**Understanding the Feeding Dynamics of Juvenile River Herring**

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**Abstract**

The purpose of this study was to further understand the early life history dynamics of river herring, collectively referring to the two species alewife (*Alosa pseudoharengus*) and blueback herring (*Alosa aestivalis)*. It was hypothesized that zooplankton population would crash midway through the season, and that this fall in population would coincide with a fall in the growth rates of river herring. It was also hypothesized that the two species of river herring would have essentially the same isotopic signatures, and that they would move slightly towards the littoral zone after the zooplankton population crashed. In recent decades, once-abundant populations of river herring have been decreasing drastically, approaching 1% of historic levels. This decline is thought to have been caused by a wide range of human factors, but countermeasures as of yet have not been successful in bringing about a rebound in the river herring population. A more thorough understanding of the species, particularly their early life stages, is needed to develop more effective conservation efforts. Juvenile river herring specimens from the 2015-2016 season in Great Herring Pond were examined for this project. Otoliths were analyzed to find birthdates, tissue samples underwent stable isotope analysis, and water samples were analyzed for zooplankton counts. A wide amount of information was gathered on the early life history of river herring, including the relationship of temperature and zooplankton population with river herring growth rates, and early life differences between alewives and blueback herring. With this information, we are able to piece together a more comprehensive picture of the early life of river herring, and to head towards more effective conservation efforts.

**Background**

The population of river herring has been declining drastically for years, for reasons that are not completely understood (ASMFC, 2009). The term “river herring” itself does not refer to a specific species, but rather two species- alewife (*Alosa pseudoharengus*) and blueback herring (*Alosa aestivalis*). The two species are quite similar in most respects, but do have significant differences. The ranges are different, for example; Alewife spawn from northeastern Labrador to around South Carolina and are most common in the Mid-Atlantic and Northeast regions, while Blueback herring range from Nova Scotia to Florida, but are most common south of the Chesapeake Bay. The two species mix in the same habitats, particularly when it is time to spawn. Both species are anadromous, traveling inland to freshwater rivers, lakes, and tributaries to spawn (Haas-Castro, 2006, Internet).

Alewives have a silvery color, with the tops of their bodies being grayish-green. Their lower jaws extend past their upper ones when their mouths are closed, and they have no teeth on the roofs of their mouth. They have faint dark lines going along their body, dusky spots behind their gill flaps, and small scutes along the midline of their stomach. They can grow to be about 15 inches long, but adults average at around 10-11 inches long (Bigelow and Schroeder, 1953).

Blueback herring look almost identical to alewives, but a careful observer can often notice slight differences. Their backs are more of a blue-green, as opposed to alewives’ grayish-green, but this difference is only apparent in freshly caught fish. Blueback herring’s eyes are about as broad as the distance from the eye to the tip of the snout, while alewives’ eyes are generally longer than this distance (Klauda, et al., 1991). The body length of a blueback is around 3.5 times as long as its body depth, while the body length of an alewife is around 3.3 times as long as its body depth. Under a microscope, the scale morphology of the two species is somewhat different (Bigelow and Schroeder, 1953). All of these mentioned differences are very slight; the surest way of telling the two species apart is to look at their peritoneal lining. Bluebacks have a dark blue to black lining, and alewives have a light, grayish to whitish, speckled lining. Beyond physical differences, the ranges of the two species is slightly different, as was mentioned, and alewives tend to live deeper in the water column (Klauda, et al., 1991).

