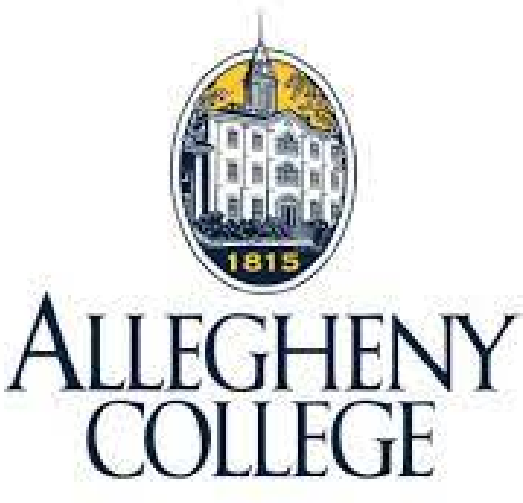
Watered Down: Exploring Hydroperiod Dynamics and Amphibian Abundance in Vernal Pools at Three Properties in Northwest Pennsylvania



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Abstract

Woodland amphibians, such as spotted salamanders and wood frogs, reproduce by laying their eggs in temporary bodies of water (i.e. vernal pools) and germinating them. This process, which starts in the early spring, lasts until the end of summer to produce juvenile amphibians. Vernal pools, a habitat devoid of predators, creates ideal breeding grounds for woodland amphibians. However, these vernal pools eventually dry, and if it dries with undeveloped eggs, those potential juvenile amphibians die. Understanding the relationship between the hydroperiod of these pools and where the amphibians decide to reproduce is important. The objectives of this study were to examine the link between the hydroperiod of vernal pools to the breeding effort within those pools. Several pools at three different sites in Northwestern Pennsylvania were surveyed repeatedly from late winter to late summer, taking note of egg masses and the water level of the pool. It was found that amphibians lay their eggs in pools with higher hydroperiod indices exponentially more than pools with lower hydroperiod indices.

Introduction

Wetlands cover just over 5% of the entire United States, at more that 110 million acres (Fish and Wildlife n.d) and provide numerous ecological services, both hydrologic and biological. Wetlands make large contributions to global water cycles, reduce flood water flows, contribute to groundwater recharging, provide base flow for streams (EPA n.d), and are an important habitat for biodiversity. They provide a habitat for a variety of both fauna and flora that utilize a diversity of different feeding and reproduction strategies. Often, due to their relatively shallow water, as well as high nutrient level and high concentration of primary producers, wetlands provide an excellent habitat for studying early organismal development (Calhoun et al. 2017).

Vernal pools are defined as seasonal wetlands, and therefore are only covered by water for variable periods from winter to spring or summer. These may completely dry during the summer and early fall (Zedler 2003). Vernal pools can be formed in several types of environments, including forests, grasslands, rocky plains, or basins (Luymes et al. 2021), and vary in size from a few meters in width all the way up to one hectare (Rothenberger et al. 2019; Michigan Vernal Pools Partnership 2024). Typically these pools will have a base of bedrock, hard clay, or some other non-porous material, and underlying geology can actually affect rates of

draining (Elam 1998; Calhoun et al. 2014). The size and duration of these pools depends heavily on the precipitation amount from winter and spring (Zedler 2003; Calhoun et al. 2017). Due to their temporary nature, these pools are often overlooked as important wetland habitats and as such, are imperiled habitats. Indeed, they are not classified as wetlands in many places, and as such are not protected under the same policies (Elam 1998). Vernal pools occur worldwide, typically in areas that have a Mediterranean climate, however they can occur in other climates, even in northern Canada (CDFW n.d; Luymes et al. 2021). Most pools dry during the summer, and are filled during the winter and spring from either rain, snowfall, or rising groundwater (Golladay et al. 2021; Brooks 2004).

This cycle of drying and filling can be categorized into three phases, the inundated phase, typically during the winter, then a slow drying during the spring, known as the flowering phase, and completion of drying during the summer, the dry phase (Brooks 2004). Due to these extreme seasonal changes, vernal pools favor native species as many non-natives cannot tolerate such variable conditions (Nagel et al. 2021). Some pools do not dry due to an impermeable surface at the pool basin, and this part is key in the development of vernal pools, as it allows for the water to evaporate instead of draining.

Vernal pool hydrology, especially the hydroperiod, directly affects the composition and productivity of pool fauna. The hydroperiod refers to the temporal pattern of water availability within an ecosystem, in this case vernal pools (Brannelly et al. 2019). It describes how long water remains within the pool year round and how this changes over time. This is influenced by precipitation, evaporation, groundwater, and the landscape itself (Calhoun et al. 2017; Cartwright et al. 2022). Hydroperiods can vary widely, ranging from permanent water presence in some areas to very temporary water presence in others (Brannelly et al. 2019). This variability plays a crucial role in the ecological processes within wetland ecosystems. Understanding the hydroperiod of the pools within an ecosystem is essential for both studying and managing wetland habitats because it affects the types of plant and animal species that can reside within different pools (Lent et al. 2020; Kneitel et al. 2017).

Vernal pools are highly critical reproduction sites for early breeding amphibians. Within the greater French Creek watershed of northwestern Pennsylvania, the species most common within the vernal pools are spotted salamanders (*Ambystoma maculatum*) and wood frogs (*Lithobates sylvaticus*) (Homan et al. 2004). Spotted salamanders are important within a wetland

ecosystem, where they act as mid level predators and provide control over species diversity and ecosystem processes (Davic et al. 2004). Wood frogs also play a crucial role in the ecosystem, as they are both predators and prey. They predate on invertebrates and are preyed on by larger predators, such as snakes, mammals, and birds; as tadpoles they are preyed upon by invertebrates such as diving beetles, as well as salamander larvae, and as eggs, they are preyed upon by invertebrates and eastern newts (Gajbhiye 2024; Khiel 2015). Both species of amphibians are most threatened by habitat loss caused by climate change. During late winter, early spring once the temperatures begin to rise, females will enter these vernal pools after the males, then lay eggs for fertilization (Babbit et al. 2003). During annual breeding migrations, Spotted salamanders utilize the secretion of spermatophores during their reproductive cycle (DiMauro et. al. 2002; Andrews et al. 2021). A spermatophore is a mass containing sperm, and their presence in water is indicative that the animals are still actively breeding. They choose to breed in vernal pools due to the inherent lack of fish within them, as fish are known to prey on the eggs of amphibians. However, some vernal pools, located near other larger bodies of water, may sometimes gain fish due to overflow from rivers or lakes. In these cases, the fishes eat the eggs within that vernal pool (Lent et al. 2020). There is limited research into how and why amphibians select their mating sites, however, there is evidence to suggest that spotted salamanders, in particular, chose deeper waters with dense submerged vegetation (Kern et al. 2013; Karraker et al. 2009), while wood frogs seem to prefer ponds with high macrophyte counts, clear water, and fewer macroinvertebrate taxa (Cook 2023).

