

## **Chapter 5**

### BLUEBACK HERRING

*(Alosa aestivalis)*

## **Section I. Blueback Herring Description of Habitat**

### **Blueback Herring General Habitat Description and Introduction**

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. 1991), 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. 1991).

## Part A. Blueback Herring 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 (Massman 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 redirection 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 redirection 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 redirection canal itself in favor of their former habitat, which was further upstream (Eversole et al. 1994).

### *Temporal spawning patterns*

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, personal communication); 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. 1991). 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. 1991). 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 associations***

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 associations***

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. 1991) 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 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 main-stream 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. 1991). 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<sup>3</sup>/s to 295 m<sup>3</sup>/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 (Cooke and Leach 2003). Although the importance of instream 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 may be an important consideration for restoring alosine habitat.

### ***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. 1991), Boger (2002) suggested a suitable range of pH 6 to 8, and an optimal range of pH 6.5 to 8 for spawning habitat.

### ***Spawning feeding behavior***

Adult blueback herring feed during upstream spawning migrations (Rulifson et al. 1982; Frankenstein 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).

### ***Spawning 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 was much lower than that of adults (Savoy and Crecco 2004).

## **Part B. Blueback Herring 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).

### ***Eggs, larvae, and the saltwater interface***

Although spawning often occurs in freshwater, blueback herring eggs and larvae can survive in salinities as high as 18 to 22 ppt (Johnston and Cheverie 1988). Klauda et al. (1991) suggest an optimal range of 0 to 2 ppt for eggs only.

### ***Egg and larval substrate associations***

As with spawning habitat, Pardue (1983) suggested that substrates with 75% silt or other soft materials containing detritus and vegetation were optimal for egg and larval habitat. In contrast, Johnston and Cheverie (1988) found eggs adhered to sticks, stones, gravel, and aquatic vegetation along the bottom of a fast-flowing stream in the Gulf of St. Lawrence.

### ***Egg and larval depth associations***

Both Wang and Kernehan (1979) and Meador et al. (1984) observed that larval blueback herring achieved the greatest density at the surface during the night. This pattern of diel periodicity has also been described for the juvenile life stage of blueback herring (Loesch and Lund 1977; Loesch et al. 1982; Johnson et al. 1978).

### ***Egg and larval water temperature***

Blueback herring eggs were collected in the upper Chesapeake Bay where temperatures ranged from 7 to 14°C; 90% were collected at 14°C (Dovel 1971). Researchers did not report a significant reduction in hatching success for eggs acclimated at 15 to 18.3°C and exposed to temperatures of 22 to 28.3°C for 5 to 30 minutes in the laboratory (Schubel 1974), as well as those acclimated at 17.9 to 21.1°C and then exposed to 31.1°C for 30 minutes (Schubel and Koo 1976). Eggs acclimated at 32.9 to 36.1°C for 5 to 15 minutes experienced significant mortality, with total egg mortality occurring at 37.9°C. In their review of the literature, Klauda et al. (1991) concluded that suitable and optimal temperature ranges for eggs were 14 to 26°C and 20 to 24°C, respectively.

Blueback herring egg incubation is complete after 80 to 94 hours at 20 to 21°C (Kuntz and Radcliffe 1917; Jones et al. 1978) and 55 to 58 hours at 22.2 to 23.7°C (Cianci 1969; Klauda

et al. 1991). Following incubation, blueback herring eggs typically require 38 to 60 hours for hatching (Adams and Street 1969; Cianci 1969; Morgan and Prince 1976).

Larval blueback herring have been collected in the upper Chesapeake Bay where water temperatures ranged from 13 to 28°C; 96% were collected at 23 to 28°C (Dovel 1971). Blueback herring eggs and larvae collected from the Washademoak River, New Brunswick, were acclimated at 19°C, and then exposed to 29 and 34°C for 1 to 3 hours in the laboratory. While egg mortality and hatchability were deemed poor indicators of the effects of temperatures, larval deformity was considered a good indicator. Deformity rates over the three hour period were 0 to 25% at 29°C, and 100% at 34°C; such deformities were permanent and would have been lethal in the natural environment (Koo and Johnston 1978). In their review of the literature, Klauda et al. (1991) concluded that suitable temperature ranges for prolarvae and postlarvae were 14 to 26°C and 14 to 28°C, respectively.

### ***Egg and larval dissolved oxygen associations***

Larvae require a minimum of 5.0 mg/L of dissolved oxygen for survival (Jones et al. 1978).

