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The Influence of Flooding on Macroinvertebrate Diversity of the James River Rock Pools

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by

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Abstract

Biodiversity within an ecosystem can be greatly influenced by environmental disturbances, such as fires, flooding, or other extreme events. Studying the effects of these disturbances on species diversity can be complicated though, due to difficulties tracking species-level responses and isolating the effects of disturbances. Model systems in community ecology, such as rock pools, are a beneficial way to scale down the study of disturbances in discrete communities without losing the ability to analyze important influences or interactions. In this study, macroinvertebrates within the James River rock pools were surveyed to investigate seasonal and annual differences in species richness and diversity, as well as changes following a flooding event. Four periods of pre- and post-flood surveys, spring and fall of 2018 and 2019, were used in this study. Flooding events occurred during all periods expect fall of 2019. Season was found to have a significant effect on biodiversity, with a higher average richness and diversity index found in the fall. The fall flooding event in 2018 was found to decrease biodiversity within the pools as expected, whereas biodiversity in the spring was found to stay the same after flooding events, or increase. These results demonstrate that community-level effects due to flooding are context-dependent, due to the complex and dynamic nature of ecological systems. Longer-term studies addressing aspects such as pool composition or spatial location, species assemblage, and even anthropogenic influence are needed to better understand how disturbance events shape the biodiversity within the James River rock pools. By understanding how disturbance shapes ecological communities, we can better asses how future disturbances may alter the biodiversity of an ecosystem. This knowledge is particularly important as the frequency and severity of climatic events and disturbances increases under climate change.

Introduction

Biodiversity, the number and composition of species within a community, plays a crucial role in ecosystem functions (Willig & Presley; 2018, Gamfeldt et al., 2008). A majority of studies have used a single-function perspective to investigate the role of biodiversity, where the response of ecosystem functions to changes in species composition can only be assessed one species at a time (Gamfeldt et al., 2008). The metacommunity concept, however, takes a more holistic approach to understanding the role of biodiversity by considering interactions that occur within and between different spatial scales within an ecosystem. Not only are the flow of resources within one patch and its immediate surroundings considered, but the interaction, dispersal, and flow of resources between separate but spatially close communities are examined as well (Leibold et al., 2004). Biodiversity within a given area can vary over space, as well as time, and environmental disturbances can serve as a driver of this variation. Disturbances tend to be discrete events that can alter an ecological system's structure and composition. They can include tectonic events, high-energy storms, wildfires, floods, and even anthropogenic events, such as land conversion (Willig & Presley, 2018). In this study, a system of rock pools along the James River was used to investigate how flooding disturbance may affect biodiversity within a metacommunity.

Rock pools are naturally occurring pockets or holes that form in rock through the process of abrasion. They are globally distributed and exist in a variety of habitats, and can therefore be filled, or emptied, by water of rivers, oceans, or from precipitation (Jocque et al., 2010). Typical formation consists of a rock, called a grinder, getting caught in a small depression of the riverbed and then fast-flowing water of the river will pass over it, causing the rock to constantly rub against the surface and slowly carve out a rock pool over the course of hundreds or thousands of years (Fig. 1). These pools can be various sizes and depths based on the size of the rock forming it, as well as the length of time of formation, and can form a network of spatially close pools (Fig. 2) (Landforms of fluvial erosion and deposition, 2012; Geography Stuff, 2013). If the height of the river decreases, dries up, or is redirected, riverbed pools originally underwater can be exposed.

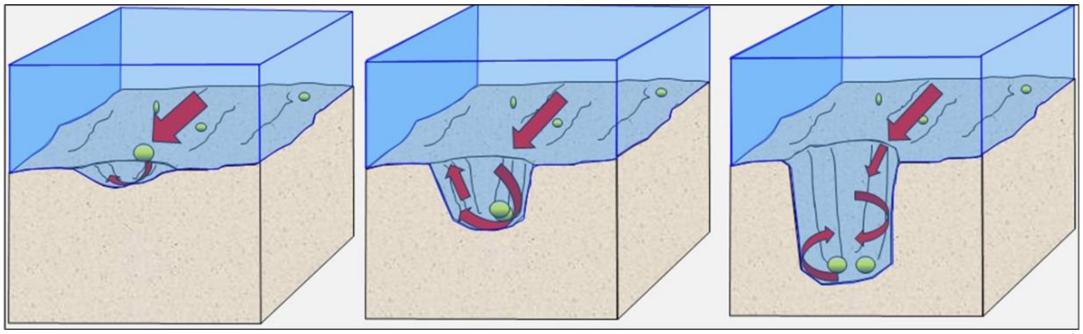

Figure 1. Cross section of a rock pool forming over time. As the fast-flowing water runs over the caught rock, the current causes the rock to rub against the river bed in a circular motion, slowly widening and deepening the original depression. (reprinted from Landforms of fluvial erosion and deposition, 2012)

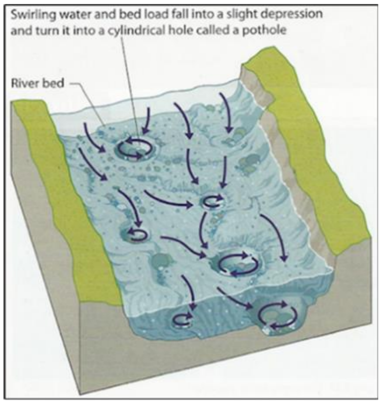

Figure 2. Top-down view of a rock pool system forming in a river bed. The size of the formed pool can depend on the size or number of grinders involved and how long the process has been occurring for. (reprinted from Geography Stuff, 2013)

