutrient management (ASMFC 1999). Programs to upgrade wastewater treatment at hog and chicken farms should be promoted (NC WRC 2005). Additionally, restoring natural stream channels and reclaiming floodplains in areas where the channel or shoreline has been altered by agricultural practices can help mitigate impacts (VA DGIF 2005).

Example: Atlantic sturgeon

Improved water quality in the Hudson River, New York, has accompanied a recovery in shortnose sturgeon populations (Secor and Niklitschek 2001). Models designed to address how to meet new EPA dissolved oxygen criteria for the Chesapeake Bay found that achieving the EPA dissolved oxygen criteria would increase habitat by 13% per year and that an increase in temperature by 1ºC would reduce habitat by 65%. The models were used to help identify four areas in the Chesapeake Bay that require special consideration to aid in the restoration of Atlantic sturgeon (Niklitschek and Secor 2005).

Section 5.2A: Logging/Forestry

Issue 5.2A.1: Logging

Logging activities can modify hydrologic balances and instream flow patterns, create obstructions, modify temperature regimes, and input additional nutrients, sediments, and toxic substances into river systems. Loss of riparian vegetation can result in fewer refuge areas for fish from fallen trees, fewer insects for fish to feed on, and reduced shade along the river, which can lead to increased water temperatures and reduced dissolved oxygen (EDF 2003). Potential threats from deforestation of swamp forests include: siltation from increased erosion and runoff; decreased dissolved oxygen (Lockaby et al. 1997); and disturbance of food-web relationships in adjacent and downstream waterways (Batzer et al. 2005).

In South Carolina, forestry BMPs for bottomland forests are voluntary. When BMPs are not exercised, plant material and disturbed soils may obstruct streams, excessive ruts may force channel-eroded sediments into streams, and partially stagnated waters may become nutrient-rich, which can lead to algal growth. These factors contribute to increased water temperature and reduced dissolved oxygen (McCord 2005c).

Example: Striped bass

For striped bass, warmer water temperatures may decrease the amount of summertime refuge habitat, which can negatively impact reproduction (Sessions et al. 2005).

Example: Atlantic sturgeon

In many systems, like the Chesapeake Bay, hard substrate has been buried under sediments resulting from erosion caused by deforestation, agriculture, and urbanization (Secor et al. 2002; Bushnoe et al. 2005). For the past two centuries, the hard substrate used by Atlantic sturgeon for spawning purposes has been lost from burial by sedimentation and siltation (Secor et al. 2000). Lack of suitable spawning substrate has been cited as one of the limiting factors for Atlantic sturgeon in the Chesapeake Bay (USFWS-NMFS 1998).

Section 5.2B: Avoiding, Minimizing, and Mitigating Logging Impacts

Approach 5.2B.1: Best management practices

Virginia advocates working with private, small foresters to implement forestry BMPs along rivers to reduce the impacts of forestry practices (VA DGIF 2005). Florida discourages new bedding on public lands where there is healthy groundcover (FFWCC 2005).

Section 5.3A: Urbanization and Non-Point Source Pollution

Issue 5.3A.1: Pollution impacts on fish and fish habitat

Urbanization can cause elevated concentrations of nutrients, organics, or sediment metals in streams (Wilber and Hunter 1977; Kelly and Hite 1984; Lenat and Crawford 1994). Recent studies conducted in Charleston Harbor, South Carolina, found that crustacean prey of estuarine fishes are directly affected by urbanization and related water quality parameters, including concentrations of a variety of toxicants (especially petroleum-related materials) (EDF 2003). Furthermore, the amount of developed land may influence use of a habitat, but other factors such as size, elevation, and habitat complexity are important as well, and in some cases may outweigh the negative effects of development (Boger 2002). More research is needed on how urbanization affects diadromous fish populations.

Example: Alewife

One study found that when the percent of land in areas increased to about 10% of the watershed, the number of alewife egg and larvae decreased significantly in tributaries of the Hudson River, New York (Limburg and Schmidt 1990).

Example: American eel

Machut (2006) found that American eel density and condition were negatively affected by urbanization in a tributary of the Hudson River. American eel from this tributary also had a higher parasite load (Machut 2006).

Section 5.3B: Avoiding, Minimizing, and Mitigating Impacts of Urbanization and Non-Point Source Pollution

Approach 5.3B.1: Best management practices

Urban BMPs include: erosion and sediment control; stormwater management; septic system maintenance; and forest buffers (ASMFC 1999). Siting stormwater treatment facilities on upland areas is recommended where possible (FFWCC 2005). Wooded buffers and conservation easements should be established along streams to protect critical shoreline areas (ASMFC 1999), and low impact development should be implemented, where practicable (NCWRC 2005).

Example: Alosines

Since the abundance of SAV is often used as an indirect measure of water quality, and there is a correlation between water quality and alosine abundance, steps should be taken to halt further reduction of underwater sea grasses (especially important in the Chesapeake Bay) (B. Sadzinski, Maryland Department of Natural Resources, personal communication).

Regarding cumulative effects on river herring spawning habitat, Boger (2002) suggested that land use and morphology within the entire watershed should be considered, and that the cumulative effects within the entire watershed may be as important as the type of land use within buffer zones. This is an important point to consider when establishing required widths of buffer zones in an effort to balance anthropogenic activities in the watershed and maintain biological integrity of streams (Boger 2002).

<u>THREAT #6: ATMOSPHERIC DEPOSITION</u>

Section 6.1A: Atmospheric Deposition

Issue 6.1A.1: Acid rain and low pH

Atmospheric deposition occurs when pollutants are transferred from the air to the earth's surface. This occurrence inputs a significant source of pollutants to many water bodies. Pollutants can get from the air into the water through rain and snow, falling particles, and absorption of the gas form of the pollutants into the water. Atmospheric deposition that causes low pH and elevated aluminum (acid rain) can contribute to changes in fish stocks. When pH declines, the normal ionic salt balance of the fish is compromised and fish lose body salts to the surrounding water (Southerland et al. 1997).

<u>Example: American shad</u>

American shad stocks that spawn in poorly buffered Eastern Shore Maryland rivers, like the Nanticoke and Choptank, were found to be vulnerable to storm-induced, toxic pulses of low pH and elevated aluminum. These stocks, therefore, may recover at a much slower rate than well-buffered Western Shore stocks, even if all other anthropogenic stressors are removed (Klauda 1994; ASMFC 1999). Streams often experience their highest levels of acidity in the spring, when adult shad are returning to spawn (Southerland et al. 1997).

There is speculation that recent precipitous declines in American shad populations may partly be due to acid rain (Southerland et al. 1997). Fertilized eggs, yolk-sac larvae, and to a lesser degree, young feeding (post yolk-sac) larvae of American shad have the highest probability for exposure to temporary episodes of pH depressions and elevated aluminum levels in, or near, freshwater spawning sites (Klauda 1994). Klauda (1994) suggests that even infrequent and temporary episodes of critical or lethal pH and aluminum exposures in the spawning and nursery areas could contribute to significant reductions in egg or larval survival of American shad and thereby slow stock recovery. Juvenile fish are more susceptible to the effects of low pH, which may effectively prevent reproduction (Klauda 1994).

Threats may be seasonal, ongoing, or even sporadic, all of which can have long-term effects on the recovery of stocks. For example, Hurricane Agnes in 1972 is suspected of causing the 1972 year-class failure for American shad, hickory shad, alewife, and blueback herring, as well as altering many spawning habitat areas in the Chesapeake Bay. Almost twenty years later, these impacts were suggested to be contributing to the slow recovery of stocks in this area (Klauda et al. 1991).

Section 6.1B: Avoiding, Minimizing, and Mitigating Impacts of Atmospheric Deposition

Approach 6.1B.1: Reduction of airborne chemicals

Supporting the reduction of airborne chemical releases from power plants, paper mills, and refineries is one way to decrease the levels of toxins in the air that eventually settle into riverine habitat. Incentives can be promoted at the state level and through cooperative interstate agreements (FFWCC 2005).

THREAT #7: REDUCED DISSOLVED OXYGEN

Section 8.1A: Reduced Dissolved Oxygen

Issue 8.1A.1: Hypoxia and anoxia

Dissolved oxygen is a fundamental requirement for all aquatic life (Summers 2001). Many states have set a threshold concentration of 4 to 5 ppm as their water quality standard. Concentrations below approximately 2 ppm are stressful to many estuarine organisms (Diaz and Rosenberg 1995; Coiro et al. 2000). Eutrophication associated with urbanization (see Threat #5 above) can lead to reduced levels of dissolved oxygen in habitats used by diadromous juveniles and adults. Many riverine and estuarine habitats occupied by migratory diadromous fish are experiencing hypoxia (reduced oxygen) and/or anoxia (absence of oxygen) more often, and over more extensive areas, than in the past (Coutant and Benson 1990; Summers 2001; Bales and Walters 2003; Chesapeake Bay Foundation 2004; Summers 2004).

For example, Summers (2001) reported that in Long Island Sound, low dissolved oxygen occurs primarily during the summer months in the central and western portions. The water in Long Island Sound tends to be highly stratified in the late summer months and has probably always experienced some periods of low dissolved oxygen. However, human inputs of nutrients have added to the problem, resulting in more significant damage to ecologically and economically important organisms. A time series of average dissolved oxygen concentrations in Long Island Sound shows generally decreasing measurements from 1963 to 1993. Conditions appeared to improve from 1987 to 1993, but remained substantially degraded with respect to measurements made prior to 1970. The number of days for which conditions were hypoxic (below 3 ppm) ranged from 35 in 1995 and 1996, to 82 in 1989 (Summers 2001).

Although overall estuarine oxygen levels are reported in the National Coastal Condition Reports (Summers 2001, 2004) as “good” coastwide, both reports note that levels in a number of East Coast estuaries are problematic. Coastwide “good” conditions are defined as meaning that less than 5% of coastal waters have "poor" dissolved oxygen concentrations (i.e., less than 2 ppm). "Fair" dissolved oxygen conditions coastwide mean that only 5% to 15% of the coastal waters have poor dissolved oxygen, and "poor" means that more than 15% of the coastal waters have poor dissolved oxygen concentrations. Specific estuaries mentioned as having dissolved oxygen problems were the Neuse River estuary, Chesapeake Bay, and Long Island Sound (Summers 2001, 2004).

A recent review of dead zones and their consequences for estuarine and marine ecosystems was conducted by Diaz and Rosenberg (2008). The researchers indicated that such dead zones in estuaries and the coastal oceans have, "...spread exponentially since the 1960's and have serious consequences for ecosystem functioning." Dead zones have formed from the increase in primary production, and consequent worldwide eutrophication, fed by riverine runoff of fertilizers and the combustion of fossil fuels. Enhanced primary production results in an accumulation of particulate organic matter, which facilitates microbial activity and the consumption of oxygen in bottom waters. Diaz and Rosenberg (2008) compiled data on dead zones globally, and documented about 101 dead zones on the East Coast of the United States, within ASMFC jurisdiction. Each Atlantic coastal state, with the exception of Pennsylvania, had from one (e.g., in Connecticut and New Hampshire) to as many as 24 (e.g., in South Carolina) dead zones. On a positive note, some of the documented dead zones were historic and have been alleviated through positive management actions (Diaz and Rosenberg 2008).

Diaz and Rosenberg (2008) also defined the degrees of hypoxia present. The most common form, *seasonal hypoxia*, occurs once per year in the summer after spring blooms, when water is warmest and stratification strongest, and usually lasts until autumn. Seasonal hypoxia is responsible for about one-third (33 of 101) of the dead zones on the East Coast. The usual ecosystem response to seasonal oxygen depletion is mortality of benthic organisms, followed by some level of recolonization when normal conditions return (Diaz and Rosenberg 2008).

Diaz and Rosenberg (2008) noted that *periodic hypoxia* was reported in almost half (46 of 101) of the East Coast dead zones. Periodic hypoxia might occur more often than seasonally, but tends to be less severe, lasting from days to weeks. Many smaller systems, such as the York River tributary to the Chesapeake Bay, experience this form of hypoxia when local weather events and spring neap-tidal cycles influence stratification intensity (Diaz and Rosenberg 1995).

Other causes of hypoxia are: 1) diel cycles, which influence production and respiration, and cause hypoxia that lasts only hours on a daily basis (Tyler and Targett 2007); and 2) wind and tides influencing areas on the margins of seasonal dead zones (Breitburg 2002). Diaz and Rosenberg (2008) noted that these are known as *episodic hypoxia* events, and are infrequent. Episodic hypoxia might occur less than once per year, sometimes with years lapsing between events. Episodic oxygen depletion is the initial sign that a system has reached the critical point of eutrophication, which in combination with stratification of the system tips it into hypoxia. Fifteen of the East Coast dead zones (or 14.8%) documented by Diaz and Rosenberg (2008) were classified as episodic.

Lastly, *persistent hypoxia* can occur where systems are prone to persistent stratification. None of the dead zones on the East Coast were classified as persistent (Diaz and Rosenberg 2008).

Example: Striped bass

The Neuse River estuary, Chesapeake Bay, and Long Island Sound are important nursery and foraging areas for migratory striped bass juveniles and adults. Eileen Setzler-Hamilton and Lenwood Hall, Jr. (1991) wrote that, "There is increasing concern that low dissolved oxygen in the deeper waters of the upper Chesapeake Bay and its tributaries has eliminated much of the summer habitat for sub-adult and adult striped bass." Those words were written seventeen years ago and remain just as true today.

Striped bass of all ages avoid waters with dissolved oxygen concentrations less than 3 to 4 mg/L. From 1984 through 1987, there was no suitable habitat (defined as water with temperature below 25°C and dissolved oxygen above 2 to 3 mg/L) for striped bass remaining in late July in the north-central segments of the Chesapeake Bay (Coutant and Benson 1990). Additionally, CBF (2004) reported that during the summer of 2004, approximately 35% of the water in the mainstem Chesapeake Bay had unhealthy dissolved oxygen levels for many forms of aquatic life, including striped bass. A "dead zone" with dissolved oxygen concentrations of less than 2 mg/L extended from off the mouth of the Rappahannock River in Virginia, to well above the Patuxent River in Maryland. Most Chesapeake Bay-associated rivers (e.g., York, Rappahannock, Potomac, and Patuxent, among others) experienced similar problems in their lower reaches at that same time (CBF 2004).

The primary cause of reduced oxygen in Chesapeake Bay and its tributary rivers was stated as nitrogen pollution that fueled large algal blooms, which in turn were decayed by oxygen-consuming bacteria. In particular, during 2004, algal blooms early in the year caused dissolved oxygen levels well below average at many locations in the Bay during February and March. While the overall size of the 2004 dead zone was smaller than the historic one of 2003, the volume of anoxic water was greater (CBF 2004).

Similarly, Wiley and Tsai (1990) reported that the Broomes Island area of the Patuxent River was no longer acceptable summer habitat for striped bass. White perch, hogchokers, and striped bass dominated monthly trawl catches at Broomes Island from 1965 through 1968, but by 1988 and 1989, striped bass were caught rarely. Eutrophication and the resulting increase in hypoxic bottom waters were stated as the probable causes of the deterioration of this summer habitat (Wiley and Tsai 1990).

THREAT #8: GLOBAL WARMING

Section 8.1A: Global Warming

In a demonstration of great foresight, the American Fisheries Society held a symposium on the effects of climate change on fish during the 1988 annual meeting (Regier et al. 1990).

The conveners noted that, "there is growing consensus that climate change will result from the continuing buildup of heat-trap gases in our atmosphere." They further noted that, "...efforts to adapt the scientific method to forecast some potential effects of climate change on fish and fisheries...," were well along and reflected by the symposium papers (Reiger et al. 1990).

Regier et al. (1990) perceived three types of causal or relational connections between atmospheric phenomena and fish in hydrological systems, including: 1) quite direct ecological pathways from the local climate to the local stock or association of fish; 2) more general, looping ecosystemic pathways involving linkages between climatological, hydrological, and biotic subsystems; and 3) even more complex pathways that involve, in addition to the above, human activities that change with climate change and the effects of those cultural changes on the natural parts of our ecosystems and biosphere (Regier et al. 1990).

The emphasis in the symposium papers was mostly on some simpler examples of the second type of causal connection. Due to the fact that fish live in water, and water temperature is a complex function of multiple factors, researchers thought that fish might offer relatively few instances of simple direct connections of the first type. As yet, they reported, few scientists knowledgeable about fish had given thought to examples of the third type; however, they did note that Coutant (1981) had suggested that a major regional effect could occur through the construction of water-storage reservoirs in areas of increased aridity (Regier et al. 1990). That prediction appears to be coming true in the wake of several recent prolonged and severe drought years, at least in the southeastern United States (W. Laney, personal observation).

In a recent study by Lassalle et al. (2008) using models to predict diadromous species distributions, the researchers found that temperature was the most explanatory variable in six of the twenty-one individual species models. In addition, longitude was the most explanatory variable in fifteen of the other species. The researchers claimed that their models could be used to predict changes in species distribution under global warming conditions. They used Allis shad (*Alosa alosa*), which is a declining European species, as an example. Biogeographical history proved to be an important component in the evaluation of these models. The researchers noted that the models could be used to predict whether a particular area would be suitable for restoration under global warming scenarios, and thought models should be used as a decision support tool to assess the suitability of conservation units (Lassalle et al. 2008).

Issue 8.1A.1: Habitat modifications

Coutant (1990) noted that a fish population's "habitat" could be defined as the volume of water that provides suitable conditions over time for sustained high performance, linked to the physiological performance of fishes under different environmental regimes. As climate changes occur, modification of such habitat is expected in local environments. Such modifications could result in changes in large-scale distribution patterns for fish species, and consequent changes in the thermal niche space available. As noted by Coutant (1990), the linkage between fish production and thermal niche space is confounded when the habitat is made unsuitable by a low dissolved oxygen concentration.

Example: Striped bass

The implications of continued global habitat warming and predicted outcomes for Atlantic migratory striped bass were discussed in detail by Coutant (1990). Based on the results of environmental change scenarios produced by two general circulation models (U.S. National Aeronautics and Space Administration's Goddard Institute for Space Studies model, GISS, and Princeton University's Geophysical Fluid Dynamics Laboratory model, GFDL) that each assume a doubling of carbon dioxide, Coutant (1990) predicted changes in habitat use and distribution of Atlantic migratory striped bass. For striped bass, the predicted outcome of continued global warming is alteration in distribution, both locally and geographically. Both climate models predicted a pronounced upward shifting of estimated annual coastal temperatures (Coutant 1990).

Issue 8.1A.2: Temperature change

Example: Striped bass

Since temperatures on striped bass spawning grounds are predicted to rise, Coutant (1990) indicated that annual events that seem related to the seasonal cycle of water temperature might increase in frequency. He noted that once day-length sets the annual maturation cycle of temperate-zone fishes, temperature plays a dominant role in keying the actual spawning events. Based on data in Westin and Rogers (1978), the average temperature at which striped bass spawning was maximized across the species' range was 16°C, and first spawning occurs at an average temperature of 14.8°C. However, Coutant (1990) noted that it was debatable whether either of those temperatures represented indices of successful recruitment because multiple spawning periods were common in many rivers, and, according to Polgar (1982), survival of eggs and larvae was dependant upon the relative timing of egg depositon and environmental vagaries within the spawning period (Coutant 1990).

Coutant (1990) noted that if the temperatures are used as indicators regardless, then the climate models predict that spawning temperatures will be reached much earlier in the season. Spawning times for the Hudson River and Chesapeake Bay were estimated to differ from three to four weeks. In more northern latitudes, exemplified by coastal water temperatures at Bar Harbor, Maine, the two models differed by nearly a month in the estimated time at which spawning temperatures would be reached. In addition, because striped bass in Canada were reported to spawn over a wide range of temperatures, it was difficult to estimate a timing change. Furthermore, river temperatures might influence spawning more than the modeled coastal temperatures (Coutant 1990).

Additionally, temperature changes might be accompanied by rising sea levels with attendant flooding of spawning habitats in estuaries and wetland nursery areas (Orson et al. 1985). Coutant (1990) noted that predictions of how the coastal environment necessary for striped bass spawning and juvenile rearing would respond to a rising sea level requires consideration of many coastal processes, including tidal ranges, storm surges, intrusion of groundwater and surface water, and sedimentary processes, as well as the response by the plant communities of coastal ecosystems to changes in these processes. Resultant impacts are likely to be highly site-specific and to include changes both in temperature and dissolved oxygen structure and in physiographic features.

As climate warms, estuaries used by striped bass as nursery areas or adult foraging areas may no longer provide suitable thermal niche space, especially in the summer. The Roanoke River-Albemarle Sound striped bass, which exist at the boundary between the coastal migratory habitats of more northern stocks and the riverine habitats of the more southern stocks, could become strictly riverine and congregate in the summer in the cooler tailwaters upstream of hydroelectric dams (Coutant 1990).

In contrast, stocks in the Bay of Fundy, the Saint John estuary (New Brunswick), the Northumberland Strait, and estuaries entering the Gulf of St. Lawrence that now live under suboptimal thermal conditions and have sporadic year classes, could benefit as global warming produces conditions closer to optimal. The juvenile striped bass thermal niche of $24^{o}C$ to $28^{o}C$ would be more likely to occur in shallow estuaries, establishing warmer conditions for juvenile rearing. Projected expansion of the striped bass range, or any increase in population abundance in the Gulf of St. Lawrence region, would depend greatly on the configuration of coastal currents there (Rulifson et al. 1987).

Issue 8.1A.3: Sea level rise

Example: Striped bass

Accompanying predicted temperature changes could be rising sea levels with attendant flooding of spawning habitats in estuaries and wetland nursery areas (Orson et al. 1985). Predictions of how striped bass spawning and juvenile rearing environments will respond to a rising sea level requires consideration of many coastal processes, including: tidal ranges, storm surges, intrusion of groundwater and surface water, sedimentary processes, and the response by the plant communities of coastal ecosystems to changes in these processes. Resultant impacts are likely to be highly site-specific and to include changes both in temperature and dissolved oxygen structure and in physiographic features (Coutant 1990).

PART II. EFFECTS OF HABITAT DEGRADATION ON HARVESTING AND MARKETABILITY

Effects of habitat degradation that result in non-natural mortality can affect the size of the population and ultimately the size of the allowable harvest. Some threats may not increase mortality, but can reduce or eliminate marketability. These threats include non-lethal limits of contaminants that may render fish unfit for human consumption, or changes in water quality that may reduce fish condition or appearance to a point where they are unmarketable (ASMFC 1999).

Example: Alosines

Table 12-1 lists threats that have been identified for shad and river herring habitat. Because the magnitude of an impact may vary locally or regionally, the degree to which each impact may occur is not specified. Instead, the likelihood to which each impact may occur within each geographical area (riverine waters, territorial waters, or EEZ) is provided. The categories are as follows: Present (P) denotes a threat that has been specifically identified in the literature; No Information Found (NIF) indicates that no information regarding this threat was found within the literature, but there is a possibility that this threat could occur within the specified geographical area; and Not Present (NP) indicates that the threat could not possibly occur within that geographical area (e.g., dam blockage in the EEZ).

THREAT	Riverine Waters	Territorial Waters	EEZ
Chemical			
Acid/aluminum pulses	P	NIF	NIF
Sedimentation	P	NIF	NIF
Suspended particles	P	NIF	NIF
Inorganic inputs	P	P	NIF
Organic chemicals	P	P	NIF
Thermal effluent	P	P	NP
Urban stormwater pollution	P	P	NIF
Sewage/animal waste	P	P	NIF
Non-point source pollution	P	P	NIF

THREAT	Riverine Waters	Territorial Waters	EEZ
Physical			
Dams/spillways	P	NP	NP
Other man-made blockages (e.g., tide gates)	P	P	NP
Non-anthropogenic blockages (e.g., vegetative debris)	P	NP	NP
Culverts	P	NP	NP
Inadequate fishways/fish-lifts	P	NP	NP
Water releases from reservoirs	P	P	NP
Non-hydropower water withdrawal facilities (e.g., irrigation, cooling)	P	P	NP
Channelization	P	NIF	NP
Dredge and fill	P	P	NP
Urban and suburban sprawl	P	NIF	NP
Land-based disturbances (e.g., de-forestation)	P	NIF	NP
Jetties	NP	P	NP
Overharvesting	P	P	P
Biological			
Excessive striped bass predation	P	P	NIF
Nuisance/toxic algae	P	NIF	NIF

Table 12-1. Threats to shad and river herring habitat

PART III. DIADROMOUS THREATS IDENTIFIED IN STATE WILDLIFE ACTION PLANS

Purpose and Scope

Congress created the State Wildlife Grants Program in 2001 to provide every state and territory with federal dollars to support conservation efforts and prevent wildlife from becoming endangered. This program supports projects that protect and restore important lands and waters, collect information on the status of wild populations, and develop partnerships with landowners to protect declining species and habitats on public and private lands. The idea is that states should take a proactive approach to protect wildlife and habitats before they become too rare and costly to protect.

To make the best use of the State Wildlife Grants Program, Congress charged each state and territory with developing a State Wildlife Action Plan (SWAP). As a result of this mandate, state fish and wildlife agencies developed strategic plans that were submitted to the U.S. Fish and Wildlife Agency by October 1, 2005. These SWAPs are intended to be tools for adaptive management, and thus, will undergo additional revisions.

