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[Management Brief]

Earlier Spring Warming of Coastal Streams and Implications for Alewife Migration Timing

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Abstract.—Seasonal temperature increases have been shown to correlate with changes in the migration timing of fish. We looked at existing temperature and fish count data for anadromous alewives *Alosa pseudoharengus* in several southern New England streams. Run initiation, defined as occurring when the first 5% of the total annual run migrated, was associated with 9°C. A weighted-mean migration temperature, considered an overall indicator of total run timing, revealed that 13°C was a consistent predictor of run timing for one historic and three recent alewife streams over several years. Because historical and recent daily water temperatures with concurrent fish counts were unavailable for any one site, we used the occurrence of 9°C and 13°C stream temperatures to determine the magnitude of any detectable shift in the migration timing of alewives between the 1970s and recent years. Stream temperatures in the spring warmed to 13°C about 12 d earlier in recent years than they did in the 1970s. This implied that alewife runs occurred about 12 d earlier on average. Run initiations occurred about 13 d earlier. Management of the water supply to fish passage facilities may need to be adjusted to accommodate these shifts in migration timing.

Despite uncertainties at all levels of analysis (Baede et al. 2001), evidence has become overwhelming that climate change is happening at a rate predicted to have global impacts on biological earth systems (Parmesan and Yohe 2003; Ficke et al. 2007). Ashizawa and Cole (1994) found that annual water temperature in the Hudson River increased from 1920 to 1990 at a rate of 0.12°C per decade, the greatest rate of increase occurring from 1971 to 1990: 0.46°C per decade. Several investigations throughout North America utilizing long- term river temperature records have all shown similar warming trends over the past century, the greatest changes occurring during the last 20–50 years (Quinn and Adams 1996; Juanes et al. 2004; Ferrari et al. 2007). The number of studies reporting plants or animals responding to the changing climate has risen substantially in recent years (Meyer et al. 1999; Rosenzweig et al. 2007). However, there are still many uncertainties in how these changes will be manifested and what the impacts will be (Ferrari et al. 2007). Because most aquatic organisms are exotherms, responses to temperature changes are continuous and involuntary (Ficke et al. 2007). Potential effects include range expansions and shifts poleward, changes in animal migrations, and organism abundance (Parmesan and Yohe 2003; Reist et al. 2006; Rosenzweig et al. 2007).

One of the simplest means of tracking changes in response to climate change is phenology (Ahas and Aasa 2006; Rosenzweig et al. 2007). Phenological shifts attributed to climate change have been identified in both terrestrial and aquatic biota (Ahas and Aasa 2006). Examples of these shifts include temporal advances in the developmental stages of plants—leaf unfolding, flowering, and fruit ripening (Rosenzweig et al. 2007). Shifts towards earlier annual spawning (Ahas and Aasa 2006) and earlier migrations of anadromous fish have been documented (Quinn and Adams 1996; Juanes et al. 2004). Anadromous alewives *Alosa pseudoharengus* are a good candidate species for such phenological investigations, given previous research documenting a correlation between temperature and the annual spring spawning migration (Beltz 1975; Libey 1976; Loesch 1987).

To contribute to the understanding of how anadromous alewives may already be affected by climate change, we investigated water temperatures and migration timing in southern New England coastal streams. We hypothesized that migration timing of anadromous alewives had advanced over the last few decades. Specific objectives used to test this hypothesis were to use daily fish counts of alewife migrations and corresponding water temperature data to identify what

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temperatures characterized the initiation of the spring migration and the overall migration timing. We also compared current and historic water temperatures to statistically test whether the temperatures selected in the first objective occurred earlier than in previous years.

Study Area

The southern New England coastline has many small streams that support alewife runs, although very few are monitored daily, and those that are were not monitored until recently. Water temperature records for streams with alewife runs were also sparse. Therefore, site selection was limited by availability of daily fish count data and historic water temperature data (Table 1). The six sites we selected were known to have hosted alewife runs throughout the period of interest (1970s to the present). The alewife run in the Parker River (fishway near Central Street in Byfield, Massachusetts) was studied during the 1970s and, to our knowledge, these daily visual estimates of fish count made by graduate students (Libey 1976; Huber 1978) are the only daily historic data that include concurrent water temperatures in the region. We avoided data from the large rivers in the region (Hudson River and Connecticut River) because alewife migrations overlapped with the similar-looking congener blueback herring *A. aestivalis* in these systems; historical data often tended to lump both species as "river herring" (Gephard and McMenemy 2004). Only one site had both historic and recent water temperatures and recent daily fish counts, the Shetucket River (at the Greeneville Fish Lift near Norwich, Connecticut). Both Mill Brook (at the Mary Steube Fishway in Old Lyme, Connecticut) and Bride Brook (outflow of Bride Lake in East Lyme, Connecticut) have had recent daily fish counts and recent water temperature. The Farmington River (at the Rainbow Fishway in Windsor, Connecticut) and the Salmon River (at the Leesville Fishway in East Haddam, Connecticut) sites provided historic and recent water temperature but not fish counts.