Both species of river herring live offshore for most of their lives, but as anadromous fish, they come inland to spawn in freshwater. Both species typically begin to swim upstream towards freshwater in the spring, but bluebacks begin later in the season when it is warmer. The decision to move inland is temperature dependent, so the exact time depends on latitude. Alewives in the southern end of their range will start to spawn in late February, while those in the northern end will spawn in late April to early June. Far southern bluebacks will begin to spawn in December or January, while in the far north they will start in June and continue as late as August (Klauda, et al., 1991). Alewives spawn at in water temperatures of 55-60 °F, and bluebacks do so in temperatures of 70-75 °F (Bigelow and Schroeder, 1953). River herring often choose to return to the area in which they were born, but they have been known to go up new streams as well (Loesch, 1987). Alewives swim to relatively calm spots such as ponds, stagnant areas of streams, or behind barrier beaches, although they can use a variety of habitats and substrates. Bluebacks sometimes go to brackish water, and they spawn in more quickly moving water, so they aren’t often in direct competition with alewives (Department of Marine Resources, 2012, Internet). Interestingly, in areas where alewives are uncommon, bluebacks are less selective about their spawning grounds and will go for a wider variety of areas. One female herring can lay 60,000 to over 100,000 eggs at a time, although only a small fraction survive (Klauda, et al., 1991). Spawning lasts just a few days, and the earliest arrivals often start heading back downstream while others are still on their way up (Bigelow and Schroeder, 1953). Spawning activity occurs all throughout the day, but there is more of it at night. It has been observed in alewives that older and bigger fish spawn first, with younger and smaller ones spawning later (Klauda, et al., 1991).

After hatching, river herring will stay in their nursery areas through their larval stage. Juveniles often stay in the area through the spring and early summer and swim upstream to avoid incoming salt water. As water temperatures decline, they begin to migrate toward the sea. Alewives typically begin to migrate earlier than bluebacks, and juvenile alewives have been found in some instances to grow more quickly. It has been observed that juvenile alewives swim deeper than juvenile bluebacks, which would reduce competition between the two species (Klauda, et al., 1991).

As adults, most river herring reach sexual maturity at age 3-5 and will return to their natal stream or pond to spawn (ASMFC, 2009). Different areas have different amounts of repeat spawners, but in general, 30-40% of alewife spawning runs are made up of them (Klauda, et al., 1991). Some individuals make seven or eight runs in their lifetime (ASMFC, 2009). It has been found that longevity and the percentage of repeat spawners for alewives is higher in the north than in the south. There have been findings that contradict this, however (Klauda, et al., 1991).

The diet of juvenile herring consists largely of different types of zooplankton. The amount of zooplankton available is incredibly important for juvenile survival; competition for zooplankton is a strong limiting factor of juvenile abundance. They can go after prey individually or filter-feed less selectively. Juvenile herring also eat insects, ostracods, oligochaete worms, and chironomid larvae. When they get to be around 12 inches long, they switch from eating mostly zooplankton to eating more benthic amphipods, and this change in diet might contribute to the decision to migrate towards the ocean. As adults at sea, river herring still eat zooplankton and amphipods, as well as decapod larvae, salps, eel, fish larvae, and other organisms. (ASMFC, 2009 and NOAA, 2009). Invasive species are reducing the amount of food available, however. For example, zebra mussels in the Hudson River have lessened the amount of food for juvenile alewives (Waldman and Limberg, 2003).

Despite eating generally the same sorts of prey, alewives and bluebacks have methods of avoiding too much direct competition. In Minas Basin, Nova Scotia, it was found that juvenile alewives preferred larger benthic prey, as they went after specific prey, and juvenile bluebacks ate smaller prey, as they filter-fed (Stone, 1985). One study in North Carolina found that juvenile alewives ate more of different types of prey than bluebacks (Davis and Cheek, 1966). The peak feeding times of juveniles of the two species are different (Burbidge, 1974 and Weaver, 1975). The fact that alewives spawn earlier mean that juvenile alewives will be larger than their blueback counterparts, and therefore have a wider selection of food available (Jessop, 1990).

River herring themselves serve as prey for a large variety of organisms. They are eaten by turtles, snakes, birds, mink, American eel, and many kinds of fish, including largemouth bass and dogfish (ASMFC, 2009).

River herring, as well as all other types of fish except for sharks, rays, and lampreys, have structures in their heads called otoliths. Each fish has three pairs of otoliths. They have the sagittae, which are the large pair, and they have the lapilli and asteriscii, the smaller pairs. The sagittae are the most well studied and most used to determine information about a fish. The otoliths are made primarily of calcium carbonate, with other proteins and trace metals, and they take different shapes and sizes depending on the species (Online Otolith Lab, Internet). One of otoliths’ primary functions is to help fish hear. The otoliths are in the inner ear, inside the skull and behind the rain, with hair cells around them. They are much denser than the rest of the fish’s body and the water, which causes them to move more slowly when hit by a sound wave. The difference in the otolith’s movement compared to the movement of the rest of the body causes the otolith to bend or move the cilia on the nearby hair cells, and this stimulation is interpreted as sound in the brain (How do Fish Hear?, 2015, Internet). Otoliths also help the fish with balance in a somewhat similar fashion. Movement of the otolith against the hair cells helps the fish to balance and to be aware of its orientation (Trivedi, 2002, Internet).