In the United States, rock pools also form a geographic network up and down the eastern coast due to a geological feature called the fall zone. The 900-mile-long fall line, which extends from Alabama up into New England, is where the upland piedmont region of higher elevation and the coastal plain region of lower elevation abruptly meet (Freitag et al., 2009). Due to this rapid decrease in elevation, waterfalls and rapids are a common aquatic feature on the fall line, and this fast-flowing water is conducive to the formation of rock pools (Rutledge et al., 2011). Many important cities have developed along the fall line, due to the historical inability to cross these rapids, including Philadelphia, PA, Trenton, NJ, Washington, D.C., and Richmond, VA (Freitag et al., 2019). In Richmond, VA, rock pools are a prominent feature of Belle Isle, an island in the middle of the James River.

Rock pools are a beneficial system for this study as a small, relatively simple, and discrete ecosystem which allows for quantification of population and community processes that are much more difficult, or even impossible, to quantify in larger or more complex systems. As there tend to be a large number of pools within a distinct spatial system, it allows for both replication and manipulation of pools, such as investigating species interaction or disturbance patterns and effects (Brendonck et al., 2010). This spatial network also makes rock pools a great metacommunity model, due to the interactions at various spatial scales. The diversity of a single pool can be surveyed and quantified, but it can also be compared to pools of similar physical characteristics or spatial location, in addition to a nearby population source such as a river (Leibold et al., 2004). The rock pools on the James River emulate the set-up of a natural mesocosm experiment, where natural variation occurs due to pool size, distribution, and connectivity, and the connectivity is driven by flooding disturbance. This offers a unique opportunity to examine how diversity may vary between small ecosystems within a well-connected system, as well as how they are affected by emptying and refilling events from environmental disturbances.

While rock pools are useful in serving as a small ecosystem, they can still have a high diversity of species, ranging from bacteria and plankton up to frogs and fish. The diversity can also vary based on the geographic location, the habitat the pool is found in, or seasonal and annual variation (Jocque et al., 2010). A study of inter-tidal pools found between 11 and 68 taxa in each pool, while another study using temporary rock pools from mountain rivers found 43 taxa (Mendonca et al., 2018; Ren et al., 2016). Within the James River rock pools used in this study, 41 macroinvertebrates have been identified, in addition to various vertebrates occasionally found in the pools. In this study, we surveyed the aquatic macroinvertebrate community and used biodiversity metrics to test the effect of flooding on species diversity and composition over time, season, and in response to extreme flooding events.

This study examines the effect of flooding events on the richness and diversity of macroinvertebrates within the James River rock pools, using surveys collected over a two-year time period. Species richness and diversity indexes will be compared between years and seasons, to determine potential differences due to annual and seasonal variation. A second set of comparison will examine these metrics before and after flooding events within these seasons. I expect that richness and diversity index will decrease following a flooding event due to species within the pools being washed out and back into the main river channel (Lepori & Hjerdt, 2006). This rock pool system provides an important test of how biological communities are affected by disturbance events, which will advance our understanding of biodiversity within a complex, dynamic, and variable environment.

Materials and Methods

The Study System: Belle Isle

This study was conducted on Belle Isle, Richmond, VA, a 540 acre island located in the middle of the James River (Belle Isle, 2020). From 1904 to 1963, the Virginia Electric Power Company ran a hydroelectric plant at this location. Dams were installed to divert the water that originally flowed through this area to the powerplant (Fig. 3a, 3b), uncovering the rocky riverbed and rock pool system (The History of Belle Isle, 2014). Using low-water drone imaging and in-

Figure 3. Photos of Belle Isle from the 1800s (a, left) before the establishment of the Virginia Electric Power Company's hydroelectric plant, and after (b, right) in 1965. The dam and water diversion due to the hydroelectric plant have revealed the rock pools, circled. (reprinted from The History of Belle Isle, 2014; Riggan, 2014)

person confirmation, 752 rock pools have been identified in the Belle Isle system as of May 15, 2019 (Fig. 4).

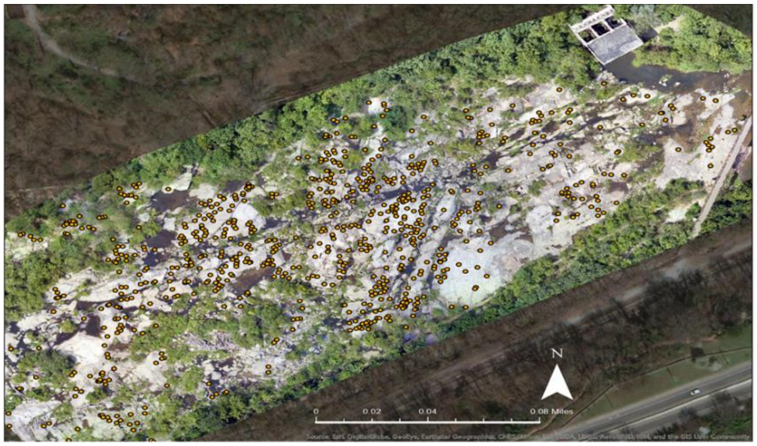

Figure 4. Low-water drone image of Belle Isle with rock pools denoted with an orange dot. Drone flown by VCU on 8/20/2017.