Recent (1996–2006) daily fish count data and water temperature data used were obtained from the Connecticut Department of Environmental Protection, Inland Fisheries Division, Diadromous Fish Program (Gephard et al. 1998, 1999, 2000, 2001, 2002; Ellis 2003, 2004, 2005, 2006, 2007, 2008). Fish counts were made by videotape and cross-channel fish traps. Counting techniques have recently transitioned to Smith-Root Model SR1601 fish counters at two of the streams (Smith-Root, Inc., Vancouver, Washington, USA). The counters were checked daily and counts and water temperatures recorded. The historic (1971–1978) water temperature records from the Farmington (station

TABLE 1.—Data gathered from southern New England streams known to have supported alewife runs from 1971 to 2007. See Methods for additional details.

Stream	Water temperature		Daily fish counts	
	Historic	Recent	Historic	Recent
Parker River	1973–1975		1973–1975	
Shetucket River	1971–1978[a]	1997–2006		1997–2006
Bride Brook		2003–2007		2003–2007
Mill Brook		2003–2007		2003–2007
Salmon River	1975–1978	2003–2007		
Farmington River	1971–1978[b]	2003–2007		

[a] 1974 data not available.
[b] 1975 and 1976 data not available.

number 01189995) and Salmon Rivers (station 01193500) were provided by U.S. Geological Survey (USGS 1972, 1973, 1974, 1975, 1976, 1977, 1978, 1979). Historic water temperatures for the Parker River site were taken from Libey (1976). Continuous daily water temperature records over the entire period of interest were not available for any of the study streams (but see Ashizawa and Cole, 1994, for a nearly complete regional time series).

Methods

In the absence of historical daily fish counts, we discerned whether the migration timing of anadromous alewives had changed by exploring the water temperatures associated with the migration of alewives. We used two characterizations of the migration to test for differences in the seasonal first occurrence of water temperatures associated with the alewife spawning migration. The first characterization method was to determine the mean water temperature that occurred during run initiation ($\check{T}_{\text{ri}}$), defined as the first 5% of the cumulative total run at a site. The second characterization method, developed by Quinn and Adams (1996), was termed the weighted-mean migration temperature of the annual run ($\check{T}_w$), given by

$$\check{T}_w = \sum n \cdot t / N,$$

where n is the daily number of fish counted, N is the annual total number of fish counted, and t is the daily temperature. Quinn and Adams (1996:1155) described $\check{T}_w$ as "an estimate of the temperature that best characterized the migration of the population as a unit stock, by weighting observed temperatures by the number of fish migrating on days when that temperature was recorded." Weighted-mean migration temperatures were calculated for each year of fish count data at a site and the "mean of means" grand mean was calculated. Likewise, the grand mean was calculated