Congress identified eight required elements that each state must address in their SWAP. Strategies should also identify and focus on the "species in greatest need of conservation," yet address the "full array of wildlife" and wildlife-related issues. The eight required elements are summarized as follows:

(1) Information on the distribution and abundance of fish and wildlife species

(2) Description of locations and relative condition of key habitats and community types

(3) Description of problems that may adversely affect species identified in element (1) above or their habitats, and priority research and survey efforts

(4) Description of conservation actions

(5) Proposed plans for monitoring

(6) Descriptions of procedures to review the strategy

(7) Plans for coordinating the development, implementation, review, and revision of the plan with Federal, State, and local agencies, and tribal governments

(8) Broad public participation

For most states, many of the diadromous fish species are identified under element (1) above as species of greatest conservation need (SCGN). States used multiple sources to identify SGCN, such as federally listed species, as well as state-listed Endangered, Threatened, and Species of Concern. Many states ranked species according to the Natural Heritage methodology, maintained by NatureServe. NatureServe is a non-profit conservation organization that provides scientific information to local, national, and global interests to help them collect and manage information on their natural resources. The following "S," or state rankings, have the same standards used to classify species in each state, but wording may vary slightly from state-to-state. Note that these are not the same as federal or global rankings.

S1 – Critically imperiled in the state

S2 – Imperiled in the state

S3 – Vulnerable to extirpation or extinction in the state

S4 – Apparently secure in the state

S5 – Secure, common, widespread, and abundant in the state

It is important to note that some species may have an S4 or S5 state ranking, but were still included in the plan. It could be that habitats in which they are present are known to have problems that could threaten their ranking. Regardless, the purpose of this document is not to note the state status of each diadromous fish species, but rather to identify threats, wherever possible. State rankings are provided simply as an additional reference.

Identifying Threats

Element (3) above requires states to identify problems or threats to species and their habitats. Because plans are required to identify SGCN, it is possible that some diadromous fish species were not identified in some state plans because they are not SGCN within that state. Some states noted the presence of other diadromous fish species within certain habitats that were not listed as SGCN within their state. Wherever possible, if a diadromous fish species is known to occur within a given state but was not listed in the SWAP, it is noted. Information about presence of species within these states was obtained from tables included on the accompanying DVD.

The threats identified may, or may not, be an inclusive list for each species. Some states are better suited to comprehensively identify diadromous fish species-habitat associations and threats because of better availability of information and greater funding. In some states, identified threats may be overarching threats to a particular habitat (e.g., upland rivers) or a broad species category (e.g., fish). The threats may apply to many, but not all, of the species within the habitat. Thus, it is possible that some of the threats may not apply to American eel, Atlantic sturgeon, American shad, hickory shad, alewife, blueback herring, or striped bass. If there is a question about a specific threat within a state, please contact a representative from the state fish and wildlife agency.

Finally, it should be emphasized that the format and content of information will vary, according to how it was presented in each individual SWAP. The text has been adapted from each plan in an effort to best summarize the data. Consult each plan for additional information (for full text, see http://www.wildlifeactionplans.org).

SWAP Information By State

<u>Maine</u>

The following diadromous fish species were ranked, general descriptions of primary and secondary habitats provided, and threats to individual species identified. Please note that although alewife and blueback herring were not identified as SGCN within the state, they occur within many rivers and streams throughout the state. Thus, it is likely that some of the threats identified may also apply to these species.

Species

American eel - S1 state ranking

Primary habitats are lakes and ponds, and rivers and streams, and secondary habitat is estuaries and bays. Threats to habitat include: dams; poorly functioning fish passage facilities for upstream and downstream movement; and habitat loss or degradation.

American shad - S2 state ranking

Primary habitat is rivers and streams, and secondary habitat is estuaries and bays. Threats to habitat include: dams and other physical obstructions; and land use (e.g., farming, logging, and urbanization).

Atlantic sturgeon - S1 state ranking

Primary habitat is rivers and streams, and secondary habitat is estuaries and bays. Threats to habitat include: habitat loss or degradation.

Striped bass - S1 state ranking

Primary habitat is rivers and streams, and secondary habitat is estuaries and bays. Threats to habitat include: habitat loss or degradation.

Citation

Maine Department of Inland Fisheries and Wildlife. 2005. Maine's Comprehensive Wildlife Conservation Strategy.

New Hampshire

New Hampshire's state ranking for each species is listed below. In addition to the state rankings, New Hampshire also compiled a list of all the associated risk factors relevant to each species and habitat, then scored, ranked, and categorized those factors. Rankings range from 1-4, with 1 being species with the least risk factors and 4 being species with the greatest risk factors. Also noted below is a brief justification for inclusion in the SWAP, but is not necessarily a comprehensive list of threats for the species.

Species

Alewife - S5 state ranking; level 2 risk

Justification for inclusion: presence of dams, which reduce access to spawning habitat.

American eel - S5 state ranking; level 3 risk

Justification for inclusion: dams, unfavorable environmental conditions in freshwater and marine habitats, pollution, and climate change.

American shad - S5 state ranking; level 3 risk

Justification for inclusion: dams and pollution.

Atlantic sturgeon - S1 state ranking; level 4 risk

Justification for inclusion: habitat degradation and barriers.

Blueback herring - S4 state ranking; level 2 risk

Justification for inclusion: dams, which severely limit access to spawning habitat.

Habitats

Although threats for these individual species are not identified in the SWAP, diadromous species are identified within their respective watershed groupings, with the most challenging threats identified for the entire watershed grouping.

Coastal Transitional Watershed

This grouping contains American eel. The most challenging threat facing coastal transitional watersheds is introduced species.

Connecticut River Mainstem Watersheds

This grouping contains American eel, American shad, and blueback herring. The most challenging threats facing Connecticut River mainstem watersheds include non-point source pollution and agriculture.

Northern Upland Watershed

This grouping contains American eel. No critical threats have been identified for northern upland watersheds. However, development and altered hydrology are likely to become problematic over time.

Non-tidal Coastal Watersheds

This grouping contains alewife, American eel, American shad, Atlantic sturgeon, and blueback herring. The most challenging threats facing this watershed include development and non-point source pollution.

Tidal Coastal Watersheds

This grouping contains alewife, American eel, American shad, Atlantic sturgeon, and blueback herring. The most challenging threat facing this watershed is development,including: urbanization, habitat loss and conversion, non-point source pollution, and other factors.

Citation

New Hampshire Fish and Game Department. 2005. New Hampshire's Wildlife Action Plan.

<u>Massachusetts</u>

Species

The Massachusetts SWAP lists the following diadromous fish species as SGCN:

Alewife - unranked (state conservation status not yet assessed)

Specific threats to this species include: dams, pollution, development, over-fishing, and poorly maintained fishways.

American eel - S5 state ranking

Specific threats to this species include: water pollution, dams that hinder migration, changes in ocean circulation patterns, and possibly overfishing.

American shad - S3 state ranking

Specific threats to this species include: dams, inadequately or poorly maintained fishways, and pollution.

Atlantic sturgeon - S1 state ranking

This is a SGCN in large and mid-sized rivers. Specific threats to this species include: dams, water pollution, historic over-fishing, and bycatch and the associated mortality rates. The late age at which Atlantic sturgeon begin spawning, and a requirement for freshwater, estuarine, and coastal habitats to complete their life cycle, make them particularly vulnerable.

Blueback herring - S4 state ranking

Specific threats to this species include: dams and pollution.

Habitats

There are four habitats that contain some or all of the SGCN listed above. Threats to the overall habitat, but not necessarily to the individual species, have been identified and are discussed below.

Connecticut and Merrimack Rivers- Mainstem Habitat

A) *Species:* Atlantic sturgeon, American shad, blueback herring, American eel, and alewife

B) *Threats*:

   1) <u>Water quality deterioration</u>: Specific threats include toxins in the river (e.g., PCBs), combined sewer overflows (CSOs), bio-accumulation of contaminants, and non-point source pollution (e.g., agricultural run-off).

CSOs in the state regularly cause temporary Class C water quality conditions in urban areas after storms. The Massachusetts Department of Public Health issued fish consumption advisories recommending that children under 12, pregnant women, and nursing mothers not consume any fish from specified areas of the Connecticut River, and the general public should not consume American eel because of elevated levels of PCBs.

2) Habitat loss and fragmentation: Specific threats include: impoundments, filling of wetlands bordering the rivers, and urbanization of the river corridor. Disconnection of the rivers from their floodplains by channelization has led to dramatic changes in habitat.

3) Air pollution: Specific threats include: acid precipitation and atmospheric deposition of mercury and other contaminants. Some sources are local, but the majority of pollution originates from sources outside of the region.

4) Hydroelectric dams: The Connecticut and Merrimack Rivers are some of the most developed rivers in the Northeast. The Massachusetts sections of each of these rivers contain two major hydroelectric dams, including the first dam upstream from the sea on each system. These large dams with operating hydroelectric facilities create unique threats to fish and wildlife populations, including:

   i. *Impoundments*: About one third of the mainstem Connecticut River, and most of the freshwater portion of the Merrimack River, is impounded. The habitat found in these impoundments is far different from that of free-flowing rivers.

   ii. *Bypasses*: Large hydroelectric dams divert much of the river flow away from the rapids habitat. This often results in rapids below both the Turners Falls dam on the Connecticut River, and the Pawtucket dam on the Merrimack River, being dry for much of the summer.

   iii. *Population fragmentation*: Dams form barriers to migration, which can dramatically reduce the habitat available to anadromous fish and may fragment resident fish populations.

   iv. *Flow alteration*: The Turners Falls Hydroelectric Project on the Connecticut River is a "peaking" project. It stores water over a period of several hours, and then releases it all at once, dramatically changing the river flow. These daily changes in flow below the dam and reservoir level above the dam disrupt fish and wildlife habitat and lead to large-scale riverbank erosion.

5) Invasive species: A number of invasive species have taken hold in these watersheds and threaten native species. These include: common reed (*Phragmites australis*), purple loosestrife (*Lythrum salicaria*), Eurasian watermilfoil (*Myriophyllum spicatum*), and water chestnut (*Trapa natans*), as well as Mute Swans, Asiatic clams (*Corbicula fluminea*), and hemlock woolly adelgid (*Adelges tsugae*).

6) Human usage: Recreational use of these rivers, whether by boat or on foot, can degrade habitat and sometimes cause outright destruction of these species of concern.

Large and Mid-size Riverine Habitat

A) *Species*: Atlantic sturgeon, American shad, blueback herring, American eel, and alewife

B) *Threats*:

1) Physical habitat alterations: Channelization, particularly near urban centers, has resulted in massive habitat loss in all watersheds, but especially in the Charles, Concord, Blackstone, North and South Coastal, and Merrimack watersheds. Portions of some rivers, for example, the Hoosic River in Adams and North Adams, have actually been completely culverted and run through food chutes instead of natural channels.

2) Dams: Dams impact all watersheds in the state. The only mainstem in Massachusetts considered to be free-flowing is the Taunton River. These dams all result in a loss of physical habitat suitable for fluvial species within the impoundment, but other habitat impacts are also apparent. Stream flow downstream of almost all impoundments is severely restricted during low flow times of the year or when lakes are being refilled after an artificially induced lake drawdown. Minimum streamflow criteria are not regulated for most reservoir situations. Likewise, maximum streamflow is not regulated during artificial drawdowns when spring-like (or greater) flows are allowed to take place in times other than spring. These dams also cause a buildup of sediment, sometimes severely contaminated, within the impoundment and result in incised channels downstream of the impoundment. Incised channels further isolate the river channel from the surrounding floodplain.

   i. *Hydroelectric power*: The Deerfield, Westfield, and Swift Rivers have the majority of hydroelectric generation (excluding the Connecticut and Merrimack River mainstems, discussed above).

   ii. *Flood protection*: Large-scale flood control projects exist on the Quinebaug, Westfield, and Millers Rivers.

   iii. *Reservoirs*: Water supply reservoirs are common statewide and range in size from the 25,000-acre Quabbin Reservoir to smaller secondary or backup water supply impoundments.

3) Sewerage treatment effluent: Many of Massachusetts's large to mid-sized rivers are impacted by effluent from centralized sewerage treatment plants. In some cases, raw sewerage continues to be released into our waters. The Blackstone, Charles, Concord, and Nashua Rivers are particularly impacted. During summer low flows, the Blackstone and Assabet rivers (a tributary to the Concord River) are composed primarily of sewerage treatment effluent.

4) Stormwater runoff: Runoff has caused substantial changes to water quality and causes erosion issues. Winter runoff often includes high concentrations of

road salt, while stormwater flows in the summer cause thermal stress and bring high concentrations of other pollutants. Road, culvert, and public water and sewer have created pathways, both intentional (CSO flows) and unintentional (inflow and infiltration), that have expedited the movement of rainfall and runoff into stream channels.

5) Water withdrawal and surface water diversion: These activities result in impacts to all of the basins to some extent, as illustrated in the Stressed Basins Report published by the Massachusetts Department of Conservation and Recreation, but especially to some of the higher quality rivers in the state. The Ipswich River continues to serve as the model for environmental degradation caused by water withdrawal. The Ipswich River is impacted by both surface water diversion and groundwater withdrawal, and was listed by American Rivers in 2003 as one of the ten most endangered rivers in America, due to worsening flow conditions.

Marine and Estuarine Habitat

A) *Species*: Atlantic sturgeon, American shad, blueback herring, American eel, and alewife

B) *Threats*:

1) Shoreline development: This is the greatest threat to the coastal bays and estuaries in the state. Massachusetts has lost close to 30% of its coastal wetlands due to development. The loss of coastal wetlands reduces the filtration ability provided by such wetlands to waters entering bays and estuaries. Shoreline development results in more impervious surface with increased stormwater runoff and accompanying potential for sedimentation and toxic contamination.

2) Wastewater treatment: Overflows and leaks from wastewater treatment plants and faulty septic systems can result in bacterial and pathogenic contamination and increase nitrogen loading in Massachusetts's coastal waters. This, in turn, promotes algal growth on eelgrass beds to the detriment of this valuable aquatic food and cover source for fish, shellfish, marine invertebrates, and waterfowl and other aquatic birds.

3) Boating: Increased commercial and recreational boat traffic re-suspends sediments, further shading submerged vegetation. Direct discharge of waste from recreational boating, and accidental oil spills from commercial shipping, have been threats in the past and will continue in the future.

4) Invasive species: A number of invasive species have taken hold in these habitats and threaten native species. These include common reed (*Phragmites australis*) and purple loosestrife (*Lythrum salicaria*).

Lake and Pond Habitat

A) *Species:* American eel and alewife

B) *Threats*:

1) Eutrophication: Accelerated eutrophication due to watershed activities is one of the greatest threats to Massachusetts's lakes. These activities can include input from: nutrient-rich effluents from sewage treatment plants, agricultural run-off, stormwater run-off from impervious surfaces, leaching from septic systems, and soil erosion from construction and timbering activities. Currently, hundreds of waters in Massachusetts do not meet their designated water quality standards. This accelerated eutrophication can contribute to an increase in the abundance of aquatic vegetation, increased turbidity, decreased dissolved oxygen levels, and increased sedimentation which ultimately decreases the depth of a lake. Most Massachusetts lakes are particularly susceptible to accelerated eutrophication due to their small watersheds.
2) Invasive species: The introduction of non-native invasive plants that can create monocultures and eliminate open water habitat is another major threat to the lakes. As with aquatic plants, the introduction of non-native animals, such as zebra mussels (*Dreissena polymorpha*) or snakeheads (*Channa* sp.), can have a devastating effect on the aquatic ecosystem.

Citation

Commonwealth of Massachusetts, Executive Office of Environmental Affairs (MEOEA). 2005. 2005 Massachusetts Comprehensive Wildlife Conservation Strategy.

Rhode Island

Species

The Rhode Island SWAP lists the following diadromous fish species as SGCN:

Alewife – S3 state ranking

American eel – S5 state ranking

American shad – S1 state ranking

Atlantic sturgeon – SH (state historical) ranking

This species is listed by Rhode Island as a Species of Special Concern, and is imperiled.

Blueback herring – S1 state ranking

Habitats

Marine and Estuarine Habitats

A) *Species*: Marine/estuarine fish, which includes diadromous fish (individual species are not indicated)

B) *Threats*:

1) Wetland loss: Direct loss and fragmentation of wetlands has been caused by shoreline development, recreational use, bulkheads, poor urban development, dredging, dredge disposal, ditching and draining, and other benthic disturbances.

2) Changing water regime: Changes in the freshwater regime have resulted from freshwater diversion, dam removal and waterway restoration, and ditching wetlands.

3) Pollution: Pollution has caused sedimentation and contamination of marshes.

   i. *Point source*: Direct contamination has come from industrial discharge, heavy metals, sediment, oil spills, marine accidents, ocean dumping, and other contaminants.

   ii. *Non-point source*: Sedimentation and contamination has come from erosion, agriculture run-off, pesticides, and septic systems.

4) Nutrient loading: Nutrient loading originating from sewage pollution (e.g., combined sewage overflow, failing and inadequate systems, and boat waste) has caused algal blooms and other issues.

5) Temperature: Temperature changes and regulation have caused problems for native species survival.

6) Invasive species: These species directly affect habitat, competitors, predators, pathogens or parasites, and/or changes in the native species dynamics, or by directly competing with the native species.

River and Stream Habitats

A) *Species*: Diadromous species (individual species associations are not identified)

B) *Threats*:

1) Habitat fragmentation: This has been caused by a lack of conservation planning capabilities and coordination, a lack of a focal area approaches to conservation, human disturbance, chemical contaminants and disease, and road effects.

2) Habitat degradation: This has been caused by chemical contaminants and disease, human disturbance, and impairment of water quality.

3) Habitat loss: This has been caused by inadequately sized preserves, plant succession, invasive species, and impairment of aquatic contiguity.

4) Lack of research: There has been a lack of information from research to address habitat and taxonomic issues.

Citation

State of Rhode Island Department of Environmental Management, Division of Fish and Wildlife. 2005. Rhode Island's Comprehensive Wildlife Conservation Strategy.

Connecticut

Species

The Connecticut SWAP lists the following diadromous fish species state rankings:

Alewife – S3 state ranking

American eel – S5 state ranking

American shad – S3 state ranking

Atlantic sturgeon – S1 state ranking

Blueback herring – S5 state ranking

Hickory shad – S2 state ranking

Striped bass – S3 state ranking

Habitats

General

A) *Species*: All fish and wildlife species collectively

B) *Threats*:

1) <u>Insufficient knowledge</u>: In general, there is insufficient scientific knowledge regarding wildlife, as well as freshwater, diadromous, and marine fish species, and their habitats (distribution, abundance and condition).

2) <u>Habitat fragmentation, degradation, and loss</u>: These problems have resulted from development or changes in land use, a lack of resources to maintain/enhance wildlife habitat, a lack of landscape-level conservation efforts, public indifference toward conservation.

3) <u>Invasive species</u>: These species (e.g., *Phragmites australis*, *Lythrum salicaria*, and Mute Swan) have caused problems for species and habitat in many areas.

4) <u>Species limitations</u>: Some species with depressed populations have experienced delayed recovery due to limited reproductive potential, dispersal ability, or other factors.

Freshwater Habitats

A) *Species*: Diadromous species (individual species associations are not identified)

B) *Threats*:

1) Habitat fragmentation, degradation, and loss: These problems have resulted from stream channel modifications, dams, channelization, filling, dredging, development, sedimentation, vegetation control, and shoreline modification. There has also been a loss of coldwater habitat due to decreased groundwater input or increased warming (e.g., wetlands filling, impoundment, removal of riparian vegetation).

2) Predation: There have been impacts to prey species from predation by striped bass in the Connecticut River.

3) Fish passage: Populations have been fragmented and access has been lost to upstream and spawning habitat due to impediments to fish movements, such as dams, barriers, culverts, and tide gates.

4) Pollution: There have been impacts of point and non-point source pollution on diadromous fish populations.

5) Boating: Excessive boat activity has lead to wake wash, sediment suspension, and propeller scarring.

6) Water withdrawal and surface water diversion: Instream flow alterations and increasing temperatures have been caused by consumptive withdrawals of surface or ground water and wetland loss. Water diversions that reduce stream flows have also resulted in fish mortality, loss of habitat, and interference with migration.

7) Regulations: Ineffective or insufficient land use regulations among towns have impacted fish habitats.

8) Lake manipulations: There have been adverse impacts to fish from lake manipulations (e.g., excessive vegetation control, water level manipulation, and dredging).

9) Nutrient loading: Excessive nutrient run-off and vegetation control has lead to a loss of the oxygenated hypo-limnetic and meta-limnetic zone.

10) Migration disruption: Dredging and development have lead to disrupted migration of diadromous fish.

11) Natural barriers: Beaver dams have impacted coldwater habitats, resulting in ponding and warming, fragmentation of habitat, and increased sedimentation and nutrient loading.

Marine Habitats

A) *Species*: All aquatic species in marine areas

B) *Threats*:

1) Habitat fragmentation, degradation, and loss: Disturbance, destruction, alteration, or loss of critical habitat structure or function is a major problem.
2) Residual contaminants: Residual contaminants in sediments and water, such as nutrients and pesticides, effect marine species in many ways.
3) Temperature: There are adverse impacts from temperature shifts, including widespread long-term (e.g., global warming) and local short-term impacts (e.g., temporary power plant shutdowns).
4) Non-native species: Predation, competition, displacement from habitat, and/or disease transmission are associated issues.
5) Fishing: Unintentional damage, injury, or mortality due to fishing (e.g., incidental catch, or injuries from fishing gear) is also a problem.

Citation

State of Connecticut Department of Environmental Protection, Bureau of Natural Resources. 2005. Connecticut's Comprehensive Wildlife Conservation Strategy.

New York

Species and Habitats

Critical habitats and sub-habitats are identified in the SWAP, including a breakdown of breeding, feeding, and nursery/juvenile life history stages. Threats to individual species within these habitats have also been identified.

Alewife – no state ranking, and has unprotected state status

Critical habitats and sub-habitats for alewife include:

1) Breeding and nursery/juvenile:
    - i. Estuarine
        - a) Shallow subtidal
    - ii. Riverine
        - a) Coastal plain stream
        - b) Deepwater river
2) Breeding only:
    - i. Riverine
        - a) Warmwater stream
3) Feeding:
    - i. Marine
        - a) Deep subtidal

Specific threats to this species include: loss of historic spawning grounds and degradation of spawning and juvenile habitat, primarily in inshore areas.

American eel – S5 state ranking, and has unprotected state status

Critical habitats and sub-habitats for American eel include:

1) Nursery/juvenile:
    i. Estuarine
        a) Cultural
        b) Shallow subtidal
        c) Deep subtidal
        d) Intertidal
    ii. Riverine
        a) Coastal plain stream
        b) Deepwater river
    iii. Lacustrine
        a) Coastal plain
2) Breeding:
    i. Marine

Specific threats to this species include: barriers to migration, especially dams, which can cause upstream and downstream passage to migration to be inadequate or absent. Contamination from industrial pollution also threatens the American eel, and may contribute to the suppression of female development. Due to their wide range of life history cycle, American eel recruitment may also be affected by climate and weather.

American shad – S4 state ranking, and has protected state status

Critical habitats and sub-habitats for American shad include:

1) Nursery/juvenile:
    i. Estuarine
        a) Intertidal
    ii. Riverine
        a) Deepwater river
2) Breeding:
    i. Estuarine
        a) Shallow subtidal
    ii. Riverine
        a) Deepwater river

Specific threats to this species include: continued shoreline development and related dredging activities due to increased commercial boat traffic in the Hudson Shallow spawning habitat. Dams located in Pennsylvania along the Susquehanna River are still a threat to migratory spawning stocks, but fish passage improvements continue.

Atlantic sturgeon – S1 state ranking, and has threatened state status

Critical habitats and sub-habitats for Atlantic sturgeon include:

1) Breeding and nursery/juvenile:
    i. Estuarine
        a) Deep subtidal

Specific threats to this species include: dredge and development activities in spawning and nursery areas. The effect of contaminants on juveniles is unknown at this point.

Blueback herring – no state ranking, and has protected state status

Critical habitats and sub-habitats for blueback herring include:

1) Breeding and nursery/juvenile:
    i. Estuarine
        a) Shallow subtidal
2) Breeding only:
    i. Riverine
        a) Warmwater stream

No specific threats to this species have been identified.

Citation

New York State Department of Environmental Conservation. 2005. A Strategy for Conserving New York's Fish and Wildlife Resources.

