Species diversity and evenness in pool and riffle habitats of Rock Creek, Washington State, USA

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ABSTRACT

Varying conditions within aquatic habitats can drive species distributions and lead to a difference in biodiversity between habitats. This is an occurrence that can be observed within rivers, specifically between pool (low velocity flow) and riffle (high velocity flow) habitats. In this study, the biodiversity and evenness of species was analyzed within pool and riffle habitats in four reaches along Rock Creek, in Washington State, USA. I hypothesized that there would be a higher biodiversity and evenness in riffle habitats due to evidence presented in previous studies that highlighted the possibility of predator aggregations and increased parasite transmission rates in pool habitats. In this study, I analyzed a multi-year dataset by calculating Shannon Diversity index and Pielou Evenness index values to determine biodiversity and evenness of the creek. Values were calculated for all riffle and all pool habitat combined from all reaches of the river, and then for each individual reach as well. Then, relative species proportions of torrent sculpin, cutthroat trout, and Coho salmon were also analyzed. I observed that torrent sculpin were found to be the numerically dominant species in every habitat. These analyses showed that biodiversity and evenness were consistently higher in riffle than in pool habitats. This difference could be attributed to higher proportions of cutthroat trout and Coho salmon in pool habitats than in riffle habitats. This may be due to the varying body morphologies and habitat preferences of cutthroat trout and Coho salmon as compared to torrent sculpin. The results of this study highlight the reliance of Coho salmon and cutthroat trout on pool habitats in rivers, and can be used as evidence to reduce deforestation, a practice seen to degrade pool habitats in rivers.

Keywords: Shannon Diversity index, Pielou Evenness index, freshwater habitats, cutthroat trout, Coho salmon, torrent sculpin

INTRODUCTION

Within aquatic ecosystems, differing habitat conditions drive species distributions, which may result in variable species diversity in contrasting habitat types. Elevation, channel slope, water velocity, and substrate embeddedness have all been seen to impact the distributions of fish species within an ecosystem (Kruse et al. 1997). These conditions can affect energy use and fitness of organisms, leading to habitat preference within species, and variations in biodiversity between habitats (Claireaux & Lefrançois 2007). A river is considered to be a lotic environment, due to the movement and flow of the water (Paul et al. 2018). However, there are pockets within a river that can be considered lentic due to their decreased flow. These areas are called pools, deep regions of the river with a low flow velocity (Yang 1971). The remainder of the river can still be considered a lotic environment, as it is made up of riffles, shallow regions of the river with a higher flow velocity (Yang 1971).

A previous analysis performed in Bangladesh found that there was a higher level of diversity in lotic ecosystems than in lentic ones (Jewel et al. 2018), suggesting that there could be systematic differences between high-flow and low-flow habitats within rivers. Varying diversity among habitats may be related to predator densities, which may in turn vary based on abiotic conditions. In a study conducted in a creek in the Cascade mountains of Washington State, it was observed that salmon and trout species were significantly more abundant in pools, and that their invertebrate prey were significantly more abundant in riffles (Naman et al. 2018). This supports the idea that species diversity can be driven by predation, and may therefore be lower in pools than riffles due to the higher density of predators. Predators inhabiting pools may drive a shift of prey into riffle habitats in order to avoid predation and increase their fitness. This would be most likely to occur if these predation threats outweighed other benefits from inhabiting pools.

Additionally, the high volume of predators in the pools could reduce the diversity in those areas due to the direct consumption of their prey.

Another reason diversity is likely to be higher in a riffle environment is the transmissibility of parasites. In an experiment conducted on polychaete parasites and Chinook salmon and rainbow trout hosts, it was found that infection rates declined with increasing water velocity (Bjork & Bartholomew 2009). This pattern may be observed due to an increased difficulty for parasites to find and attach to a host in high-velocity environments. A high rate of infection in waters of slower velocities would likely lead to a lower diversity in these areas, such as pools. This is because infection with a parasite can lead to decreased fitness and individual health, which would make it more likely for organisms to avoid these areas and spend more time in riffles (Ebert 2005).

However, we might also expect to observe the opposite pattern of a higher diversity in pools than in riffles. This is because swimming costs and difficulty of finding food sources are much higher in riffles than in pools (Rosenfeld & Boss 2001). These conditions support the idea that species would likely spend more time in pools in order to expend less energy on swimming and foraging in a high-velocity flow. Growth rates have also been seen to be higher in pools, which supports this idea as well because prey are more likely to survive predator attacks when they are large, relative to the predator (Lundvall et al. 1999).