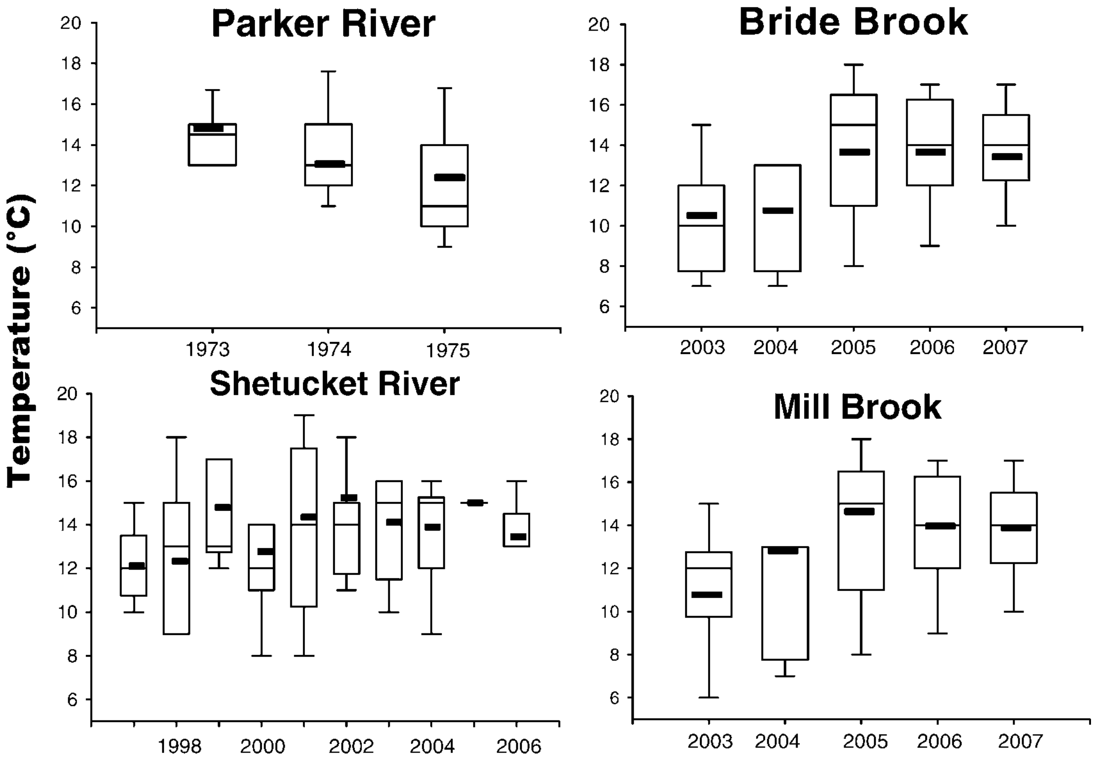

FIGURE 1.—Box-and-whisker plots of the temperature distributions of the daily counts of anadromous alewives within the total annual run for the Parker River, Bride Brook, Mill Brook, and the Shetucket River. Whiskers of all plots represent the minimum and maximum temperatures observed during daily counts at each site and year. The lower and upper quartiles of each box represent the 25th and 75th percentiles, and median temperatures are represented by thin black horizontal lines. The thick black horizontal lines are the weighted-mean migration temperatures ($\check{T}_w$) for each site and year; the grand mean was 13°C. Note that the *x*-axes differ among panels.

for $\check{T}_{ri}$. Then, the day of year during the spring of each year when water temperatures reached the grand mean temperature associated with $\check{T}_{ri}$ and $\check{T}_w$ were identified. Days of year were also identified for the historic water temperature data. The median day of year values for both $\check{T}_{ri}$ and $\check{T}_w$ were compared by using a two-tailed Mann–Whitney U-test ($\alpha = 0.05$). Only the Connecticut streams were used in this step; the Parker River was excluded from the comparison because its location north of Cape Cod raises concerns that it might naturally warm later in the year than would streams emptying into Long Island Sound. Loesch (1987) reported that alewife migration timing varied predictably with latitude.

Results

Mean temperatures during the first 5% ($\check{T}_{ri}$) of the run ranged from 10°C to 13°C during 1973–1975 at the Parker River. Means were 8–15°C at the Shetucket River, 7–10°C for Bride Brook, and 6–10°C at Mill Brook in recent years. The grand mean water temperature associated with $\check{T}_{ri}$ was 9.4°C with a standard error of 0.47. Weighted-mean migration temperatures at Parker River in the 1970s ranged from 12°C to 15°C, nearly identical to recent $\check{T}_w$ values; the Shetucket River ranged from 12°C to 15°C, from 11°C to 14°C at Bride Brook, and from 11°C to 14°C at Mill Brook (Figure 1). The grand mean temperature associated with $\check{T}_w$ was 13.29°C with a standard error of 0.29. We plotted the day of year at which each stream first reached 9°C and 13°C for both historic (1971–1978) and recent (1997–2007) water temperature data sets (Figure 2).

Shifts toward earlier first day of year occurrences were detected in both $\check{T}_{ri}$ and $\check{T}_w$. Over the course of approximately 30 years, migration initiation, as indicated by stream temperatures reaching 9°C, shifted to 13 d earlier (Mann–Whitney $U = 191.0$; $P = 0.044$). The median first occurrence of 13°C, characterizing the grand mean $\check{T}_w$, had shifted to 12 d earlier (Mann–Whitney $U = 257.5$; $P = 0.015$). Translated into calendar days, $\check{T}_{ri}$ occurred near April 12th in the 1970s and around March 30th more recently. Similarly, $\check{T}_w$ historically occurred near May 1 but recently occurred nearer April 19.