New Jersey

Species

Currently, the SGCN identified within New Jersey include the following categories: endangered, threatened, special concern and regional priority species, species of unknown status, and species identified as extirpated. Additionally, species that have not been reviewed through the Delphi Status Review, but hold a global element rank of G1-G3, and/or a state element rank of S1-S3, have been included among the species of special concern and regional priority. At this time, only the following diadromous species have been listed as SGCN in New Jersey:

Atlantic sturgeon – S3 state ranking, and a state species of special concern

Hickory shad - S3 state ranking

Habitats

Threats are identified for the five different landscapes in the state. Landscape regions are ecoregions within the state that were delineated based on land forms, soils, vegetation, and hydrological regimes. Landscape regions are further divided into conservation zones, based on the variable habitats that exist within these regions. Specific habitat threats and conservation goals for each conservation zone are also identified. Listed below are the landscapes and conservation zones that contain Atlantic sturgeon or hickory shad, and associated threats within these zones. Please note that although American shad, alewife, blueback herring, American eel, and striped bass were not identified as SGCN, they occur within many rivers and streams throughout the state. Thus, it is likely that some of the threats identified may also apply to these species.

Atlantic Coastal Landscape Ecoregion

A) Atlantic Ocean Conservation Zone

1) *Species*: Atlantic sturgeon and hickory shad
2) *Threats*:
   i. Habitat loss and degradation: This results from commercial fishing practices, such as gillnetting for monkfish and dogfish sharks impacting sturgeon.
   ii. Oil spills: In particular, large events always loom as a threat due to the large amount of oil routinely transported to ports in the Delaware River near Philadelphia and New York Harbor are. Oil spills have potentially serious short and long-term impacts on all marine species.
   iii. Aquaculture: The impacts of this practice are largely unmeasured and poorly understood.
   iv. Hydraulic crab dredging: The impacts of this practice are largely unmeasured and poorly understood.

B) Atlantic Coastal Cape May Zone; Atlantic City Area Zone; Brigantine – Great Bay Area Zone; Barnegat Bay – Little Egg Harbor Zone; and Northern Atlantic Coastal Conservation Zone

1) *Species:* Atlantic sturgeon and hickory shad
2) *Threats*:
   i. Aquaculture: The impacts of this practice are largely unmeasured and poorly understood.
   ii. Hydraulic crab dredging: The impacts of this practice are largely unmeasured and poorly understood.

Delaware Bay Landscape Ecoregion

A) Tuckahoe River Watershed Conservation Zone

1) *Species:* Atlantic sturgeon
2) *Threats*:
   i. Invasive species: These species threaten the ecological integrity of habitats in the region.

B) Delaware Bay Shoreline Conservation Zone

1) *Species:* Atlantic sturgeon and hickory shad

2) *Threats*:

   i. Oil and hazardous materials spills: Delaware Bay is the second largest port for oil transport on the East coast, so oil spills are a real threat to habitats and animal populations.

C) Cape May Peninsula Conservation Zone

1) *Species:* Atlantic sturgeon and hickory shad

2) *Threats*:

   i. Development: This can lead to habitat fragmentation, water quality declines, and pressure on groundwater resources.

Piedmont Landscape Ecoregion

A) Central Piedmont Plains Conservation Zone

1) *Species:* Atlantic sturgeon and hickory shad

2) *Threats*:

   i. Development: This removes upland buffers and wetlands.

   ii. Chemical contamination: Pesticides and herbicides are potential threats.

B) Southern Piedmont Plains Conservation Zone

1) *Species*: Atlantic sturgeon and hickory shad

2) *Threats*:

   i. Chemical contamination: Run-off of pesticides and other contaminants (e.g., PCBs) from residential and agriculture areas into waterways is problematic.

   ii. Physical habitat alterations: Ditching, draining, and filling of marshes eliminates habitat and degrades the remaining surrounding areas. Clearing of vegetation along rivers and streams is a leading cause of habitat loss, fragmentation, and degradation of riparian and aquatic ecosystems. Loss of vegetated buffers along streams and rivers increases runoff of contaminants from roads and developed areas, impacting aquatic communities.

   iii. Oil spills: This zone is situated entirely within the ports of Wilmington, Delaware, and Philadelphia, Pennsylvania, which together support some of the largest petro-chemical facilities in the United States. This results in potentially catastrophic spill and contaminants-related threats.

   iv. Dredging: Shipping channel expansion or deepening in the Delaware River could have significant implications on salinity levels in tidal freshwater emergent marshes.

v. Invasive species: Aquatic nuisance species may render some freshwater systems unsuitable for many fish and aquatic invertebrate species.

vi. Natural barriers: In riparian areas, North American beavers can create wetland habitat suitable for many species by damming up streams, but may, in turn, alter riparian habitat downstream from the dam.

Skylands Landscape Ecoregion

A) Southern Highlands Conservation Zone

1) *Species*: Hickory shad

2) *Threats*:

i. Development: This practice causes disturbance, culvert construction, habitat loss, fragmentation, and degradation.

ii. Chemical contamination: The use of pesticides, mowing, and other agricultural practices may impact species in this area. The effects of contamination and alteration of waterways and wetlands, is exasperbated by increased human encroachment into riparian areas.

iii. Non-point source pollution

iv. Unrestricted livestock access to waterways

v. Reduction in stream flows

vi. Stream cleaning activities

vii. Dams

Citation

New Jersey Department of Environmental Protection, Division of Fish and Wildlife. 2008. New Jersey Wildlife Action Plan for Wildlife of Greatest Conservation Need.

Delaware

Species

Due to staff and funding limitations, the Natural Heritage Program does not track many of Delaware's species, especially estuarine and marine fish. Although SGCN were divided into two tiers, mapping of SGCN did not allow the original intent of the use of the tiers to be realized. Thus, for the first iteration of the SWAP, all SGCN are treated as being in equal need of conservation. The SGCN received the following state rankings, and are associated with these primary and secondary habitats:

Atlantic sturgeon –S2 state ranking on Tier 1, and is state endangered

Primary habitats for Atlantic sturgeon include: Freshwater Aquatic Habitat and Brackish and Marine Habitat. Secondary habitats for the species include: Coastal Plain Streams Habitat and Nearshore Habitat (note that this habitat is listed as a habitat of conservation concern).

Hickory shad –S2 state ranking on Tier 2

Primary habitats for hickory shad include: Freshwater Aquatic Habitat and Brackish and Marine Habitat. Secondary habitats for the species include: Coastal Plain Streams Habitat and Nearshore Habitat (note that this habitat is listed as a habitat of conservation concern).

Habitats

Delaware uses the term "conservation issues" synonymously with "threats" or "stresses," and defines it as, "human actions that adversely impact wildlife, native plants, and natural communities, and the ecological processes that sustain them." Listed below are the habitats that contain Atlantic sturgeon or hickory shad, and associated threats within these zones. Please note that although American shad, alewife, blueback herring, American eel, and striped bass were not identified as SGCN, they occur within many rivers and streams throughout the state. Thus, it is likely that some of the threats identified may also apply to these species.

Non-tidal Coastal Plain Streams Habitat

A) *Species*: Atlantic sturgeon, hickory shad, and American eel

B) *Threats*:

1) Development: Residential and commercial development practices, including altered hydrology, nutrients and sediments in the water, and the use of pesticides all influence this habitat.

2) Agricultural and forestry operations: Practices from these industries, including ditching and draining, altered hydrology, nutrients and sediments in the water, and use of pesticides, impact this habitat.

3) Shoreline protection: Practices, including artificial shoreline hardening, impact this habitat.

4) Industrial operations: These operations cause air pollution, accidental spills of toxins and sewage, chronic water pollution, impingement, entrapment, and entrainment at water intakes, and sedimentation from sand and gravel quarrying.

5) Transportation and utility operations and maintenance: These operations cause transportation infrastructure, altered hydrology, commercial ships and boats, road salt, and channel dredging.

6) Invasive species: These species (e.g., Snow Goose, resident Canada Goose, Asiatic clam, and invasive plants) cause problems in this habitat.

7) Water use: Problems associated with water use include: dams, dam operations, groundwater withdrawals, and surface water withdrawals.

8) Recreational activities: Issues with these activities include: recreational use on foot and with boats, personal watercraft, and off-road vehicles.
9) Wildlife harvest: This includes inappropriate hunting and fishing activities.
10) Resource management

Nearshore Habitat

A) *Species*: Atlantic sturgeon and hickory shad

B) *Threats*:

1) Development: Residential and commercial development practices, including altered hydrology, nutrients and sediments in the water, and the use of pesticides all influence this habitat.
2) Agricultural and forestry operations: Practices from these industries, including ditching and draining, altered hydrology, nutrients and sediments in the water, and use of pesticides, impact this habitat.Shoreline protection: Practices, including beach nourishment, impact this habitat.
3) Industrial operations: These operations cause air pollution, accidental spills of toxins and sewage, chronic water pollution, impingement, entrapment, and entrainment at water intakes, and sedimentation from sand and gravel quarrying.
4) Transportation and utility operations and maintenance: These operations cause commercial ships and boats and channel dredging.
5) Solid waste disposal: This is a problem because of trash ingestion.
6) Invasive species: The species most impacting this habitat are green crab and Japanese shore crab.
7) Energy production: Concerns with energy production involve wind farm facilities, tidal turbines, and thermal pollution from power plants.
8) Recreational activities: These activities are problematic with recreational use on foot and with boats, personal watercraft, and off-road vehicles.
9) Wildlife harvesting: Issues with harvest include: inappropriate hunting and fishing, fishing gear entanglement, fisheries bycatch, and commercial fisheries dredging.
10) Resource management

Citation

Delaware Division of Fish and Wildlife and Delaware Department of Natural Resources and Environmental Control. 2006. Delaware Wildlife Action Plan 2007-2017.

Maryland

Species

The Maryland SWAP lists the following diadromous fish species as SGCN:

Atlantic sturgeon – S1 state ranking

American shad – S3 state ranking

Hickory shad – S3 state ranking

Habitats

Maryland has identified SGCN found within specific habitats and threats to these habitats, which are as follows:

Coastal Plain Streams Habitat

A) *Species*: American eel, American shad, and hickory shad

B) *Threats*:

1) Development: Urban land use and impervious surfaces can result in chemical and hydrologic changes and fragmentation and isolation.
2) Sedimentation
3) Habitat loss and degradation: Issues associated with this threat include: Removal or degradation of riparian buffers; loss of headwater areas; deforestation that results in loss of forested watershed; and bank erosion.
4) Atmospheric deposition
5) Invasive species
6) Agricultural and forestry operations: Issues associated with this threat include: Pesticide/herbicide application results in pollution or degradation of water quality; liming practices; livestock and grazing practices; inappropriate timber harvest practices impact water quality or cause loss of coarse woody debris; and nutrient enrichment.
7) Stream blockages: This issue includes blockages caused by dams.
8) Dumping
9) Recreational activities
10) Point-source pollution
11) Reduction in stream flows: Activities associated with this issue include: Groundwater and stream water withdrawals; stream channelization
12) Sea-level rise

Coastal Plain Rivers Habitat

A) *Species*: American shad, hickory shad, alewife, and blueback herring

B) *Threats*:

Threats include #1-12 listed above in the ***Coastal Plain Streams Habitat***, as well as the following:

1) Oil and chemical spills

Piedmont Rivers Habitat

A) *Species*: American eel, American shad, hickory shad, alewife, and blueback herring

B) *Threats*:

Threats include #1-12 listed above in the ***Coastal Plain Streams Habitat***, as well as the following:

1) Hydroelectric power generation

Highland Rivers Habitat

A) *Species*: American eel

B) *Threats*:

Threats include #1-12 listed above in the ***Coastal Plain Streams Habitat***, as well as the following:

1) Acid mine drainage
2) Hydroelectric power generation

Oligohaline Estuarine Habitat

A) *Species*: Atlantic sturgeon, American eel, American shad, hickory shad, alewife, and striped bass

B) *Threats*:

1) Invasive species: This includes: ballast water release.
2) Dredge spoil dumping
3) Habitat loss and degradation: This includes: development, agriculture, human activities, recreation, and environmental contaminants result in habitat degradation.
4) Oil and chemical spills
5) Pollution: This issue includes: metalloids, changes in pH, thermal and toxic discharges, nutrients (especially nitrogen and phosphorus), and sedimentation that result in water quality degradation.
6) Loss of submerged aquatic vegetation

7) Hydrologic and ground water alterations: These alterations result in changes in salinity.

Mesohaline Estuarine Habitat and Polyhaline Estuarine Habitat

A) *Species*: Atlantic sturgeon, American eel, American shad, hickory shad, alewife, and striped bass

B) *Threats*:

Threats include #1-7 listed above in the ***Oligohaline Estuarine Habitat***, as well as the following:

1) Loss of dissolved oxygen: This can lead to fish kills.
2) Oyster reef extraction: This results in habitat loss for diadromous species.
3) Dredges and scrapes: This issue impacts: SAV and bottom sediments.

Watersheds

Maryland has also listed the following threats that may be present for every watershed within the state. For a more complete listing of the extent, trend, severity, persistence, reversibility, prevention, and restoration factors for each watershed, refer to the state wildlife action plan. Threats include:

1) Non-point source pollution: Problems are caused by chemical changes from acid deposition/low pH, acid mine drainage, excess nitrates, excess phosphorus, mercury deposition, and organic matter retention.
2) Point source pollution: Problems are caused by chemical changes from agricultural pesticides, dissolved oxygen, industrial sources, and pathogens.
3) Habitat alteration: This is caused by channelization, forest fragmentation, ground water withdrawal, migration barriers, runoff/baseflow/down cutting, sedimentation, surface water withdrawal, and wetland loss.
4) Invasive species: Changes are caused by invasive riparian plants and non-native aquatic plants.
5) Future changes: Concerns are from land conversion and sea level rise.

Citation

Maryland Department of Natural Resources. 2005. Maryland Wildlife Diversity Conservation Plan.

District of Columbia

Species

The following anadromous fish species have been identified as SGCN within the District of Columbia. In addition to including species that are globally ranked as G1-G3 species, selection criteria also included declining species, species that are SGCN in Maryland or Virginia, and species with small, localized "at-risk populations." Based on the criteria selected by the District, the following species have been identified:

Atlantic sturgeon – Ranked G1-G3, possibly extirpated from the District

Alewife – Stable population in the District

American eel – Declining population in the District

American shad – Increasing population in the District

Blueback herring – Stable population in the District

Hickory shad – Increasing population in the District

Habitats

Species-habitat associations have been identified, as well as threats within each habitat. Threats have also been ranked #1 through 3, with 1 being the lowest threat and 3 being the highest threat. The species-habitat associations and threats are as follows:

Rivers and Streams Habitat

A) *Species*: Atlantic sturgeon, alewife, American eel, American shad, blueback herring, and hickory shad

B) *Threats*:

1) Sedimentation: (2.3 rank) Sedimentation in the District is mainly a function of activities occurring in jurisdictions bordering the Potomac and Anacostia Rivers outside of the District. Due to land disturbance caused by housing and road construction, changes in the hydrologic regime caused by development, and the concurrent increase in impervious surfaces, stormwater runoff during rain events move large quantities of soil from land surfaces into the waterways. Once the rivers begin to widen and slow in the District, the sediment which had been transported downstream with the swift upstream current begins to settle out as sediment. Sedimentation is also caused by water moving oil from disturbed sites in the District.

2) Hydrologic regime changes: (3 rank) Changes to hydrologic regimes have a number of sources. Urban development with associated draining, paving, topography changes, and other changes in land use can either increase or

decrease the quantity of water flow. Converting forests to lawns, roadways, driveways, or rooftops changes the hydrologic regime by removing the effect of water uptake and transpiration by the trees. The water not normally taken up and transpired by the trees may flow overland and directly into a receiving waterbody. Changing hydrologic regimes in the District are generally leading to reduced recharging of the aquifers and more runoff directly into creeks, streams and rivers. The runoff also tends to lead to increased rates or erosion, increased pollutant loads, and sedimentation.

3) Stormwater erosion: (3 rank) Increases in stormwater erosion occur concurrently with increases in impervious surfaces and changes in land use that occur during development. Due to the highly developed character of the District, stormwater has a tendency to produce a lot of erosion even in naturally vegetated areas. When stormwater is unregulated, or improperly directed to a receiving pond, it leads to sedimentation, transport of pollutants, and dramatic changes in water temperature in the District's creeks, streams, and rivers into which the water flows.

4) Pollution: (2.5 rank) Pollution can enter a habitat in a variety of ways ranging from urban runoff to air pollution. Nutrient loading can create conditions in which native plants cannot compete with invasive and alien species. Airborne pollutants, such as nitrogen and carbon dioxide, can contribute to this excess nutrient loading. The District, as an urban center, is especially vulnerable to both point and non-point source water pollution. Point source pollution includes municipal wastewater and stormwater discharges. For example, millions of gallons of raw sewage are released into the Anacostia River every year. Non-point source pollution results from vast urban development and road construction. Urban development in the District and upstream in Maryland brings pollutants from building and streets into the Anacostia River.

5) Erosion of rivers and streams: (2.9 rank) Erosion is caused both by high flows, typically caused by heavy rains, in the spring falling on frozen ground incapable of absorbing the precipitation, and in the summer and fall associated with passing hurricanes or other large scale meteorological events. It can also occur in the winter, caused by the scouring of river and stream bottoms and banks by ice flows. This type of erosion is believed to be partially responsible for the loss of submerged aquatic vegetation in the District.

6) Invasive species: (2.3 rank)

7) Recreation: (1 rank)

8) Hardened shorelines: (1.9 rank)

9) Migration barriers: (1.4 rank)

10) Piped streams/channelization: (2.4 rank)

Emergent Tidal Wetlands Habitat

A) *Species:* American eel

B) *Threats*:

1) Sedimentation: (2.8 rank) See *Rivers and Streams Habitat* for more information.
2) Hydrologic regime changes: (1.5 rank) Low-lying habitats, such as emergent tidal wetlands are impacted by changes in hydrologic regimes when their associated upland habitats are developed. Riparian woodlands are impacted by changes in hydrologic regimes when the channelization of streams lowers the water table. This eliminates the connection between streams and riparian woodlands, except during floods. This, in turn, increases sedimentation in floodplain forests due to floods.
3) Stormwater erosion: (1.8 rank) See *Rivers and Streams Habitat* for more information.
4) Pollution: (2.7 rank) See *Rivers and Streams Habitat* for more information.
5) Erosion of rivers and streams: (1.3 rank) See *Rivers and Streams Habitat* for more information.
6) Invasive species: (2.5 rank)
7) Hardened shorelines: (1.3 rank)
8) Habitat loss: (1.8 rank) Habitat loss is a threat most closely linked to resident Canada geese. The overly abundant resident geese enter these wetlands to feed, but due to their numbers, end up destroying the habitat.

Tidal Mudflats Habitat

A) *Species*: American eel

B) *Threats*:

1) Sedimentation: (2.6 rank) See *Rivers and Streams Habitat* for more information.
2) Hydrologic regime changes: (2 rank) Low-lying habitats, such as tidal mudflats are impacted by changes in hydrologic regimes when their associated upland habitats are developed. Riparian woodlands are impacted by changes in hydrologic regimes when the channelization of streams lowers the water table. This eliminates the connection between streams and riparian woodlands, except during floods. This, in turn, increases sedimentation in floodplain forests due to floods.
3) Stormwater erosion: (2.2 rank) See *Rivers and Streams Habitat* for more information.
4) Pollution: (2.6 rank) See *Rivers and Streams Habitat* for more information.

5) Erosion of rivers and streams: (1.8 rank) See *Rivers and Streams Habitat* for more information.

6) Invasive species: (2.8 rank)

Submerged Aquatic Vegetation Habitat

A) *Species*: Alewife, American eel, American shad, blueback herring, and hickory shad

B) *Threats*:

1) Sedimentation: (2.1 rank) See *Rivers and Streams Habitat* for more information.

2) Hydrologic regime changes: (1.4 rank) See *Tidal Mudflats Habitat* for more information.

3) Stormwater erosion: (2.4 rank) See *Rivers and Streams Habitat* for more information.

4) Pollution: (2.1 rank) See *Rivers and Streams Habitat* for more information.

5) Invasive species: (2.2 rank)

6) Recreation: (1 rank)

7) Habitat loss: (2.6 rank) Habitat loss is caused by poor water quality and physical erosion and scouring. High turbidity, often caused by wind and wave induced erosion in aquatic systems, and overland stormwater erosion in terrestrial environments, prohibits light penetration needed for vegetative growth. Physical erosion and scouring of stream and river bottoms by either high flows or ice can cause the uprooting of established plants. All of these processes are negatively affecting SAV in the District.

Citation

Government of the District of Columbia, Department of Health, Environmental Health Administration, Fisheries and Wildlife Division. 2005. District of Columbia Comprehensive Wildlife Conservation Strategy.

Virginia

Species

Virginia categorized SGCN into four tiers, which are rankings separate from the Federal and Virginia endangered species lists. There are also six section-level ecoregions within Virginia. Within these ecoregions, ecoregional drainage units (EDU) have been delineated. The diadromous fish species have been identified as occurring within the following ecoregions (listed first) and EDUs (in parentheses). Because none of the diadromous fish species in Virginia are categorized as tier I species, individual threats are not identified for these species within their EDUs. The following diadromous fish species were listed as SGCN:

Atlantic sturgeon – Tier II

This species has a very high conservation need because it has a high risk of extinction or extirpation from the state. Ecoregional delineations include: Coastal Plain (James EDU; York EDU; Rappahannock EDU; Potomac EDU).

Alewife - Tier IV

This species has a moderate conservation need because the species may be in rare parts of its range, particularly on the periphery. Ecoregional delineations include: Coastal Plain (James EDU; York EDU; Rappahannock EDU; Potomac EDU; Delmarva EDU; Chesapeake Bay EDU; Albemarle Sound EDU) and Piedmont (James EDU; York EDU; Rappahannock EDU; Potomac EDU).

American shad – Tier IV

This species has a moderate conservation need because the species may be in rare parts of its range, particularly on the periphery. Ecoregional delineations include: Coastal Plain (James EDU; York EDU; Rappahannock EDU; Potomac EDU; Delmarva EDU; Chesapeake Bay EDU; Albemarle Sound EDU) and Piedmont (Chowan EDU; James EDU; York EDU; Rappahannock EDU; Potomac EDU).

American eel – Tier IV

This species has a moderate conservation need because the species may be in rare parts of its range, particularly on the periphery. Ecoregional delineations include: Coastal Plain (James EDU; York EDU; Rappahannock EDU; Potomac EDU; Delmarva EDU; Chesapeake Bay EDU; Albemarle Sound EDU), Piedmont (Chowan EDU; James EDU; York EDU; Rappahannock EDU; Potomac EDU; Pee Dee EDU), Blue Ridge (Roanoke EDU; Pee Dee EDU; James EDU; Rappahannock EDU; Potomac EDU), and Ridge and Valley (Roanoke EDU; James EDU; Potomac EDU).

Habitats

In addition to identifying SCGN contained within EDUs, habitat groups have been identified for SGCN, as well as the associated threats for those habitats. The following lists contain the source of threat, the threat itself, and the scope and severity of the threat in parenthesis (scale = 1 (least severe) to 4 (most severe); U is for unknown). Please note that although blueback herring and hickory shad were not identified as SGCN within the state, they occur within many rivers and streams throughout the state. Thus, it is likely that some of the threats identified may also apply to these species.

Chowan River Habitat

A) *Species*: Alewife, American shad, and American eel

B) *Sources of threat*:

   1) <u>Industrial – mineral extraction</u>: This causes turbidity alteration (2, 3).

2) Industrial – other: This causes hydrologic regime alteration from water supply dams (1, 3), nutrient input regime alteration from paper mills (1, 3), turbidity alteration from paper mills (1, 3), dissolved oxygen regime alteration from paper mills (1, 2), and organic pollutants from paper mills (1, 2).
3) Forestry: This causes sediment load alteration (4, 3).
4) Municipal development: This causes nutrient input regime alteration (from wastewater treatment plants, straight pipes, septic systems from Franklin and Emporia (1, 2), sediment load alteration from Franklin and Emporia (1, 2), toxins from Franklin and Emporia (1, 2), and hydrologic regime alteration from water supply extraction (1, 2).
5) Agriculture: This causes herbicides and fungicides (4, 2), insecticides (4, 2), toxins from pig farm lagoon spills (3, 4), sediment load alteration (3, 3), dissolved oxygen regime alteration from pig farms (3, 2), and nutrient input regime alteration from pig farms (3, 2).

Delmarva Peninsula Habitat

A) *Species*: Alewife, American shad, and American eel

B) *Sources of threat*:

1) Industrial – rights-of-way: This causes organic pollutants from roads and railways (2, 1), and herbicides and fungicides from roads and railways (2, 1).
2) Industrial – other: This causes toxins from spills on roads and rails (2, 1).
3) Municipal development: This causes nutrient input regime alteration from septic systems (2, 3), and channel and shoreline alteration from installation of bulkheads (2, 2).
4) Agriculture: This causes herbicides and fungicides from poultry and tomatoes (4, 3), insecticides from tomatoes and other crops (4, 3), dissolved oxygen regime alteration from poultry and tomatoes (4, 3), nutrient input regime alteration from poultry and tomatoes (4, 4), and organic matter input regime alteration from poultry and tomatoes (4, 4).