In this study, I used the Shannon Diversity index to compare species diversity between pool and riffle habitats of Rock Creek, a tributary of the Cedar river in Washington State, USA. The diversity of ecological communities can be calculated through a variety of methods, including the Shannon Diversity index. The Shannon Diversity index is a mathematical calculation that yields a value representative of the diversity of an ecosystem (Diversity Indices

2020). It considers not only the number of species in an ecosystem, but also their relative abundances (Diversity Indices 2020). Additionally, the species evenness will be analyzed by calculating Pielou Evenness E_H from the Shannon Diversity index values, which will yield a value between 0 and 1. The closer a value is to 1, the less a habitat is dominated by one or a few species, showing a more evenly distributed community (Diversity Indices 2020). Based on the evidence collected regarding the possible accumulation of predators in pool habitats and the increased transmission rates of parasites in riffle habitats, I hypothesized that the Shannon Diversity index would be higher in the riffle habitats than the pool habitats. As Pielou Evenness E_H was also analyzed, I hypothesized that this would yield a number closer to 1 for the riffle habitats than the pool habitats. This would suggest a more even distribution of species within the riffle habitats.

METHODS

Study Site.

The study took place in Rock Creek, a tributary of the Cedar River in Washington State, USA. Four different reaches of the creek were studied: lower, middle, upper, and Webster Creek (Fig. 1).

Data Collection

At each of the three sites, one riffle and one pool were studied. At each riffle and pool, both fish and habitat measurements were collected. Fish measurements included the species and the length of each fish caught through the use of a backpack electrofisher. Habitat measurements consisted of the velocity and the depth at each pool and riffle site. Data were collected on one day in each season that the previous FISH 312 class visited the stream. This data collection occurred in October (Fall) and April (Spring) from the year 2003-2007, and only during Spring from the year 2008-2019. Data were collected for the Webster Creek reach only during the Spring 2013 sampling.

Shannon Diversity Index

The Shannon Diversity Index was calculated for riffle and pool environments in order to determine the diversity within each habitat type. Firstly, the catch data were filtered into separate Excel sheets containing only pool and only riffle catch data. Next, the counts by species were determined using pivot tables. Once this was accomplished, the proportions of each species were calculated. Then, the natural logs of those proportions were calculated. Finally, the values were combined in the equation

$$H^1 = \Sigma \, [-Pi * (\ln Pi)]$$

in which Pi is the proportion of the species i in the data set, and lnPi is the natural log of that proportion. First, I used this equation to calculate Shannon Diversity index values of all riffle or all pool habitats combined across the reaches in Rock Creek. In addition, I calculated Shannon Diversity index values from all riffle or all pool habitats within each separate reach. These calculations were performed for all years combined.

Pielou Evenness Index

The evenness of species was calculated using the Pielou Evenness Index, which is based on the values of H^1 collected from the Shannon Diversity Index. This Index is calculated using the equation

$$E = H^1 / H^1 \max$$

in which H^1 max, or the maximum diversity, is equal to the natural log of r, and r is equal to the total number of species observed in that habitat. This equation was used to calculate the Pielou Evenness index values of all riffle and all pool habitats combined across the reaches in Rock Creek. In addition, I calculated the Pielou Evenness index values from all riffle or all pool habitats within each separate reach. These calculations were performed for all years combined.

Species Proportions and Richness

In order to attempt to explain any difference observed between riffle and pool H and E values, the relative species abundances were observed and analyzed. The proportions of torrent sculpin (*Cottus rhotheus*), cutthroat trout (*Oncorhynchus clarkii*), and Coho salmon (*Oncorhynchus kisutch*) of the total catch were calculated for the riffle and pool habitats. This was achieved by dividing the number caught of each species by the total number of individuals caught in either all riffle or all pool habitat. These calculations were performed for all years combined.

Species richness was determined by comparing the number of species caught in pool habitats versus the number of species caught in riffle habitats, across all reaches. Species richness was also determined for the pool and riffle habitats at each individual reach.

RESULTS

All pool and riffle habitats

The Shannon Diversity Index (*H*) value calculated for all pool habitat (1.35) was higher than the value calculated for all riffle habitat (0.82) (Fig. 2). The Pielou Evenness Index (*E*) value calculated for all pool habitat (0.54) was also higher than the value calculated for all riffle habitat (0.33) (Fig. 2).