Data Collection: Rock Pool Surveying

Data collection from the rock pools began in July of 2009, and in that time 1,251 individual pool surveys have been collected by students and researchers at Virginia Commonwealth University, University of Richmond, and Richmond high schools. These surveys include data on the pools size, composition of bottom substrate, presence/absence of vegetation, and presence/absence overhead cover from trees. Macroinvertebrate richness was determined by surveying each pool with a nine-sweep protocol. One sweep consisted of sweeping a 5”x6” quick-net™ in a quick, smooth motion along 25 centimeters of either the open water column, side of the pool, or bottom of the pool. After a sweep was performed, the contents were poured into a white tray, rinsed, and the abundance for each species was counted and recorded. The tray was emptied back into the pool and rinsed after each sweep. In total 41 macroinvertebrate species have been identified within the James River rock pools. Any vertebrates, such as frogs or tadpoles, were also counted or their presence noted if visible but not caught, but they were not separated by individual species. This process was performed three times for each location within the pool for a total of nine sweeps. Data was recorded and uploaded using the ArcCollector app and Survey123 for ArcGIS app.

<u>Survey Data Selection</u>

Although the James River rock pools have been surveyed and recorded since 2009, data collection has only been annually consistent since 2016, with an increasing number of surveys taken in each subsequent year. This study chose to use data from only 2018 and 2019 as they had the highest number of surveys, 382 and 599 respectively, which would allow for both seasonal and annual analysis within and between years (Fig 5). For both years, surveys are collected from March to November, with the highest survey collection occurring during the summer months (Fig. 6).

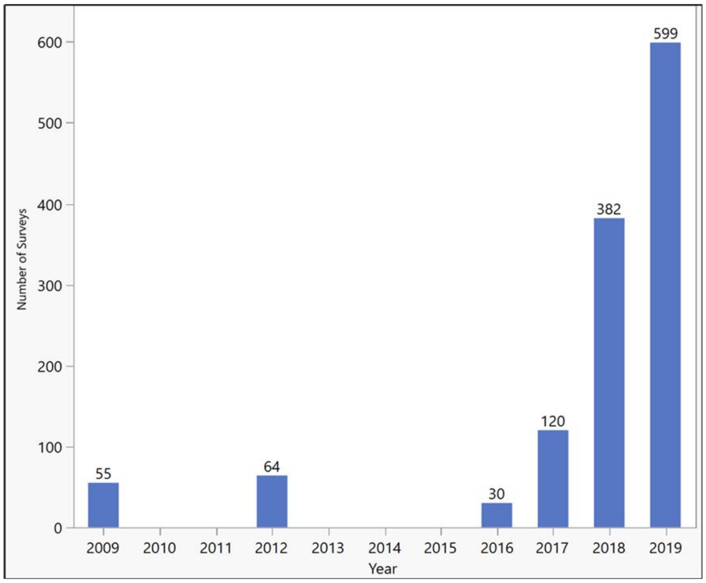

Figure 5. Number of surveys collected from the James River rock pools each year. N_{toalt}=1,251.

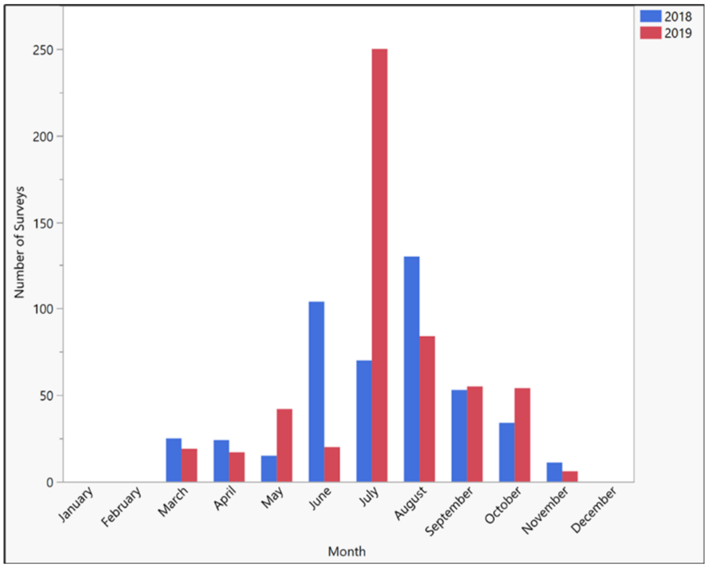

Figure 6. Number of surveys collected from the James River rock pools during each month of 2018 (blue) and 2019 (red). N_{total}=981, N_{2018}=382, N_{2019}=599.

To determine when flooding occurred, the James River water gage height was analyzed for 2018 and 2019. The height of the James River is collected every 15 minutes by the US Geological Survey, but this was consolidated by taking the daily maximum, with a flooding event defined as the duration the height is above nine feet. Nine feet was used at the flooding height minimum as a majority of the pools within the James River rock pool system are flooded at this height and this height coincides with the National Weather Service's action stage flood category (USGS, 2020; NWS, 2020). Maximum flood heights were graphed, with peaks over the red threshold line indicating occurrence of a flood. This data was also shown in relation to annual season, which demonstrated most of these flooding events occur in winter, spring, and fall (Fig. 7). Despite higher surveys occurring during summer months (Fig. 6), I elected to focus on spring and fall surveys to analyze potential flooding events, though flooding events were absent from fall of 2019.

