*Atlantic States Marine Fisheries Commission*

# AMENDMENT 2 to the Interstate Fishery Management Plan For SHAD AND RIVER HERRING (River Herring Management)

***ASMFC Vision Statement:***
***Healthy, self-sustaining populations for all Atlantic coast fish species or successful restoration well in progress by the year 2015.***

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# Amendment 2 to the Interstate Fishery Management Plan for Shad and River Herring

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# 1. INTRODUCTION

The Atlantic States Marine Fisheries Commission (Commission) is developing an amendment to its Interstate Fishery Management Plan for Shad and River Herring (FMP) under the authority of the Atlantic Coastal Fisheries Cooperative Management Act (ACFCMA). Shad and river herring management authority lies with the coastal states and is coordinated through the Commission. Responsibility for compatible management action in the Exclusive Economic Zone (EEZ) from 3-200 miles from shore lies with the Secretary of Commerce through ACFCMA in the absence of a federal fishery management plan.

**PLEASE NOTE:** While the FMP is the management document for American shad (*Alosa sapidissima*), hickory shad (*Alosa mediocris*), blueback herring (*Alosa aestivalis*) and alewife (*Alosa pseudoharengus*), **this amendment pertains only to blueback herring and alewife.** The adoption of this amendment would not alter the monitoring requirements or fishery management measures for either American shad or hickory shad.

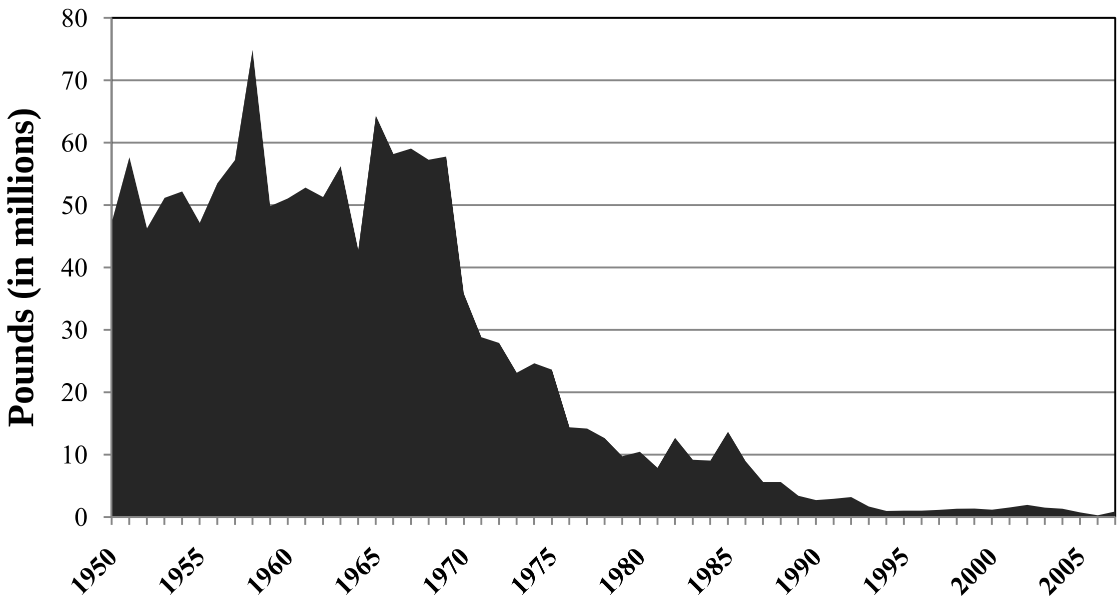
## 1.1 BACKGROUND INFORMATION

### 1.1.1 Statement of the Problem

Many populations of blueback herring (*Alosa aestivalis*) and alewife (*Alosa pseudoharengus*), collectively known as *river herring*, have faced anthropogenic threats since colonial times, including fishing (commercial and recreational) and both habitat loss and degradation (e.g., dam construction, siltation, pollution). Stock assessments have identified that many populations of river herring along the Atlantic coast are in decline or are at depressed but stable levels (NC DMF 2006; Crecco and Gibson 1990); however, lack of fishery-dependent and independent data make it difficult to ascertain the status of river herring stocks coastwide. Based on available landings records from the National Marine Fisheries Service (NMFS), commercial landings dropped from 13.7 million pounds in 1985 to under a million pounds in 2007, which represents a difference of 93% (Figure 1; NMFS, Fisheries Statistics Division, Silver Spring, MD, pers. comm.).

The closure of river herring fisheries by Atlantic coastal states (i.e., Massachusetts, Rhode Island, Connecticut, Virginia and North Carolina) and observed declines in river herring abundance have led to questions about the adequacy of current management of the species to promote healthy fish stocks. Amendment 1 to the FMP states in its objectives that existing regulations for river herring fisheries “should keep fishing mortality sufficiently low to ensure survival and enhancement of depressed stocks and the maintenance of stabilized stocks” (ASMFC 1999); however, questions regarding mortality levels and whether they are low enough to prevent further stock declines have arisen. The Commission and the public have also expressed concern over the lack of monitoring of river herring populations, fisheries and bycatch. This document has been developed to address these questions and concerns.

**Figure 1.** Total (in-river and ocean) commercial landings (pounds) of river herring for the U.S. Atlantic coast, 1950-2007 (Source: NMFS, Fisheries Statistics Division, Silver Spring, MD, pers. comm.). Note: Prior to 2000, NMFS landings do not differentiate between alewife and blueback herring and all river herring landings are listed as “alewife” landings.




### 1.1.2 Benefits of Implementation

***Social and Economic Benefits***

Maintaining the stability of the overall river herring population will enhance the economic and social benefits attributable to this population in Commission member states and the nation. Economic benefits would include use (e.g., consumptive use values related to commercial and recreational fishing) and non-use values (e.g., existence values) for current and future generations. The alternative state management (“conservation equivalency”) approach for river herring will also be beneficial because it facilitates flexibility for state fishery management agencies to address socioeconomic considerations within their own states while achieving conservation targets. Identifying monitoring requirements and research needs is critical. Considering the socioeconomic aspects of river herring management at the state and regional level should increase the likelihood of implementing or continuing those monitoring and research tasks.

#### *1.1.2.1 Ecological Benefits*[1]

During all life stages, river herring contribute greatly to the dynamics of food chains in freshwater, estuarine or marine habitats (Facey *et al*. 1986; MacKenzie *et al*. 1985; Weiss-Glanz *et al*. 1986). While at sea, river herring are prey for many species including sharks, tunas, mackerel and marine mammals, including porpoise and dolphin (ASMFC 1999; Weiss-Glanz *et al*. 1986). In fresh and brackish waters, American eel and striped bass consume both adult and juvenile alosines (Facey *et al*. 1986; Mansueti and Kolb 1953; Savoy and Crecco 1995; Walburg and Nichols 1967). Juvenile herring are high quality prey for largemouth bass (*Micropterus salmoides*); accelerated growth of young bass occurs when herring consumption is high (Yako *et al*. 2000). Tissues taken from predatory fish in tidal freshwaters following the residency of migrating alosines had between 35 and 84 percent of their carbon-biomass derived from marine sources (Garman and Macko 1998; MacAvoy *et al*. 2000). East Coast river herring, particularly populations in the southeast where post-spawning mortality is highest, likely provide nutrients and carbon into riverine systems, similar to nutrient dynamics provided by salmon in the Pacific Northwest (Freeman *et al*. 2003). For example, the James River, Virginia may have received annual biomass input from alosines of 155 kg/ha (138 pounds/acre) before dams blocked migrations above the fall line (Garman 1992).

More than 40 species of birds and mammals congregate to feed on migrating anadromous fish in southeastern Alaska (Willson and Halupka 1995; Willson *et al*. 1998). Similar relationships likely occur between East Coast river herring and birds and mammals (Steven Gephard, Connecticut Department of Environmental Protection, pers. comm.). Fish-eating birds like osprey (*Pandion haliaetus*) and bald eagle (*Haliaeetus leucocephalus*), prey upon river herring (John W. McCord, South Carolina DNR, pers. comm.) and may have evolved their late winter and spring nesting strategies in response to the availability of food resources supplied by pre and post-spawning alosines. In addition, nutrients released from carcasses of post-spawning alosines can substantially subsidize aquatic food webs by stimulating productivity of bacteria and aquatic vegetation (Kline *et al*. 1993; Richey *et al*. 1975), thereby stimulating the assimilation of marine-derived nutrients into aquatic invertebrates and fish (Bilby *et al*. 1996).

## 1.2 DESCRIPTION OF THE RESOURCE

A comprehensive description of the Atlantic coast stocks of American shad, hickory shad, alewife, and blueback herring can be found in the 1985 Interstate Fishery Management Plan for Shad and River Herring and in the 2007 American shad stock assessment (ASMFC 2007). This section provides the basic information necessary to understand how anadromous alosines relate to their essential habitats and the significance of the commercial and recreational alosine fisheries to the economy and culture of the Atlantic coast.

[1] This section of the Amendment has been adapted from the South Carolina Department of Natural Resources website (http://www.dnr.sc.gov/cwcs/pdf/Alosid.pdf).

### 1.2.1 Alewife and Blueback Herring Life Histories

Alewife and blueback herring (collectively known as *river herring*) are anadromous fishes, spending most of their lives in ocean waters, migrating to their natal freshwater areas in the spring months to spawn. Alewife are most abundant in the mid-Atlantic and northeastern states. Blueback herring are found from Nova Scotia to northern Florida and are most abundant in waters from the Chesapeake Bay south (Scott and Scott 1988). Alewife generally spawn earlier than blueback herring in areas where both species occur. Alewife spawn in rivers, creeks, lakes and ponds, over rocks, detritus, submerged aquatic vegetation and sand. Blueback herring generally prefer to spawn over sand or gravel in swift-flowing areas of rivers and tributaries. In more southerly areas where both species exist, blueback herring utilize flooded back swamps, oxbows and stream edges for spawning. For both species, adults return to the ocean after spawning. Juveniles use the rivers and estuaries as nursery areas and migrate to the ocean as water temperatures decline in the fall. River herring reach sexual maturity at 3-6 years of age. Post-spawning mortality is highest in the states south of North Carolina as most populations are considered to be semelparous (i.e., spawn once and die). Little information is available on the life history of river herring once the juveniles emigrate to the ocean and until they return as mature adults to the freshwater areas to spawn.

### 1.2.2 River Herring Stock Assessment Summaries

#### *1.2.2.1 Stock Assessment of River Herring from Selected Atlantic Coast Rivers – Crecco and Gibson 1990*

Crecco and Gibson (1990) conducted the Commission's first assessment of Atlantic coastal river herring stocks. This assessment evaluated the status of six blueback herring stocks and nine alewife stocks between New Brunswick, Canada and North Carolina, USA using long-term commercial catch and effort, age composition, and relative abundance data for juveniles and adults. The assessment developed benchmark estimates of maximum sustained yield (MSY) and of fishing rates ($\mu$) at MSY ($\mu_{msy}$) and at stock collapse ($\mu_{coll}$). Benchmark fishing rates were then compared to recent [prior to 1990] estimates of u. Stocks were considered overfished if the observed u exceeded $\mu_{msy}$ and severely overfished if $\mu$ exceeded $u_{coll}$. Stocks were considered fully exploited if u was within 75% of $\mu_{msy}$ and partially exploited if $\mu$ was less than 75% of $\mu_{msy}$. Models were modified to include both in-river and ocean fishing to allow predictions of effects of change in ocean fishing on benchmark estimates for in-river fisheries in two blueback herring stocks.

To obtain benchmark estimates of MSY and $\mu$, the 1990 assessment combined biomass-per-recruit (B/R) and yield-per-recruit (Y/R) from species specific (stocks combined) Thompson-Bell yield-per-recruit models with stock-specific Shepherd stock recruitment relationships to generate equilibrium spawning stock biomass, recruitment, and yield at a range of instantaneous fishing rates (F). Resulting curves were then used to identify MSY, F at MSY, and F at stock collapse. Instantaneous fishing mortality rates were then converted to estimates of $\mu_{msy}$ and $\mu_{coll}$ assuming a type I fishery.

Five stocks were determined to be overfished: St. John River alewife and blueback herring, Damariscotta River alewife, Potomac River (VA) alewife, and Chowan River alewife. Four stocks were determined to be experiencing recent stock declines, however, they were not overfished: Potomac River blueback herring, Chowan River blueback herring, Nanticoke River (MD) alewife, and Rappahannock River (VA) alewife (Table 1).

The assessment estimated ocean landings as constituting 20-30% of total river herring landings. This is contrary to Harris and Rulifson's 1989 paper that reports ocean landings from all Atlantic coast states as approximately 3% of total landings between 1978 and 1987. There are potential sources of discrepancy between landings from the coastal river herring fishery and the non-directed ocean fishery: (1) potential high discard mortality; (2) underreporting of total ocean river herring landings or overestimation of in-river landings; (3) computation of weight of ocean landings to numbers of fish could produce erroneous numbers because the ocean fishery harvests both juvenile and adult river herring; and (4) estimation of M too low.

The assessment reported that in all fisheries with depleted or overfished stocks there were significant weir or pound net fisheries. This led to the recommendation that additional conservation measures be adopted to reduce fishing mortality (F). Heavy fishing pressure in Maine, Virginia, and North Carolina were identified in the assessment as being primarily responsible for the continued decline of river herring stocks in the Damariscotta, Rappahannock, and Chowan rivers.

**Table 1.** Status of several blueback and alewife runs along the Atlantic coast based on data from the 1990 River Herring Stock Assessment. Classifications: *Severely Overfished* ($\mu$ exceeds $\mu_{coll}$), *overfished* ($\mu$ exceeds $\mu_{msy}$), *fully exploited* (u is within 75% of $\mu_{msy}$), and *partially exploited* (u is less than 75% of $\mu_{msy}$).

| River | Species | Status | Stock Condition* |
|---|---|---|---|
| St. John, NB | Alewife | Severely Overfished | Severely Depleted |
| | Blueback Herring | Overfished | No Trend |
| Damariscotta, ME | Alewife | Severely Overfished | Severely Depleted |
| Lamprey, NH | Alewife | Partially Exploited | No Trend |
| Herring, MA | Alewife/Blueback Herring | Partially Exploited | No Trend |
| Annaquatucket, RI | Alewife | Partially Exploited | No Trend |
| Connecticut, CT | Blueback Herring | Partially Exploited | No Trend |
| Nanticoke, MD | Alewife | Fully Exploited | Severely Depleted |
| | Blueback Herring | Partially Exploited | No Trend |
| Potomac, VA | Alewife | Severely Overfished^ | Severely Depleted |
| | Blueback Herring | Fully Exploited | Severely Depleted |
| Rappahannock, VA | Alewife | Partially Exploited | Severely Depleted |
| | Blueback Herring | Partially Exploited | No Trend |
| Chowan, NC | Alewife | Overfished | Severely Depleted |
| | Blueback Herring | Fully Exploited | Severely Depleted |

**Severely depleted* was defined as at least a 50% decline in recent landings or juvenile indices relative to the landings and juvenile indices from the first five years of data.

### *1.2.2.2 2005 North Carolina Stock Assessment*

An updated stock assessment on blueback herring and alewife was conducted in 2005 as part of Amendment 1 to North Carolina's River Herring Fishery Management Plan (NCRHFMP). Historically, river herring have been harvested in many systems in North Carolina; however, the main harvest component has been the Albemarle Sound area, primarily the Chowan River pound net fishery. Based on this information, the 2005 stock assessment update was based on data from the Albemarle Sound area and the Chowan River pound net fishery. Furthermore, blueback herring was used as the indicator species in development of Amendment 1 to the NCRHFMP.

Catch-at-age data from the Chowan River pound net fishery were used to estimate abundance and exploitation rates from 1972-2003. Cohort and annual catch curves provided mortality estimates, while a catch-at-age model incorporating a multinomial error distribution provided estimates of annual recruitment, abundance-at-age and fishing mortality. Bootstraping and log-likelihood profiling were used to evaluate the precision of model estimates (Grist 2005).

Past assessments of river herring stocks assume various levels of natural mortality. Crecco and Gibson (1990) use a value of 1.0 in the first Commission coastwide assessment of river herring stocks. A North Carolina Division of Marine Fisheries (NCDMF) assessment of the Chowan River blueback herring stock by Schaaf (1998) selects a natural mortality value of 0.3. Both the Hoenig (1983) and Pauly (1980) methods of estimating natural mortality yield estimates of 0.51 (Hilborn and Walters 1992) for blueback herring and alewife. The assumed instantaneous rate of natural mortality for the NCDMF 2005 assessment is 0.5 for blueback herring and alewife (Grist, 2005).

Estimated fishing mortality for blueback herring from 1972-1994 was 0.90 and except for 1995 and 1997, fishing mortality ranged from 0.98 in 1998 to 1.91 in 2003, with a corresponding exploitation ranging from 63 to 85%. Alewife estimated fishing mortality from 1972-1994 was 0.98 and except for 1995 and 1997, has ranged from 1.01 in 1998 to 1.86 in 2002, with corresponding exploitation rates ranging from 64 to 85%. The 1972-2003 average fishing mortality rates (based on catch curve analysis) for alewife and blueback herring were 1.27 and 1.17, respectively (Grist 2005).

Chowan River blueback herring and alewife recruitment are based on age-3 fish, considering this is the earliest age the fish are present in the catch. Blueback herring recruitment averaged 28.9 million fish per year from 1972-1985. Recruitment continued to fall, averaging 3.6 million fish since 1986, and declining further to an average of 552,000 fish from 1999-2003. Alewife recruitment averaged 7.5 million fish from 1972-1985, declining to 890,000 fish from 1986-2003. Recruitment averaged 317,000 fish from 1999-2003. Both alewife and blueback herring exhibit extreme variability in recruitment across years and any improvements in recruitment dissipated with high fishing mortality (Grist 2005).

Spawning stock biomass (SSB) estimates were made using mean weight-at-age, the estimated maturity schedule and estimated numbers-at-age from 1972-2003. Trends show a drastic decline for both species of river herring. Blueback herring SSB averaged 4.4 million pounds from 1972-1986, dropping to 1.0 million pounds in 1994 as a response to further declines in recruitment.

Blueback herring SSB reached a record low of 89,678 pounds in 2003. Alewife SSB declined rapidly during the early 1990s, with a record low of 10,862 pounds in 1995. Alewife SSB ranged from 1.1 million pounds to 3.1 million pounds from 1971 to 1988 and declined rapidly in early 1990s. From 1994-1999, alewife SSB averaged 22,953 pounds. The decline in SSB corresponds with historically low recruitment values in the 1990s. A slight increase in alewife SSB has been observed since 2000, however, the 2003 SSB value (92,442 pounds) was only 7.5% of the 1972-2003 SSB average (Grist 2005).

Based on information from the 2005 stock assessment, it was determined that river herring were overfished and overfishing was occurring. North Carolina adopted management measures in Amendment 1 of the NCRHFMP that included a "no-harvest" restriction (commercial and recreational) for river herring, with an annual research set-aside allocation of up to 7,500 pounds that is managed at the North Carolina Division of Marine Fisheries Director's discretion.

## 1.3 HABITAT CONSIDERATIONS

### 1.3.1 Alewife Habitat Description

The alewife (*Alosa pseudoharengus*) is an anadromous, highly migratory, euryhaline, pelagic, schooling species. The species spends the majority of its life at sea, returning to freshwater river systems along the Atlantic coast of the United States to spawn (ASMFC 1985). While most alewife are native-anadromous fish, some have been introduced to landlocked systems. Researchers examined two distant anadromous alewife stocks to test whether landlocked stocks were more closely related to St. Croix anadromous stocks or to more geographically distant anadromous stocks. Landlocked alewife were found to be distantly related to all the anadromous stocks tested. A variety of statistical tests confirmed that anadromous and landlocked populations of alewife in the St. Croix are genetically divergent (FST = 0.244). These results implied that very little, if any, interbreeding occurs between the two life history types (Bentzen and Paterson 2006; Willis 2006). Furthermore, significant genetic differences were observed between anadromous alewife populations in the St. Croix and anadromous populations in the LaHave and Gaspereau Rivers, as well as between the two anadromous St. Croix samples (Dennis Stream and Milltown). These results imply homing of alewives to their natal streams and, consequently, at least partial reproductive isolation between spawning runs, even at the level of tributaries within the St. Croix River (Willis 2006).

The historical coastal range of the anadromous alewife was from South Carolina to Labrador, Nova Scotia, and northeastern Newfoundland (Berry 1964; Winters *et al*. 1973; Burgess 1978). However, more recent surveys indicate that they do not currently occur in the southern range beyond North Carolina (Rulifson 1982; Rulifson *et al*. 1994). Alewife from the southernmost portion of the species' range migrate long distances (over 2000 km) in ocean waters of the Atlantic seaboard. Patterns of migration may be similar to those of American shad (*Alosa sapidissima*) (Neves 1981). Although alewife and blueback herring co-occur throughout much of their respective ranges, alewife are typically more abundant than blueback herring in the northern portion of their range (Schmidt *et al*. 2003).

Recent analyses to determine the current status of alewife in the Connecticut, Hudson, and Delaware River systems, suggest that alewife are showing signs of overexploitation (for example, lower mean age, fewer returning spawners, and lower overall abundance) in all of these rivers. However, researchers noted that recently some runs in the northeastern U.S. and Canada have shown increased alewife abundance (Schmidt *et al*. 2003). Furthermore, alewife appeared to be thriving in inland waters, colonizing many freshwater bodies, including all five Great Lakes (Waldman and Limburg 2003).

While this document will focus primarily on the anadromous alewife populations, much of the research on specific environmental requirements of alewife, such as temperature, dissolved oxygen, salinity, and pH, has been conducted on landlocked populations, not anadromous stocks; therefore data should be interpreted with discretion (Klauda *et al*. 1991a).

#### *1.3.1.1 Spawning Habitat*

***Geographical and Temporal Patterns of Migration***

The spring adult alewife migration to spawning grounds in freshwater and brackish water progresses seasonally from south to north, with populations further north returning later in the season as water temperatures rise. Neves (1981) suggested that alewife migrate from offshore waters north of Cape Hatteras, encountering the same thermal barrier as American shad. Alewife then move south along the Atlantic coast for fish homing to southern rivers, while northbound pre-spawning adults continue traveling up the coast (Stone and Jessop 1992). The species spawns in rivers, ponds, and lakes (lacustrine habitat), as far south as North Carolina and as far north as the St. Lawrence River, Canada (Neves 1981; S. Lary, U.S. Fish and Wildlife Service, per. comm.).

Alewife typically spawn from late February to June in the south, and from June through August in the north (Table 2; Marcy 1976b; Neves 1981; Loesch 1987). Spawning is triggered most predictably by a change in the water temperature. Movement upstream may be controlled by water flow, with increased movement occurring during higher flow periods (Collins 1952; Richkus 1974). However, extreme high flows can act as a velocity barrier delaying or preventing upstream migration and access to spawning habitat (S. Lary, U.S. Fish and Wildlife Service, pers. comm.).

Although adult alewife will move upstream at various times of the day, peak migration typically occurs between dawn and noon, and from dusk to midnight (Richkus 1974; Rideout 1974; Richkus and Winn 1979). Researchers have found that high midday movement is restricted to overcast days, and nocturnal movement occurs when water temperatures are abnormally high (Jones *et al*. 1978). Typically, males arrive before females at the mouths of spawning rivers (Cooper 1961; Tyus 1971; Richkus 1974).

**Table 2.** Reported spawning seasons for alewife along the Atlantic coast of North America.

| State or region | Spawning season | Citations |
|---|---|---|
| Bay of Fundy tributaries | Late April or early May | Leim and Scott 1996; Dominy 1971 |
| Gulf of St. Lawrence tributaries | Late May or early June | Leim and Scott 1996; Dominy 1971 |
| Maine | Late April to mid-May | Rounsefell and Stringer 1943; Bigelow and Schroeder 1953; Havey 1961; Libby 1981 |
| | Mid-May to mid-June | S. Lary, U.S. Fish and Wildlife Service, pers. comm. |
| Massachusetts | Early to mid-April | Belding 1921; Bigelow and Schroeder 1953 |
| Mid-Atlantic and southern New England | Late March or early April | Cooper 1961; Kissil 1969; Marcy 1969b; Smith 1971; Saila *et al*. 1972; Richkus 1974; Zich 1978; Wang and Kernehan 1979 |
| Chesapeake Bay region | Mid-March | Jones *et al*. 1978; Loesch 1987 |
| North Carolina | Late February-late March | Holland and Yelverton 1973; Frankensteen 1976 |

There is strong evidence suggesting that alewife home to their natal rivers to reproduce; however, some individuals have been found to colonize new areas. Alternatively, alewife may reoccupy systems from which they have been extirpated (Havey 1961; Thunberg 1971; Messieh 1977; Loesch 1987). Messieh (1977) found that alewife strayed considerably to adjacent streams in the St. Johns River, Florida, particularly during the pre-spawning period (late winter, early spring), but not during the spawning run. It appears that olfaction is the primary means for homing behavior (Ross and Biagi 1990).

### *Spawning Location (Ecological)*

Alewife select slow-moving sections of rivers or streams to spawn, where the water may be as shallow as 30 cm (Jones *et al*. 1978). The species may also spawn in lakes or ponds, including freshwater coves behind barrier beaches (Smith 1907; Belding 1921; Leim and Scott 1966; Richkus 1974; Colette and Klein-MacPhee 2002). In watersheds where dams are an impediment, spawning may occur in shore-bank eddies or deep pools below the dams (Loesch and Lund 1977). Additionally, in New England and Nova Scotia, alewife spawn in lakes and ponds located within coastal watersheds (Loesch 1987). For this reason, they are typically more abundant than blueback herring in rivers with abundant headwater ponds. In rivers where headwater ponds are absent or scarce, alewife are less abundant in headwater reaches; however, blueback herring utilize the mainstream proper for spawning in those systems (Ross and Biagi 1990). In tributaries of the Rappahannock River, Virginia, upstream areas were found to be more important than downstream areas for spawning alewife (O'Connell and Angermeier 1997). Although earlier studies suggested that alewife ascend further upstream than blueback herring (Hildebrand 1963; Scott and Crossman 1973), Loesch (1987) noted that both species have the ability to ascend rivers far upstream.

Boger (2002) found that river herring within the Rappahannock River watershed spawned in larger, elongated watersheds with greater mean elevation and greater habitat complexity. This researcher suggested that such areas are likely to have more stable base flows that can maintain suitable spawning habitat even during dry years. Additionally, spawning areas had a greater percentage of deciduous forest and developed areas and less grassland areas (Boger 2002).

***Temporal Spawning Patterns***

Alewife usually spawn 3 to 4 weeks before blueback herring in areas where they co-occur; however, there may be considerable overlap (Loesch 1987) and peak spawning periods may differ by only 2 to 3 weeks (Jones *et al*. 1978). In a tributary of the Rappahannock River, Virginia, O'Connell and Angermeier (1997) found that blueback herring eggs and larvae were more abundant than those of alewife, but alewife used the stream over a longer period of time. The researchers also reported a minor three-day overlap of spawning by these two alosine species. It has been hypothesized that alewife and blueback herring select separate spawning sites in sympatric areas to reduce competition (Loesch 1987). O'Connell and Angermeier (1997) reported that the two species used different spawning habitat due to a temporal, rather than spatial, segregation that minimizes the competition between the two species.

Alewife may spawn throughout the day, however, most spawning occurs at night (Graham 1956). One female fish and up to 25 male fish broadcast eggs and sperm simultaneously just below the surface of the water or over the substrate (Belding 1921; McKenzie 1959; Cooper 1961). Spawning lasts two to three days for each group or "wave" of fish that arrives (Cooper 1961; Kissil 1969; Kissil 1974), with older and larger fish usually spawning first (Belding 1921; Cooper 1961; Libby 1981, 1982). Following spawning, the adult spent fish quickly return downstream (Colette and Klein-MacPhee 2002).

***Maturation and Spawning Periodicity***

Many alewife are repeat spawners, with some individuals completing seven or eight spawning events in a lifetime (Table 3) (Jessop *et al*. 1983). It is not clear whether there is a clinal trend from south to north for repeat spawning (i.e., more in the north than south) (Klauda *et al*. 1991a), or if there is a typical percent of the annual return population that repeat spawns (i.e., 30 to 40% repeat spawners throughout their range) (Richkus and DiNardo 1984). Furthermore, Kissil (1974) suggested that alewife might spawn more than once in a season.

**Table 3.** Percentage of repeat spawners for alewife along the Atlantic coast of North America.

| State | % Repeat Spawners | Citations |
|---|---|---|
| Nova Scotia | 60% | O'Neill 1980 |
| Maryland | 30-72% | Weinrich *et al*. 1987; Howell *et al*. 1990 |
| Virginia | 61% | Joseph and Davis 1965 |
| North Carolina | 0.5-15.9% | K. Rawls, North Carolina Division of Marine Fisheries, pers. comm. |

Adults will typically spend two to four years at sea before returning to their natal rivers to spawn (Neves 1981). The majority of adults reach sexual maturity at 3, 4, or 5 years of age, although some adults from North Carolina (Richkus and DiNardo 1984) have returned to spawn at age-2 (Jessop *et al*. 1983). The oldest alewife recorded in North Carolina were age-9 (Street *et al*. 1975; Johnson *et al*. 1979); age-10 fish have been caught in New Brunswick (Jessop *et al*. 1983) and Nova Scotia (O'Neill 1980). Additionally, Kissil (1974) found that alewife spawning in Bride Lake, Connecticut, spent three to 82 days on the spawning grounds, while Cooper (1961) reported that most fish left within five days of spawning in Rhode Island.

### *Spawning Salinity Association*

While it is known that alewife can adjust to a wide range of salinities, published data on alewife tolerance ranges are lacking (Klauda *et al*. 1991a). Richkus (1974) found that adults that were transferred from freshwater to saline water (32 ppt), and vice versa, experienced zero mortality. In the north, Leim (1924) studied the life history of American shad and noted that they do not ascend far beyond the tidal influence of the river, yet alewife migrate as far upstream as they can travel. He concluded that alewife may be less dependent on saltwater for development (Leim 1924). Also, unlike American shad, some populations of alewife have become landlocked and are not at all dependent on saltwater (Scott and Crossman 1973).

### *Spawning Substrate Association*

The spawning habitat of alewife can range from sand, gravel, or coarse stone substrates, to submerged vegetation or organic detritus (Edsall 1964; Mansueti and Hardy 1967; Jones *et al*. 1978). Boger (2002) found that river herring spawning areas along the Rappahannock River, Virginia, had substrates that consisted primarily of sand, pebbles, and cobbles (usually associated with higher-gradient streams). In contrast, areas with little or no spawning activity were dominated by organic matter and finer sediments (usually associated with lower-gradient streams and comparatively more agricultural land use) (Boger 2002).

Pardue (1983) evaluated studies of cover component in alewife spawning areas, suggesting that substrate characteristics and associated vegetation were a measure of the ability of a habitat to provide cover to spawning adults, their eggs, and developing larvae. In high flow areas, there is little accumulation of vegetation and detritus, while in low flow areas, detritus and silt accumulate and vegetation has the opportunity to grow (Pardue 1983). Pardue (1983) suggested that substrates with 75% silt (or other soft material containing detritus and vegetation) and sluggish waters are optimal for alewife**.**

### *Spawning Depth*

Water depth in spawning habitat may be a mere 15 cm deep (Bigelow and Schroeder 1953; Rothschild 1962), or as deep as 3 m (Edsall 1964); however, spawning typically occurs at less than 1 m (Murdy *et al*. 1997). Adults may utilize deeper water depths when not spawning in order to avoid high light intensities (Richkus 1974).

### *Spawning Water Temperature*

Adult alewife have been collected in temperatures ranging from 5.7°C to 32°C (Marcy 1976b; Jones *et al*. 1978). Spawning temperatures along the Atlantic coast fall within this broader range (Table 4). There is some discrepancy regarding the minimum spawning temperature for alewife. Although running ripe fish of both sexes have been reported at temperatures as low as 4.2°C in the Chesapeake Bay area (Mansueti and Hardy 1967), some researchers suggest that the minimum spawning temperature for adult alewife is 10.5°C (Cianci 1965; Loesch and Lund 1977). Additionally, lower temperatures may be dangerous for spawning alewife. Otto *et al*. (1976) found that the lower incipient lethal temperature range for adults acclimated at 15.0°C and 21.0°C was between 6°C and 8°C. In this study, no fish survived below 3°C, regardless of acclimation temperature (Otto *et al*. 1976). Furthermore, at temperatures below 4.5°C, normal schooling behavior was significantly reduced for adult alewife from Lake Michigan (Colby 1973).

**Table 4.** Alewife spawning temperatures for locations along the Atlantic coast of North America.

| Location | Temperature (ºC) | Citation |
|---|---|---|
| Rhode Island | 14.0 – 15.5 (peak) | Jones *et al*. 1978 |
| Lower Connecticut River | 7.0 – 10.9 | Marcy *et al*. 1976a |
| Chesapeake Bay | 10.5 – 21.6 | Jones *et al*. 1978 |
| Patuxent River, MD | 11 – 19 | J. Mowrer, Morgan State University, unpublished data |
| Lake Mattamuskeet, NC | 13 (peak) | Tyrus 1974 |

As water temperatures rise, alewife migration eventually slows. Cooper (1961) noted that upstream migration ceased in a Rhode Island stream when temperatures reached 21°C, while Edsall (1970) reported that spawning ceases altogether at 27.8°C. Ultimately, higher temperatures may cause problems for alewife. In fact, Otto *et al*. (1976) found that upper incipient lethal temperatures (temperature at which 50% of the population survives) ranged from 23.5°C to 24.0°C for adults that were acclimated at temperatures of 10°C, 15°C, and 20°C.

Another study reported upper incipient lethal temperatures of 29.8°C and 32.8°C at acclimation temperatures of 16.9°C and 24.5°C, respectively (Stanley and Holzer 1971). In addition, McCauley and Binkowski (1982) reported upper incipient lethal temperatures of 31°C to 34°C after acclimation at 27°C for a northern population of adults.

