AQUATIC INVERTEBRATE MONITORING IN SAGUARO NATIONAL PARK: BIODIVERSITY AND COMMUNITY SCIENCE ENGAGEMENT

By

MAYA S TAIINATONGO

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Approved by:

Michael Bogan
School of Natural Resources and the Environment

Aquatic Invertebrate Monitoring in Saguaro National Park: Biodiversity and Community Science Engagement

Maya Tainatongo*[1,2]

[1] School of Natural Resources and the Environment, University of Arizona, Tucson, Arizona, USA

[2] Saguaro National Park, Tucson, Arizona, USA

* Corresponding author: maya.tainatongo@gmail.com

Abstract

The tinajas (rock pools) of Saguaro National Park are unique aquatic ecosystems that provide habitat for many aquatic species throughout the year in the Sonoran Desert. However, as climate change continues to impact drought and rainfall, these tinaja ecosystems will be irreversibly impacted. Over two years, we led community science monitoring of five tinajas in the Wildhorse Drainage at Saguaro National Park's Rincon District with the goal of understanding aquatic invertebrate diversity across seasons. Volunteers assisted in the collection of field data and samples collected in the field were used to create an extensive list of aquatic invertebrates that was used to identify specimens. After analyzing both field and lab samples, we found that the largest pool, which was also the only permanent pool, had the highest species richness across all surveys. There was reduced species richness post-monsoon due to streamflow connecting the pools and altering which species were present. Using community science to complete this project was useful because it allowed us to complete repeated surveys with limited staff.

Introduction

Tinajas (globally known as freshwater rock pools or potholes) in Saguaro National Park, Arizona, USA, can be found in shallow depressions in bedrock (Washko, 2023). These pools are often small and can dry for long periods of time, however, they act as an important water resource for local organisms in the arid Sonoran Desert (Swann et al., 2008; Zylstra et al., 2015). Tinajas also have important sociological connections with the land; the term 'tinaja' is the Spanish name given to rock pools in the Southwest and they hold important cultural value for many Indigenous communities across the land (Hartmann & Thurtle, 2001). Unfortunately, climate change is altering the hydroperiods, or inundation durations, of many temporary aquatic ecosystems (Washko, 2023), which can affect overall biodiversity and community composition in and around these pools (Schriever et al., 2015).

In desert tinajas globally, aquatic invertebrate communities are greatly affected by hydroperiod (Washko & Bogan, 2019). Many aquatic invertebrates must develop adaptations that allow them to complete their life cycles over a short period of time before tinajas dry

(Washko, 2023). Because of this, aquatic invertebrate taxa richness and community composition can provide important information about the varying hydroperiods within a system of tinajas. Tinajas in particular are useful for studying aquatic invertebrates because they are consistent in their physical structure and one stream drainage (i.e. a canyon) can include many pools of varying hydroperiod lengths (Jocque et al., 2010). The tinajas found across Saguaro National Park are ideal for aquatic invertebrate surveys because the region experiences annual flash flood and drought events. To better inform management of tinajas and predict changes as climate alters hydroperiods, we need to understand more about the aquatic invertebrate communities in tinajas of Saguaro National Park. We also conducted this study using the help of community science volunteers, to explore whether long-term monitoring of tinajas and similar ecosystems could be done by the general public.

We sampled five pools in Saguaro National Park on ten occasions between the years 2021 and 2023 in order to address three questions. First, how does aquatic invertebrate community diversity change seasonally and across pools with different hydroperiods? We expected that community diversity would decrease during months with floods and above average rainfall because aquatic invertebrates are either washed downstream or choose to relocate to calmer water bodies. Within this, we believe that winter and spring will have higher diversity levels due to inconsistencies in water volume and lower likelihood of intense flood events. Furthermore, we hypothesized that pools with longer hydroperiods will have higher taxa richness. Second, how do indicator species' abundances vary seasonally? We hypothesized that indicator species will differ both across seasons and between pools with different hydroperiods. Lastly, how can community scientists be helpful in collecting data for consistent monitoring projects, such as this? We expected that there would be constraints to data quality collected by volunteers, but we believed that the learning experience the project provides is critically important in connecting the public with their natural spaces.