Despite a traditional focus on vernal pools being considered as isolated wetlands, individuals that utilize them for breeding and other purposes are classified as a metapopulation (Ilkka 1998; Wang et al. 2019). Metapopulations refer to a group of populations of the same species which are spatially separated and interact with each other through migration or dispersal. These populations maintain genetic diversity due to the movement of individuals. These separate patches of individuals vary in size, quality and suitability, which introduces the concept of source-sink dynamics. A population surplus happens in a habitat of good quality (source) and a deficit occurs in habitats of poor quality (sink) (Dias 1996; Zamberletti et al. 2018). These are not always easy to identify, most of the time requiring a long term study as single generation studies cannot properly show trends within the population as populations fluctuate over time (Dias 1996; Zamberletti et al. 2018). A habitat can be deemed a source or sink by looking at

birth rates, death rates, emigration rates, and immigration rates. If a habitat is consistently producing more individuals compared to those that die, then it is a source habitat. It is important to identify these source habitats for conservation, regardless of their proportion to the landscape, as they represent some of the only sites where amphibian breeding can be ultimately successful (Compton et al. 2007; Kieran et al. 2021).

Failure to conserve vulnerable habitats, such as vernal pools can lead to either complete loss or fragmentation of amphibian populations. Habitat loss and fragmentation are among the biggest threats to amphibian populations (Cushman et al. 2006). When an area containing vernal pools is not properly protected or managed it can lead to degradation of the habitat, and eventual loss and/or fragmentation (DeMaynadier et al. 1995). This can limit dispersal of amphibians, and since many vernal pools are formed in clusters, this can effectively fragment major portions of existing habitat for amphibians (Cushman et al. 2006).

The primary objective of this project was to correlate vernal pool hydroperiod with recruitment of spotted salamanders and wood frogs. The secondary objective of this project was to create a metric for representing the hydroperiod of both individual vernal pools and the overall hydroperiod of the sampled properties. I hypothesize that as hydroperiod increases, there will be a nonlinear increase in amphibian abundance, as I expect there to be a point at which there is a spike in abundance as hydroperiod reaches a length which can support both species' full development. This is because while both species take relatively similar times for their offspring to develop, wood frogs begin breeding months before spotted salamanders do, and as such, I expect that vernal pools with hydroperiods > 6 months will show a larger breeding effort.

Methods

This study is focused on the vernal pools in Northwest Pennsylvania. This area is a continental climate, meaning it has significantly variable temperatures and precipitation. The forests are mainly deciduous, and the region has the geography of rolling hills with some plains. The properties that are to be surveyed are owned by the French Creek Valley Conservancy (FCVC) and Allegheny College. The FCVC is a non profit land trust which is focused on the conservation and improvement of the French Creek Watershed and its surrounding land. They work with landowners who volunteer their properties to be conserved. On several of these

properties, vernal pools are highly abundant, as they form in clusters. Understanding the relationship between vernal pool hydroperiods and amphibian abundance will help further local conservancy and environmental groups' ability to conserve and understand both amphibians and the broader ecosystem in which they reside.

Three properties containing vernal pools were surveyed in northwestern Pennsylvania. Bousson Environmental Research Forest (BERR), Raup Wildlife Sanctuary, and Vernal Pool Preserve. BERR is located near Tamarack lake with an outflow of Tamarack running through it. It is 283 acres (114.52 hectares), with a variety of habitats such as woodlands, ponds, streams, wetlands, and vernal pools (Figure 1). This forest is owned by Allegheny College and is reserved for research purposes (Venesky n.d). It was acquired by Allegheny College in 1935. It contains many vernal pools, with a mixture of manmade and natural, as well as a mixture of pools that fully dry and those that do not.