Otoliths aren’t just useful for the fish, however: they can give researchers quite a bit of information. Otoliths grow as the fish grows, and they will never get smaller. Crystallized calcium carbonate (in the form of aragonite) and matrix protein are deposited onto the otolith in rings, making alternating translucent and opaque sections. The matrix protein is primarily otolin, which is similar to collagen (Beatriz, 1992). Otolin takes the shape of fibers with 8nm diameters. The fibers are densely packed together to make the matrix sheet-like. The matrix forms thin, opaque bands, while the calcium carbonate forms thicker, translucent ones. The rings can be counted to figure out how old a fish is in days or years, similarly to how tree rings can be used to determine the age of a tree (Campana and Nielson, 1985). Since the rings correspond with the fish’s growth, the distance between rings can be used to determine how much a fish grew on a certain day (Llopiz, pers. comm., January 20, 2015). Otoliths might also show geochemical signals that can tell us a fish’s migration pathways (Trivedi, 2002, Internet).

The exact reasons for how and why otoliths have rings once each day, as well as matrix formation, are not completely understood. Photoperiod is thought to have an effect on the diel cycle of ring creation, with one ring for each day-night cycle. Temperature fluctuations and feeding periodicity might also have an effect on the deposition of new rings. It has been theorized that ring formation is caused by an endogenous circadian rhythm driven by the endocrine system. This circadian rhythm could be entrained at a very young by the photoperiod (Campana and Nielson, 1985). Another reason could be that the difference in feeding activity during the day as opposed to the night. The thicker section of the ring could be from during the day, when the fish eat, and during the night, when the fish are not eating as much, the matrix is added to form the darker sections (Llopiz, pers. comm., January 20, 2015).

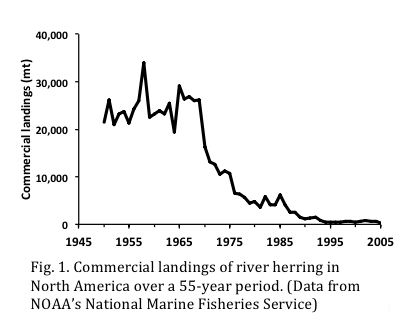
In addition to otoliths, another way to learn about a river herring specimen’s life history is through stable isotope analysis. In the environment, the majority of elements naturally occur in the forms of several different isotopes. Some of the most useful isotopes for studying ecology are those of carbon and nitrogen. Carbon is most commonly found in the form of carbon 12, with about 99 percent of naturally occurring carbon taking this form (Meier-Augenstein and Kemp, 2012). However, carbon 13 and carbon 14 also occur. Carbon 14 is radioactive, but carbon 13 is stable, meaning it can be used in stable isotope analysis to uncover ecological information. Photosynthesis can have a variety of metabolic pathways in different organisms, which causes different photosynthetic organisms to have different rations of carbon 13 to carbon 12 (this ratio is called δ13C). This, combined with differences in water turbulence, causes the primary producers of the littoral zone, such as algae, and of the pelagic zone, such as phytoplankton, to have notable different δ13C measurements (France, 1995).

Difference in δ13C are not only present in these primary producers; they last in the consumers of these organisms as well. This means that if a consumer largely eats the phytoplankton of a lake, it should have the same δ13C as those phytoplankton. As such, a δ13C reading of an organism can allow for its prey and feeding area to be determined. The tissue of the consumer is built of what it was eating at the time, but turnover rates for different tissues and between different species vary quite a bit, meaning it might take longer to notice a change in diet depending on where you look. For muscle tissue in river herring, a shift would take about a month to have its effect (Hayden, 2016).