Methods

Study Site

Saguaro National Park is located in southern Arizona on the outskirts of the Tucson metropolitan area. There are two districts of the park: The Tucson Mountain District and the Rincon Mountain District. The national park contains tinaja systems in various drainages across the park. The data in this study was collected at RMD from the Wildhorse Drainage (32.211257, -110.684888), about a two-mile hike from the Douglas Springs Trailhead. We chose to consistently survey this tinaja system because it was located in a designated wilderness area within the park and was also located off a main trail system in the park. It was fairly inaccessible to visitors who weren't aware of its existence but was also relatively close to the trailhead to allow for easy access for community scientists. Using water data from the National Park Service, ten pools were chosen within the drainage. Pools had been named by the park service and pools 4, 5, 10, 10f, 10g, 12, 13, 15, 15a, and 15c were chosen for the survey due to their proximity to the trail. After a couple surveys, we discontinued sampling at the five downstream pools (4-10g) due to accessibility for volunteers and reducing field time to a more manageable time frame. In this paper, we focus only on results from five pools, which were 12 through 15c.

Sampling Procedure

In March 2021, one pilot aquatic invertebrate sample was collected from each of the ten pools (4-15c) for lab analysis to create a comprehensive taxa list. Pilot samples were collected using a D-net and a timed 1m sweep sampling technique to begin a species list for identification in the field. During the pilot survey of these pools, water quality data was also collected. This included pH, conductivity, and dissolved oxygen. From the original set of ten pools, pools 12, 13, 15, 15a, and 15c at the top of the drainage were chosen as the citizen science survey plots. All five of these pools were visited and surveyed in September and November in 2021; January, February, April, September, October, and November in 2022; and January and February in 2023. During each field survey, invertebrates were released back into the pool after visual identification and enumeration. Getting volunteers into the field and interested in desert pools was one of the main goals of this project. Because volunteer engagement is important, we didn't want to employ field methods that were too technical or time-consuming.

Aquatic invertebrates were sampled from each pool using a timed D-net sweep. To perform the sweep, the net (500µm mesh size) was plunged into the water and repeatedly swept across one meter of the pool benthos. While sweeping, we turned the net 180 degrees to catch the trail of disturbed substrate and invertebrates. The D-net was approximately 30cm wide on the flat side, providing a semi-quantitative sample area of $0.3m^2$. Small pools ($1\text{-}10m^2$ surface area) were swept for 10 seconds, medium pools ($11\text{-}100m^2$) were swept for 100 seconds, and large pools ($101\text{-}200m^2$) were swept for 200 seconds. Contents of the net were placed in white plastic bins (such as those used for household cleaning; Appendix 1) filled with water for volunteers to look through. Volunteers were taught to identify taxa and count the total number of individuals of each species present in the bins (Appendix 3). These numbers were recorded on paper data sheets and entered into an online master dataset. At the end of the two-year survey, invertebrate data were analyzed for patterns of biodiversity.

Statistical Analysis

All data was analyzed in the R statistical program (R Core Team, 2022). Invertebrate taxonomic richness data was analyzed for each pool sample (*specnumber* function). We tested the richness data for normality using a Shapiro-Wilk test (*shapiro.test* function), finding that richness was not distributed normally. We then compared richness data across pools using a Kruskal-Wallis test (*kruskal.test* function), followed by a post-hoc Pairwise Wilcoxon Rank Sum Test to elucidate where significant differences were between pools.

Pool sample data was organized into a community matrix, which was analyzed using the 'vegan' package (Oksanen et al., 2019). Differences in the aquatic invertebrate communities between pools and between seasons were visualized using nonmetric multidimensional scaling (NMDS; *metaMDS* function). Then, we tested for differences in community composition between pools and between seasons using PERMANOVA (*adonis2* function). We performed post-hoc pairwise adonis tests to find where the differences were among pools and across seasons.

Finally, the ‘indicspecies’ package (Caceres & Legendre, 2009) was utilized to identify indicator taxa for each of the Wildhorse tinajas (*multipatt* function to distinguish indicators, then *signassoc* function for multiple testing adjustment on the p-values).

Results

Aquatic Invertebrate Overview

There were 61 different aquatic invertebrate taxa found across the field samples. Of these 61 taxa, 34% were identified to species, 33% were identified to genus, and 32% of the taxa were identified to family.

Richness & Biodiversity

Taxa richness in the samples per visit ranged from one taxon observed to 32 taxa observed, with a mean richness of 14 taxa per pool across all samples. Richness was significantly different by pool (Kruskal-Wallis, chi-squared = 17.992, df = 4, p-value = 0.001). This difference was due to significantly higher taxa richness in pool 12 than 14 (Pairwise Wilcoxon Test, p-value = 0.029) and higher richness in pool 15c than 14 (Pairwise Wilcoxon Test, p-value = 0.021). There were marginal differences between pools 15c and 15 (Pairwise Wilcoxon Test, p-value = 0.071) and between pools 15c and 15a (Pairwise Wilcoxon Test, p-value = 0.057). In both cases, pool 15c had higher richness. Pool 15c had the highest richness out of all pools sampled during eight sampling events (Figure 1A), and pool 12 had the highest richness during two sampling events (n = 10 sampling events).