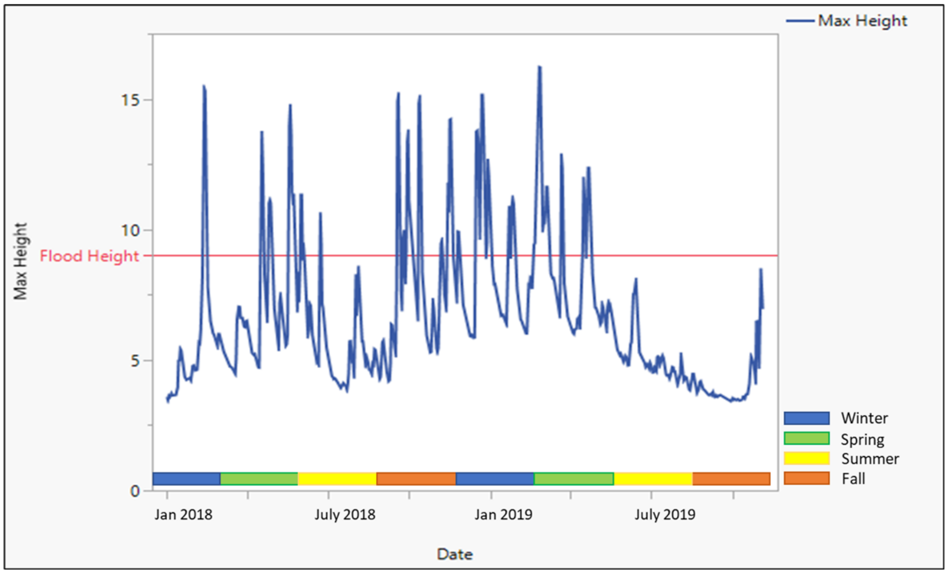

Figure 7. Maximum height of the James River each day from January 1, 2018 to November 4, 2019. The red line denotes the flood height threshold of nine feet. Colour-coded bars at the bottom of the graph represent the seasons.

The instances where flooding occurred was graphed in relation to the 2018 and 2019 surveys to determine specific periods of time where survey data was available before and after a flooding event. A total of 486 surveys were selected across four discrete periods: spring and fall of 2018 and 2019 (Fig. 8a). Each period was divided into a "pre" and "post" category depending on whether the survey was taken before or after the flooding event (Fig. 8b-e). A flooding event could consist of more than one instance of flooding if these occurred in a close time frame where insufficient surveys were collected in-between. For example, the fall 2018 "flooding event" consisted of four discrete flood occurrences, where the water rose above nine feet, fell below, and then rose back up again. However, survey data taken immediately prior to the fall 2018 flood, which was collected by students and not experienced researchers, was excluded due to the unlikely number of reported zeroes (Fig. 8c). In the case of surveys taken in fall of 2019, where there was no flood, these were separated as "pre" and "post" using dates that similarly matched the range used in fall of 2018 (Fig 8e). The pools included in the 486 surveys can be seen in figure 9, which shows these pools are fairly representative of the entire rock pool system (Fig. 4), both in geographic spread and general density. Details on the date ranges, number of surveys, flood height, and duration can be found in Table 1.

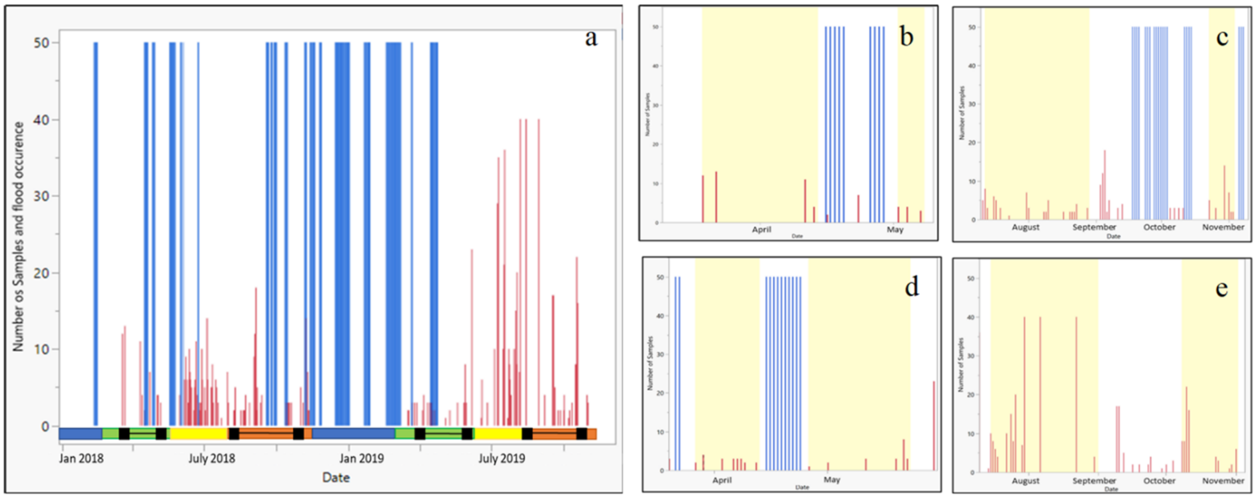

Figure 8a. Number of rock pool surveys collected per day, the red bar, in relation to daily flooding occurrences, the blue bar. Y-axis units are only related to the number of surveys, as the flooding event is binomial yes/no. Colour-coded bars indicate the same season as figure 7. The black squared-off segments indicate the four periods of survey data used in this study. N_{total}=486. Figures 8b-e are close-ups of each period and the specific surveys used as "pre" and "post" data. Figure 8b is Spring 2018 surveys, 8c is Fall 2018 surveys, 8d is Spring 2019 surveys, and 8e is Fall 2019 surveys.

