Shifting Environmental Factors Influence the Abundance and Fitness of Juvenile American Eels

Colleen Schmid

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*All figures were created by student researcher unless otherwise noted

1.0 Abstract

The American eel (*Anguilla rostrata*) is a catadromous migratory species, whose drastic decline has placed this fish on the IUCN endangered list. This study examined environmental factors linked to climate change that may influence the abundance and fitness of juvenile eels during their spring migration into a Hudson River tributary. A fyke net was deployed annually (2008-2019) in Furnace Brook to track seasonal glass eel migration. Eels were counted daily, weighed, as a proxy for fitness, and released upstream. A HOBO Logger, installed above the head of tide, measured water depth (a proxy for flow), with water temperature recorded separately. Our eleven-year analysis reveals an annual peak arrival of glass eels, occurring mid-season, likely in response to optimal water temperatures ~55°F between Julian dates 95-116. It was found that the fittest eels arrive at lower water temperatures and higher water flows, earlier in the season. Glass eels arriving later were lighter and therefore weaker, likely the result of longer, more strenuous migrations. These findings suggest that the fittest eels have the highest chance at survival; however, shifting environmental conditions, particularly water temperature and flow may pose challenges for migrating eels in terms of overall energy reserves and food availability, furthering the grim outlook for this species. Collectively, our findings provide novel insight on patterns of American eel abundance and fitness in a tributary of the Hudson River, a critical habitat for this culturally, economically, and ecologically important species.

2.0 Introduction

The American eel (*Anguilla rostrata*) population is categorised as endangered on the International Union for Conservation of Nature (IUCN) Red List (Jacoby, Casselman, DeLucia, and Gollock, 2017) due to its drastically decreasing population (Suhay 2015). Much remains to be known about this once highly abundant species, including the fundamental reason for the observed population decline. Anthromorphic activities such as the construction of dams, overfishing, pollution, and habitat loss are thought to have severely influenced eel populations (Prosek 2011; ASMFC 2018; Eyler, Hitt, Wofford 2012; Brase 2016). The decline has already had a detrimental effect due to the eel's cultural (David 2000) and economic significance (David 2000; Prosek 2011), as well as the critical role they play within ecosystems (Lake, Petersson, Schmidt 2006; Prosek 2011).

The American eel, the only catadromous fish species in the Hudson River (NYSDEC), has a complex life history (Figure 1); spawning in the Sargasso Sea and as leptocephali (larvae), they migrate using ocean currents to coastal waters, where they develop into Young-of-Year glass eels, the life stage our research focuses upon (Figure 2). As glass eels travel inland in search of suitable habitat, they gain a brown pigment and transition to the elver stage, the last of the juvenile stages. Elvers eventually transition to the yellow and silver eel stages in preparation for their return to the Sargasso Sea where they spawn and soon thereafter die (Chesapeake Bay Program 2019; ASMFC). The transatlantic migration requires a large amount of energy and therefore, any changing environmental conditions can influence their overall energy reserves and chances of arrival in freshwater tributaries, their target habitat.

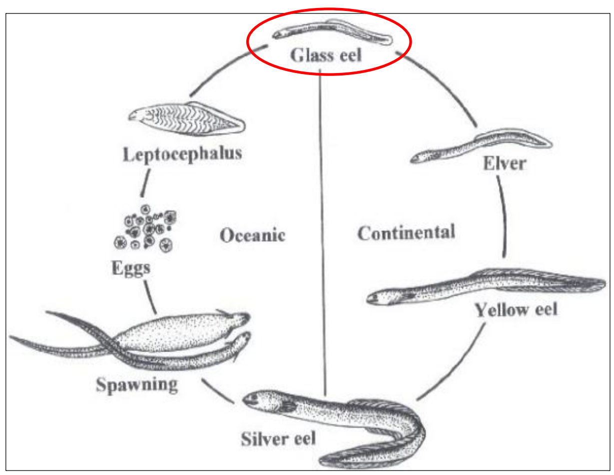


Figure 1: The American eel life cycle. American eels spawn in the Sargasso Sea and then travel to coastal waters where they become glass eels. Once they are fully inland and in freshwater, they become elvers growing to full maturity later becoming silver eels, and then returning to the Sargasso to spawn. (https://www.fws.gov/).

Juvenile American eels migrate in the early spring to a variety of freshwater habitats in the Northeast, including the Hudson River in New York State, the region this study investigated. Freshwater tributaries diverge from the brackish Hudson River, providing a variety of suitable habitats for American eels. However, no previous study has taken a comprehensive and longitudinal look at the environmental variables specific to the Hudson River region that may affect eel abundance, particularly the abundance of juvenile eels, a stage particularly sensitive to environmental changes.

Figure 2: American glass eels collected from fyke net at Furnace Brook.

Previous research has found that certain environmental factors influence eel migration including water temperature (Tosi et al. 1988) weather, moon/tides (Dutil et al. 1988), and river/stream currents (Edeline et al.2005; Tosi et al. 1988). Furthermore, it has been reported that water temperature is one of the most influential factors (Martin 1995). Water flow is also seen to be an important factor as juvenile eels did not enter freshwater at high flows (Sloane 1984). These variables, are known to impact juvenile eel migration and can contribute to patterns of springtime juvenile eel arrival to inland tributaries, including the Hudson River.

Like many other fish species, optimal water temperatures result in the most growth, body condition, and survival (Walsh et al. 1983; Portner and Knust 2007; Portner and Farrell 2008; Portner 2010; Blakeslee, Galbraith, Deems 2018). Additionally, as seen in a study by Edeline et al. 2005, cooler water temperatures can greatly reduce locomotor activity and preference for freshwater, influencing estuarine migration and river recruitment of juvenile eels. Further complicating their migration is the shift from saltwater to freshwater aquatic environments, posing further impacts on body condition and energetic status as physiological changes must take place to enable eels to adapt (Edeline et al. 2005).

This study is unique in that we followed American eel migration at the glass eel stage; it is crucial to monitor changes as juvenile eels rely heavily on water currents, water flow, and water temperature as migration cues (Tongiorgi et al 1986; Tosi et al. 1990). These factors have been shifting due to changes in climatic conditions (NOAA 2019), thus research is needed to better understand and predict the potential impact of climate change on juvenile eels as little is still known about this (Engman, Lilyestrom, Kwak 2018). For instance, ocean temperatures have risen (IUCN 2017), patterns in ocean currents (NOAA 2011) and circulation (NOAA 2013; SOS-NOAA) have shifted and could have a major influence on the eel's migration (Knights 2003). By tracking the timing of arrivals of juvenile eels to tributaries in early spring, we can better elucidate eel migration patterns and determine if there is a correlation with spring flood (water flow) and water temperature.

Another valuable contribution of our study is the close examination of fitness, a variable that has not yet been investigated for migrating American eels in the juvenile stage. Previously, fitness of the American eels was only measured within the lab setting with adult eels (Van Ginneken 2005; Clark, Sandblom, Jutfelt 2013; Tudorache 2015), however, due to the size of glass eels and setting of my study, a novel approach was required. Herein, we take the novel approach of utilising glass eels body weight as a proxy for the fitness/overall health of the eels. It is assumed that, generally, heavier eels are stronger/healthier and better prepared to reach habitat destinations and ultimately full maturity, while the smaller, lighter eels tend to be weaker. Moreover, analysing juvenile eel health across an 11-year period gives a much more accurate insight that can better predict population shifts and best practices for conservation.