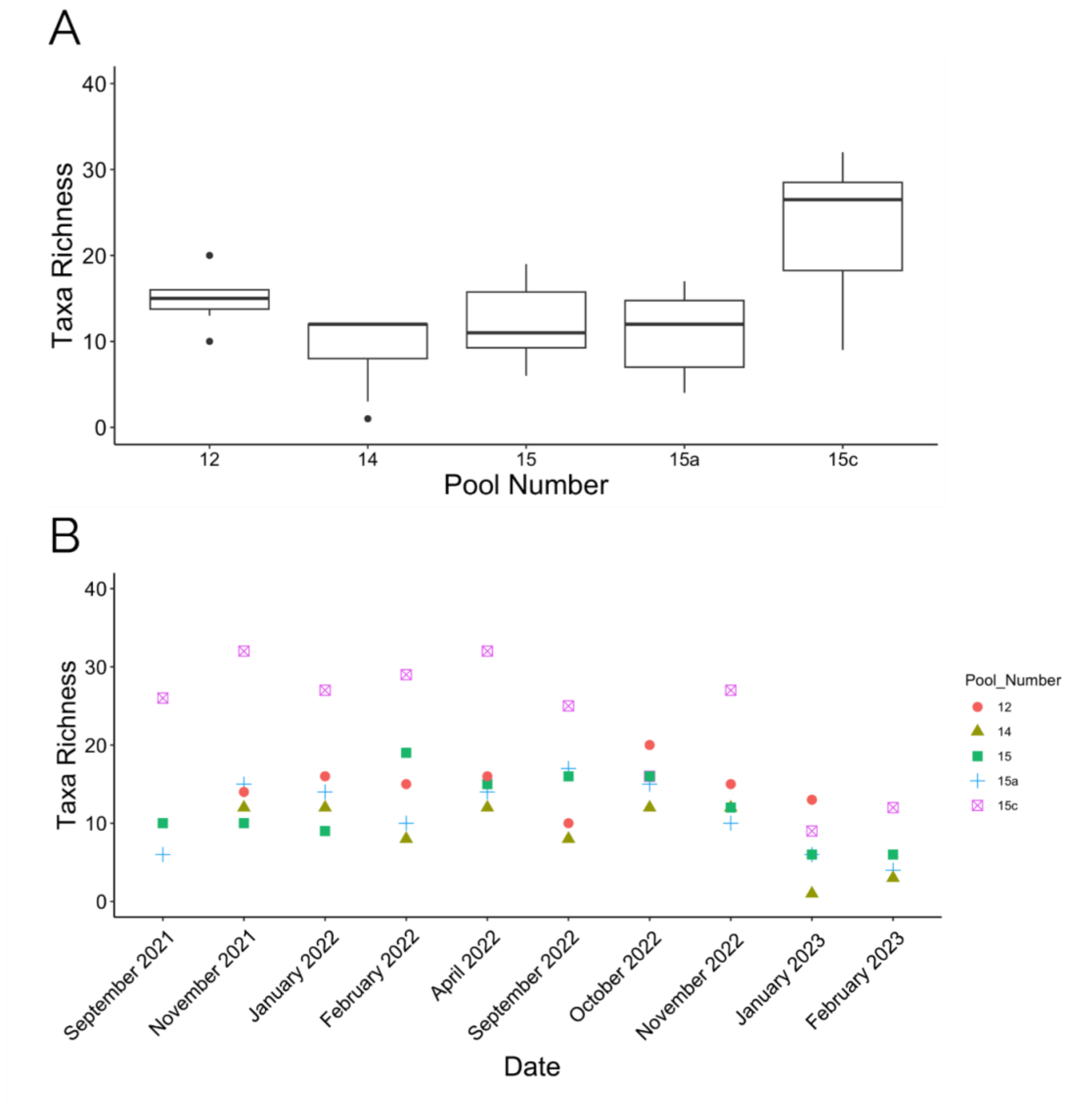

Figure #1. A) Taxonomic richness was similar across most pools except pool 15c, which had higher observed taxonomic values. **B)** Taxa richness over ten months for each pool in Wildhorse drainage.