Nitrogen isotopes are also useful for uncovering ecological information. The ratio of nitrogen 15 to nitrogen 14 (this ratio is called δ15N) in primary producers of an ecosystem depends greatly on the environment. δ15N values of consumers, similarly to their δ13C values, depend on what they eat. Unlike δ13C, however, δ15N values of consumers are not the same as in δ15N. With each increase in trophic level, there is an increase of 0.3%. This change is due to the fact that nitrogen 14 plays a bigger part in the breakdown of proteins, and it is excreted at a higher rate than nitrogen 15. With δ15N values, then, an organism’s relative position on the food chain can be determined (Schulz, 2006, Internet).

Stable isotope analysis is the actual process of finding out the ratios of different isotopes in a sample. This is done using a mass spectrometer. Samples are incinerated and ionized, typically being made into positive ions. The ions are then shot in a beam down a straight tube, with magnets at the curve of the tube that pull on the positively charged ions. Depending on each ion’s mass, it is pulled a different amount by the magnet, meaning its course is dependent on its mass. This allows different isotopes, which have different masses, to be sorted from each other, and the amounts of each type can then be counted.

Unfortunately for river herring and the environment as a whole, the two species of fish have been in a sharp decline in recent history. River herring populations have been estimated to be approaching 1% of historic sizes (Limburg and Waldman, 2009). From 1985 to 2007, commercial landings of river herring dropped from 13.7 million pounds to under one million, which is more than a 93% drop (ASMFC, 2009).



*Figure 16: Commercial Landings of River Herring in North America*

(Haas-Castro, 2006, Internet).

The precise reasons for such dramatic river herring population declines aren’t exactly understood, but there are a multitude of reasons likely contributing to the problem. One major cause has been the construction of dams and other structures that block spawning rivers, preventing mature river herring from making their way up. Another reason for lower populations is habitat degradation, largely from heavy industrial pollution that makes areas unsuitable for migration or spawning (Department of Marine Resources, 2012, Internet). Global warming has the potential to make more habitat unsuitable for river herring, further limiting their population (Lynch, et al., 2014). The river herring fishery has historically been very important, and river herring were overfished because of it. Offshore harvesting by distant water fleets likely contributed strongly to the population decline (Fogarty and Murawski, 1998). Even now, although the problem is known, they are frequently caught up as bycatch in the Atlantic Herring Fishery, making their problem even more critical (Cieri, et al., 2008). Yet another reason for river herring’s troubles is the resurgence of striped bass, which prey on them (Haas-Castro, 2006, Internet).

In light of the problem, measures have been taken to try to bring alewife populations back to historical levels. There have been efforts to give river herring ways around impediments such as dams through the use of fish ladders, and to clean up rivers to lessen the effects of pollution. There have also been attempts to move spawning adult river herring to certain locations to enhance the population there (“River Herring,” 1998, Internet). The states of Massachusetts, Rhode Island, Connecticut, North Carolina, and Virginia have implemented moratoria on the harvest of river herring to help preserve their population. The species have been listed as Species of Concern throughout their range by the National Marine Fisheries Service, as well (Haas-Castro, 2006, Internet). The National Marine Fisheries Service has also petitioned for the inclusion of river herring on the endangered species list and for the designation of critical habitat for the species (“Shad & River Herring,” 2014, Internet). All of these measures still do not seem to have fixed the problem, however. A 2012 stock assessment that examined 52 stocks of river herring found 23 stocks to be depleted, and one to be increasing, and 28 could not be adequately assessed (“Shad & River Herring,” 2014, Internet). It is worth noting that most of these measures act to protect adult river herring, while the most critical life history stages are typically considered to be the egg larval, and early juvenile stages (Klauda, et al., 1991).

The issue of river herring population decline is a very significant one, and the effects of it could be drastic. They have been called keystone species, as they are linked to the health of many other species, and their own health represents the overall state of their ecosystem. River herring inhabit a variety of different ecosystems throughout their lifecycle, and as a result, they are vital to the dynamics of freshwater, estuarine, and marine food chains. In fresh and brackish water, they are an important food source for American eel and striped bass, among other organisms. In the ocean, river herring are an important source of prey for many species, including sharks, tunas, and dolphins. Fish eating birds such as bald eagles and ospreys eat river herring, and might have even evolved their late winter and spring nesting strategies in response to river herring patterns (ASMFC, 2009). River herring help species in other ways, as well; they provide cover for migrating fish species, which would suffer from having fewer river herring around (Department of Marine Resources, 2012, Internet).