Discussion

Water temperatures in coastal streams reached 9°C and 13°C at earlier calendar dates in recent years than they did in the 1970s. We claim that this corresponds to a detectable advance in the phenology of anadromous alewife migrations. This detectable advance is based on the assumption that alewife runs in the past occurred around the same $\check{T}_w$, an assumption well supported by the historic data presented from the Parker River. Mean-weighted migration temperatures from the 1970s runs were within the range observed in recent years. Further, Huber (1978) reported that the first observed appearance of alewives in the Parker River occurred between the 7th and 17th of April from 1972 to 1977. This is remarkably similar to the April 12th median value for $\check{T}_{ri}$ that we calculated from historic water temperatures in the Connecticut streams. Loesch (1987) summarized the literature on the migratory behavior of alewives as generally beginning at water temperatures between 5°C and 10°C, which also closely compares with our calculated $\check{T}_{ri}$ of 9°C.

We acknowledge that the availability of more historic daily fish count data would have been desirable (although we found none); nonetheless, tracking the occurrence of phenological events by using temperature records has been applied across a broad range of plants and animals to evaluate the effects of climate change (Parmesan and Yohe 2003; Ahas and Aasa 2006). Juanes et al. (2004) evaluated the migration timing of Atlantic salmon *Salmo salar* in the Connecticut River on the basis of 23 years of daily fish counts and reported an advance in migration timing similar to our findings. American shad *Alosa sapidissima*, a congener of alewives, showed a remarkably constant temperature associated with peak runs over 32 years (1938–1969) and several watersheds (Leggett and Whitney 1972). The similarity across sites and narrow ranges of both $\check{T}_{ri}$ and $\check{T}_w$ values (historic and recent) suggests that the timing of alewife migrations are also able to be characterized by the occurrence of certain temperatures.

Our analyses for alewives were further challenged by the lack of a complete time series of temperature data for small coastal streams. There is always some risk of selecting warm and cool periods when subdecadal chunks of temperature data are compared, as was done here. We are confident in our comparisons, however, because of the existence of nearby time series data that confirm the overall trend in warming water temperatures, such as those presented by Jacobson et al. (2004) for the lower Connecticut River, by Ashizawa and Cole (1994) for the nearby Hudson River, and by Juanes et al. (2004) for the Connecticut River Atlantic salmon results already mentioned. Assuming our study streams followed the general trends of the region, our historic versus recent comparison was not confounded by notable warm or cool periods.

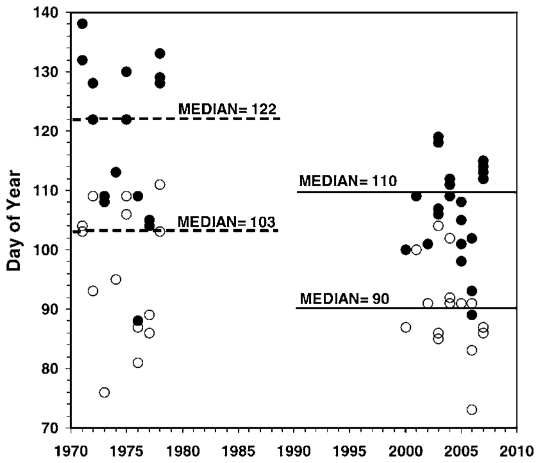

FIGURE 2.—First day of year at which each site reached 9°C (open circles) and 13°C (filled circle). The dashed lines show the medians of the historical data and the solid lines the medians of recent data.

The management implications of these results principally affect fishway operations. Currently both state- and privately-owned fishways use agreed-upon operational seasons. Most of the small fishways installed in the past 15 years for alewife runs in southern New England do not receive water year-round. The acknowledgment that run timing has shifted to earlier dates (and will probably continue to shift) suggests that fishways also will need to be operated earlier. Although state-owned fishways may be easily adaptively managed, such may not be the case for privately owned fishways, particularly at hydroelectric facilities where operations are governed by complex agreements and water has an associated dollar value. Moving fishway operations to earlier dates should also be considered in context of positive and negative benefits to other species that may be using the fishways in southern New England: American eel *Anguilla rostrata*, American shad, and blueback herring are all potentially sympatric at many locations.

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