Community Composition

Pool

Although all of the pool samples are clustered together in the NMDS plot, visually not revealing a difference in community composition, statistical testing suggested a significant difference in community composition between pools (PERMANOVA, $F_{4, 42} = 1.55$, $R^2 = 0.13$, $p = 0.015$; Figure 2A). The composition in pool 15c was different from that of pool 12 (Pairwise PERMANOVA, $F = 2.73$, $R^2 = 0.146$, $p = 0.03$) and of pool 14 (Pairwise PERMANOVA, $F = 2.18$, $R^2 = 0.114$, $p = 0.05$).

Season

In the NMDS plots, winter samples were grouped on the left side of the plot (Figure 2B). There were significant differences in aquatic invertebrate community composition by season (PERMANOVA, $F_{3,43} = 1.96$, $R^2 = 0.12$, $p = 0.002$). However, the only significant difference in community composition was between the monsoon and winter seasons (Pairwise PERMANOVA, $F = 2.60$, $R^2 = 0.09$, $p = 0.018$).

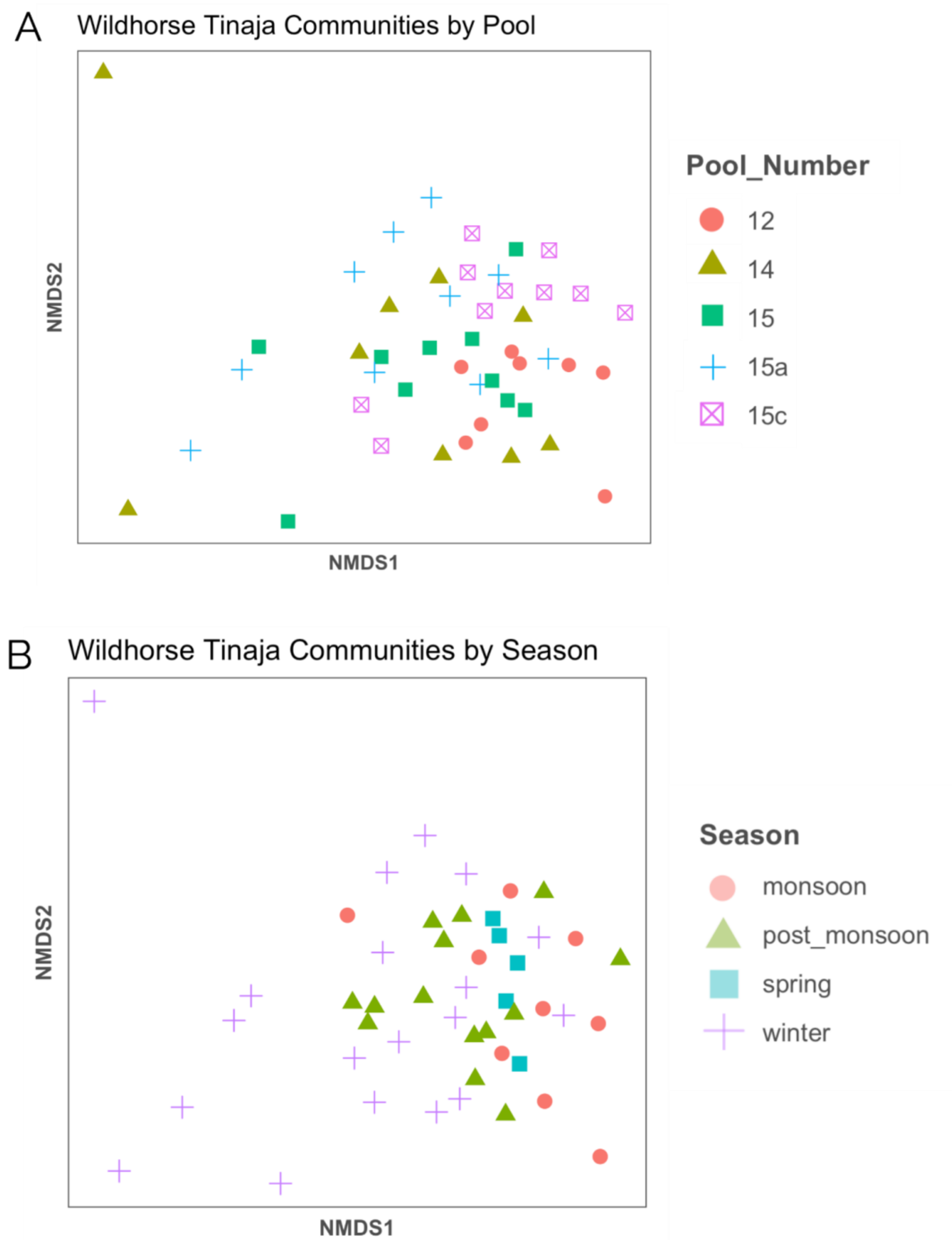

Figure #2. Nonmetric Multi-Dimensional Scaling ordination plots visualizing **A)** aquatic invertebrate community composition by pool number and **B)** community composition by season.