3.0 Purpose

This research:

1. Monitored juvenile eels entering the Hudson River tributary, Furnace Brook, during their spring migration season across a 12-year period (2008-2019).
2. Investigated the influence of water temperature and tributary water flow on juvenile eel abundance and fitness.
3. Evaluated the relationship between juvenile eel arrival time with water temperature and flow, abundance, and fitness.

4.0 Hypotheses

It was hypothesised that:

1. Tributary temperature is negatively correlated with eel fitness and abundance, due to seasonality.
2. Juvenile eel catches, and weights peak during the middle of the migration season (April) due to optimal environmental conditions.
3. Water flow will be the highest at the start of the season and the magnitude of water flow plays a role in arrival time of glass eels.

5.0 Methods and Materials

5.1 Furnace Brook Study Site

Furnace Brook is one of 14 established American eel monitoring study sites located in freshwater tributaries of the Hudson River. Sites are monitored by the New York State Department of Environmental Conservation (NYSDEC; Figure 3); this is a citizen science project ongoing for over a decade (2008-2019). A sampling permit was obtained by the NYSDEC. Furnace Brook is located in Cortlandt, New York, in the lower part of the Hudson River within the brackish water zone (Figure 4). It is a unique study site as it is one of three locations where seasonal eel ingress has been monitored annually over a twelve-year period. The site is located within a setting with woody vegetation, a salt marsh, and few private residencies (Figure 3). Furnace Brook is positioned between a local unpaved road and a recreational hiking trail with steep slopes and marshy banks to either side.

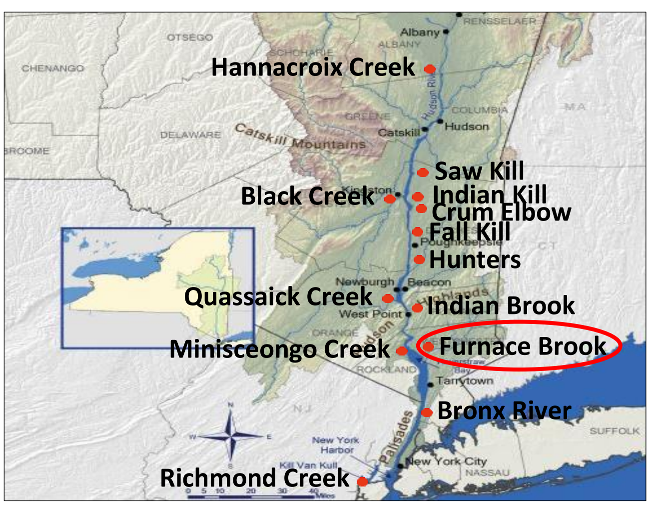


Figure 3: NYSDEC American glass eel monitoring sites. Location of Furnace Brook Sample Site highlighted in red. Furnace Brook is located within the lower Hudson River area- a brackish water zone; Adapted from gufsee.org (2018).

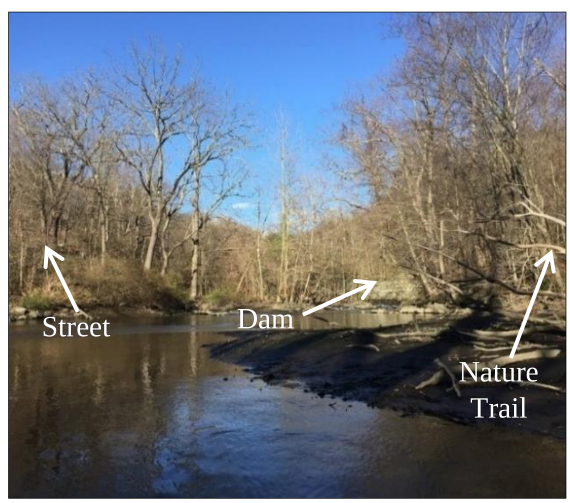


Figure 4: Furnace Brook Sampling Site. Located within a wooded area, the site has steep, marshy banks with a trail to one side and a street on the other. A dam is located further upstream.

5.2 Fyke Net Placement

Similar to the sampling procedure at all other DEC eel monitoring sites, a Sheldon type fyke net (provided by the NYSDEC) was installed annually in early spring (March-May) near the mouth of Furnace Brook, measuring 13 feet wide at the mouth of the net and held in place with garden stakes pounded into the streambed. It was strategically placed on the northern bank of the tributary to capture juvenile eels who follow the stronger current along the north edge of the stream. The fyke net was placed with the mouth opening downstream to capture eels on their upstream migration; glass eels and elvers enter into the fyke net through the mouth and into the funnels and are then unable to leave the net (Figure 5).

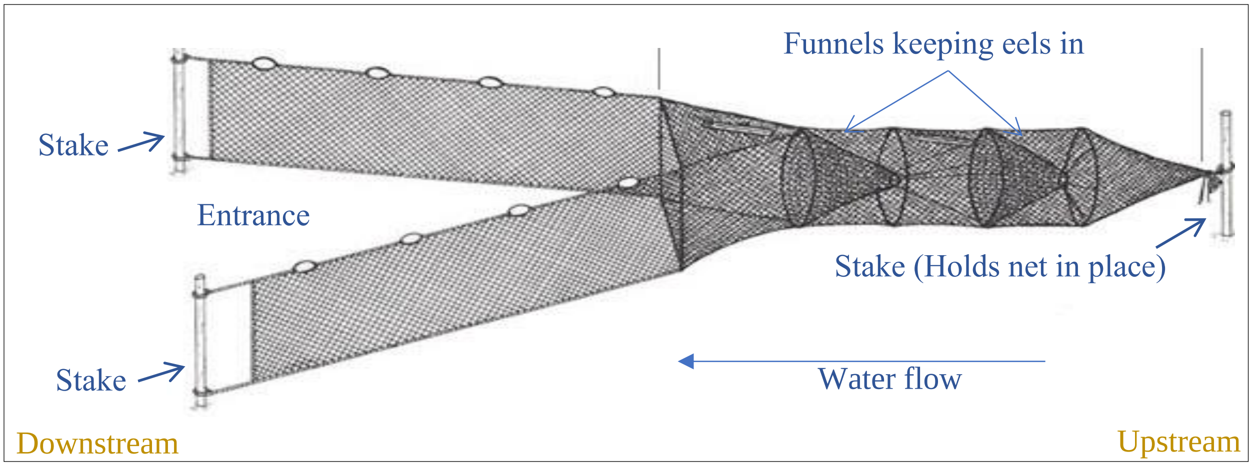


Figure 5: Diagram of Sheldon Type Fyke Net (fipec.qc.ca)

5.3 Juvenile Eel Data Collection

Glass eel counts were obtained daily by visiting the fyke net for the duration of the glass eel migration season (approximately March-May). A standard protocol was followed each year and historical data from 2008-2016 (NYSDEC), were used to supplement the work of the student researcher (2017-2019). Sampling was performed within two hours of low tide as a safety precaution. Every day during the glass eel migration season, a minimum of two volunteers wearing chest waders visited the fyke net and carefully removed juvenile eels from the fyke net. Eels were immediately placed into a small three-gallon bucket containing fresh stream water and counted.