### ***Egg and larval pH and aluminum associations***

Klauda (1989) conducted laboratory research on blueback herring fertilized eggs and yolk-sac larvae, and suggested that critical acidity conditions (defined as laboratory and field test exposures associated with greater than 50% direct mortality) for successful blueback herring reproduction in Maryland coastal plain streams occur during a single 8 to 96 hour pulse of acid (pH 5.5 to 6.2), with concomitant total monomeric aluminum concentrations of 15 to 137 µg/L. Eggs that were subjected to four treatments ranging from pH 5.7 to 7.5 and five aluminum treatments of 0 to 400 µg/L at a continuous exposure time between 96 and 120 h revealed the following results: 4-hour old embryos were sensitive to aluminum in the test treatments of pH 5.7 to 6.7; 12-hour old embryos were most sensitive to pH 5.7 with no aluminum present; and 24-hour old embryos suffered no mortality at all pH and aluminum levels (Klauda and Palmer 1987a).

Laboratory tests by Klauda et al. (1987) found a pH-induced mortality threshold for yolk-sac larvae of pH 5.7 to 6.5, and a 96-hour LC<sub>50</sub> pH of 6.37 (pH that induced 50% mortality); no aluminum was administered. Additional tests by Klauda and Palmer (1987b) found that as the exposure time was doubled (12 to 24 hours), mortality rates increased among yolk-sac larvae (25 to 49%) at a pH value of 5.5. When coupled with a concomitant exposure of total aluminum maxima of 100 to 150 µg/L, mortality increased to 19, 66, 98, and 100% after 4, 8, 12, and 24 hours exposure, respectively. Tests also revealed highly variable mortality rates (3 to 75%) for yolk-sac larvae at a pH of 6.7. In general, the data indicated that blueback herring larvae were more sensitive to lower pH values (5.7 and 6.2) with no aluminum added, and were more tolerant of higher pH values (6.7 and 7.5) (Klauda and Palmer 1987b). Furthermore, yolk-sac larvae were more sensitive than 4-hour old embryos to pH and aluminum treatments (Klauda and Palmer 1987a). Klauda et al. (1991) suggested overall suitable ranges for eggs and prolarvae of 5.7 to 8.5 and 6.2 to 8.5, respectively; optimal ranges were suggested to be 6.0 to 8.0 and 6.5 to 8.0, respectively.

Median pH values (6.27) where blueback herring were spawning in the Rappahannock River, Virginia, reported by O'Connell and Angermeier (1997) were within the lethal range (5.7 to 6.5) and below a 96-h LC<sub>50</sub> of 6.37 for larvae. Reduced pH levels may represent episodic events, such as acid precipitation, but additional study is required to determine what the effects of occasional pH depressions might be.

### ***Egg and larval 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 may be a forcing mechanism on another abiotic factor, perhaps turbidity, which directly affects larval growth and survival (Dixon 1996).

### ***Egg and larval suspended solid associations***

As with alewife, blueback herring eggs have proven extremely tolerant to suspended solids, with no significant reduction in hatching success at concentrations up to 1000 mg/L (Auld and Schubel 1972). Schubel and Wang (1973) demonstrated that high levels of suspended solids during and after spawning significantly increase the rate of egg infections from naturally occurring fungi in alewife, which cause delayed mortalities; it may be likely that the same effects would be observed in blueback herring eggs (Klauda et al. 1991). Two *in situ* studies (Klauda and Palmer 1987b; Greening et al. 1989) note that yolk-sac larvae appear to be more sensitive to suspended solids than eggs, but given that observations were made following storm events, which also resulted in changes to pH and current velocity, the effects of turbidity alone were inconclusive. Klauda et al. (1991) later noted a suitable concentration range of less than 500 mg/L for the prolarva life stage.

***Egg and larval feeding behavior***

First-feeding larvae in the Connecticut River primarily consumed rotifers; they shift to cladocerans as they grow larger (Crecco and Blake 1983). In general, it has been suggested that clupeids have evolved to synchronize the larval stage with the optimal phase of annual plankton production cycles (Blaxter et al. 1982).

***Egg and larval 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. 1991). 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 1976a; Loesch and Kriete 1980).

***Eggs, larvae, and chlorine***

Morgan and Prince (1977) reported an 80 h LC<sub>50</sub> of 0.33 mg/L total residual chlorine (TRC) for blueback herring eggs incubated at 20.9°C in freshwater. The LC<sub>50</sub> for 1-day old larvae exposed to TRC for 48 and 54 h ranged from 0.24 to 0.32 mg/L; LC<sub>50</sub> for 2-day old larvae was between 0.25 and 0.32 mg/L (Morgan and Prince 1977). TRC concentrations that were greater than or equal to 0.30 mg/L increased the percentage of abnormally developed larvae (Morgan and Prince 1978).