River herring likely provide significant amounts of nutrients and carbon into riverine systems, which aids the well-being of other organisms present. River herring carcasses can also greatly help aquatic food webs, as they stimulate productivity of bacteria and aquatic vegetation, which in turn stimulates the assimilation of important nutrients into aquatic invertebrates and fish (ASMFC, 2009). River herring could also incorporate phosphorus into their bodies to develop, thereby removing it from lakes and reducing the chance of algal blooms (Department of Marine Resources, 2012, Internet).

There are also historical and cultural reasons for trying to preserve river herring. The river herring fishery is one of the oldest industries in New England, dating back to colonial times, and has historically been a major part of coastal towns’ cultures and lifestyles. River herring and their migration are also important culturally to various native tribes in the United States and Canada. The herring are still important to many people today, and they are also used as bait to catch other species (Department of Marine Resources, 2012, Internet).

**Hypothesis**

It was hypothesized that zooplankton population would crash midway through the season, and that this fall in population would coincide with a fall in the growth rates of river herring. It was also hypothesized that the two species of river herring would have essentially the same isotopic signatures, and that they would move slightly towards the littoral zone after the zooplankton population crashed.

**Materials**

Materials used for this experiment include river herring specimens captured from Monument River, water samples from Great Herring Pond, , a Leica M60 microscope with a Leica KL300 LED, a Leica DM2500 microscope with a Leica MC120 HD camera, Leica Application Suite V4.3 running on an iMac with Bootcamp, deionized water, non-drying immersion oil Type B, digital calipers, a balance, pipettes, glass slides, plastic trays, metal probes and forceps, an X-Acto knife, sealable plastic bags, tin capsule, a freezer, and the mass spectrometer at the Marine Biological Laboratory.

**Methods**

In the months leading up to experimentation, water samples were taken from Great Herring Pond in Bournedale, Massachusetts, to later be used for zooplankton counts. The samples were taken with vertical tows by a 150 μm mesh net. The samples were then filtered through a 20 μm mesh net to remove phytoplankton. Also during the months, juvenile river herring were captured from the herring run of Monument River, which leads out of Great Herring Pond into the Cape Cod Canal. The specimens were captured by the Herring Run Motel as they made their way towards the ocean. The fish were sorted and according to when they were captured, and were kept frozen at -20 degrees Celsius.

Water samples from various dates ranging from May 8, 2015 to October 12, 2015 were analyzed. Samples were divided into manageable amounts and then examined under a microscope. Counts were taken of the four main types of zooplankton: Bosmina, Daphnia, Cyclopoids, and Calanoids. Counts were also taken of Harpacticoids, Holpedium, and other species.

Juvenile river herring caught on dates from June 25, 2015 through November 4, 2015 were also analyzed. Individual specimens from each designated date were chosen randomly. After being taken from the freezer, specimens were weighed, and their standard lengths and fork lengths were taken. After these measurements were completed, the fish’s stomach was cut open and its peritoneal lining was observed in order to identify the species of fish. Specimens with light colored peritoneal linings were classified as alewives, and specimens with dark peritoneal linings were classified as bluebacks.

Tissue was then cut off of each specimen’s back, from behind the dorsal fin. This tissue was dried for several days at 60 degrees Celsius, before being ground up into a powder using a mortar and pestle. Between 0.8 to 1.1 mg of each tissue sample was weighed out and then sent to the mass spectrometer at the Marine Biological Lab in order to determine the ratios of Carbon-12 to Carbon-13 and of Nitrogen-14 to Nitrogen-15. Additionally, otoliths were extracted from the specimens and analyzed under a microscope to find each specimen’s age.