Riffle habitat by reach

The *H* value calculated for the riffle habitat analyzed in the middle reach of the creek (0.96) was the highest value when compared to the *H* values calculated for riffle habitat in the other three reaches included in the study (Fig. 3). The *H* values of the upper reach (0.65) and lower reach (0.68) were similar, and the *H* value calculated for the Webster Creek reach (0.45) comparatively lower (Fig. 3). When compared to the *H* value calculated for all riffle habitat in the study (0.82), the only reach that yielded a higher value was the middle reach of the creek (Fig. 3).

The *E* value calculated for the riffle habitat in the middle reach of the creek (0.42) was again the highest value when compared to the *E* values calculated for the riffle habitat in the other three reaches included in the study (Fig. 3). The *E* values of the lower reach (0.33) and Webster Creek (0.32) were the most similar (Fig. 3). The upper reach riffle habitat yielded the lowest comparative *E* value (0.27) (Fig. 3). When compared to the *E* value calculated for all the riffle habitat in the study (0.33), the lower and Webster Creek reach *E* values were very similar to it, and the only reach that yielded a higher value was the middle reach of the creek (Fig. 3).

Pool habitat by reach

The *H* values of the pool habitat followed a similar pattern to those observed across the riffle habitat. The *H* value calculated for the pool habitat in the middle reach of the creek (1.57) was the highest value when compared to the *H* values calculated for the pool habitat in the other three reaches (Fig. 4). The lower reach pool habitat yielded an *H* value of 1.19, and the upper reach pool habitat yielded an *H* value of 1.04 (Fig. 4). The Webster Creek reach yielded the lowest *H* value (0.86) (Fig. 4). When compared to the *H* value calculated for all pool habitats in the study (1.35), the only reach that yielded a higher value was the middle reach of the creek (Fig. 4).

The *E* values of the pool habitat also followed a similar pattern to those observed across the riffle habitat. The *E* value calculated for the pool habitat in the Webster Creek reach (0.79) was the highest value when compared to the *E* values calculated for the pool habitat in the other three reaches analyzed within the study (Fig. 4). The *E* values calculated for the pool habitat in the upper reach (0.48) and lower reach (0.50) of the creek were the most similar, and were also the lowest comparative *E* values (Fig. 4). The middle reach *E* value (0.68) fell between those of the Webster Creek and lower reaches (Fig. 4). When compared to the *E* value calculated for all pools in the study (0.54), both the middle and Webster Creek reaches yielded a higher value (Fig. 4).

Species Proportions and Richness

In both the pool and riffle habitat, torrent sculpin were seen to be the most numerically dominant. In the riffle habitat, the proportion of torrent sculpin to the total catch was 0.81. In the same habitat, the proportion of cutthroat trout was 0.09, and the proportion of Coho salmon was 0.02. In the pool habitat, the proportion of torrent sculpin to the total catch was 0.62. In the same habitat, the proportion of cutthroat trout was 0.11 and the proportion of Coho salmon was 0.12. These data show a larger proportional abundance of cutthroat trout and Coho salmon in the pool habitat than in the riffle habitat, as compared to the total catch.

The species richness observed in all pool habitats (12) was equal to the species richness observed in all riffle habitats (12). The species richness observed in the pool habitats of the lower reach (11) was higher than the species richness observed in the riffle habitats of the lower reach (8). The species richness observed in the pool habitats of the middle reach (10) was equal to the species richness observed in the riffle habitats of the middle reach (10). The species richness observed in the pool habitats of the upper reach (9) was lower than the species richness observed in the riffle habitats of the upper reach (11). The species richness observed in the pool habitats of the Webster creek reach (3) was lower than the species richness observed in the riffle habitats of the Webster creek reach (4).

DISCUSSION

Analysis of the Rock Creek data set yielded Shannon Diversity (*H*) and Pielou Evenness (*E*) Index values that were consistently higher in pool than in riffle habitats. These results did not support my hypotheses that the *H* and *E* values would be higher in riffle than in pool habitats. The order of *H* values among reaches was the same for pools and riffles, with the middle reach having the highest *H* values in both habitats when compared to the other reaches of Rock Creek (Fig. 3, 4). The lower reach had the second highest *H* values, the upper reach had the third highest *H* values, and the Webster Creek reach had the lowest *H* values for both habitats when compared to the other analyzed reaches (Fig. 3, 4). Factors that may support high biodiversity in the middle reach include depth, nutrient flow, elevation, food delivery rates, sunlight availability, and geomorphology. A future study comparing differences between these factors at each reach could yield valuable information regarding the distributions and evenness of species. Regarding the matching orders between riffle and pool H values, these factors may also be involved.