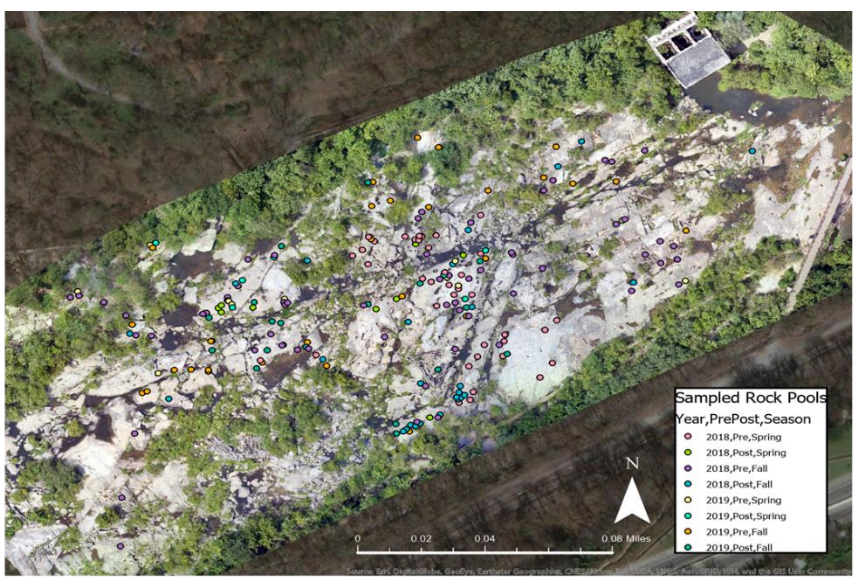

Figure 9. Low-water drone image of Belle Isle with rock pools used in the study denoted with a coloured dot. Colours represent survey year, season, and whether the survey is from before or after the flood. Drone flown by VCU on 8/20/2017.

Diversity Metrics

Many different metrics may be used in determining the biodiversity of a rock pool community. Abundance provides the total number of individuals within the community, while richness, often considered the simplest measurement of diversity, is the number of species within a community. Richness can be an estimate of the total number of species within a community, as it is possible to miss one or more species while surveying. For this study, I assumed that surveying effort for each pool was equal, so any potential difference between the recorded and the actual number of species should be similar for all surveys. The richness and evenness of a community can be combined for a diversity metric known as Shannon's Index. The index increases as both richness and evenness increase, with typical values between 1.5 and 3.5 (Kerkhoff, 2010).

Statistical Analysis

General seasonal and annual trends in richness and diversity, using Shannon's Index, were analyzed through two-sample t-tests. It was not possible to make direct pre-post flood comparisons for specific pools, so the surveys for each pre and post period were groups together and analyzed using two-way ANOVA for each season. The two fall periods were compared to each other, and likewise for the two spring periods, to determine effects based on year, pre or post, and the interaction of year and pre/post. Data selection and analysis was performed using Microsoft Excel and JMP Pro 15 statistical software.

Year	Season	Pre/Post	Date Range	Number of Samples	Number of Pools	Minimum Flood Height (feet)	Maximum Flood Height (feet)	Duration of Flood	Number of times flooded during "event"
2018	Spring	Pre	3/19/2018-4/13/2018	40	39				
						9.27	13.64	4/16/2018-4/29/2018	2
2018	Spring	Post	5/2/2018-5/7/2018	11	11				
2018	Fall	Pre	7/12/2018-8/28/2018	79	73				
						9.07	15.02	9/18/2018-10/15/2018	4
2018	Fall	Post	10/23/2018-11/3/2018	33	32				
2019	Spring	Pre	3/27/2019-4/12/19	22	22				
						9.01	12.35	4/15/2019-4/24/2019	1
2019	Spring	Post	4/26/2019-5/22/2019	20	19				
2019	Fall	"Pre"	7/15/2019-8/30/2019	212	72				
						No Flooding Occurred	No Flooding Occurred	No Flooding Occurred	No Flooding Occurred
2019	Fall	"Post"	10/8/2019-11/1/2019	69	65				

Table 1. All survey data used in this study, separated by year, season, and pre or post flood. Date ranges for each survey period, as well as the number of surveys and number of different pools surveyed is provided. Flood metrics, such as minimum and maximum height reached, the duration of the total flooding event, and the number of discrete flooding occurrences during each event are also provided. N_{total}=486.

Results

Annual and Seasonal Variation

When comparing richness and Shannon's Index between 2018 and 2019, there was no statistically significant difference due to year (2-sample t-test, t=1.29, df=300.62, p=0.20, Fig. 10a; 2-sample t-test, t=-0.27, df=275.63, p=0.79, Fig. 10b). Average species richness for 2018 and 2019 was 3.40 ± 0.18 and 3.68 ± 0.12, respectively, and Shannon's Index was 0.78 ± 0.04 and 0.77 ± 0.03, respectively (Mean Richness/Diversity ± Standard Error). A statistically significant difference was found when comparing richness and Shannon's Index between season (Fig. 10a 2-sample t-test, t=3.09, df=139.9, p=0.002; Fig. 10b 2-sample t-test, t=-2.76, df=135.44 p=0.007). Richness for spring and fall were 2.96 ± 0.23 and 3.74 ± 0.11, respectively, and Shannon's Index was 0.64 ± 0.53 and 0.80 ± 0.03, respectively (Mean Richness/Diversity ± Standard Error).