**Results**

The results of this experiment provide an array of information on the early life of river herring. Table 1 shows information on each fish specimen, whether physical or isotopic. Table 2 shows the raw zooplankton population data that was gathered, and Table 3 shows the zooplankton data after adjustments were made to account for divisions of the water sample. Table 5 shows otolith measurements for each specimen. Table 5 shows carbon information for each species, and Table 6 shows nitrogen information for each species. Figure 1 compares individual specimens’ hatch dates to emigration dates, with a distinction being made between species. Figure 2 shows the average growth rates for fish of each species by the age of the fish. Figure 3 shows the same information as Figure 2, but solely for alewives. Figure 4 shows this information solely for blueback herring. Figure 5 shows individual growth rates over the course of the season. Figure 6 also shows individual growth rates over the course of the season, but makes a distinction between the two species. Figure 7 shows zooplankton population levels over the sampled period of the year, with Bosmina, Daphnia, Calanoids, and Cyclopoids shown individually. Figure 8 shows the makeup of the zooplankton population over time, displaying what percentage of the population is made up of each species. Figure 9 shows zooplankton population levels over time with individual river herring growth rates overlaid. Figure 10 shows water temperature of Great Herring Pond over time. Figure 11 shows water temperature over time with individual growth rates. Figure 12 shows individual growth rates of fish and what the water temperature was at the time of each growth rate. Figure 13 displays the average standard length of specimens on each sampled date of emigration, sorted by species Figure 14 shows average 𝛿13C values of alewives, blueback herring, mussels, and snails over time. Figure 15 shows average 𝛿15N values of alewives, blueback herring, mussels, and snails over time.

**Analysis**

The purpose of this study was to get a deeper understanding of the early life of river herring, or the two species of alewife (Alosa pseudoharengus) and blueback herring (Alosa aestivalis). Feeding habits in particular were examined. It was hypothesized that zooplankton population would crash midway through the season, and that this fall in population would coincide with a fall in the growth rates of river herring. It was also hypothesized that the two species of river herring would have essentially the same isotopic signatures, and that they would move slightly towards the littoral zone after the zooplankton population crashed. This hypothesis was mostly unsupported; the experiment presented a different picture of the early life dynamics of river herring.

It was found that alewives begin to hatch significantly earlier than blueback herring (see Figure 1), and these results are consistent with previous findings (Klauda, et al., 1991). The earliest hatchers were entirely alewife, with later hatchers being mixed. The early hatchers emigrated earlier, and later hatchers waited much longer. These results are also consistent with earlier research. The earlier hatchers were likely driven to emigrate earlier in the season due to increased competition once late hatchers arrived. Only early hatchers would potentially be mature enough to emigrate before temperatures dropped later in the season, and many of them did emigrate. Late hatchers likely needed more time to grow and did not have the choice to leave, even with high competition.

The growth rates of each species followed similar patterns, with both species growing the fastest at around 50-60 days old (see Figures 2, 3, and 4). Both have about the same growth rates in their very early life, but alewives grow more quickly than blueback herring from around day 10 through day 60. This increased growth for alewives is definitely an advantage, and it’s likely due to them hatching first. By the time blueback herring arrive and hatch, competition is high, making them unable to reach their full growth potential in their very early life. By the time blueback herring reach their juvenile stages, temperatures are warmer and competition is lower as other fish are leaving, allowing growth rates to rise to be equivalent with those of alewives.

Looking at growth rates over time of river herring specimens (see Figure 5), it appears that growth was at its highest around the beginning of July. Growth was low at the beginning of the season before increasing in June and then decreasing again by late July. Breaking it down by species (see Figure 6), there seem to be differences between the two species. Alewives hatch earlier, and their growth rates quickly rise. Even after blueback herring become prevalent, alewives generally maintain a higher growth rate. By late July, their growth rates are about the same on average. It seems, then, that hatching earlier is an advantage, but ultimately growth rates rise and fall as temperatures do.

The zooplankton population of Great Herring Pond was analyzed (see Figure 7) through water samples, giving an idea of the density of zooplankton in the pond throughout the season. The density of zooplankton rose a large amount from early May to mid-May, from about 55 individuals per liter to about 115 individuals per liter. The population declined after that before rising to around 130 individuals per liter around the end of May. The zooplankton population density sharply declined in June, reaching almost zero by July, and not rising significantly again. Such a dramatic drop suggests that it could have been caused by a good portion of the river herring population reaching the juvenile stage. Juveniles move much more quickly and eat much more, explaining the crash in the zooplankton population.