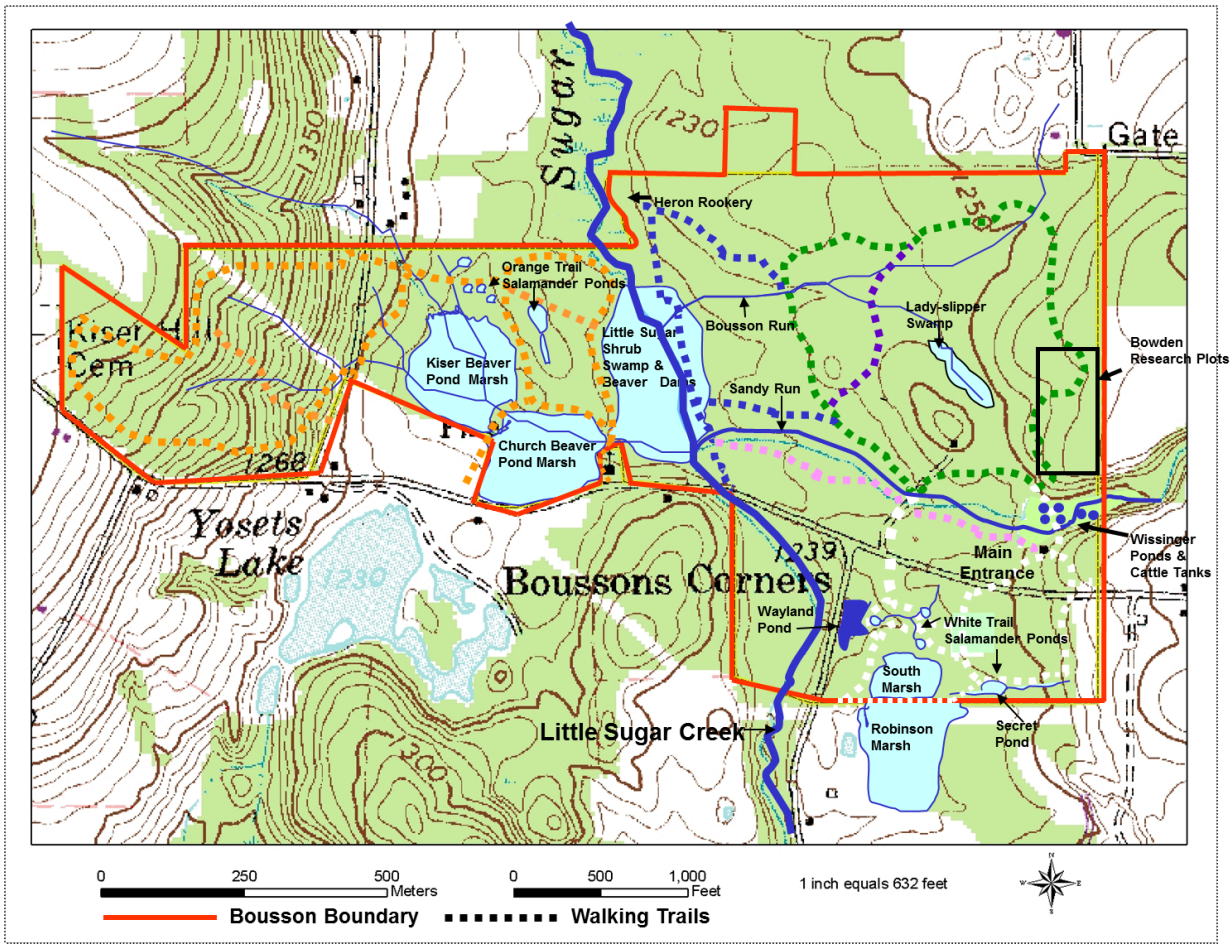


Fig 1. Bousson Environmental Research Forest (BERR) - Map of property, located in Crawford County, PA (41.59793744556043, -80.04550659761159)

Raup Wildlife Sanctuary is located in the headwaters of a tributary of the French Creek. The property has been owned by the French Creek Valley Conservancy since 2009 and is publicly accessible (FCVC 2022). It contains 31 acres (12.5 hectares) of forest, emergent wetlands, and vernal pools (Figure 3). These vernal pools are all natural, again with a mixture of pools that fully dry and some that do not. The Vernal Pool Preserve is also located in Crawford county. It is a FCVC property, and is a protected area (FCVC 2022; Figure 2), and has the fewest number of vernal pools of our study properties.



Fig 2. Vernal Pool Preserve (VPP) FCVC - Map of Property, located in Crawford County, PA (41.59463509618709, -79.9188303812307)

To characterize the pool habitat, I visited pools every other week throughout the summer from June 2024 through October 2024. I also used previous surveys dating to March of 2024. I tracked pool hydrology through measurements of wet surface area, and noted when pools are completely dried. In-pool habitat was characterized by the form of a standardized vernal pool survey form (Pennsylvania National Heritage Program). This includes a general description of the pool and the surrounding 100 ft envelope. Then the actual pool size was measured in meters by the way of length and width of the wet portion of the pool. Then a maximum pool size was

measured by estimating where the water has come up to during the Spring inundation period. Then the connectivity was recorded as apparently isolated, seasonally connected to another pool, stream, or wetland. If the pool is seasonally connected, then it is recorded if it is an inlet or outlet. A count was taken on the scale of 0-4+ standing dead trees within the envelope, as well as recording the presence of trees and shrubs, naturally fallen branches and limbs within the pool, as well as woody debris and other shelter in the envelope. The water color was marked as either clean, moderately stained, highly stained, or dry. The canopy above the pool basin was recorded as either Closed, Partially open, or open. A photo was then taken of the canopy. The pool basin vegetation was recorded as a % composition estimate with the categories being open water, marshy herbaceous vegetation, shrubby woody vegetation, and trees.

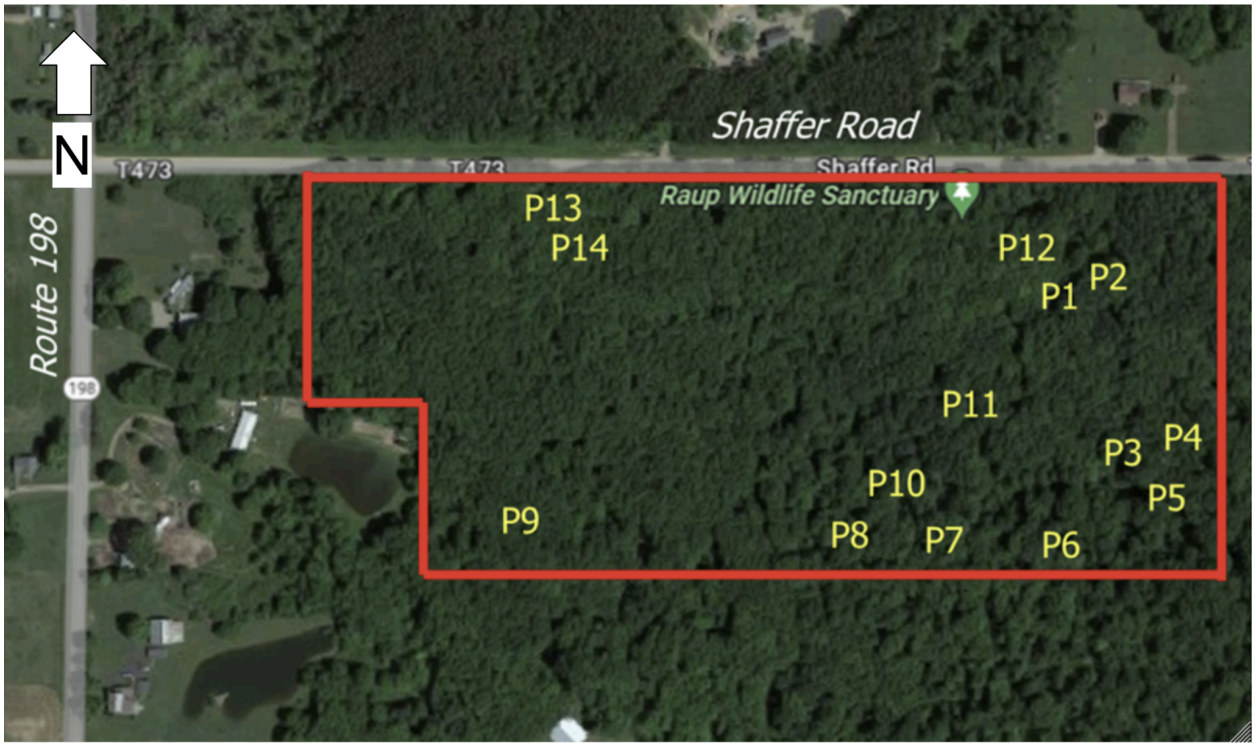


Fig 3. Raup Wildlife Sanctuary, FCVC - Map of Property, Located in Crawford County, PA (41.6109334469558, -79.93383464048672)

Wood frogs and spotted salamanders were the target species for this study. The breeding effort of both of these species is used as a metric to designate important vernal pools according to many state regulations in the northeastern US (Calhoun et al. 2003). To quantify these species breeding efforts, I conducted a visual survey and counted egg masses in each pool after peak oviposition in the spring. Peak oviposition was determined based on the maximum count from

weekly counts. I also noted any adults I observed during visual surveys. When spotting egg masses, a walk was done around the perimeter of the pool looking for egg masses. This is a slow walk to fully check every angle. In some cases, a walk into the pool was conducted.