## Part C. Blueback Herring 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. 1991), with growth occurring very rapidly (Colette and Klein-MacPhee 2002).

Massman (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, personal communication) 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 (1969), 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 overwinter 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 overwintering 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 overwinter 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. (1991) 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 substrate associations***

Juvenile blueback herring have been found among submerged aquatic vegetation (SAV) beds of the lower Chesapeake Bay, and researchers have suggested that juveniles may benefit from reduced predation in such areas (Olney and Boehlert 1988). It is important to note, however, that no link has been made between the presence of SAV and abundance of alosines. Rather, SAV is known to improve the water quality, which may increase the abundance of alosines (B. Sadzinski, Maryland Department of Natural Resources, personal communication). Moreover, juvenile blueback herring are a pelagic schooling fish that likely do not rely on SAV

to the extent of other anadromous fishes, such as striped bass (D. A. Dixon, Electric Power Research Institute, personal communication).

### *Juvenile depth associations*

Unlike alewife, juvenile blueback herring in the Potomac River remained at the surface or at mid-water depths during daylight hours from July through November, with almost no fish appearing at the bottom. However, at night over half of juvenile blueback herring captured were taken in bottom trawls (Warinner et al. 1970). Burbidge (1974) also reported that juvenile blueback herring were more abundant in surface waters of the James River, Virginia, during the day. Contrary to these results, Jessop (1990) found that abundance of juvenile bluebacks was greater in surface waters at night than during the day, but fish did not exhibit a strict negative phototropism. One explanation for these observed differences is the minimal sewage treatment that was required during the 1970's, which led to major phytoplankton and algal blooms in freshwater areas, reducing light penetration. Since that time, water clarity has greatly improved (Dennison et al. 1993).

In an additional study, Dixon (1996) found that juvenile blueback herring were more available to surface sampling gear approximately 30 minutes after sunset and before sunrise, where there was a corresponding light intensity of  $10^{-2}$  to  $10^{-3}$   $\mu\text{E}/\text{m}^2/\text{s}$ . Because he did not detect a corresponding change in availability of primary zooplankton prey, he concluded that juveniles migrate to the surface water within a specific isolume with changes in incident light intensity, not as a response to prey movement. A light intensity of  $10^{-2}$  to  $10^{-3}$   $\mu\text{E}/\text{m}^2/\text{s}$  may be a threshold that controls retinomotor responses to support selective feeding and schooling behavior in this species. Dixon (1996) concluded that juveniles find a depth and isolume that optimizes schooling (for predation protection) and selective feeding during the day, balancing predation risks versus preferred food availability. These results further support and refine the observations of Loesch et al. (1982), who first reported the diel changes in movement of juveniles.

### *Juvenile water temperature*

Characterization	Temperature Range (°C)	Acclimation Temperature (°C)	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. 1991
Optimal	20 – 30			Many	Pardue 1983
Selection	20 – 22	15 – 20	4 – 6	Delaware River,	Meldrim and

Characterization	Temperature Range (°C)	Acclimation Temperature (°C)	Salinity (ppt)	Location	Citation
				NJ	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 to 6 minutes	19		Laboratory	Marcy and Jacobson 1976
100% Mortality	32 – 33 for 4 to 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

Table 5-1. Juvenile blueback herring water temperature associations

Juvenile blueback herring have a wide range of temperature tolerances (Table 5-1). 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 overwintering 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.

#### ***Juvenile dissolved oxygen associations***

Juvenile blueback herring have been collected in waters of the Cape Fear River, North Carolina, where dissolved oxygen concentrations ranged from 2.4 to 10.0 mg/L (Davis and Cheek 1966). In the laboratory, juveniles that were exposed to dissolved oxygen concentrations of 2.0 to 3.0 mg/L for 16 hours experienced a 33% mortality rate. Researchers determined that the juveniles were unable to detect and avoid waters with low dissolved oxygen (Dorfman and

Westman 1970). As a result, mass mortalities of juveniles resulted from low dissolved oxygen in the Connecticut River over several years during June and July, most notably in the early morning hours when dissolved oxygen was below 3.6 mg/L and temperature was 27.6°C (Moss et al. 1976). In addition, Klauda et al. (1991) concluded that juveniles require a minimum of 4.0 mg/L of dissolved oxygen.