In general, alewife may prefer cooler water, and northern populations may be more cold tolerant than other migratory anadromous fish (Stone and Jessop 1992). Richkus (1974) showed that the response of migrating adults to a particular hourly temperature was determined by their relationship to a changing baseline temperature, and not on the basis of the absolute value of temperature. Stanley and Colby (1971) found that decreasing temperatures (from 16°C to 3°C at a rate of 2.5°C per day) reduced adult alewife ability to osmoregulate. Adults were also shown to survive temperature decreases of 10°C, regardless of acclimation temperature, if the temperature did not drop below 3°C (Otto *et al*. 1976).

***Spawning Dissolved Oxygen Associations***

There is little information regarding sensitivities of various life history stages of alewife to dissolved oxygen (Klauda *et al*. 1991a). In one study, adults exposed to dissolved oxygen concentrations ranging from 2.0 to 3.0 mg/L for 16 hours in the laboratory experienced a 33% mortality rate. Alewife were able to withstand dissolved oxygen concentrations as low as 0.5 mg/L for up to 5 minutes, as long as a minimum of 3.0 mg/L was available, thereafter (Dorfman and Westman 1970). Additionally, Jones *et al*. (1988) suggested that the minimum dissolved oxygen concentration for adult alewife is 5.0 mg/L.

***Spawning pH Association***

Few researchers have reported on pH sensitivity in alewife (Klauda *et al*. 1991a). Byrne (1988) found that the average pH level was 5.0 in several streams in New Jersey where alewife spawning was known to occur. Laboratory tests found that fish from those streams could successfully spawn at a pH as low as 4.5 (Byrne 1988). In another study, adult alewife tolerated a pH range of 6.5 to 7.3 (Collins 1952). When aluminum pulses were administered in the laboratory, critical conditions for spawning could occur during an acidic pulse between pH 5.5 and 6.2, with concomitant concentrations of total monomeric aluminum ranging from 15 to 137 µg/L for a pulse duration of 8 to 96 hours (Klauda 1989). Klauda *et al*. (1991a) suggested a pH range of 5 to 8.5 as suitable for alewife eggs, but no range was provided for spawning.

***Spawning Water Velocity/Flow***

Increased movement upstream occurs during higher water flows (Collins 1952; Richkus 1974), while spawning typically takes place in quiet, slow-moving waters for alewife (Smith 1907; Belding 1921; Marcy 1976a). Some researchers have noted differential selection of spawning areas in alewife. For example, in Connecticut, alewife choose slower moving waters in Bride Lake (Kissil 1974) and Higganum and Mill creeks, while blueback herring select fast-moving waters in the upper Salmon River and Roaring Brook (Loesch and Lund 1977). In other areas where alewife and blueback herring are forced to spawn in the same vicinity due to blocked passage (Loesch 1987), alewife generally spawn along shorebank eddies or deep pools, whereas, blueback herring will typically select the main stream flow for spawning (Loesch and Lund 1977). In North Carolina, alewife utilize slow moving streams and oxbows (Street *et al*. 2005).

### *Feeding Behavior*

Adult alewife typically do not feed during their upstream spawning run (Bigelow and Schroeder 1953; Colby 1973). Spent fish that have reached brackish waters on their downstream migration will feed voraciously, mostly on mysids (Colette and Klein-MacPhee 2002). While adults may consume their own eggs during the spawning run (Edsall 1964; Carlander 1969), juveniles reportedly feed more actively on them (Colette and Klein-MacPhee 2002).

### *Competition and Predation*

Adult alewife and blueback herring play an important role in the food web and in maintaining the health of the ecosystem. In the inland freshwater and coastal marine environments they provide forage for bass, trout, salmonids, other fish, ospreys, herons, eagles, kingfishers, cormorants, and aquatic fur-bearing mammals (Colby 1973; Royce 1943; Scott and Scott 1988; Loesch 1987; S. Lary, U.S. Fish and Wildlife Service, pers. comm.). In the marine environment, they are eaten by a variety of predators, such as bluefish, weakfish, striped bass, cod, pollock, and silver hake, as well as marine mammals and sea birds. Additionally, alewife are a host to some species of native freshwater mussels, and are essential to upstream movement of mussels through transport of parasitic glochidia. Furthermore, spawning alewife heading upriver give cover to out-migrating Atlantic salmon smolts in the spring (S. Lary, U.S. Fish and Wildlife Service, pers. comm.).

Erkan (2002) notes that predation of alosines has increased dramatically in Rhode Island rivers in recent years, especially by the double-crested cormorant, which often takes advantage of fish staging near the entrance to fishways. Populations of nesting cormorant colonies have increased in size and expanded into new areas. Predation by otters and herons has also increased, but to a lesser extent (D. Erkan, Rhode Island Department of Environmental Management, pers. comm.).

In many coastal communities, the annual alewife run is an integral part of the local culture, and local residents have initiated efforts to protect and restore their cultural link to this fishery, to develop effective management strategies for restoration, to establish self-sustaining harvest levels, and to enhance community education (S. Lary, U.S. Fish and Wildlife Service, pers. comm.).

## *1.3.1.2 Egg and Larval Habitat*

### *Geographical and Temporal Movement Patterns*

Fertilized eggs remain demersal and adhesive for several hours (Mansueti 1956; Jones *et al*. 1978), after which they become pelagic and are transported downstream (Wang and Kernehan 1979). Marcy (1976a) observed eggs more often near the bottom than at the surface in the Connecticut River. Eggs may hatch anywhere from 50 to 360 hours (2 to 15 days) after spawning, depending on water temperature (Fay *et al*. 1983); however, eggs most often hatch within 80 to 95 hours (3 to 5 days) (Edsall 1970).

Within two to five days of hatching, the yolk-sac is absorbed and larvae begin feeding exogenously (Cianci 1965; Jones *et al*. 1978). Post-yolk-sac larvae are positively phototropic (Odell 1934; Cianci 1965). Dovel (1971) observed larvae near or slightly downstream of presumed spawning areas in the Chesapeake Bay, where the water was less than 12 ppt salinity (Dovel 1971). Larvae were also found in or close to observed spawning areas in Nova Scotia rivers in relatively shallow water (2 m) over sandy substrate (O'Neill 1980).

***Eggs, Larvae, and Water Velocity/Flow***

Sismour (1994) observed a rapid decline in abundance of early preflexion river herring larvae in the Pamunkey River, Virginia, following high river flow in 1989. This observation lead to speculation that high flow leads to increased turbidity, which reduces prey visibility, leading to starvation of larvae (Sismour 1994). Additionally, O'Connell and Angermeier (1997) found that current velocity and dissolved oxygen were the strongest predictors of alewife early egg presence in a Virginia stream. Further north, drought conditions in Rhode Island in the summer of 1981 were strongly suspected of impacting the 1984-year class, which was only half of its expected size (ASMFC 1985). In tributaries of the Chowan system, North Carolina, water flow was related to recruitment of larval river herring (O'Rear 1983).

***Egg and Larval Predation***

Alewife eggs may be consumed by yellow perch, white perch, spottail shiner, and other alewife (Edsall 1964; Kissil 1969). Alewife larvae are preyed upon by both vertebrate and invertebrate predators (Colby 1973).

### *1.3.1.3 Juvenile Riverine/Estuarine Habitat*

***Geographical and Temporal Movement Patterns***

In North Carolina, juveniles may spend the summer in the lower ends of rivers where they were spawned (Street *et al*. 1975). In the Chesapeake Bay, juveniles can be found in freshwater tributaries in spring and early summer, but may head upstream in mid-summer when saline waters encroach on their nursery grounds (Warriner *et al*. 1970). Some juveniles in the Chesapeake Bay remain in brackish water through the summer (Murdy *et al*. 1997).

Further north, juveniles in the Hudson River usually remain in freshwater tributaries until June (Schmidt *et al*. 1988). In contrast to the inshore abundance of American shad and blueback herring during the day, juvenile alewife were found to be most abundant in inshore areas at night in the Hudson River (McFadden *et al*. 1978; Dey and Baumann 1978). Hudson River juveniles were observed in shallow portions of the upper and middle estuary in late June and early July, where they remained for several weeks before moving offshore (Schmidt *et al*. 1988). Alewife typically spend three to nine months in their natal rivers before returning to the ocean (Kosa and Mather 2001).

In the summer in the Potomac River, juveniles are abundant near surface waters during the day; however, they shift to mid-water and bottom depths in September, where they remain until they emigrate in November (Warriner *et al*. 1970). Juvenile alewife respond negatively to light and follow diel movement patterns similar to blueback herring. Nevertheless, there appears to be some separation between the alewife and blueback herring as they emigrate from nursery grounds in the fall. The difference occurs most notably at night when alewife can be found more frequently at mid-water depths, while blueback herring are found mostly at the surface (Loesch and Kriete 1980). This behavior may reduce inter-specific competition for food, given that the species' diets are similar (Davis and Cheek 1966; Burbidge 1974; Weaver 1975).

Once water temperatures begin to drop in the late summer through early winter (depending on geographic area), juveniles start heading downstream, initiating their first phase of seaward migration (Pardue 1983; Loesch 1987). Some researchers have found that movement of alewife peaks in the afternoon (Richkus 1975a; Kosa and Mather 2001), while others have found that it peaks at night (Stokesbury and Dadswell 1989). Migration downstream is also prompted by changes in water flow, water levels, precipitation, and light intensity (Cooper 1961; Kissil 1974; Richkus 1975a, 1975b; Pardue 1983). Other researchers have suggested that water flow plays only a minor role in providing migration cues under riverine conditions. Rather, these researchers think that migration timing is triggered by water temperature and moon phases that provide dark nights (i.e., new and quarter moons) (O'Leary and Kynard 1986; Stokesbury and Dadswell 1989). Additionally, Stokesbury and Dadswell (1989) found that alewife remained in the offshore region of the Annapolis estuary, Nova Scotia, for nearly one month before the correct migration cues triggered emigration. Furthermore, large juveniles begin moving downstream before smaller juveniles (Schmidt *et al*. 1988), inhabiting saline waters before they begin their seaward migration (Loesch 1969; Marcy 1976a; Loesch and Kriete 1980).

The influence and magnitude of migration cues on emigrating alewife may vary considerably. Richkus (1975a) observed waves of juvenile alewife leaving systems following environmental changes (e.g., changes in water flow, water levels, precipitation, and light intensity), but the number of fish leaving was unrelated to the level of magnitude of the change. Most fish (60% to 80%) emigrated during a small percentage (approximately 8%) of available days. These waves also lasted two to three days, regardless of the degree of environmental change (Richkus 1975a). Similarly, other researchers have observed that the majority (>80%) of river herring emigrate in waves (Cooper 1961; Huber 1978; Kosa and Mather 2001). Richkus (1975a) also noted that in some instances, high abundances of juvenile alewife might trigger very early (i.e., summer) emigration of large numbers of small juveniles from the nursery area, which is likely a response to a lack of forage. Additionally, juvenile migration of alewife occurs about one month earlier than that of blueback herring (Loesch 1969; Kissil 1974).

Although most juveniles emigrate offshore during their first year, some over-winter in the Chesapeake (Hildebrand 1963) and Delaware bays (Smith 1971). Marcy (1969b) suggested that many juveniles (age-1+) spend their first winter close to the mouth of their natal river due to their presence in the lower portion of the Connecticut River in early spring. Other researchers concur that some juvenile alewife may remain in deep estuarine waters through the winter (Hildebrand and Schroeder 1928). There is some indication that alewife in northern states may remain in inshore waters for one to two years (Walton 1981). Conversely, since juvenile river herring cannot survive water temperatures of 3°C or below (Otto *et al*. 1976), they likely do not over-winter in coastal systems where temperatures are below 3°C (Kosa and Mather 2001).

### *Juveniles and the Saltwater Interface*

Richkus (1974) reported that juvenile alewife that were transferred from freshwater to saline water (32 ppt), and vice versa, experienced zero mortality. Juvenile alewife in the upper Chesapeake Bay were found in salinities ranging from 0 to 8 ppt, but most (82%) were collected from freshwater (Dovel 1971). Furthermore, Pardue (1983) suggested that salinities less than or equal to 5 ppt are optimal for juveniles of this species.

### *Juvenile Water Temperature Associations*

Temperature tolerance range estimates for juvenile alewife vary somewhat between researchers (Table 5). Dovel (1971) found that ninety-eight percent of juvenile alewife in the upper Chesapeake Bay were collected at 25°C.

**Table 5.** Juvenile alewife temperature tolerances/preferences along the Atlantic coast.

| Characterization | Acclimation Temp (°C) | Temp Range (°C) | Location | Citation |
|---|---|---|---|---|
| Optimal | N/A | 15 - 20 | Many | Pardue 1983 |
| Suitable | N/A | 10 - 28 | Many | Klauda *et al*. 1991a |
| Present | N/A | 4 - 27 | Upper Chesapeake Bay | Dovel 1971 |
| Present | N/A | 13.5 – 29.0 | Cape Fear River, NC | Davis and Cheek 1966 |
| Avoidance | 26 | >34 | Delaware River | PSECG 1984 |
| Preferred | 15 - 21 | 17 – 23 (at 4 – 7 ppt) | Delaware River | Meldrim and Gift 1971; PSE&G 1982 |
| Preferred | 15 - 18 | 25.0 | Lake Michigan | Otto *et al*. 1976 |

According to McCauley and Binkowski (1982), the upper lethal temperature for juvenile alewife is approximately 30°C. Concurrently, in Lake Michigan, upper incipient lethal limits (i.e., temperature at which 50% of the population survives) for young-of-the-year alewife acclimated to 10°C, 20°C, and 25°C, was estimated to be slightly less than 26.5°C, 30.3°C, and 32.1°C, respectively (Otto *et al*. 1976). Another study found that juveniles exposed to water at 35°C for 24 hours, after acclimation to water at 18.9 to 20.6°C, had a 20% survival rate (Dorfman and Westman 1970). Moreover, young-of-the-year alewife seem to have critical thermal maxima (CTM) that are 3 to 6°C higher than adults (Otto *et al*. 1976).

Alternatively, when juvenile alewife were subjected to decreasing temperatures (15.6°C down to 2.8°C) over the course of 15 days, they suffered greater than 90% mortality (Colby 1973). In another study, juvenile alewife exposed to 9°C, following acclimation at 20°C in 5.5 ppt salinity, suffered no mortality. However, when the temperature was decreased to 7°C for 96 h, they suffered 27 to 60% mortality (PSE&G 1984). Comparatively, the lower limit at which juvenile river herring are unable to survive is 3°C or less (Otto *et al*. 1976).

***Juveniles and Water Velocity/Flow***

Water discharge is an important variable influencing relative abundance and emigration of juvenile alewife. Extremely high discharges may adversely affect juvenile emigration, and high or fluctuating discharges may lead to a decrease in the relative abundance of adults and juveniles (Kosa and Mather 2001). Laboratory experiments suggest that juvenile alewife avoid water velocities greater than 10 cm/s, especially in narrow channels (Gordon *et al*. 1992). In large rivers where greater volumes of water can be transported per unit of time without substantial increases in velocity, the effects of discharge may differ (Kosa and Mather 2001).

Kissil (1974) observed juvenile alewife leaving Lake Bride, Connecticut, between June and October; they noted especially high migration occurring during times of heavy water flow. These results are consistent with Cooper's (1961) observations that 98% of juveniles left after periods of heavy rainfall. Huber (1978) also noted that juvenile emigration in the Parker River, Massachusetts, was triggered by an increase in water flow. Furthermore, Jessop (1994) found that the juvenile abundance index (JAI) of alewife decreased with mean river discharge during the summer. Daily instantaneous mortality also increased with mean river discharge from July to August at the Mactaquac Dam headpond on the Saint John River, New Brunswick, Canada (Jessop 1994).

***Juvenile Feeding***

Juvenile alewife are opportunistic feeders that usually favor seasonally available items (Gregory *et al*. 1983). For example, in the Hamilton Reservoir, Rhode Island, juveniles feed primarily on dipteran midges in July, and cladocerans in August and September (Vigerstad and Colb 1978). Juveniles either select their prey individually or switch to a non-selective filter-feeding mode, which is a behavior utilized more at night (Janssen 1976). Grabe (1996) found that juvenile alewife fed on chironomids, odonates, and other amphipods during the day and early evening hours in the Hudson River. Juveniles have also been observed consuming epiphytic fauna especially at night (Weaver 1975; Grabe 1996). Juveniles may also feed extensively on benthic organisms, including ostracods, chironomid larvae, and oligochaete worms (Watt and Duerden 1974).

The number of zooplankton per liter consumed is assumed to be critical for the survival and growth of juvenile alewife. Pardue (1983) suggests that habitats containing 100 or more zooplankton per liter are optimal. Walton (1987) found that juvenile alewife abundance in Damariscotta Lake, Maine, was controlled by competition for zooplankton, rather than parental stock abundance and recruitment. It has been suggested that clupeids evolved to synchronize the larval stage with the optimal phase of annual plankton production cycles (Blaxter and Hunter

1982). In addition, Morsell and Norden (1968) found that juvenile alewife consume zooplankton until they reach 12 cm TL, and may then switch to increasing amounts of the benthic amphipod Pontoporeia sp. Several researchers (Vigerstad and Colb 1978; O'Neill 1980; Yako 1998) hypothesize that a change in food availability may provide a cue for juvenile anadromous herring to begin emigrating seaward, but no causal link has been established.

Unfortunately, invasive species may threaten food sources for alewife. There is strong evidence that juveniles in the Hudson River have experienced a reduced forage base as a result of zebra mussel colonization (Waldman and Limburg 2003).

***Juvenile Competition and Predation***

It is often noted throughout the literature that alewife and blueback herring co-exist in the same geographic regions, yet inter-specific competition is often reduced through several mechanisms. For example, juveniles of both species may consume different sizes of prey (Crecco and Blake 1983). Juvenile alewife in the Minas Basin, Nova Scotia, Canada, favor larger benthic prey (particulate-feeding strategy) compared to juvenile blueback herring (filter-feeding strategy) (Stone 1985; Stone and Daborn 1987). In the Cape Fear River, North Carolina, juvenile alewife consume more ostracods, insect eggs, and insect parts than blueback herring (Davis and Cheek 1966).

Alewife also spawn earlier than blueback herring, thereby giving juvenile alewife a relative size advantage over juvenile bluebacks, allowing them a larger selection of prey (Jessop 1990). Differences in juvenile diel feeding activity further reduce competition. One study noted that diurnal feeding by juvenile alewife was bimodal, with peak consumption about one to three hours before sunset and a minor peak occurring about two hours after sunrise (Weaver 1975). In comparison, juvenile blueback herring begin to feed actively at dawn, increasing throughout the day and maximizing at dusk, then diminishing from dusk until dawn (Burbidge 1974).

With regard to predation, juvenile alewife are consumed by American eel, white perch, yellow perch, grass pickerel, largemouth bass, pumpkinseed, shiners, walleye and other fishes, as well as turtles, snakes, birds, and mink (Kissil 1969; Colby 1973; Loesch 1987). In the estuarine waters of Maine, juvenile bluefish prey heavily on alewife (Creaser and Perkins 1994). In Massachusetts's rivers, juvenile alewife are energetically valuable and a key food source for largemouth bass during late summer (Yako *et al*. 2000).

### ***1.3.1.4 Late Stage Juvenile and Adult Marine Habitat***

***Geographical and Temporal Movement Patterns***

Some young-of-the-year alewife over-winter in deep, high salinity areas of the Chesapeake Bay (Hildebrand and Schroeder 1928). Dovel (1971) reported juvenile populations in the upper Chesapeake Bay that did not emigrate until early spring of their second year. Milstein (1981) found that juvenile alewife over-wintered in waters approximately 0.6 to 7.4 km from the shore of New Jersey, at depths of 2.4 to 19.2 m, in what is considered an offshore estuary. This area is warmer with higher salinity than the cooler, lower salinity river-bay estuarine nurseries where alewife reside in fall. The majority of alewife are present in March when bottom temperatures range from 4.4 to 6.5°C and salinity is between 29.0 and 32.0 ppt (Cameron and Pritchard 1963).

Young alewife have been found over-wintering off the North Carolina coast from January to March, concentrated at depths of 20.1 to 36.6 m (Holland and Yelverton 1973; Street *et al*. 1973). However, other sources have noted that juvenile alewife tend to remain near the surface during their first year in saltwater (Bigelow and Schroeder 1953). In Lake Michigan, age-1 fish are usually pelagic, except in spring and fall, where they often occur on the bottom; age-2 fish are typically found on the bottom (Wells 1968).

Information on the life history of young-of-the-year and adult alewife after they emigrate to the sea is sparse (Klauda *et al*. 1991a). Sexual maturity of alewife is reached at a minimum of age-2, but timing may vary regionally. In North Carolina, sexual maturity occurs mostly at age-3. In Connecticut, most males achieve maturity at age-4, and most females at age-5 (Jones *et al*. 1978). It is generally accepted that juveniles join the adult population at sea within the first year of their lives and follow a north-south seasonal migration along the Atlantic coast, similar to that of American shad (Neves 1981). Despite a lack of conclusive evidence, it is thought that alewife are similar to other anadromous clupeids in that they may undergo seasonal migrations within preferred isotherms (Fay *et al*. 1983). In fact, alewife typically migrate in large schools of similar sized fish, and may even form mixed schools with other herring species (Colette and Klein-MacPhee 2002).

During spring, alewife from the Mid-Atlantic Bight move inshore and north of 40° latitude to Nantucket Shoals, Georges Bank, coastal Gulf of Maine, and the inner Bay of Fundy. Commercial catch data indicates that alewife are most frequently caught on Georges Bank and south of Nantucket Shoals (Neves 1981; Rulifson *et al*. 1987). Distribution in the fall is similar to the summer, but alewife concentrate along the northwest perimeter of the Gulf of Maine. In the fall, individuals move offshore and southward to the mid-Atlantic coast between latitude 40°N and 43°N, where they remain until early spring (Neves 1981). It is not known to what extent alewife over-winter in deep water off the continental shelf, but they have rarely been found more than 130 km from the coast (Jones *et al*. 1978).

Alewife also experience diel movement patterns. At sea alewife are more available to bottom trawling gear during the day, suggesting that they follow the diel movement of plankton in the water column and are sensitive to light (Neves 1981). It also seems that feeding and vertical migration are likely controlled by light intensity patterns within thermal preference zones (Richkus and Winn 1979; Neves 1981).

Results from Canadian spring surveys show river herring distributed along the Scotian Gulf, southern Gulf of Maine, and off southwestern Nova Scotia from the Northeast Channel to the central Bay of Fundy; they are found to a lesser degree along the southern edge of Georges Bank and in the canyon between Banquereau and Sable Island Banks (Stone and Jessop 1992). A large component of the over-wintering population on the Scotian Shelf (and possibly some of the U.S. Gulf of Maine population) moves inshore during spring to spawn in Canadian waters. Summer aggregations of river herring in the Bay of Fundy/eastern Gulf of Maine may consist of a mixture of stocks from the entire Atlantic coast, as do similar aggregations of American shad (Dadswell *et al*. 1987). However, based on commercial offshore catches by foreign fleets in the late 1960s, it was believed that coastal river herring stocks did not mingle to the extent that American shad stocks apparently did, at least during the seasons that foreign harvests were made (ASMFC 1985).

***Adults and the Saltwater Interface***

As noted above, young-of-the-year alewife have been found over-wintering offshore of New Jersey, where salinities range from 29.0 to 32.0 ppt (Milstein 1981). For sub-adults and non-spawning adults that remain in the open ocean, they will reside in full strength seawater. Since alewife may follow a north-south seasonal migration along the Atlantic coast similar to that of American shad (Neves 1981), and pre-spawning adult American shad may detour into estuaries (Neves and Depres 1979), alewife may inhabit more brackish waters during migration.

***Depth Associations at Sea***

National Marine Fisheries Service catch data found that in offshore areas, alewife were caught most frequently in waters with depths of 56 to 110 m. The vertical position of alewife in the water column may be influenced by zooplankton concentrations (Neves 1981). Zooplankton usually concentrate at depths <100 m in the Gulf of Maine (Bigelow 1926). Stone and Jessop (1992) found that alewife offshore of Nova Scotia, the Bay of Fundy, and the Gulf of Maine, were at depths of 101 to 183 m in the spring; they were in shallower nearshore waters (46 to 82 m) in the summer, and in deeper offshore waters (119 to 192 m) in the fall.

Stone and Jessop (1992) also found differences in depth distribution between smaller fish (sexually immature) and larger fish. Smaller fish occurred in shallow regions (<93 m) during spring and fall, while larger fish were found in deeper areas (≥93 m) throughout the year (Stone and Jessop 1992). Furthermore, Jansen and Brandt (1980) reported that the nocturnal depth distribution of adult landlocked alewife differed by size class, with the smaller fish present at shallower depths.

Interestingly, in coastal waters juvenile alewife are found in deeper water than blueback herring despite their identical diets (Davis and Cheek 1966; Burbidge 1974; Watt and Duerden 1974; Weaver 1975).

***Adult Water Temperature Associations***

From Cape Hatteras to Nova Scotia, alewife have been caught offshore where surface water temperatures ranged from 2 to 23°C and bottom water temperatures ranged from 3 to 17°C. Catches in this area were most frequent where the average bottom water temperature was between 4 and 7°C (Neves 1981). Stone and Jessop (1992) reported a temperature range of 7 to 11°C for alewife in the northern range off Nova Scotia, the Bay of Fundy, and the Gulf of Maine. The researchers also noted that the presence of a cold (<5°C) intermediate water mass over warmer, deeper waters on the Scotian Shelf, where the largest catches of river herring occurred, may have restricted the extent of vertical migration during the spring. Since few captures were made where bottom temperatures were <5°C, vertical migration may have been confined by a water temperature inversion in this area during the spring (Stone and Jessop 1992).

Alewife may prefer and be better adapted to cooler water than blueback herring (Loesch 1987; Klauda *et al*. 1991a). Northern populations may also exhibit more tolerance to cold temperatures (Stone and Jessop 1992). Additionally, antifreeze activity was found in blood serum from an alewife off Nova Scotia, but not in any captured in Virginia (Duman and DeVries 1974).

### *Feeding at Sea*

At sea, alewife feed largely on particulate zooplankton including euphausiids, calanoid copepods, mysids, hyperiid amphipods, chaetognaths, pteropods, decapod larvae, and salps (Edwards and Bowman 1979; Neves 1981; Vinogradov 1984; Stone and Daborn 1987; Bowman *et al*. 2000). Alewife also consume small fishes, including Atlantic herring, other alewife, eel, sand lance, and cunner (Colette and Klein-MacPhee 2002). They feed either by selectively preying on individuals or non-selectively filter-feeding with gill rakers. Feeding mode depends mostly on prey density, prey size, and water visibility, as well as size of the alewife (Janssen 1976, 1978a, 1978b). In Minas Basin, Bay of Fundy, alewife diets shift from micro-zooplankton in small fish to mysids and amphipods in larger fish. Feeding intensity also decreases with increasing age of fish (Stone 1985).

Alewife generally feed most actively during the day; nighttime predation is usually restricted to larger zooplankton that are easier to detect (Janssen 1978; Janssen and Brandt 1980; Stone and Jessop 1993). In Nova Scotia, alewife feeding peaks at midday during the summer and mid-afternoon during the winter. Alewife also have a higher daily ration in the summer than in the winter (Stone and Jessop 1993). Although direct evidence is lacking, alewife catch in specific areas along Georges Bank, the perimeter of the Gulf of Maine, and south of Nantucket Shoals, may be related to zooplankton abundance (Neves 1981).

### *Competition and Predation at Sea*

Schooling fish such as bluefish, weakfish, and striped bass, prey upon alewife (Bigelow and Schroeder 1953; Ross 1991). Other fish such as dusky shark, spiny dogfish, Atlantic salmon, goosefish, cod, pollock, and silver hake, also prey on alewife (Bowman *et al*. 2000; R. Rountree, University of Massachusetts, unpublished data). Of these species, spiny dogfish appears to have the greatest affinity for alewife (R. Rountree, University of Massachusetts, unpublished data). Also, see Part C of this chapter for additional information.

### *1.3.1.5 Significant Environmental, Temporal and Spatial Factors Affecting Distribution of Alewife*

**Table 6.** Significant environmental, temporal, and spatial factors affecting distribution of alewife. Please note that, although there may be subtle variations between systems, the following data include a broad range of values that encompass the different systems that occur along the East Coast. Where a specific range is known to exist, it will be noted. For the sub-adult–estuarine/oceanic environment and non-spawning adult–oceanic environment life history phases, the information is provided as a general reference, not as habitat preferences or optima. NIF = No Information Found.

| Life Stage | Time of Year and Location | Depth (m) | Temperature (°C) | Salinity (ppt) | Substrate | Current Velocity (m/sec) | Dissolved Oxygen (mg/L) |
|---|---|---|---|---|---|---|---|
| **Spawning Adult** | Late February (south) through August (north); slow-moving sections of streams/ponds/ lakes, and shorebank eddies or deep pools, from North Carolina to Labrador & Newfoundland | **Tolerable:** 0.2-3 **Optimal:** NIF **Reported:** Typically spawn in shallower (<1) areas | **Tolerable:** 7-27.8 **Optimal:** 13-20 **Reported:** Broad range; disagreement on minimum temperature for spawning | **Tolerable:** NIF **Optimal:** NIF **Reported:** Migrate as far upstream in freshwater as possible | **Tolerable:** NIF **Optimal:** NIF **Reported:** Usually sand, gravel, cobble, and other coarse stone; some report SAV and detritus | **Tolerable:** NIF **Optimal:** NIF **Reported:** Slow-moving waters | **Tolerable:** >5.0 **Optimal:** NIF **Reported:** Only tolerate low DO for short periods |
| **Egg** | Late February (south) through August (north); hatch 50-360 hours after fertilization, but usually within 80-95 hours at spawning site or slightly downstream | **Tolerable:** NIF **Optimal:** NIF **Reported:** NIF | **Tolerable:** 10.6-26.7 **Optimal:** 17.2-21.1 **Reported:** Average time to median hatch varies inversely w/temperature | **Tolerable:** NIF **Optimal:** 0-2 **Reported:** Mostly found in freshwater | **Tolerable:** NIF **Optimal:** NIF **Reported:** NIF | **Tolerable:** NIF **Optimal:** NIF **Reported:** Usually found in low flow; w/DO, strongest predictor of egg presence | **Tolerable:** ≥5.0 **Optimal:** NIF **Reported:** With velocity, strongest predictor of egg presence |
| **Prolarvae** | Hatch in 50 to 360 hours, but usually within 80-95 hours downstream of spawning site | **Tolerable:** NIF **Optimal:** NIF **Reported:** NIF | **Tolerable:** 8-31 **Optimal:** 15-24 **Reported:** Variable | **Tolerable:** NIF **Optimal:** 0-3 **Reported:** Mostly found in freshwater | **Tolerable:** NIF **Optimal:** NIF **Reported:** NIF | **Tolerable:** NIF **Optimal:** NIF **Reported:** Usually found in low flow | **Tolerable:** ≥5.0 **Optimal:** NIF **Reported:** NIF |

| Life Stage | Time of Year and Location | Depth (m) | Temperature (°C) | Salinity (ppt) | Substrate | Current Velocity (m/sec) | Dissolved Oxygen (mg/L) |
|---|---|---|---|---|---|---|---|
| **Postlarvae** | 2 to 5 days downstream of spawning site after prolarvae stage is reached | **Tolerable:** NIF **Optimal:** NIF **Reported:** NIF | **Tolerable:** 14-28 **Optimal:** 20-26 **Reported:** Variable | **Tolerable:** NIF **Optimal:** NIF **Reported:** Larvae grow faster in saltwater | **Tolerable:** NIF **Optimal:** NIF **Reported:** NIF | **Tolerable:** NIF **Optimal:** NIF **Reported:** Usually found in low flow | **Tolerable:** ≥5.0 **Optimal:** NIF **Reported:** NIF |
| **Early Juvenile – Riverine** | 3-9 months in natal rivers after reaching juvenile stage in brackish waters or upstream in freshwater | **Tolerable:** NIF **Optimal:** NIF **Reported:** Absent from near-surface during daylight | **Tolerable:** 10-28 **Optimal:** 15-20 **Reported:** 4-29 | **Tolerable:** NIF **Optimal:** NIF **Reported:** Variable | **Tolerable:** NIF **Optimal:** NIF **Reported:** SAV for protection | **Tolerable:** NIF **Optimal:** NIF **Reported:** Avoid >10cm/s; high migration rates in heavy flow | **Tolerable:** ≥3.6 **Optimal:** NIF **Reported:** NIF |
| **Sub-adult & Non-spawning Adult – Estuarine/ Oceanic** | 2-5 years after hatching in nearshore estuarine waters or offshore marine waters | **Tolerable:** NIF **Optimal:** 46-192 **Reported:** Zooplankton may influence depth; smaller fish generally in shallower water | **Tolerable:** 2-23 **Optimal:** 4-7 (bottom temp) **Reported:** Northern populations may be more cold tolerant | **Tolerable:** NIF **Optimal:** NIF **Reported:** Brackish to saltwater | **Tolerable:** NIF **Optimal:** NIF **Reported:** NIF | **Tolerable:** NIF **Optimal:** NIF **Reported:** NIF | **Tolerable:** NIF **Optimal:** NIF **Reported:** NIF |

### 1.3.2 Blueback Herring Habitat Description

Blueback herring (*Alosa aestivalis*) are an anadromous, highly migratory, euryhaline, pelagic, schooling species. Both blueback herring and alewife are often referred to as "river herring," which is a collective term for these two often inter-schooling species (Murdy *et al*. 1997). This term is often used generically in commercial harvests with no distinction between the two species (ASMFC 1985); to further this lumping tendency, landings for both species are reported as alewife (Loesch 1987). Blueback herring spend most of their lives at sea, returning to freshwater only to spawn (Colette and Klein-MacPhee 2002). Their range is commonly cited as spanning from the St. Johns River, Florida (Hildebrand 1963; Williams *et al*. 1975) to Cape Breton, Nova Scotia (Scott and Crossman 1973) and the Miramichi River, New Brunswick (Bigelow and Schroeder 1953; Leim and Scott 1966). However, Williams *et al*. (1975) have reported that blueback herring occur as far south as Tomoka River, a small freshwater tributary of the Halifax River in Florida (a brackish coastal lagoon). Additionally, some landlocked populations occur in the Southeast (Klauda *et al*. 1991a), but landlocking occurs less frequently in blueback herring than in alewife (Schmidt *et al*. 2003).