James River Habitat

A) *Species*: Alewife, American shad, American eel, and Atlantic sturgeon

B) *Sources of threat*:

1) Industrial – mineral extraction: This causes sediment load alteration from sand mining in Coastal Plain (1, 1), and turbidity alteration from sand mining in Coastal Plain (1, 1).
2) Industrial – power generation: This causes habitat fragmentation from dams (3, 3), and metals (2, 3).
3) Industrial – rights-of-way: This causes organic pollutants from roads and railways (3, 3), and herbicides and fungicides from roads and railways (3, 2).

4) Industrial – other: This causes toxins from industry particularly around Hopewell (2, 4), toxins from spills on roadways and rails, and accidents at industrial sites (1, 4), and habitat fragmentation from remnant mill dams) (3, 3).
5) Forestry: This causes organic matter input regime alteration (1, 1), sediment load alteration (3, 3), and turbidity alteration (2, 1).
6) Municipal development: This causes nutrient input regime alteration (4, 3), nutrient input regime alteration from wastewater treatment plants and straight pipes (2, 4), dissolved oxygen regime alteration (2, 3), channel or shoreline alteration (2, 4), other toxins from pharmaceuticals and drugs in wastewater (U, U), hydrologic regime alteration from water withdrawal (1, 3), hydrologic regime alteration from dam installation for water sources (1, 3), and turbidity alteration from road building and bridges (1, 2).
7) Other land management: This causes channel or shoreline alteration from landowners in the stream (1, 3).
8) Agriculture: This involves herbicides and fungicides (4, 3), insecticides (4, 3), sediment load alteration (4, 3), dissolved oxygen regime alteration (2, 3), channel or shoreline alteration (4, 2), turbidity alteration (4, 3), and organic matter input regime alteration (2, 1).
9) Atmospheric deposition: This causes pH regime alteration (2, 3).

Piankatank River Habitat

A) *Species*: Alewife

B) *Sources of threat*:

1) Atmospheric deposition: This causes toxins from aerial mercury from power plants) (4, 2).
2) Forestry: This causes sediment load alteration (3, 2).
3) Agriculture: This causes sediment load alteration (2, 2).

Potomac River Habitat

A) *Species*: Atlantic sturgeon, Alewife, American shad, and American eel

B) *Sources of threat*:

1) Industrial – mineral extraction: This causes sediment load alteration (1, 1), and turbidity alteration (1, 1).
2) Industrial – power generation: This causes habitat fragmentation from dams (3, 3), metals from atmospheric deposition (2, 3), pH regime alteration from acid precipitation (2, 3), and unintentional capture or killing of eels killed in turbines (2, 2).

3) Industrial – rights-of-way: This causes organic pollutants from roads and railways (3, 3), and herbicides and fungicides from roads and railways (3, 2).

4) Industrial – other: This causes toxins (2, 4), toxins from Shenandoah spills and others (3, 2), toxins from spills and accidents at industrial sites (1, 4), and habitat fragmentation from remnant mill dams (3, 3).

5) Forestry: This causes turbidity alteration (2, 1), organic matter input regime alteration (2, 1), and sediment load alteration (3, 3).

6) Municipal development: This causes nutrient input regime alteration (3, 2), nutrient input regime alteration from wastewater treatment plants and straight pipes (2, 4), channel or shoreline alteration (3, 4), dissolved oxygen regime alteration (3, 3), herbicides and fungicides (3, 2), insecticides (3, 2), turbidity alteration from road building/bridges (1, 2), toxins from pharmaceuticals and their by-products (U, U), hydrologic regime alteration from impervious surfaces (3, 4), hydrologic regime alteration from water withdrawal (2, 3), and hydrologic regime alteration from dam installation for water sources (2, 3).

7) Other land management: This causes channel or shoreline alteration from landowners bulldozing in streams (1, 3).

8) Agriculture: This involves herbicides and fungicides (4, 3), insecticides (4, 3), toxins from poultry farms and other livestock (3, 2), sediment load alteration (4, 3), dissolved oxygen regime alteration (3, 3), nutrient input regime alteration from poultry farms and other livestock (3, 4), channel or shoreline alteration (4, 2), turbidity alteration (4, 3), and organic matter input regime alteration (2, 1).

9) Exotic or introduced species: This causes competition from zebra mussels (1, 4), competition from snakehead (1, 2), and predation from snakehead (1, 2).

Rappahannock River Habitat

A) *Species*: Atlantic sturgeon, Alewife, American shad, and American eel

B) *Sources of threat*:

1) Industrial – mineral extraction: This causes sediment load alteration from sand mines in Coastal Plain (1, 1).

2) Industrial – power generation: This causes habitat fragmentation from dams (1, 1), metals from atmospheric deposition (2, 3), and pH regime alteration from acid precipitation (2, 3).

3) Industrial – rights-of-way: This causes organic pollutants from roads and railways (3, 2), and herbicides and fungicides from roads and railways (2, 2).

4) Industrial – other: This causes toxins from spills and accidents at industrial sites (1, 4), toxins from various industry in and below Fredericksburg (1, 2), and habitat fragmentation from remnant mill dams (3, 3).

5) Forestry: This causes organic matter input regime alteration (1, 1), and sediment load alteration (2, 2).

6) Municipal development: This causes nutrient input regime alteration from wastewater treatment plans and straight pipes (2, 4), channel or shoreline alteration (2, 4), dissolved oxygen regime alteration (2, 2), turbidity alteration from road and bridge building (1, 2), toxins from pharmaceuticals and their by-products (U, U), and hydrologic regime alteration from water withdrawal (1, 1).

7) Other land management: This causes channel or shoreline alteration from landowners bulldozing in stream (1, 3).

8) Agriculture: This involves herbicides and fungicides (4, 3), insecticides (4, 3), sediment load alteration (4, 3), dissolved oxygen regime alteration (2, 2), nutrient input regime alteration (4, 3), channel or shoreline alteration (4, 2), and turbidity regime alteration (4, 3).

9) Exotic or introduced species: This causes competition from blue catfish (2, 1), and predation from blue catfish (2, 1).

Roanoke River Habitat

A) *Species*: American eel

B) *Sources of threat*:

1) Industrial – mineral extraction: This causes sediment load alteration from sand mines in Coastal Plain (2, 2), and turbidity alteration from sand mines in Coastal Plain (2, 2).

2) Industrial – power generation: This causes habitat fragmentation from dams (4, 3), hydrologic regime from dams (4, 3), metals (2, 3), and water temperature regime alteration from Philpott Dam operations (1, 4).

3) Industrial – rights-of-way: This involves organic pollutants from roads and railways (2, 2), and herbicides and fungicides from roads and railways (3, 2).

4) Industrial – other: This causes toxins (2, 3), toxins from spills on roads and rails and accidents at industrial sites (1, 4), and habitat fragmentation from remnant mill dams (3, 3).

5) Forestry: This causes organic matter input regime alteration (1, 1), and sediment load alteration (3, 3).

6) Municipal development: This causes nutrient input regime alteration from wastewater treatment plans and straight pipes (2, 4), channel or shoreline alteration (2, 4), channel or shoreline alteration from alteration of Roanoke River at Roanoke (1, 2), dissolved oxygen regime alteration (2, 2), turbidity alteration from road and bridge building (2, 2), other toxins from pharmaceuticals/drugs and their by-products (U, U), and hydrologic regime alteration from water withdrawal (1, 2).

7) Other land management: This causes channel or shoreline alteration from landowners bulldozing in streams (1, 3).

8) Agriculture: This involves herbicides and fungicides (4, 3), insecticides (4, 3), sediment load alteration (4, 3), dissolved oxygen regime alteration (2, 2), nutrient input regime alteration (4, 3), nutrient input regime alteration from aquaculture (1, 1), channel or shoreline alteration (4, 2), turbidity alteration (4, 3), organic matter input regime alteration (2, 1), and parasitism (1, 1).

9) Introduced/exotic species: This causes competition from blue and flathead catfish (2, 1; scope of effects on mainstem species is higher, 3), and predation from blue and flathead catfish (2, 1; scope of effects on mainstem species is higher, 3).

York River Habitat

A) *Species*: Alewife, American shad, American eel, and Atlantic sturgeon

B) *Sources of threat*:

1) Industrial – mineral extraction: This causes sediment load alteration from sand mines in Coastal Plain (1, 1).

2) Industrial – power generation: This causes habitat fragmentation from Lake Anna (1, 2), and metals from atmospheric mercury (2, 3).

3) Industrial – rights-of-way: This involves organic pollutants from roads and railways (3, 2), and herbicides and fungicides from roads and railways (2, 2).

4) Industrial – other: This causes toxins from paper mill and oil refinery at mouth (2, 3), toxins from spills on roadways and rails and accidents at industrial sites (1, 4), and habitat fragmentation from remnant mill dams (3, 3).

5) Forestry: This causes turbidity alteration (3, 2), organic matter input regime alteration (3, 2), and sediment load alteration (2, 2).

6) Municipal development: This causes nutrient input regime alteration from wastewater treatment plans, straight pipes (1, 2), channel or shoreline alteration (2, 4), turbidity alteration from road and bridge building (1, 2), dissolved oxygen regime alteration (1, 1), and hydrologic regime alteration from water withdrawal and the proposed King William reservoir (1, 2).

7) Municipal: This involves other toxins from pharmaceutical/drugs and their by-products (U, U).

8) Agriculture: This involves herbicides and fungicides (4, 3), insecticides (4, 3), sediment load alteration (4, 3), dissolved oxygen regime alteration (2, 2), nutrient input regime alteration (4, 3), channel or shoreline alteration (4, 2), turbidity alteration (3, 2), and organic matter input regime alteration (3, 2).

9) Invasive species: This causes competition from blue catfish (2, 1), and predation from blue catfish (2, 1).

Citation

Virginia Department of Game and Inland Fisheries (VA DGIF). 2005. Virginia's Comprehensive Wildlife Conservation Strategy.

North Carolina

Habitats

Threats have been identified for freshwater and marine habitats, but only priority conservation status species-habitat associations are listed. At this time, ***Atlantic sturgeon*** is the only diadromous fish species identified as having priority conservation status within the state. Since habitats were grouped by river basins, additional sources (including tables on the DVD supplement to this document) were used to list known presence of other diadromous fish species within these habitats. These species include: American shad, hickory shad, alewife, blueback herring, and Atlantic sturgeon. Therefore, it is likely that some of the threats identified for Atlantic sturgeon under the various habitats may also apply to these species. The following species-habitat associations have been identified, and relevant threats are presented below:

Roanoke River Basin Habitat

A) *Species*: Atlantic sturgeon is a priority aquatic species that is present in this habitat; also present are American shad, hickory shad, alewife, blueback herring, and striped bass

B) *Threats*:

1) Sedimentation: Agriculture, forestry, and construction have degraded water and habitat quality.
2) Contamination: Dioxin, selenium (from historic discharge from ash pond basins), and mercury levels are degrading aquatic habitats.
3) Water withdrawls: Current and future water withdrawals have the potential to reduce flows to the lower Roanoke River and increase salinity levels downstream.
4) Non-point source pollution
5) Point source pollution: Sources include: municipal wastewater treatment plants, selenium ash pond discharge, industrial facilities, small package treatment plants, and urban and industrial stormwater systems. Wastewater treatment plants can cause elevated nitrogen, phosphorus, copper, and fecal coliform levels. They have also led to elevated ammonia nitrogen (NH_3) concentrations at San Souci.
6) Growth: Especially in Stokes and Granville counties, growth will affect land use, cover, and water quality.
7) Dams: Amount and timing of water releases from dams, particularly along the Roanoke River, can alter downstream aquatic and riparian flora and fauna. Changes in flow regime in the lower mainstem Roanoke River, and associated

draining of the backswamps, is likely to be partially responsible for increased frequency of low dissolved oxygen (less than 5 mg/l), primarily in June.

Cape Fear River Basin Habitat

A) *Species*: Atlantic sturgeon is a priority aquatic species that is present in this habitat; also present are American shad, hickory shad, alewife, and blueback herring

B) *Threats*:

1) Water quality degradation: This impairment has been caused by: sediment, fecal coliform, ammonia, chlorides, low dissolved oxygen, turbidity, nutrients, mercury, and other point and non-point source pollutants.

2) Sedimentation: This issue comes from agriculture, forestry, construction, and stormwater discharge in urbanized areas.

3) Locks and dams: These obstructions block migration routes for diadromous and resident species, reduce recolonization and dispersal potential, and create unnatural flow regimes.

Neuse River Basin Habitat

A) *Species*: Atlantic sturgeon is a priority aquatic species that is present in this habitat; also present are American shad, hickory shad, alewife, and blueback herring

B) *Threats*:

1) Animal waste: The byproducts from animals and fertilizers increase levels of nitrates and phosphates; this, in turn, can lead to excess growth of aquatic plants (such as algae), and decreased dissolved oxygen levels (especially during summer months), resulting in fish kills.

2) Channelization: Channelization of streams for agriculture can cause bank erosion.

3) Forestry: This activity contributes 13% and 6% of nitrogen and phosphorus, respectively.

4) Dams and other impoundments: These structures affect aquatic species by altering water hydrology and habitat, reducing flows and dissolved oxygen, and causing erosion. Modification of flow regimes by upstream impoundments impact various life history characteristics of downstream migratory fishes and other aquatic fauna, such as limiting dispersal and recolonization.

5) Water withdrawals: Withdrawals for irrigation reduce the quantity of available habitat and alter water hydrology.

6) Water demands and wastewater discharges: These issues have increased from the growing population. There are over 400 point source waste discharge permits for the basin from municipal wastewater treatment plants, industrial

facilities, small package treatment plants, and large urban and industrial stormwater.

7) Sedimentation: Losses of natural areas and increases in impervious surfaces from construction lead to high sediment runoff. there is also increased lawn fertilizer runoff from more homes, and heavy metal runoff, which contributes to elevated mercury levels in fish tissue.

8) Atmospheric deposition: This comes from nitrogen in cars and factories, which can lead to decreased water quality.

9) Non-point source pollution: Large quantities of nutrients, especially nitrogen, from non-point sources are considered the greatest threat to water quality of the Neuse River estuary.

Tar-Pamlico River Basin Habitat

A) *Species*: Atlantic sturgeon is a priority aquatic species that is present in this habitat; also present are American shad, hickory shad, alewife, and blueback herring

B) *Threats*:

1) Sedimentation: This results from land clearing activities, streambank erosion, and channelization associated with construction and agriculture.

2) Agriculture: Activities including swine, dairy, and poultry, contribute to nutrient inputs, erosion, and sedimentation. Influxes of sediment reduce the quality and quantity of necessary habitat for aquatic organisms.

3) Water withdrawals: These activities, plus inter-basin transfers, reduce the quantity of available habitat for aquatic species.

4) Growth: Increased drinking water, wastewater discharge, and stormwater control from a growing population cause problems for aquatic species.

5) Urban expansion: Cumulative and secondary impacts due to urban expansion (e.g., greater Raleigh and Rocky Mount) will cause increased impervious surfaces, which in turn may lead to increased stream sedimentation.

6) Point source pollution: Discharges from municipal wastewater treatment plants, industrial facilities, small package treatment plants, large urban and industrial stormwater systems, degrade water quality. Wastewater treatment plant effluent increases conductivity, elevates nitrogen levels, and lowers dissolved oxygen.

Chowan River Basin Habitat

A) *Species*: Atlantic sturgeon is a priority aquatic species that is present in this habitat; also present are American shad, hickory shad, alewife, and blueback herring

B) *Threats*:

1) The Chowan River was classified as “nutrient sensitive waters” in 1979 (NCDWQ 2002) as a result of excessive levels of nitrogen and phosphorus in

wastewater and runoff. Chronic episodes of hypoxia exist in the river and its tributaries from late June through September during most years. Dissolved oxygen levels frequently fall below 3.0 mg/l, which negatively affects aquatic biota. Cyclonic events and their accompanying rainfall, storm surge, inundation and flushing of bottomland swamp habitats have occurred repeatedly within the basin since 1995.

2) Non-point source pollution: Degradation of water quality results from: agriculture, animal operation, urban development, forestry, stormwater discharge, rural residential development, hydrologic modifications, and septic systems.

3) Point source pollution: Point sources may include: municipality waste water treatment plants, industrial facilities, and urban and industrial stormwater systems. As of 2001, there were 11 permitted wastewater discharges and 34 registered animal operations in the basin.

4) Water withdrawals: These withdrawals are made for agriculture purposes.

Pasquotank River Basin Habitat

A) *Species*: Atlantic sturgeon is a priority aquatic species that is present in this habitat; also present are alewife and blueback herring

B) *Threats*:

1) Physical habitat destruction: This is the primary threat within this basin, and results from loss of riparian vegetation, straightening of streams, erosion of banks, and reductions of aquatic vegetation.

2) Water withdrawals: These withdrawals are made for agriculture purposes.

3) Non-point source pollution: The point sources that degrade water quality include: agriculture, animal operation, urban development, forestry, stormwater discharge, rural residential development, hydrologic modifications, and septic systems.

4) Point-source pollution: The non-point sources that degrade water quality may include: municipal wastewater treatment plants, industrial facilities, reverse-osmosis water treatment facilities, and urban and industrial stormwater systems. As of 2001, there were 34 permitted wastewater discharges, 51 general stormwater permits, and 29 registered animal operations in the basin .

5) Growth: Increasing population growth in the basin will continue to put more pressure and demand on wastewater treatment systems.

White Oak River Basin Habitat

A) *Species*: Atlantic sturgeon is a priority aquatic species that is present in this habitat; also present are American shad, alewife, and blueback herring

B) *Threats*:

1) Eutrophication: Excessive nutrient input from such things as wastewater treatment plants, industry, agriculture, and hog/chicken farms degrade water quality.
2) Wastewater discharge: In the White Oak River basin there are 50 permitted discharges, four of which are major discharges with greater than, or equal to, 1 million gallons per day.

Marine Habitat

A) *Species*: Atlantic sturgeon is a priority aquatic species that is present in this habitat; also present are American shad, blueback herring, and striped bass

B) *Threats*:

1) Vessel interaction: This includes collisions; higher frequencies occur in areas that have heavy boating and vessel traffic.
2) Oil and gas exploration: Oil deposits on the ocean floor can reduce food sources for all marine species and result in ingestion of tar balls.
3) Dredging: Dredging in navigation channels and boat basins, especially areas with fine sediment and low flushing, can cause direct destruction or degradation of habitat and/or incidental take of marine species. Additionally, channelization of inshore and nearshore habitats can result in the disposal of dredge material in shallow habitats, impacting foraging grounds. Channelization of streams and ditching can also lead to hydrologic modifications.
4) By-catch: By-catch of marine organisms occurs in a number of different fisheries, some of which may cause injury or kill fish.
5) Entrainment: Saltwater cooling intake systems at coastal power plants have been reported to entrap marine species.
6) Explosives: Use of underwater explosives to remove abandoned oil platforms, for military activities, or for oil exploration can result in injury or death to marine species in the vicinity of the explosion.
7) Dams and other impoundments: These structures obstruct and modify water flow to the coast; there are over 2,000 dams in North Carolina.
8) Water withdrawals: These withdrawals result in hydrologic changes.
9) Road fill and culverts: These activities cause obstructions and flow alterations.
10) Forestry: Log salvage operations may impact anadromous fish nursery areas.
11) Growth: Development and excessive impervious cover degrades water quality.

12) Eutrophication: Loading of nutrients from sources such as sewage treatment facilities, land disposal sites, onsite wastewater treatment facilities, agricultural sources, homeowners, and golf courses, has the potential to degrade water quality.

13) Sedimentation: This occurs from erosion along the coast.

14) Contamination: Fecal coliform bacteria from sewage treatment facilities, stormwater outfalls, and possibly oceanfront septic systems, contaminate the water supply. Additionally, toxic chemicals from sources such as roads, parking lots, associated transportation, marine wood preservatives, dredging, and marina development, all impact habitat.

15) Invasive species

Citation

North Carolina Wildlife Resources Commission (NC WRC). 2005. North Carolina Wildlife Action Plan.

South Carolina

Species

American eel – SNR ranking; highest priority ranking for greatest conservation concern

American shad – S5 state ranking; highest priority ranking for greatest conservation concern

Atlantic sturgeon – S3 state ranking; highest priority ranking for greatest conservation concern

Blueback herring – S3 state ranking; highest priority ranking for greatest conservation concern

Hickory shad – S4 state ranking; highest priority ranking for greatest conservation concern

Striped bass – SNR ranking; moderate priority ranking for greatest conservation concern

Threats

In addition to discussing the general effects of different threats that challenge species present in the state, the SWAP identifies specific threats to the following species and species groupings:

Alosines (includes American Shad, Hickory Shad, and Blueback Herring)

A) *Watersheds:* Waccamaw-Pee Dee, Santee-Cooper and Savannah River Basins

B) *Threats*:

1) Dams: Dams restrict migrations, and have eliminated populations of alosines from historical habitats. The result has been a general reduction in alosine populations, even in currently accessible river reaches. The Santee Basin has nearly 45 dams in the South Carolina portions of the basin alone.
2) Water withdrawal: Tidal freshwater marshes along the Cooper River (many of which are relic rice impoundments with breached or eroded dikes), which were used extensively as spawning habitat by blueback herring prior to rediversion of flows into the Santee River, are less extensive under reduced flows, and many are now partly dewatered or influenced by brackish water. The flow regimens in both the Cooper and Santee Rivers is typically in highs and lows (with more abrupt changes from peaked power generation and flood releases) than are characteristic of more gradual river flow changes that occur in open rivers where waters expand into, and withdraw from, floodplains.
3) Fish passage: Fish passage efficiency for blueback herring at the St. Stephen Dam is low. Fish passage designs and flow protocols currently used at dams on the lower Santee-Cooper Basin were initially designed for passing blueback herring into the lakes for forage and do not maximize passage efficiency for alosines in either direction. Dams on the Santee-Cooper Basin that currently incorporate passage for alosines, do not employ methodologies that accommodate timely outmigration and maximized survival of post-spawning adults or emigrating juveniles.
4) Predation: Large concentrations of double-crested cormorants (*Phalacrocorax auritus*) occur immediately below dams. The cormorant population has increased dramatically over the past decade, and these birds have been shown to feed heavily on alosines (up to 64.5% of diet). Although the impact of cormorant predation on alosine populations has not been quantified, it appears that cormorants have to potential to negatively impact both upstream passage success for blueback herring and out-of-lake passage for all juvenile alosines.
5) Invasive species: Competition and predation from non-native species, in particular flathead catfish (*Pylodictis olivaris*) and blue catfish (*Ictalurus furcatus*), may be additive to 'more natural' sources of mortality, and may be particularly problematic below dams where catfish density is often high.

American Eel

Note: Due to its complicated life cycle, the American eel population faces a broad range of challenges, some of which are specific to a particular growth stage. Since males and females largely utilize separate habitats, impacts in a given region may affect the sex ratio of the eel population.

A) *Watersheds:* Pee Dee, Edisto, and Santee River Basins

B) *Threats*:

1) Dams: Dams and causeways obstruct access to a diversity of habitats, which may limit basin-specific and statewide populations. The Pee Dee, Edisto, and Santee coastal drainages have suffered an 83% reduction in unobstructed stream habitat.

2) Invasive species: Issues exist, particularly with flathead catfish (*Pylodictis olivaris*) and blue catfish (*Ictalurus furcatus*). Both of these catfish are piscivorous and opportunistic; they will feed on any fish that can fit in their mouths. Additionally, non-indigenous pathogens or parasites such as the Asian swimbladder nematode (*Anguillicola crassus*), has been shown to have significant negative impacts on the European eel (*Anguilla anguilla*) and on captive American eels in South Carolina and Texas.

Atlantic Sturgeon

A) *Watersheds*: Waccamaw-Pee Dee, Santee-Cooper, and Savannah River Basins

B) *Threats:*

1) Dams: Obstructed access to a diversity of habitats may limit basin-specific populations of both Atlantic and shortnose sturgeon. Dams can block spawning migrations and severely restrict the availability of spawning and nursery habitat, particularly in large river systems when dams are near the coast, as in the Santee River. Dams and other impediments to migration have eliminated sturgeons from many historical habitats in South Carolina; the result being a general reduction in sturgeon populations in even currently accessible river reaches. Reduced flows caused by dams can also reduce dissolved oxygen to levels unsuitable for sturgeon.

2) Fish passage: Both the Pinopolis navigational lock and St. Stephen fish passage facility provide passage for blueback herring and American shad. However, these facilities do not effectively pass sturgeons, nor do they incorporate efficient outmigration technologies, even for alosines. Effective passage designs for sturgeons have not yet been determined. In fact, poorly designed fish passage facilities may negatively impact sturgeon populations by increasing mortality.

3) Contamination: Bioaccumulation of contaminants, such as dioxin, in parts of Winyah Bay, may reduce productivity or increase susceptibility to diseases or stress.

Striped Bass

A) *Watersheds*: Savannah and Pee Dee Rivers

B) *Threats*:

1) Sedimentation: Clearing forests and riparian areas of coastal rivers and their tributaries have caused this problem.

2) Water temperature: Increased temperatures have resulted from clearing forests and riparian areas of coastal rivers and their tributaries. Warmer water temperatures may decrease the amount of summertime refuge habitat for striped bass and negatively impact reproduction.
3) Hydrologic modification
4) Overfishing
5) Dams: Dams disrupt migrations and altering thermal and hydrologic regimes. The presence of impoundments along the Savannah and Pee Dee Rivers may partially account for limited reproduction in those systems.