I created a metric for hydroperiod from 0-1 by quantifying the pool as being wet or dry (1 or 0) each survey. I then added all of the hydroperiod scores and divided by the total times the pool was surveyed. This gives a score from 0-1, with a score of 0.90+ being considered effectively permanent (wet all or almost all the time), 0.6-0.89 being semipermanent (wet for > 4 months), below 0.60 being considered temporary (wet for < 4 months), and 0 being dry (Tarr et al. 2025). I added the total masses counted for each species as well as total masses for both species for each pond. I then cross referenced this total count against the hydroperiod index for that pool.

Results

Hydroperiod index scores ranged from 0-1 across all sites. Two pools at BERR, OT5 and OT6 were completely dry each time they were surveyed in mid-June, resulting in hydroperiod indices of 0. Seven pools in total ranging across each of the properties had a hydroperiod index of 1. All properties experienced pool drying to some degree in mid to late June. In BERR, the first instance of a pool drying was ‘Secret’ pool and WT1, which were both discovered to be dry when they were surveyed on 6/11/2024. In the Raup location the first instance of pool drying was during the 6/28/2024 survey where it was found that pools 2-7, 9-10, and 12-17 were found to be dry. In the VPP site, the first instance of pool drying was on a 6/23/2024 survey where pools 3-9 and 11-12 were found to be dry.

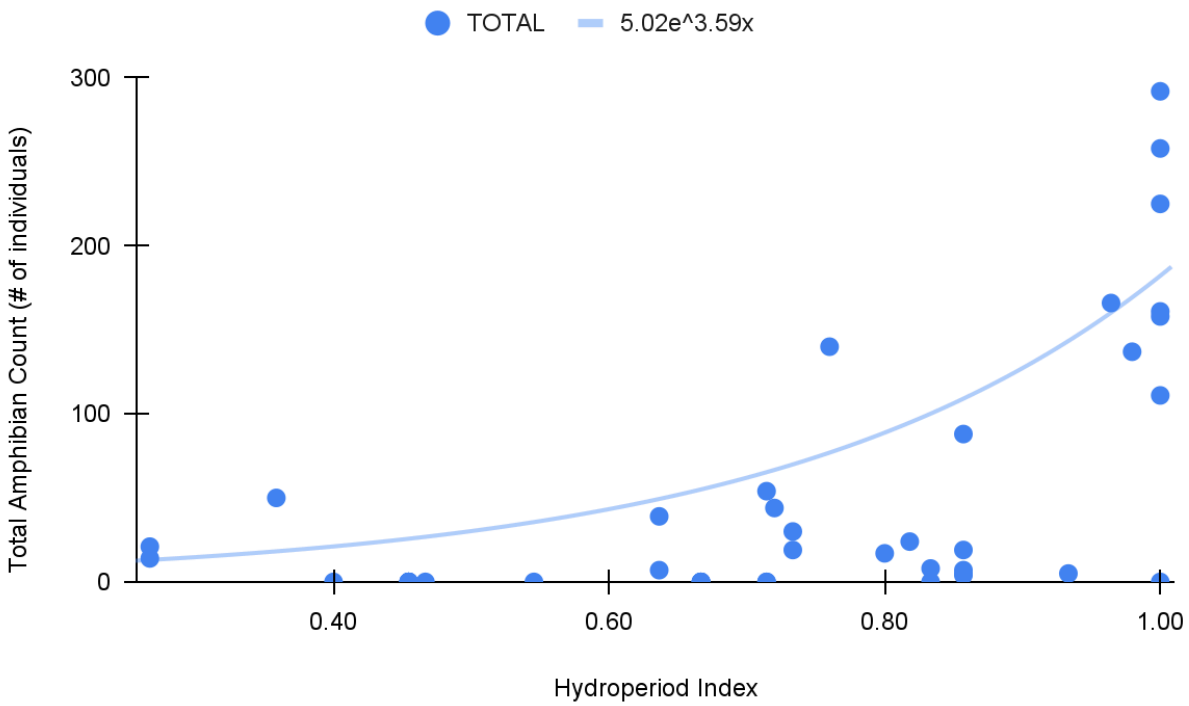
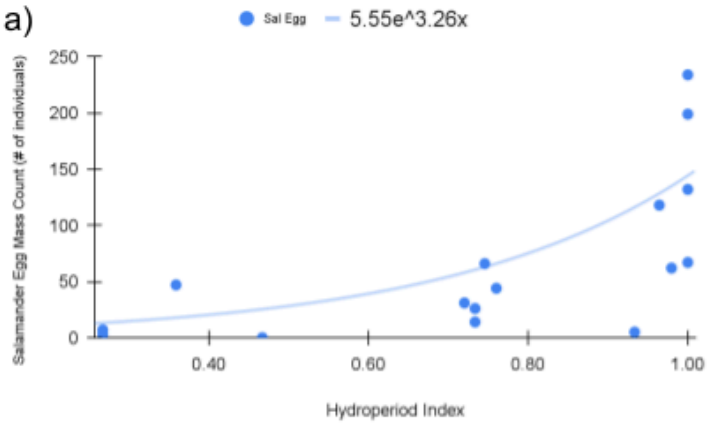
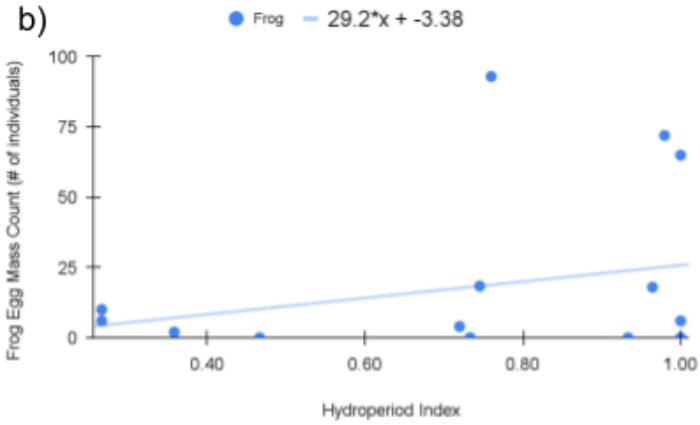


Fig 4. Hydroperiod Index vs. Total Amphibian Mass Count Across All Sites R^2= 0.355
The total amphibian count for all sites compared to all hydroperiod indices for all sites, data follows an exponential curve. A standard linear regression test resulted in a significant p value of <0.05.