Another factor that may be leading to this similarity may be increased fish movement between nearby pool and riffle habitats. This relationship may lead to identical ranks of *H* values of the two habitats at a given reach.

When analyzing the species-specific data collected throughout the study, it became apparent that species richness was very similar between the pool and riffle habitats of each reach. For this reason, it can be assumed that the species richness is not the driver of observed differences in H values among sites and habitat types. It also became apparent that the torrent sculpin was the most abundant species in both pool and riffle habitats, at every reach. Additionally, cutthroat trout and Coho salmon were observed to have had a large disparity in relative abundances between the riffle and pool habitats, when compared to the total catch. The data showed that the cutthroat trout and Coho salmon made up a higher proportion of the total catch in riffle than in pool habitats. Therefore, torrent sculpin made up a lower proportion of the total catch in riffle than in pool habitats. Although the torrent sculpin is still the numerically dominant species in pools, the cutthroat trout and Coho salmon are present in higher numbers in these habitats. These differences in cutthroat trout and Coho salmon abundances contributed to the observed difference between the *H* and *E* values of the pool and riffle habitats.

One way to explain these differences in cutthroat trout and Coho salmon abundances may be due to the difference in habitat suitability between pools and riffles for the species. Cutthroat trout seem to perform best in habitats with areas of slow, deep water, or pools, where they can successfully feed (Hickman & Raleigh 1982). This suggests that cutthroat trout are better adapted for life in pool habitats of rivers or streams, and supports the difference in observed abundances between the two habitats analyzed in this study. However, cutthroat trout are able to grow in riffles as well, which can explain why they were also found in these habitats (Rosenfeld

& Boss 2001). Coho salmon were also seen to spend a majority of their time in low velocity habitats, supporting the finding that Coho salmon were found in greater abundances in the pool habitat than in the riffle habitat (Rosenfeld et al. 2005, Bustard & Narver 1975). In contrast, sculpin have been found to exhibit little to no preference regarding physical habitat features (Mebane 1999). This supports the findings in this study that show torrent sculpin being the numerically dominant species in both pool and riffle habitats.

These findings may be explained by differences in body morphology between the two species, which likely has an effect on the fitness of each species in the pool and riffle habitats. The torrent sculpin has a dorso-ventrally flattened body plan that allows them to stay close to the bottom of the river and find shelter from the higher velocity flow in cracks between rocks (Torrent Sculpin 2020). Additionally, the shape of their heads can minimize energy use, making it possible for the species to successfully exploit a riffle habitat (Gaston et al. 2012). Comparatively, the cutthroat trout and Coho salmon body plans are more laterally flattened with a truncate tail (Machtinger 2007, Bisson et al. 1988). This might allow the species to have large bursts of speed and have high maneuverability (Fish Morphology 2020, Bisson et al. 1988). However, this body plan is not evolved to sustain swimming at high velocities for large periods of time (Bisson et al. 1988). This allows the species to be able to spend short periods of time travelling or searching for food in riffle habitats, but to return to the safety of the pool habitats to preserve energy for a large portion of time. This body plan difference can help explain the greater abundance of cutthroat trout and Coho salmon in pool habitat than in riffle habitat.

Additionally, the torrent sculpin, cutthroat trout, and young Coho salmon share a food source of aquatic insects, so it is also likely that the torrent sculpin is able to outcompete for resources at a higher efficiency in the riffle habitats (Torrent Sculpin, Machtinger 2007). This in combination with the differences in body plans might explain why torrent sculpin are present in proportionally greater abundance in the riffles than the pools. The torrent sculpin is able to have both a higher energy intake and a lower energy output from swimming than the cutthroat trout or Coho salmon in the riffle habitats, which would naturally suggest that cutthroat trout and Coho salmon are outcompeted by torrent sculpin in these areas.