### ***Juvenile pH and aluminum associations***

In the Cape Fear River, North Carolina, juvenile blueback herring were collected where pH was between 5.2 and 6.8 (Davis and Cheek 1966), but the length of time spent within these areas was unknown. In contrast, Kosa and Mather (2001) found that abundance of juvenile river herring peaked at a pH of 8.2 in coastal systems in Massachusetts. Researchers speculated that between 7.2 and 8.2, increases in river herring abundance may be related to changes in system productivity. Although researchers were unable to determine the exact mechanism for the impact of pH on river herring, they suggested that pH does appear to contribute to variations in juvenile abundance (Kosa and Mather 2001).

### ***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 behavior***

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***

Young-of-the-year blueback herring are preyed upon by many freshwater and marine fishes, birds, amphibians, reptiles, and mammals. 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 interspecific 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 intraspecific competition may be greater than interspecific 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 interspecific 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).

### ***Juveniles and alkalinity, carbon dioxide, and chlorine***

Davis and Cheek (1966) captured juvenile blueback herring in the Cape Fear River, North Carolina, where the alkalinity ranged from 5 to 32 mg/L. This same study also found that juveniles selected areas where free carbon dioxide concentrations were between 4 and 22 ppm (Davis and Cheek 1966). Another study found that juvenile blueback herring held in freshwater avoided 0.1 mg/L total residual chlorine (TRC) at 17.5°C (PSE&G 1978).

## **Part D. Blueback Herring Late Stage Juvenile and Adult Marine Habitat**

### *Geographical and temporal patterns at sea*

Juvenile river herring have been found overwintering 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 overwintering 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. 1991). 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 overwintering 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 overwinter 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 overwintering 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. 1991). 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 overwinter 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 averse 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 ( $\geq 93$  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 behavior 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.

**Section II. Significant Environmental, Temporal, and Spatial Factors Affecting Distribution of Blueback Herring**

Table 5-2. 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 subadult–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)
<b>Spawning Adult</b>	December (Florida) through late August (Nova Scotia) in Atlantic coast rivers from St. Johns River, FL to Nova Scotia <b>Sympatric range:</b> Freshwater or brackish water above the head of the tide in fast-moving waters, also brackish ponds <b>Allopatric range:</b> Slower-flowing tributaries and flooded low-lying areas adjacent to main streams	<b>Tolerable:</b> NIF <b>Optimal:</b> NIF <b>Reported:</b> Variable	<b>Tolerable:</b> 13-27 <b>Optimal:</b> 20-25 <b>Reported:</b> Variable	<b>Tolerable:</b> 0-6 <b>Optimal:</b> <1 <b>Reported:</b> Generally freshwater	<b>Tolerable:</b> NIF <b>Optimal:</b> NIF <b>Reported:</b> Sympatric: gravel, sand; Allopatric: Variable	<b>Tolerable:</b> NIF <b>Optimal:</b> NIF <b>Reported:</b> Fast flow	<b>Tolerable:</b> NIF <b>Optimal:</b> NIF <b>Reported:</b> Minimum 5
<b>Egg</b>	December to August (south to north progression) at spawning site or slightly downstream of spawning site	<b>Tolerable:</b> NIF <b>Optimal:</b> NIF <b>Reported:</b> Usually found at bottom	<b>Tolerable:</b> 7-14 <b>Optimal:</b> NIF <b>Reported:</b> Variable	<b>Tolerable:</b> 0-22 <b>Optimal:</b> 0-2 <b>Reported:</b> Usually freshwater	<b>Tolerable:</b> NIF <b>Optimal:</b> NIF <b>Reported:</b> Variable	<b>Tolerable:</b> NIF <b>Optimal:</b> NIF <b>Reported:</b> NIF	<b>Tolerable:</b> NIF <b>Optimal:</b> NIF <b>Reported:</b> Minimum 5
<b>Larvae</b>	38-60 hours after fertilization downstream of spawning site	<b>Tolerable:</b> NIF <b>Optimal:</b> NIF <b>Reported:</b> Diel movement	<b>Tolerable:</b> 13-28 <b>Optimal:</b> NIF <b>Reported:</b> Variable	<b>Tolerable:</b> 0-22 <b>Optimal:</b> NIF <b>Reported:</b> Usually freshwater	<b>Tolerable:</b> NIF <b>Optimal:</b> NIF <b>Reported:</b> Variable	<b>Tolerable:</b> NIF <b>Optimal:</b> NIF <b>Reported:</b> NIF	<b>Tolerable:</b> $\geq 5$ <b>Optimal:</b> NIF <b>Reported:</b> Minimum 5

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

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