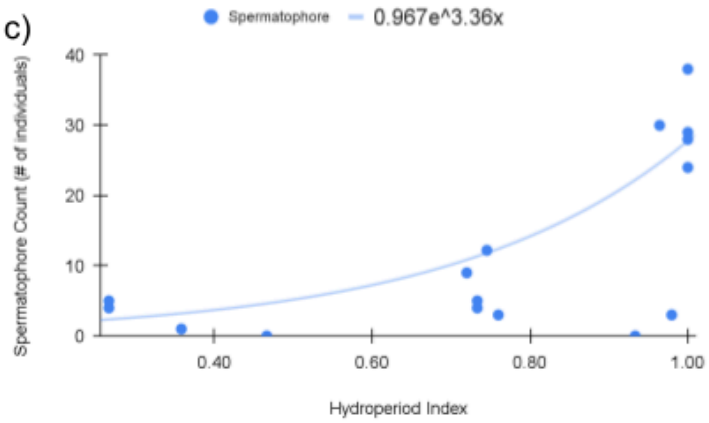
Fig 5.



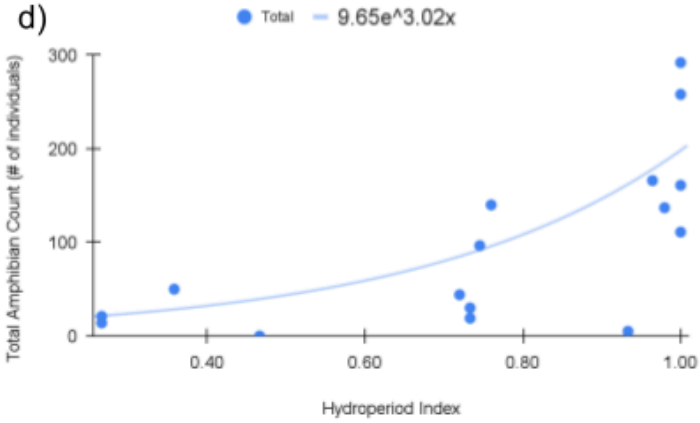
a) Hydroperiod Index vs. BERR Salamander Egg Mass Count $R^2 = 0.456$



b) Hydroperiod Index vs. BERR Frog Egg Mass Count $R^2 = 0.069$



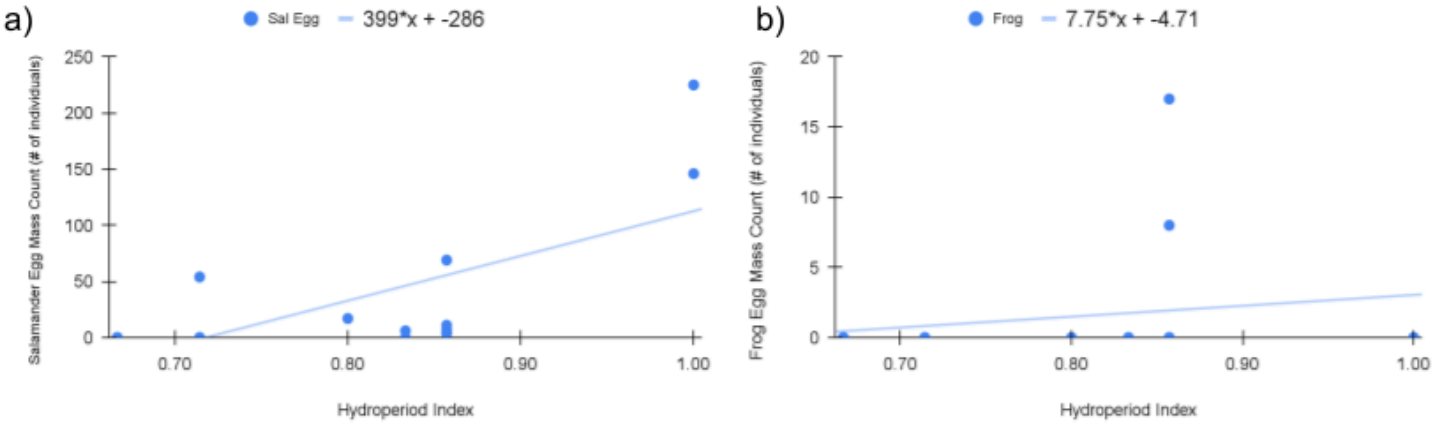
c) Hydroperiod Index vs. BERR Salamander Spermatophore Count $R^2 = 0.456$