The data analyzed in this study provides ideas for future research and management policies to help maintain biodiversity in creeks. For example, these data showed the reliance of cutthroat trout and Coho salmon on pool habitats. For this reason, these results can be used to support future management to maintain these habitats. Deforestation has been linked to increasing velocities and narrowing streams, which would lead to a transition to a largely riffle-based river habitat (Sweeney et al. 2004). Changes in the habitat composition of the river would likely change the abundance of cutthroat trout by reducing the suitable rearing habitat for the species, which may have a large impact on the river ecosystem (Rosenfeld & Boss 2001).

In conclusion, the data in this study showed that the H and E values of pool habitats in the reaches of Rock Creek were larger than those calculated for the riffle habitats. This pattern was likely due to the increased presence of cutthroat trout and Coho salmon in the pool habitats. Additionally, the middle reach of the creek had the highest H and E values for both riffle and pool habitats, when compared to the other reaches. The contrasting environmental conditions and adaptations between cutthroat trout, Coho salmon, and torrent sculpin led to a difference in diversity and evenness between habitats in the reaches of Rock Creek. Such variations can likely be observed in many other ecosystems as a result of similar occurrences.

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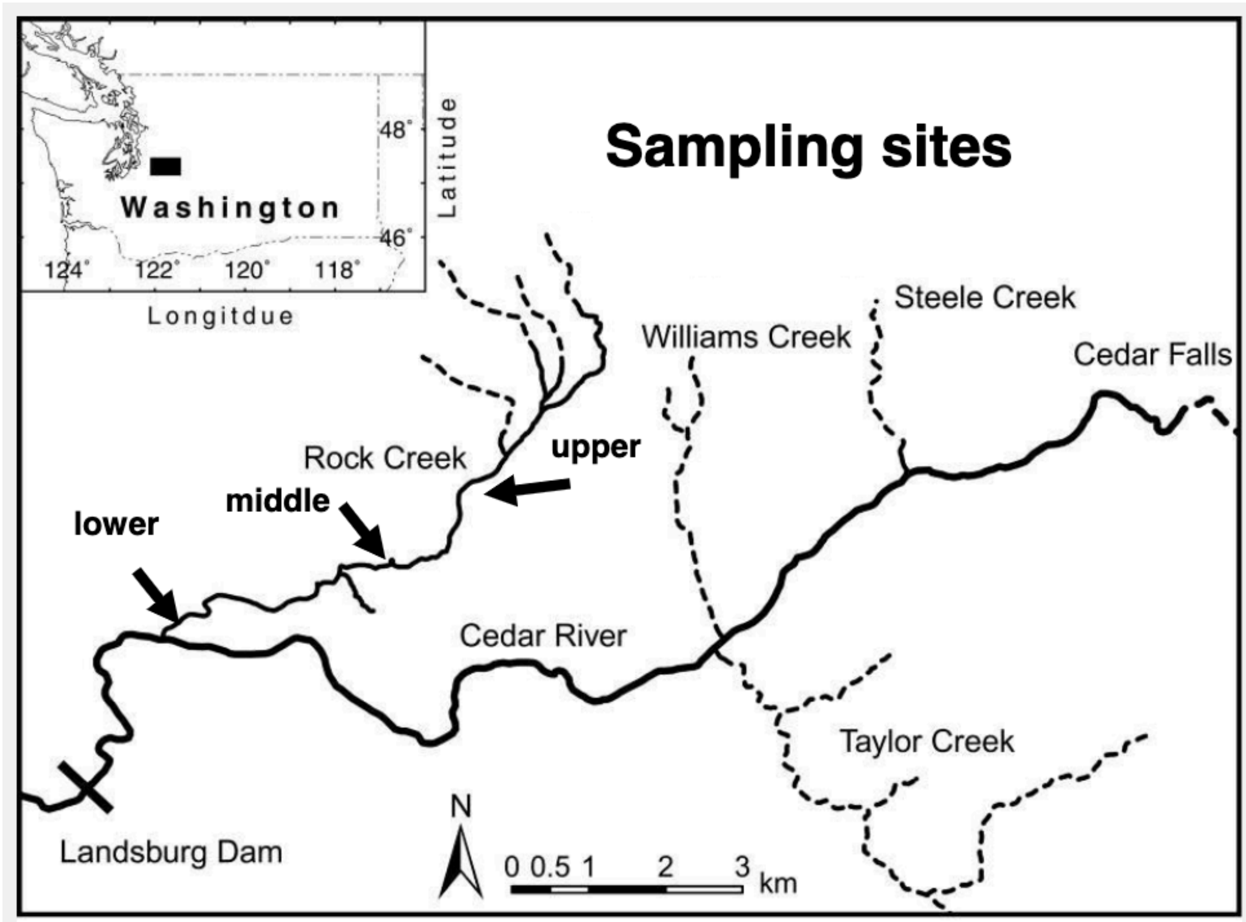

Figure 1. Map showing Rock Creek and the three reaches studied in this experiment. Adopted without changes from RockCreek.pdf (FISH 312 course materials). Webster Creek not shown.