20 glass eels were randomly selected and weighed on an OHAUS electrical scale, however, if less than 20 glass eels were counted, they were not weighed. Average weight per glass eel was calculated as an indicator of individual fitness. Lastly, all juvenile eels were released upstream unharmed, preventing the recapture of these eels in the fyke net and helping them continue their upstream migration in search of suitable habitat. Glass eels were not harmed and there was no mortality of glass eels occurred.

5.4 Environmental Factors

Handheld water and air thermometers were placed each day by the sampler to monitor air and water temperatures (°F). Additionally, an Onset U20L HOBO Logger was deployed above the head of tide at the location of eel release during years 2017-2019 only. The HOBO Logger continuously records water temperature, absolute barometric pressure, and sensor depth. Herein, we used sensor depth (water depth at the logger's sensor) as a proxy for water flow.

5.5 Data Analysis

Handwritten field observations were recorded in a data binder and were then transferred to Microsoft Excel 2016 and analysed with GraphPad Prism 8 to create graphical representations and run statistical tests; statistical significance was held at $p \leq 0.05$. An overall correlation was run including data from all years as well as individual correlations for each year for water temperature relationships. Julian dates were used to track arrival at the site over the years. For the analysis of peak arrival, the number of days in the particular season was divided by three to distnguish between early, mid, and late spring arrival. Data was analysed for the years 2008-2018. However, only data from the years 2017 and 2018 was analysed for water flow because the HOBO logger was introduced in 2017. Data collected in 2019 was not included in these analyses because data collected was insufficient for the analysis.

6.0 Results

6.1: Variability in Annual Glass Eel Catch and Weight

Glass eel abundance (Figure 6) and average weight (Figure 7) varied annually. This may be due to variations in interannual environmental conditions such as wind driven currents, weather, and temperatures.

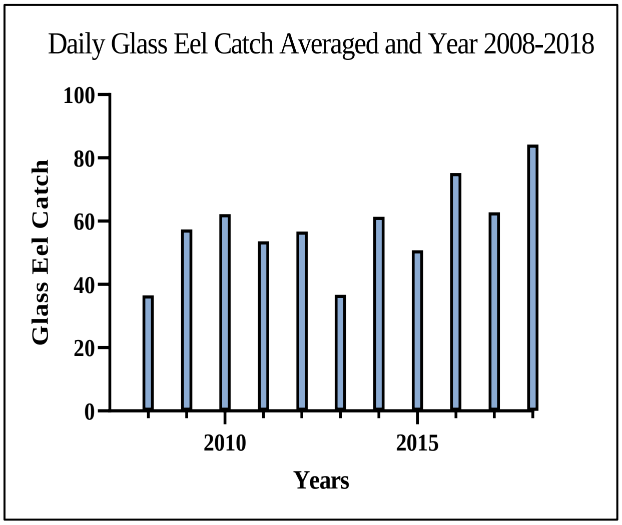


Figure 6: American glass eel catches tend to fluctuate at Furnace Brook during 2008-2018. They vary year to year. Averages tend to generally increase.

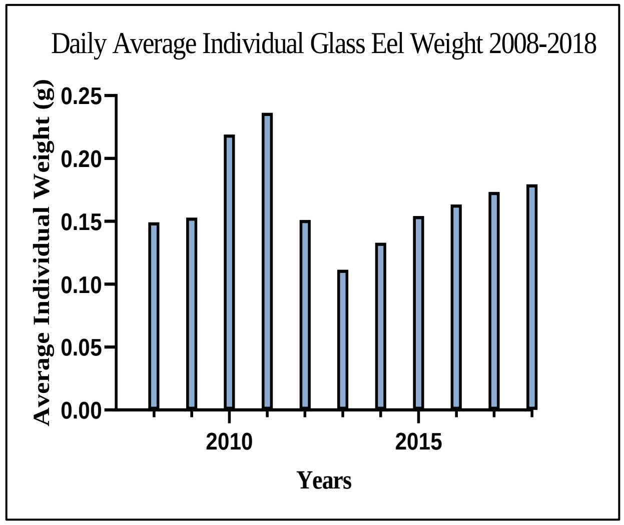


Figure 7: American glass eel weights also tend to fluctuate at Furnace Brook during 2008-2018. They vary year to year.

6.2: General Increase in Water Temperature with Julian Date

One assumed premise when studying spring migrants is that water temperatures rises throughout the season with the approach of spring. Our data supports this as water temperature was found to generally increase with Julian date (Figure 8).

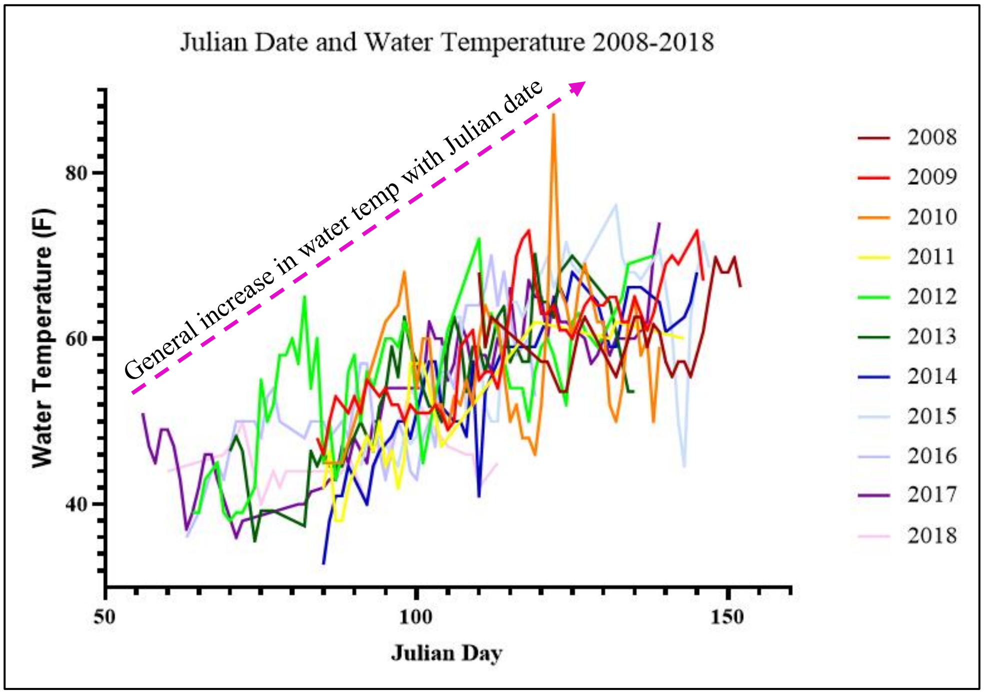


Figure 8: There are many fluctuations in water temperature at Furnace Brook 2008-2018, however, there is a general increase with Julian date.

6.3: Glass Eel Catch Decreases with Increasing Water Temperatures

Next, we examined possible relationships between abundance and water temperatures within the tributary. Generally, it was found that as water temperature increased, glass eel catches decreased. This is attributed to the nature of eel arrivals; most years we see a peak arrival in glass eel catches. This may occur at optimal water temperatures or conditions, therefore, explaining why we observe both positive and negative trends when correlations were run year each year (Figure 9 A-K), most however failed to reach statistical significance ($p \leq 0.05$).

6.4: Peak Arrival of Glass Eels at Mid-Season Near 55̊F

The timing of peak arrival (spike in abundance of glass eels caught) varied annually, however, peak arrival typically occurred mid-season, between Julian dates 95-115 (Figure 10 A-K). A peak arrival may occur due to glass eels having an optimal water temperature occurring around these times (Figure 11).