Citation

South Carolina Department of Natural Resources. 2005. South Carolina Comprehensive Wildlife Conservation Strategy.

Georgia

Species

At this time, none of the diadromous fish species are listed as SGCN by the state of Georgia and no habitat associations have been identified in their wildlife action plan. However, the designation of high priority waters in the Southern Coastal Plain Ecoregion was based, in part, on suitable habitat for diadromous fish species, as well as others.

Habitat

Given that diadromous species can be found in the Southern Coastal Plain Ecoregion, threats identified for that region are highlighted below. However, no individual species are identified with any particular threat.

Threats:

1) Development: This has resulted in habitat loss and fragmentation.
2) Water withdrawals
3) Dams: These obstructions result in altered hydrological regimes and sediment transport processes.
4) Eutrophication: These impacts on systems from human activities include: increased flow variability, reduced dissolved oxygen, and increased silt loads.
5) Invasive species
6) Global warming

Citation

Georgia Department of Natural Resources, Wildlife Resources Division. 2005. A Comprehensive Wildlife Conservation Strategy for Georgia.

Florida

Species

Many of the diadromous fish species are listed as SGCN under Florida's Comprehensive Wildlife Conservation Strategy. Although state ranking information is not provided, a number of criteria were used to determine eligibility. The following species have been listed, with their status and trend indicated:

American eel – low status; unknown trend

American shad – low status; declining trend

Atlantic sturgeon – low status; declining trend

Blueback herring – low status; unknown trend

Hickory shad – low status; declining trend

Striped bass – low status; stable trend

Habitats

Species-habitat associations have been identified, as well as threats and sources of threat. The sources of threat are ranked and their corresponding threats are also ranked. The threat levels are as follows: VH=very high; H=high; M=medium; and L=low.

Calcareous Stream Habitat

Statewide Threat Rank of Habitat: High

A) *Species*: Striped bass

B) *Sources of Threat*:

1) <u>Nutrient loads</u> (H in urban and agriculture areas): This has caused altered species composition/dominance (H), and altered water quality of surface water or aquifers by nutrients (H).

2) <u>Invasive plants</u> (H): This has caused altered species composition/dominance (H).

3) <u>Invasive animals</u> (M): This has caused altered species composition/dominance (H), and erosion/sedimentation (H).

4) Development (M): Conversion to housing and urban development has caused altered water quality of surface water or aquifers by nutrients (H), erosion/sedimentation (H), and altered landscape mosaic or content (M).
5) Chemicals and toxins (M): This has caused altered water quality of surface water or aquifer by contaminants (M).
6) Roads (M): This has caused erosion/sedimentation (H).
7) Forestry (L): This has caused altered species composition/dominance (H), and erosion/sedimentation (H).
8) Agriculture (L): This has caused altered water quality of surface water or aquifers by nutrients (H), and erosion/sedimentation (H).
9) Mining/drilling (L): This has caused erosion/sedimentation (H).

Coastal Tidal River or Stream Habitat

Statewide Threat Rank of Habitat: Very High

A) *Species*: Atlantic sturgeon, American eel, blueback herring, hickory shad, American shad, and striped bass

B) *Sources of Threat*:

1) Water withdrawal (H): This has caused altered species composition/ dominance (H), altered hydrologic regime (H), altered landscape mosaic or content (H), altered water salinity, pH, conductivity, or other physical water quality characteristics of surface water or aquifers (M), and altered community structure (M).
2) Channel modifications/shipping lanes (H): This has caused altered species composition/dominance (H), altered hydrologic regime (H), habitat destruction or conversion (M), altered water salinity, pH, conductivity, or other physical water quality characteristics of surface water or aquifers (M), and altered community structure (M).
3) Dam operations (H): This has caused altered species composition/dominance (H), altered hydrologic regime (H), altered water salinity, pH, conductivity, or other physical water quality characteristics of surface water or aquifers (M), altered community structure (M), and fragmentation of habitats, communities, and ecosystems (M).
4) Conversion to housing and urban development (H): This has caused altered hydrologic regime (H), altered landscape mosaic or content (H), and habitat destruction or conversion (M).
5) Shoreline hardening (H): This has caused altered species composition/ dominance (H), habitat destruction or conversion (M), fragmentation of habitats, communities, and ecosystems (M), and altered community structure (M).

6) Management of nature – vegetable clearing/snagging for water conveyance (M): This has caused altered species composition/dominance (H), altered hydrologic regime (H), fragmentation of habitats, communities, and ecosystems (M), and altered community structure (M).
7) Roads (M): This has caused habitat destruction or conversion (M).
8) Chemicals and toxins (M): This has caused altered species composition/ dominance (H), and altered water quality of surface water or aquifer by contaminants (M).
9) Conversion to commercial and industrial development (M): This has caused habitat destruction or conversion (M).
10) Nutrient loads (M): This has caused altered species composition/dominance (H), and altered water quality of surface water or aquifer by nutrients (M).
11) Invasive plants (M): This has caused altered species composition/dominance (H), and altered community structure (M).
12) Invasive animals (L): This has caused altered species composition/dominance (H).
13) Sea level rise (L): This has caused altered hydrologic regime (H).

Marine and Estuarine Habitats

Statewide Threat Rank of Habitat: Very High

A) *Sources of Threat*:

1) Coastal development (VH): This has caused altered hydrologic regime (VH), altered species composition (VH), habitat destruction (VH), missing key communities or functional guilds/trophic shift (H), and sedimentation contamination (M).
2) Dam operations/incompatible release of water (VH): This has caused altered hydrologic regime (VH), altered species composition (VH), altered water quality by contaminants (VH), altered water quality/physical chemistry (VH), habitat disturbance (VH), and altered water quality by nutrients (H).
3) Channel modifications/shipping lanes (VH): This has caused altered hydrologic regime (VH), altered water quality/physical chemistry (VH), habitat destruction (VH), habitat disturbance (VH), and sedimentation contamination (M).
4) Inadequate stormwater management (VH): This has caused altered hydrologic regime (VH), altered species composition (VH), altered water quality by contaminants (VH), altered water quality/physical chemistry (VH), habitat disturbance (VH), altered water quality by nutrients (H), and sedimentation contamination (M).
5) Shoreline hardening (VH): This has caused altered hydrologic regime (VH), and habitat destruction (VH).

6) Management of nature (beach nourishment, impoundment) (H): This has caused altered hydrologic regime (VH), altered species composition (VH), altered water quality by contaminants (VH), altered water quality/physical chemistry (VH), habitat disturbance (VH), and missing key communities or functional guilds/trophic shift (H).

7) Chemicals and toxins (H): This has caused altered water quality by contaminants (VH), and sedimentation (M).

8) Industrial spills (H): This has caused altered water quality by contaminants (VH), habitat disturbance (VH), and sedimentation (M).

9) Incompatible industrial operations: This has caused altered hydrologic regime (VH), altered species composition (VH), altered water quality by contaminants (VH), and missing key communities or functional guilds/trophic shift (H).

10) Surface water withdrawal: This has caused altered hydrologic regime (VH), altered species composition (VH), and altered water quality/physical chemistry (VH).

11) Invasive animals (H): This has caused altered species composition (VH), and habitat disturbance (VH).

12) Invasive plants (H): This has caused altered species composition (VH), and sedimentation contamination (M).

13) Incompatible resource extraction: mining/drilling (H): This has caused altered water quality/physical chemistry (VH).

14) Climate variability (H): This has caused altered weather regime/sea level rise (H).

15) Nutrient loads (H): This has caused altered water quality by nutrients (H).

16) Utility corridors (M): This has caused altered hydrologic regime (VH), and habitat destruction (VH).

17) Vessels impacts (M): This has caused habitat destruction (VH), and habitat disturbance (VH).

18) Boating impacts (M): This has caused habitat destruction (VH), and habitat disturbance (VH).

19) Incompatible recreational activities (M): This has caused altered species composition (VH), and habitat disturbance (VH).

20) Groundwater withdrawal (M): This has caused altered hydrologic regime (VH), altered species composition (VH), and altered water quality/physical chemistry (VH).

21) Incompatible fishing pressure (M): This has caused altered species composition (VH), and missing key communities or functional guilds/trophic shift (H).

22) Solid waste (M): This has caused habitat disturbance (VH).

23) Roads, bridges, and causeways (M): This has caused altered hydrologic regime (VH), habitat destruction (VH), and sedimentation contamination (M).

24) Thermal pollution (M): This has caused altered water quality/physical chemistry (VH).

25) Fishing gear impacts (M): This has caused habitat disturbance (VH).

Inlet Habitat

Statewide Threat Rank of Habitat: Very High

A) *Species*: American eel, Atlantic sturgeon, American shad, and blueback herring

B) *Sources of Threat*:

1) Channel modification/shipping lanes (H): This has caused habitat disturbance (H), altered water quality/physical chemistry (M), erosion (M), habitat destruction (M), altered hydrologic regime (M), and sedimentation (M).

2) Shoreline hardening (H): This has caused altered structure (M), erosion (M), habitat destruction (M), and sedimentation (M).

3) Dam operation/incompatible release of water (H): This has caused habitat disturbance (H), altered water quality/physical chemistry (M), altered hydrologic regime (M), and sedimentation (M).

4) Disruption of longshore transport of sediments (H): This has caused erosion (M), and sedimentation (M).

5) Coastal development (H): This has caused altered species composition (M), altered structure (M), altered water quality/physical chemistry (M), habitat destruction (M), and altered hydrologic regime (M).

6) Management of nature (beach nourishment, impoundments) (H): This has caused habitat disturbance (H), altered species composition (M), and sedimentation (M).

7) Boating impacts (H): This has caused habitat disturbance (H).

8) Incompatible boating activities (H): This has caused habitat disturbance (H)

9) Light pollution (H): This has caused altered species composition (M).

10) Industrial spills (M): This has caused habitat disturbance (H).

11) Harmful algal blooms (M): This has caused altered species composition (M).

12) Roads, bridges, and causeways (M): This has caused altered structure (M), habitat destruction (M), and altered hydrologic regime (M).

13) Inadequate stormwater management (M): This has caused altered species composition (M), altered water quality/physical chemistry (M), and altered hydrologic regime (M).

14) Incompatible industrial operations (M): This has caused altered species composition (M), and habitat destruction (M).

15) Invasive plants (M): This has caused altered species composition (M).
16) Acoustic pollution (M): This has caused habitat disturbance (H).
17) Vessel impacts (M): This has caused habitat disturbance (H), and habitat destruction (M).
18) Utility corridors (M): This has caused habitat disturbance (H).
19) Fishing gear impacts (M): This has caused habitat disturbance (H).
20) Military activities (M): This has caused habitat disturbance (H).
21) Invasive animals (M): This has caused habitat disturbance (H), and altered species composition (M).
22) Surface water withdrawal (M): This has caused altered water quality/physical chemistry (M).

Large Alluvial Stream Habitat

Statewide Threat Rank of Habitat: High

A) *Species*: American eel and striped bass

B) *Sources of Threat*:

1) Dam operations (H): This has caused altered species composition/dominance (M), altered community structure (M), habitat destruction or conversion (M), fragmentation of habitats, communities, and ecosystems (M), altered hydrologic regime (M), and erosion/sedimentation (M).
2) Management of nature-water control structures (H): This has caused altered species composition/dominance (M), altered community structure (M), habitat destruction or conversion (M), fragmentation of habitats, communities, and ecosystems (M), altered hydrologic regime (M), and erosion/sedimentation (M).
3) Channel modification/shipping lanes (H): This has caused altered species composition/dominance (M), altered community structure (M), habitat destruction or conversion (M), fragmentation of habitats, communities, and ecosystems (M), altered hydrologic regime (M), and erosion/sedimentation (M).
4) Invasive animals (M): This has caused altered species composition/dominance (M), altered community structure (M), habitat destruction or conversion (M), and erosion/sedimentation (M).
5) Surface water withdrawal (M): This has caused fragmentation of habitats, communities, and ecosystems (M), and altered hydrologic regime (M).
6) Groundwater withdrawal (L): This has caused altered hydrologic regime (M).
7) Incompatible forestry practices (L): This has caused altered species composition/dominance (M), altered community structure (M), habitat destruction or conversion (M), fragmentation of habitats, communities, and

ecosystems (M), altered hydrologic regime (M), and erosion/sedimentation (M).

8) Chemicals and toxins (L): This has caused altered species composition/dominance (M).

9) Incompatible recreational activities (L): This has caused altered species composition/dominance (M), altered community structure (M), habitat destruction or conversion (M), and erosion/sedimentation (M).

Softwater Stream Habitat

Statewide Threat Rank of Habitat: Very High

A) *Species*: Atlantic sturgeon and striped bass

B) *Sources of Threat*:

1) Surface water withdrawal (H): This causes fragmentation of habitats, communities, and ecosystems (H), altered hydrologic regime (H), altered landscape mosaic or context (H), and altered community structure (M).

2) Conversion to agriculture (H): This causes fragmentation of habitats, communities, and ecosystems (H), altered landscape mosaic or context (H), and altered community structure (M).

3) Nutrient loads from agriculture (H): This causes altered water quality of surface water or aquifer by nutrients (H).

4) Roads (H): This causes fragmentation of habitats, communities, and ecosystems (H), erosion/sedimentation (H), altered water quality of surface water or aquifer by nutrients (H), and habitat destruction or conversion (M).

5) Conversion to housing and urban development (H): This causes fragmentation of habitats, communities, and ecosystems (H), altered landscape mosaic or context (H), erosion/sedimentation (H), and habitat destruction or conversion (M).

6) Dam operations (M): This causes fragmentation of habitats, communities, and ecosystems (H), and altered hydrologic regime (H).

7) Nutrient loads from urban (M): This causes altered water quality of surface water or aquifer by nutrients (H).

8) Incompatible resource extraction: mining/drilling (M): This causes erosion/sedimentation (H), and habitat destruction or conversion (M).

9) Chemicals and toxins (M): This causes altered water quality of surface water or aquifer by contaminants (M).

10) Conversion to commercial and industrial development (M): This causes erosion/sedimentation (H), and habitat destruction or conversion (M).

11) Invasive species (M): This causes altered species composition/dominance (M).

12) Incompatible recreational activities (L): This causes erosion/sedimentation (H), and habitat destruction or conversion (M).

13) Incompatible forestry practices (L): This causes altered hydrologic regime (H), erosion/sedimentation (H), and habitat destruction or conversion (M).

14) Groundwater withdrawal (L): This causes altered hydrologic regime (H).

15) Incompatible agricultural practices (L): This causes altered hydrologic regime (H), and erosion/sedimentation (H).

Spring and Spring Run Habitat

Statewide Threat Rank of Habitat: Very High

A) *Species*: Atlantic sturgeon and striped bass

B) *Sources of Threat*:

1) Nutrient loads from urban (VH): This has caused altered species composition/dominance (VH), altered water quality of surface water or aquifer by nutrients (VH), altered community structure (H), and habitat destruction or conversion (H).

2) Invasive plants (VH): This has caused altered species composition/dominance (VH), altered community structure (H), and habitat destruction or conversion (H).

3) Nutrient loads from agriculture (H): This has caused altered species composition/dominance (VH), altered water quality of surface water or aquifer by nutrients (VH), altered community structure (H), and habitat destruction or conversion (H).

4) Invasive animals (H): This has caused altered species composition/dominance (VH), and altered community structure (H).

5) Incompatible recreational activities (M): This has caused altered species composition/dominance (VH), altered water quality of surface water or aquifer by nutrients (VH), altered community structure (H), habitat destruction or conversion (H), and erosion/sedimentation (M).

6) Surface water withdrawal (M): This has caused altered hydrologic regime (H).

7) Groundwater withdrawal (M): This has caused altered community structure (H), habitat destruction or conversion (H), and altered hydrologic regime (H).

8) Conversion to recreation areas (L): This has caused altered species composition/dominance (VH), altered community structure (H), and habitat destruction or conversion (H).

9) Incompatible forestry practices (L): This has caused altered community structure (H), and habitat destruction or conversion (H).

10) Conversion to commercial and industrial development (L): This has caused habitat destruction or conversion (H).

Subtidal Unconsolidated Marine/Estuary Sediment Habitat

Statewide Threat Rank of Habitat: High

A) *Species*: Atlantic sturgeon and striped bass

B) *Sources of Threat*:

1) Dam operation/incompatible release of water (H): This has caused altered water quality of surface water or aquifer by contaminants (H), habitat disturbance (H), altered water quality by nutrients (M), altered water quality physical and chemical (M), and altered hydrologic regime (M).

2) Inadequate stormwater management (H): This has caused altered water quality of surface water or aquifer by contaminants (H), habitat disturbance (H), altered species composition (M), altered water quality by nutrients (M), altered water quality physical and chemical (M), and altered hydrologic regime (M).

3) Coastal development (H): This has caused altered water quality of surface water or aquifer by contaminants (H), habitat disturbance (H), habitat destruction (M), and altered hydrologic regime (M).

4) Chemicals and toxins (H): This has caused altered water quality of surface water or aquifer by contaminants (H), habitat disturbance (H), and altered species composition (M).

5) Incompatible industrial operations (H): This has caused altered water quality of surface water or aquifer by contaminants (H), habitat destruction (M), and altered hydrologic regime (M).

6) Channel modification/shipping lanes (M): This has caused habitat disturbance (H), habitat destruction (M), and altered hydrologic regime (M).

7) Fishing gear impacts (M): This has caused habitat disturbance (H), and habitat destruction (M).

8) Incompatible recreational activities (M): This has caused habitat disturbance (H).

9) Roads, bridges, and causeways (M): This has caused habitat disturbance (H).

10) Management of nature (beach nourishment, impoundments) (M): This has caused altered water quality physical and chemical (M).

11) Boating (L): This has caused habitat disturbance (H).

12) Nutrient loads (L): This has caused altered species composition (M).

13) Invasive animals (L): This has caused habitat disturbance (H).

14) Thermal pollution (L): This has caused habitat disturbance (H), and altered water quality physical and chemical (M).

15) Solid waste (L): This has caused habitat disturbance (H).
16) Surface water withdrawal (L): This has caused altered water quality physical and chemical (M).

Submerged Aquatic Vegetation Habitat

Statewide Threat Rank of Habitat: Very High

A) *Species*: American eel

B) *Sources of Threat*:

1) Coastal development (VH): This has caused altered water quality physical and chemical (VH), habitat destruction (VH), altered species composition (VH), sedimentation (VH), altered water quality by contaminants (H), altered water quality by nutrients (H), altered structure (H), erosion (H), altered hydrologic regime (H), and habitat fragmentation (M).
2) Harmful algal blooms (VH): This has caused altered water quality physical and chemical (VH), habitat destruction (VH), altered species composition (VH), altered water quality by nutrients (H), and altered primary productivity (H).
3) Inadequate stormwater management (VH): This has caused altered water quality physical and chemical (VH), habitat destruction (VH), altered species composition (VH), sedimentation (VH), altered water quality by contaminants (H), altered water quality by nutrients (H), erosion (H), and altered primary productivity (H).
4) Channel modification/shipping lanes (VH): This has caused altered water quality physical and chemical (VH), habitat destruction (VH), sedimentation (VH), altered structure (H), erosion (H), altered hydrologic regime (H), altered primary productivity (H), and habitat fragmentation (M).
5) Nutrient loads (all sources) (H): This has caused altered water quality physical and chemical (VH), habitat destruction (VH), altered species composition (VH), sedimentation (VH), altered water quality by contaminants (H), altered water quality by nutrients (H), altered structure (H), altered primary productivity (H), and habitat fragmentation (M).
6) Incompatible industrial operations (H): This has caused altered water quality physical and chemical (VH), habitat destruction (VH), altered species composition (VH), sedimentation (VH), altered water quality by contaminants (H), altered structure (H), erosion (H), altered primary productivity (H), and habitat fragmentation (M).
7) Dam operation/incompatible release of water (H): This has caused altered water quality physical and chemical (VH), habitat destruction (VH), altered species composition (VH), sedimentation (VH), altered water quality by contaminants (H), altered water quality by nutrients (H), erosion (H), altered hydrologic regime (H), and altered primary productivity (H).

8) Climate variability (H): habitat destruction (VH), altered species composition (VH), altered structure (H), erosion (H), altered hydrologic regime (H), and altered primary productivity (H).

9) Surface water withdrawal (H): This has caused altered water quality physical and chemical (VH), habitat destruction (VH), altered species composition (VH), altered hydrologic regime (H), and altered primary productivity (H).

10) Invasive plants (H): This has caused habitat destruction (VH), altered species composition (VH), altered water quality by nutrients (H), altered structure (H), and altered primary productivity (H).

11) Groundwater withdrawal (H): This has caused altered water quality physical and chemical (VH), habitat destruction (VH), altered species composition (VH), altered hydrologic regime (H), and altered primary productivity (H).

12) Roads, bridges, and causeways (H): This has caused altered water quality physical and chemical (VH), habitat destruction (VH), altered species composition (VH), sedimentation (VH), altered water quality by contaminants (H), altered water quality by nutrients (H), altered structure (H), erosion (H), altered hydrologic regime (H), altered primary productivity (H), and habitat fragmentation (M).

13) Shoreline hardening (H): This has caused altered water quality physical and chemical (VH), habitat destruction (VH), altered species composition (VH), sedimentation (VH), altered water quality by contaminants (H), altered water quality by nutrients (H), erosion (H), and altered primary productivity (H).

14) Invasive animals (H): This has caused habitat destruction (VH), and altered species composition (VH).

15) Destruction of longshore transport of sediments (H): This has caused altered water quality physical and chemical (VH), altered species composition (VH), sedimentation (VH), altered water quality by nutrients (H), erosion (H), and altered primary productivity (H).

16) Management of nature (beach nourishment, impoundments) (M): This has caused altered water quality physical and chemical (VH), habitat destruction (VH), altered species composition (VH), sedimentation (VH), erosion (H), altered hydrologic regime (H), altered primary productivity (H), and habitat fragmentation (M).

17) Boating impacts (M): This has caused altered water quality physical and chemical (VH), habitat destruction (VH), altered species composition (VH), sedimentation (VH), altered water quality by contaminants (H), altered water quality by nutrients (H), altered structure (H), erosion (H), altered primary productivity (H), and habitat fragmentation (M).

18) Chemicals and toxins (M): This has caused altered water quality physical and chemical (VH), habitat destruction (VH), altered species composition (VH), and altered primary productivity (H).

19) Incompatible recreational activities (M): This has caused altered water quality physical and chemical (VH), habitat destruction (VH), altered species composition (VH), sedimentation (VH), altered water quality by contaminants (H), altered water quality by nutrients (H), altered structure (H), and erosion (H).

20) Key predator/herbivore losses (M): This has caused habitat destruction (VH), altered species composition (VH), and altered primary productivity (H).

21) Utility corridors (M): This has caused habitat destruction (VH), altered structure (H), and habitat fragmentation (M).

22) Fishing gear impacts (M): This has caused habitat destruction (VH), altered species composition (VH), altered structure (H)

23) Industrial spills (M): This has caused altered water quality physical and chemical (VH), habitat destruction (VH), altered species composition (VH), altered water quality by contaminants (H), and altered primary productivity (H).

24) Incompatible aquaculture operations (M): This has caused altered water quality physical and chemical (VH), habitat destruction (VH), altered species composition (VH), sedimentation (VH), altered water quality by nutrients (H), altered structure (H), erosion (H), altered primary productivity (H), and habitat fragmentation (M).

25) Vessel impacts (M): This has caused habitat destruction (VH), altered water quality by contaminants (H), and altered structure (H).

26) Placement of artificial structure (M): This has caused habitat destruction (VH), altered species composition (VH), sedimentation (VH), altered structure (H), and altered primary productivity (H).

27) Thermal pollution (M): This has caused habitat destruction (VH), and habitat fragmentation (M).

28) Solid waste (L): This has caused habitat destruction (VH), altered structure (H), and altered primary productivity (H).

Canal/Ditch Habitat

A) *Species*: American eel

B) *Sources of Threat*:

1) Conversion to housing and development (north region): This has caused habitat destruction/conversion (including loss of existing ditch or swale habitat to curb and gutter underground storm-sewer-type drainage systems associated with more intensive urban or suburban development) (applies only in north region), and loss of riparian cover along canals/ditches as a result of canal maintenance practices (applies to central and south regions).