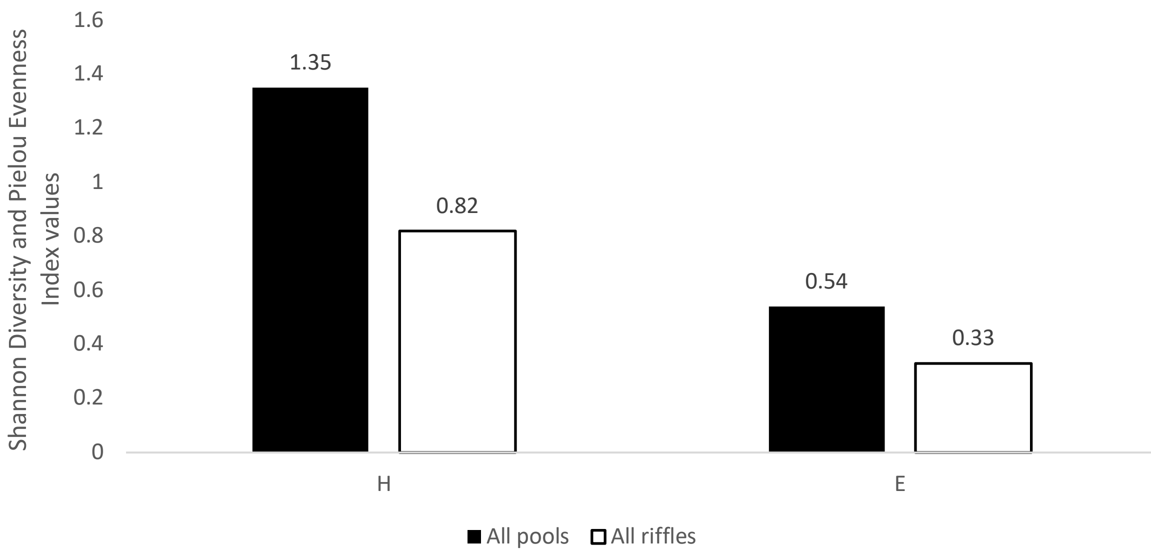

Figure 2. Shannon Diversity Index (H) and Pielou Evenness Index (E) values of all pools and all riffles analyzed within the study, throughout all years.