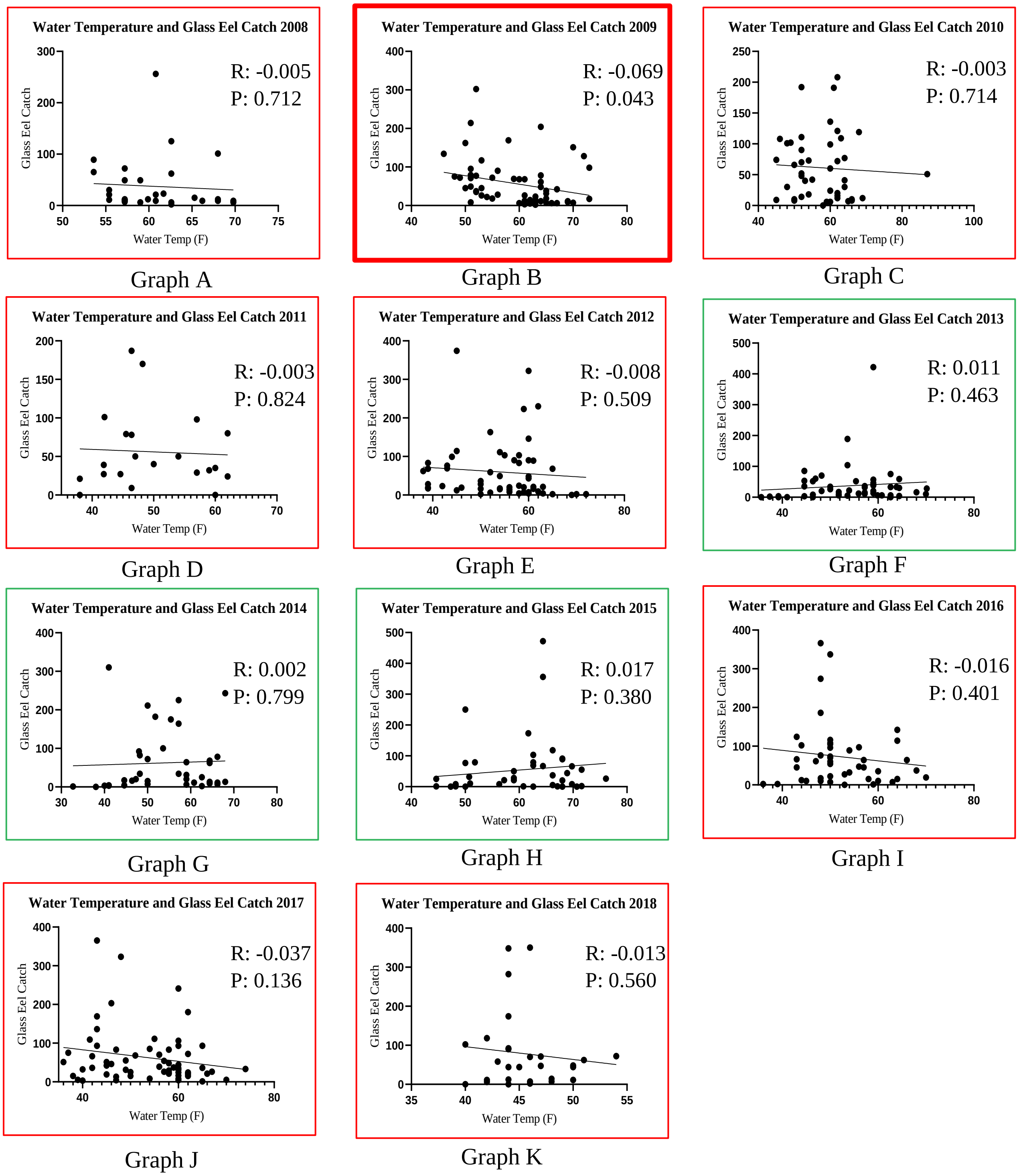
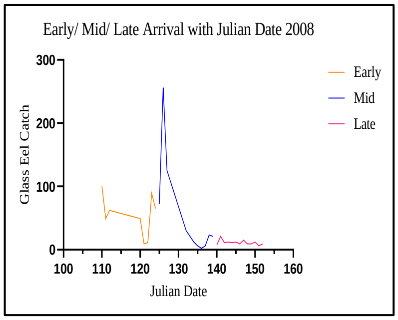
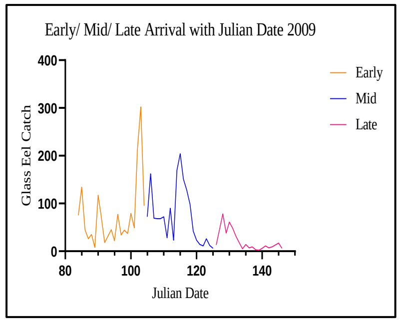


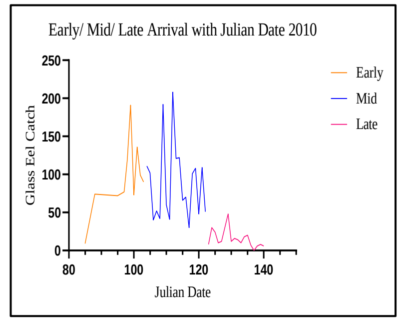
Figure 9 A-K: Water temperature and American glass eel catch 2008-2018 at Furnace Brook. Overall, as water temperature increased, glass eel catches decreased, however, most correlations failed to reach statistical significance ($p \leq 0.05$). Exceptions: 2009 had a **significant** negative correlation, 2013-2015 had positive correlations, as water temperature increased, so did the catch.