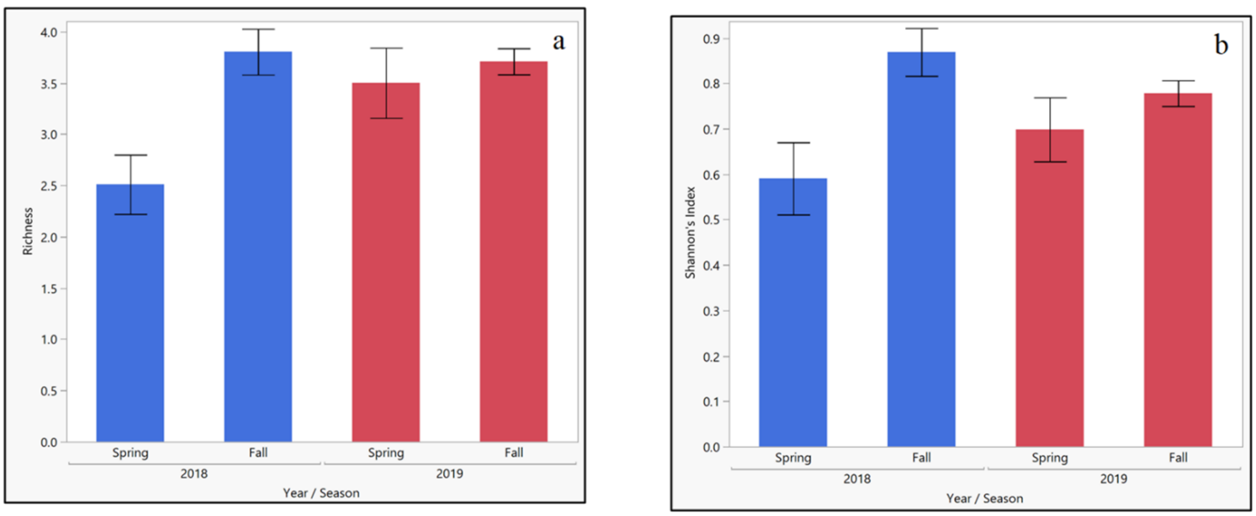

Figure 10. Average richness (a) and diversity (b), measured using Shannon's Index, for spring and fall of 2018 and 2019. Error bars indicate standard error of the mean.

Effects of Flooding

When comparing richness and Shannon's index between fall 2018 and fall 2019, there was a statistically significant difference between pre-flood and post-flood, but it was dependent on the year (Two-way ANOVA Year:, t=1.41, df=391, p=0.158; Pre/Post: t=-3.62, df=391, p<0.001; Year*Pre/Post: t=4.39, df=391, p<0.001, Fig. 11a; Two-way ANOVA Year: t=0.13, df=391, p=0.896; Pre/Post: t=-2.96, df=391, p=0.003; Year*Pre/Post: t=3.84, df=391, p<0.001, Fig. 11b). Richness decreased in fall of 2018 whereas it stayed about the same in 2019, the year and season without a flood event. These trends were similar for Shannon's index in both years.

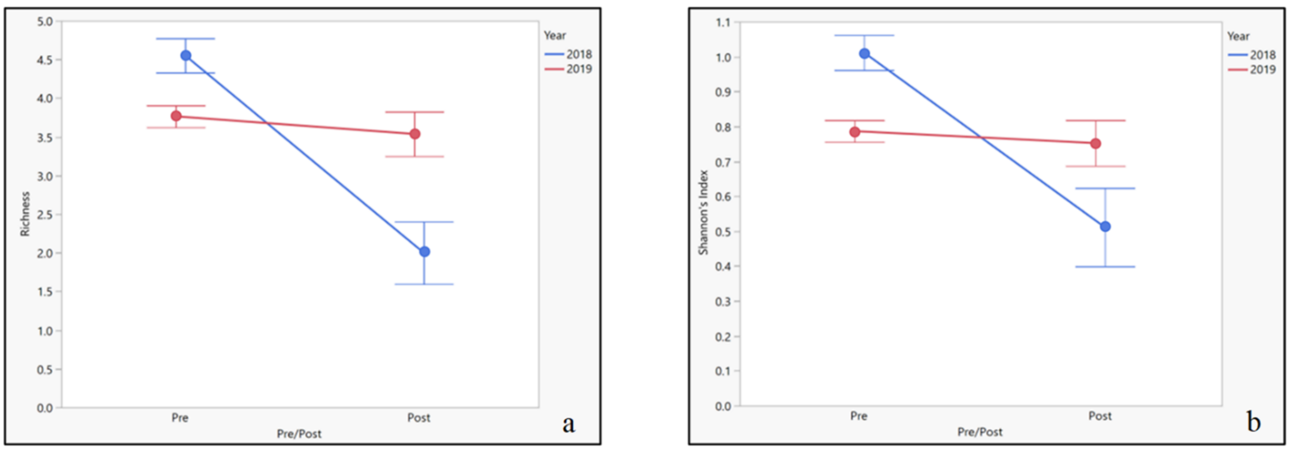

Figure 11. Change in average richness (a) and diversity (b), measured using Shannon's Index, pre and post flood for fall of 2018 and 2019. Error bars indicate standard error of the mean.