Blueback herring from the South are capable of migrating extensive distances (over 2000 km) along the Atlantic seaboard, and their patterns of migration may be similar to those of American shad (Neves 1981). This species is most abundant south of the warmer waters of the Chesapeake Bay (Manooch 1988; Scott and Scott 1988), occurring in virtually all tributaries to the Chesapeake Bay, the Delaware River, and in adjacent offshore waters (Jones *et al*. 1978). Although blueback herring and alewife co-occur throughout much of their range, blueback herring are more abundant by one or perhaps two orders of magnitude along the middle and southern parts of their ranges (Schmidt *et al*. 2003).

Several long-term data sets were recently analyzed to determine the current status of blueback herring in large river systems along the East Coast, including the Connecticut, Hudson, and Delaware rivers. Blueback herring show signs of overexploitation in all of these rivers, including reductions in mean age, decreases in percentage of returning spawners, and decreases in abundance. Although researchers did not include smaller drainages in the analysis, they did note that some runs in the northeastern U.S. and Atlantic Canada have observed increased population abundance of blueback herring in recent years (Schmidt *et al*. 2003).

Please note that some of the data presented in this chapter have been derived from studies of landlocked populations and the applicability of environmental requirements is unknown; therefore, they should be interpreted with discretion (Klauda *et al*. 1991a).

#### *1.3.2.1 Spawning Habitat*

***Geographical and Temporal Patterns of Migration***

Adult blueback herring populations in the South return earliest to spawn in freshwater and sometimes brackish waters, with populations further north migrating inland later in the spring when water temperatures have increased. Researchers believe that blueback herring migrate inland from offshore waters north of Cape Hatteras, North Carolina, encountering the same thermal barrier as American shad. Individuals then turn south along the coast if they are homing to South Atlantic rivers (Neves 1981); northbound pre-spawning adults head north along the coast (Stone and Jessop 1992). Adults begin migrations from the offshore region in response to changes in water temperature and light intensity (Pardue 1983). It is assumed that adults return to the rivers in which they were spawned, but some may stray to adjacent streams or colonize new areas; some individuals have even reoccupied systems in which the species was previously extirpated (Messieh 1977; Loesch 1987).

Blueback herring will ascend freshwater far upstream (Massmann 1953; Davis and Cheek 1966; Perlmutter *et al*. 1967; Crecco 1982); their distribution is a function of habitat suitability and hydrological conditions, such as swift flowing water (Loesch and Lund 1977). Earlier hypotheses that blueback herring do not ascend as far upstream as alewife are unfounded (Loesch 1987). In fact, in tributaries of the Rappahannock River, Virginia, upstream areas were found to be more important for blueback herring spawning than downstream areas (O'Connell and Angermeier 1997).

### *Spawning Location (Ecological)*

Generally, blueback herring and alewife attempt to occupy different freshwater spawning areas. However, if blueback herring and alewife are forced to spawn in the same vicinity (i.e., due to blocked passage) (Loesch 1987), some researchers have suggested that the two species occupy separate spawning sites to reduce competition. For example, Loesch and Lund (1977) note that blueback herring typically select the main stream flow for spawning, while neighboring alewife spawn along shorebank eddies or deep pools. In rivers where headwater ponds are absent or poorly developed, alewife may be most abundant farther upstream in headwater reaches, while blueback herring utilize the mainstream proper for spawning (Ross and Biagi 1990). However, in some areas blueback herring are abundant in tributaries and flooded low-lying areas adjacent to main streams (Erkan 2002).

In the allopatric range, where there is no co-occurrence with alewife (south of North Carolina), blueback herring select a greater variety of spawning habitat types (Street 1970; Frankensteen 1976; Christie 1978), including small tributaries upstream from the tidal zone (ASMFC 1999), seasonally flooded rice fields, small densely vegetated streams, cypress swamps, and oxbows, where the substrate is soft and detritus is present (Adams and Street 1969; Godwin and Adams 1969; Adams 1970; Street 1970; Curtis *et al*. 1982; Meador *et al*. 1984). Furthermore, despite the fact that blueback herring generally do not spawn in ponds in their northern range (possibly to reduce competition), they have the ability to do so (Loesch 1987).

Loesch (1987) has reported that blueback herring can adapt their spawning behavior under certain environmental conditions and disperse to new areas if the conditions are suitable. This behavior was demonstrated in the Santee-Cooper System, South Carolina, where hydrological alterations resulting from the creation of a rediversion canal led to changes in spawning site selection in both rivers. In the Cooper River, blueback herring lost access to formerly impounded rice fields along the river, which were important spawning areas. Following the construction of the rediversion canal, there was an increase in the number and length of tributaries along the river that were used as spawning habitat. In the adjacent Santee River, adults dispersed into the rediversion canal itself in favor of their former habitat, which was further upstream (Eversole *et al*. 1994).

### *Temporal Spawning Trends*

Spawning of blueback herring typically commences in the given regions at the following times: 1) Florida – as early as December (McLane 1955); 2) South Carolina (Santee River) – present in February (Bulak and Christie 1981), but spawning begins in early March (Christie 1978; Meador 1982); 3) Chesapeake Bay region - lower tributaries in early April and upper reaches in late April (Hildebrand and Schroeder 1928); 4) Mid-Atlantic region – late April (Smith 1971; Zich 1978; Wang and Kernehan 1979); 5) Susquehanna River - abundance peaks in early to mid-May (R. St. Pierre, U.S. Fish and Wildlife Service, pers. comm.); 6) Connecticut River – present in lower river mid-April, but spawning begins in mid-May (Loesch and Lund 1977); and 7) Saint John River, New Brunswick – present in May (Messieh 1977; Jessop *et al*. 1983), but spawning doesn't commence until June and may run through August (Leim and Scott 1966; Marcy 1976b).

Blueback herring generally spawn 3 to 4 weeks after alewife in areas where they co-occur; however, there may be considerable overlap (Loesch 1987) and peak spawning periods may differ by only 2 to 3 weeks (Hildebrand and Schroeder 1928). In a tributary of the Rappahannock River, Virginia, researchers found that blueback eggs and larvae were more abundant than those of alewife, but that alewife used the stream over a longer period of time. In addition, there was only a three- day overlap of spawning by alewife and blueback herring (O'Connell and Angermeier 1997). Although it has been suggested that alewife and blueback herring select separate spawning sites in sympatric areas to reduce competition (Loesch 1987), O'Connell and Angermeier (1997) did not find that the two species used different spawning habitat in the areas they examined. The researchers suggested that there was a temporal, rather than spatial, segregation that minimized the competition between the two species (O'Connell and Angermeier 1997).

Spawning may occur during the day, but blueback herring spawning activity is normally most prolific from late afternoon (Loesch and Lund 1977) into the night (Johnston and Cheverie 1988). During spawning, a female and two or more males will swim approximately one meter below the surface of the water; subsequently, they will dive to the bottom (Loesch and Lund 1977), simultaneously releasing eggs and sperm over the substrate (Colette and Klein-MacPhee 2002). Spawning typically occurs over an extended period, with groups or "waves" of migrants staying 4 to 5 days before rapidly returning to sea (Hildebrand and Schroeder 1928; Bigelow and Schroeder 1953; Klauda *et al*. 1991a). In a temporal context, the majority of spent adult blueback herring emigrating from the Connecticut River moved through fish passage facilities between 1700 and 2100 hours (Taylor and Kynard 1984).

### *Maturation and Spawning Periodicity*

Blueback herring are repeat spawners at an average rate of 30 to 40% (Richkus and DiNardo 1984). In general, there appears to be an increase in repeat spawning from south to north (Rulifson *et al*. 1982). Researchers have found that approximately 44 to 65% of the blueback herring in Chesapeake Bay tributaries had previously spawned (Joseph and Davis 1965), while 75% of those in Nova Scotia had previously spawned (O'Neill 1980). In the Chowan River, North Carolina, as many as 78% of individuals were first-time spawners (Winslow and Rawls 1992). First spawning occurs when adults are between 3 and 6 years old, but most first-time spawners are age 4 fish (Messieh 1977; Loesch 1987). Joseph and Davis (1965) reported that some blueback herring spawn as many as six times in Virginia.

Jessop (1990) found a stock-recruitment relationship for the spawning stock of river herring and year-class abundance at age 3. Despite these results, most studies have been unable to detect a strong relationship between adult and juvenile abundance of clupeids (Crecco and Savoy 1984; Henderson and Brown 1985; Jessop 1994). Researchers have suggested that although year-class is driven mostly by environmental factors, if the parent stock size falls below a critical level, the size of the spawning stock may become a factor in determining juvenile abundance (Kosa and Mather 2001). To the extent that environmental factors have been linked to year-class abundance, they will be discussed in subsequent sections.

### *Spawning and the Saltwater Interface*

Blueback herring generally spawn in freshwater above the head of tide; brackish and tidal areas are rarely used for spawning by this species (Nichols and Breder 1927; Hildebrand 1963; Fay *et al*. 1983; Murdy *et al*. 1997). Adults, eggs, larvae, and juveniles can tolerate a wide range of salinities, but seem to prefer a more narrow range, depending on life history stage. For example, while spawning may occur in salinities ranging from 0 to 6 ppt, it typically takes place in waters that are less than 1 ppt (Klauda *et al*. 1991a). Boger (2002) presented a modified salinity range for Virginia rivers, suggesting that a suitable salinity range for spawning adults is 0 to 5 ppt. Alternatively, spawning adult blueback herring have been found in brackish ponds at Woods Hole, Massachusetts (Nichols and Breder 1927; Hildebrand 1963).

### *Spawning Substrate Association*

In areas where blueback herring and alewife co-occur (sympatric region), blueback herring prefer to spawn over gravel and clean sand substrates where the water flow is relatively swift, and actively avoid areas with slow-moving or standing water (Bigelow and Welsh 1925; Marcy 1976b; Loesch and Lund 1977; Johnston and Cheverie 1988).

In the allopatric range, there seems to be some variation in blueback herring spawning substrate. Where water flow is more sluggish, there is ample opportunity for detritus and silt to accumulate. Pardue (1983) considered substrates with 75% or more silt and other soft materials (e.g., detritus and vegetation) as optimal for blueback herring spawning because it provides cover for eggs and larvae. However, more recently Boger (2002) found that river herring spawning areas along the Rappahannock River, Virginia, had substrates that consisted primarily of sand, pebbles, and cobbles (usually associated with higher-gradient streams), while areas with little or no spawning were dominated by organic matter and finer sediments (usually associated with lower-gradient streams and comparatively more agricultural land use).

### *Spawning Depth*

During their freshwater migration, blueback herring swim at mid-water depths (compared to deeper water used by American shad) (Witherell 1987). This species is reported to spawn in both shallow (Jones *et al*. 1978) and deep streams (Johnston and Cheverie 1988).

### *Spawning Water Temperature*

O'Connell and Angermeier (1997) found that temperature was the strongest predictor of blueback herring adult and early egg presence in a tributary of the Rappahannock River, Virginia. Blueback herring are reported to spawn at temperatures ranging from a minimum of 13°C (Hawkins 1979; Rulifson *et al*. 1982) to a maximum of 27°C (Loesch 1968). Loesch and Lund (1977) noted that spawning adults were found in the lower Connecticut River in mid-April when water temperatures were as low as 4.7°C, but spawning did not occur until several weeks later when the water temperature had risen. Meador *et al*. (1984) noted that rapid changes in water temperature appeared to be an important factor influencing the timing of spawning. Optimal spawning temperature range is suggested to be 21 to 25°C (Cianci 1969; Marcy 1976b; Klauda *et al*. 1991a) and 20 to 24° C (Pardue 1983). Fish in the laboratory acclimated to 15°C and 29 ppt salinity exhibited a final temperature preference of 22.8°C (Terpin *et al*. 1977).

### *Spawning Dissolved Oxygen Associations*

Adult blueback herring require a minimum of 5.0 mg/L of dissolved oxygen (Jones *et al*. 1978). For example, adults caught in the Cooper and Santee Rivers, South Carolina, were always captured in areas that had a dissolved oxygen concentration of 6 mg/L or higher (Christie *et al*. 1981).

### *Spawning pH and Aluminum Associations*

Adult blueback herring captured in the Santee-Cooper River system, South Carolina, were found within a range of pH 6.0 to 7.5 (Christie and Barwick 1985; Christie *et al*. 1981). Further north, within tributaries of the Delaware River, New Jersey, spawning runs were found within a broader range of pH 4.7 to 7.1 (mean pH 6.2) (Byrne 1988). Based on suggested ranges for eggs (cited in Klauda *et al*. 1991a), Boger (2002) suggested a suitable range of pH 6 to 8, and an optimal range of pH 6.5 to 8 for spawning habitat.

### *Water Velocity/Flow*

In the sympatric range, blueback herring prefer to spawn in large rivers and tributaries where the water flow is relatively swift, actively avoiding areas with slow-moving or standing water (Bigelow and Welsh 1925; Marcy 1976b; Johnston and Cheverie 1988). In such areas, blueback herring will concentrate and spawn in the mainstream flow, while alewife favor shorebank eddies or deep pools for spawning (Loesch and Lund 1977). In Connecticut, blueback herring select the fast-moving waters of the upper Salmon River and Roaring Brook, while alewife are found in the slower-moving waters of Higganum and Mill creeks (Loesch and Lund 1977) and Bride Lake

(Kissil 1974). Researchers suggest that there is differential selection of spawning in these areas (Loesch and Lund 1977).

In the allopatric range, blueback herring favor lentic sites, but may also occupy lotic sites (Loesch 1987; Klauda *et al*. 1991a). Additionally, they may select slower-flowing tributaries and flooded low-lying areas adjacent to main streams with soft substrates and detritus (Street *et al*. 1975; Sholar 1975; 1977; Fischer 1980; Hawkins 1979).

Meador *et al*. (1984) found that high flows (and accompanying low water temperatures) associated with flood control discharges in the Santee River, South Carolina, immediately prior to the spawning season, resulted in lower numbers of blueback herring larvae that year. In the preceding year without flood control discharges, spawning occurred farther upstream (Meador *et al*. 1984). Furthermore, ripe adults were found below the sampling site heading downstream the year that high flows occurred, apparently without having spawned (Bulak and Christie 1981). Concurrently, other studies (Bulak and Curtis 1977; West *et al*. 1988) have found spawning adults moving downstream from spawning areas following a sudden change in water discharge.

In a similar example in the same river system, a rediversion canal and hydroelectric dam with a fish passage facility were constructed between the Cooper River and Santee River, which increased the average flow of the Santee River from 63 $m^3$/s to 295 $m^3$/s (Cooke and Leach 2003). Following the rediversion, blueback herring did not concentrate below the dam and few were attracted into the fish lock during periods of zero discharge. Too much water flow also posed a problem, as adults were found concentrating below the dam during periods of discharge, but were unable to locate the entrance to the fish lock due to high turbulence (Chappelear and Cooke 1994). As a result, blueback herring changed migration patterns by abandoning the Santee River, and following the dredged canal to the higher flow of the St. Stephen Dam. Subsequently, access to spawning grounds was increased, which contributed to increases in blueback herring populations (Cook and Leach 2003). Although the importance of in-stream flow requirements has been previously recognized (Crecco and Savoy 1984; ASMFC 1985; Crecco *et al*. 1986; Ross *et al*. 1993), it has usually been with regard to spawning habitat requirements or recruitment potential (Moser and Ross 1994). Cooke and Leach (2003) concluded that the study of, and possible adjustment of, river flow might be an important consideration for restoring alosine habitat.

### *Feeding Behavior*

Adult blueback herring feed during upstream spawning migrations (Rulifson *et al*. 1982; Frankensteen 1976), consuming large and diverse quantities of copepods, cladocerans, ostracods, benthic and terrestrial insects, molluscs, fish eggs, hydrozoans, and stratoblasts (Creed 1985). Sampling of adult blueback herring along the St. Johns River, Florida, found that they also consume vegetation (FWC 1973).

### *Competition and Predation*

Information is lacking that identifies which predator species prey on adult blueback herring during their spawning runs, but it is assumed that they are consumed by other fish, reptiles (e.g., snakes and turtles), birds (e.g., ospreys, eagles, and cormorants), and mammals (e.g., mink) (Loesch 1987; Scott and Scott 1988). Erkan (2002) notes that predation of alosines has increased dramatically in Rhode Island rivers in recent years, especially by the double-crested cormorant, which often takes advantage of fish staging near the entrance to fishways. Populations of nesting cormorant colonies have increased in size and have expanded into areas in which they were not previously observed. Predation by otters and herons has also increased, but to a lesser extent (Erkan 2002).

Several researchers have found evidence of striped bass predation on blueback herring (Trent and Hassler 1966; Manooch 1973; Gardinier and Hoff 1982). A recent study by Savoy and Crecco (2004) strongly supports the hypothesis that striped bass predation in the Connecticut River on adult blueback herring has resulted in a dramatic and unexpected decline in blueback herring abundance since 1992. The researchers further suggest that striped bass prey primarily on spawning adults because their predator avoidance capability may be compromised at that time, due to the strong drive to spawn during upstream migration. Rates of predation on age-0 and 1 alosines were much lower than that of adults (Savoy and Crecco 2004).

#### *1.3.2.2 Egg and Larval Habitat*

##### *Geographical and Temporal Movement Patterns*

On average, blueback herring eggs are hatched within 38 to 60 hours of fertilization (Adams and Street 1969). Yolk-sac larvae drift passively downstream with the current to slower moving water, where they grow and develop into juveniles (Johnston and Cheverie 1988). Yolk-sac absorption occurs in 2 to 3 days after hatching, and soon thereafter larvae begin to feed exogenously (Cianci 1969). Larvae are sensitive to light, so larval abundance at the surface increases as dusk approaches and reaches a maximum by dawn (Meador 1982).

##### *Water Velocity/Flow*

Initially, blueback herring eggs are demersal, but during the water-hardening stage, they are less adhesive and become pelagic (Johnston and Cheverie 1988). In general, blueback herring eggs are buoyant in flowing water, but settle along the bottom in still water (Ross and Biagi 1990).

Water flow rates may have a notable impact on larval populations of blueback herring. For example, year-class size of blueback herring decreased with increasing discharge during May-June from the headpond at the Mactaquac Dam (Saint John River, New Brunswick) (Jessop 1990). Researchers speculated that this was due to a low abundance of phytoplankton and zooplankton that larvae rely on at first feeding; these reductions can result when high discharges occur (Laberge 1975). This effect was not observed for alewife, which spawn 2 to 3 weeks earlier than blueback herring. Sismour (1994) also observed a rapid decline in abundance of early preflexion river herring larvae (includes both alewife and blueback herring) in the Pamunkey River, Virginia, following high river flow in 1989. Similar to Jessop (1990), Sismour (1994) speculated that high flow led to increased turbidity, which reduced prey visibility, leading to starvation of larvae. Furthermore, in tributaries of the Chowan system, North Carolina, water flow was determined to be related to recruitment of larval river herring (O'Rear 1983).

Dixon (1996) found that seasonally high river flow and low water temperature during one season in several Virginia rivers were associated with delayed larval emergence, reduced relative abundance, depressed growth rate, and increased mortality compared with the previous season. It was suggested that high river flow might be a forcing mechanism on another abiotic factor, perhaps turbidity, which directly affects larval growth and survival (Dixon 1996).

***Competition and Predation***

All life stages of blueback herring, including the egg and larval stages, are important prey for freshwater fishes, birds, amphibians, reptiles, and mammals (Klauda *et al*. 1991a). The ability of blueback herring to feed extensively on rotifers is offered as an explanation for their dominance over American shad in some rivers along the East Coast (Marcy 1976c; Loesch and Kriete 1980).

### *1.3.2.3 Juvenile Riverine/Estuarine Habitat*

***Geographical and Temporal Movement Patterns***

Recruitment to the juvenile stage for blueback herring begins later in the year than for other alosines because they spawn later and have a shorter growing season (Hildebrand and Schroeder 1928; Schmidt *et al*. 1988). The juvenile stage is reached when fish are about 20 mm TL (Klauda *et al*. 1991a), with growth occurring very rapidly (Colette and Klein-MacPhee 2002).

Massmann (1953), Warriner *et al*. (1970), and Burbidge (1974) have reported that juvenile blueback herring are most abundant upstream of spawning grounds in waters of Virginia. While Burbidge (1974) noted a greater prey density at these locations, he was unsure if fish were actually moving upstream in large numbers, if survival rates upstream were higher compared to survival rates downstream, or if fish were simply moving out of tributaries and oxbows into these areas. Michael Odom (U.S. Fish and Wildlife Service, pers. comm.) has noted that juvenile blueback herring select the pelagic main channel portion of tidal waters of the Potomac River, while American shad juveniles select shallower nearshore flats adjacent to and within submerged aquatic vegetation (SAV) beds. Odom speculates that these two species tend to partition the habitat in this river.

In North Carolina waters, Street *et al*. (1975) found that juveniles typically reside in the lower ends of the rivers in which they were spawned. In Chesapeake Bay tributaries, young-of-the-year blueback herring can be found throughout tidal freshwater nursery areas in spring and early summer; they subsequently head upstream later in the summer when saline waters encroach on their nursery grounds (Warriner *et al*. 1970). Schmidt *et al*. (1988) reasoned that juvenile blueback herring in the Hudson River remained in the vicinity of their natal areas throughout the summer because they were relatively absent downriver until late September.

Nursery areas of the Neuse River, North Carolina, have been characterized as relatively deep, slow-flowing, black waters that drain hardwood swamps (Hawkins 1979). In South Carolina, juvenile blueback herring and American shad were found to co-occur predominantly in deeper, channel habitats of estuarine systems, during fall and winter, while hickory shad selected shallow expanses of sounds and bays. Small crustaceans, favored by blueback herring and American shad, are generally abundant near the bottom in estuarine channels (McCord 2005).

Juvenile blueback herring spend three to –nine months in their natal rivers before returning to the ocean (Kosa and Mather 2001). Observations by Stokesbury and Dadswell (1989) found that blueback herring remained in the offshore region (25 to 30% seawater) of the Annapolis estuary (Nova Scotia) for almost a month before the correct migration cues triggered emigration. Once water temperatures begin to drop in the late summer through early winter (depending on geographic area), juveniles start heading downstream, initiating their first phase of seaward migration (Pardue 1983; Loesch 1987). Migration downstream is also thought by some researchers to be prompted by changes in water flow, water levels, precipitation, and light intensity (Kissil 1974; Pardue 1983). In contrast, other researchers have suggested that water flow plays little role in providing the migration cue under riverine conditions; these researchers think that migration timing is more dependent on water temperature and new to quarter moon phases, which provide dark nights (O'Leary and Kynard 1986; Stokesbury and Dadswell 1989).

In the Connecticut River, juvenile blueback herring were found to move out of river systems rapidly, within a 24-hour period, with peak migration occurring in the early evening at 1800 hours (O'Leary and Kynard 1986). Kosa and Mather (2001) studied juvenile river herring movement from 11 small coastal systems in Massachusetts, and found that most individuals emigrated between 1200 and 1600 hours. Farther north, emigration by juvenile blueback herring in the Annapolis River, Nova Scotia, peaked at night between 1800 and 2300 hours (Stokesbury and Dadswell 1989).

Juvenile blueback herring (age 1+) were found in the lower portion of the Connecticut River in early spring by Marcy (1969b), which led him to speculate that many juveniles likely spend their first winter close to the mouth of the river. To the South, some young-of-the-year may over-winter in deeper, higher salinity areas of the Chesapeake Bay (Hildebrand and Schroeder 1928). In fact, Dovel (1971) reported juvenile populations in the upper Chesapeake Bay that did not emigrate until the early spring of their second year. Juveniles have also been reported over-wintering in the Delaware Bay (Jones *et al*. 1978). Since juvenile river herring do not survive temperatures of 3°C or less (Otto *et al*. 1976), they would not be expected to over-winter in coastal systems where such temperatures persist (Kosa and Mather 2001).

### *Juveniles and the Saltwater Interface*

Juvenile blueback herring are found most often in waters of 0 to 2 ppt prior to fall migration (Jones *et al*. 1988), but are tolerant of much higher salinities early in life. Pardue (1983) concluded that juveniles prefer low salinities in the spring and summer, with an optimal range between 0 and 5 ppt. Chittenden (1972) captured older juveniles in freshwater and subjected them to 28 ppt salinity at 22°C and all but one fish survived (mortality may have been due to handling stress). Furthermore, Klauda *et al*. (1991a) suggested that 0 to 28 ppt was a suitable range for juveniles. Their ability to tolerate salinities as low as 0 ppt, and as high as 28 ppt, allows them to utilize both freshwater and marine nursery areas. However, both Loesch (1968) and Kissil (1968) found that juvenile blueback herring remained in freshwater up to one month longer than juvenile alewife.

In some cases, changes in one environmental factor may impact other environmental factors causing changes in behavior patterns. For example, in the Chowan River, North Carolina, juvenile blueback herring became scarce in sampling areas following drought conditions during the summer of 1981, which resulted in saline waters encroaching farther upriver into nursery areas. Researchers suggested that blueback herring had possibly moved further upstream to freshwater areas to avoid the saltwater intrusion (Winslow *et al*. 1983).

### *Juvenile Water Temperature Associations*

Juvenile blueback herring have a wide range of temperature tolerances (Table 7). Additionally, certain temperatures create cues for the juveniles to begin migration. For example, in the Connecticut River, emigration began when the water temperatures dropped to 21°C in September, peaked at 14 to 15°C, and ended when the temperature dropped to 10°C, in late October and early November (O'Leary and Kynard 1986). Milstein (1981) found juveniles over-wintering in an estuary off the coast of New Jersey where bottom temperatures ranged from 2.0 to 10.0°C. These waters were warmer and had a higher salinity than the cooler, lower salinity estuarine nurseries where the juveniles reside in the fall.

**Table 7.** Juvenile blueback herring water temperature associations.

| Characterization | Temperature Range ($^oC$) | Acclimation Temperature ($^oC$) | Salinity (ppt) | Location | Citation |
|---|---|---|---|---|---|
| Present | 11.5 – 32.0 | N/A | | Cape Fear River, NC | Davis and Cheek 1966 |
| Present | 6.7 – 32.5 | N/A | | Connecticut River | Marcy 1976b |
| Suitable | 10 – 30 | N/A | | Chesapeake Bay | Klauda *et al*. 1991a |
| Optimal | 20 – 30 | | | Many | Pardue 1983 |
| Selection | 20 – 22 | 15 – 20 | 4 – 6 | Delaware River, NJ | Meldrim and Gift 1971 |
| Preference | 24 – 28 | 25 – 26 | 7 – 8 | Laboratory | PSE&G 1978 |
| Avoidance | 36 | 25 – 26 | 7 – 8 | Laboratory | PSE&G 1978 |
| 62% Mortality | 32 – 33 for 4-6 minutes | 19 | | Laboratory | Marcy and Jacobson 1976 |
| 100% Mortality | 32 – 33 for 4-6 minutes | 22.7 | | Laboratory | Marcy and Jacobson 1976 |
| 100% Mortality | 30.5 for 6 minutes | 15 | | Laboratory | PSE&G 1984 |
| 100% Mortality | 32 for 6 minutes | 15 | 29 | Laboratory | Terpin *et al*. 1977 |
| 100% Mortality | 10 | 25 | 6.5 – 7 | Laboratory | PSE&G 1978 |
| 100% Mortality | 0.2 | 5 | 8.5 – 10 | Laboratory | PSE&G 1978 |

### *Juveniles and Water Velocity/Flow*

Discharge is an important factor influencing variability in relative abundance and emigration of juvenile river herring across smaller systems. Extremely high discharge may adversely affect juvenile emigration, and high or fluctuating discharge may decrease relative abundance of adult and juvenile blueback herring (Meador *et al*. 1984; West *et al*. 1988; Kosa and Mather 2001). In laboratory experiments, juvenile river herring avoided water velocities greater than 10 cm/s, especially in narrow channels (Gordon *et al*. 1992). However, in large rivers, where greater volumes of water can be transported per unit of time without substantial increases in velocity, the effects of discharge may differ (Kosa and Mather 2001). Jessop (1994) found that the juvenile abundance index (JAI) of blueback herring decreased, and daily instantaneous mortality increased, with mean July-August river discharge from the Mactaquac Dam headpond on the Saint John River, New Brunswick, Canada. Impacts may have been the result of advection from the headpond, or from mortality as a result of reduced phytoplankton and zooplankton prey (Jessop 1994).

### *Juvenile Feeding*

Juvenile blueback herring in nursery areas feed mostly on copepods, cladocerans (Domermuth and Reed 1980), and larval dipterans (Davis and Cheek 1966; Burbidge 1974). In fact, as much as 40% of the juvenile's diet may consist of benthic organisms (Watt and Duerden 1974). Additionally, Burbidge (1974) found that juveniles often select larger items in the James River, Virginia, such as adult copepods, rather than smaller prey, such as *Bosminia* sp., except where there is a high relative abundance of smaller prey. Several researchers (Vigerstad and Colb 1978; O'Neill 1980; Yako 1998) have hypothesized that a change in food availability may provide a cue for juvenile anadromous herring to begin emigrating seaward, but no causal link has been established.

Juvenile blueback herring feed mostly at the surface, below the surface of the water, and to a lesser degree, on benthic prey (Domermuth and Reed 1980; Colette and Klein-MacPhee 2002). Some researchers (Burbidge 1974; Jessop 1990) observed juveniles feeding somewhat at dawn, and increasing feeding throughout the day with a maximum at dusk, then declining overnight. It is suggested that during the day, juveniles will remain within, or near, their zone of preferred light intensity, and feed in a selective mode (Dixon 1996), such as a "particulate" feeding mode (Janssen 1982).

Dixon (1996) noted that the size and age of juvenile blueback herring in the nursery zone increased in the downstream direction. Burbidge (1974) made similar observations that larger juveniles were found in downstream reaches of the James River. Dixon (1996) noted that the relative age distribution and density of juveniles (center of abundance) persisted in the nursery zone throughout the sampling season, which precluded the hypothesis that cohorts move downriver as a function of age and size. Instead, Dixon (1996) referenced Sismour's (1994) theory that as river herring larvae hatch at different times and locations along the river, they will encounter varying concentrations and combinations of potential prey. It is these differences that will affect larval nutrition and survival. In early spring, larvae that are closer to the center of the chlorophyll maxima along the river (which likely support development and expansion of zooplankton assemblages) are more likely to find suitable prey items. Early in the season, sufficient prey in upriver areas may be lacking. As the season progresses and the zooplankton prey field expands to upriver reaches, larvae in these areas may find suitable prey quantities and grow to the juvenile stage (Sismour 1994; Dixon 1996). Pardue (1983) considered habitats that contained 100 or more zooplankton per liter as optimum, which he suggested was critical for survival and growth at this stage. Burbidge (1974) demonstrated a direct relationship between density of zooplankton and distribution and growth of blueback herring. This differential survival rate within the nursery zone over time may account for younger juveniles in upstream reaches (Dixon 1996).

### *Juvenile Competition and Predation*

Many freshwater and marine fishes, birds, amphibians, reptiles, and mammals prey upon young-of-the-year blueback herring. Eels, yellow perch, white perch, and bluefish are among the fish species that prey on blueback herring (Loesch (1987; Juanes *et al*. 1993). Researchers have suggested that excessive predation by striped bass may be contributing to the decline of blueback herring stocks in the Connecticut River (Savoy and Crecco 1995). Furthermore, suitably sized juvenile blueback herring were found to be energetically valuable and potentially a key prey item for largemouth bass in two Massachusetts rivers during the late summer. Although largemouth bass do not consistently consume blueback herring, they are energy-rich prey, which provide the highest growth potential (Yako *et al*. 2000).

It is often noted throughout the literature, that alewife and blueback herring co-exist in the same geographic regions, yet inter-specific competition is often reduced through several mechanisms. For example, juveniles of both species in the Connecticut River consume or select different sizes of prey, leading researchers to conclude that intra-specific competition may be greater than inter-specific competition (Crecco and Blake 1983). This behavior is also evident in the Minas Basin, Nova Scotia, where juvenile blueback herring favor smaller and more planktonic prey (filter feeding strategy) than do juvenile alewife (particulate-feeding strategy) (Stone 1985; Stone and Daborn 1987). In addition, alewife spawn earlier than blueback herring, thereby giving juvenile alewife a relative size advantage over juvenile blueback herring, which allows them access to a larger variety of prey (Jessop 1990).

Furthermore, differences in juvenile diel feeding activity serve to reduce competition. One study noted that diurnal feeding by juvenile alewife is bimodal, with peak consumption about one to three hours before sunset and a minor peak occurring about two hours after sunrise (Weaver 1975). Another study found that juvenile blueback herring begin to feed actively at dawn, with feeding increasing throughout the day and maximizing at dusk, then diminishing from dusk until dawn (Burbidge 1974). Blueback herring are also found closer to the surface at night than alewife that are present at mid-water depths; this behavior may further reduce inter-specific competition for food between the two species (Loesch 1987).

Blueback herring and American shad juveniles also co-occur in shallow nearshore waters during the day, but competition for prey is often reduced by: 1) more opportunistic feeding by American shad; 2) differential selection for cladoceran prey; and 3) higher utilization of copepods by blueback herring (Domermuth and Reed 1980). Juvenile blueback herring are more planktivorous, feeding on copepods, larval dipterans, and cladocerans (Hirschfield *et al*. 1966, Burbidge 1974).