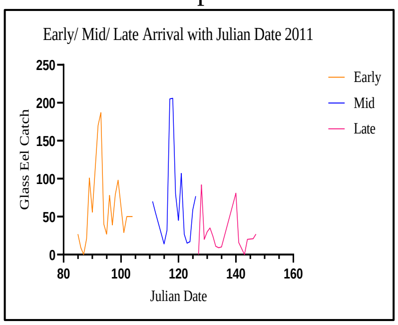
Graph A



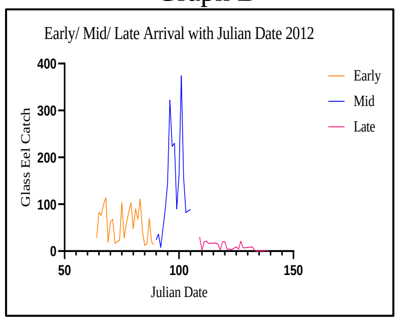
Graph B



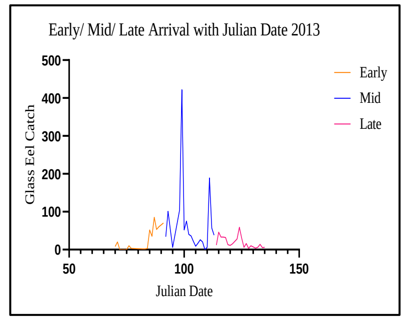
Graph C



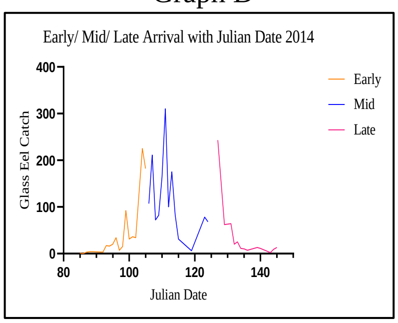
Graph D



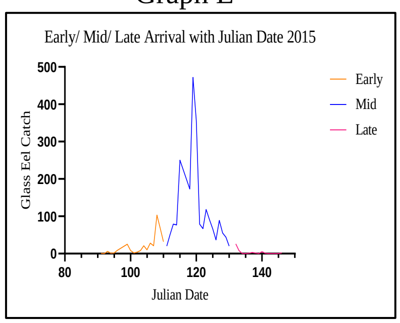
Graph E



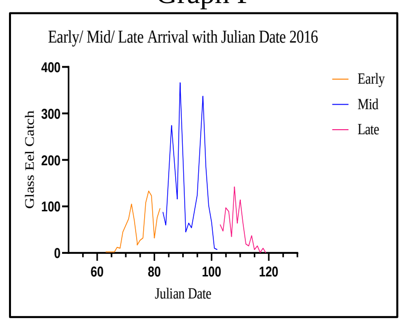
Graph F



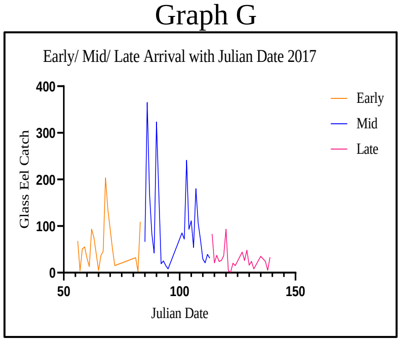
Graph G



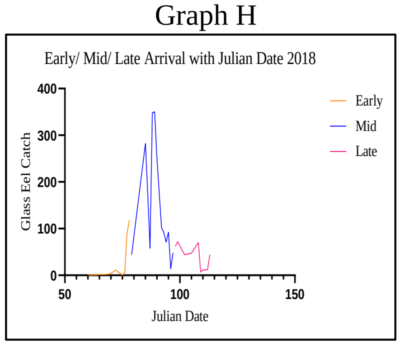
Graph H



Graph I



Graph J



Graph K

Figure 10 A-K: Peak arrival of American glass eels occurs at mid Julian dates 2008-2018 at Furnace Brook. Peak arrival typically occurred mid-season between Julian dates 95-115, around late April. Sampling window was divided into thirds indicating early, mid, late season counts.

Additional Pearson's correlations were run for each year, however, glass eel catch did not correlate with Julian date ($p \leq 0.05$), however, we observe that generally glass eel catch decreased throughout the season (Figure 9 A-K). As seen previously, glass eel catches decrease at warmer temperatures which were seen later in the season. Most years display a spike in eel abundance at Julian days 95-116, or early April (Table 1).

Table 1: The peak Julian date range and average were seen to shift to an earlier time throughout the years at Furnace Brook. The average water temperature during these peak arrivals were near 55 degrees Fahrenheit- possibly indicating the optimal temperatures for juvenile American eels. Colours correspond with Figure 7.

Year	Peak Julian Date Range	Average Peak	Water Temperature Average (F)	Water Temperature Range (F)
2008	122-130	126	57.2	53.6-62.6
2009	102-118	110	58.3	49-73
2010	95-121	108	56	46-68
2011	88-120	104	49.3	38-62
2012	93-105	99	57	45-62
2013	98-111	104	56.8	51.8-62.6
2014	102-126	114	55.9	41-68
2015	113-121	117	63.5	50-69.8
2016	72-110	91	51.3	43-64
2017	87-110	98	53.7	43-62
2018	77-107	92	45.9	40-54
Averages	**95-116**	**106**	**55**	**45.5-64.4**

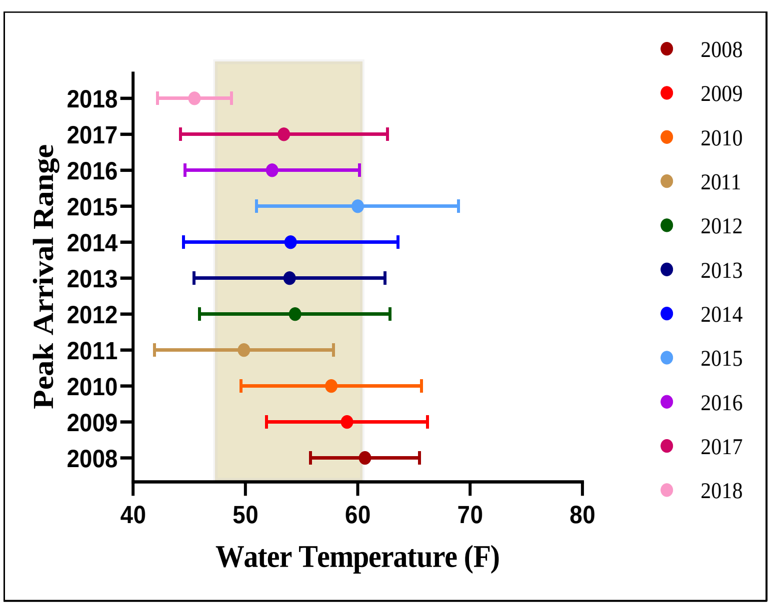


Figure 11: Mean water temperatures during American glass eel peak arrival window in Furnace Brook for years 2008-2018. Shaded area represents mean peak date range. Coloured dot represents the average of the peak arrival range of each year. Peak arrival of glass eels typically occurs between Julian dates 95-116 when water temperatures approached 55 degrees Fahrenheit at Furnace Brook 2008-2018. Colours correspond with Figure 7.

A peak arrival typically occurred within Julian dates 95-116, however, with the availability of 11 years of data, a visual shift in the Julian date range of peak arrivals was seen (Table 1); generally, to an earlier peak arrival. Within this peak arrival, water temperatures averaged 55 degrees Fahrenheit and often stayed between 45.5-64.4 degrees Fahrenheit (Table1; Figure 11). These temperatures may act as the optimal temperature for juvenile American eels, where they may achieve the highest body condition possible resulting in their peak arrival.

6.5: Glass Eel Weight Decreases Throughout the Migration Season

Our study builds upon previous research by incorporating glass eel weight as a measure of fitness. We reveal a decrease in glass eel weight throughout the season. The heaviest, fittest eels were found to arrive earlier in the migration season (Figure 12 A-K); those arriving later are lighter and presumably weaker. On average, the fittest eels arrived between Julian days 70-100, approximately late March.