The composition of the zooplankton population also changed over time (see Figure 8). Towards the beginning of May, it was fairly diverse, with Bosmina, Daphnia, and Cyclopoids all making up a large percentage of the population. However, the percentage of Daphnia sharply decreased towards the end of May, and the percentage of Cyclopoids decreased in mid-June, as the percentage of Bosmina grew dramatically. By late June, the population was almost entirely made up of Bosmina. The population became much more evenly distributed once again as it crashed to very low numbers. Comparing river herring growth rates to zooplankton population levels (see Figure 9), there is no clear relationship. Growth rates increase as the zooplankton population increases, but growth rates do not crash alongside the zooplankton population. This indicates that high zooplankton populations are not essential to the growth of river herring; they can perhaps sustain themselves on low levels of zooplankton, or perhaps they switch to other sources of prey.

The water temperature of Great Herring Pond was recorded throughout the season (see Figure 10), and it was found that temperatures generally rose until mid-July, where they plateaued at around 26 degrees Celsius. Temperature then began to decline in early September. Comparing growth rates of river herring to temperature (see Figure 11), it again becomes clear that temperature and growth are highly linked, as growth rates increase and temperature increases and decrease as temperature decreases.

In fact, one key factor that was associated with growth of river herring was water temperature (see Figure 12). Higher temperatures seemed to foster higher growth rates in both species. Temperature did not outright determine growth and did not seem to control the minimum amount of growth, but it did seem to play a large role in setting the maximum for how fast fish could grow. Temperature acting as a limiting factor makes sense and is concurrent with previous findings. Higher temperatures allow for increases physiological processes and metabolic rates (Llopiz, pers. comm., January 20, 2015), allowing fish to function at a higher rate and to take in and utilize more nutrients, growing to a larger size. The effect this has on growth seems to be quite potent, overriding other potential factors.

A notable difference between the two species of river herring was the size of the fish at the time of emigration (see Figure 13). Early in the season, emigrating specimens of both species were about the same length. Late in the season, however, there was a large difference in the average size of emigrating alewives and that of emigrating blueback herring. The average length of alewife specimens emigrating on October 5th was 83.54 mm, and the average length of blueback specimens was 45.34 mm. This large difference is likely indicative of the situation within the environment of the pond they inhabited. Later arriving blueback herring may not be able to compete with alewives who are already approaching their juvenile stages, especially as temperature and prey supplies drop. Being unable to compete successfully against much larger and more mature fish, blueback herring might be inclined to emigrate from the pond at a smaller state. Additionally, the alewife population is likely simply larger because many members of the population were born earlier.

Analysis of 𝛿13C values over time presents us with valuable information on how the two species of river herring might behave differently (see Figure 14). These values indicate what sorts of prey the fish were eating, and therefore where in the pond they were. Mussels provided a baseline for 𝛿13C values in the pelagic zone, and their average values throughout the season were consistently around -24. Snails provided a baseline for 𝛿13C values in the littoral zone, and their average values were consistently around -12. Alewives and blueback herring both spent most of the season with very negative 𝛿13C values, indicating they were eating in the pelagic zone, most likely on zooplankton (France, 1995). What is especially notable is that later in the season, the average 𝛿13C value of alewives became more positive, while the average 𝛿13C of blueback herring stayed very negative, not becoming much different from that of mussels. The fact that the average 𝛿13C value of alewives became less negative than that of bluebacks suggests that they might have been spending less time in the pelagic zone, moving instead towards the littoral zone. The shift in the alewives’ feeding habits could be due to the crash of the zooplankton population, and they might be more able to move to another area of the pond because they hatched first and are already entering their juvenile stages. The younger blueback herring might be more confined in their movement, so they stay solidly in the pelagic zone even while zooplankton populations decline. The potential differences in behavior between the two species could indicate that they cannot simply be grouped together for all purposes. It could be beneficial to research each species specifically, and to tailor conservation efforts to each particular species rather than just towards river herring as a collective group.