Blueback herring have shown signs of being impacted by invasive species as well. For example, there is strong evidence that juveniles in the Hudson River have experienced a reduced forage base as a result of zebra mussel colonization (Waldman and Limburg 2003).

### *1.3.2.4 Late Stage Juvenile and Adult Marine Habitat*

#### *Geographical and Temporal Patterns at Sea*

Juvenile river herring have been found over-wintering in an offshore estuary (Cameron and Pritchard 1963) 0.6 to 7.4 km from the shore of New Jersey, at depths of 2.4 to 19.2 m (Milstein 1981). This estuary is warmer and has a higher salinity than the cooler, lower salinity river-bay estuarine nurseries where river herring reside in the fall. The majority of river herring are present in this offshore estuary during the month of March, when bottom temperatures range from 4.4 to 6.5°C and salinity varies between 29.0 and 32.0 ppt (Cameron and Pritchard 1963). Further south, young blueback herring have been found over-wintering off the North Carolina coast from January to March, concentrated at depths of 5.5 to 18.3 m (Holland and Yelverton 1973; Street *et al*. 1975).

Sexual maturity is reached between ages 3 and 6 for blueback herring**.** Life history information for young-of-the-year and adult blueback herring after they emigrate to the sea, and before they return to freshwater to spawn, is incomplete (Klauda *et al*. 1991a). Researchers assume that most juveniles join the adult population at sea within the first year of their lives, and follow a north-south seasonal migration along the Atlantic coast, similar to that of American shad; changes in temperature likely drive oceanic migration (Neves 1981).

Neves (1981) reported that 16 years of catch data showed that blueback herring were distributed throughout the continental shelf from Cape Hatteras, North Carolina, to Nova Scotia during the spring. Most were found south of Cape Cod, but, unlike alewife, no blueback herring catches were recorded for Georges Bank. During the summer, blueback herring moved north and inshore, but catch records were too infrequent to determine summer occurrence for the species, although several catches were made near Nantucket Shoals and Georges Bank. This species was never collected south of 40° N in the summer. By early fall, the blueback herring were found along Nantucket Shoals, Georges Bank, and the inner Bay of Fundy, but were concentrated mostly along the northwest perimeter of the Gulf of Maine (Neves 1981). In the autumn, they began moving southward and offshore for over-wintering along the mid-Atlantic coast until early spring (Neves 1981; Rulifson *et al*. 1987). Although winter sampling stations were inadequate to define wintering grounds, the few catches that were reported were primarily between latitude 40° N and 43° N. It is unknown to what extent blueback herring over-winter in deep water off the continental shelf of the United States (Neves 1981). This species has been found offshore as far as 200 km (Bigelow and Schroeder 1953; Netzel and Stanek 1966), but they are rarely collected more than 130 km from shore (Jones *et al*. 1978).

Canadian spring survey results also reveal river herring distributed along the Scotian Gulf, southern Gulf of Maine, and off southwestern Nova Scotia from the Northeast Channel to the central Bay of Fundy. They are also found to a lesser degree along the southern edge of Georges Bank and in the canyon between Banquereau and Sable Island Banks. A large component of the over-wintering population on the Scotian Shelf moves inshore during spring to spawn in Canadian waters, but may also include the U.S. Gulf of Maine region (Stone and Jessop 1992).

### *Salinity Associations at Sea*

Adult blueback herring have been collected in salinities ranging from 0 to 35 ppt (Klauda *et al*. 1991a). Chittenden (1972) subjected adults to gradual and abrupt changes in salinity, including direct transfers from fresh to saltwater and vice versa, with no mortality. Non-spawning adults that do not ascend freshwater streams will likely be found mostly in seawater, and possibly brackish estuaries as they make their way up the coast to their summer feeding grounds (Chittenden 1972).

### *Depth Associations at Sea*

The extent to which blueback herring over-winter in deep waters off the continental shelf is unknown. Individuals have been caught most frequently at 27 to 55 m throughout their offshore range. While at sea, blueback herring are more susceptible to bottom trawling gear during the day; this concept led early researchers to conclude that the species is aversive to light and follows the diel movement of plankton in the water column (Neves 1981). In the Gulf of Maine region, zooplankton concentrations are at depths less than 100 m (Bigelow 1926). Since blueback herring are rarely found in waters greater than 100 m in this area, it is speculated that zooplankton influence the depth distribution of blueback herring at sea (Neves 1981). A more recent study of juveniles within the riverine environment (see ***Juvenile depth*** under Part C of this chapter) found that they migrate to the surface within a specific isolume as light intensity changes (Dixon 1996).

Stone and Jessop (1992) found blueback herring offshore of Nova Scotia, the Bay of Fundy, and the Gulf of Maine, at mid-depths of 101 to 183 m in the spring, in shallower nearshore waters of 46 to 82 m in the summer, and in deeper offshore waters of 119 to 192 m in the fall. The researchers also found differences in depth distribution, with smaller fish (sexually immature) occurring in shallow regions (<93 m) during spring and fall, while larger fish occurred in deeper areas (≥93 m) in all seasons (Stone and Jessop 1992). In addition, the semi-pelagic nature of juveniles may provide them with protection from the effects of overfishing (Dadswell 1985).

### *Temperature Associations at Sea*

Although data on offshore temperature associations is limited, researchers speculate that blueback herring are similar to other anadromous clupeids, in that they may undergo seasonal migrations within preferred isotherms (Fay *et al*. 1983). Neves (1981) found that blueback herring were caught in an offshore area where surface water temperatures were between 2 and 20°C and bottom water temperatures ranged from 2 to 16°C; almost all of the fish were caught in water temperatures less than 13°C. Catches were most frequent where bottom temperatures averaged between 4 and 7°C (Neves 1981).

Stone and Jessop (1992) found that the presence of a cold (<5°C) intermediate water mass over warmer, deeper waters on the Scotian Shelf (Hatchey 1942), where the largest catches of river herring occurred, may have restricted the extent of vertical migration during the spring. Since few captures were made where bottom temperatures were less than 5°C during the spring, researchers concluded that vertical migration may be confined by a water temperature inversion in this area (Stone and Jessop 1992).

### *Feeding at Sea*

Blueback herring are size-selective zooplankton feeders (Bigelow and Schroeder 1953), whose diet at sea consists mainly of ctenophores, calanoid copepods, amphipods, mysids and other pelagic shrimps, and small fish (Brooks and Dodson 1965; Neves 1981; Stone 1985; Stone and Daborn 1987; Scott and Scott 1988; Bowman *et al*. 2000). In Minas Basin, Bay of Fundy, smaller blueback herring feed mostly on microzooplankton, while larger fish consume larger prey, including mysids and amphipods; feeding intensity also decreases with increasing age of fish (Stone 1985).

Neves' (1981) analysis of offshore survey results led to the conclusion that blueback herring follow the diel movement of zooplankton while at sea. As discussed above (see Juvenile depth under Part C of this chapter), Dixon's (1996) study in freshwater concluded that juvenile blueback herring followed diel movements in response to light intensity, not prey movement. Although direct evidence is lacking, catches of blueback herring in specific areas along Georges Bank, the perimeter of the Gulf of Maine, and south of Nantucket Shoals may be related to zooplankton abundance (Neves 1981).

### *Competition and Predation at Sea*

Complete information on predation at sea is lacking for blueback herring (Scott and Scott 1988). Fish that are known to prey on blueback herring in the marine environment include spiny dogfish, American eel, cod, Atlantic salmon, silver hake, white hake, and Atlantic halibut, as well as larger schooling species, including bluefish, weakfish, and striped bass (Dadswell 1985; Ross 1991; Bowman *et al*. 2000). Seals, gulls, and terns may also feed on blueback herring in the ocean.

### *1.3.2.5 Significant Environmental, Temporal and Spatial Factors Affecting Distribution of Blueback Herring*

**Table 8.** Significant environmental, temporal, and spatial factors affecting distribution of blueback herring. Please note that, although there may be subtle variations between systems, the following data include a broad range of values that encompass the different systems that occur along the East Coast. Where a specific range is known to exist, it will be noted. For the sub-adult–estuarine/oceanic environment and non-spawning adult–oceanic environment life history phases, the information is provided as a general reference, not as habitat preferences or optima. NIF = No Information Found.

| Life Stage | Time of Year and Location | Depth (m) | Temperature (°C) | Salinity (ppt) | Substrate | Current Velocity (m/sec) | Dissolved Oxygen (mg/L) |
|---|---|---|---|---|---|---|---|
| **Spawning Adult** | December (Florida) through late August (Nova Scotia) in Atlantic coast rivers from St. Johns River, FL to Nova Scotia **Sympatric range:** Freshwater or brackish water above the head of the tide in fast-moving waters, also brackish ponds **Allopatric range:** Slower-flowing tributaries and flooded low-lying areas adjacent to main streams | **Tolerable:** NIF **Optimal:** NIF **Reported:** Variable | **Tolerable:** 13-27 **Optimal:** 20-25 **Reported:** Variable | **Tolerable:** 0-6 **Optimal:** <1 **Reported:** Generally freshwater | **Tolerable:** NIF **Optimal:** NIF **Reported:** Sympatric: gravel, sand; Allopatric: Variable | **Tolerable:** NIF **Optimal:** NIF **Reported:** Fast flow | **Tolerable:** NIF **Optimal:** NIF **Reported:** Minimum 5 |
| **Egg** | December to August (south to north progression) at spawning site or slightly downstream of spawning site | **Tolerable:** NIF **Optimal:** NIF **Reported:** Usually found at bottom | **Tolerable:** 7-14 **Optimal:** NIF **Reported:** Variable | **Tolerable:** 0-22 **Optimal:** 0-2 **Reported:** Usually freshwater | **Tolerable:** NIF **Optimal:** NIF **Reported:** Variable | **Tolerable:** NIF **Optimal:** NIF **Reported:** NIF | **Tolerable:** NIF **Optimal:** NIF **Reported:** Minimum 5 |

| Life Stage | Time of Year and Location | Depth (m) | Temperature (°C) | Salinity (ppt) | Substrate | Current Velocity (m/sec) | Dissolved Oxygen (mg/L) |
|---|---|---|---|---|---|---|---|
| **Larvae** | 38-60 hours after fertilization downstream of spawning site | **Tolerable:** NIF **Optimal:** NIF **Reported:** Diel movement | **Tolerable:** 13-28 **Optimal:** NIF **Reported:** Variable | **Tolerable:** 0-22 **Optimal:** NIF **Reported:** Usually freshwater | **Tolerable:** NIF **Optimal:** NIF **Reported:** Variable | **Tolerable:** NIF **Optimal:** NIF **Reported:** NIF | **Tolerable:** ≥ 5 **Optimal:** NIF **Reported:** Minimum 5 |
| **Early Juvenile – Riverine Environment** | 3-9 months in natal rivers after reaching juvenile stage upstream or downstream of spawning sites, as far as offshore estuaries | **Tolerable:** NIF **Optimal:** NIF **Reported:** Surface or mid-water (daytime); bottom (nighttime) | **Tolerable:** 11-32 **Optimal:** 20-30 **Reported:** Variable; temp gives migration cues | **Tolerable:** 0-28 **Optimal:** 0-5 (summer) **Reported:** Variable | **Tolerable:** NIF **Optimal:** NIF **Reported:** SAV | **Tolerable:** NIF **Optimal:** NIF **Reported:** Variable | **Tolerable:** NIF **Optimal:** NIF **Reported:** Minimum 4 |
| **Sub-adult & Non-spawning Adult– Estuarine / Oceanic Environment** | 3-6 years after hatching in nearshore estuarine waters or offshore marine waters | **Tolerable:** NIF **Optimal:** NIF **Reported:** Diel migrations with zooplankton; most frequently caught at 27-55 | **Tolerable:** NIF **Optimal:** NIF **Reported:** Probably travel in preferred isotherm like other alosines | **Tolerable:** NIF **Optimal:** NIF **Reported:** Brackish to saltwater | **Tolerable:** NIF **Optimal:** NIF **Reported:** NIF | **Tolerable:** NIF **Optimal:** NIF **Reported:** NIF | **Tolerable:** NIF **Optimal:** NIF **Reported:** NIF |

## 1.3.3 Overlapping Habitat and Habitat Areas of Particular Concern for Alosines

### *1.3.3.1 Identification and Distribution of Habitat and Habitat Areas of Particular Concern for Alosines*

*NOTE: Due to the dearth of information on Habitat Areas of Particular Concern (HAPC) for alosine species, this information is applicable to American shad, hickory shad, alewife, and blueback herring combined. Information about one alosine species may be applicable to other alosine species, and is offered for comparison purposes only. Certainly, more information should be obtained at individual HAPCs for each of the four alosine species.*

All habitats described in the preceding chapters (spawning adult, egg, larval, juvenile, sub-adult, and adult resident and migratory) are deemed essential to the sustainability of anadromous alosine stocks, as they presently exist (ASMFC 1999). Klauda *et al*. (1991b) concluded that the critical life history stages for American shad, hickory shad, alewife, and blueback herring, are the egg, prolarva (yolk-sac or pre-feeding larva), post-larva (feeding larva), and early juvenile (through the first month after transformation). Nursery habitat for anadromous alosines consists of areas in which the larvae, post-larvae, and juveniles grow and mature (ASMFC 1999). These areas include spawning grounds and areas through which the larvae and post-larvae drift after hatching, as well as the portions of rivers and estuaries in which they feed, grow, and mature. Juvenile alosines, which leave the coastal bays and estuaries prior to reaching adulthood, also use the nearshore Atlantic Ocean as a nursery area (ASMFC 1999).

Sub-adult and adult habitat for alosines consists of: the nearshore Atlantic Ocean from the Bay of Fundy in Canada to Florida; inlets, which provide access to coastal bays and estuaries; and riverine habitat upstream of the spawning grounds (ASMFC 1999). American shad and river herring have similar seasonal distributions, which may be indicative of similar inshore and offshore migratory patterns (Neves 1981). Although the distribution and movements of hickory shad are essentially unknown after they return to the ocean (Richkus and DiNardo 1984), due to harvest along the southern New England coast in the summer and fall (Bigelow and Schroeder 1953) it is assumed that they also follow a migratory pattern similar to American shad (Dadswell *et al*. 1987).

Critical habitat in North Carolina is defined as, "The fragile estuarine and marine areas that support juvenile and adult populations of economically important seafood species, as well as forage species important in the food chain." Among these critical habitats are anadromous fish spawning and nursery areas in all coastal fishing waters (NCAC 3I.0101 (20) (NCDEHNR 1997). Although most states have not formally designated essential or critical alosine habitat areas, most states have identified spawning habitat, and some have even identified nursery habitat.

Tables in Section II of each alosine species chapter contain significant environmental, temporal, and spatial factors that affect the distribution of American shad, hickory shad, alewife, and blueback herring. Additional tables found on the included DVD contain confirmed, reported, suspected, or historical state habitat for American shad, hickory shad, alewife, and blueback herring. Alosines spend the majority of their life cycle outside of state waters, and the Commission recognizes that all habitats used by these species are essential to their existence.

#### *1.3.3.2 Present Condition of Riverine Habitats and Habitat Areas of Particular Concern*

Fisheries management measures cannot successfully sustain anadromous alosine stocks if the quantity and quality of habitat required by all species are not available. Harvest of fisheries resources is a major factor impacting population status and dynamics, and is subject to control and manipulation. However, without adequate habitat quantity and quality, the population cannot exist (ASMFC 1999).

***Habitat Quantity***

Thousands of kilometers of historic anadromous alosine habitat have been lost due to development of dams and other obstructions to migration. In the 19$^{th}$ century, organic pollution from factories created zones of hypoxia or anoxia near large cities (Talbot 1954; Chittenden 1969). Gradual loss of spawning and nursery habitat quantity and quality, and overharvesting are thought to be the major causative factors for population declines of American shad, hickory shad, alewife, and blueback herring (ASMFC 1999). Although these threats are considered the major causative factors in the decline of shad and river herring, additional threats are discussed in the Threats chapter.

It is likely that American shad spawned in all rivers and tributaries throughout the species' range on the Atlantic coast prior to dam construction in this country (Colette and Klein-MacPhee 2002). While precise estimates are not possible, it is speculated that at least 130 rivers supported historical runs; now there are fewer than 70 systems that support spawning. Individual spawning runs may have numbered in the hundreds of thousands. It is estimated that runs have been reduced to less than 10% of historic sizes. One recent estimate of river kilometers lost to spawning is $4.36 \times 10^3$ compared to the original extent of the runs. This is an increase in available habitat over estimates from earlier years, with losses estimated at $5.28 \times 10^3$ in 1898 and $4.49 \times 10^3$ in 1960. The increase in available habitat has largely been due to restoration efforts and enforcement of pollutant abatement laws (Limburg *et al*. 2003).

Some states have general characterizations of the degree of habitat loss, but few studies have actually quantified impacts in terms of the area of habitat lost or degraded (ASMFC 1999). It has been noted that dams built during the 1800's and early to mid-1900's 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). North Carolina characterized river herring habitat loss as "considerable" from wetland drainage, stream channelization, stream blockage, and oxygen-consuming stream effluent (NCDENR 2000).

Some attempts have been made to quantify existing or historical areas of anadromous alosine habitat, including spawning reaches. For example, Maine estimated that the American shad habitat area in the Androscoggin River is 10,217,391 $yd^2$. In the Kennebec River, Maine, from Augusta to the lower dam in Madison, including the Sebasticook and Sandy rivers, and Seven Mile and Wesserunsett streams, there is an estimated 31,510,241 $yd^2$ of American shad habitat and 24,606 surface acres of river herring habitat. Lary (1999) identified an estimated 90,868 units (at 100 $yd^2$ each) of suitable habitat for American shad and 296,858 units (at 100 $yd^2$ each) for alewife between Jetty and the Hiram Dam along the Saco River, Maine. Above the Bosher's Dam on the James River, Virginia, habitat availability was estimated in terms of the number of spawning fish that the main-stem area could support annually, which was estimated at 1,000,000 shad and 10,000,000 river herring (Weaver *et al*. 2003).

Although many stock sizes of alosine species are decreasing or remain at historically low levels, some stock sizes are increasing. It has not been determined if adequate spawning, nursery, and adult habitat presently exist to sustain stocks at recovered levels (ASMFC 1999).

### *Habitat Quality*

Concern that the decline in anadromous alosine populations is related to habitat degradation has been alluded to in past evaluations of these stocks (Mansueti and Kolb 1953; Walburg and Nichols 1967). This degradation of alosine habitat is largely the result of human activities. However, it has not been possible to rigorously quantify the magnitude of degradation or its contribution to impacting populations (ASMFC 1999).

Of the habitats used by American shad, spawning habitat has been most affected. Loss due to water quality degradation is evident in the northeast Atlantic coast estuaries. In most alosine spawning and nursery areas, water quality problems have been gradual and poorly defined; it has not been possible to link those declines to changes in alosine stock size. In cases where there have been drastic declines in alosine stocks, such as in the Chesapeake Bay in Maryland, water quality problems have been implicated, but not conclusively demonstrated to have been the single or major causative factor (ASMFC 1999).

Toxic materials, such as heavy metals and various organic chemicals (i.e., insecticides, solvents, herbicides), occur in anadromous alosine spawning and nursery areas and are believed to be potentially harmful to aquatic life, but have been poorly monitored. Similarly, pollution in nearly all of the estuarine waters along the East Coast has certainly increased over the past 30 years, due to industrial, residential, and agricultural development in the watersheds (ASMFC 1999). Specific challenges that currently exist are identified and discussed in greater detail in the Threats Chapter.

### 1.3.4 Threats to Alosine Species

*NOTE: Due to broad geographic ranges, alosine 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.*

#### *1.3.4.1 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 waterpower, 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).

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.

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 19$^{th}$ century through the mid-20$^{th}$ 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).

*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).

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).

*Issue 1.1A.3: Delayed migration*

When juvenile alosines delay out-migration, they may concentrate behind dams, making them more susceptible to actively feeding predators. They may also be more vulnerable to anglers that targ*et al*osines as a source of bait. Delayed out-migration 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).

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).

*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).

It is estimated that the annual biomass contribution of anadromous alosines to the non-tidal 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).

<u>Example: Successful Dam Removals</u>

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*

#### 1. For Upstream Passage

*a) 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 (VDGIF 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).

In 1999, a vertical slot fishway was opened at Bosher's 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). (Note: This increase was dominated by hatchery-raised fish, thus, fish passage may have had little to do with the increased population in this situation; M. Hendricks, Pennsylvania Fish and Boat Commission, pers., comm.)

*b) 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).

*c) 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 fishlift involves a chamber that fish swim into. A steel bucket recessed in the chamber floor is lifted up to or above the head pond level, a gate is opened and the fish are dumped out. 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, pers. comm.).

### 2. 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, alternatively, they 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 and through a sluiceway (Martin *et al*. 1994).

*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 in-stream 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).

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).

*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).

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.

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).

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*. 1991b). 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). 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).

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 (1976c) 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 1976c).

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).

*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.

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).

## *THREAT #3: TOXIC AND THERMAL DISCHARGES*

### 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.

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 might 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).

*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).

### 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).

The estimated lost spawning habitat for American shad in 1898 was $5.28 \times 10^3$ river km, and in 1960 it was estimated at $4.49 \times 10^3$ km. The most recent estimate is now $4.36 \times 10^3$ 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).

*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*. 1991b).

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).

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).

### *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*

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 2000). 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.

**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).

*THREAT #5: LAND USE CHANGE*

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 $18^{th}$ 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*. 1991b).

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).

Uzee and Angermeier (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).

**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 (VDGIF 2005).

**Section 5.2A: Logging/Forestry**

*Issue 5.2A.1: Logging*

Logging activities can modify hydrologic balances and in-stream 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 2005b).

### 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 (VDGIF 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.

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).

### 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).

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, pers. comm.).

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).

*THREAT #6: ATMOSPHERIC DEPOSITION*

## 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).

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. High mortalities of hatchery-reared American shad larvae in 2006 and 2007 were thought to be due to pH depression and elevated aluminum (M. Hendricks, Pennsylvania Fish and Boat Commission, pers. comm.). In 2008, treatment of raw hatchery water with limestone sand raised pH from 6.0 to above 7.0, and resulted in high survival and healthy larvae. 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*. 1991b).

**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).

### *1.3.4.2 Effects of Habitat Degradation on Harvesting/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).

The following table 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.

**Table 9.** Threats identified for shad and river herring. 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 |
| ***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 |

## 1.4 DESCRIPTION OF THE FISHERIES

Alewife and blueback herring formerly supported important commercial and recreational fisheries along the entire Atlantic coast; however, all of these fisheries have declined dramatically. Two types of fisheries have exploited spring spawning migrations of alosines: in-river and ocean-intercept. In-river fisheries only exploit the stock native to that system, whereas ocean-intercept fisheries exploit mixed stocks of different river origins.

Catch statistics for both ocean and in-river alosine fisheries on the Atlantic coast are compiled by the National Marine Fisheries Service and state agencies for both commercial and recreational fisheries; however, there are data gaps in these records. It is important to note that harvest from fishers operating in-river or from fisheries that are not federally licensed might not be reported to NMFS. Information provided below is based on state reports, which are on file with the Commission, and data available from NMFS.

### 1.4.1 Commercial Fishery

River herring have supported one of the oldest documented fisheries in North America (CRASC 2004). During colonial times in-river stocks of anadromous species such as river herring became subject to intensive exploitation as well as habitat degradation related to clear-cutting, damming for mills and wetland conversion to agricultural lands (Purinton *et al.* 2003). For Massachusetts, the decline in coastal alewife fisheries had become so extensive that between 1790 and 1860 regulations were adopted for most Massachusetts rivers to manage in-river alewife fisheries (Belding 1921). In North Carolina, river herring were the most economically important finfish harvested during the late 1880s, but by 1918 the Atlantic menhaden had become more economically viable than river herring (NC DMF 2007).

Uses of harvested river herring have changed from a major local food source for human consumption in the form of smoked, salted and/or pickled fish (e.g., Belding 1921) toward primarily being used for fishmeal, pet food ingredients, and bait for commercial and sport fishing (Fay *et al*. 1983). During the 20$^{th}$ century, river herring supported a small commercial bait industry in the New England states (Purinton *et al.* 2003). These harvests, which were also used for pet food and fishmeal as well as for bait, declined considerably throughout New England between the turn of the 20$^{th}$ century and the 1980s (CRASC 2003). Yet river herring, when available, have become desirable bait species for recreational anglers, as well as remaining a significant bait source for commercial fisheries such as the American lobster (*Homarus americanus*) fishery (e.g., Anonymous n.d.). For example, Schmidt *et al*. (2003) reported that river herring in the Hudson River are used as striped bass (*Morone saxatilis*) bait but noted that smoked herring processed from the spring was still available.

Commercial harvest of river herring in state waters primarily occurs in the late winter and spring, depending upon location. Fishermen use a variety of gear to target river herring, including gillnet, weir, pound net, fish trap, dip net, cast net, fyke net, drop net, lift net, seine, otter trawl and hook-and-line. While most states have or have had commercial fisheries for river herring in the past, some states have recently implemented moratoria on the harvest of river herring, including Massachusetts, Connecticut, Rhode Island and North Carolina. Virginia has implemented complementary regulations for river herring fisheries in river systems that flow into North Carolina. Pennsylvania and the District of Columbia prohibit commercial fisheries within their jurisdiction and have never had commercial river herring fisheries. Although not unlawful, no commercial fishery for river herring has ever existed in Georgia's rivers or coastal waters. In 1994, Florida implemented a net ban in state waters (Adams *et al*. 2000) that effectively eliminated the river herring commercial fishery. Descriptions of other state's commercial fisheries for river herring follow.

In Maine, commercial fisheries for river herring are cooperatively managed by the municipalities that have been granted fishing rights and the Maine Department of Marine Resources (MDMR). Municipal fisheries have a three-day per week, closed period that requires all fishing gear to be opened to allow for free passage upstream or a spawning escapement equivalent. Commercial bait gillnet fishermen operate in coastal waters and may catch river herring, although participation in this fishery is low (27 fishermen in 2007; M. Brown, MDNR, pers. comm.). There are two active fish traps in Maine coastal waters that have an annual combined landings of river herring less than 500 pounds; this fishery is opportunistic and landings are based on seasonal availability.

River herring serve as a significant bait source for commercial fisheries in New Hampshire. New Hampshire Fish and Game Department (NHFGD) requires permits for the harvest of river herring and a license for the sale of the fish. NHFGD prohibits the harvest of river herring on Wednesdays. In New Hampshire waters, there are various restrictions for seines and gillnets (mesh size, length, season, etc.) and other gear and no mobile gear may be used to harvest finfish within the state.

Commercial fisheries for river herring exist within the Hudson River, NY and it tributaries. All commercial take and sale requires a marine permit issued by the New York State Department of Environmental Conservation. Primary gears include gill nets, fished in the main stem Hudson River and scap (lift) or dip nets, which are fished in the smaller tributaries. Other gears used include cast nets, and to a small extent, trap or fyke nets. Fishing season occurs from March 15$^{th}$ through June 15$^{th}$. Regulations include gear restrictions on net and mesh sizes, as well as area closures along for the main stem river. Permitees are required to fill out an annual report, which includes a descriptions of when / where fishing occurred, along with catch, bycatch and effort expended (amount and type of gear and fishing time). The number of gill net fishers has grown in recent years following the popularity of the Hudson's striped bass fishery; river herring are the primary bait used.

National Marine Fisheries Service reports river herring landings from a variety of commercial fishing operations (primarily otter trawl) off Long Island, NY. Since 2000, all river herring landings, regardless of season, are classified as blueback herring. Any *Alosa spp*. could be in the catch, including alewife (more prevalent in the spring) and hickory shad (more prevalent in the late summer and fall). It is not clear why this single species classification occurs. There are limited fisheries in a few eastern Long Island streams which support small spawning runs of alewives. For ocean waters off of Long Island, a mandatory reporting system exists; however, the accuracy of this reporting has not been verified. Other Long Island gears may encounter river herring as bycatch such as pound net (trap nets), otter trawls, small mesh gill nets and bait seines used for menhaden. The extent of this bycatch is unknown.

River herring are harvested in New Jersey's small-mesh gillnet fishery. The majority of river herring landings from this fishery are categorized as bait. There are likely bait fisheries that operate in New Jersey rivers and creeks where there are large populations of river herring. River herring may also be taken in a variety of other fisheries that operate in New Jersey waters, especially the early spring white perch fishery.

The Delaware commercial fishery for river herring is relatively small, but has produced highly variable landings ranging from 500-36,000 lbs since 1985. All commercial river herring landings come from small-mesh gillnets set for white perch and herring. No specific regulations have been adopted to reduce or restrict commercial landings of river herring; however, there are regulations that apply to the entire commercial fishery that limit commercial fishing effort and have a direct effect on catch. These restrictions include a limited entry license system, limitations on the amount of gear that may be fished, a gillnet season and area restrictions. There is currently proposed legislation that would prohibit the use of any net within 300 feet of any dam and also prohibit the use of any gillnet within the Nanticoke River. These two pieces of legislation would effectively eliminate the commercial fishery for river herring in Delaware.

Maryland's commercial river herring fishery is seasonally restricted, running from 1 January to 5 June, but because most fish have returned to the ocean by June, this law has little, if any, management consequence. Up until 2005, the commercial river herring fishery was a directed fishery employing drift gillnets. Since 2005, the directed fishery reported minimal landings and effort declined. Many commercial gillnet fishermen no longer target river herring. A limited pound net and fyke net bycatch fishery for river herring also exists.

In the Potomac River, the Potomac River Fisheries Commission (PRFC) regulates commercial fishing activity. According to PRFC records, the Potomac river herring fishery has been almost exclusively a pound net fishery since 1964. Pound net fishery effort in the Potomac River has been capped at 100 licenses since 1995.

Virginia's management of fisheries has two regions: (1) those within aquatic reaches affected by the tide are managed by Virginia Marine Resources Commission (VMRC) and (2) those reaches above tidal influence are managed by Virginia Division of Game and Inland Fisheries (VDGIF). Commercial fishing for river herring primarily occurs in areas under VMRC's management. There are restrictions on both length of gear and mesh size for gillnets.

In South Carolina, the river herring commercial fishery is managed with seasons, harvest caps, gear restrictions, weekly lift periods, and licenses. South Carolina's commercial fishery targets adult pre-spawning blueback herring for bait and human consumption, particularly roe. Most fish harvested in the riverine gillnet fishery are consumed locally or sold as bait.

Total commercial landings of river herring from Maine to Florida were approximately 10.5 million pounds in 1980 (NMFS, Fisheries Statistics Division, Silver Spring, MD, pers. comm.). Yet by 1992, total landings decreased to 3.2 million pounds (NMFS, Fisheries Statistics

Division, Silver Spring, MD, pers. comm.). Since 1994, state-reported commercial landings for the East Coast have not exceeded two million pounds. Recent landings by state are presented in Table 10. There are many factors influencing the reported commercial river herring landings that might explain the large degree of variability observed in data on a state-by-state basis.

**Table 10.** State-reported commercial landings (pounds) of river herring, 2003-2007. †Landings from Maine are from the directed commercial municipal fisheries only; these numbers do not include bait gillnet, bycatch, weir or inland commercial permits, or VTR reports from coastal fisheries. *Under moratorium. ^ Some rivers under moratorium in 2007. ^^ Under moratorium in 2007; landings from research set-asides only.

| State | 2003 | 2004 | 2005 | 2006 | 2007 |
|---|---|---|---|---|---|
| Maine† | 969,360 | 885,582 | 340,060 | 1,178,758 | 740,915 |
| New Hampshire | 16,516 | 9,093 | 1,514 | 1,717 | 1,408 |
| Massachusetts* | - | - | 8,952 | - | - |
| Rhode Island* | - | - | - | - | - |
| Connecticut* | - | - | - | - | - |
| New York | - | 15,200 | 12,782 | 9,748 | 14,354 |
| New Jersey | 3,439 | 4,583 | 3,247 | 2,945 | 223 |
| Pennsylvania | - | - | - | - | - |
| Delaware | 6,371 | 3,925 | 3,715 | 3,355 | 1,896 |
| Maryland | 117,515 | 60,055 | 32,255 | 32,045 | 54,821 |
| DC | - | - | - | - | - |
| PRFC | 20,132 | 19,739 | 8,507 | 6,819 | 6,011 |
| Virginia^ | 209,327 | 203,273 | 91,662 | 48,865 | 104,923 |
| North Carolina^^ | 199,716 | 188,541 | 250,021 | 109,243 | 1,103 |
| South Carolina | 129,259 | 66,735 | 152,225 | 82,798 | 152,558 |
| Georgia | - | - | - | - | - |
| Florida | - | - | - | - | - |
| **Total** | **1,671,635** | **1,456,726** | **904,940** | **1,476,293** | **1,078,212** |

There are no consistent regional or U.S. Atlantic time series data of river herring ex-vessel values and related prices. Prior to 2000, NMFS recorded all river herring landings as *alewife* and did not differentiate between the two species (alewife and blueback herring). Consequently, in the following ex-vessel value and price analysis, only data on "alewife" landings and reported total ex-vessel revenues for the Atlantic states during the period 1985-2005 were used. These data were obtained from the Fisheries Statistics Division of the National Marine Fisheries Service.

Using alewife as an overall indicator of recent (1986-2006) river herring ex-vessel value trends, the nominal total (aggregate) ex-vessel value of the U.S. Atlantic coast alewife harvest has ranged from a low of about $123,000 in 2006 to a high of approximately $625,000 in 1986 (Table 11). (Since 1949, the highest nominal total ex-vessel value, ~$1.1 million, reported by NMFS, occurred in 1967.) Annual average nominal, ex-vessel value during the 1987-1996 period, ~$316,000, declined to an average of about $247,000 after 1996. When ex-vessel values are adjusted for inflation using the Consumer Price Index[2], the average total ex-vessel value of alewife landings was about $183,000 coastwide after 1996 (Table 11), only 65% of the total real ex-vessel value for previous period (1987-1996). Since 1987, nominal U.S. Atlantic coast prices per pound for alewife generally increased over time (Figure 2) and peaked at $0.45 per pound in 2006 (Table 11). The U.S. Atlantic real (deflated) price also generally trended upward from 1987, peaking at a ~$0.27 per pound in 2006. With declining landings, the real average real ex-vessel price for alewife during the 1997-2006 period, ~$0.16 per pound, was 45% higher than the ex-vessel price, about $0.11 per pound during the previous 10-year period. Real river herring ex-vessel prices in North Carolina also generally trended upward since 1985, but have not exceeded $0.10 per pound since 1995 (NC DMF 2007).