Between spring of 2018 and 2019, there was also a statistically significant difference between pre-flood and post-flood dependent on year (Two-way ANOVA Year: t=2.52, df=92, p=0.013; Pre/Post: t=3.18, df=92, p=0.002; Year*Pre/Post: t=3.75, df=92, p<0.001, Fig. 12a; Two-way ANOVA Year: t=1.02, df=92, p=0.309; Pre/Post: t=1.99, df=92, p=0.050; Year*Pre/Post: t=2.14, df=92, p=0.035, Fig. 12b). Both average richness and Shannon's index stayed about the same in spring of 2018, whereas they increased in 2019. Both years in the spring experienced flooding events.

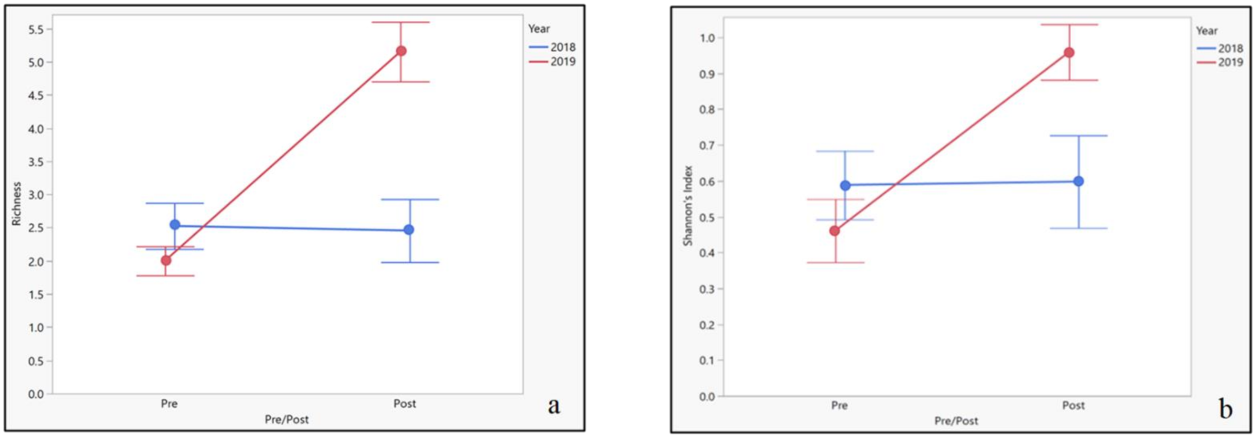

Figure 12. Change in average richness (a) and diversity (b), measured using Shannon's Index, pre and post flood for spring of 2018 and 2019. Error bars indicate standard error of the mean.

Discussion

This study details the responses of species diversity to flooding over two years, focusing on the spring and fall periods where surveys occurred both before and after defined flooding events. Overall richness and diversity were found to be similar between 2018 and 2019, but varied between season, with richness and diversity lower in the spring than in the fall (Fig. 10). Few macroinvertebrate species are able to overwinter in the rockpools, due to freezing temperatures, ice formation, and decreased oxygen levels, resulting in generally lower richness and diversity in the spring compared to the fall (Oswood et al. 1991). In the spring, vegetative growth and colonization of pools begins, but initial richness and diversity is still low following winter die-offs (Pajunen & Pajunen, 2003;Mackay & Kalff, 1969). Continued warming temperatures and increases in colonizing species leads to a peak in richness and diversity mid-summer. Species diversity continues to be high into the fall period of this study, due to the late date of below-freezing temperature days in the Piedmont region of Virginia, allowing for persistence of summer species well into October (Slobodchikoff & Parrott, 1977; Mackay & Kalff, 1969). In a study on riverine rock pools in Maine, macroinvertebrate diversity was also found to increase over the summer and peak in the fall (Gagne, 2017).

Seasonal flooding occurred during the fall of 2018, but not the fall of 2019. With a fall flood, species richness and diversity were found to decrease after the event compared to these metrics before the flood occurred. Without a flooding event in 2019, richness and diversity remained the same between the two fall survey periods (Fig. 11). This result is consistent with my expectation that a flooding event would empty out the pools and wash species back into the main river channel, decreasing richness and diversity within pools. In the same rock pool study in Maine, they also found that frequently flooded pools become more similar to one another during the fall as they lost their lotic taxa, similar to my results of decreasing diversity during a fall flood year (Gagne, 2017). The differences in initial richness and diversity between the two years in this study may be due to environmental factors or could be from differences in sample size (Lepori & Hjerdt, 2006).