d) Hydroperiod Index vs BERR Total Amphibian Count $R^2 = 0.495$

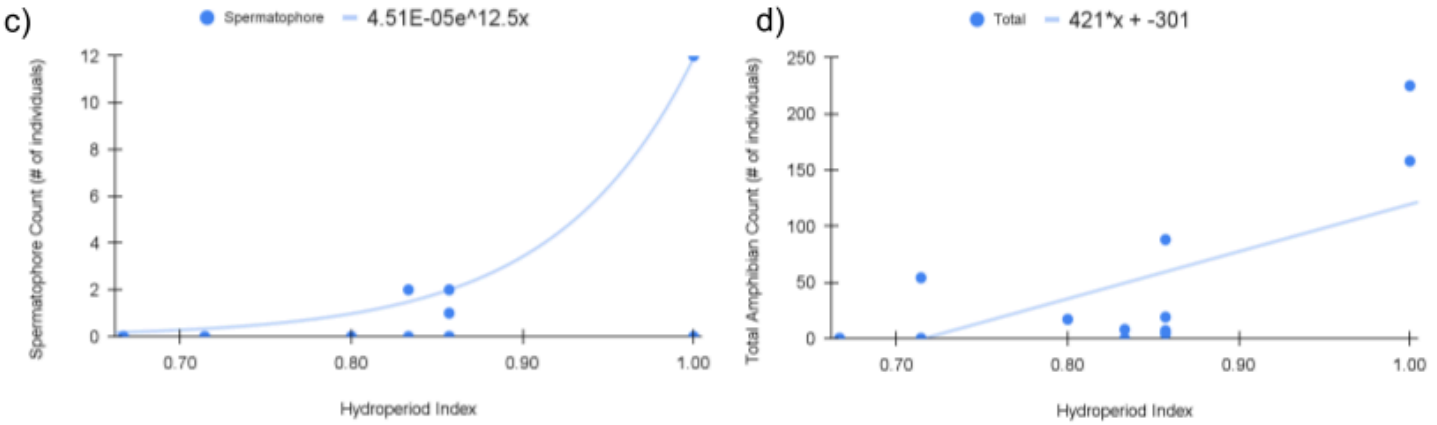
a) The salamander egg count total compared to the hydroperiod index of the BERR site; data follows an exponential curve. A standard linear regression resulted in a significant p value <0.05. b) The frog egg count total compared to the hydroperiod index of the BERR site, data follows a linear line. A standard linear regression resulted in a significant p value of >0.05. c) The salamander spermatophore count total compared to the hydroperiod index of the BERR site; data follows an exponential curve. A standard linear regression resulted in a significant p value <0.05. d) The total amphibian count versus all hydroperiod indices of the BERR site; data follows an exponential curve. A standard linear regression test resulted in a significant p value < 0.05.

Fig 6.



a) Hydroperiod Index vs Raup Salamander Egg Mass Count $R^2 = 0.485$

b) Hydroperiod Index vs. Raup Frog Egg Mass Count $R^2 = 0.036$

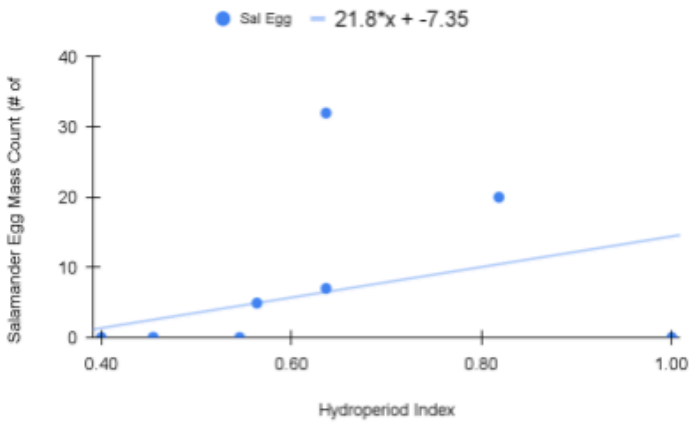


c) Hydroperiod Index vs Raup Salamander Spermatophore Count $R^2 = 0.498$

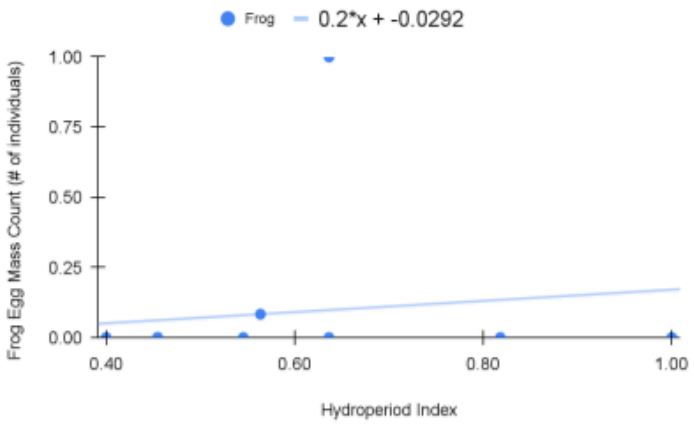
d) Hydroperiod Index vs Raup Total Amphibian Count $R^2 = 0.506$

a) The salamander egg mass count total compared to the hydroperiod index of the Raup site; data follows a linear line. A standard linear regression resulted in a significant p value < 0.05. b) The frog egg mass count total compared to the hydroperiod index of the Raup site, data follows a linear line. A standard linear regression resulted in an insignificant p value >0.05. c)The salamander spermatophore mass count total compared to the hydroperiod index of the Raup site; data follows an exponential curve. A standard linear regression resulted in a significant p value < 0.05. d) The total amphibian count versus all hydroperiod indices of the Raup site; data follows a linear line. A standard linear regression test resulted in a significant p value < 0.05.

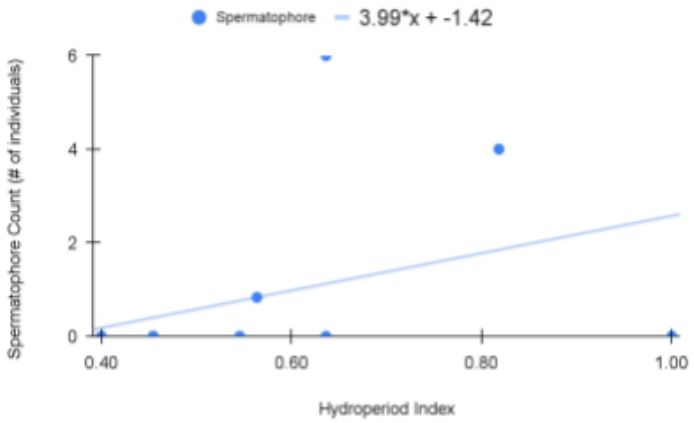
Fig 7.