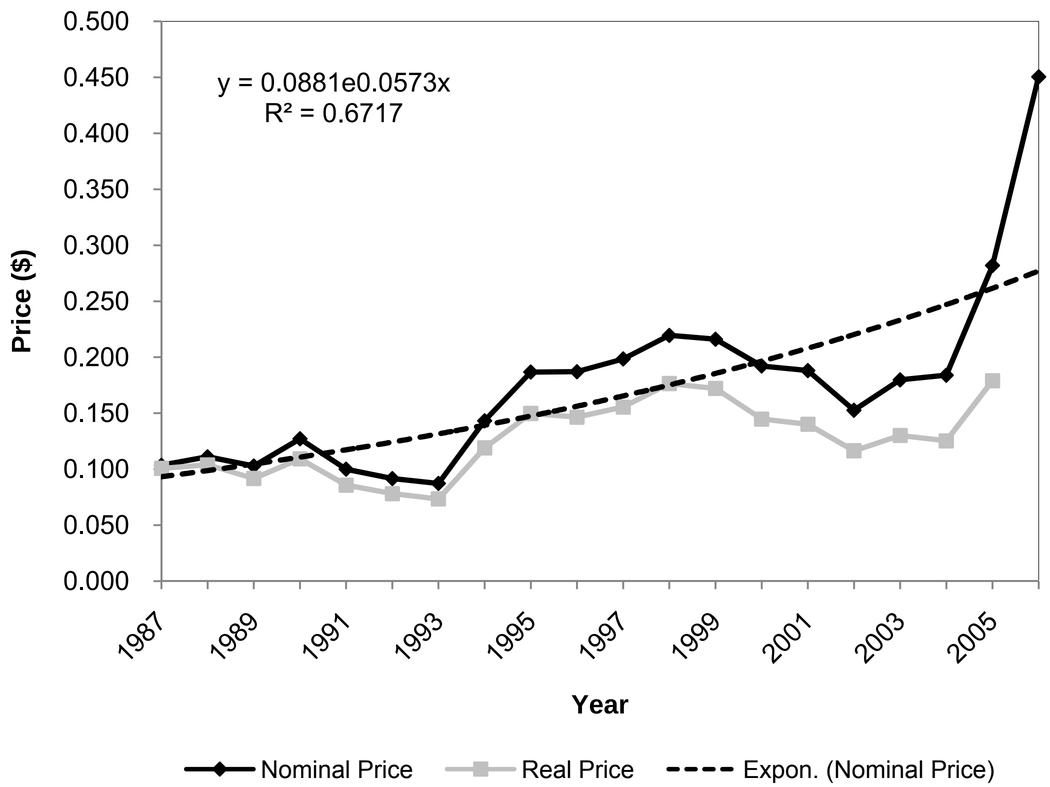
**Table 11.** Total annual U.S. Atlantic landings, ex-vessel values and prices of the alewife as reported to the National Marine Fisheries Service, 1986-2006 (Source: NMFS, Fisheries Statistics Division, Silver Spring, MD, pers. comm.).

| Year | Landings (lbs) | Total Ex-vessel Value ($): | | Ex-vessel Price, ($/Lb): | |
|---|---|---|---|---|---|
| | | Nominal | Real^ | Nominal | Real^ |
| 1987 | 5,614,390 | 581,529 | 565,690 | 0.104 | 0.101 |
| 1988 | 5,622,963 | 625,037 | 584,693 | 0.111 | 0.104 |
| 1989 | 3,413,277 | 351,407 | 313,197 | 0.103 | 0.092 |
| 1990 | 2,726,369 | 346,800 | 298,194 | 0.127 | 0.109 |
| 1991 | 2,922,301 | 292,361 | 250,954 | 0.1 | 0.086 |
| 1992 | 3,213,133 | 294,672 | 251,427 | 0.092 | 0.078 |
| 1993 | 1,682,532 | 146,978 | 123,615 | 0.087 | 0.073 |
| 1994 | 970,237 | 139,071 | 115,507 | 0.143 | 0.119 |
| 1995 | 1,010,874 | 188,824 | 151,423 | 0.187 | 0.15 |
| 1996 | 1,023,057 | 191,489 | 149,952 | 0.187 | 0.147 |
| 1997 | 1,160,070 | 230,280 | 180,470 | 0.199 | 0.156 |
| 1998 | 1,331,720 | 292,434 | 235,076 | 0.22 | 0.177 |
| 1999 | 1,351,686 | 292,241 | 232,861 | 0.216 | 0.172 |
| 2000 | 1,171,685 | 225,212 | 169,715 | 0.192 | 0.145 |
| 2001 | 1,537,171 | 289,301 | 215,575 | 0.188 | 0.14 |
| 2002 | 1,953,379 | 298,345 | 227,571 | 0.153 | 0.117 |
| 2003 | 1,499,030 | 269,612 | 195,230 | 0.18 | 0.13 |
| 2004 | 1,331,878 | 245,134 | 167,099 | 0.184 | 0.125 |
| 2005 | 732,979 | 206,683 | 131,311 | 0.282 | 0.179 |
| 2006 | 272,826 | 122,899 | 74,620 | 0.45 | 0.274 |
| **Means: All Years:** | | **$281,515** | **$231,709** | **$0.18** | **$0.13** |
| **Means: 1987-1996:** | | **$315,817** | **$280,465** | **$0.124** | **$0.106** |
| **Means: 1997-2006:** | | **$247,214** | **$182,953** | **$0.226** | **$0.161** |

**^Total ex-vessel values and prices deflated using the Consumer Price Index.**

[2]Given the scope of this analysis, the Consumer Price Index (CPI) was selected for deflating ex-vessel prices out of convenience as well as allowing comparability with other deflated ex-vessel price series. However, as others have noted (e.g., Tomek & Robinson 2003), deflating prices should be approached with caution especially when applying consumer oriented price index series to producer prices.

**Figure 2.** Real and nominal ex-vessel price ($/lb) for U.S. Atlantic alewife landings, 1986-2006 (Source: NMFS, Fisheries Statistics Division, Silver Spring, MD, pers. comm.).




Schmidt *et al.* (2003) noted that there was no published literature supporting the notion that river herring landings associated with large rivers on the East Coast of North American had been declining "due to the lack of market demand." At least during recent decades, the general increase in annual real alewife ex-vessel prices (Figure 2) is consistent with their observation (i.e., a general decrease or lack of market demand as a major factor contributing to the decline in river herring landings seems very unlikely).

Ex-vessel prices for river herring, like other market commodities, are determined jointly by demand and supply including exogenous factors that impact markets such as harvest constraints or moratoriums. Interacting factors that could be impacting river herring prices besides regulatory constraints on river herring may also include the apparent escalation in market demand for river herring as recreational fishing bait especially for anglers targeting striped bass (e.g., Capone 2007, Volstad *et al*. 2003). For example, retail prices of $3 and $2 for individual live and dead river herring, respectively, have recently been reported for New Jersey bait shops (Geiser 2008) and as high as $5 per fish elsewhere (PFBC 2008).

Recognizing that several factors may affect the level of demand and supply over time, given observed levels of apparent quantities demanded and supplied, an equilibrium price per pound (i.e., an ex-vessel price) can be approximated. Specifically, if it can be shown that a measurable and statistically significant relationship existed between quantities supplied and ex-vessel prices, it is possible to provide some historical insight on how commercial landings have impacted the ex-vessel market segment as well as perhaps forecasting how future prices may be impacted by proposed regulatory actions.

Alewife data (see Table 19) were used to estimate a simple annual ex-vessel price model for characterizing how changes in river herring landings could have recently affected ex-vessel market prices. The following semi-log price model[3] was specified:

$$\textit{Real Ex-vessel Price}_t = \alpha + \beta(\ln)\textit{Landings}_t;$$

where the *Real Ex-vessel Price* is the observed annual (deflated) ex-vessel price per pound for alewife landings in U.S. Atlantic states, *(ln)Landings* is the natural log of the annual amount (poundage) of reported landings, $t$ is time and $\alpha$ and $\beta$ are parameter coefficients to be estimated for the above model. There are many complicated models or functional forms that could be used to explore the relationship between landings and ex-vessel prices but the choice of this semi-linear form was based on the limitations of the available data and the related need to have a relatively simple price model that is capable of adequately representing the variation in river herring ex-vessel prices associated with different levels of landings. Additionally, since the expected relationship between reported landings and ex-vessel prices is not likely to be linear, a semi-log (non-linear) functional form was selected. The semi-log model was estimated using ordinary least squares (OLS).

The estimated model parameters were the following:

$$\textit{Real Ex-vessel Price}_t = 1.2136 - 0.0756(\ln)\textit{Landings}_t$$

*t-Statistics:* (8.26) (-7.17)

*Durbin-Watson statistic:* 1.39

The adjusted $R^2$ was 0.848 (N=10) and the F-value (51.39) for the equation was significant ($p \leq 0.0001$).

The t-statistic for the alewife landings parameter is statistically significant at the 1% level, and landings are estimated to be negatively (inversely) related to annual alewife ex-vessel price. The estimated model as indicated by the $R^2$ "explains" about 85% of the ex-vessel price trend variability during 1985-2005. Of course, a more complex demand system is needed to consider other factors (e.g., recreational fishing bait demand, fishery regulatory actions, river herring bait substitutes) that have influenced alewife ex-vessel prices. Regardless, the inverse relationship between prices and landings is consistent with supply-demand relationship over a relatively long time period (i.e., 21 years). Using the estimated coefficient of the landings parameter, *– 0.0756*, and the means of the annual prices and quantities landed, the price flexibility[4], $F_P$, was estimated

[3]This simple model is often described as an inverse semi-log demand model but it usually includes more than one explanatory (independent) variable.

[4]It is actually the estimated own-price flexibility coefficient which is predicated on the causality of price changes stemming from quantity changes to the ex-vessel price, instead of the usual price to quantity causality (Tomek & Robinson 2003).

to be approximately *–6.5*. This $F_P$ value suggests that the ex-vessel own-price elasticity of demand for alewife during the years analyzed and perhaps river herring in general is inelastic since the absolute value of $F_P$ coefficient is greater than one (Tomek and Robinson 2003).

This apparent relative flexibility of river herring ex-vessel prices in regard to its own landings at least during the 1985-2005 period may also be symptomatic of market factors that could have historically encouraged harvesters to actually escalate their fishing effort because they perceived an ex-vessel market segment with the potential of offsetting declining harvest quantities with higher ex-vessel prices. Stated another way, river herring harvesters and primary processors in past decades may have perceived a long-term market capable of generating them increasing gross revenues even if quantities harvested were declining (i.e., a relatively flexible ex-vessel price situation). For open access fisheries, flexible prices (i.e., inelastic demand) along with other factors have been implicated in the depletion of various fishery stocks (e.g., Brandt 1999). Consequently, from a historical perspective, total revenue changes at the harvester level associated with declining river herring stocks, including declines independent of commercial fishing effort, such as habitat degradation, may have been partially buffered if river herring prices were generally flexible relative to its own landings.

### 1.4.2 Recreational Fishery

Recreational fisheries for alosines are often poorly documented, if at all. The National Marine Fisheries Service operates the Marine Recreational Fisheries Statistics Survey (MRFSS) to obtain information on recreational fisheries for marine species. MRFSS does not adequately capture information on anadromous fisheries, including those for alewife and blueback herring. Data collected by MRFSS for recreational alosine fisheries are unreliable due to the current survey design that focuses on active fishing sites along coastal and estuarine areas. Error associated with data on harvest, catch, and effort is often high.

While recreational fisheries for river herring are poorly documented and monitored, it is believed that extensive recreational fisheries exist for river herring in many rivers along the East Coast and in coastal waters. Recreational anglers target river herring mainly for bait (lobster and striped bass) and personal consumption. Moreover, it is apparent that recreational anglers in the Mid-Atlantic and New England states commonly harvest river herring as bait species for targeting striped bass.

Some in-river fisheries operate at the base of spillways where river herring are aggregated while waiting to ascend fish ladders or where upstream progress is retarded by dams. Each state and jurisdiction has different regulations for the recreational harvest of river herring, including licensing requirements, size limits, area closures and gear restrictions. Gears used by recreational anglers to target river herring include: rod and reel, dip net, lift net, gillnet and cast net. Recreational creel limits vary by state, ranging from no limit to 10 fish to one bushel per day. The total quantity of fish landed by these recreational fishers for personal use is unknown. The majority of these landings is unreported and thus, represents a large potential error in recorded recreational river herring harvests. The recreational fisheries for river herring in Massachusetts, Rhode Island, and North Carolina are closed under each state’s moratorium.

### 1.4.3 Subsistence Fishing

There are known subsistence fisheries for alosine fisheries, but the extent of effort and harvest is undocumented. An example of subsistence fisheries for river herring is the Mashpee Wampanoag Indian Tribe on Cape Cod, Massachusetts, which has reported annual harvests ranging between 1,200 and 3,400 fish for the years 2006 through 2008.

### 1.4.4 Non-Consumptive Factors

People interested in conservation and wildlife have been known to observe alosine migrations through natural corridors and fish passage facilities. In some regions, this non-consumptive use of the alosine resources is an important part of public education, local heritage, ecotourism and outdoor recreation. For example, the Massachusetts Division of Marine Fisheries (MDMF n.d.) prepared a brochure that "provides location and viewing dates for several of our most impressive and accessible river herring runs." Real-time video of spring spawning migrations of alosines are available via online webcams for both the fishway at Bosher's Dam on the James River and Fairmount Dam on the Schuyllkill River (available at: http://www.dgif.virginia.gov/fishing/shadcam/index.asp?pop=3 and http://fairmountwaterworks.com/sony/fishpop.php, respectively). In addition, volunteer involvement in non-consumptive cooperative fishery projects has included activities related to river herring such as the Ipswich River Watershed Association's annual herring counts on the Ipswich River in Massachusetts (Bowling and Morkeski 2002).

### 1.4.5 Interactions with Other Fisheries, Species and Other Uses

#### *1.4.5.1 Bycatch*

Catch of anadromous alosines that occurs in fisheries directed at other species is referred to as bycatch. Bycatch also refers to illegal or unmarketable alosines caught in directed fisheries. Estimates of bycatch are difficult to obtain since few studies have focused specifically on that issue. Bycatch losses contribute to the overall mortality of alosines and are important to consider in the current and future management of these fisheries.

Bycatch of river herring, which includes the harvest of sexually mature and immature fish, occurs in non-directed fisheries that employ small-mesh mobile gear, both at-sea and in-river. Much of this incidental catch is utilized, although it goes undocumented or unreported. The NMFS Sea Sampling (Observer) Program estimated harvest and bycatch from a limited number of Atlantic herring trips taken between 2005 and 2007. Observers documented bycatch of river herring to be 41,458 pounds in 2005, 50,681 pounds in 2006, and 121,246 pounds in 2007 (the 2007 value is preliminary as only observed trips from January to April have been recorded in the Observer Database; NEFMC 2006; Steele 2007). Preliminary analysis indicate in some years, the total bycatch of river herring species in the Atlantic herring fleet alone could be equal to the total landings from the entire in-river directed fishery on the East Coast (Matt Cieri, Maine Department of Marine Resources, pers. comm.). Bycatch of river herring also occurs in inshore and freshwater areas in small-mesh mobile gear, pound nets and anchored gillnets.

### *1.4.5.2 Protected Species Considerations*

***Marine Mammals***

In October 1995, Commission member states, NMFS and USFWS began discussing ways to improve implementation of the Marine Mammal Protection Act (MMPA) and the Endangered Species Act (ESA) in state waters. Historically, these policies have been only minimally implemented and enforced in state waters (0-3 miles). It was agreed that the Commission's plans describe impacts of state fisheries on certain marine mammals and endangered species—collectively termed protected species—and recommend ways to minimize these impacts. Section 117 of the MMPA requires that NMFS and the U.S. Fish and Wildlife Service (USFWS) develop stock assessment reports (Reports) for all marine mammal stocks within U.S. waters or that enter U.S. waters (e.g., stocks for which only the margins of the range extends into U.S. waters or that enter U.S. waters only during anomalous current or temperature shifts). Each Report is required to estimate the annual human-caused mortality and serious injury of the stock, by source, and, for a strategic stock, other factors that may be causing a decline or impeding recovery of the stock, including effects on marine mammal habitat and prey, and commercial fisheries that interact with the stock.

Section 3(20) of the MMPA defines a strategic stock is defined as a stock: (1) for which the level of direct human-caused mortality exceeds the potential biological removal (PBR) level; (2) which is declining and is likely to be listed under the Endangered Species Act (ESA) within the foreseeable future; or (3) which is listed as a threatened or endangered species under the ESA or as a depleted species under the MMPA.

Section 3(20) of the MMPA defines the term *potential biological removal* (PBR) as:

> [T]he maximum number of animals, not including natural mortalities, that may be removed from a marine mammal stock while allowing that stock to reach or maintain its optimum sustainable population.

For strategic stocks interacting with Category I and II fisheries, Section 118(f) of the MMPA requires NMFS to appoint a Take Reduction Team (TRT), which must develop a Take Reduction Plan (TRP) designed to assist in the recovery of or to prevent the depletion of the strategic stock that interacts with a commercial fishery. Section 118(f)(2) of the MMPA states that the immediate goal of a TRP for a strategic stock shall be to reduce, within six months of its implementation, the incidental mortality or serious injury of marine mammals incidentally taken in the course of commercial fishing operations to levels less than the PBR level established for that stock under Section 117.

Upon the completion of draft stock assessment reviews developed under Section 117 of the MMPA, NMFS recognized the need to establish TRTs to reduce serious injury and mortality of coastal bottlenose dolphins, harbor porpoises and large whales in several coastal gillnet fisheries along the Atlantic coast.

There are two strategic stocks of marine mammals that are taken by gillnets in coastal state waters at the time alosine fisheries occur, designated as the Mid-Atlantic gillnet fishery under the MMPA's List of Fishery process. The Mid-Atlantic gillnet fishery operates year-round west of a line drawn at 72° 30' W. long. south to 36° 33.03' N. lat. and east to the eastern edge of the EEZ and north of the North Carolina/South Carolina border, not including waters where Category II and Category III inshore gillnet fisheries operate in bays, estuaries and rivers (72 FR 66048; November 27, 2007). Harbor porpoise and coastal bottlenose dolphins are the strategic stocks of marine mammals that are taken by gillnets in coastal state waters at the time that alosine fisheries occur. Both are known to enter tidal estuaries.

***Harbor Porpoise***

Harbor porpoises that are found along the eastern United States are considered to be one stock or population: the Gulf of Maine/Bay of Fundy stock. This population is dispersed in the Gulf of Maine and Mid-Atlantic in the winter and spring, and then is more concentrated in the Bay of Fundy/upper Gulf of Maine in the summer. The Harbor Porpoise Take Reduction Plan (HPTRP) became effective in January 1999 and implemented regulations in New England and the Mid-Atlantic to reduce the serious injury and mortality of harbor porpoises in commercial gillnet fisheries. The timing and location of the HPTRP management areas coincide with the temporal and seasonal distribution of harbor porpoises.

In July 1993, the Northeast Fisheries Science Center's Sea Sampling (Observer) program initiated an observer program in the Mid-Atlantic coastal gillnet fishery. From 1995 to 2000, 114 harbor porpoises were observed taken (Waring *et al.* 2002). During that time, observed fishing effort was scattered between New York and North Carolina from the beach to 50 miles from shore. Most of the animals taken in state waters are taken in the months of March, April and May, from North Carolina to New Jersey. After 1995, documented bycatch was observed from December to May. The timing and location of stranding data in Mid-Atlantic States follow the timing and location(s) of the ocean-intercept shad fishery as it moves north along the coastline. It is important to note that the East Coast American shad ocean-intercept fishery closed in 2005.

Annual average estimated harbor porpoise mortality and serious injury from the Mid-Atlantic coastal gillnet fishery between 1995 and 1998, before implementation of the Harbor Porpoise Take Reduction Plan, (63 FR 66464, December 2, 1998), was 358 animals (Waring *et al.* 2002). Subsequently, between 2000 and 2004, the average annual harbor porpoise mortality and serious injury in this fishery was 65 animals (Waring *et al.* 2006). However, NMFS has observed an increase in harbor porpoise takes in commercial gillnet fisheries in recent years, due to a lack of compliance with the HPTRP requirements and takes occurring outside HPTRP management areas. The most recent Report estimates that between 2001 and 2005, the total annual estimated average human-caused mortality was 734 harbor porpoises per year (652 from U.S. fisheries), which is higher than the current PBR of 610 (Waring *et al.* 2007).

NMFS reconvened the Harbor Porpoise Take Reduction Team (HPTRT) in December 2007 to discuss updated harbor porpoise abundance and bycatch information. An additional HPTRT meeting was held in January 2008 via teleconference. The HPTRT made recommendations for modifying the HPTRP to address the recent increases in harbor porpoise takes in both the New England and Mid-Atlantic regions.

### *Bottlenose Dolphin*

There are at least two morphologically and genetically distinct stocks of bottlenose dolphin along the eastern coast of the United States: (1) a coastal migratory stock that occurs in coastal waters from Long Island, New York to as far south as central Florida; and (2) an offshore stock primarily distributed along the outer continental shelf and slope in the Northwest Atlantic Ocean. The coastal morphotype is comprised of a complex mosaic of 7 spatial and temporal management units. Resident estuarine stocks are likely demographically distinct from the coastal management units; however, they are currently included in the coastal management unit definitions (Waring *et al.* 2007). Although the estuarine stocks are currently reported with the management units, abundance, mortality and PBR estimates do not include estuarine stocks. Research continues to further define the coastal stock management units and the degree of movement of estuarine dolphins into nearshore, coastal waters, as the spatial overlap remains unclear.

The coastal bottlenose stock was designated as depleted under the Marine Mammal Protection Act due to a large-scale, natural die-off in 1987-1988. Therefore, the coastal stock is listed as strategic because of this die-off and exceeding PBR from serious injuries and mortalities incidental to commercial fisheries. Because one or more of the management units may be depleted, all of the management units currently retain the depleted status.

Estimated annual mortality previously exceeded PBR in at least one management unit. From 2001-2005, the total estimated average annual fishery-related mortality was 61 dolphins attributed to the Mid-Atlantic gillnet fishery. These takes occurred in the Northern Migratory, Northern North Carolina and Southern North Carolina Management Units during both summer and winter months. From 2001-2005, an annual estimate of at least 5 (CV= 0.53) mortalities occurred in the shark drift gillnet fishery off the coast of Florida, affecting the Central Florida Management Unit. Currently, there are no observer data for other fisheries interacting with the coastal stock. However, stranding data indicate interactions with the Virginia Pound Net Fishery and the Atlantic Blue Crab Trap/Pot Fishery. Therefore, the total average annual mortality estimate is a lower bound of the actual annual human-caused mortality for each coastal management unit (Waring *et al*. 2007).

The Bottlenose Dolphin Take Reduction Team (BDTRT) was convened in 2001, and the Bottlenose Dolphin Take Reduction Plan was implemented in May 26, 2006 (71 FR 24776) to address the serious injuries and mortalities incidental to nine Category I and II fisheries. Estimated fishery mortality currently does not exceed PBR for any of the management units due to recent declines in fishery efforts (Waring *et al*. 2007).

### *Sea Turtles*

Sea turtles that occur in U.S. waters are listed as either endangered or threatened under the ESA. Five species occur along the Atlantic coast of the United States: loggerhead (*Caretta caretta*), Kemps ridley (*Lepidochelys kempii*), green (*Chelonia mydas*), leatherback (*Dermochelys coriacea*), and hawksbill (*Eretmochelys imbricata*).

Shad and river herring are harvested primarily with anchored, staked and drift gillnets; however, there is also a pound net, trawl, and hook and line component to these fisheries. All of these gear types are documented to impact sea turtles. Because these fisheries occur inshore, it is likely to interact with sea turtles depending on the location and season.

A. Gillnets

Stranded loggerhead and Kemp's ridley sea turtles have been partially or completely entangled in gillnet material, and are most likely to come in contact with the gear in shallow coastal waters. Loggerheads and leatherbacks have been captured in the Mid-Atlantic gillnet fishery. Green sea turtles are present in small numbers in these areas and could also be taken in this fishery. Leatherbacks are also present, especially when warmer waters bring jellyfish, their preferred prey, into coastal areas. Hawksbill sea turtles are only rare visitors to the areas where fishing effort occurs, preferring coral reefs with sponges for forage, so interaction would be limited; however, entanglement in gillnets has been identified as a serious problem for hawksbills in the Caribbean (NMFS and USFWS 1993).

Spring and fall gillnet operations have been strongly implicated in coincident sea turtle stranding events from North Carolina through New Jersey. On average, the highest numbers of interactions occurred in spring, followed by summer and fall. The southern states appear to have had more spring interactions, while the northern states had more summer interactions, probably due to the northern migration of sea turtles in the warmer months.

Netting gear found on stranded turtles varied widely, from 2-11.5-inch (5-29-cm) stretch mesh, and ranged from small, cut pieces of net, to lengths of abandoned net (up to 1200 feet (365 m)). Net gear was of various materials including nylon, cotton, and propylene, and in various colors including blue, black and green. Gear type included flounder, sturgeon, and mullet nets, monofilament, twine, gillnets, pound nets, trammel nets, seines, sink nets, and nets attached to anchors, cork floats and buoys.

B. Pound Nets

Most of pound net fishery interactions result in live releases and are documented primarily from North Carolina, Virginia, Long Island and Rhode Island. In Chesapeake Bay, Virginia, turtles become entangled in pound nets starting in mid-May with increasing numbers of entanglements until late June. The construction of leaders in pound nets was found to be a significant factor in these entanglements (Musick *et al*. 1987). Entanglement was found to be insignificant for small mesh (8-12 inch mesh = small; >12-16 inch mesh = large). Large-mesh nets and nets with stringers spaced 16-18 inches apart entangled a large number of turtles. Therefore, the potential to entangle sea turtles in pound nets could be alleviated by decreasing the mesh size in the leaders (Musick *et al*. 1987). The pound net component of the shad and river herring fishery for North Carolina occurs in Albemarle Sound, which is not frequented by turtles due to the relatively low salinities found there.

C. Hook-and-Line

From 1991 through 1995, a total of 112 stranded turtles had fishing hooks associated with some part of their bodies. Sea turtles have also been caught on recreational hook and line gear. For example, from May 24 to June 21, 2003, five live Kemp's ridleys were reported as being taken by recreational fishermen on the Little Island Fishing Pier near the mouth of the Chesapeake Bay. Many other similar anecdotal reports exist. These animals are typically alive and, while the hooks should be removed whenever possible and when it would not further injure the turtle, NOAA fisheries suspects that the turtles are probably often released without hooks being removed. Thus, hook and line fishing does impact sea turtles.

D. Recommendations for Sea Turtle Protection

1. A conservation plan and application for a Section 10 ESA incidental take permit should be developed for those states where the fishery occurs when sea turtles are present.
2. Research into gear development/deployment for gillnets should be conducted to minimize the impact on sea turtles.
3. Pound net leaders should be no larger than 12-inch mesh.
4. Public outreach material should be developed to improve awareness of sea turtle entanglement with hooks and monofilament line.

***Migratory Coastal Birds***

An unknown, but possibly significant, number of migratory birds are drowned each year in anchored gillnets in the nearshore marine waters of the mid-Atlantic region. Preliminary estimates, based on a study underway by the U.S. Fish and Wildlife Service and incidental mortality data from the Services Madison Wildlife Health Laboratory, indicate that many thousands of loons and sea ducks are killed each year. Before the ocean-intercept shad fishery closure, most shad/bird interactions occur during January through March from North Carolina to New Jersey. South Carolina banned anchored gillnets in their coastal fishery because of excessive bird mortalities.

All of the species listed in Table 12 are diving birds which pursue fish underwater or feed on benthic invertebrates. Fish eating birds are especially vulnerable to drowning in gillnets because they pursue prey underwater. Additionally, fish eating birds may be attracted to the vicinity of nets that are anchored for days at a time to feed on forage fish feeding near the nets. All of the birds listed are present along the Atlantic coast from October through April, depending on weather and timing of migration. Double-crested cormorants are present throughout the year but are most abundant in the middle and northern Atlantic states during the summer.

The actual populations of most migratory coastal birds are largely unknown. Except for some diving ducks (*Aythya*), current surveys sample only a small portion of the populations of sea ducks and do not survey for non-game birds such as loons and grebes. The U.S. Migratory Bird Treaty Act prohibits the take and possession of protected migratory birds, except as may be permitted by regulations. Take means to pursue, hunt, shoot, wound, kill, trap, capture or collect.

Possession means to detain and control.

A list of protected bird species most likely to interact with shad and river herring fisheries along the Atlantic coast are listed in Table 12 and their status can be found in Table 13.

**Table 12**. List of protected birds in nearshore marine coastal waters most likely to interact with gillnets.

| Common Name | Species Name |
|---|---|
| Common Loon | *Gavia immer* |
| Red-throated Loon | *Gavia stellata* |
| Horned Grebe | *Podiceps auritus* |
| Red-necked Grebe | *Podiceps grisegena* |
| Double-crested Cormorant | *Phalacrocorax auritus* |
| Northern Gannet | *Sula bassanus* |
| Oldsquaw | *Clangula byemalis* |
| Black Scoter | *Melanitta nigra* |
| Surf Scoter | *Melanitta perspicillata* |
| Red-breasted Merganser | *Mergus serrator* |

**Table 13**. Protected birds in coastal bays most likely to interact with gillnets and their East Coast population status.

| Species | | Status |
|---|---|---|
| Common Name | Species Name | |
| Common Loon | *Gavia immer* | Unknown |
| Red-throated Loon | *Gavia stellata* | Unknown, 50,000+ winter south of NJ |
| Horned Grebe | *Podiceps auritus* | Unknown |
| Red-necked Grebe | *Podiceps grisegena* | Unknown |
| Double-crested Cormorant | *Phalacrocorax auritus* | Abundant and increasing |
| Redhead | *Aythya americana* | Depressed but increasing slightly |
| Canvasback | *Aythya valisineria* | Slightly increasing |
| Greater Scaup | *Aythya marila* | Decreasing |
| Lesser Scaup | *Aythya affinis* | Stable |
| Ring-necked Duck | *Aythya collaris* | Unknown |
| Red-breasted Merganser | *Mergus serrator* | Stable |
| Common Goldeneye | *Bucephala clangula* | Stable |
| Bufflehead | *Bucephala albcola* | Increasing |
| Oldsquaw | *Clangula hyemalis* | Stable |
| Black Scoter | *Melanitta nigra* | Probably declining |
| White-winged Scoter | *Melanitta fusca* | Probably declining |
| Surf Scoter | *Melanitta perspicillata* | Probably declining |
| Ruddy Duck | *Oxyura jamaiccasis* | Stable |

***Shortnose Sturgeon***

The shad gillnet fishery has long been know to capture large numbers of sturgeon (Leland 1968), including adult shortnose sturgeon (Collins and Smith 1995). In the southeast, the shad fishery is likely the primary source of injury and direct mortality of shortnose sturgeon (Collins *et al*. 1996). Existing data indicate that in the southeastern U.S., this species occurs in the shad gillnet bycatch in every river system that supports both a shad gillnet fishery and a shortnose sturgeon population.

The riverine shad gillnet season and the shortnose sturgeon spawning migration normally coincide in the southeastern U.S., resulting in capture of individuals intending to spawn (females apparently spawn only once every 2-3 years). Preliminary data suggest that non-lethal encounters of migrating sturgeon with gillnets may result in fallback (i.e., individuals abort the migration, move back downriver, and presumably resorb their gametes) (unpublished data; pers. comm., M. Moser, UNC Wilmington). Thus, in addition to causing injury and direct mortality of spawners, the non-lethal capture of sturgeon in the shad gillnet fishery may cause reduced spawning success and low year class strength.

A. Recommendation for Shortnose Sturgeon Protection

A conservation plan and application for a Section 10 ESA incidental take permit should be developed for those states where the fishery occurs when shortnose sturgeons are present.

# 2. AMENDMENT GOALS AND OBJECTIVES

## 2.1 AMENDMENT 2 GOALS AND OBJECTIVES

*Goal*: Protect, enhance, and restore East Coast migratory spawning stocks of American shad (*Alosa sapidissima*), hickory shad (*Alosa mediocris*), alewife (*Alosa pseudoharengus*), and blueback herring (*Alosa aestivalis*) in order to achieve stock restoration and maintain sustainable levels of spawning stock biomass.

*Objectives of Amendment 2*:

1. Prevent further declines in river herring (alewife and blueback herring) abundance.
2. Improve our understanding of bycatch mortality by collecting and analyzing bycatch data.
3. Increase our understanding of river herring fisheries, stock dynamics and population health through fishery-dependent and independent monitoring, in order to allow for evaluation of management performance.

4. Retain existing or more conservative regulations for American shad and hickory shad. Requirements for American shad and hickory shad regulations and monitoring are detailed in Amendment 1 to the Shad and River Herring Fishery Management Plan.
5. Promote improvements in degraded or historic alosine critical habitat throughout the species' range.

### 2.2 MANAGEMENT UNIT

The management units for alosines species under this Fishery Management Plan include all migratory American shad, hickory shad, alewife and blueback herring stocks of the East Coast of the United States. Landlocked alosine populations are not included in the management unit.

Recommendations on management for migratory alosines in the Exclusive Economic Zone (3-200 nautical miles offshore) can be found in Section 4.9.