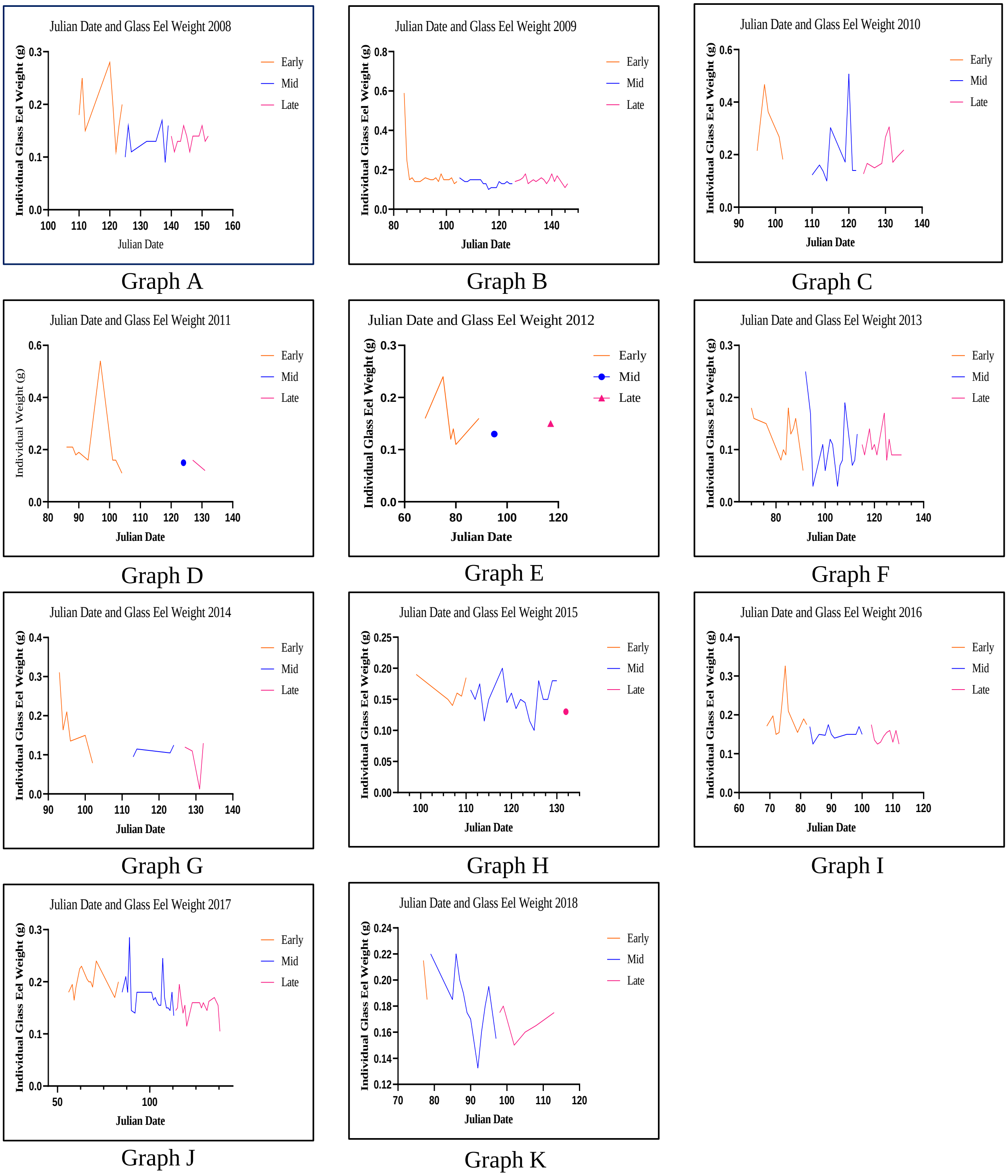


Figure 12 A-K: American glass eel weight decreased with Julian date 2008-2018 at Furnace Brook. Glass eel weights decrease with later Julian dates. Those arriving at later Julian dates or later in the migration season weigh less and are presumably weaker. Those arriving earlier are fitter. Data collection for fitness was only available for select days hence the gaps in the graphs.

6.6: Water Flow Decreases Throughout the Migration Season

Water flow was seen to decrease with later Julian dates, we observed moderate negative correlations (r= -0.069, P= 0.038, 2017; r= -0.601, P< 0.0001, 2018; Figure 13). The flow is thought to be higher at earlier Julian dates, earlier in the season, due to snow melts and precipitation events. Days with higher flows may affect the migration of glass eels within the Hudson River.

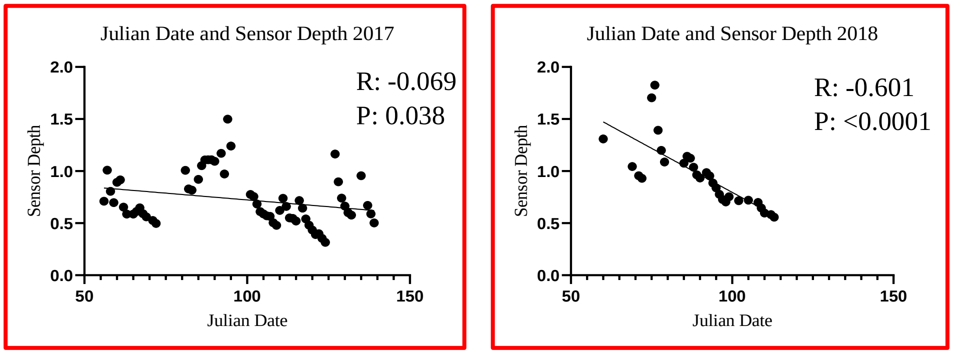


Figure 13: Julian date and sensor depth 2017-2018 at Furnace Brook, measured via U20L HOBO Logger. Water flow decreases throughout the migration season. **Significant,** negative relationships were seen.

6.7: Glass Eels Weigh More at Higher Water Flows

To determine if water flow in the tributary corresponded with eel fitness, we ran correlations for the years when the HOBO sensor depth data were available (2017-2018). A Pearson's correlation revealed a moderate positive relationship between eel weight and sensor depth for the 2018 data (P<0.001, R= 0.35). Therefore, glass eels weighed more with stronger water flows (Figure 14 A&B). It is possible that heavier/fitter glass eels are better able to withstand the higher flows of water associated with spring melt and therefore arrive earliest in the season. A similar trend was not observed in 2017, possibly due to changes in weather events. However, it is also possible that the relationships relate to timing. As seen previously, glass eels weigh more earlier in the migration season where water flows were higher.

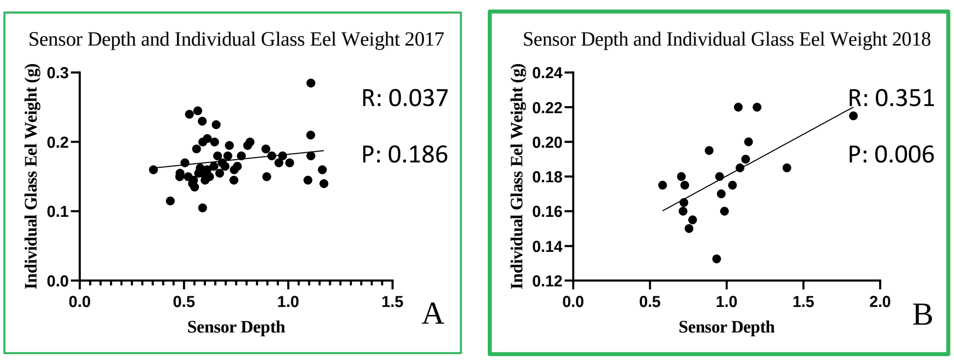


Figure 14: Sensor depth and American glass eel weight 2017-2018 at Furnace Brook, measured via U20L HOBO Logger. Glass eel weight increases with increased water flow. A significant positive relationship was seen for 2018 (B). Both showed positive relationships.

6.8: Decrease in Glass Eel Weight with Increase in Water Temperature

Three of the 11 years analysed revealed weak to moderate negative correlations between eel weight and tributary water temperatures (Figure 15 A-K). The heaviest, fittest eels are arriving with lower water temperatures, relating to the lower temperatures seen earlier in the season. It is plausible that lower temperatures induce lower locomotor activity and energy resulting in them being weaker and less heavy.