Analysis of 𝛿15N could also indicate differences between the two species (see Figure 15). 𝛿15N values consistently rise based off of what trophic level an organism is on, meaning their relative spot on the food chain can be determined. Mussels provided a baseline for 𝛿15N values in the pelagic zone, with their values consistently averaging around 9.5 and trending slightly upwards. Snails provided a baseline for 𝛿15N in the littoral zone, with their values consistently averaging around 8.5 and trending slightly downwards. The 𝛿15N values of alewives and blueback herring are much higher, around 12.5, meaning that they are in a higher trophic level. However, 𝛿15N values of blueback herring trend slightly upwards over time, while those of alewives trend slightly downward. It is unlikely that the two species move to different trophic levels; instead, the relative 𝛿15N values of their environments could be changing. The shift in 𝛿15N values of blueback herring coincides with the shift in 𝛿15N values of mussels, and the shift in 𝛿15N values of alewives corresponds more with that of snails. This evidence further suggests that alewives shift more towards the littoral zone of a pond, where snails inhabit, while blueback herring stay in the pelagic zone. Again, this could mean that conservation efforts need to be more specifically tailored to each species.

There were, of course, multiple possible sources of error during this project. One possibility is that otolith rings were improperly counted due to them being obscured. Otoliths could have been scratched, fractured, or otherwise altered during extraction, which could change their appearance. Sub-daily rings also pose a problem. Older fish sometimes eat at different periods of the day and cause fainter rings to appear on their otoliths between two daily rings. These sub-daily rings were known of and avoided, but there is the possibility that they were counted. Another less likely source of error is that tissue samples were contaminated before being sent in for stable isotope analysis.

A study of this scope has a lot of room for expansion. A greater sampling size would help quite a bit with increasing accuracy, as environmental projects such as this tend to have a lot of variability that can only be counteracted by a large sample size. More consistent sampling from throughout the season would also help create a better picture of what is going on, perhaps giving information on when the majority of herring decide to emigrate. Sampling from a wider variety of environments and over a longer period of time would also help to clarify the situation. Another helpful study to conduct would be one to determine more exactly the turnover rate for river herring tissue. River herring could be kept in a controlled environment and given food that resembles prey found in the pelagic and littoral zones, and measurements could periodically be done on specimens to find turnover rate.

The results of this experiment give us even more vital information on the early life history of river herring, two vastly important species. Even with river herring’s essential environmental role, comparatively little is known about them and their life history, which makes conservation efforts more difficult to design. A further scientific understanding of the species is needed to prevent them from being wiped out, and early life stages in particular are very important. The early life stages are the most important for ultimate recruitment, and these stages of life are the least known about, making them all the more important to study (Llopiz, pers. comm., January 20, 2015). Knowledge of what elements river herring need to grow can help us better protect the environment for them. Relocation efforts in particular can be better designed, and other efforts such as pollution cleanup can be better prioritized. Knowing of differences between alewives and blueback herring and tailoring efforts to those differences could be very important in saving both species.

**Conclusion**

The purpose of this study was to get a deeper understanding of the early life of river herring, referring to the two species of alewife (*Alosa pseudoharengus*) and blueback herring (*Alosa aestivalis*). Zooplankton population levels were analyzed, and the population crashed midway through the season, indicating that the juvenile river herring population has a drastic effect on the zooplankton population, and that zooplankton are not what sustain the river herring population throughout the entire season. Temperature was found to have a strong effect on growth rates, seeming to determine the maximum rate of growth. Competition also seemed to be a factor affecting growth. Importantly, changes in 𝛿13C and 𝛿15N values suggest that alewives move towards the littoral zone as the season goes on, while blueback herring do not. Differences such as this could mean that conservation efforts need to be tailored either towards alewives or blueback herring in particular, rather than river herring in general. It was hypothesized that the zooplankton population would crash midway through the season, and that this fall in population would correlate with a decline in river herring growth. It was also hypothesized that alewives and blueback herring would have essentially the same isotopic signatures throughout the season, remaining mostly pelagic but moving towards the littoral zone as zooplankton levels fell. The hypothesis was mostly unsupported, and the information that was gathered, along with further research, could help in the conservation of these two species.

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