### 2.3 DEFINITION OF OVERFISHING

There are currently no overfishing definitions proposed for river herring stocks.

## 3. MONITORING PROGRAM SPECIFICATIONS

The collection of quality data is necessary to achieve the goal and objectives of the management program, specifically Objectives 2 and 3. It also enables managers to monitor the performance of management measures by improving stock assessment capabilities. This amendment does not propose changes to the monitoring programs specifications for American shad or hickory shad in previous management documents. Monitoring programs for American shad and hickory shad will remain the same as identified in Amendment 1, Technical Addendum #1 and Addendum I to the Shad and River Herring Fishery Management Plan, unless otherwise modified through future plans.

This section describes the operational (as opposed to regulatory) procedures for states to following implementing Amendment 2. The requirements described below concern both fishery-independent and fishery-dependent monitoring programs as well as stocking and hatchery operations.

States and jurisdictions are required to maintain current monitoring programs and sampling for river herring. States and jurisdictions are also required to implement additional monitoring programs in conjunction with current American shad monitoring programs. Complete monitoring requirements for states and jurisdictions are specified in Tables 15 and 16.

Monitoring of alewife and blueback herring stocks, collectively, must occur on an annual basis. Results of monitoring must be reported annually to the Commission as per Section 7. Requirements for fishery-dependent and independent monitoring are described in Section 3.1 and 3.2.

States and jurisdictions must submit proposals to change their required monitoring programs as per Section 5 of this document. Proposals must be submitted in writing to the Commission along with the annual compliance report. The Technical Committee will review the proposals and prepare recommendations and technical advice to the Management Board. The Management Board will determine final approval for changes to required monitoring programs.

While conducting fishery independent and dependent monitoring programs is vital to the achievement of the goals of Amendment 2, the Commission recognizes the financial investment that such programs require. States and jurisdictions must notify the Commission if they are unable to perform compliance requirements, due to financial reasons, prior to the start of annual monitoring, or as soon as such information becomes available. The Commission will attempt to work with states and jurisdictions to develop a plan to satisfy the needs outlined in Amendment 2. The Management Board has the authority to issue a finding of compliance to states that are unable to complete required monitoring for financial reasons during the annual FMP review.

## 3.1 FISHERY-INDEPENDENT MONITORING

Annual juvenile recruitment—appearance of juveniles in the ecosystem—of alewife and blueback herring assesses juvenile production, predicts future yearclass strength, and provides a signal for recruitment failure or major habitat changes. Recruitment is measured by sampling current-year juvenile fish abundance in estuaries and river systems with discreet populations of alewife or blueback herring.

### 3.1.1 Juvenile Abundance Indices

Juvenile abundance indices are important indicators of juvenile production throughout the management unit; however, in many other systems, juvenile production of river herring is not monitored. Results of all juvenile surveys shall be reported to the Commission annually as per Section 7.1.3.

#### *3.1.1.1 Calculation of Juvenile Abundance Indices*

All juvenile abundance indices, or JAIs, shall be reported as a geometric mean. The method for calculating the geometric mean is described in ASWC (1992) and Crecco (1992). Use of the geometric mean will reduce the probability of a single value unduly influencing management action.

#### *3.1.1.2 Elements for Measurement and Use of Juvenile Indices*

The sampling protocol (stations, sampling intensity and gear type) should be consistent over time for the period that the index is to be used. For new sampling programs, states and jurisdictions must prepare a report for the Commission with the following information: details of the sampling design, a description of the analyses performed, and a presentation of the results of those analyses. The Technical Committee shall review any such submittal and either recommend to the Management Board that it accept or reject the new sampling program. If the recommendation is to reject the new sampling program, the Technical Committee will provide a written explanation to the Management Board explaining the reasons for the recommendation. Validation is not required for any particular JAI survey. Validation of river herring juvenile indices has been proven difficult and will not be a criterion for accepting or rejecting any given JAI survey.

#### *3.1.1.3 Evaluation of Juvenile Abundance Indices*

The Technical Committee shall annually examine trends in all required juvenile abundance indices. If any JAI shows recruitment failure (i.e., JAI is lower than 90% of all other values in the dataset) for three consecutive years, then appropriate action should be recommended to the Management Board. The Management Board shall be the final arbiter in all management decisions. The Management Board may require juvenile abundance surveys for newly reestablished river herring runs.

### 3.1.2 Assessing Adult Population Size

Indices of adult spawning stocks are important when determining the efficacy of a particular management approach. Coupled with juvenile abundance indices and mortality estimates, they clarify population dynamics and progress toward management goals. Adult stock indices can include mark-recapture studies, enumeration at fish passage facilities, catch-per-unit-effort, and measurement of mortality and survival rates.

States and jurisdictions are required to implement adult spawning or population monitoring in the systems listed in Table 15. States and jurisdictions may employ a variety of survey techniques to monitor their adult spawning populations of alewife and blueback herring. These include gillnet surveys, mark-recapture studies, hydroacoustic surveys and fish passage enumeration. As part of spawning stock surveys, states are required to take representative samples of adults to determine sex and age composition, repeat spawning (for states north of South Carolina), and size distribution of each stock and species they are monitoring. When possible, states and jurisdictions should calculate mortality and survival estimates for each species and stock. On fishways where passage is monitored, states should enumerate passage of alewife and blueback herring, and passage inefficiencies should be reported, when possible. Results of all adult spawning population monitoring shall be reported to the Commission annually as per Section 7.1.3.

### 3.1.3 Hatchery Evaluation

Most Commission jurisdictions are actively involved in alosine habitat surveys, identification of stream blockages and fish passage development, management planning, permit review, and stock assessment related to recovery efforts. Although potential exists in many rivers for stock supplementation and re-introductions using adult transplants and cultured fish, this has occurred only intermittently for river herring species. Hatchery rearing and stocking is much more common for American shad and hickory shad.

#### *3.1.3.1 Stocking and Hatchery Evaluation*

States and jurisdictions with active hatchery programs for alosine species shall report annually on hatchery contributions (% wild vs. hatchery). Any state wishing to initiate stocking programs for any alosine must present a program description for Commission review. States should work in cooperation with appropriate federal or regional programs to ensure that marking schemes are coordinated with other sates to prevent conflicts in their operations. Results of all stocking and hatchery activities shall be reported to the Commission annually as per Section 7.1.3.

#### *3.1.3.2 Stocking Techniques*

Three basic elements of ongoing restoration efforts for anadromous alosines along the Atlantic coast include: (1) control of harvest to allow sufficient spawning escapement; (2) removal of barriers to migration or development of fish passage facilities at dams; and (3) active stock rebuilding, which typically involves larvae or juvenile fish introductions into waters above blockages. Population rebuilding techniques most frequently used include culture and stocking of larvae or juveniles, or stocking of pre-spawned adults that have been netted or trapped from nearby or distant waters.

***Culture and Marking***

Techniques for culture and marking of American shad are more widely known and are presented here as a reference for river herring culture and marking. Modern American shad culture techniques have been largely developed and refined since the mid-1970s by the Pennsylvania Fish and Boat Commission (PFBC) for the Susquehanna River restoration program. Using eggs stripped and fertilized from spawning adult shad on many East Coast rivers (and the Columbia River), PFBC researchers developed or improved incubation and hatching techniques, first feeds and artificial diets, larval rearing densities, flow and water quality requirements, mass-marking using oxytetracycline, and handling and stocking procedures sufficient to produce 10-20 million shad larvae each year. Pennsylvania and Maryland have also refined techniques for rearing and marking fingerling shad in ponds using artificial and natural diets. One of the high costs associated with culture and stocking programs relates to collection and delivery of eggs. Large-scale programs such as those on the Susquehanna and James rivers may require 15-20 million shad eggs to produce ten million fry. Since spawners are not yet sufficiently abundant in rivers undergoing restoration, these eggs are taken and delivered nightly during spawning seasons from neighboring rivers such as the Delaware, Hudson and Pamunkey. Strip spawning produces 10,000-30,000 eggs per female and viability averages 60-75%. Of those shad that hatch, 90% or more typically survive to stocking.

The Maryland Department of Natural Resources (MDNR) has successfully used tank-spawning techniques for shad that were initially developed for striped bass in cooperation with the University of Maryland's Center for Marine Biotechnology. This method involves use of timed-release hormone implants in gravid fish and free-spawning in tanks over a several day period. An airlift system delivers eggs to collection boxes for incubation on-site or delivery to distant hatcheries. With individual females providing 50,000- 100,000 eggs, high fertilization rates and very little labor requirement, fewer adult fish are needed and costs are greatly reduced. This technique has also proven effective for hickory shad, but has thus far been unsuccessful with river herring because of the adhesive nature of their eggs.

Cultured shad larvae are typically stocked at 7-22 days of age and carry one to several fluorescent tags on their otoliths. Marking involves a two-four hour immersion in 200-ppm oxytetracycline antibiotic and can be repeated at three-four day intervals. In addition to allowing discrimination between wild and hatchery fish, use of distinct marks allows for analysis of relative survival or abundance based on egg source, stocking location, time of release or other parameters. Tetracycline marking is 100% effective and the tags appear to stay with the fish throughout their lives. Fish being analyzed for marks must be sacrificed for otolith removal and processing. MDNR has also had success placing binary coded wire tags in fingerling shad.

***Trap and Transport***

Trapping and live transfer of adult shad and river herring has been used by many jurisdictions since the 1960s. These activities may occur within a specific river system, such as taking fish from lifts at downstream hydroelectric projects for stocking above blockages (e.g., Connecticut and Susquehanna rivers) or they may involve collecting fish with nets or traps in one river for transport and release in another. Examples include shad transfers from Holyoke Dam on the Connecticut River to spawning rivers in Maine, New Hampshire, Rhode Island, and eastern Massachusetts, and herring transfers from Conowingo Dam on the Susquehanna to the Patapsco and Patuxent rivers in Maryland. Shad and river herring have also been netted and hauled to upstream or distant spawning waters undergoing restoration (e.g., Hudson River shad to the Susquehanna River; Delaware River shad to the Raritan River, New Jersey). Well-developed hauling techniques use insulated circular tanks with oxygenation. A properly equipped 1,200-gallon tank can handle 150 adult shad or 1,000 river herring for two-four hour trips with minimal mortality.

## 3.2 FISHERY-DEPENDENT MONITORING

### 3.2.1 Commercial Fishery-Dependent Surveys Required

States and jurisdictions are required to monitor the river herring commercial fisheries operating within their state. Each year, the Plan Review Team shall review the results of fishery-dependent monitoring and review progress made to the goals and objectives of Amendment 2. States and jurisdictions may employ a variety of survey techniques in monitoring commercial fisheries in river systems within their management authority. States and jurisdictions are required to report catch (numbers, weight and location) and effort of commercial fisheries for those systems listed in Table 16. Sub-sampling of commercial catches for length, weight, age, sex, repeat spawning (for states north of South Carolina), and species composition must be conducted for the rivers listed in Table 16. Additional sub-sampling is encouraged. Results of all commercial fishery monitoring shall be reported to the Commission annually as per Section 7.1.3.

### 3.2.2 Recreational Fishery Surveys Required

States and jurisdictions must monitor recreational catch and effort within the rivers listed in Table 16. Techniques used to gather this data may include creel surveys, surveys of license/permit holders, Marine Recreational Fisheries Statistical Survey (MRFSS) / Marine Recreational Information Program (MRIP) and reporting requirements for obtaining/maintaining license or permit. Results of all recreational fishery monitoring shall be reported to the Commission annually as per Section 7.1.3.

## 3.3 BYCATCH MONITORING AND REDUCTION

Bycatch and discard of river herring in other commercial fisheries can impact river herring populations on a local and coastwide level. River herring interactions with commercial species during specific times and within specific areas may increase bycatch levels. Quantifying current levels of river herring bycatch is essential to determining stock status and implementing effective management programs. Improvements to current monitoring of bycatch and discards are needed to determine the effects on river herring populations and improve management. See Section 6.8 for Recommendations to the Secretaries concerning river herring bycatch in federal waters.

## 3.4 SUMMARY OF MONITORING PROGRAMS

### 3.4.1 Biological Information

States and jurisdictions are mandated to implement the fishery-dependent and independent monitoring programs identified for river herring in Section 3.2 and 3.3. In addition, states are required to continue or augment the monitoring programs for American shad and hickory shad. Results of all monitoring shall be reported to the Commission annually as per Section 7.1.3. Whenever practical, state harvest and effort reporting requirements will coincide with current and future mandates of the Atlantic Coastal Cooperative Statistics Survey (ACCSP). Data needs not covered by the ACCSP will still be covered by annual reports submitted in conjunction with this FMP.

**Table 14.** Summary of monitoring requirements for river herring under Amendment 2. See Tables 15 and 16 for applicable river systems.

| | | |
|---|---|---|
| **Fishery-Independent** | Annual spawning stock survey and representative sampling for biological data | |
| | Calculation of mortality/survival estimates (when available) | |
| | Juvenile Abundance Index | |
| | Hatchery evaluation (hatchery vs. wild)--when in place | |
| | Fishway counts; report inefficiencies (when available) | |
| **Fishery-Dependent** | Commercial | Mandatory reporting of catch (numbers, weight, location) and effort.<br>• Sub-samples shall indicate size, age, spawning marks, sex, and species composition of catch (when available) |
| | Recreational | Monitor recreational catch and effort:<br>• Creel surveys<br>• Survey license/permit holders<br>• MRIP<br>• Reporting requirements for obtaining/maintaining license or permit |

**Table 15.** Summary of mandatory fishery-independent monitoring programs for River Herring.

| STATE | SYSTEM | SAMPLING PROGRAM (ANNUAL UNLESS OTHERWISE NOTED) |
|---|---|---|
| Maine | Androscoggin, St. Croix & Saco Rivers | • Annual spawning stock survey and representative sampling for biological data<br>• Calculation of mortality and/or survival estimates (excluding St. Croix River)<br>• JAI: Juvenile Abundance Index (GM) (Androscoggin River only)<br>• Hatchery Evaluation |
| New Hampshire | Exeter, Lamprey, Cocheco, Taylor, Winnicut and Oyster Rivers | • Annual spawning stock survey and representative sampling for biological data<br>• Calculation of mortality and/or survival estimates (Exeter River only) |
| Massachusetts | Merrimack River | • Annual spawning stock survey and representative sampling for biological data<br>• Calculation of mortality and/or survival estimates |
| Rhode Island | Pawcatuck, Nonquit, Gilbert-Stuart Rivers and Buckeye Brook | • Annual spawning stock survey and representative sampling for biological data<br>• Calculation of mortality and/or survival estimates (excluding Buckeye Brook)<br>• JAI: Juvenile Abundance Index (GM) (excluding Buckeye Brook) |
| | Ocean | • Juvenile and Adult trawl survey |
| | Coastal Ponds and Narragansett Bay | • JAI: Juvenile Abundance Index |
| Connecticut | Connecticut River | • Annual spawning stock survey and representative sampling for biological data (blueback herring)<br>• Calculation of mortality and/or survival estimates<br>• JAI: Juvenile abundance survey (GM) |
| New York | Hudson River | • Annual spawning stock survey and representative sampling for biological data<br>• Calculation of mortality and/or survival estimates<br>• JAI: Juvenile abundance survey (GM) |
| | Delaware River (Cooperative effort between New Jersey, New York, Pennsylvania, and Delaware) | • Annual spawning stock survey and representative sampling for biological data<br>• Calculation of mortality and/or survival estimates<br>• JAI: Juvenile abundance survey (GM) |
| New Jersey | Delaware River (Cooperative effort between New Jersey, New York, Pennsylvania, and Delaware) | • Annual spawning stock survey and representative sampling for biological data<br>• Calculation of mortality and/or survival estimates<br>• JAI: Juvenile abundance survey (GM) |

**Table 15.** Summary of mandatory fishery-independent monitoring programs for River Herring (continued).

| STATE | SYSTEM | SAMPLING PROGRAM (ANNUAL UNLESS OTHERWISE NOTED) |
|---|---|---|
| Pennsylvania | Susquehanna and Lehigh Rivers | • Annual spawning stock survey and representative sampling for biological data<br>• Calculation of mortality and/or survival estimates<br>• JAI: Juvenile abundance survey (GM) (Susquehanna Only) |
| | Delaware River (Cooperative effort between New Jersey, New York, Pennsylvania, and Delaware) | • Annual spawning stock survey and representative sampling for biological data<br>• Calculation of mortality and/or survival estimates<br>• JAI: Juvenile abundance survey (GM) |
| Delaware | Delaware River (Cooperative effort between New Jersey, New York, Pennsylvania, and Delaware) | • Annual spawning stock survey and representative sampling for biological data<br>• Calculation of mortality and/or survival estimates |
| | Upper Nanticoke River | • JAI: Juvenile Abundance Index (GM) |
| Maryland | Upper Chesapeake Bay | • Annual spawning stock survey and representative sampling for biological data<br>• Calculation of mortality and/or survival estimates<br>• JAI: Juvenile abundance survey (GM) |
| D.C. | Potomac River | • Annual spawning stock survey and representative sampling for biological data<br>• Calculation of mortality and/or survival estimates<br>• JAI: Juvenile Abundance Index (GM) |
| Virginia | James, York, and Rappahannock Rivers | • Annual spawning stock survey and representative sampling for biological data (excluding York River)<br>• Calculation of mortality and/or survival estimates<br>• JAI: Juvenile abundance survey (GM) |
| North Carolina | Albemarle Sound and its tributaries, Tar-Pamlico, Neuse, and Cape Fear Rivers | • Annual spawning stock survey and representative sampling for biological data<br>• Calculation of mortality and/or survival estimates<br>• JAI: Juvenile Abundance Index (GM) |
| South Carolina | Santee-Cooper system, Eidsto River, Winyah Bay and tributaries (Waccwnaw and Pee Dee Rivers)* | • Annual spawning stock survey and representative sampling for biological data<br>• Calculation of mortality and/or survival estimates<br><br>* State may elect to sample these systems on a rotational basis (i.e., one system evaluated per year) |
| Georgia | • There are currently no known river herring populations in Georgia. Should populations be established, the Management Board has the authority to require a fisheries independent monitoring program be implemented. | |
| Florida | St. Johns River | • Annual spawning stock survey and representative sampling for biological data<br>• Calculation of mortality and/or survival estimates<br>• JAI: Juvenile Abundance Index (GM) |

**Table 16.** Summary of mandatory fishery-dependent monitoring programs for river herring.

| STATE | SYSTEM | SAMPLING PROGRAM |
|---|---|---|
| Maine | Inriver | • Monitor recreational landings, catch and effort<br>• Mandatory reporting of catch (numbers and weight) and effort from commercial fisheries; subsamples shall indicate size, age, and sex composition of catch. |
| New Hampshire | Inriver | • Monitor recreational landings, catch and effort<br>• Mandatory reporting of catch (numbers and weight) and effort from commercial fisheries; subsamples shall indicate size, age, and sex composition of catch. |
| Massachusetts * | Inriver | • Monitor recreational landings, catch, and effort<br>• Mandatory reporting of catch (numbers and weight) and effort from commercial fisheries; subsamples shall indicate size, age, and sex composition of catch. |
| Connecticut * | Connecticut River | • Monitor recreational landings, catch, and effort<br>• Mandatory reporting of catch (numbers and weight) and effort from commercial fisheries; subsamples shall indicate size, age, and sex composition of catch. |
| Rhode Island * | Pawcatuck River | • Monitor recreational catch and effort<br>• Mandatory reporting of catch (numbers and weight) and effort from commercial fisheries; subsamples shall indicate size, age, and sex composition of catch. |
| New York | Hudson River | • Monitor recreational landings, catch, and effort.<br>• Mandatory reporting of catch (numbers and weight) and effort from commercial fisheries; subsamples shall indicate size, age, and sex composition of catch. |
| | Delaware River | • Monitor recreational landings, catch, and effort<br>(Cooperative effort between New Jersey, New York, Pennsylvania, and Delaware) |
| New Jersey | Delaware River and Bay | • Monitor recreational landings, catch, and effort<br>• Mandatory reporting of catch (numbers and weight) and effort from commercial fisheries; subsamples shall indicate size, age, and sex composition of catch.<br>(Cooperative effort between New Jersey, New York, Pennsylvania, and Delaware) |
| Delaware | Delaware River and Bay | • Monitor recreational landings, catch, and effort<br>• Mandatory reporting of catch (numbers and weight) and effort from commercial fisheries; subsamples shall indicate size, age, and sex composition of catch.<br>(Cooperative effort between New Jersey, New York, Pennsylvania, and Delaware) |
| | Nanticoke River Chesapeake Bay tributary (upstream portion) | • Monitor recreational landings, catch, and effort<br>• Mandatory reporting of catch (numbers and weight) and effort from commercial fisheries; subsamples shall indicate size, age, and sex composition of catch. |

* A moratorium is currently in place. Monitoring program listed in Table 16 would be required to re-open of the fishery.

**Table 16.** Summary of mandatory fishery-dependent monitoring programs for river herring (continued)

| STATE | SYSTEM | SAMPLING PROGRAM |
|---|---|---|
| Pennsylvania | Delaware River | • Monitor recreational landings, catch, and effort<br>(Cooperative effort between New Jersey, New York, Pennsylvania, and Delaware) |
| Maryland | Inriver | • Monitor recreational landing, catch, and effort.<br>• Mandatory reporting of catch (numbers and weight) and effort from commercial fisheries; subsamples shall indicate size, age, and sex composition of catch. |
| D.C. | Potomac River | • Monitor recreational landings, catch, and effort |
| Virginia | Inriver | • Monitor recreational landings, catch, and effort<br>• Mandatory reporting of catch (numbers and weight) and effort from commercial fisheries; subsamples shall indicate size, age, and sex composition of catch. |
| North Carolina* | Albemarle Sound and its tributaties, Tar-Pamlico, Neuse, and Cape Fear Rivers | • Monitor recreational landings, catch, and effort<br>• Mandatory reporting of catch (numbers and weight) and effort from commercial fisheries; subsamples shall indicate size, age, and sex composition of catch. |
| South Carolina | Edisto River, Santee River, Winyah Bay and its tributaries (Waccwnaw and Pee Dee Rivers) | • Monitor recreational landings, catch, and effort<br>• Mandatory reporting of catch (numbers and weight) and effort from commercial fisheries; subsamples shall indicate size, age, and sex composition of catch.<br>* *State may elect to sample these systems on a rotational basis (i.e., one system evaluated per year) |
| Georgia | • There are currently no known river herring populations in Georgia. Should populations be established, the Management Board has the authority to require a fisheries dependent monitoring program be implemented. | |
| Florida | St. Johns River | • Monitor recreational landings, catch and effort<br>• Mandatory reporting of catch (numbers and weight) and effort from commercial fisheries; subsamples shall indicate size, age, and sex composition of catch. |

* A moratorium is currently in place. Monitoring program listed in Table 16 would be required to re-open of the fishery.

### 3.4.2 Social Information

Consumptive use (e.g. commercial fishing activities before closures) and non-consumptive use (e.g. ecotourism activities) surveys focusing on social data should be conducted periodically in a manner consistent with the intent of the Atlantic Coastal Fisheries Cooperative Management Act (ACFCMA) and the ACCSP Implementation Plan.

### 3.4.3 Economic Information

Consumptive use (e.g. commercial fishing activities before closures) and non-consumptive use (e.g. ecotourism activities) surveys focusing on economic data should be conducted periodically in a manner consistent with the intent of the ACFCMA and the ACCSP implementation Plan.

# 4. MANAGEMENT PROGRAM IMPLEMENTATION

States and jurisdictions must implement the regulatory program requirements as per Section 7. The Management Board has the ultimate authority to determine the approval of a regulatory program. States and jurisdictions must also submit proposals to change their required regulatory programs as per Section 7.1.2. The Management Board will determine final approval for changes to required regulatory programs.

## 4.1 COMMERCIAL AND RECREATIONAL FISHERIES MANAGEMENT MEASURES

The Shad and River Herring Management Board approved the following commercial and recreational fishery management measures:

**Close Fisheries (Commercial/Recreational) with Exceptions for Systems with a Sustainable Fishery**

Systems with a sustainable fishery are defined as those that demonstrate their alewife or blueback herring stock could support a commercial and/or recreational fishery that will not diminish potential future stock reproduction and recruitment. In order to maintain a commercial or recreational river herring fishery, states and jurisdictions are required to develop sustainability targets that meet the above definition, which will include specific and practicable criteria for current management and are based on the best available science. Data to substantiate these claims may include, but is not limited to, repeat spawning ratio, spawning stock biomass, juvenile abundance levels, fish passage counts, hatchery contribution to stocks and bycatch rates. Member states or jurisdictions could potentially develop different sustainability target(s) for river herring based on the unique ecosystem interactions and the available data for a given system. Targets can be applied state-wide or can be river and species specific. Targets for river systems managed by more than one state/jurisdiction should be cooperatively developed. Targets should include a quantifiable means of estimating improvements in populations. As new information becomes available, states should review and update targets in a timely manner.

Examples of proposed sustainability targets could include (but are not limited to):

1. River specific stocks that return spawning stock biomass in excess of spawning habitat saturation (e.g. as determined by *X* number of fish per acre).
2. River specific stocks that return commercially viable numbers of river herring without supplementing brood stock or escapement.
3. River specific river herring catch rates that are not less than a defined percentage of the latest average ten-year catch rate for a number of consecutive years.
4. Stock should contain at least a minimum percentage of repeat spawners.
5. Recruitment of age-*X* fish should be restored to a three-year moving average that is above a defined minimum.

States and jurisdictions must also submit a management plan that describes how the fishery will be conducted and annually monitored in order to show that the sustainability target(s) are being achieved. If a stock is below optimum level the management plan must detail restrictions that will be enacted to allow for an increase in spawning stock abundance and juvenile recruitment. If a stock is at optimum levels, then that level will need to be sustained. The frame of reference for determining the optimum level will vary from system to system, but should be based on an appropriate time scale. States should develop their sustainability targets within this general framework. The Technical Committee is responsible for developing a standard optimum level and timeframe basis.

States and jurisdictions are required to submit sustainability targets and corresponding management plans by January 1, 2010, which will be reviewed by the technical committee. Once a plan is approved by the management board, states and jurisdictions must submit updates on the achievement and maintenance of sustainability targets as part of annual compliance reports, per Section 7.

Fisheries that do not have an approved management plan in place, or are not covered by an approved management plan, by January 1, 2012 will be closed. The Management Board has the final authority to approve management plans for an alewife or blueback herring commercial or recreational fishery on any system under its jurisdiction.  Proposals to reopen closed fisheries may be submitted as part of the annual Compliance Report, and will be subject to review by the Plan Development Team, Technical Committee and Management Board.

## 4.2 HABITAT CONSERVATION AND RESTORATION

River herring stocks along the Atlantic Coast are greatly diminished compared to historic levels. Much of this reduction is related to spawning and nursery habitat degradation brought on by effects of human population increase (sewage and storm water runoff, industrialization, dam construction), increased erosion, sedimentation and nutrient enrichment associated with agricultural practices, and losses of riparian forests and wetland buffers.

Protection, restoration and enhancement of river herring habitat including spawning, nursery, rearing, production, and migration areas, is critical for preventing further declines in river herring abundance, and restoring healthy, self-sustaining river herring populations and their ecological, social, and economic functions and values to the East Coast of the United States.

Each state should identify, categorize and prioritize important existing and historic river herring habitat within its area of jurisdiction.

Periodic monitoring should be designed and implemented to ensure the long-term health and viability of important river herring habitat.

Each state should develop a plan to improve the quality of and restore adequate access to river herring habitat within its area of jurisdiction.

#### 4.2.1 Freshwater Spawning and Larval Rearing Habitat

Barriers that restrict or prevent migration to and/or from currently available and historical freshwater habitat (spawning, nursery, rearing habitat) will reduce juvenile recruitment and limit total production.

Successful upstream and downstream fish passage (safe, timely and effective) past anthropogenic barriers (e.g., *physical* such as dams, weirs, and culverts; and *water quality* such as thermal and chemical discharges, and in-stream flow alterations such as flow regulation and water withdrawal) is essential for adequate access to and utilization of critical freshwater spawning and larval rearing habitat.

Protection and enhancement of freshwater habitat and adjacent riparian interfaces and buffers is important to ensuring the long-term health and viability of river herring spawning and larval habitat, and migratory corridors.

In areas where water resource or shore side development projects are proposed adjacent to identified or potential river herring habitat, state marine fisheries agencies should engage in review of proposed development projects by engaging in licensing and permitting consultation opportunities (e.g., Federal Energy Regulatory Commission hydroelectric project licensing, Section 401 water quality permits, Army Corps of Engineers, Sections 1135(b), 206, 404 permits) in order to assess potential impacts to river herring habitat. The state marine fisheries agencies should then comment on the merits of the development project, and where applicable, propose terms, conditions and prescriptions designed to avoid, minimize and mitigate negative impacts of the development project on critical river herring habitat.

State marine fisheries agencies should also coordinate with state water quality agencies and other governmental entities responsible for developing and implementing river basin and wetland restoration plans and projects, in order to ensure that river herring habitat is identified and adequately protected or enhanced by these plans and projects during their implementation.

State marine fisheries agencies should coordinate with their state inland fisheries agencies to identify important inland freshwater spawning and rearing habitat, and migration corridors. This should be accomplished through site-specific data collection and monitoring. This information should be used to develop comments and recommendations during consultations with permitting agencies regarding potential impacts of a proposed development on river herring production or migration. As an example, construction activities should be avoided during critical migration periods, and seasonal construction restriction for any particular area should be based on site-specific information, and appropriate monitoring to ensure the river herring resource is protected.

States should consider developing plans to protect shore land adjacent to critical river herring production, migration, and staging areas in order to ensure their long-term viability and contribution to the sustainability of the specific population. Protection of river herring habitat or areas of particular concern should be pursued through acquisition, deed restrictions or conservation easements. State fisheries agencies should also work with their state soil and water conservation agencies and agricultural agencies to provide information on these habitats, to be used in their decisions regarding the state's riparian buffer program.

### 4.2.2 Estuarine Juvenile Rearing and Migration Corridors

The importance of estuaries to river herring as juvenile rearing habitat is not yet fully understood. The impacts of declines in submerged aquatic vegetation beds should be further investigated to determine their importance and juvenile cover and rearing habitat.

The impacts of thermal power generation projects (e.g., nuclear and coal) that withdraw water for cooling (potential entrainment and impingement of fish) and discharge heated water (thermal barriers to migration, habitat degradation) need to be further studied.

The impacts to migrating river herring (both spawning adults and out-migrating juveniles) by proposed in-stream power generation developments such as tidal stream generation that draws energy from currents in much the same way as wind turbines needs to be better understood.

Similar to the situation with riverine areas where water resource or shore side development projects are proposed adjacent to identified or potential river herring habitat or migration corridors, state marine fisheries agencies should engage in review of proposed development projects by engaging in licensing and permitting consultation opportunities in order to assess potential impacts to river herring habitat and comment on the project's merits and mitigation needs.

### 4.2.3 Coastal Production and Migration Corridors

Potential threats and their level of impact to coastal river herring habitat such as: marine acidification; pharmaceutical, wastewater, pesticide contamination; invasive species; niche displacement; and global climate change are in need of further study.

The impacts to migrating river herring (both spawning adults and migrating juveniles) by proposed wind power generation developments such needs to be better understood.

Similar to the situation with riverine and estuarine areas where water resource or shore side development projects are proposed adjacent to identified or potential river herring habitat or migration corridors, state marine fisheries agencies should engage in review of proposed development projects by taking advantage of licensing and permitting consultation opportunities in order to assess potential impacts to river herring habitat and comment on the project's merits and mitigation needs to protect coastal river herring habitat.

### 4.2.4 Habitat Restoration, Improvement and Enhancement

States should leverage the existing production capacity of historic, but currently volitionally inaccessible freshwater spawning and larval rearing habitat through a process of trap and transport of excess spawning stock, or planting of aquaculture produced fry and fingerlings. This will help to both increase juvenile recruitment for the population, and will develop a stock of river herring imprinted to that upstream habitat that can take advantage of it once access is restored through barrier removal or installation of fish passage.

The Commission and participating states' and jurisdictions' marine fisheries agencies are encouraged to support fish passage research and development with the goal of improving the efficiency of existing and future installations of fish passage measures and facilities in order to restore desired access to and utilization of critical river herring spawning and juvenile rearing habitat.

The Commission and participating states' and jurisdictions' marine fisheries agencies are encouraged to characterize passage-associated efficiency, mortality, migration delay, and sub-lethal effects for river herring at existing fish passage facilities installed at hydroelectric and other dams. This information should be used to identify and address passage problems at barriers and further the understanding of best available fish passage technology.

States should work to improve and develop safe, timely and effective upstream and downstream fish passage for adults and juveniles at all barriers to river herring migration to and from critical existing and historic spawning, rearing and production habitat.

States should strive to maintain water quality in all suitable habitats for all life stages of river herring in all rivers with existing or potential spawning, juvenile rearing and production habitat.

In rivers with flow regulation (e.g., storage and peak hydroelectric power generation dams), and consumptive water withdrawals (e.g., irrigation, domestic water supply, industrial use) states should strive to maintain in-stream flows at levels that ensure adequate fish passage, water quality and habitat protection for river herring.

State and federal agencies should monitor and report on the amount of freshwater habitat opened through upstream passage projects and any associated changes in emigrating river herring abundance associated with improved habitat access.

### 4.2.5 Avoidance of Incompatible Activities

Each state should establish seasonal windows of compatibility for activities known or suspected to adversely affect river herring life stages and their habitats (e.g., dredging, filling, aquatic construction) as well as notify the appropriate construction or regulatory agencies in writing.

Projects involving water withdrawal from important habitats (e.g., feeding grounds) should be scrutinized to ensure that adverse impacts resulting from impingement, entrainment or modification of flow, temperature and salinity regimes due to water removal will not adversely impact river herring habitat.