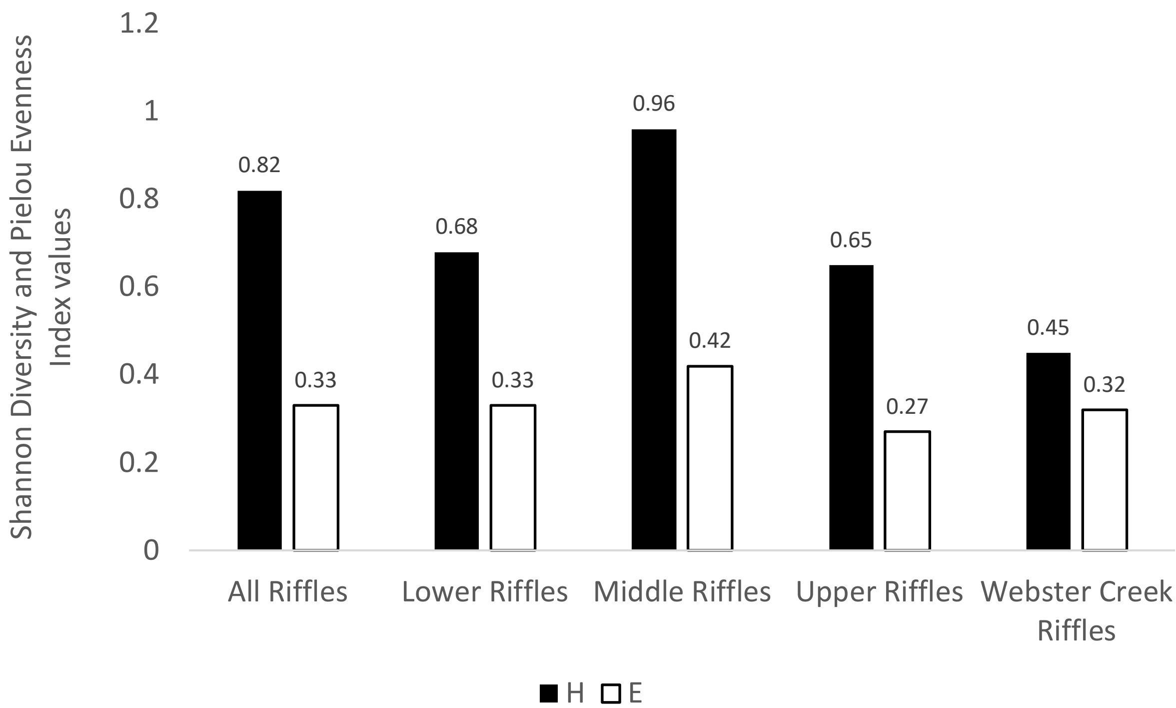

Figure 3. The calculated Shannon Diversity Index (H) and Pielou Evenness Index (E) values for the riffle habitats analyzed in each reach of the creek. Values calculated for "all riffles" are included for comparison.

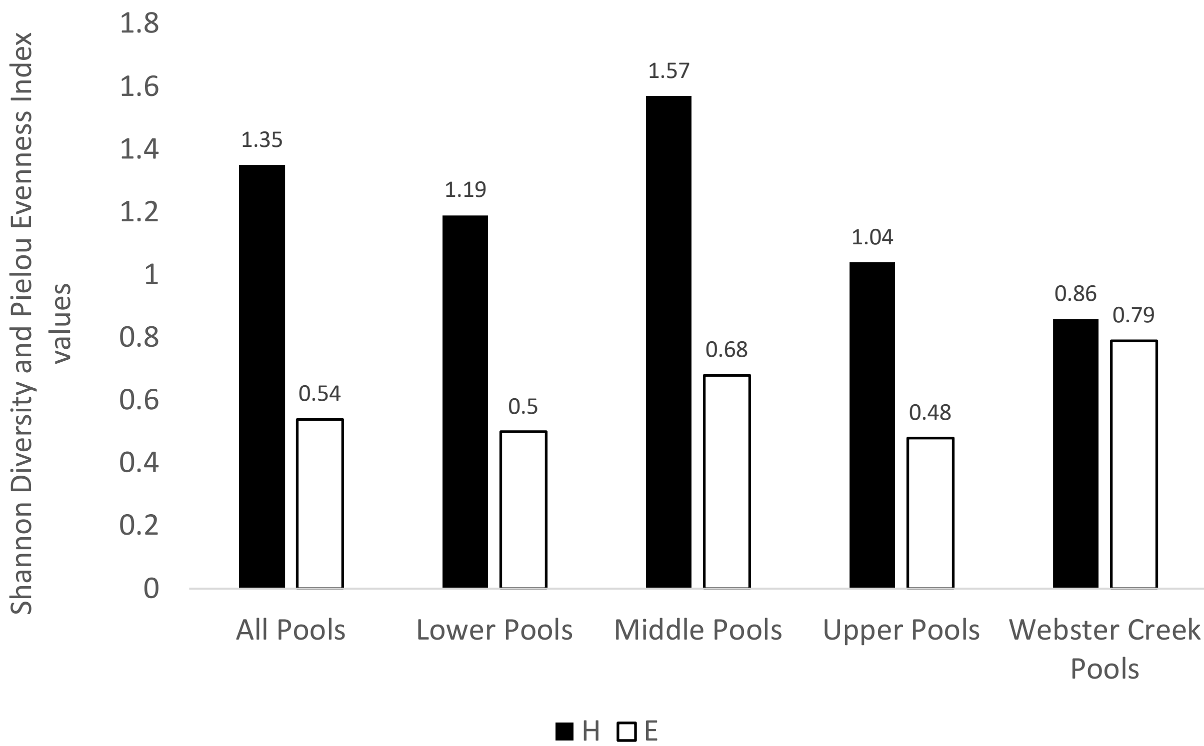

Figure 4. The calculated Shannon Diversity Index (H) and Pielou Evenness Index (E) values for the pool habitats analyzed in each reach of the creek. Values calculated for “all pools” are included for comparison.