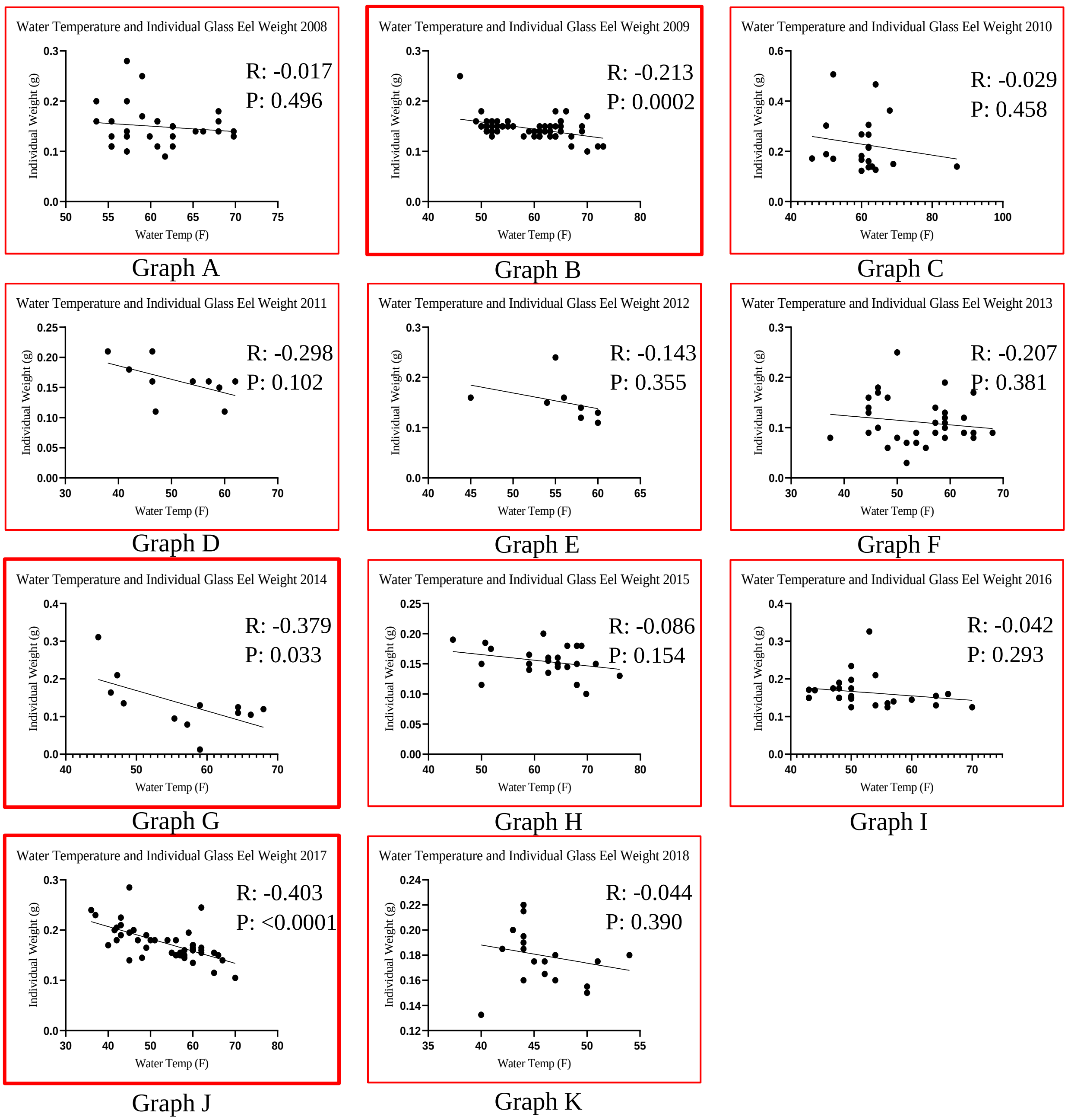


Figure 15 A-K: Water temperature and American glass eel weight 2008-2018 at Furnace Brook. Negative relationships were seen indicating a decrease in weight with an increase in water temperature. Exceptions: 2009, 2014, & 2017 saw **significant** correlations ($p \leq 0.05$).

7.0 Discussion

7.1: Shifting Environmental Conditions are Influencing Health and Abundance of Glass Eels

This study offers novel insight on the role of seasonal environmental factors affecting the American eel, an endangered species once ubiquitous in the Northeastern Atlantic. Moreover, we examined the glass eel stage and considered, for the first-time, glass eel fitness across an 11-year span. Due to the longitudinal nature of our data (2008-2019), this study was able to monitor variability in glass eel abundance and fitness at Furnace Brook, an important tributary that serves as an eel habitat. Glass eel abundance and fitness varied throughout the migration season likely due to variations in interannual environmental conditions such as wind currents, weather, water flow, and water temperature. Glass eel abundance was highest at lower water temperatures (46-64˚F) and higher water flows, conditions typical of the start of the migration season. However, an annual peak arrival of glass eels was observed mid-season (Julian dates 95-115), likely due to optimal environmental conditions (weather events, temperatures, winds, etc.). Furthermore, we show for the first time that glass eel fitness was highest at the start of the migration season with the fittest eels arriving earliest. Eels arriving later have reduced body mass and are thus in a less fit state for survival. The peak arrival was also seen to shift to earlier dates throughout the 11 years, suggesting a phenological shifts in American eels (Kuczynski 2017). The American eel may be a harbinger of climate change in the Hudson Valley.

Migratory behaviour of glass eels may be influenced by water temperature and body condition as supported by the findings of this study. Reduced environmental temperatures lowers muscle activity, influencing swimming performance and activity of eels (Edeline et al. 2005; Clark, Sandblom, Jutfelt 2013; Blakeslee, Galbraith, Deems 2018). However, if the water temperature is too high, it can result in mortality. Therefore, we propose that there is an optimal water temperature range for migrating glass eels (46-64 ˚F), a possible reason for a peak arrival at mid-season. Recently, with changes in climate conditions, such as increases in water temperatures (NOAA 2019) and changes in currents (NOAA 2019), we must consider the possible influence on species such as the American eel which rely on these environmental factors for migration, as manifested in this study. Our findings help to identify the scope of shifting environmental conditions on American eels. While the effects of climate change are only beginning to appear in the Hudson Valley, continued monitoring efforts for sensitive/ declining species such as the American eel should be continued as ecological asynchronies may emerge with changing phenological patterns (Kuczynski 2017).

In 2003 Knights hypothesised that global warming trends, such as changes to the Sub-Tropical Gyre (STG) impede thermocline mixing in spring as well as nutrient circulation, resulting in negative influences on productivity and thus food for larvae. Additionally, concurrent gyre spin-up also disturbs major currents. This deceleration of oceanic migration is likely to have augmented starvation and predation losses. As a result, fewer eels may be recruited in freshwater tributaries as some did not make it through the migration to reach freshwater habitats. I created a figure to explain this cycle (Figure 15).

This may also serve as an explanation for differences in eel body mass; certain eels receive less food therefore making them weaker. Changes in environmental factors can influence their migration making it longer and harder. Therefore, the eels arriving later, as seen in our results, may have done more travelling and are weaker as a result. In addition, provincial conditions, such as unfavourable wind-driven currents, may also influence arrival of glass eels on continental shelves (Knights 2003). This may explain why we observe a large amount of variability or discrepancies in glass eel recruitment each season- as seen in our results. This study was able to provide a bigger picture of the changes in environmental conditions within the 11 years of data and their influence on the glass eel arrival.