Each state that has human population growth areas within its jurisdiction should develop water use and flow regime guidelines which are protective of river herring habitat and will ensure to the extent possible the long-term health and sustainability of the population.

States should endeavor to ensure that proposed water diversions or withdrawals from river tributaries would not reduce or eliminate river herring habitat.

### 4.2.6 Fisheries Practices

The use of any fishing gear or practice that is documented to have unacceptable negative impacts on river herring habitat or migration (e.g., habitat damage, bycatch mortality) should be prohibited within the area of that habitat or corridor.

### 4.2.7 Habitat Recommendations

#### *4.2.7.1 Dams and Other Obstructions*

- A focused, coordinated, well supported effort among federal, state and associated interests should be undertaken to address the issue of fish passage development and efficiency. The effort should attempt to develop new technologies and approaches to improve alosine passage efficiency with the premise that existing technology is insufficient to achieve restoration and management goals for several East Coast river systems.
- Where obstruction removal is not feasible, install passage facilities, including fish lifts, fish locks, fishways, navigation locks or notches (low-head dams and culverts). Passage facilities should be designed specifically for passing alosines for optimum efficiency.
- At sites with passage facilities, evaluate the effectiveness of upstream and downstream passage; when passage is inadequate, facilities should be improved.
- To enhance survival at dams during emigration (either post-spawning fish or juveniles), evaluate survival of fish passed via each route (e.g., turbines, spillage, bypass facilities, or a combination of the three) at any given facility, and pass fish via the route with the best survival rate.

- To prevent fish from becoming entrained in intake flow areas of hydropower facilities, construct behavioral barrier devices and re-direct them to safer passage areas.
- Before designing and constructing fish passage systems, determine the behavioral response to major physical factors so that effectiveness can be maximized.
- Conduct studies to determine whether passing migrating adults upstream earlier in the year in some rivers would increase production and larval survival, and opening downstream bypass facilities sooner would reduce mortality of early emigrants (both adult and early-hatched juveniles).
- States should identify and prioritize barriers in need of fish passage based on clear ecological criteria (e.g., amount and quality of habitat upstream of barrier, size, status of affected populations). These prioritizations could apply to a single species, but are likely to be more useful when all diadromous species are evaluated together.
- Where practicable, remove obstructions to upstream and downstream migration.
- Ensure that decisions on river flow allocation (e.g., irrigation, evaporative loss, out of basin water transport, hydroelectric operations) take into account flow needs for alosine migration, spawning and nursery use, and minimize deviation from natural flow regimes.
- Ensure that water withdrawal effects do not impact alosine stocks by impingement/entrainment, and employ intake screens or deterrent devices as needed to prevent egg and larval mortality.
- Alter water intake velocities, if necessary, to reduce mortality to alosines.
- Locate facilities along the river where impingement rates are likely to be lowest.
- To mitigate hydrological changes from dams, consider operational changes such as turbine venting, aerating reservoirs upstream of hydroelectric plants, aerating flows downstream and adjusting in-stream flows.
- When considering options for restoring alosine habitat, include study of, and possible adjustment to, dam-related altered river flows.
- Evaluate performance of existing fishways and determine features common to effective fishways and those common to ineffective fishways.
- Conduct basic research into alosine migratory behavior as it relates to depth, current velocity, turbulence, entrained air, light, structures, etc.
- Use information from (a) and (b) to conduct computer fluid dynamics (CFD) modeling to develop more effective fishway designs.
- Research technologies (barriers, guidance systems, etc.) for directing emigrating fish to preferred passage routes at dams.
- Document the impact of power plants and other water intakes on larval, postlarval, and juvenile mortality in spawning areas, and calculate the resultant impact to adult population size.

#### *4.2.7.2 Water Quality and Other Contamination*

- Non-point and point source pollution should be reduced in spawning and nursery habitat.
- Implement best management practices (BMPs) along rivers and streams, restore wetlands, and utilize stream buffers to control non-point source pollution.
- Implement erosion control measures and BMPs in agricultural, suburban and urban areas to reduce sediment input, toxic materials and nutrients and organics into streams.
- Upgrade wastewater treatment plants and remove biological and organic nutrients from wastewater.
- Reduce the amount of thermal effluent into rivers. On larger rivers, include a thermal zone of passage.
- Provide management options regarding water withdrawal and land use to minimize the impacts of climate change on temperature and flow regimes.
- Discharge earlier in the year to reduce impacts to migrating fish.
- Conduct studies to determine the effects of dredging on alosine habitat and migration; appropriate best management practices, including environmental windows, should be considered whenever navigation dredging or dredged material disposal operations would occur in a given waterway occupied by alosine species.
- Review studies dealing with the effects of acid deposition on anadromous alosines.
- Determine if intermittent episodes of pH depressions and aluminum elevations (caused by acid rain) affect any life stage in freshwater that might lead to reduced reproductive success, especially in poorly buffered river systems.
- Determine if chlorinated sewage effluents are slowing the recovery of depressed shad stocks.

#### *4.2.7.3 Habitat Protection and Restoration*

- States should identify and quantify potential shad and river herring spawning and nursery habitat not presently utilized, including a list of areas that would support such habitat if water quality and access were improved or created, and analyze the cost of recovery within those areas. States may wish to identify areas targeted for restoration as essential habitat.
- When states have identified habitat protection or restoration as a need, state marine fisheries agencies should coordinate with other agencies to ensure that habitat restoration plans are developed, and funding is actively sought for plan implementation and monitoring.
- Resource management agencies in each state shall evaluate their respective state water quality standards and criteria to ensure that those standards and criteria account for the special needs of alosines. Primary emphasis should be on locations where sensitive egg and larval stages are found.

- ASMFC should designate important shad and river herring spawning and nursery habitat as Habitat Areas of Particular Concern (HAPCs).
- Any project resulting in elimination of essential habitat (e.g., dredging, filling) should be avoided.

#### *4.2.7.4 Permitting*

- All state and federal agencies responsible for reviewing impact statement for projects that may alter anadromous alosine spawning and nursery areas shall ensure that those projects will have no impact or only minimal impact on those stocks. Of special concern are natal rivers of newly established stocks or stocks considered depressed or severely depressed.
- Develop policies for limiting development projects seasonally or spatially in spawning and nursery areas; define, and codify, minimum riparian buffers and other restrictions where necessary.

#### *4.2.7.5 Stock Restoration and Management*

- When populations have been extirpated from their habitat, coordinate alosine stocking programs, including: (a) reintroduction to the historic spawning area; (b) expansion of existing stock restoration programs; and (c) initiation of new strategies to enhance depressed stocks.
- When releasing hatchery-reared larvae into river systems for purposes of restoring stocks, synchronize the release with periods of natural prey abundance to minimize mortality and maximize nutritional condition. Determine functional response of predators on larval shad at restoration sites to ascertain appropriate stocking level so that predation is accounted for, and juvenile out-migration goals are met. Also, determine if night stocking will reduce mortality.
- Promote cooperative interstate research monitoring and law enforcement. Establish criteria, standards, and procedures for plan implementation as well as determination of state compliance with management plan provisions.

#### *4.2.7.6 Habitat Change*

- Use multi-scale approaches (including GIS) to assess indicators of suitable habitat, using watershed and stream-reach metrics, if possible (it should be noted, that where site-specific data is lacking, it may not be appropriate to assess at this scale).
- Use multi-scale approaches for restoring alosine habitat, including vegetated buffer zones along streams and wetlands, and implementing measures to enhance acid-neutralizing capacity.
- Conduct additional studies on the effects of land use on riverine life stages.
- Examine how deviation from the natural flow regime impacts all alosines. This work should focus on key parameters such as rate of change (increase and decrease), seasonal

peak flow, and seasonal base flow, so that the results can be more easily integrated into a year-round flow management recommendation by state officials.

# 5. ALTERNATIVE STATE MANAGEMENT REGIMES

Once the Shad and River Herring Management Board approves a management program, states and jurisdictions are required to obtain approval from the Management Board prior to changing their management program in any way that might alter a compliance measure. Changes to management programs that affect measures other than compliance measures must be reported to the Management Board but may be implemented without prior approval. States and jurisdictions submitting alternative proposals must demonstrate the proposed management program will not contribute to overfishing of the resource or inhibit restoration of the resource. The Management Board can approve an alternative management program proposed by a state or jurisdiction if the state or jurisdiction can show to the Management Board's satisfaction that the alternative proposal will have the same conservation value as the measure contained in this amendment or any addenda prepared under Adaptive Management (Section 5.5). All changes in state and jurisdictional plans must be submitted in writing to the Management Board and the Commission either as part of the annual FMP Review process or with the annual compliance report.

## 5.1 General Procedures

A state may submit a proposal to the Commission for a change to its regulatory program or any mandatory compliance measure under this amendment, including a proposal for *de minimis* status. Such changes shall be submitted to the Chair of the Plan Review Team, who shall then distribute the proposal to the Management Board, Plan Review Team, Technical Committee, Stock Assessment Subcommittee and Advisory Panel, as necessary.

The Plan Review Team is responsible for gathering the comments from the Technical Committee, Stock Assessment Subcommittee and Advisory Panel, and presenting the comments to the Management Board in a timely fashion.

The Shad and River Herring Management Board can approve an alternative management program proposed by a state or jurisdiction if the state or jurisdiction can show to the Management Board's satisfaction that the alternative proposal will have the same conservation value as the measure contained in this amendment or any addenda prepared under Adaptive Management (Section 5.5).

## 5.2 Management Program Equivalency

The Shad and River Herring Technical Committee, under the direction of the Plan Review Team, will review any alternative management program proposals and provide the Management Board its evaluation of the adequacy of the proposals.

## 5.3 *De Minimis* Fishery Guidelines

The Commission's Interstate Fisheries Management Program Charter defines *de minimis* as "a situation in which, under the existing condition of the stock and scope of the fishery, conservation and enforcement actions taken by an individual state would be expected to contribute insignificantly to a coastwide conservation program required by a Fishery Management Plan or amendment" (ASMFC 2003).

States that report commercial landings of river herring that are less than 1% of the coastwide commercial total are exempted from sub-sampling commercial and recreational catch for biological data, as outlined in Section 3.2.

States and jurisdictions may petition the Shad and River Herring Management Board at any time for *de minimis* status if their fishery falls below the threshold level. Once *de minimis* status is granted, designated states and jurisdictions must submit annual compliance reports to the Management Board and request *de minimis* status on an annual basis.

## 5.4 ADAPTIVE MANAGEMENT

The Shad and River Herring Management Board may vary the requirements specified in this amendment as part of adaptive management in order to conserve the American shad, hickory shad, alewife and blueback herring resources. Specifically, the Management Board may change Sections 1.3, 2.3, 3 and 4 (see Section 5.5.2). Such changes will be instituted to be effective on January 1 or the first fishing day of the following year, but may be put in place at an alternative time when deemed necessary by the Management Board.

### 5.4.1 General Procedures

The Shad and River Herring Plan Review Team will monitor the status of the fishery and the resource and report on that status to the Management Board annually, or as directed to do so by the Management Board. The Plan Development Team will consult with the Technical Committee, Stock Assessment Subcommittee and Advisory Panel, when making such a review and report. The report may contain recommendations for proposed adaptive management revisions to the amendment.

The Management Board will review the Plan Review Team report and may consult further with the Technical Committee, Stock Assessment Subcommittee or the Advisory Panel. The Management Board can direct the Plan Development Team to prepare an addendum to make changes that it deems necessary. The addendum shall contain a schedule for the states and jurisdictions to implement its provisions.

The Plan Development Team will prepare a draft addendum as directed by the Management Board and, upon approval from the Board, shall distribute it for review and comment to all states and jurisdictions with declared interest in the fishery. A public hearing will be held in any state or jurisdiction that requests one. The Plan Development Team will also request public comment from federal agencies and the public at large. After a 30-day review period, the Plan Development Team will summarize the comments and present them to the Management Board.

After considering the comments, the Management Board will direct the Plan Development Team on what to include in the final addendum. The Management Board shall review the final version of the addendum. The Management Board shall then consider whether to adopt or revise and then adopt the addendum.

Upon the adoption of an addendum to implement adaptive management, states and jurisdictions shall prepare plans, when necessary, to implement the addendum and submit those plans to the Management Board for approval, following the schedule contained in the addendum.

### 5.5.2 Measures Subject to Change

The following measures are subject to change under adaptive management upon approval by the Management Board:

1. Habitat considerations;
2. Overfishing definition;
3. Rebuilding targets and schedules;
4. Fishery-independent monitoring requirements;
5. Fishery-dependent monitoring requirements;
6. Bycatch monitoring and reduction requirements;
7. Reporting requirements;
8. Effort controls;
9. Area closures;
10. Gear restrictions or limitations;
11. Catch controls;
12. Fishing year and/or seasons;
13. Possession limits;
14. Quotas;
15. Bycatch limits and reporting;
16. Observer requirements;
17. Closures;
18. Regulatory measures for the recreational fishery;
19. Recommendations to the Secretaries for complementary actions in federal jurisdictions;
20. *De minimis* specifications;
21. Compliance report due dates; and
22. Any other management measures currently included in the Shad and River Herring Interstate Fishery Management Plan.

## 5.6 EMERGENCY PROCEDURES

The Shad and River Herring Management Board may authorize or require emergency action that is not covered by, or is an exception or change to, any provision in Amendment 2. Procedures for implementation of emergency action are addressed in the Commission's Interstate Fisheries Management Program Charter, Section Six (c)(10) (ASMFC 2003).

# 6 MANAGEMENT INSTITUTIONS

The management institutions for shad and River herring shall be subject to the provisions of the ISFMP Charter (ASMFC 2003). The following are not intended to replace any or all of the provisions of the ISFMP Charter. All committee roles and responsibilities are included in detail in the ISFMP Charter and are only summarized here.

## 6.1 The Commission and the ISFMP Policy Board

The Atlantic States Marine Fisheries Commission and the ISFMP Policy Board are generally responsible for the oversight and management of the Commission's fisheries management activities. The Commission must approve all fishery management plans and amendments, including this Amendment 2, and must also make final determinations concerning state compliance or non-compliance. The ISFMP Policy Board reviews any non-compliance recommendations from the various management boards and sections and, if it concurs, forwards them on to the Commission for action.

## 6.2 Shad and River Herring Management Board

The Shad and River Herring Management Board is established by the Commission's ISFMP Policy Board and is generally responsible for carrying out all activities under this amendment. It establishes and oversees the activities of the Plan Review Team, Plan Development Team, Technical Committee and Stock Assessment Subcommittee, and requests the establishment of the Commission's Shad and River Herring Advisory Panel. Among other things, the Management Board makes changes to the management program under adaptive management and approves the state and jurisdictional programs implementing the amendment and alternative state programs under Section 4.5. The Management Board reviews the status of state compliance with the FMP at least annually and, if it determines that a state or jurisdiction is out of compliance, reports that determination to the ISFMP Policy Board under the terms of the ISFMP Charter.

## 6.3 Shad and River Herring Plan Review Team and Plan Development Team

The Shad and River Herring Plan Review Team and Plan Development Team are small groups whose responsibility is to provide all necessary staff support to carry out and document the decisions of the Management Board. Both teams are directly responsible to the Management Board for providing all of the information and documentation necessary to carry out the Board's decisions.

The teams shall be comprised of personnel from state and federal agencies who have scientific or management knowledge of shad and river herring and will be chaired by the Commission's Shad and River Herring FMP Coordinator. The Plan Development Team will be responsible for preparing all documentation necessary for the development of Amendment 2, using the best scientific information available and the most current stock assessment information. Once the Commission adopts Amendment 2, the Plan Review Team will provide annual advice concerning implementation, review, monitoring and enforcement of the amendment.

### 6.4 Shad and River Herring Technical Committee

The Shad and Rive Herring Technical Committee will consist of representatives from each jurisdiction and federal agency with a declared interest in shad and river herring fisheries. Its role is to act as a liaison to the individual jurisdictions and federal agencies, providing information to the management process and reviewing and making recommendations concerning the management program. The Technical Committee will provide scientific advice to the Management Board, Plan Development Team and Plan Review Team in the development and monitoring of a fishery management plan or amendment.

### 6.5 Shad and River Herring Stock Assessment Subcommittee

The Shad and River Herring Stock Assessment Subcommittee will consist of scientists with expertise in stock assessment methods or the assessment of shad and river herring populations. Its role is to assess shad and river herring populations and provide scientific advice concerning the implications of proposed or potential management alternatives for the stocks, as well as to respond to other scientific questions from the Management Board, Technical Committee, Plan Development Team or Plan Review Team. The Stock Assessment Subcommittee will report to the Management Board as well as to the Technical Committee.

### 6.6 Shad and River Herring Advisory Panel

The Shad and River Herring Advisory Panel is established according to the Commission's Advisory Committee Charter. Members of the Advisory Panel are citizens who represent a cross-section of commercial and recreational fishing interests and other who are concerned about shad and river herring conservation and management. The Advisory Panel provides the Management Board with advice directly concerning the Commission's shad and river herring management program.

### 6.7 Secretaries of Commerce and the Interior

Under the Atlantic Coastal Fisheries Cooperative Management Act, if the Commission determines that a state is out of compliance with the Fishery Management Plan, it reports that finding to the Secretary of Commerce. The Secretary of Commerce must determine that the measures not taken by the state are necessary for conservation and if such a finding is determined, the Secretary is then required by federal law to impose a moratorium on fishing for shad or river herring in that jurisdiction's waters until the state comes back into compliance. In addition, the Commission has accorded the National Marine Fisheries Service and the U.S. Fish and Wildlife Service voting status on the ISFMP Policy Board and the Shad and River Herring

Management Board; the federal agencies participate on the Plan Review Team, Plan Development Team, Technical Committee and Stock Assessment Subcommittee.

### 6.8 Recommendations to Secretaries

ASMFC recommends that the Secretary of Commerce direct the National Marine Fisheries Service (NMFS) support efforts underway by the New England and Mid-Atlantic Fishery Management Councils to effectively monitor bycatch of river herring in small-mesh fisheries. Additionally, the ASMFC recommends the Secretary of Commerce provide additional resources to support the cooperative efforts between the Commission and the councils to better manage anadromous fisheries. Finally, the ASMFC requests that the Secretary of Commerce take emergency action with regard to implementing the bycatch monitoring measures that have been under discussion at the New England Fishery Management Council to Amendment 4 to the Sea Herring Plan.

# 7. COMPLIANCE

Full implementation of the provisions in this amendment is necessary for the management program to be equitable, efficient and effective. States and jurisdictions are expected to implement these measures faithfully under state laws. Although the Atlantic States Marine Fisheries Commission does not have authority to directly compel state implementation of these measures, it will continually monitor the effectiveness of state implementation and determine whether states are in compliance with the provisions of this fishery management plan. This section sets forth the specific elements that the Commission will consider in determining state compliance with this fishery management plan and the procedures that govern the evaluation of compliance. Additional details of the procedures are found in the 2003 ASMFC Interstate Fisheries Management Program (ISFMP) Charter. States should be aware that federal law requires their compliance with the provisions of this fishery management plan.

## 7.1 MANDATORY COMPLIANCE ELEMENTS FOR STATES

A state will be determined out of compliance with the provision of this fishery management plan according to the terms of Section 7 of the ISFMP Charter if:

1. Its regulatory and management programs to implement Sections 3 and 4 have not been approved by the Shad and River Herring Management Board; or
2. It fails to meet any schedule required by Section 7.2, or any addendum prepared under adaptive management (Section 5.4); or
3. It has failed to implement a change to its program when determined necessary by the Shad and River Herring Management Board; or
4. It makes a change to its monitoring programs required under Section 3 or its regulations required under Section 4 without prior approval of the Shad and River Herring Management Board.

### 7.1.1 Mandatory Elements of State Programs

A state will be found out of compliance if it's regulatory and management programs for shad and river herring have not been approved by the Management Board in section 3 and 4.

All state programs must include a regime of restrictions on commercial and recreational fisheries consistent with the requirements of Section 4. Except, a state may propose an alternative management program under Section 5, which if approved by the Management Board, may be implemented as an alternative regulatory requirement for compliance under the law.

### 7.1.2 Regulatory Requirements

States may begin to implement Amendment 2 after final approval by the Commission. Each state must submit its required shad and river herring regulatory program to the Commission through Commission staff for approval by the Management Board. During the period between submission of the regulatory plan and the Management Board's decision to approve or reject it, a state may not adopt a less protective management program than contained in this Amendment or contained in current state law. Once a regulatory program is approved by the Management Board, states may not implement any regulatory changes concerning shad and river herring, nor any management program changes that affect their responsibilities under this Amendment, without first having those changes approved by the Management Board.

### 7.1.3 Monitoring Requirements

All state programs must include the mandatory monitoring requirements contained in Section 3. States must submit proposals for all intended changes to required monitoring programs that may affect the quality of the data or the ability of the program to fulfill the needs of the fishery management plan. In the event that a state realizes that it will not be able to fulfill its monitoring requirements, it should immediately notify the Commission. The Commission will work with the state to develop a plan to secure funding or plan an alternative program to satisfy the needs outlined in Amendment 2. If the plan is not implemented 90 days after it has been adopted, the state may be found out of compliance with Amendment 2.

### 7.1.4 Research Requirements

No mandatory research requirements have been identified at this time; however, elements of state plans may be added to address any needs identified during the course of developing Amendment 2.

### 7.1.5 Law Enforcement Requirements

All state programs must include law enforcement capabilities adequate for successfully implementing the state's shad and river herring regulations. The adequacy of a state's enforcement activity will be measured by an annual report to the Commission's Law Enforcement Committee and the Plan Review Team.

### 7.1.6 Habitat Requirements

No mandatory habitat requirements have been identified at this time; however, elements of state plans may be added to address any needs identified during the course of developing Amendment 2.

## 7.2 COMPLIANCE SCHEDULE

States must implement this Amendment according to the following schedule:

January 1, 2010: States and jurisdictions must submit fishery management plans, as detailed in Section 4.1.

January 1, 2012: Fisheries that do not have an approved management plan in place, or are not covered by an approved management plan, by January 1, 2012 will be closed as detailed in section 4.1

Reports on compliance should be submitted to the Commission by each jurisdiction annually, no later than July 1.

## 7.3 COMPLIANCE REPORT CONTENT

Each state must submit an annual report concerning its shad and river herring fisheries and management program for the previous years. The report shall cover:

1. The previous calendar year's fishery and management program including, activity and results of monitoring, regulations that were in effect, harvest, and estimates of non-harvest losses, following the outline contained in Table 23.
2. The planned management program for the current calendar year, summarizing regulations that will be in effect and monitoring programs that will be performed, and highlighting any changes from the previous year.

**Table 17.** Required format for annual state compliance reports.

I. HARVEST AND LOSSES
- A. COMMERCIAL FISHERY
  - 1. Characterization of fishery (seasons, cap, gears, regulations)
  - 2. Characterization of directed harvest for all alosines
    - a. Landings and method of estimation
    - b. Catch composition
      - i. Age frequency
      - ii. Length frequency
      - iii. Sex ratio
      - iv. Degree of repeat spawning (estimated from scale data)
    - c. Estimation of effort
  - 3. Characterization of other losses (poaching, bycatch, etc.)
    - a. Estimate and method of estimation
    - b. Estimate of composition (length and/or age)

- B. RECREATIONAL FISHERY
  - 1. Characterization of fishery (seasons, cap, regulations)
  - 2. Characterization of directed harvest
    - a. Landings and method of estimation
    - b. Catch composition
      - i. Age frequency
      - ii. Length frequency (legal and sub-legal catch)
    - c. Estimation of effort
  - 3. Characterization of other losses (poaching, hook/release mortality, etc.)
    - a. Estimate and method of estimation
    - b. Estimate of composition (length and/or age)

- C. OTHER LOSSES (FISH PASSAGE MORTALITY, DISCARDED MALES, BROOD STOCK CAPTURE, RESEARCH LOSSES, ETC.)

- D. TABLE 1. HARVEST AND LOSSES - INCLUDING ALL ABOVE ESTIMATES IN NUMBERS AND WEIGHT (POUNDS) OF FISH AND MEAN WEIGHT PER FISH FOR EACH GEAR TYPE

II. REQUIRED FISHERY INDEPENDENT MONITORING
- A. DESCRIPTION OF REQUIREMENT AS OUTLINED IN AMENDMENT 1, TABLE 2
- B. BRIEF DESCRIPTION OF WORK PERFORMED
- C. RESULTS
  - 1. Juvenile indices
    - a. Index of abundance
    - b. Variance
  - 2. Spawning stock assessment
    - a. Length frequency
    - b. Age frequency
    - c. Sex
    - d. Degree of repeat spawning
  - 3. Annual mortality rate calculation
  - 4. Hatchery evaluation (%wild vs. hatchery)

## 7.4 PROCEDURES FOR DETERMINING COMPLIANCE

Detailed procedures regarding compliance determinations are contained in the ISFMP Charter, Section Seven.

In brief, all states are responsible for the full and effective implementation and enforcement of fishery management plans in areas subject to their jurisdiction. Written compliance reports as specified in the Plan or Amendment must be submitted annually by each state with a declared interest. Compliance with Amendment 2 will be reviewed at least annually. The Shad and River Herring Management Board, ISFMP Policy Board or the Commission may request the Plan Review Team to conduct a review of Plan implementation and compliance at any time.

The Management Board will review the written findings of the Plan Review Team within 60 days of receipt of a state's compliance report. Should the Management Board recommend to the Policy Board that a state be determined to be out of compliance, a rationale for the recommended noncompliance finding will be included addressing specifically the required measures of Amendment 2 that the state has not implemented or enforced, a statement of how failure to implement or enforce required measures jeopardizes shad and river herring conservation, and the actions a state must take in order to comply with Amendment 2 requirements.

The ISFMP Policy Board will review any recommendation of noncompliance from the Management Board within 30 days. If it concurs in the recommendation, it shall recommend at that time to the Commission that a state be found out of compliance.

The Commission shall consider any noncompliance recommendation from the ISFMP Policy Board within 30 days. Any state that is the subject of a recommendation for a noncompliance finding is given an opportunity to present written and/or oral testimony concerning whether it should be found out of compliance. If the Commission agrees with the recommendation of the ISFMP Policy Board, it may determine that a state is not in compliance with the Amendment 2, and specify the actions the state must take to come into compliance.

Any state that has been determined to be out of compliance may request that the Commission rescind its noncompliance findings, provided the state has revised its shad and river herring conservation measures.

# 8. MANAGEMENT RESEARCH NEEDS

The following list of research needs have been identified in order to enhance the state or knowledge of the shad and river herring resources, population dynamics, ecology and the various fisheries for alosine species. The Technical Committee, Advisory Panel, and Management Board will review this list annually and an updated prioritized list will be included in the Annual Shad and River Herring FMP Review.

## 8.1 STOCK ASSESSMENT AND POPULATION DYNAMICS

- Continue to assess current aging techniques for American shad and river herring, using known-age fish, scales, otoliths and spawning marks. Conduct biannual aging workshops to maintain consistency and accuracy in aging fish sampled in state programs.
- Investigate the relation between juvenile production and subsequent yearclass strength for alosine species, with emphasis on the validity of juvenile abundance indices, rates and sources of immature mortality, migratory behavior of juveniles, natural history and ecology of juveniles, and essential nursery habitat in the first few years of life.
- Validate the different values of M for shad stocks through verification of aging techniques and repeat spawning information and develop methods for calculating M.
- Evaluate additional sources of mortality for alosine species, including bait and reduction fisheries.
- Determine which stocks are impacted by mixed stock fisheries (including bycatch fisheries). Methods to be considered could include otolith microchemistry, oxy-tetracycline otolith marking, and/or tagging.
- Evaluate predation by striped bass as a factor of mortality for alosines. Research predation rates and impacts on alosines.
- Quantify fishing mortality (in-river, ocean bycatch, bait fisheries) for major river stocks after ocean closure of directed fisheries.
- Develop comprehensive angler use and harvest survey techniques for use by Atlantic states to assess recreational fisheries for American shad.
- Determine and update biological benchmarks used in assessment modeling (fecundity-at-age, mean weight-at-age for both sexes, partial recruitment vector/maturity schedules) for American shad and river herring stocks in a variety of coastal river systems, including both semelparous and iteroparous stocks.
- Conduct population assessments on river herring—particularly needed in the south.
- Evaluate and ultimately validate large-scale hydroacoustic methods to quantify American shad escapement (spawning run numbers) in major river systems. Identify how shad respond (attract/repelled) by various hydroacoustic signals.

## 8.2 RESEARCH AND DATA NEEDS

### 8.2.1 Habitat

- Identify ways to improve fish passage efficiency using hydroacoustics to repel alosines or pheromones or other chemical substances to attract them. Test commercially available acoustic equipment at existing fish passage facility to determine effectiveness. Develop methods to isolate/manufacture pheromones or other alosine attractants.

- Determine the effects of passage impediments on all life history stages of shad and river herring, conduct turbine mortality studies and downstream passage studies.
- Develop and implement techniques to determine shad and herring population targets for tributaries undergoing restoration (dam removals, fishways, supplemental stocking, etc.).
- Characterize tributary habitat quality and quantity for Alosine reintroductions and fish passage development.
- Identify and quantify potential American shad spawning and rearing habitat not presently utilized and conduct an analysis of the cost of recovery.
- Development of appropriate Habitat Suitability Index Models for alosine species in the fishery management plan. Possibly consider expansion of species of importance or go with the most protective criteria for the most susceptible species.
- Determine factors that regulate and potentially limit downstream migration, seawater tolerance, and early ocean survival of juvenile alosines.
- Review studies dealing with the effects of acid deposition on anadromous alosines.
- Determine effects of change in temperature and pH for all life stages.
- Determine optima and tolerance for salinity, dissolved oxygen, pH, substrate, current velocity, depth, temperature, and suspended solids.
- Determine hard limits and range levels for water quality deemed appropriate and defensible for all alosines.
- There has been little research conducted on habitat requirements for hickory shad. Although there are reported ranges of values for some variables, such as temperature or depth, there is no information on tolerances or optima for all life stages. Research on all life stages is necessary to determine habitat requirements.

### 8.2.2 Life History

- Conduct studies on energetics of feeding and spawning migrations of alosines on the Atlantic coast.
- Conduct studies of egg and larval survival and development.
- Focus research on within-species variation in genetic, reproductive, morphological, and ecological characteristics, given the wide geographic range and variation at the intraspecific level that occurs in alosines.
- Ascertain how abundance and distribution of potential prey affect growth and mortality of early life stages.
- Conduct research on hickory shad migratory behavior. This may explain why hickory shad populations continue to increase while other alosines are in decline.

### 8.2.3 Stocking and Hatcheries

- Develop effective culture and marking techniques for river herring.
- Refine techniques for hormone induced tank spawning of American shad. Secure adequate eggs for culture programs using native broodstock.

### 8.2.4 Socioeconomic

- Conduct and evaluate historical characterization of socio-economic development (potential pollutant sources and habitat modification) of selected alosine rivers along the East Coast.
- Collect information from consumptive and non-consumptive users on: demographic information (e.g., age, gender, ethnicity/race), social structure information (e.g., historical participation, affiliation with NGOs, perceived conflicts), other cultural information (e.g., occupational motivation, cultural traditions related to resource's use), and community information.
- In order to improve the management-oriented understanding of historical stock trends and related assessments, the social and economic history of the river herring fisheries should be documented for time periods equivalent to the stock return level sought by the biological standards and this analysis should including documenting market trends, consumer preferences including recreational anglers, the role of product substitutes such as Atlantic herring and menhaden, and the levels of subsistence fisheries as can be obtained.
- Before recommending, re-authorizing and/or implementing stock enhancement programs for a given river system, it is recommended that state agencies or other appropriate management organization conduct *ex-ante* socioeconomic cost and benefit (e.g., estimate non-consumptive and existence values, etc.) analysis of proposed stocking programs.

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## 10. GLOSSARY

* Definitions taken from: *NOAA Fisheries Glossary*, NOAA Technical Memorandum NMFS-F/SPO-69, October 2005, Revised Edition June 2006.

** Definitions taken from: Stock Assessment Report No. 07-01 (Supplement) of the Atlantic States Marine Fisheries Commission, *American Shad Stock Assessment Report For Peer Review*, August 2007, List of Terms.

All other definitions were developed by the Plan Development Team.

**Anadromous***
Fishes that migrate as juveniles from freshwater to saltwater and then return as adults to spawn in freshwater; most Pacific salmon are anadromous.

**Area Under the Curve**
An estimate of the relative annual abundance of a fish spawning run based on daily fish sample counts over the entire run period. Sample counts can be from fish passage counts at a fishway, or from systematic fishery sampling located downstream of the in-river spawning area, prior to spawning.

**Baseline***
A set of reference data sets or analyses used for comparative purposes; it can be based on a reference year or a reference set of (standard) conditions.

**Benchmarks****
A particular value of stock size, catch, fishing effort, fishing mortality, and total mortality that may be used as a measurement of stock status or management plan effectiveness. Sometimes these may be referred to as biological reference points.

**Biological Reference Points***
1. A biological benchmark against which the abundance of the stock or the fishing mortality rate can be measured in order to determine its status. These reference points can be used as limits or targets, depending on their intended usage;
2. Specific values for the variables that describe the state of a fishery system which are used to evaluate its status. Reference points are most often specified in terms of fishing mortality rate and/or spawning stock biomass. These may indicate (a) a desired state of the fishery, such as a fishing mortality rate that will achieve a high level of sustainable yield, or (b) a state of the fishery that should be avoided, such as a high fishing mortality rate which risks a stock collapse and long-term loss of potential yield. The former are referred to as “target reference points,” and the latter are referred to as “limit reference points” or “thresholds.” Some common examples are $F_{0.1}$, $F_{MAX}$, and $F_{MSY}$.

**Biomass (B)***
1. Or standing stock. The total weight of a group (or stock) of living organisms (e.g. fish, plankton) or of some defined fraction of it (e.g. spawners) in an area, at a particular time; 2.

Measure of the quantity, usually by weight in pounds or metric tons (2,205 pounds or 1 metric ton), of a stock at a given time.