When comparing results of richness and diversity between the spring of 2018 and 2019, both metrics remained about the same from pre to post flood for 2018, but increased in 2019 (Fig. 12). Floods occurred in both years, but it is possible that growth and colonization during the spring greatly outweighed the negative effects of the flood, particularly in 2019 (Pajunen & Pajunen, 2003). Environmental variation between 2018 and 2019 most likely accounts for the differences seen between the two springs. The last day of below-freezing temperatures was examined for each year to serve as a proxy for the start of the growing season. However, these dates were similar, with March 27, 2018 and April 3, 2019 being the last day that fell below freezing for each year. The average temperature and humidity were also examined for spring 2018 and 2019 as another metric of growing season conditions. For 2018, average temperature and humidity was 44°F 61% in March, 56°F 66% in April, and 72°F 77% in May, and 47°F 62%, 62°F 67%, and 72°F 72% for March, April, and May of 2019 (Past Weather, 2020). While these coarse comparisons do not strongly support the differences between spring 2018 and 2019, environmental conditions and dynamics are much more complex than simple temperature outputs and would require further investigation. It is also possible that these flooding events more evenly disperse species throughout the rock pool system which would increase heterogeneity and diversity, though there is no clear support for why this would have occurred during the spring study set but not the fall (Lepori & Hjerdt, 2006). Similarly to fall, difference in sample size may also affect the variation in richness and diversity.

In addition to seasonal variation due to environmental factors, such as temperature or growing period, higher levels of disturbance may also affect the difference seen between fall and spring and then between the two springs. The highest flood height in fall of 2018 was 15.02 feet, but only 13.64 and 12.35 feet in spring of 2018 and 2019, respectively. The duration of the flooding event was longer for fall of 2018 and consisted of more instances of flooding. While four discrete flooding instances occurred the total flooding event, which lasted about a month, the roughly two-week flooding event in spring 2018 consisted of two flooding instances and the roughly one-week flooding event in spring 2019 consisted of on flooding occurrence (Table 1). From these results, increasing flood height, duration, frequency coincide with decreasing richness and diversity post-flood. One study found that a series of pulsed flash-flooding events were shown to negatively affect plankton abundance, mosquito larvae abundance, and mosquito oviposition, resulting in an overall lower biodiversity (Duchet et al. 2017). These determinants of diversity were not tested in this study, but they may impact macroinvertebrate assemblages within the rock pools.

While studies have shown small-scale macroinvertebrate diversity may be negatively affected by disturbance, these events may also maintain community heterogeneity, which is an underlying driver of higher long term and large scale biodiversity. These conflicting results, which were investigated by Lepori and Hjerdt, were similar to my conflicting results following spring and fall flooding events (2006). Using a stream system, their aim was to determine how flood disturbances affect benthic invertebrates, looking specifically at contextual factors and spatiotemporal scales. Ultimately they found that flood predictability, flood severity, and resource availability were the main factors regulating invertebrate response to disturbances. For flood severity, they found that increased frequency, magnitude, and duration were associated with extensive disturbance and loss of many species, as well as slower recovery (Lepori & Hjerdt, 2006). This may be why flooding during the fall of 2018 had a more negative effect on biodiversity than either spring, as the fall flood event reached a higher height, was more frequent, and lasted longer. These studies also emphasize the need for further research on how the response of species diversity to flooding is shaped by the physical pool characteristics, specific species assemblages, and complex environmental or climatic influences.

Some of the drawbacks of this study include lack of direct pool comparison and variation in sample size. Pools were not surveyed with this study in mind, resulting in different pool identities and a different number of surveys before and after each flooding event time-frame. Additionally, while the date ranges of pre- and post-flood surveys were matched as closely as possible between 2018 and 2019, some differences between the years added to the variation in my data set (Table 1). For example, over 200 pre-flood surveys were collected during fall 2019, a bit under half of all surveys included in this study. While a large sample size such as this could provide a better sense of the richness and diversity of the entire rock pool system, it makes comparison to other periods of the study with fewer surveys more difficult. The study's flood height of nine feet may also have been insufficient to account for flooding of all pools within the system. While a majority do flood at this height, some pools at higher elevation do not flood until 12 or 15 feet. Many zeroes were recorded during surveys, which may have contributed to the lower richness and Shannon's Index falling below the typical range found in my results, but these were included within my selected date range as it is possible these could have been true zeroes.

Conclusion

In aquatic systems, the effects due to flooding are context dependent; in this study the responses in species richness and diversity were found to vary by both season and year. Ultimately, this demonstrates that the rock pools are a dynamic and variable system, and they do not function in the same way as laboratory or artificial mesocosm experiments, where it is possible to control for many more variables. At the rock pools, variability can be attributed to many causes with undeterminable weight, such as weather, season, or even anthropogenic influence. Belle Isle is a frequently visited location within Richmond, VA, and presence of humans, or human impact such as fires and garbage, could influence species within the rock pools. This study may also illustrate the differences between general surveying, where as many pools are surveyed within the system as possible before resampling, versus targeted repeated surveying of specific pools. The data available for this study lacked many repeated pools, which restricted direct pre- and post-flood comparisons of the same pool.

As the James River rock pool system is so dynamic and variable, it offers several opportunities for future studies. While this study looked at overall diversity, there is potential for investigating the effects of flooding on particular species. Some species may be more flood resilient, such as those that can cling to the sides of the pool or dive into the substrate. Predator-prey interactions between key community species, such as mosquitoes and dragonflies, could also be studied. Artificially flooded mesocosms have been shown to have decreased mosquito oviposition compared to non-flooded, which could be further analyzed using the natural rock pool system (Duchet et al. 2017). Rock pools may also be manipulated, such as emptying the pool to assess rates of recovery in relation to various pool parameters, or species could be introduced to further expand on predator-prey dynamics or niche partitioning. Finally, a robust, ever-growing data-set has already been created due to the continual surveying and research efforts from VCU and UR, which can be used to both answer and generate potential future questions.

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