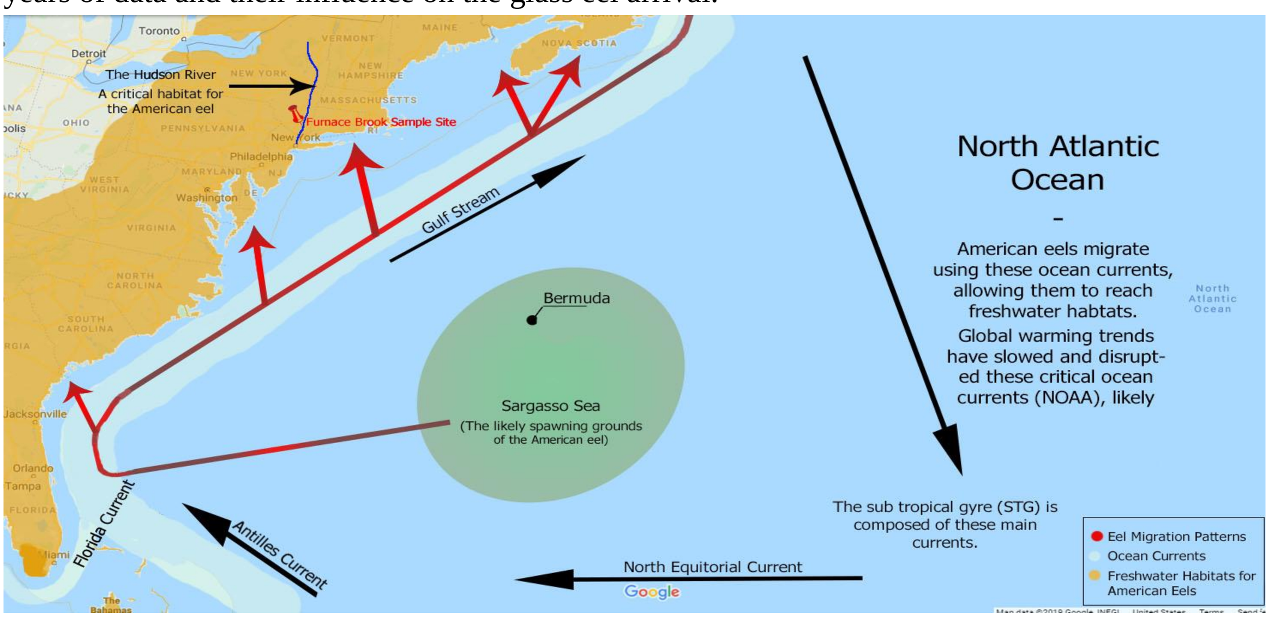


Figure 15: Disruption of migration of American eels by global warming trends. American eels migrate using ocean currents, however, with global warming, ocean circulation has been disrupted, resulting in negative impacts on food availability as well as slowing of the currents (Knights 2003). This has possible consequences including starvation and lower fitness of juvenile eels, resulting in greater mortality for this already declining species. (Figure created by student researcher, adapted from; Google Maps; NOAA 2019; Kuffner 2018; U.S. Fish and Wildlife Service 2019)

7.2: Significance and Applications

Our findings highlight the possible effects of climatic change and the impact on local and oceanic environmental conditions which in turn affect glass eels during their spring migration. Furthermore, with 11 years of data, we are able to make more accurate conclusions and provide valuable insight for this declining fish species. The findings provide a rationale for future conservation strategies to help the American eel population. Additionally, data collected through this citizen science project is sent as an annual report to the Atlantic States Marine Fisheries Commission (ASMFC). The ASMFC manages eel and other fish species via interstate management plans and associated addendum regulating commercial and recreating harvest, thus our research helps to build stronger conservation plans.

7.3: Creative Approach & Future Research

This study took a novel approach examining the effects of shifting environment factors on juvenile eel catch and fitness. It was one of the first to examine glass eel migration into Northern freshwater tributaries. In addition, we analysed 11 years of data providing more reliable findings specifically for the scope of monitoring response to climate change. Research must be continued to fully understand the continuing effects of climate change on this population. Furthermore, this research provides crucial information on a species at the glass eel stage whom not much is known about.

Future research should analyse other study sites along the Hudson River as well as other prime habitats to have an even larger scope of the fitness and abundance of glass eels. Additionally, weather events throughout the migration season should be examined and analysed for their effects upon catch and fitness of glass eels. To better understand eels, it would also be useful to understand why changes in weight occur; possibly from parasites, disease, or other factors not considered in our study.

8.0 Conclusion

Our study monitored juvenile eel fitness, abundance, and environmental metrics to reveal a peak in eel abundance mid migration season (Julian days 95-115) which related to preferred water temperatures ranges (45.5-64.4℉), and water flow. In addition, the peak arrival of glass eels shifted to earlier Julian dates throughout the 11 years of data collection. The fittest eels were seen to arrive first, at lower water temperatures and higher water flow, typical of the beginning of the season. However, shifting environmental conditions, i.e. water currents, water temperature, and water flow, in relation to climate change, may be causing later arriving eels to be weaker which in turn lowers their overall chances at survival. They may also be resulting in shifts to earlier arrival, possibly inducing detrimental phenological shifts in glass eels. These findings contribute insight on the scope of climate change at a local level, in a tributary of the Hudson River, a vital environment for the American eel. Furthermore, our research highlights necessary measures needed for their future conservation.

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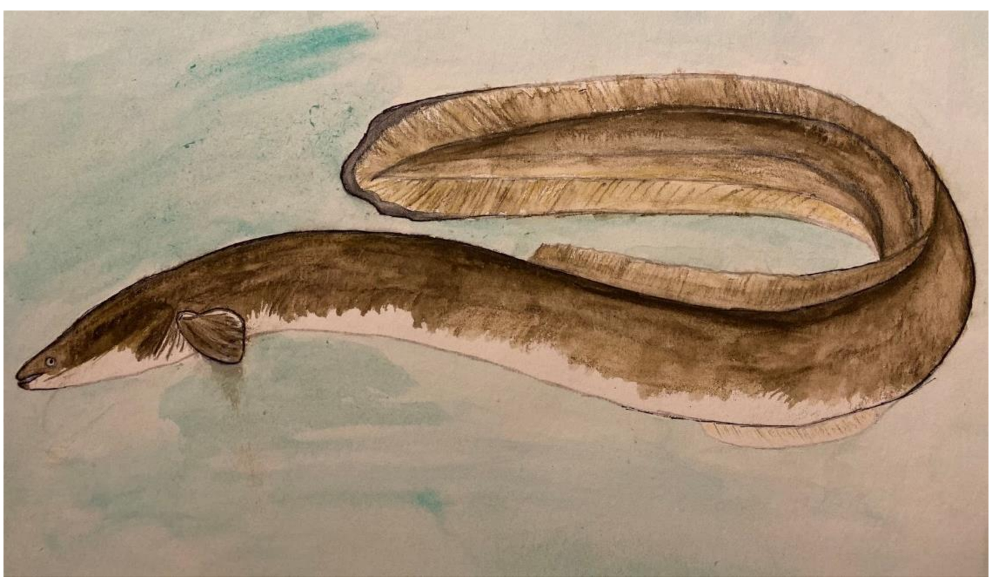

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