2) Intensification of surface water diversion/drainage associated with more intensive development (north region): This has caused habitat destruction/conversion (including loss of existing ditch or swale habitat to curb and gutter underground storm-sewer-type drainage systems associated with more intensive urban or suburban development) (applies only in north region), and loss of riparian cover along canals/ditches as a result of canal maintenance practices (applies to central and south regions).
3) Incompatible canal maintenance practices (e.g., removing all canal bank vegetation through herbicide applications, etc.) (all regions): This has caused habitat destruction/conversion (including loss of existing ditch or swale habitat to curb and gutter underground storm-sewer-type drainage systems associated with more intensive urban or suburban development) (applies only in north region), and loss of riparian cover along canals/ditches as a result of canal maintenance practices (applies to central and south regions).
4) Conversion to housing and development (north region): This has caused an altered landscape mosaic (including destruction or conversion of wet flatwoods adjacent to roadside ditches) (north region).
5) Nutrient loads (all regions): This has caused altered water quality by contaminants.
6) Chemicals/toxins (e.g., oil/grease and heavy metals from roads) (north region): This has altered water quality from contaminants.
7) Incompatible agricultural practices (e.g., pesticides in runoff or drainage water) (all regions): This has altered water quality from contaminants.
8) Incompatible residential practices (e.g., pesticides in runoff) (all regions); mosquito control (north region): This has altered water quality from contaminants.
9) Management of dams/control structures (central/south regions):
10) Incompatible agricultural practices (e.g., management of runoff) (all regions): This has caused altered hydrologic regime (e.g., large pulses of flood water or storm runoff that disrupts life cycle requirements or alters or removes physical habitat).
11) Incompatible residential practices (e.g., management of runoff) (all regions): This has caused altered hydrologic regime (e.g., large pulses of flood water or storm runoff that disrupts life cycle requirements or alters or removes physical habitat).

Citation

Florida Fish and Wildlife Conservation Commission. 2005. Florida’s Wildlife Legacy Initiative, Florida’s Comprehensive Wildlife Conservation Strategy.

PART IV. THREATS LITERATURE CITED

Adams, B., and D. U. Schwevers. 1997. Behavioral surveys of eels (*Anguilla anguilla*) migrating downstream under laboratory conditions. Institute of Applied Ecology, Neustader Weg 25, 36320 Kirtorf-Wahlen, Germany.

Aprahamian, M. W., K. M. Smith, P. McGinnity, S. Mckelvey, and J. Taylor. 2003. Restocking of salmonids: Opportunities and limitations. Fisheries Research 62: 211-227.

Armstrong, J. L., and J. E. Hightower. 2002. Potential for restoration of the Roanoke River population of Atlantic sturgeon. Journal of Applied Ichthyology 18: 475-480.

Ashley, J. T. F., R. Horwitz, J. C. Steinbacher, and B. Ruppel. 2003. A comparison of congeneric PCB patterns in American eel and striped bass from the Hudson and Delaware River estuaries. Marine Pollution Bulletin 46: 1294-1308.

ASMFC (Atlantic States Marine Fisheries Commission). 1985. Fishery management plan for American shad and river herring. Atlantic States Marine Fisheries Commission Fisheries Management Report No. 6, Washington, D.C.

ASMFC (Atlantic States Marine Fisheries Commission). 1990. Fishery management plan for Atlantic sturgeon. Atlantic States Fisheries Commission Marine Fisheries Management Report No. 17, Washington, D.C.

ASMFC (Atlantic States Marine Fisheries Commission). 1998. Atlantic sturgeon stock assessment report. Atlantic States Marine Fisheries Commission, Washington, D.C.

ASMFC (Atlantic States Marine Fisheries Commission). 1999. Amendment 1 to the fishery management plan for shad and river herring. Atlantic States Marine Fisheries Commission Fisheries Management Report No. 35, Washington, D.C.

ASMFC (Atlantic States Marine Fisheries Commission). 2000a. Atlantic States Marine Fisheries Commission interstate fishery management plan for American eel. Atlantic States Marine Fisheries Commission Fishery Management Report No. 36, Washington, D.C.

ASMFC (Atlantic States Marine Fisheries Commission). 2000b. 2000 Review of the Atlantic States Marine Fisheries Commission fishery management plan for shad and river herring (*Alosa* sp.). Atlantic States Marine Fisheries Commission Shad and River Herring Plan Review Team, Washington, D.C.

Atkins, C. G. 1887. The river fishes of Maine. Pages 673-728 *in* George B. Goode and Associates. History and methods of the fisheries: The fisheries and fishery industry of the United States, volume I (section 5). Bulletin of the United States Fish Commission, Washington, D.C.

Atran, S. M., J. G. Loesch, W. H. Kriete, Jr., and B. Rizzo. 1983. Feasibility study of fish passage facilities in the James River, Richmond, Virginia – final report. Virginia Institute of Marine Science Special Report No. 269 in Applied Marine Science and Ocean Engineering, Gloucester Point, Virginia.

Aust, W. M., S. H. Schoenholtz, T. W. Zaebst, and B. A. Szabo. 1997. Recovery status of a tupelo-cypress wetland seven years after disturbance: Silvicultural implications. Forest Ecology and Management 90: 161-169.

Bales, J. D., and D. A. Walters. 2003. Relations among floodplain water levels, instream dissolved oxygen conditions, and stream flow in the lower Roanoke River, North Carolina, 1997-2001. U.S. Geological Survey, Water Resources Division, Water Resources Investigations Report No. 03-4295, Raleigh, North Carolina.

Barnthouse L. W., and W. Van Winkle. 1988. Analysis of impingement on Hudson River fish populations. American Fisheries Society, Monograph 4: 182-190.

Basnyat, P., L. D. Teeter, K. Flynn, and B. G. Lockaby. 1999. Relationships between landscape characteristics and nonpoint source pollution inputs to coastal estuaries. Environmental Management 2: 539-549.

Batzer, D. P., B. M. George, and A. Braccia. 2005. Aquatic invertebrate responses to timber harvest in a bottomland hardwood wetland of South Carolina. Forest Science 51: 1-8.

Beamesderfer, R. C. P., and R. A. Farr. 1997. Alternatives for the protection and restoration of sturgeons and their habitat. Environmental Biology of Fishes 48: 407-417.

Beasley, C. A., and J. E. Hightower. 2000. Effects of a lowhead dam on the distribution and characteristics of spawning habitat used by striped bass and American shad. Transactions of the American Fisheries Society 129: 1372–1386.

Beaulieu, G. 1985. Rapport sur la situation du bar rayé (*Morone saxatilis*). Faune et flore à protéger au Quebéc. Association des Biologistes due Quebéc, Publication 7, Quebéc, Canada.

Bell, C. E., and B. Kynard. 1985. Mortality of adult American shad passing through a 17-megawatt Kaplan turbine at a low-head hydroelectric dam. North American Journal of Fisheries Management 5: 33-38.

Berg, R. 1986. Fish passage through Kaplan turbines at a power plant on the River Neckar and subsequent eel injuries. Vie et Milieu Paris 36: 307-310.

Boger, R. A. 2002. Development of a watershed and stream-reach spawning habitat model for river herring (*Alosa pseudoharengus* and *A. aestivalis*). Doctoral dissertation. The College of William and Mary, Williamsburg, Virginia.

Borodin, N. 1925. Biological observations on the Atlantic sturgeon (*Acipenser sturio*). Transactions of the American Fisheries Society 55: 184-190.

Boubee, J. A. T., and R. Barrier. 1996. Karapiro catch and transfer programme 1966/97. NIWA Client Report No. ELE602.11/1.0, and prepared for ECNZ, Hamilton, New Zealand.

Boynton, W. R., E. M. Setzler, K. V. Wood, H. H. Zion, and M. Homer. 1977. Final report of Potomac River fisheries study: Ichthyoplankton and juvenile investigations. University of Maryland, Center for Environmental and Estuarine Studies, Chesapeake Biological Laboratory Reference No. 77-169, Solomons, Maryland.

Breitburg, D. L. 1988. Effects of turbidity on prey consumption by striped bass larvae. Transactions of the American Fisheries Society 117: 72-77.

Breitburg, D. L. 2002. Effects of hypoxia, and the balance between hypoxia and enrichment, on coastal fishes and fisheries. Estuaries and Coasts 25: 767-781.

Brookes, A. 1988. Channelized rivers: Perspectives for environmental management. John Wiley and Sons, New York.

Brusle, J. 1991. The eel (*Anguilla* sp.) and organic chemical pollutants. Science of the Total Environment 102: 1-19.

Brusle, J. 1994. L'anguille Europeenne *Anguilla anguilla* un poisson sensible aux stress environnementaux et vulnerable a diverses atteintes pathogenes. Bulletin Francais de la Pêche et de la Pisciculture 335: 237-260.

Budavari, S., M. J. O'Neil, A. Smith, and P. E. Heckelman. 1989. The Merck Index, 11th edition. Merck and Company, Inc. Whitehouse Station, New Jersey.

Burdick, S. M. 2005. Distribution of spawning activity by migratory fishes in the Neuse River, North Carolina, after removal of a low-head dam. Masters thesis. North Carolina State University, Raleigh, North Carolina.

Busch, W. D. N., S. J. Lary, C. M. Castilione, and R. P. McDonald. 1998. Distribution and availability of Atlantic Coast freshwater habitats for American eel (*Anguilla rostrata*). U.S. Fish and Wildlife Service Administrative Report No. 98-2, Amherst, New York.

Bushnoe, J. A., D. S., and D. S. Ha. 2005. Essential spawning and nursery habitat of Atlantic sturgeon (*Acipenser oxyrinchus*) in Virginia. VIMS Special Report No. 145. Virginia Institute of Marine Science, Gloucester Point, Virginia.

Cairns, D. K., J. C. Shiao, Y. Iizuka, W. –N. Tzeng, and C. D. MacPherson. 2004. Movement patterns of American eels in an impounded watercourse, as indicated by otoliths microchemistry. North American Journal of Fisheries Management 24: 452-458.

Calhoun, A. J., C. A. Woodhull, and W. C. Johnson. 1950. Striped bass reproduction in the Sacramento River system in 1948. California Fish and Game 36: 135-145.

Calow, P. 1991. Physiological costs of combating chemical toxicants: Ecological implications. Comparative Biochemistry and Physiology 100C: 3-6.

Carlson, F. T., and J. A. McCann. 1969. Hudson River fisheries investigations 1965-1968: Evaluations of a proposed pumped storage project at Cornwall, New York in relation to fish in the Hudson River. Hudson River Policy Committee, Consolidated Edison Company, New York, New York.

Carlson, D. M., and K. W. Simpson. 1987. Gut contents of juvenile shortnose sturgeon in the upper Hudson estuary. Copeia 3: 796-802.

Caron, F., and S. Tremblay. 1999. Structure and management of an exploited population of Atlantic sturgeon (*Acipenser oxyrinchus*) in the St. Lawrence Estuary, Quebec, Canada. Journal of Applied Ichthyology 15: 153-156

Casselman, J. M., L. A. Marcogliese, and P. V. Hodson. 1998. The American eel, *Anguilla rostrata*, stock of the upper St. Lawrence River and Lake Ontario: Long-term trends, decreasing abundance, cause and effect. 1998 American Fisheries Society Annual Meeting, 26 August 1998, Session 4, Hartford, Connecticut.

Castonguay, M., J. D. Dutil, and C. Desjardins. 1989. The distinction between American eels (*Anguilla rostrata*) of three different geographic origins on the basis of their organochlorine contaminant levels. Canadian Journal of Fisheries and Aquatic Sciences 46: 836-843.

Castonguay, M., P. V. Hodson, C. M. Couillard, M. J. Eckersley, J. -D. Dutil, and G. Verreault. 1994a. Why is recruitment of the American eel, *Anguilla rostrata*, declining in the St. Lawrence River and Gulf? Canadian Journal of Fisheries and Aquatic Sciences 51: 479-488.

Castonguay, M., P. V. Hodson, C. Moriarty, K. F. Drinkwater, and B. M. Jessop. 1994b. Is there a role in the ocean environment in American and European eel decline? Fisheries Oceanography 3: 197-203.

CBF (Chesapeake Bay Foundation). 2004. 2004 state of the bay report. Chesapeake Bay Foundation, Annapolis, Maryland.

Chadwick, H. K. 1974. Entrainment and thermal effects on a mysid shrimp and striped bass in the Sacramento-San Joaquin Delta. Pages 23-30 *in* L. D. Jensen, editor. Second workshop on entrainment and intake screening. Electric Power Research Institute Publication No. 74-049-00-5, Palo Alto, California.

Charles Mitchell and Associates. 1995. Trapping the adult eel migration at Aniwhenua Power Station: Investigation No. 140. Charles Mitchell & Associates, Rotorua, New Zealand.

Chesapeake Executive Council (CEC). 1988. Habitat requirements for Chesapeake Bay living resources. Chesapeake Bay Program Report, Annapolis, Maryland.

Chittenden, M. E., Jr. 1969. Life history and ecology of the American shad, *Alosa sapidissima*, in the Delaware River. Doctoral dissertation. Rutgers University, New Brunswick, New Jersey.

Chittenden, M. E., Jr. 1972. Responses of young American shad, *Alosa sapidissima*, to low temperatures. Transactions of the American Fisheries Society 101: 680-685.

Christie, R. W, P. T. Walker, A. G. Eversole, and T. A. Curtis. 1981. Distribution of spawning blueback herring on the west branch of Cooper River and the Santee River, South Carolina. Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies 35: 632-640.

Chutter, F. M. 1969. The effects of silt and sand on the invertebrate fauna of streams and rivers. Hydrobiologia 34: 57-77.

Clark, D. G., and D. H. Wilber. 2000. Assessment of potential impacts of dredging operations due to sediment resuspension. Dredging Operations and Environmental Research Program Technical Notes Collection No. ERDC TN DOER-E9, U.S. Army Engineer Research and Development Center, Vicksburg, Mississippi.

Clay, C. H. 1995. Design of fishways and other fish facilities, second edition. CRC Press, Inc., Boca Raton, Florida.

Coiro, L., S. L. Poucher, and D. Miller. 2000. Hypoxic effects on growth of *Palaemonetes vulgaris* larvae and other species: Using constant exposure data to estimate cyclic exposure response. Journal of Experimental Biology and Ecology 247: 243-255.

Collette, B. B., and G. Klein-MacPhee, editors. 2002. Bigelow and Schroeder's Fishes of the Gulf of Maine, 3rd edition. Smithsonian Institution Press, Washington, D.C.

Collier, R. S., and M. C. Odom. 1989. Obstructions to anadromous fish migration. North Carolina Department of Natural Resources and Community Development, Environmental Protection Agency, and National Estuary Program, APES Project No. 88-12, Raleigh, North Carolina.

Collins, M. R., S. G. Rogers, T. I. J. Smith, and M. L. Moser. 2000. Primary factors affecting sturgeon populations in the southeastern United States: Fishing mortality and degradation of essential habitats. Bulletin of Marine Science 66: 917-928.

Comeleo, R. L., J. F. Paul, P. V. August, J. Copeland, C. Baker, S. S. Hale, and R. W. Latimer. 1996. Relationships between watershed stressors and sediment contamination in Chesapeake Bay estuaries. Landscape Ecology 11: 307-319.

Cooke, D. W., and S. D. Leach. 2001. Santee-Cooper blueback herring studies: Rediversion project. South Carolina Department of Natural Resources, Columbia, South Carolina.

Cooke, D. W., and S. D. Leach. 2004. Santee River sturgeon studies: Santee Cooper FERC studies. Report to South Carolina Public Service Authority, Moncks Corner, South Carolina.

Cooper, S. R., and G. S. Brush. 1993. A 2,500 year history of anoxia and eutrophication in the Chesapeake Bay. Estuaries 16: 617-626.

Correll, D. L. 1987. Nutrients in Chesapeake Bay. Pages 298-320 *in* S. K. Majumdar, L. W. Hall, Jr., and H. M. Austin, editors. Contaminant Problems and Management of Living Chesapeake Bay Resources. Pennsylvania Academy of Science, Easton, Pennsylvania.

Couillard, C. M., P. V. Hodson, and M. Castongusy. 1997. Correlations between pathological changes and chemical contamination in American eel, *Anguilla rostrata*, from the St. Lawrence River. Canadian Journal of Fisheries and Aquatic Sciences 54: 1916-1927.

Coutant, C. C. 1981. Foreseeable effects of CO_2-induced climate change: Freshwater concerns. Environmental Conservation 8: 285-297.

Coutant, C. C. 1990. Temperature-oxygen habitat for freshwater and coastal striped bass in a changing climate. Transactions of the American Fisheries Society 119: 240-253.

Coutant, C. C., and D. L. Benson. 1990. Summer habitat suitability for striped bass in Chesapeake Bay: Reflections on a population decline. Transactions of the American Fisheries Society 119: 757-778.

Crecco, V. A., and T. Savoy. 1987. Review of recruitment mechanisms of the American shad: The critical period and match-mismatch hypotheses reexamined. Pages 455-468 *in* M. J. Dadswell, R. J. Klauda, C. M. Moffitt, and R. L. Saunders, editors. Common Strategies of Anadromous and Catadromous Fishes. American Fisheries Society Symposium 1, Bethesda, Maryland.

Cronin, E. L., R. B. Biggs, D. A. Flemer, G. T. Pfitzmeyer, F. Goodwin, Jr., W. L. Dovel, and D. E. Richie. 1970. Gross physical and biological effects of overboard spoil disposal in upper Chesapeake Bay. Chesapeake Biological Laboratory, Natural Resource Institute, Special Report No. 3, University of Maryland, Solomons, Maryland.

Cushman, R. M. 1985. Review of ecological effects of rapidly varying flows downstream from hydroelectric facilities. North American Journal of Fisheries Management 5: 330-339.

Dadswell, M. J., G. D. Melvin, and P. J. Williams. 1983. Effect of turbidity on the temporal and spatial utilization of the inner Bay of Fundy by American shad (*Alosa sapidissima*) (Pisces: Clupeidae) and its relationship to local fisheries. Canadian Journal of Fisheries and Aquatic Sciences 40: 322-330.

Dadswell, M. J., and R. A. Rulifson. 1994. Macrotidal estuaries: A region of collision between migratory marine animals and tidal power development. Biological Journal of the Linnean Society 51: 93-113.

DBC (Delaware Basin Fish and Wildlife Management Cooperative). 1980. Strategic fishery management plan for the American shad (*Alosa sapidissima*) in the Delaware River Basin.

Dennison, W. C., R. J. Orth, K. A. Moore, J. C. Stevenson, V. Carter, S. Kollar, P. W. Bergstrom, and R. A. Batiuk. 1993. Assessing water quality with submerged aquatic vegetation. Bioscience 43: 86-94.

Desrochers, D. 1994. Suivi de la migration de l'anguille d'amerique, *Anguilla rostrata*, au complexe Beauharnois, 1994, par MILIEU & Associates inc., pour le service Miliew naturel, vice presidence Environment et collectivities. Hydro-Quebec, Canada.

Desrochers, D. 1996. Etude de faisabilite d'une passe migratoire a anguilles, *Anguilla rostrata*, a la centrale de Beauharnois. Par. Milieu inc., pour le service Miliew naturel, vice-presidence Environment et collectivities. Hydro-Quebec, Canada.

Diaz, R. J., and R. Rosenberg. 1995. Marine benthic hypoxia: A review of its ecological effects and the behavioural responses of benthic macrofauna. Oceanography and Marine Biology Annual Review 33: 245-303.

Diaz, R. J., and R. Rosenberg. 2008. Spreading dead zones and consequences for marine ecosystems. Science 321: 926-929.

Dixon, D. A. 1996. Contributions to the life history of juvenile blueback herring (*Alosa aestivalis*): Phototactic behavior and population dynamics. Doctoral dissertation. College of William and Mary, Virginia Institute of Marine Science, School of Marine Science, Gloucester Point, Virginia.

Dovel, W. L., A. W. Pekovitch, and T. J. Berggren. 1992. Biology of the shortnose sturgeon (*Acipenser brevirostrum* LeSueur, 1818) in the Hudson River estuary, New York. Pages 187-216 *in* C. L. Smith, editor. Estuarine research in the 1980's. State University of New York Press, Albany, New York.

Durkas, S. J. 1992. Impediments to the spawning success of anadromous fish in tributaries of the NY/NJ Harbor Watershed. American Littoral Society, Highlands, New Jersey.

Dutil, J. -D., M. Besner, and S. D. McCormick. 1987. Osmoregulatory and ionoregulatory changes and associated mortalities during the transition of maturing American eels to a marine environment. American Fisheries Society Symposium 1: 175-190.

Ellis, M. M., B. A. Westfall, D. K. Meyer, and W. S. Platner. 1947. Water quality studies of the Delaware River with reference to shad migration. U.S. Fish and Wildlife Service, Special Scientific Report No. 38, Washington, D.C.

EDF (Environmental Defense Fund). 2003. Draft Edenton Bay watershed restoration plan. Edenton, North Carolina.

EPRI (Electric Power Research Institute). 1999. American eel (*Anguilla rostrata*) scoping study: A literature review of life history, stock status, population dynamics, and hydroelectric impacts. EPRI Report No. TR-111873, Palo Alto, California.

Erkan, D. E. 2002. Strategic plan for the restoration of anadromous fishes to Rhode Island coastal streams. Rhode Island Department of Environmental Management, Division of Fish and Wildlife, Completion Report in Fulfillment of Federal Aid in Sportfish Restoration Project No. F-55-R, Wakefield, Rhode Island.

Everett, G. 1983. The impact of pulp mill effluent on the Chowan River herring fishery. North Carolina Department of Natural Resources and Community Development, Division of Environmental Management, Water Quality Planning Branch, Report No. 83-08, Raleigh, North Carolina.

Fajen, O. F., and J. B. Layzer. 1993. Agricultural Practices. Pages 257-270 *in* C. F. Bryan, and D. A. Rutherford, editors. Impacts on warmwater streams: Guidelines for evaluation. Southern Division of the American Fisheries Society, Little Rock, Arkansas.

Farley, T. C. 1966. Striped bass, *Roccus saxatilis,* spawning in the Sacramento-San Joaquin River system, during 1963 and 1964. Pages 28-43 *in* J. L. Turner and D. W. Kelley, compilers. Ecological studies of the Sacramento-San Joaquin estuary, part II: Fishes of the delta. California Department of Fish and Game Fish Bulletin 136, Sacramento, California.

Ferguson, J. W. 1992. Analyzing turbine bypass systems at hydro facilities. Hydro Review 1992: 46-56.

FFWCC (Florida Fish and Wildlife Conservation Commission). 2005. Florida's Wildlife Legacy Initiative, Florida's Comprehensive Wildlife Conservation Strategy. Available: http://myfwc.com/wildlifelegacy/review/FL_Strategy.pdf.

Fisher, R. K., S. Brown, and D. Mathur. 1997. The importance of the point of operation of a Kaplan turbine on fish survivability. Proceedings of Waterpower '97, Atlanta, Georgia.

Folz, D. J., and L. S. Meyers. 1985. Management of the lake sturgeon, *Acipenser fulvescens*, population in the Lake Winnebago system, Wisconsin. Developments in Environmental Biology of Fishes 6: 135-146.

Frankensteen, E. D. 1976. Genus *Alosa* in a channelized and an unchannelized creek of the Tar River basin, North Carolina. Masters thesis. East Carolina University, Greenville, North Carolina.

Freeman, M. C., C. M. Pringle, E. A. Greathouse, and B. J. Freeman. 2003. Ecosystem-level consequences of migratory faunal depletion caused by dams. Pages 255-266 *in* K. E. Limburg, and J. R. Waldman, editors. Biodiversity, status, and conservation of the world's shads. American Fisheries Society Symposium 35, Bethesda, Maryland.

Funderburk, S. L., S. L. Jordan, J. A. Mihursky, and D. Riley, editors. 1991. Habitat requirements for Chesapeake Bay living resources. Chesapeake Bay Program, Living Resources Subcommittee, Annapolis, Maryland.

Gammon, J. R. 1970. The effects of inorganic sediment on stream biota. Environmental Protection Agency Water Pollution Conservation Research Series No. 18050 DWC 12170, Washington, D.C.

Garman, G. C. 1992. Fate and potential significance of postspawning anadromous fish carcasses in an Atlantic coastal river. Transactions of the American Fisheries Society 121: 390–394.

Garman, G. C., and S. A. Macko. 1998. Contribution of marine-derived organic matter to an Atlantic coast, freshwater, tidal stream by anadromous clupeid fishes. Journal of the North American Benthological Society 17: 277-285.

Gibson, M. R. 1987. Disparities between observed and expected stock dynamics in American shad exposed to dredge operations. Rhode Island Department of Environmental Management Research Reference Document No. 87/6, Providence, Rhode Island.

Gilbert, B., and B. Wenger. 1996. Entrainment mortality of American eels at two hydroelectric plants in Virginia: Problems and solutions. American eel passage workshop transcripts, July 31, 1996. U.S. Fish and Wildlife Service, Hadley, Massachusetts.

Gloss, S. P. 1982. Estimates of juvenile American shad (*Alosa sapidissima*) turbine mortality at low-head hydropower sites. Page 22 *in* R. G. Howey, editor. Proceedings of 1981 American shad workshop -- culture, transportation, and marking. U. S. Fish and Wildlife Service Lamar Informational Leaflet No. 82-01, Hadley, Massachusetts.

Gross, M. R., J. Repka, C. T. Robertson, D. H. Secor, and W. Van Winkle. 2002. Sturgeon conservation: Insights from elasticity analysis. Pages 13-30 *in* W. Van Winkle, P. J. Anders, D. H. Secor, and D. A. Dixon, editors. Biology, management, and protection of North American sturgeon. American Fisheries Society Symposium 28, Bethesda, Maryland.