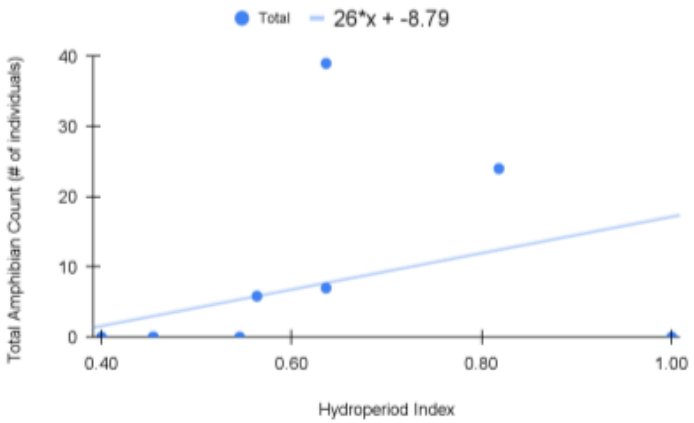
a) Hydroperiod Index vs VPP Salamander Egg Mass Count $R^2 = 0.146$



b) Hydroperiod Index vs. VPP Frog Egg Mass Count $R^2 = 0.016$



c) Hydroperiod Index vs VPP Salamander Spermatophore Count $R^2 = 0.133$



d) Hydroperiod Index vs Raup Total Amphibian Count $R^2 = 0.141$

a) The salamander egg mass count total compared to the hydroperiod index of the VPP site; data follows a linear line. A standard linear regression resulted in an insignificant p value > 0.05. b) The frog egg mass count total compared to the hydroperiod index of the VPP site, data follows a linear line. A standard linear regression resulted in an insignificant p value >0.05. c)The salamander spermatophore mass count total compared to the hydroperiod index of the VPP site; data follows a linear line. A standard linear regression resulted in an insignificant p value > 0.05. d) The total amphibian count versus all hydroperiod indices of the VPP site; data follows a linear line. A standard linear regression test resulted in an insignificant p value > 0.05.

The pool with the highest presence of amphibians in total in BERR was pool 4, which had a HI of 1. The pool with the highest presence of amphibians in total in the Raup site was pool 1, which had a HI of 1. The pool with the highest presence of amphibians in total in the VPP site was pool 10, which had a HI of ~0.63.

All sites surveyed consisted of a range of hydroperiods. The BERR site, on average, had a hydroperiod of 0.745. The Raup site had an average hydroperiod of 0.797. Interestingly, the VPP site had an average of 0.563, which is much lower than the other sites. The VPP location, after surveys were completed, resulted in much lower amphibian counts relative to the rest of the sites (BERR and Raup). In fact, there was only one single frog egg found within the entire site, which makes it very difficult to perform any sort of statistical test. However, when combining the three different categories of amphibians (Frog eggs, spotted salamander eggs, and spotted salamander spermatophores), the trend does follow the rest of the sites, albeit less accurately due to the significantly lower amount of data available. The linear regression run on the site resulted in a P value of 0.22, which is too high to draw accurate correlations. I used linear regression because this resulted in the best p values.

This research shows a relationship between the HI and amphibian abundance. Within the BERR site, all amphibian groups (frog egg masses, salamander egg masses, and salamander spermatophores) show a significant relation to hydroperiod (with p values < 0.05) (Figure 4). At the Raup site, only salamander egg mass and total amphibian count yielded significant results ($p < 0.05$), which could be attributed to the lack of frog egg masses and salamander spermatophores found (Figure 6a, Figure 6b, Figure 6c). At Raup, frog egg masses were only detected in pools 4 and 8, both of which had a hydroperiod of 0.857 (Table 2). Salamander spermatophores were only detected in 4 pools (4,6,7,8 respectively) (Table 2). These pools all exhibited hydroperiods of 0.8 and higher. In the VPP site, there were few detections of any amphibians at all. One total frog egg was detected among all the pools, in pool 10. There were salamander eggs found in only 3 pools, P2, P5, and P10, which had a hydroperiod of 0.81, 0.63, and 0.63, respectively. There were only spermatophores found in P2 and P10. These are much lower levels of detection compared to the other two sites.

It was found that BERR had a mean HI of 0.745, Raup had a mean HI of 0.79, and VPP had a mean HI of 0.56 (Table 1, Table 2, Table 3). Both BERR and Raup had a significantly higher amount of amphibians detected compared to VPP. This corresponds to the hypothesis that increased hydroperiod results in increased amphibian abundance. However, even though Raup had a higher HI, it did not have higher abundances of any amphibians compared to BERR, suggesting that there are more factors at play here, and that perhaps after a certain point, the HI doesnt matter as much, and other limiting factors may be important. VPP had the ponds with the shortest hydroperiods and the most ponds with zero detections (Table 3), suggesting that the property has more expedited hydroperiods. Along with this, it has the least number of pools (12) compared to both BERR and Raup (15 and 17 respectively), and all of the major pools at VPP are isolated, whereas several at Raup and BERR have some form of inlet or outlet connectivity. Connectivity is very important to these woodland amphibians. This is because vernal-pool dwelling amphibians exist in local populations associated with their specific breeding pools, and due to their low dispersal rates, maintaining connectivity among pools is essential for long term population persistence (Zamberletti et al. 2018; Compton et al. 2007).

Discussion

Vernal pools often have what is known as a top down hydrology, which is where the water collects due to rainwater or other hydrologic events, and eventually seeps into the ground via infiltration (Zedler et al. 2003). However, there is another kind known as bottom up hydrology, where the pools are created by the seasonal rise in the water table, which fills up the basins that come to be vernal pools, and therefore go away when the water table sinks (Zedler et al. 2003). This could be one reason as to why the VPP site has a lower average HI, as shown in Table 3. It is doubtful that the cause of the lower average HI is due to a difference in precipitation, as the VPP and Raup sites are less than 2.5 km away, meaning that the two sites receive a relatively similar amount of precipitation.

When looking at the BERR site, it is interesting to see that the pools that had the highest abundances of frog egg masses did not align with the pools that had the highest abundances of salamander egg masses. The pools with the highest abundance of salamander eggs, those being

pools P1, P4, P5, and WT4, all of which had counts over 100. Only P4 had a relatively large amount of frog eggs, 65, which is the third highest presence in a pool in the BERR site for frog eggs. This could be attributed to competition between the two species, as they are occupying a similar ecological niche (Ocampo et al. 2022). It could also be due to a difference in the species habitat preferences, as it has been shown that wood frog reproductive effort increases due to pool size, depth, and closed canopy forest (DiMauro et al. 2002; Cushman et al. 2006). The proximity of nearby pools has also been shown to have a positive effect on amphibian reproductive effort (DiMauro et al. 2002, Compton et al. 2007).

Interestingly, secret pond on the BERR property supported the highest amount of frog eggs out of any of the surveyed sites, while only having a hydroperiod of 0.76, which is much lower than the other high abundance supporting ponds. Hence, I speculate that there is a hydroperiod 'threshold' for supporting amphibian breeding, as beyond a certain hydroperiod, the developmental threshold required for both species would be overcome, and that pool would be able to support breeding and development of both amphibians.