**Bycatch***
Fish other than the primary target species that are caught incidental to the harvest of the primary species. Bycatch may be retained or discarded. Discards may occur for regulatory or economic reasons.

**Carrying Capacity***
1. The maximum population of a species that an area or specific ecosystem can support indefinitely without deterioration of the character and quality of the resource;
2. The level of use, at a given level of management, at which a natural or man-made resource can sustain itself over a long period of time. For example, the maximum level of recreational use, in terms of numbers of people and types of activity that can be accommodated before the ecological value of the area declines.

**Catch Curve****
An age-based analysis of the catch in a fishery that is used to estimate total mortality of a fish stock. Total mortality is calculated by taking the negative slope of the logarithm of the number of fish caught at successive ages (or with 0, 1, 2... annual spawning marks).

**Catch Per Unit (of) Effort (CPUE)***
The quantity of fish caught (in number or in weight) with one standard unit of fishing effort; e.g. number of fish taken per 1,000 hooks per day or weight of fish, in tons, taken per hour of trawling. CPUE is often considered an index of fish biomass (or abundance). Sometimes referred to as catch rate. CPUE may be used as a measure of economic efficiency of fishing as well as an index of fish abundance. Also called: catch per effort, fishing success, availability.

**Catch Rate***
Means sometimes the amount of catch per unit time and sometimes the catch per unit effort.

**Cohort***
1. In a stock, a group of fish generated during the same spawning season and born during the same time period;
2. In cold and temperate areas, where fish are long-lived, a cohort corresponds usually to fish born during the same year (a year class). For instance, the 1987 cohort would refer to fish that are age 0 in 1987, age 1 in 1988, and so on. In the tropics, where fish tend to be short lived, cohorts may refer to shorter time intervals (e.g. spring cohort, autumn cohort, monthly cohorts). (see *Year Class*)

**Cohort Analysis***
A retrospective analysis of the catches obtained from a given year class at each age (or length interval) over its life in the fishery. Allows estimation of fishing mortality and abundance at each age as well as recruitment. Involves the use of a simplified algorithm based on an approximation that assumes that, in a given time period, all fishing takes place instantaneously in the middle of the time period.

**De minimis****
Status obtained by states with minimal fisheries for a certain species and that meet specific provisions described in fishery management plans allowing them to be exempted from specific management requirements of the fishery management plan to the extent that action by the particular States to implement and enforce the plan is not necessary for attainment of the fishery management plan's objectives and the conservation of the fishery.

**Depleted Stock***
A stock driven by fishing to very low level of abundance compared to historical levels, with dramatically reduced spawning biomass and reproductive capacity. It requires particularly energetic rebuilding strategies and its recovery time will depend on the present condition, the level of protection, and the environmental conditions.

**Directed Fishery***
Fishing that is directed at a certain species or group of species. This applies to both sport and commercial fishing.

**Discard***
To release or return fish to the sea, dead or alive, whether or not such fish are brought fully on board a fishing vessel.

**Economic Overfishing***
A level of fish harvesting that is higher than that of economic efficiency; harvesting more fish than necessary to have maximum profits for the fishery.

**Economic Value***
The most people are willing to pay to use a given quantity of a good or service; or, the smallest amount people are willing to accept to forego the use of a given quantity of a good or service.

**Ecosystem Approach to Fisheries (EAF)***
An approach to fisheries management that strives to balance diverse societal objectives by taking into account the knowledge and uncertainties about biotic, abiotic, and human components of ecosystems and their interactions and applying an integrated approach to fisheries within ecologically meaningful boundaries. The purpose of EAF is to plan, develop, and manage fisheries in a manner that addresses the multiple needs and desires of society, without jeopardizing the options for future generations to benefit from the full range of goods and services provided by marine ecosystems.

**Ecosystem Approach to Management (EAM)***
Management that is adaptive, is specified geographically, takes into account ecosystem knowledge and uncertainties, considers multiple external influences, and strives to balance diverse social objectives.

**Ecosystem Function***
An intrinsic ecosystem characteristic related to the set of conditions and processes whereby an ecosystem maintains its integrity. Ecosystem functions include such processes as decomposition, production, nutrient cycling, and fluxes of nutrients and energy.

**Ecosystem-Based Management***
An approach that takes major ecosystem components and services—both structural and functional—into account in managing fisheries. It values habitat, embraces a multispecies perspective, and is committed to understanding ecosystem processes. Its goal is to rebuild and sustain populations, species, biological communities, and marine ecosystems at high levels of productivity and biological diversity so as not to jeopardize a wide range of goods and services from marine ecosystems while providing food, revenue, and recreation for humans.

**Equilibrium Catch***
The catch (in numbers) taken from a fish stock when it is in equilibrium with fishing of a given intensity, and (apart from the effects of environmental variation) its abundance is not changing from one year to the next.

**Equilibrium Yield (EY)***
The yield in weight taken from a fish stock when it is in equilibrium with fishing of a given intensity, and (apart from effects of environmental variation) its biomass is not changing from one year to the next. Also called: sustainable yield, equivalent sustainable yield.

**Escapement***
The number or proportion of fish surviving (escaping from) a given fishery at the end of the fishing season and reaching the spawning grounds. The term is generally used for salmon management.

**Exclusive Economic Zone (EEZ)***
The EEZ is the area that extends from the seaward boundaries of the coastal states (3 nautical miles (n.mi.) in most cases, the exceptions are Texas, Puerto Rico and the Gulf coast of Florida at 9 n.mi.) to 200 n.mi. off the U.S. coast. Within this area the United States claims and exercises sovereign rights and exclusive fishery management authority over all fish and all continental shelf fishery resources.

**Existence Value***
The economic value of knowing that a resource exists, irrespective of the ability to use the resource now or in the future.9

**Exploitable Biomass***
Refers to that portion of a stock's biomass that is available to fishing.

**Exploitation****
The annual percentage of the stock removed by fishing either recreationally or commercially.

**Exploitation Pattern***
The distribution of fishing mortality over the age composition of the fish population, determined by the type of fishing gear, area and seasonal distribution of fishing, and the growth and migration of the fish. The pattern can be changed by modifications to fishing gear; for example, increasing mesh or hook size, or by changing the ratio of harvest by gears exploiting the fish (e.g. gillnet, trawl, hook and line, etc.).

**Exploitation Rate***
The proportion of a population at the beginning of a given time period that is caught during that time period (usually expressed on a yearly basis). For example, if 720,000 fish were caught during the year from a population of 1 million fish alive at the beginning of the year, the annual exploitation rate would be 0.72.

**Ex-Vessel***
Refers to activities that occur when a commercial fishing boat lands or unloads a catch. For example, the price received by a captain (at the point of landing) for the catch is an ex-vessel price.

**Fecundity***
The potential reproductive capacity of an organism or population expressed in the number of eggs (or offspring) produced during each reproductive cycle. Fecundity usually increases with age and size. The information is used to compute spawning potential.

**Fish Passage****
The movement of fish above or below an river obstruction, usually by fish-lifts or fishways.

**Fish Passage Efficiency****
The percent of the fish stock captured or passed through an obstruction (i.e., dam) to migration.

**Fishery-Dependent***
Data collected directly on a fish or fishery from commercial or sport fishermen and seafood dealers. Common methods include logbooks, trip tickets, port sampling, fishery observers, and phone surveys. (see *Fishery-Independent*)

**Fishery-Independent***
Characteristic of information (e.g. stock abundance index) or an activity (e.g. research vessel survey) obtained or undertaken independently of the activity of the fishing sector. Intended to avoid the biases inherent to fishery-related data. (see *Fishery-Dependent*)

**Fishery Management Unit (FMU)***
A fishery or a portion of a fishery identified in a fishery management plan (FMP) relevant to the FMP's management objectives. The choice of stocks or species in an FMU depends upon the focus of FMP objectives, and may be organized around biological, geographic, economic, technical, social, or ecological perspectives.

**Fishing Mortality (F)***
1. F stands for the fishing mortality rate in a particular stock. It is roughly the proportion of the fishable stock that is caught in a year;
2. A measurement of the rate of removal from a population by fishing. Fishing mortality can be reported as either annual or instantaneous. Annual mortality is the percentage of fish dying in one year. Instantaneous mortality is that percentage of fish dying at any one time.

**$F_{30}$**
The fishing mortality rate that reduces the spawning stock biomass per recruit (SSB/R) to 30% of the amount present in the absence of fishing.

**$F_{MSY}$***
The fishing mortality rate that, if applied constantly, would result in maximum sustainable yield (MSY). Used as a biological reference point, FMSY is the implicit fishing mortality target of many regional and national fishery management authorities and organizations. $F_{MSY}$ can be estimated in two ways: a) from simple biomass aggregated production models; b) from age-structured models that include a stock-recruitment relationship.

**$F_{MAX}$***
1. The level of fishing mortality (rate of removal by fishing) that produces the greatest yield from the fishery;
2. A biological reference point. It is the fishing mortality rate that maximizes equilibrium yield per recruit. FMAX is the F level often used to define growth overfishing. In general, FMAX is different (and higher) than FMSY depending on the stock-recruitment relationship. By definition, FMAX is always higher than $F_{0.1}$.

**Index of Abundance***
A relative measure of the abundance of a stock; for example, a time series of catch per unit effort data.

**Indicators***
1. A variable, pointer, or index. Its fluctuation reveals the variations in key elements of a system. The position and trend of the indicator in relation to reference points or values indicate the present state and dynamics of the system. Indicators provide a bridge between objectives and action;
2. Signals of processes, inputs, outputs, effects, results, outcomes, impacts, etc., that enable such phenomena to be judged or measured. Both qualitative and quantitative indicators are needed for management learning, policy review, monitoring, and evaluation;
3. In biology, an organism, species, or community whose characteristics show the presence of specific environmental conditions, good or bad.

**Instantaneous Rate of Fishing Mortality (F)***
When fishing and natural mortality act concurrently, F is equal to the instantaneous total mortality rate, multiplied by the ratio of fishing deaths to all deaths. Also called: rate of fishing; instantaneous rate of fishing.

**Instantaneous Rate of Mortality (Z)***
When fishing and natural mortality act concurrently, the natural logarithm of the survival rate (with sign changed) for deaths due to either natural causes (instantaneous rate of natural mortality, M) or due to fishing mortality (instantaneous rate of fishing mortality, F). The instantaneous rate of total mortality, Z, is the sum of these two rates: $Z = F + M$, also called the coefficient of decrease.

Comment: Usually given on a yearly basis; the figure just described is divided by the fraction of a year represented by the "short interval" in question. This concept is used principally when the size of the vulnerable stock is not changing or is changing only slowly, since among fishes recruitment is not usually associated with stock size in the direct way in which mortality and growth are.

**Larvae**
Fish developmental stage well differentiated form the later young-of-year and juvenile stages and intervening between the time of hatching and time of transformation or loss of larval character (i.e., fish resembles a young or juvenile individual by absence of a yolk sac, and presence of continuous finfolds and pigmented young-of-year character).

**Life Cycle***
Successive series of changes through which an organism passes in the course of its development.

**Limit Reference Points***
Benchmarks used to indicate when harvests should be constrained substantially so that the stock remains within safe biological limits. The probability of exceeding limits should be low. In the National Standard Guidelines, limits are referred to as thresholds. In much of the international literature (e.g. United Nations Food and Agricultural Organization, FAO) thresholds are used as buffer points that signal when a limit is being approached.

**M**
(see Natural Mortality)

**Management Objective***
A formally established, more or less quantitative target that is actively sought and provides a direction for management action.

**Management Reference Points***
Conventional (agreed values) of indicators of the desirable or undesirable state of a fishery resource of the fishery itself. Reference points could be biological (e.g. expressed in spawning biomass or fishing mortality levels), technical (fishing effort or capacity levels) or economic (employment or revenues levels). They are usually calculated from models in which they may represent critical values.

**Management Strategy***
The strategy adopted by the management authority to reach established management goals. In addition to the objectives, it includes choices regarding all or some of the following: access

rights and allocation of resources to stakeholders, controls on inputs (e.g. fishing capacity, gear regulations), outputs (e.g. quotas, minimum size at landing), and fishing operations (e.g. calendar, closed areas, and seasons).

**Mature Individuals***
The number of individuals known, estimated, or inferred to be capable of reproduction.

**Maturity***
Refers to the ability, on average, of fish of a given age or size to reproduce. Maturity information, in the form of percent mature by age or size, is often used to compute spawning potential.

**Maximum Spawning Potential (MSP)***
This type of reference point is used in some fishery management plans to define overfishing. The MSP is the spawning stock biomass per recruit (SSB/R) when fishing mortality is zero. The degree to which fishing reduces the SSB/R is expressed as a percentage of the MSP (i.e. %MSP). A stock is considered overfished when the fishery reduces the %MSP below the level specified in the overfishing definition. The values of %MSP used to define overfishing can be derived from stock-recruitment data or chosen by analogy using available information on the level required to sustain the stock.

**Maximum Sustainable Yield (MSY)***
The largest average catch or yield that can continuously be taken from a stock under existing environmental conditions. For species with fluctuating recruitment, the maximum might be obtained by taking fewer fish in some years than in others. Also called: maximum equilibrium catch; maximum sustained yield; sustainable catch.

**Minimum Stock Size Threshold (MSST, $B_{threshold}$)***
Another of the status determination criteria (SDC). The greater of (a) 1/2 $B_{MSY}$ , or (b) the minimum stock size at which rebuilding to $B_{MSY}$ will occur within 10 years while fishing at the maximum fishing mortality threshold (MFMT). MSST should be measured in terms of spawning biomass or other appropriate measures of productive capacity. If current stock size is below $B_{threshold}$, the stock is overfished.

**Moratorium***
A mandatory cessation of fishing activities on a species (e.g. the blue whale), in an area (e.g. a sanctuary), with a particular gear (e.g. large scale driftnets), and for a specified period of time (temporary, definitive, seasonal, or related to reopening criteria).

**Mortality***
Measures the rate of death of fish. Mortality occurs at all life stages of the population and tends to decrease with age. Death can be due to several factors such as pollution, starvation, and disease but the main source of death is predation (in unexploited stocks) and fishing (in exploited ones).

**Mortality Rate***
The rate at which the numbers in a population decrease with time due to various causes. Mortality rates are critical parameters in determining the effects of harvesting strategies on stocks, yields, revenues, etc. The proportion of the total stock (in numbers) dying each year is called the "annual mortality rate."

**Native Species***
A local species that has not been introduced. (see *Introduced Species, Invasive Species*)

**Natural Mortality (M)***
1. Deaths of fish from all causes except fishing (e.g. ageing, predation, cannibalism, disease, and perhaps increasingly pollution). It is often expressed as a rate that indicates the percentage of fish dying in a year; e.g. a natural mortality rate of 0.2 implies that approximately 20 percent of the population will die in a year from causes other than fishing;
2. The loss in numbers in a year class from one age group to the subsequent one, due to natural death.

Comment: These many causes of death are usually lumped together for convenience, because they are difficult to separate quantitatively. Sometimes natural mortality is confounded with losses of fish from the stock due to emigration. M has proven very difficult to estimate directly, and is often assumed based on the general life history. The M value is also often assumed to remain constant through time and by age, a very unlikely assumption.

**Natural Mortality (M)****
The instantaneous rate at which fish die from all causes other than harvest or other human-induced cause (i.e., turbine mortality). Some sources of natural mortality include predation, spawning mortality, and senescence (old age).

**Non-Consumptive Use***
Individuals may use (i.e. observe), yet not consume, certain living ocean resources, like whale watching, sight-seeing, or scuba diving. Additionally, individuals might value the mere existence of living ocean resources without actually observing them.

**Non-Point Sources***
Sources of sediment, nutrients, or contaminants that originate from many locations.

**Non-Target Species***
Species not specifically targeted as a component of the catch; may be incidentally captured as part of the targeted catch.

**Ocean-Intercept Fishery****
A fishery for American shad conducted in state or federal ocean waters targeting the coastal migratory mixed-stock of American shad.

**Optimum Yield (OY)***

1. The harvest level for a species that achieves the greatest overall benefits, including economic, social, and biological considerations. Optimum yield (OY) is different from maximum sustainable yield (MSY) in that MSY considers only the biology of the species. The term includes both commercial and sport yields;
2. The amount of fish that will provide the greatest overall benefit to the Nation, particularly with respect to food production and recreational opportunities and taking into account the protection of marine ecosystems. MSY constitutes a "ceiling" for OY. OY may be lower than MSY, depending on relevant economic, social, or ecological factors. In the case of an overfished fishery, OY should provide for the rebuilding of the stock to
BMSY.

**Overexploited***

When stock abundance is too low. The term is used when biomass has been estimated to be below a limit biological reference point that is used as the threshold that defines "overfished conditions."

**Overfished***

1. An overfished stock or stock complex "whose size is sufficiently small that a change in management practices is required to achieve an appropriate level and rate of rebuilding." A stock or stock complex is considered overfished when its population size falls below the minimum stock size threshold (MSST). A rebuilding plan is required for stocks that are deemed overfished;
2. A stock is considered "overfished" when exploited beyond an explicit limit beyond which its abundance is considered 'too low' to ensure safe reproduction. In many fisheries the term is used when biomass has been estimated to be below a limit biological reference point that is used as the signpost defining an "overfished condition." This signpost is often taken as being $F_{MSY}$, but the usage of the term may not always be consistent. (see *Minimum Stock Size Threshold*)

Comment: The stock may remain overfished (i.e. with a biomass well below the agreed limit) for some time even though fishing pressure might be reduced or suppressed.

**Overfishing***

1. According to the National Standard Guidelines, "overfishing occurs whenever a stock or stock complex is subjected to a rate or level of fishing mortality that jeopardizes the capacity of a stock or stock complex to produce maximum sustainable yield (MSY) on a continuing basis." Overfishing is occurring if the maximum fishing mortality threshold (MFMT) is exceeded for 1 year or more;
2. In general, the action of exerting fishing pressure (fishing intensity) beyond the agreed optimum level. A reduction of fishing pressure would, in the medium term, lead to an increase in the total catch. (see *National Standard Guidelines*, *Maximum Fishing Mortality Threshold*, *Maximum Sustainable Yield*)

Comment: For long-lived species, overfishing (i.e. using excessive effort) starts well before the stock becomes overfished. The use of the term "overfishing" may not always be consistent.

**Overfishing Limit (OFL)***
Point at which fishing seriously compromised a fishery's continued, sustained productivity. Overfishing limits may be set based on standardized biological criteria established for a particular fishery. Overfishing limits may also incorporate economic and social considerations relevant to a particular fishery.

**Oxytetracycline (OTC)****
An antibiotic used to internally mark otoliths of hatchery produced fish.

**Predation***
Relationship between two species of animals in which one (the predator) actively hunts and lives off the meat and other body parts of the other (the prey).

**Pre-Recruits***
Fish that have not yet reached the recruitment stage (in age or size) to a fishery.

**Production***
1. The total output especially of a commodity or an industry;
2. The total living matter (biomass) produced by a stock through growth and recruitment in a given unit of time (e.g. daily, annual production). The "net production" is the net amount of living matter added to the stock during the time period, after deduction of biomass losses through mortality;
3. The total elaboration of new body substance in a stock in a unit of time, irrespective of whether or not it survives to the end of that time.

**Production Model***
1. The highest theoretical equilibrium yield that can be continuously taken (on average) from a stock under existing (average) environmental conditions without affecting significantly the reproduction process. Also referred to sometimes as potential yield;
2. Maximum sustainable yield (MSY) or sustainable yield (SY). The largest average catch or yield that can continuously be taken from a stock under existing environmental conditions. For species with fluctuating recruitment, the maximum might be obtained by taking fewer fish in some years than in others. (see *Carrying Capacity*, *Maximum Sustainable Yield*, *Sustainable Yield*)

**Productivity***
Relates to the birth, growth and death rates of a stock. A highly productive stock is characterized by high birth, growth, and mortality rates, and as a consequence, a high turnover and production to biomass ratios (P/B). Such stocks can usually sustain higher exploitation rates and, if depleted, could recover more rapidly than comparatively less productive stocks.

**Rebuilding***
1. Implementing management measures that increase a fish stock to its target size1; 2. For a depleted stock, or population, taking action to allow it to grow back to a predefined target level. Stock rebuilding at least back to the level (BMSY) at which a stock could produce maximum sustainable yield (MSY).

**Rebuilding Analysis***
An analysis that uses biological information to describe the probability that a stock will rebuild within a given time frame under a particular management regime.

**Rebuilding Plan***
1. A document that describes policy measures that will be used to rebuild a fish stock that has been declared overfished;
2. A plan that must be designed to recover stocks to the BMSY level within 10 years when they are overfished (i.e. when biomass [B] < minimum stock size threshold [MSST]). (see *Minimum Stock Size Threshold*)

**Recruit***
1. A young fish entering the exploitable stage of its life cycle;
2. A member of "the youngest age group which is considered to belong to the exploitable stock."

**Recruitment (R)***
1. The amount of fish added to the exploitable stock each year due to growth and/or migration into the fishing area. For example, the number of fish that grow to become vulnerable to the fishing gear in one year would be the recruitment to the fishable population that year;
2. This term is also used in referring to the number of fish from a year class reaching a certain age. For example, all fish reaching their second year would be age 2 recruits.

**Recruitment Overfishing***
A situation in which the rate of fishing is (or has been) such that annual recruitment to the exploitable stock has become significantly reduced. The situation is characterized by a greatly reduced spawning stock, a decreasing proportion of older fish in the catch, and generally very low recruitment year after year. If prolonged, recruitment overfishing can lead to stock collapse, particularly under unfavorable environmental conditions.

**Recruits***
The numbers of young fish that survive (from birth) to a specific age or grow to a specific size. The specific age or size at which recruitment is measured may correspond to when the young fish become vulnerable to capture in a fishery or when the number of fish in a cohort can be reliably estimated by a stock assessment.

**Reference Level***
A particular level of an indicator (e.g. level of fishing effort, fishing mortality, or stock size) used as a benchmark for assessment and management performance.

**Reference Point***
1. A reference point indicates a particular state of a fishery indicator corresponding to a situation considered as desirable (target reference point) or undesirable and requiring immediate action (limit reference point and threshold reference point);
2. An estimated value derived from an agreed scientific procedure and/or model, which corresponds to a specific state of the resource and of the fishery, and that can be used as a guide

for fisheries management. Reference points may be general (applicable to many stocks) or stock-specific;
3. Values of parameters (e.g. $B_{MSY}$, $F_{MSY}$, $F_{0.1}$) that are useful benchmarks for guiding management decisions. Biological reference points are typically limits that should not be exceeded with significant probability (e.g. MSST) or targets for management (e.g. OY).

**Relative Exploitation****
An approach used when catch is known or estimated, but no estimates of abundance are available. For example, it may be calculated as the catch divided by a relative index of abundance. Long-term trends in relative exploitation are can be useful in evaluating the impact of fishing versus other sources of mortality.

**Restoration****
In this assessment, this describes the stocking of hatchery produced young-of-year American shad to augment wild cohorts and the transfer of adult American shad to rivers with depleted spawning stocks. Restoration also includes efforts to improve fish passage or remove barriers to migration.

**Risk***
1. In general, the possibility of something undesirable happening, of harm or loss. A danger or a hazard. A factor, thing, element, or course involving some uncertain danger;
2. In decision-theory, the degree or probability of a loss; expected loss; average forecasted loss. This terminology is used when enough information is available to formulate probabilities;
3. The probability of adverse effects caused under specified circumstances by an agent in an organism, a population, or an ecological system.

**Risk Assessment***
A process of evaluation including the identification of the attendant uncertainties, of the likelihood and severity of an adverse effect(s)/event(s) occurring to man or the environment following exposure under defined conditions to a risk source(s). A risk assessment comprises hazard identification, hazard characterization, exposure assessment, and risk characterization.

**Risk Management***
The process of weighing policy alternatives in the light of the result of a risk assessment and other relevant evaluation and, if required, selecting and implementing appropriate control options (which should, where appropriate, include monitoring or surveillance).

**River Complex**
The freshwater portions of an Atlantic coast river, and its associated tributaries and estuary that encompass the freshwater migration, spawning, and nursery habitat for an American shad stock.

**Robustness***
The capacity of a population to persist in the presence of fishing. This depends on the existence of compensatory mechanisms. (see *Reliability*)

**Run***
Seasonal migration undertaken by fish, usually as part of their life history; for example, spawning run of salmon, upstream migration of shad. Fishers may refer to increased catches as a "run" of fish, a usage often independent of their migratory behavior.

**Run Size****
The magnitude of the upriver spawning migration of American shad.

**Semelparous****
Life history strategy in which an organism only spawns once before dying.

**Spawning Biomass***
The total weight of all sexually mature fish in the population.

**Spawning Ground**
The area of suitable spawning habitat associated with a stock.

**Spawning Stock***
1. Mature part of a stock responsible for reproduction;
2. Strictly speaking, the part of an overall stock having reached sexual maturity and able to spawn. Often conventionally defined as the number or biomass of all individuals beyond "age at first maturity" or "size at first maturity"; that is, beyond the age or size class in which 50 percent of the individuals are mature.

**Spawning Stock Biomass (SSB)***
1. The total weight of all fish (both males and females) in the population that contribute to reproduction. Often conventionally defined as the biomass of all individuals beyond "age at first maturity" or "size at first maturity," i.e. beyond the age or size class in which 50 percent of the individuals are mature;
2. The total biomass of fish of reproductive age during the breeding season of a stock.

Comment: Most often used as a proxy for measuring egg production, the SSB depends on the abundance of the various age classes composing the stock and their past exploitation pattern, rate of growth, fishing and natural mortality rates, onset of sexual maturity, and environmental conditions.

**Spawning Stock Biomass****
The total weight of mature fish (often females) in a stock.

**Spawning Stock Biomass per Recruit (SSB/R or SBR)***
The expected lifetime contribution to the spawning stock biomass for the average recruit, SSB/R is calculated assuming that fishing mortality is constant over the life span of a year class. The calculated value is also dependent on the exploitation pattern and rates of growth and natural mortality, all of which are also assumed to be constant.

**Standing Stock***
1. The total weight of a group (or stock) of living organisms (e.g. fish, plankton) or of some defined fraction of it (e.g. spawners), in an area, at a particular time. Example: the spawning biomass of the cod stock on the Georges Bank in 1999;
2. The weight of a fish stock or of some defined portion of it. (see *Abundance*)

**Stock***
A part of a fish population usually with a particular migration pattern, specific spawning grounds, and subject to a distinct fishery. A fish stock may be treated as a total or a spawning stock. Total stock refers to both juveniles and adults, either in numbers or by weight, while spawning stock refers to the numbers or weight of individuals that are old enough to reproduce.

Comment: In theory, a unit stock is composed of all the individual fish in an area that are part of the same reproductive process. It is self-contained, with no emigration or immigration of individuals from or to the stock. On practical grounds, however, a fraction of the unit stock is considered a "stock" for management purposes (or a management unit), as long as the results of the assessments and management remain close enough to what they would be on the unit stock.

**Stock-Recruitment Relationship (SRR)***
The relationship between the level of parental biomass (e.g. spawning stock size) and subsequent recruitment level. Determination of this relationship is useful to analyze the sustainability of alternative harvesting regimes and the level of fishing beyond which stock collapse is likely. The relation is usually blurred by environmental variability and difficult to determine with any accuracy.

Comment: Such a relationship always exists in principle, in that the existence of a parent stock is a prerequisite for the generation of recruitment. However, in many cases there exist regulatory mechanisms such that the number of recruits is not strongly related to the parent stock size over the range of stock sizes observed: this situation is sometimes described as the absence of a stock recruitment relationship, but is more logically described as a special case of a stock-recruitment relationship. Some stock assessment methods incorporate the estimation of such a relationship directly into the model, either explicitly (e.g. some age-structured assessments) or implicitly (most stock production models).

**Stock Status****
The agreed perspective of the SASC of the relative level of fish abundance.

**Sub-adult****
Juvenile American shad which are part of the ocean migratory mixed stock fish.

**Surplus Production***
1. The amount of biomass produced by the stock (through growth and recruitment) over and above that which is required to maintain the total stock biomass at a constant level between consecutive time periods;
2. Production of new biomass by a fishable stock, plus recruits added to it, less what is removed by natural mortality. This is usually estimated as the catch in a given year plus the increase in

stock size (or less the decrease). Also called: natural increase, sustainable yield, and equilibrium catch.

**Survival Rate***
Number of fish alive after a specified time interval, divided by the initial number. Usually on a yearly basis.

**Survival Ratio***
1. Ratio of recruits to spawners (or parental biomass) in a stock-recruitment analysis. Changes in survival ratios indicate that the productivity of a stock is changing;
2. Number of fish alive after a specified time interval, divided by the initial number. Usually calculated on a yearly basis.

**Sustainability***
1. Ability to persist in the long-term. Often used as "short hand" for sustainable development;
2. Characteristic of resources that are managed so that the natural capital stock is non-declining through time, while production opportunities are maintained for the future.

**Sustainable Catch (Yield)***
The number (weight) of fish in a stock that can be taken by fishing without reducing the stock biomass from year to year, assuming that environmental conditions remain the same.

**Sustainable Fishery**
Systems that demonstrate their stocks could support a commercial and/or recreational fishery that will not diminish potential future stock reproduction and recruitment.

**Sustainable Fishing***
Fishing activities that do not cause or lead to undesirable changes in the biological and economic productivity, biological diversity, or ecosystem structure and functioning from one human generation to the next.
Comment: Fishing is sustainable when it can be conducted over the long-term at an acceptable level of biological and economic productivity without leading to ecological changes that foreclose options for future generations.

**Sustainable Yield***
1. Equilibrium yield;
2. The amount of biomass or the number of units that can be harvested currently in a fishery without compromising the ability of the population/ecosystem to regenerate itself.

**Target Reference Point (TRP)***
1. Benchmarks used to guide management objectives for achieving a desirable outcome (e.g. optimum yield, OY). Target reference points should not be exceeded on average;
2. Corresponds to a state of a fishery or a resource that is considered desirable. Management action, whether during a fishery development or a stock rebuilding process, should aim at bringing the fishery system to this level and maintaining it there. In most cases a TRP will be

expressed in a desired level of output for the fishery (e.g. in terms of catch) or of fishing effort or capacity, and will be reflected as an explicit management objective for the fishery.

**Target Species***
Those species primarily sought by the fishermen in a particular fishery. The subject of directed fishing effort in a fishery. There may be primary as well as secondary target species.

**Thresholds***
1. Levels of environmental indicators beyond which a system undergoes significant changes; points at which stimuli provoke significant response;
2. A point or level at which new properties emerge in an ecological, economic, or other system, invalidating predictions based on mathematical relationships that apply at lower levels. For example, species diversity of a landscape may decline steadily with increasing habitat degradation to a certain point, and then fall sharply after a critical threshold of degradation is reached. Human behavior, especially at group levels, sometimes exhibits threshold effects. Thresholds at which irreversible changes occur are especially of concern to decision-makers.

**Total Mortality (Z)***
1. A measurement of the rate of removal of fish from a population by both fishing and natural causes. Total mortality can be reported as either annual or instantaneous. Annual mortality is the percentage of fish dying in 1 year. Instantaneous mortality is that percentage of fish dying at any one time;
2. The sum of natural (M) and fishing (F) mortality rates.

**Turbine Mortality****
American shad mortalities that are caused by fish passing through the turbines of hydroelectric dams during return migrations to the sea.

**Unit Stock***
A population of fish grouped together for assessment purposes, which may or may not include all the fish in a stock. (see *Stock*)

**Variable***
Anything changeable. A quantity that varies or may vary. Part of a mathematical expression that may assume any value.

**Virgin Biomass ($B_0$)***
The average biomass of a stock that has yet not been fished (in an equilibrium sense). Biomass of an unexploited (or quasi unexploited) stock. Rarely measured. Most often inferred from stock modeling. Used as a reference value to assist the relative health of a stock, monitoring changes in the ratio between current and virgin biomass ($B/B_0$). It is usually assumed that, in absence of better data, $B = 0.30\ B_0$ is a limit below which a stock should not be driven.

Comment: Virgin Biomass corresponds to a stock's theoretical carrying capacity.

**Vulnerability***
A term equivalent to catchability (*q*) but usually applied to separate parts of a stock, for example those of a particular size, or those living in a particular part of the range.

**Water Quality***
The chemical, physical, and biological characteristics of water in respect to its suitability for a particular purpose.

**Water Quality Criteria***
Specific levels of water quality desired for identified uses, including drinking, recreation, farming, fish production, propagation of other aquatic life, and agricultural and industrial processes.

**Watershed***
The areas which supplies water by surface and subsurface flow from rain to a given point in the drainage system.

**Year Class***
Fish in a stock born in the same year. For example, the 1987 year class of cod includes all cod born in 1987. This year class would be age 1 in 1988, age 2 in 1989, and so on. Occasionally, a stock produces a very small or very large year class that can be pivotal in determining stock abundance in later years. (see *Cohort*)

**Yield***
1. The yield curve is the relationship between the expected yield and the level of fishing mortality or (sometimes) fishing effort;
2. Catch in weight. Catch and yield are often used interchangeably. Amount of production per unit area over a given time. A measure of agricultural production.

**Yield per Recruit (Y/R or YPR)***
1. A model that estimates yield in terms of weight, but more often as a percentage of the maximum yield, for various combinations of natural mortality, fishing mortality, and time exposed to the fishery;
2. The average expected yield in weight from a single recruit. Y/R is calculated assuming that fishing mortality is constant over the life span of a year class. The calculated value is also dependent on the exploitation pattern, rate of growth, and natural mortality rate, all of which are assumed to be constant.

**Yield-per-Recruit Analysis***
Analysis of how growth, natural mortality, and fishing interact to determine the best size of animals at which to start fishing them, and the most appropriate level of fishing mortality. The yield-per-recruit models do not consider the possibility of changes in recruitment (and reproductive capacity) due to change in stock size. They also do not deal with environmental impacts.

**Young-of-Year**
(see Age 0)

**Z**
(see Total Mortality)