Hadderingh, R. H., J. W. Stoep, and P. W. Habraken. 1992. Deflecting eels from water inlets of power stations with light. Irish Fisheries Investigations Series A (Freshwater) 36: 80-89.

Hadderingh, R. H., and H. D. Bakker. 1998. Fish mortality due to passage through hydroelectric power stations on the Meuse and Vecht rivers. Pages 315-328 *in* M. Jungwirth, S. Schmutz, and S. Weiss, editors. Fish migration and fish bypasses. Fishing News Books, Oxford, England.

Haro, A., and T. Castro-Santos. 2000. Behavior and passage of the silver-phase American eels, *Anguilla rostrata* (LeSueur) at a small hydroelectric facility. Dana 12: 33-42.

Haro, A., W. Richkus, K. Whalen, A. Hoar, W. -D, Busch, S. Lary, T. Brush, and D. Dixon. 2000. Population decline of the American eel: Implications for research and management. Fisheries 25: 7-16.

Haro, A., T. Castro-Santos, K. Whalen, G. Wippelhauser, and L. McLaughlin. 2003. Simulated effects of hydroelectric project regulation on mortality of American eels. Pages 357-366 *in* D. A. Dixon, editor. Biology, management, and protection of catadromous eels. American Fisheries Society Symposium 33, Bethesda, Maryland.

Hartman, G. F., J. C. Scrivener, and M. J. Miles. 1996. Impacts of logging in Carnation Creek, a high-energy coastal stream in British Columbia, and their implication for restoring fish habitat. Canadian Journal of Fisheries and Aquatic Sciences 53: 237-251.

Hauck, F. R., and Q. A. Edson. 1976. Pumped storage: Its significance as an energy source and some biological ramifications. Transactions of the American Fisheries Society 105: 158-164.

Hauser, G. E., and W.G. Brock. 1994. Aerating weirs for environmental enhancement of hydropower tailwaters. Tennessee Valley Authority Engineering Laboratory, Norris, Tennessee.

Hawkins, J. H. 1979. Anadromous fisheries research program – Neuse River. North Carolina Department of Natural Resources and Community Development, Division of Marine Fisheries Progress Report No. AFCS13-2, Raleigh, North Carolina.

Heisey, P. G., D. Mathur, and E. T. Euston. 1996. Passing fish safely: A closer look at turbine vs. spillway survival. Hydro Review 15: 42-50.

Helfman, G. S., D. E. Facey, L. S. Hales Jr., and E. L. Bozeman, Jr. 1987. Reproductive ecology of the American eel. Pages 42-56 *in* M. J. Dadswell, R. J. Klauda, C. M. Moffitt, and R. L. Saunders, editors. Common strategies of anadromous and catadromous fishes. American Fisheries Society Symposium 1, Bethesda, Maryland.

Hendricks, M. L. 2003. Culture and transplant of alosines in North America. Pages 303-312 *in* K. E. Limburg, and J. R. Waldman, editors. Biodiversity, status, and conservation of the world's shads. American Fisheries Society Symposium 35, Bethesda, Maryland.

Hightower, J. E., and K. L. Sparks. 2003. Migration and spawning habitat of American shad in the Roanoke River, North Carolina. Pages 193-199 *in* K. E. Limburg, and J. R. Waldman, editors. Biodiversity, status, and conservation of the world's shads. American Fisheries Society Symposium 35, Bethesda, Maryland.

Hill, J. 1996. Environmental considerations in licensing hydropower projects: Policies and practices at the Federal Energy Regulatory Commission. Pages 190-199 *in* L. E. Miranda, and D. R. DeVries, editors. Multidimensional approaches to reservoir fisheries management. American Fisheries Society Symposium 16, Bethesda, Maryland.

Hodson, P. V., M. Castonguay, C. M. Couillard, C. Desjardins, E. Pellitier and R. McLeod. 1994. Spatial and temporal variations in chemical contamination of American eel (*Anguilla rostrata*) captured in the estuary of the St. Lawrence River. Canadian Journal of Fisheries and Aquatic Sciences 51: 464-478.

Hubbard, W. D. 1993. Channelization. Pages 135-155 *in* C. F. Bryan, and D. A. Rutherford, editors. Impacts on warmwater streams: Guidelines for evaluation. Southern Division, American Fisheries Society, Little Rock, Arkansas.

IAN (Integration and Application Network). 1999. Science & Site 104: Long-term options for dredged sediment placement. University of Maryland Center for Environmental Science, Cambridge, Maryland.

Jessop, B. M., and C. J. Harvie. 2003. A CUSUM analysis of discharge patterns by a hydroelectric dam and discussion of potential effects on the upstream migration of American eel elvers. Canadian Technical Report of Fisheries and Aquatic Sciences No. 2454, Department of Fisheries and Oceans, Dartmouth, Nova Scotia, Canada.

Johnson, J. H., R. M. Ross, and C. M. Adams. 1999. Diet composition and fish consumption of double-crested cormorants in eastern Lake Ontario, 1998. New York State Department of Environmental Conservation Special Report, Feb. 1, 1999.

Johnson, J. H., R. M. Ross, and R. D. McCullough. 2000. Diet composition and fish consumption of double-crested cormorants from the Little Galloo Island Colony of Eastern Lake Ontario in 1999. New York State Department of Environmental Conservation Special Report, March 1, 2000.

Johnston, C. A., N. E. Detenbeck, and G. J. Niemi. 1990. The cumulative effect of wetlands on stream water quality and quantity: A landscape approach. Biogeochemistry 10: 105-141.

Jordan, S., C. Stenger, M. Olson, R. Batiuk, and K. Mountford. 1992. Chesapeake Bay dissolved oxygen goal for restoration of living resource habitats. Maryland Department of Natural Resources, Annapolis, Maryland.

Kaiser, K. L. E. 1978. The rise and fall of mirex. Environmental Science and Technology 12: 520-524.

Kelly, R., and H. K. Chadwick. 1971. Some observations on striped bass temperature tolerances. California Department of Fish and Game Administrative Report No. 71.9: 1-11.

Kemp, W. M., P. A. Sampou, J. Garber, J. Tuttle, and W. R. Boynton. 1992. Seasonal depletion of oxygen from bottom waters of Chesapeake Bay: Roles of benthic and planktonic respiration and physical exchange processes. Marine Ecology Progress Series 85: 137-152.

Kerr, J. E. 1953. Studies on fish preservation at the Contra Costa Steam Plan of the Pacific Gas and Electric Company. California Department of Fish and Game Fish Bulletin No. 92: 1-66.

Khodorevskaya, R. P. 1972. Falling of fry fish into hydraulic dredges. Pages 169-170 *in* Report on the Session of the Central Sturgeon Farming Restoration Institute, Astrakhan.

Khoroshko, P. N., and A. D. Vlasenko. 1970. Artificial spawning grounds of sturgeon. Journal of Ichthyology 10: 286-292.

Keller, E. A. 1978. Pools, riffles, and channelization. Environmental Geology 2: 119-127.

Kelly, M. H., and R. L. Hite. 1984. Evaluation of Illinois stream sediment data: 1974-1980. Illinois Environmental Protection Agency Report No. IEPA/WPC/84-004, Illinois.

Kennish, M. J., T. J. Belton, P. Hauge, K. Lockwood, and B. E. Ruppert. 1992. Polychlorinated biphenyls in estuarine and coastal marine waters of New Jersey: A review of contamination problems. Reviews in Aquatic Sciences 6: 275-293.

Killgore, K. J., R. P. Morgan, Jr., and N. B. Rybicki. 1989. Distribution and abundance of fishes associated with submerged aquatic plants in the Potomac River. North American Journal of Fisheries Management 9: 101-111.

Klauda, R. J. 1994. Lethal and critical effects thresholds for American shad eggs and larvae exposed to acid and aluminum in the laboratory, with speculation on the potential role of habitat acidification on stock status in Maryland. Pages 7-39 *in* J. E. Cooper, R. T. Eades, R. J. Klauda, and J. G. Loesch, editors. Anadromous *Alosa* symposium. American Fisheries Society Tidewater Chapter, Bethesda, Maryland.

Klauda, R. J., S. A. Fischer, L. W. Hall, Jr., and J. A. Sullivan. 1991. American shad and hickory shad. Pages 9.1-9.27 *in* S. L. Funderburk, J. A. Mihursky, S. J. Jordan, and D. Riley, editors. Habitat requirements for Chesapeake Bay living resources, 2nd edition. Chesapeake Bay Program, Living Resources Subcommittee, Annapolis, Maryland.

Knights, B. 1997. Risk assessment and management of contamination of eels (*Anguilla* sp.) by persistent xenobiotic organochlorine compounds. Chemical Ecology 13: 171-12.

Knights, B., and E. White. 1995. A review of eel passes. Update of report to National Rivers Authority, Research and Development Project No. 256/13/ST, Bristol, England.

Knights, B., and M. White. 1998. Enhancing immigration and recruitment of eels: The use of passes and associated trapping systems. Fisheries Management and Ecology 5: 459-471.

Kortschal, K., R. Brandstatter, A. Gomahr, H. Junger, M. Palzenberger, and M. Zaunreiter. 1991. Brain and sensory systems. Pages 284-329 *in* I. J. Winfield, and S. J. Neilson, editors. Cyprinid fishes: Systematics, biology and exploitation. Chapman and Hall, London, England.

Krauthamer, J., and W. Richkus. 1987. Characterizations of the biology of and fisheries for Maryland stocks of American and hickory shad. Prepared for Tidewater Administration, Maryland Department of Natural Resources, Annapolis, Maryland.

Krueger, W. K., and K. Oliveira. 1997. Sex, size and gonad morphology of silver American eels, *Anguilla rostrata*. Copeia: 415-420.

Krueger, W., and K. Oliveira. 1999. Evidence for environmental sex determination in the American eel, *Anguilla rostrata*. Environmental Biology of Fishes 55: 381-389.

Lal, B., and T. P. Singh. 1987. The effect of malathion and y-BHC on the lipid metabolism in relation to reproduction in the tropical teolost, *Clarias batrachus*. Environmental Pollutants 48: 37-47.

Laffaille, P., A. Acou, J. Guillouët, and A. Legault. 2005. Temporal changes in European eel, *Anguilla anguilla*, stocks in a small catchment after installation of a fish pass. Fisheries Management 12: 123-129.

Lassalle, G., M. Beguer, L. Beaulaton, and E. Rochard. 2008. Diadromous fish conservation plans need to consider global warming issues: An approach using biogeographical models. Biological Conservation 141: 1105-1118.

Layzer, J. B., and J. A. O'Leary. 1978. Northfield Mountain pumped storage hydroelectric project anadromous fish study, part III: Out migration of radio-tagged Atlantic salmon (*Salmo salar*) smolts in the Connecticut River with particular reference to the Northfield Mountain Pumped Storage Hydroelectric Project, 1976-1978. Report to Northeast Utilities Service Company, Berlin, Connecticut.

Leathery, S. 1998. Euthrophication primary nonpoint pollution problem. Fisheries 23: 38.

Leatherland, J. F., and R. A. Sunstegard. 1977. On the effect of dietary mirex or PCB (Arochlor 1254) on serum thyroxine (T_4) and triiodothyronine (T_3) levels in rainbow trout. Acta Endocrinologica (Supplement) 212: 234.

Leatherland, J. F., and R. A. Sunstegard. 1978. Lowering of serum thyroxine and triiodothyronine levels in yearling coho salmon, *Oncorhynchus kisutch*, by dietary mirex and PCBs. Journal of the Fisheries Research Board Canada 35: 1285-1289.

Leatherland, J. F., and R. A. Sunstegard. 1980. Effect of dietary Mirex and PCB's in combination with food deprivation and testosterone administration on thyroid activity and bioaccumulation of organochlorines in rainbow trout, *Salmo gairneri* Richardson. Journal of Fish Diseases 3: 115-124.

Legault, A. 1988. Le franchissement des barrages par l'escalade de l'anguille etude en Sevre Niortase. Bulletin Francaise de la Pêche et de la Pisciculture 335: 33-41.

Lenat, D. R. 1984. Agricultural and stream water quality: A biological evaluation of erosion control practices. Environmental Management 8: 333-344.

Lenat, D. R., and J. K. Crawford. 1994. Effects of land use on water quality and aquatic biota of three North Carolina Piedmont streams. Hydrobiologia 294: 185-199.

Leslie, J. A., K. A. Abood, E. A. Maikish, and P. J. Keeser. 1988. Recent dissolved oxygen trends in the Hudson River. Pages 287-303 *in* C. L. Smith, editor. Fisheries research in the Hudson River. State University of New York, Albany, New York.

Liew, P. H. L. 1982. Impact of the eel ladder on the upstream migrating eel (*Anguilla rostrata*) population in the St. Lawrence River at Cornwall: 1974-1978. Pages 17-22 *in* K. H. Loftus, editor. Proceedings of the 1980 North American Eel Conference, Ontario Fisheries Technical Report Series No. 4, Ontario Ministry of Natural Resources, Toronto, Canada.

Limburg, K. E. 1996. Growth and migration of 0-year American shad (*Alosa sapidissima*) in the Hudson River estuary: Otolith microstructural analysis. Canadian Journal of Fisheries and Aquatic Sciences 53: 220-238.

Limburg, K. E., K. A. Hattala, and A. Kahnle. 2003. American shad in its native range. Pages 125-140 *in* K. E. Limburg and J. R. Waldman, editors. Biodiversity, status, and conservation of the world's shads. Proceedings of the Anadromous *Alosa* symposium, American Fisheries Society, Bethesda, Maryland.

Limburg, K. E., and R. E. Schmidt. 1990. Patterns of fish spawning in Hudson River tributaries: Response to an urban gradient? Ecology 7: 1238-1245.

Lockaby, B. G., R. H. Jones, R. G. Clawson, J. S. Meadows, J. A. Stanturf, and F. C. Thornton. 1997. Influences of harvesting on functions of floodplain forests associated with low-order, blackwater streams. Forest Ecology and Management 90: 217-224.

Loesch, J. G. 1987. Overview of life history aspects of anadromous alewife and blueback herring in freshwater habitats. Pages 89-103 *in* M. J. Dadswell, R. J. Klauda, C. M. Moffitt, and R. L. Saunders, editors. Common strategies of anadromous and catadromous fishes. American Fisheries Society Symposium 1, Bethesda, Maryland.

Loesch, J. G., and S. M. Atran. 1994. History of *Alosa* management: Virginia, a case example. Pages 1-6 *in* J. E. Cooper, R. T. Eades, R. J. Klauda, and J. G. Loesch, editors. Proceedings of the Anadromous *Alosa* Symposium, American Fisheries Society, Bethesda, Maryland.

Lofton, L. 1978. Delaware River water intake screen impingement investigations. Delaware River Basin Anadromous Fishery Project, Special Report #6.

Longwell, A. C., S. Chang, A. Herbert, J. Hughes, and D. Perry. 1992. Pollution and developmental abnormalities of Atlantic fishes. Environmental Biology of Fishes 35: 1-21.

Mac, M. J., and C. C. Edsall. 1991. Environmental contaminants and the reproductive success of lake trout in the Great Lakes: An epidemiological approach. Journal of Toxicology and Environmental Health 33: 375-394.

Machut, L. S. 2006. Population dynamics, *Anguillicola crassus* infection, and feeding selectivity of American eel (*Anguilla rostrata*) in tributaries of the Hudson River, New York. Masters thesis. State University of New York, College of Environmental Science and Forestry, Syracuse, New York.

Mackiernan, G. B. 1987. Dissolved oxygen in the Chesapeake Bay: Processes and effects. Maryland Sea Grant, College Park, Maryland.

Maldeis, R. W. 1978. Relationship between fishes and submerged aquatic vegetation in the Chesapeake Bay. Chesapeake Bay Foundation, Annapolis, Maryland.

Mallin, M. A., M. H. Posey, M. L. Moser, G. C. Shank, M. R. McIver, T. D. Alphin, S. H. Ensign, and J. F. Merritt. 1997. Environmental assessment of the lower Cape Fear River system, 1996-1997. University of North Carolina at Wilmington, Center for Marine Science Research Report No. 97-01, Wilmington, North Carolina.

Mansueti, R. J. 1962. Eggs, larvae, and young of the hickory shad, *Alosa mediocris*, with comments on its ecology in the estuary. Chesapeake Science 3: 173-205.

Mansueti, R. J., and E. H. Hollis. 1963. Striped bass in Maryland tidewater. University of Maryland Natural Resources Institute, Educational Series No. 61, College Park, Maryland.

Mansueti, R. J., and H. Kolb. 1953. A historical review of the shad fisheries of North America. Chesapeake Biological Laboratory Publication 97, Solomons, Maryland.

Marcy, B. C., Jr. 1973. Vulnerability and survival of young Connecticut River fish entrained at a nuclear power plant. Journal of the Fisheries Research Board of Canada 30: 1195-1203.

Marcy, B. C., Jr. 1976a. Planktonic fish eggs and larvae of the lower Connecticut River and effects of the Connecticut Yankee plant including entrainment. Pages 141-168 *in* D. Merriman, and L. M. Thorper, editors. The Connecticut River ecological study: The impact of a nuclear power plant. American Fisheries Society Monograph No. 1, Bethesda, Maryland.

Marcy, B. C., Jr. 1976b. Fishes of the lower Connecticut River and the effects of the Connecticut Yankee plant. Pages 61-114 *in* D. Merriman, and L. M. Thorper, editors. The Connecticut River ecological study: The impact of a nuclear power plant. American Fisheries Society Monograph No. 1, Bethesda, Maryland.

Marcy, B. C., Jr., and R. C. Galvin. 1973. Winter-spring sport fishery in the heated discharge of a nuclear power plant. Journal of Fish Biology 5: 541-547.

Marcy, B. C., Jr., P. M. Jacobson, and R. L. Nankee. 1972. Observations on the reactions of young American shad to a heated effluent. Transactions of the American Fisheries Society 191: 740-743.

Martin, P., N. Taft, and C. Sullivan. 1994. Reducing entrainment of juvenile American shad using a strobe light diversion system. Pages 57-63 *in* J. E. Cooper, R. T. Eades, R. J. Klauda, and J. G. Loesch, editors. Anadromous *Alosa* Symposium, Tidewater Chapter, American Fisheries Society, Bethesda, Maryland.

Martineau, D., P. Béland, C. Desjardins, and A. Lagacé. 1987. Levels of organochlorine chemicals in tissues of beluga whales *Delphinaoterus leucas* from the St. Lawrence Estuary, Québec, Canada. Archives of Environmental Contamination and Toxicology 16: 137-147.

Massé, R., D. Martineau, L. Tremblay, and P. Béland. 1986. Concentrations and chromatographic profile of DDT metabolites and polychlorobiphenyl (PCB) residues in stranded beluga whales *Delphinaoterus leucas* from the St. Lawrence estuary, Canada. Archives of Environmental Contamination and Toxicology 15: 567-579.

Mathur, D., and P. G. Heisey. 1992. Debunking the myths about fish mortality at hydro plants. Hydro Review 11: 54-60.

Matthews, T. D., F. W. Stapor, Jr., C. R. Richter, J. V. Miglarese, M. D. McKenzie and L. A. Barclay, editors. 1980. Ecological characterization of the Sea Island coastal region of South Carolina and Georgia, volume I: Physical features of the characterization area. U.S. Fish and Wildlife Service, Office of Biological Services Report No. FWS/OBS-79/40, Washington, D.C.

Maurice, K. R., R. W. Blye, and P. L. Harmon. 1987. Increased spawning by American shad coincident with improved dissolved oxygen in the tidal Delaware River. Pages 79-88 *in* M. J. Dadswell, R. J. Klauda, C. M. Moffitt, and R. L. Saunders, editors. Proceedings of the international symposium on common strategies of anadromous and catadromous fishes. American Fisheries Society, Bethesda, Maryland.

McBride, M. 2006. Managed fisheries of the Chesapeake Bay. Pages 13-79 *in* Chesapeake Bay Fisheries Ecosystem Advisory Panel (National Oceanic and Atmospheric Administration Chesapeake Bay Office)). Fisheries ecosystem planning for Chesapeake Bay. American Fisheries Society Trends in Fisheries Management 3, Bethesda, Maryland.

McCleave, J. D. 2001. Simulation of the impact of dams and fishing weirs on reproductive potential of silver-phase American eels in the Kennebec River Basin, Maine. North American Journal of Fisheries Management 21: 592-605.

McCord, J. W. 2003. Investigation of fisheries parameters for anadromous fishes in South Carolina. Completion Report to the National Marine Fisheries Service, Project No. AFC-53. South Carolina Department of Natural Resources, Charleston, South Carolina.

McCord, J. W. 2005a. South Carolina's Comprehensive Wildlife Conservation Strategy: Alosids. South Carolina Department of Natural Resources, Columbia, South Carolina.

McCord, J. W. 2005b. South Carolina's Comprehensive Wildlife Conservation Strategy: American eel. South Carolina Department of Natural Resources, Columbia, South Carolina.

McCord, J. W. 2005c. South Carolina's Comprehensive Wildlife Conservation Strategy: Sturgeon. South Carolina Department of Natural Resources, Columbia, South Carolina.

McGrath, K. J., S. Ault, J. Skalski, C. Fleury, and A. Fairbanks. 2003. Avoidance of artificial light by downstream migrating American eel (*Anguilla rostrata*) in the St, Lawrence River. Conference abstract from American Fisheries Society Annual Meeting – Eel Symposium, Quebec City, Quebec, Canada.

MEOEA (Commonwealth of Massachusetts, Executive Office of Environmental Affairs). 2005. 2005 Massachusetts Comprehensive Wildlife Conservation Strategy. Available: http://www.mass.gov/dfwele/dfw/habitat/cwcs/pdf/mass_cwcs_final.pdf.

Mesing, C. L., and L. A. Ager. 1987. Dredged material disposal impact on habitat quality and gamefish populations of the Apalachicola River. Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies 41: 111-118.

Miller, J. P., F. R. Griffiths, and P. A. Thurston-Rogers. 1982. The American shad (*Alosa sapidissima*) in the Delaware River Basin. Delaware Basin Fish and Wildlife Management Cooperative.

Mitchell, S. 1999. A simple model for estimating mean monthly stream temperatures after riparian canopy removal. Environmental Management 24: 77-83.

Mobley, M. H., and W. G. Brock. 1996. Aeration of reservoirs and releases using TVA porous hose line diffuser. American Society of Civil Engineers North American Congress on Water and Environment, Anaheim, California.

Moffitt, C. M., B. Kynard, and S. G. Rideout. 1982. Fish passage facilities and anadromous fish restoration in the Connecticut River basin. Fisheries 7: 1-10.

Monk, K. S. 1988. The effect of submerged aquatic vegetation on zooplankton abundance and diversity in the tidal freshwater Potomac River. Masters thesis. George Mason University, Fairfax, Virginia.

Monten, E. 1985. Fish and turbines: Fish injuries during passage through power station turbines. Vattenfall, Stockholm.

Morgan, R. P., II, R. E. Ulanowicz, V. J. Rasin, Jr., L. A. Noe, and G. B. Gray. 1976. Effects of shear on eggs and larvae of striped bass, *Morone saxatilis*, and white perch, *M. americana*. Transactions of the American Fisheries Society 105: 149-154.

Morrison, W. E., and D. H. Secor. 2003. Demographic attributes of yellow-phase American eels (*Anguilla rostrata*) in the Hudson River estuary. Canadian Journal of Fisheries and Aquatic Sciences 60: 1487-1501.

Morrison, W. E., D. H. Secor, and P. M. Piccoli. 2003. Estuarine habitat use by Hudson River American eels as determined by otolith strontium : calcium ratios. Pages 87-99 *in* D. A. Dixon, editor. Biology, management, and protection of catadromous eels. American Fisheries Society, Symposium 33, Bethesda, Maryland.

Morton, J. W. 1977. Ecological effects of dredging and dredge disposal: A literature review. U.S. Fish and Wildlife Service, Technical Paper No. 94, Washington, D.C.

Murty, A. S., and A. P. Devi. 1982. The effect of endosulfan and its isomers on tissue protein Glycogen, and lipids in the fish, *Channa punctata*. Pesticide Biochemistry and Physiology 17: 280-286.

NA (Normandeau Associates, Inc.). 2001. Adult American shad movement and behavior in the vicinities of Conowingo and Holtwood Hydroelectric Stations, Susquehanna River, during spring 2001. Report prepared for Pennsylvania Power & Light Company, Exelon Corporation, and the USFWS, Allentown, Pennsylvania.

NA (Normandeau Associates, Inc.), and J. R. Skalski. 1998. Estimation of survival of American eel after passage through a turbine at the St. Lawrence-FDR Power Project, New York. Draft Final Report prepared for New York Power Authority, White Plains, New York.

NCDENR (North Carolina Department of Environment and Natural Resources). 2000. North Carolina fishery management plan: Albemarle Sound area river herring. North Carolina Division of Marine Fisheries, Morehead City, North Carolina.

NC WRC (North Carolina Wildlife Resources Commission). 2005. North Carolina Wildlife Action Plan. Available: http://www.wildlifeactionplans.org/pdfs/action_plans/nc_action_plan.pdf.