There is a strong exponential correlation between HI and salamander breeding effort (Figure 5a). A majority of the breeding effort is concentrated in pools with a HI > 0.6, with very few below that number. Contrarily, as shown in Figure 5b, frog breeding effort is less prone to this relationship, and while it does still show a positive linear relationship, there is numerically more breeding effort done in pools with a HI < 0.6 when compared to salamander breeding effort. This can be explained by the timing of when the two species breed. Wood frogs are often the 'first in, first out' in these vernal pools. Wood frogs will begin breeding as early as possible and often have juveniles leaving the pools around July, much earlier than the spotted salamanders (Andrews et al. 2021; Berven 1990). Spotted salamanders have a longer developmental time, as well as begin breeding later, when compared to wood frogs. This may make them more selective in the pools they breed in, opting for pools with longer hydroperiods to give their young the best chance of survival (Kern et al. 2013). From this, it can be said that wood frogs are more adapted to variable hydroperiods compared to spotted salamanders (Lent et al. 2020; Brannelly et al. 2019).

Limitations during this study include only one season's worth of data. 2024 showed slightly below average annual precipitation, 39.03 inches compared to the 25 year average of 41.01, and showcased above average temperatures, 52.6 F compared to the 25 year average of

48.3 F (NOAA 2025). Additional years worth of data would allow for analysis on years with differing precipitation, temperatures, and other phenomena. It is also hard to get an accurate reading of how many amphibians are within each pool. Many locations, such as VPP are large and can be impossible to assess the middle of the pool. It is also difficult to determine how many of the eggs end up fully developing into juveniles, which makes it hard to quantify pool productivity.

The scope of my research was limited to looking at only the hydroperiod and amphibian counts for various pools at three sites. In order to continue the progression of this research, future projects relating to this can expand to include multiple other variables and factors. Firstly, a long-term monitoring project would be helpful to track the changes in hydroperiods as well as amphibian populations over many years. Additionally, there could be a project looking into the development and testing of creating or restoring vernal pools in areas impacted by habitat fragmentation, with optimal hydroperiods to promote healthy amphibian populations. This could also tie into a project investigating the effects of land history, such as urban development and agricultural practices, and how that affects both the hydroperiods of the pools and the populations of amphibians that reside in them.

In terms of conservation, it is important to identify the hydroperiod of each pool, as it can help identify which pools are more important to conserve and which may become a source or sink habitat for various species (Dias 1996; DiMauro et al. 2002). This is especially important due to many states not classifying vernal pools as wetlands, and therefore do not include them in protective legislature, which can lead to development on the lands where vernal pools reside, leading to a significant loss in habitat for the species which rely on them to breed, resulting in an eventual decline in their population (Zedler et al. 2003; Zamberletti et al. 2018; Meshaka et al. 2009). Along with human development disrupting these vulnerable habitats, another driving factor is climate change. Due to the effects of climate change, which can produce earlier evapotranspiration as well as increasing both the intensity and frequency of droughts and shifts in precipitation timing, can cause pools to become dry earlier in the year, which can interfere with the completion of the development of amphibians (Cartwright et al. 2021). According to my analysis, amphibians exponentially prefer higher hydroperiods when selecting which pools to breed in, as the amphibians showed much more breeding effort in pools with $HI > 0.6$. I think that the hydroperiod tool that I developed can be a useful metric for identifying which vernal

pools are going to be significant sources for local amphibian populations, which can be used to show local legislators the importance of protecting these vulnerable habitats. Linking hydroperiods to breeding effort highlights the importance of preserving certain habitat conditions, those being hydroperiods of certain length, which is critical in mitigating the impacts of habitat loss, climate change, and other threats to amphibians. Ultimately, this research has contributed to the broader goal of conserving biodiversity and maintaining healthy ecosystems for future generations.

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Appendix A

Pond Name	Hydroperiod Index	Frog	Sal Egg	Spermatophore	Total
P1	1.00	0	132	29	161
P2	1.00	6	67	38	111
P3	0.98	72	62	3	137
P4	1.00	65	199	28	292
P5	1.00	0	234	24	258
WT1	0.36	2	47	1	50
WT2/WT3	0.72	4	31	9	44
WT4	0.96	18	118	30	166
Secret	0.76	93	44	3	140
OT1	0.47	0	0	0	0
OT2	0.73	0	26	4	30
OT3	0.73	0	14	5	19
OT4	0.93	0	5	0	5
OT5	0.27	6	3	5	14
OT6	0.27	10	7	4	21
Mean	0.75	18.40	65.93	12.20	96.53

Table 1. Berr Pools with Respective HI and Amphibian Counts

All of the pools for the BERR site, along with their hydroperiod indices, total amphibian counts, and the averages for all categories.

Pond Name	Hydroperiod Index	Frog	Sal Egg	Spermatophore	Total
1	1.00	0	225	0	225
2	0.67	0	0	0	0
3	0.71	0	54	0	54
4	0.86	17	69	2	88
5	0.71	0	0	0	0
6	0.86	0	4	1	5
7	0.83	0	6	2	8
8	1.00	0	146	12	158
9	0.67	0	0	0	0
10	0.86	8	11	0	19
11	0.86	0	7	0	7
12	0.71	0	0	0	0
13	0.67	0	0	0	0
14	0.67	0	0	0	0
15	0.86	0	4	0	4
16	0.83	0	0	0	0
17	0.80	0	17	0	17
Mean	0.80	1.47	31.94	1.00	34.41

Table 2. Raup Pools with Respective HI and Amphibian Counts

All of the pools for the Raup site, along with their hydroperiod indices, total amphibian counts, and the averages for all categories.

Pond Name	Hydroperiod Index	Frog	Sal Egg	Spermatophore	Total
P1	1.00	0	0	0	0
P2	0.82	0	20	4	24
P3	0.55	0	0	0	0
P4	0.40	0	0	0	0
P5	0.64	0	7	0	7
P6	0.45	0	0	0	0
P7	0.45	0	0	0	0
P8	0.45	0	0	0	0
P9	0.45	0	0	0	0
P10	0.64	1	32	6	39
P11	0.45	0	0	0	0
P12	0.45	0	0	0	0
Mean	0.56	0.08	4.92	0.83	5.83

Table 3. VPP Pools and Respective HI and Amphibian Counts

This table shows all of the pools for the VPP site, along with their hydroperiod indices, total amphibian counts, and averages for each category.