Neves, R. J., A. E. Bogan, J. D. Williams, S. A. Ahlstedt, and P. W. Hartfield. 1997. Status of aquatic mollusks in the southeastern United States: A downward spiral of diversity. Pages 43-85 *in* G. W. Benz, and D. E. Collins, editors. Aquatic fauna in peril: The southeastern perspective. Southeast Aquatic Research Institute, Special Publication 1, Decatur, Georgia.

Niklitschek, E. J. 2001. Bioenergetics modeling and assessment of suitable habitat for juvenile Atlantic and shortnose sturgeons (*Acipenser oxyrinchus* and *A. brevirostrum*) in the Chesapeake Bay. Doctoral dissertation. University of Maryland at College Park, Solomons, Maryland.

Niklitschek, E. J., and D. H. Secor. 2005. Modeling spatial and temporal variation of suitable nursery habitats for Atlantic sturgeon in the Chesapeake Bay. Estuarine and Coastal Shelf Science 64: 135-148.

NRC (National Research Council). 1996. Upstream: Salmon and society in the Pacific Northwest. National Academy Press, Washington, D.C.

Officer, C. B., R. B. Biggs, J. L. Taft, L. E. Cronin, M. A. Tyler, and W. R. Boynton. 1984. Chesapeake Bay anoxia: Origin, development, and significance. Science 223: 22-27.

Oliveira, K., and J. D. McCleave. 2000. Variation in population and life history traits of the American eel, *Anguilla rostrata,* in four rivers in Marine. Environmental Biology of Fishes 59: 141-151.

Olney, J. E., D. A. Hopler, Jr., T. P. Gunter, Jr., K. L. Maki, and J. M. Hoenig. 2003. Signs of recovery of American shad in the James River, Virginia. Pages 323-329 *in* K. E. Limburg and J. R. Waldman, editors. Biodiversity, status, and conservation of the world's shads. American Fisheries Society Symposium 35, Bethesda, Maryland.

Orlando, S. P., Jr., P. H. Wendt, C. J. Klein, M. E. Pattillo, K. C. Dennis, and G. H. Ward. 1994. Salinity characteristics of South Atlantic estuaries. National Oceanic and Atmospheric Administration, Office of Ocean Resources Conservation and Assessment, Silver Spring, Maryland.

Orson, R., W. Panageotou, and S. P. Leatherman. 1985. Response of tidal salt marshes of the U.S. Atlantic and Gulf coasts to rising sea levels. Journal of Coastal Research 1: 29-37.

Orth, R. J., J. F. Nowak, A. A. Frisch, K. Kiley, and J. Whiting. 1991. Distribution of submerged aquatic vegetation in the Chesapeake Bay and tributaries and Chincoteague Bay – 1990. U.S. Environmental Protection Agency, Chesapeake Bay Program, Annapolis, Maryland.

Osborne, L. L., and M. J. Wiley. 1988. Empirical relationships between land use/cover and stream water quality in an agricultural watershed. Journal of Environmental Management 26: 9-27.

Paerl, H. W., M. B. Harrington, and T. L. Richardson. 1999. The role of atmospheric N deposition in coastal eutrophication: Current issues and perspectives. Page 46 *in* V. P. Anega, Chair. Workshop on atmospheric nitrogen compounds II: Emissions, transport, transformation, deposition and assessment. Abstracts Book. Department of Marine, Earth, and Atmospheric Sciences, North Carolina State University, Raleigh, North Carolina.

Parsley, M. J., L. G. Beckman, and G. T. McCabe, Jr. 1993. Spawning and rearing habitat use by white sturgeons in the Columbia River downstream from McNary Dam. Transactions of the American Fisheries Society 122: 217-228.

Patrick, P. H., R. W. Sheehan, and B. Sim. 1982. Effectiveness of a strobe light eel exclusion scheme. Hydrobiologia 94: 269-277.

Peterjohn, W. T., and D. L. Correll. 1984. Nutrient dynamics in an agricultural watershed: Observations on the role of a riparian forest. Ecology: 1466-1475.

Polgar, T. T. 1982. Factors affecting recruitment of Potomac River striped bass and resulting implications for management. Pages 427-442 *in* V. S. Dennedy, editor. Estuarine comparisons. Academic Press, New York, New York.

Polis G. A., S. D. Hurd, C. T. Jackson, and F. Sanchez-Piñero. 1997. El Niño effects on the dynamics and control of an island ecosystem in the Gulf of California. Ecology 78: 1884-1897.

Post, G. W. 1987. Revised and expanded textbook of fish health. T. F. H. Publications, Neptune City, New Jersey.

Quinn, T. P. 1994. Anthropogenic influences on fish populations of the Georgia Basin, part I: Salmonids. Pages 219-229 *in* R. C. H. Wilson, R. J. Beamish, F. Aitkens, and J. Bell, editors. Review of the Marine Environment and Biota of Strait of Georgia, Puget Sound and Juan de Fuca Strait. Canadian Technical Report of Fisheries and Aquatic Sciences 1948, Vancouver, British Columbia.

Quinn, J. M., R. B. Williamson, R. K. Smith, and M. L. Vickers. 1992. Effects of riparian grazing and channelization on streams in Southland, New Zealand, Number 2: Benthic macroinvertebrates. New Zealand Journal of Marine and Freshwater Research 26: 259-273.

Ramade, F., R. Cosson, M. Echaubard, S. Le bras, J. C. Moreteau, and E. Thybaud. 1984. Détection de la pollution des eaux en milieu agricole. Bulletin D'Ecologie 15: 21-37.

Regier, H. A., J. J. Magnuson, and C. C. Coutant. 1990. Introduction to proceedings: symposium on effects of climate change on fish. Transactions of the American Fisheries Society 119: 173-175.

Rehwoldt, R. E., W. Mastrianni, E. Kelley, and J. Stall. 1978. Historical and current heavy metal residues in Hudson River fish. Bulletin of Environmental Toxicology 19: 335-339.

Reine, K. J., D. D. Dickerson, and D. G. Clarke. 1998. Environmental windows associated with dredging operations. Dredging Operations and Environmental Research Technical Notes Collection No. TN DOER-E2. U.S. Army Engineer Ressearch and Development Center, Vicksburg, Mississippi.

Reinert, T. R., C. A. Jennings, T. A. Will, and J. E. Wallin. 2005. Decline and potential recovery of striped bass in a southeastern U.S. estuary. Fisheries 30: 18-25.

Richkus, W. A., and D. A. Dixon. 2003. Review of research and technologies on passage and protection of downstream migrating catadromous eels at hydroelectric facilities. American Fisheries Society Symposium 33: 377-388.

Richkus, W. A., and K. G. Whalen. 1999. American eel (*Anguilla rostrata*) scoping study report. Final Report prepared by Versar, Inc., for Electric Power Research Institute, Palo Alto, California.

RMC (Research, Management, and Conservation Environmental Services Ltd.). 1991. Preliminary evaluation of the log chute at Holtwood hydroelectric project as a downstream passage route and effects of stream station thermal discharge on emigrating juvenile shad. Report prepared for Pennsylvania Power and Light Company, Allentown, Pennsylvania.

RMC (Research, Management, and Conservation Environmental Services Ltd.). 1992. Turbine passage survival of juvenile American shad (*Alosa sapidissima*) at the Holtwood Hydroelectric Station, Pennsylvania. Report prepared for Pennsylvania Power and Light Company, Allentown, Pennsylvania.

RMC (Research, Management, and Conservation Environmental Services Ltd.). 1994. Turbine passage survival of juvenile American shad (*Alosa sapidissima*) at Conowingo Hydroelectric Station (FERC Project No. 405), Susquehanna River, Maryland. Report prepared for Susquehanna Electric Company, Darlington, Maryland.

RMC (Research, Management, and Conservation Environmental Services Ltd.). 1995. Luray/Newport Hydro Project, Warren Hydro Project, and Shenandoah Hydro Project, Shenandoah River, Virginia: Report on studies to evaluate American eel passage. Report prepared for Allegheny Power Service Corporation, Greensburg, Pennsylvania.

Robbins, T. W., and M. Mathur. 1976. The Muddy Run pumped storage project: A case history. Transactions of the American Fisheries Society 105: 165-172.

Robinet, T., and E. Feunteun. 2002. Sublethal effects of exposure to chemical compounds: A cause for the decline in Atlantic eels? Ecotoxicology 11: 265-277.

Roseboom, D., R. L. Evans, J. Erickson, and L. G. Brooks. 1982. An inventory of Court Creek watershed characteristics that may relate to water quality in the watershed. SWS Contract Report No. 322, Illinois Department of Energy and Natural Resources, Springfield, Illinois.

Ross, R. M., R. M Bennett, and T. W. H. Backman. 1993. Habitat use and spawning adult, egg, and larval American shad in the Delaware River. Rivers 4: 227-238.

Rounsefell, G. A., and L. D. Stringer. 1943. Restoration and management of the New England alewife fisheries with special reference to Maine. U. S. Fish and Wildlife Service, Fishery Leaflet 42, Washington, D.C.

Rulifson, R. A. 1994. Status of anadromous *Alosa* along the east coast of North America. Pages 134-159 *in* J. E. Cooper, R. T. Eades, R. J. Klauda, and J. G. Loesch, editors. Anadromous *Alosa* Symposium. Tidewater Chapter, American Fisheries Society Symposium, Bethesda, Maryland.

Rulifson, R. A., S. A. McKenna, and M. L. Gallagher. 1987. Tagging studies of striped bass and river herring in upper Bay of Fundy, Nova Scotia. North Carolina Department of Natural Resources and Community Development, Division of Marine Fisheries, Project No. AFC-28-1 Completion Report, Morehead City, North Carolina, and East Carolina University, Institute for Coastal and Marine Resources, Technical Report No. 87-02, Greenville, North Carolina.

Rybicki, N. B., and R. Hammerschlag. 1991. Effects of submerged macrophytes on dissolved oxygen, pH, and temperature under different conditions of wind, tide, and bed structure. Journal of Freshwater Ecology 6: 121-133.

Safe, S. 1990. Polychlorinated biphenyls (PCBs), dibenzo-*p*-dioxins (PCDDs), dibenzofurans (PCDFs), and related compounds: Environmental and mechanistic considerations which support the development of toxic equivalency factors. Critical Reviews in Toxicology 21: 51-88.

Sancho, E., M. D. Ferrando, and E. Andreu. 1998. Effects of sublethal exposure to a pesticide on levels of energetic compounds in *Anguilla rostrata*. Journal of Environmental Science and Health, Part B 33: 411-424.

Scarratt, D. J., and M. J. Dadswell. 1983. New approaches to tidal power. Fisheries and Environmental Sciences, Department of Fisheries and Oceans, Biological Station, St. Andrews, New Brunswick, Canada.

Schofield, C. L. 1992. The watershed as an experimental unit in fisheries research. American Fisheries Society Symposium 13: 69-79.

Schubel, J. R., T. S. Y. Koo, and C. F. Smith. 1976. Thermal effects of power plant entrainment on survival of fish eggs and larvae: A laboratory assessment. Johns Hopkins University, Chesapeake Bay Institute, Special Report No. 52, Reference No. 76-5, Baltimore, Maryland.

Secor, D. H., P. J. Anders, W. Van Winkle, and D. A. Dixon. 2002. Can we study sturgeons to extinction? What we do and don't know about the conservation of North American sturgeons. Pages 3-10 *in* W. Van Winkle, P. J. Anders, D. H. Secor, and D. A. Dixon, editors. Biology, management, and protection of North American sturgeon. American Fisheries Society Symposium 28, Bethesda, Maryland.

Secor, D. H., and T. E. Gunderson. 1998. Effects of hypoxia and temperature on survival, growth, and respiration of juvenile Atlantic sturgeon, *Acipenser oxyrinchus*. Fisheries Bulletin 96: 603-613.

Secor, D. H., and E. J. Niklitschek. 2001. Hypoxia and sturgeons. Chesapeake Biological Laboratory, University of Maryland Center for Environmental Science Technical Report Series No. TS-314-01-CBL, Solomons, Maryland.

Secor, D. H., and E. Niklitschek. 2002. Sensitivity of sturgeons to environmental hypoxia: A review of the physiological and ecological evidence. Pages 61-78 in R. V. Thurston, editor. Fish Physiology, Toxicology, and Water Quality. Proceedings of the Sixth International Symposium, La Paz, Mexico. U.S. Environmental Protection Agency Office of Research and Development, Ecosystems Research Division Report No. EPA/600/R-02/097, Athens, Georgia.

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

Sessions, F., S. Lamprecht, and J. Bettinger. 2005. South Carolina's comprehensive wildlife conservation strategy: Moderate conservation priority- Big river species. South Carolina Department of Natural Resources, Columbia, South Carolina.

Sherk, J. A., J. M. O'Connor, and D. A. Neumann. 1975. Effects of suspended and deposited sediments on estuarine environments. Pages 541-558 *in* L. E. Cronin, editor. Estuarine research 2. Academic Press, New York.

Sherk, J. A., J. M. O'Connor, D. A. Neumann, R. D. Prince, and K. V. Wood. 1974. Effects of suspended and deposited sediments on estuarine organisms, phase II. Reference No. 74-20, Natural Resource Institute, University of Maryland, College Park, Maryland.

Simpson, P. W., J. R. Newman, M. A. Keirn, R. M. Matter, and P. A. Guthrie. 1982. Manual of stream channelization impacts on fish and wildlife. U.S. Fish and Wildlife Service Report No. FWS/OBS-82/24, Washington, D.C.

Singh, P. B. 1992. Impact of malathion and y-BHC on lipid metabolism in the freshwater female catfish, *Heteropneutes fossilus*. Ecotoxicology and Environmental Safety 23: 22-32.

Skinner, J. E. 1974. A functional evaluation of a large louver screen installation and fish facilities research on California water diversion project. Pages 225-250 *in* L. D. Jensen, editor. Second workshop on entrainment and screening. Electric Power Research Institute, Publication No. 74-049-00-5, Palo Alto, California.

Smith, T. I. J., and J. P Clugston. 1997. Status and management of Atlantic sturgeon, *Acipenser oxyrhinchus*, in North America. Environmental Biology of Fishes 48: 335-346.

Smogor, R. A., P. L. Angermeier, and C. K. Gaylord. 1995. Distribution and abundance of American eels in Virginia streams: Test of null models across spatial scales. Transactions of the American Fisheries Society 124: 789-803.

Soloman, D. J., and M. H. Beach. 2004. Fish pass design for eel and elver (*Anguilla anguilla*). Environment Agency Research and Development Technical Report No. W2-070/TR1, Bristol, England.

Southerland, M., E. Rzemien, N. Roth, and L. Corio. 1997. Atmospheric deposition in Maryland: Assessment of status, trends, and environmental effects. Versar, Inc. Report No. CBWP-MANTA-AD-97-6, and NTIS No.PB98-119274, Springfield, Virginia.

Spagnoli, L. L., and L. C. Skinner. 1977. PCB's in fish from selected waters of New York State. Pesticide Monitoring Journal 11: 69-87.

Squiers, T. S. 2001. State of Maine: Atlantic sturgeon compliance report to the Atlantic States Marine Fisheries Commission. Atlantic States Marine Fisheries Commission, Washington, D.C.

St. Pierre, R. 1994. American shad restoration in the Susquehanna River. Pages 81-85 *in* J. E. Cooper, R. T. Eades, R. J. Klauda, and J. G. Loesch, editors. Anadromous *Alosa* Symposium, Tidewater Chapter, American Fisheries Society, Bethesda, Maryland.

St. Pierre, R. A. 2003. A case history: American shad restoration on the Susquehanna River. Pages 315-321 *in* K. E. Limburg, and J. R. Waldman, editors. Biodiversity, status, and conservation of the world's shads. American Fisheries Society Symposium Series 35, Bethesda, Maryland.

Stein, A. B., K. D. Friedland, and M. Sutherland. 2004. Sturgeon marine distribution and habitat use along the northeast coast of the United States. Transactions of the American Fisheries Society 133: 527-537.

Summers, K. 2001. National coastal condition report. U. S. Environmental Protection Agency, Office of Research and Development, Office of Water Report No. EPA-620/R-01/005, Washington, D.C.

Summers, K. 2004. National coastal condition report II. U. S. Environmental Protection Agency, Office of Research and Development, Office of Water Report No. EPA-620-R-03/002, Washington, D.C.

Svedäng, H., and H. Wickström. 1997. Low fat contents in female silver eels: Indications of insufficient energetic stores for migration and gonadal development. Journal of Fish Biology 50: 475-486.

Taylor, G. L. 1977. The effect of clearcutting on benthic macroinvertebrates in a forest stream in the southern coastal plain. Masters thesis. Stephen F. Austin State University, Nagodoches, Texas.

Taylor, R., and B. Kynard. 1984. Studies of downrunning adult alosids in the Holyoke Dam canal system -1983. Final Report to Northeast Utilities Service, Hartford, Connecticut.

Travade, F., and M. Larinier. 1992. La migration de devalaison: Problemes et dispositifs. Bulletin Francaise de la Peche et de la Pisciculture 326-327: 165-176.

Tuttle, J. H., R. B. Jonas, and T. C. Malone. 1987. Origin, development and significance of Chesapeake Bay anoxia. Pages 442-472 *in* S. K. Majumdar, L. W. Hall, Jr., and H. M. Austin, editors. Contaminant problems and management of living Chesapeake Bay resources. Pennsylvania Academy of Science, Easton, Pennsylvania.

Tyler, R. M., and T. E. Targett. 2007. Juvenile weakfish *Cynoscion regalis* distribution in relation to diel-cycling dissolved oxygen in an estuarine tributary. Marine Ecology Progress Series 333: 257-267.

USFWS-NMFS (United States Fish and Wildlife Service and National Marine Fisheries Service). 1998. Status review of Atlantic sturgeon (*Acipenser oxyrinchus oxyrinchus*). Special report submitted in response to a petition to list the species under the Endangered Species Act. Hadley and Gloucester, Massachusetts.

USFWS (United States Fish and Wildlife Service), NMFS (National Marine Fisheries Service), and SC DNR (South Carolina Department of Natural Resources). 2001. Santee-Cooper Basin diadromous fish passage restoration plan.

Uzee, A. M., and P. L. Angermeier. 1993. Analysis of impediments to spawning migrations of anadromous fishes in Rappahannock and Chickahominy river drainages, Virginia. Final Report, Virginia Highway Research Council, Virginia Department of Highways and Transportation, Charlottesville, Virginia.

VA DGIF (Virginia Department of Game and Inland Fisheries). 2005. Virginia's Comprehensive Wildlife Conservation Strategy. Available: http://www.wildlifeactionplans.org/pdfs/action_plans/va_action_plan.pdf.

VA DGIF (Virginia Department of Game and Inland Fisheries). 2006. Bosher's Dam and Fishway. 22 March 2006. http://www.dgif.state.va.us/fishing/shad/boshers.html.

Valdes-Murtha, L. M., and K. S. Price. 1998. Analysis of critical habitat requirements for restoration and growth of submerged vascular plants in Delaware and Maryland coastal bays. Masters thesis. University of Delaware College of Marine Studies, Lewes, Delaware.

Van der Oost, R., H. Heida, and A. Opperhuizen. 1988. Polychlorinated biphenyl congeners in sediments, plankton, molluscs, crustaceans, and eel in a freshwater lake: Implications of using reference chemicals and indicator organisms in bioaccumulation studies. Archives of Environmental Contamination and Toxicology 17: 721-729.

Vaughn, C. C., and C. M. Taylor. 1999. Impoundments and the decline of freshwater mussels: A case study in extinction gradient. Conservation Biology 13: 912-920.

Verdon, R. 1998. Upstream fishways for eels. American eel biology and management symposium, August 26, 1998. American Fisheries Society Annual Meeting, Hartford, Connecticut.

Verdon, R., D. Desrochers, and P. Dumont. 2003. Recruitment of American eels in the Richelieu River and Lake Champlain: Provision of upstream passage as a regional-scale solution to a large scale problem. Pages 125-138 *in* D. A. Dixon, editor. Biology, management, and protection of catadromous eels. American Fisheries Society Symposium 33, Bethesda, Maryland.

Verreault, G., P. Dumont, and Y. Mailhot. 2004. Habitat losses and anthropogenic barriers as a cause of population decline for American eel (*Anguilla rostrata*) in the St. Lawrence watershed, Canada. Preliminary Report No. ICES CM 2004/S:04 from 2004 ICES Annual Science Conference held September 22-25, 2004, Vigo, Spain.

Veshchev, P. V. 1981. Effect of dredging operations in the Volga River on migration of sturgeon larvae. Journal of Ichthyology 21: 108-112.

Walburg, C. H., and P. R. Nichols. 1967. Biology and management of the American shad and status of the fisheries, Atlantic coast of the United States, 1960. U.S. Fish and Wildlife Service Special Science Report for Fisheries 550, Washington, D.C.

Waldman, J. R., and K. E. Limburg. 2003. The world’s shads: Summary of their status, conservation, and research needs. Pages 363-369 *in* K. E. Limburg, and J. R. Waldman, editors. Biodiversity, status, and conservation of the world's shads. American Fisheries Society Symposium Series 35, Bethesda, Maryland.

Watters, G. T. 1996. Small dams as barriers to freshwater mussels (Bivalvia, Unionoida) and their hosts. Biological Conservation 75: 79-85.

Weaver, L. A., M. T. Fisher, B. T. Bosher, M. L. Claud, and L. J. Koth. 2003. Boshers Dam vertical slot fishway: A useful tool to evaluate American shad recovery efforts in the upper James River. Pages 323-329 *in* K. E. Limburg, and J. R. Waldman. Biodiversity, status, and conservation of the world's shads. American Fisheries Society Symposium 35, Bethesda, Maryland.

Webster, J. R., S. W. Golladay, E. F. Benfield, J. L. Meyer, W. T. Swank, and J. B. Wallace. 1992. Catchment disturbance and stream response: An overview of stream research at Cowetta Hydrologic Laboratory. Pages 231-254 *in* P. J. Boon, P. Calow, and G. E. Petts, editors. River conservation and management. John Wiley & Sons Ltd., New York, New York.

Wesche, T. A. 1985. Stream channel modifications and reclamation structures to enhance fish habitat. Pages 103-163 *in* J. A. Gore, editor. The restoration of rivers and streams. Butterworth Publishers, Stoneham, Massachusetts.

Westin, D. T., and B. A. Rogers. 1978. Synopsis of the biological data on the striped bass. University of Rhode Island Marine Technical Report No. 67: 1-154.

Wilber, W. G., and J. V. Hunter. 1977. Aquatic transport of heavy metals in the urban environment. Water Resources Bulletin 13: 721-734.

Wiley, D. J., R. P. Morgan, II, R. H. Hilderbrand, R. L. Raesly, and D. L. Shumway. 2004. Relations between physical habitat and American eel abundance in five river basins in Maryland. Transactions of the American Fisheries Society 133: 515-526.

Wiley, M., and C. -F. Tsai. 1990. Comparision of fish community structure and fish stock abundance in the Patuxent Estuary between 1965-1968 and 1988-1989. Pages 566-605 *in* B. J. Rothschild, editor. Development of a sampling expert system: "FISHMAP". University of Maryland Chesapeake Biological Laboratory Final Report CEES Reference No. [UMCEES]CBL 90-090, Solomons, Maryland.

Williams, J. D., M. L. Warren, Jr., K. S. Cummings, J. L. Harris, and R. J. Neves. 1993. Conservation status of freshwater mussels of the United States and Canada. Fisheries 18: 6-22.

Winslow, S. E., N. S. Sanderlin, G. W. Judy, J. H. Hawkins, B. F. Holland, Jr., C. A. Fischer, and R. A. Rulifson. 1983. North Carolina anadromous fisheries management program. North Carolina Division of Marine Fisheries Completion Report for Project No. AFCS-16, Morehead City, North Carolina.

Wippelhauser, G. S., L. Flagg, J. D. McCleave, J. Moring, K. Oliveira, J. Brockway, M. Cieri, and L. Daniels. 1998. Eel and elver progress report February 1998. Maine Department of Marine Resources, Stock Enhancement Division, Augusta, Maine.

Wires, L. R., F. J. Cuthbert, D. R. Trexel, and A. R. Joshi. 2001. Status of the double-crested cormorant (*Phalacrocorax auritus*) in North America. Final Report to U.S. Fish and Wildlife Service. University of Minnesota, Department of Fisheries and Wildlife, St. Paul, Minnesota.

Yadav, A. K., and T. P. Singh. 1987. Pesticide-induced impairment of thyroid physiology in the freshwater catfish, *Heteropneutes fossilis*. Environmental Pollution 43: 29-38.

Yeager, B. 1995. Dams. Pages 57-92 *in* C. F. Bryan, and D. Allen Rutherford, editors. Impacts on warmwater streams: Guidelines for evaluation. American Fisheries Society, Bethesda, Maryland.

Zale, A. V., O. E. Maughan, D. J.Orth, and W. Layher. 1993. Withdrawals. Pages 271-280 *in* C. F. Bryan, and D. A. Rutherford, editors. Impacts on warmwater streams: Guidelines for evaluation, second edition. American Fisheries Society Southern Division, Little Rock, Arkansas.