Indicator Taxa

Pool

Indicator species are those that are prominent in the communities of given groups of samples. When analyzing the pools individually, pool 15c was the only pool for which indicator taxa were identified, and the taxa represented a wide variety of traits and life histories. These taxa spanned numerous orders and classes, including Odonata, Coleoptera, Hemiptera, Diptera, Acari, and Turbellaria. The taxa spanned different functional feeding groups including gatherers, filterers, and predators. Only six of the indicator species found in pool 15c were classified as herbivores; the remaining taxa were predators (Schriever et al., 2015). Herbivorous taxa encompassed two collector-gatherers, one filter-feeder, two scraper-grazers, and one shredder (Schriever et al., 2015; Table 1). Along with this, we noted that a majority of the taxa were active aerial dispersers, with only five taxa using a different dispersal method (Schriever et al., 2015; Table 1). The communities in the other pools were similar enough to one another that no indicator taxa were identified.

POOL

15c	**Stat**	**Adjusted P**	**FFG**	**Dispersal**
Neoclypeodytes_unknown2	0.857	0.025	Predator	Active aerial
Chironomidae	0.803	0.025	Collector-gatherer	Passive aquatic
Culicidae	0.779	0.025	Collector-gatherer	Active aerial
Cladocera	0.745	0.049	Filter-feeder	Passive aquatic
Neoclypeodytes	0.737	0.025	Predator	Active aerial
Libellulidae	0.725	0.025	Predator	Active aerial
Microvelia_sp.	0.712	0.049	Predator	Active aerial
Hydrophilidae	0.699	0.025	Scraper-grazer	Active aerial
Tropisternus_lateralis	0.698	0.025	Scraper-grazer	Active aerial
Enochrus	0.687	0.025	Shredder	Active aerial
Laccophilus_fasciatus	0.684	0.025	Predator	Active aerial
Acari	0.651	0.025	Predator	Aerial passive
Progomphus borealis	0.640	0.025	Predator	Active aerial
Hydroporus	0.634	0.025	Predator	Active aerial
Naucoridae	0.592	0.025	Predator	Active aquatic
Ranatra	0.566	0.025	Predator	Active aerial
Platyhelminthes	0.548	0.025	Predator	Passive aquatic

Table #1. Indicator species present in pool 15c and their functional feeding groups (FFG) and dispersal methods.

Season

We then analyzed for indicator species with a grouping of season. Only monsoon, spring, and winter seasons had indicator taxa (Table 2). During the monsoon season, *Thermonectus marmoratus* (Dytiscidae), a predator that utilizes active aerial dispersal, was the only indicator species. In spring, *Graptocorixa abdominalis* (Corixidae) was particularly prominent, and is also a predator that utilizes active aerial dispersal. Lastly, for winter, Limnephilidae was an indicator taxa, and is a shredder (herbivore) that uses active aerial dispersal as an adult (Table 2).

SEASON

Monsoon	**Stat**	**Adjusted P**	**FFG**	**Dispersal**
Thermonectus_marmoratus	0.584	0.039	Predator	Active aerial
Spring				
Graptocorixa_abdominalis	0.707	0.020	Predator	Active aerial
Winter				
Limnephilidae	0.607	0.020	Shredder	Active aerial

Table #2. Indicator taxa present for the seasons when tinaja invertebrates were collected. Traits listed include functional feeding groups (FFG) and dispersal modes.

Citizen Science Surveys

Overview of Volunteer Efforts

During surveying, we led between 1-9 volunteers. These volunteer groups consisted of University of Arizona undergraduate and graduate students, volunteers from the Saguaro National Park volunteer program (some of whom were consistent volunteers on the survey), and National Park Service staff members. Surveying was led by the author (an intern at Saguaro National Park), with assistance from a graduate student collaborator, both of whom had a high level of field knowledge and identification experience and supported volunteers with identification and enumeration in the field.

Observations from Volunteer Surveys

Identification of smaller invertebrates was challenging for volunteers, who had difficulty noticing the smaller invertebrate species and distinguishing the diagnostic morphological characteristics of smaller species as well. Lack of field guides specific to tinaja invertebrates also contributed to difficulties identifying invertebrates in the field (only guides for stream insects inhabiting flowing water were available). Field conditions also presented physical challenges for volunteers, such as sitting on the ground for long periods of time, hiking the relatively flat two-mile trail to the field site, and working in hot temperatures.

Discussion

Community Composition & Richness

The goal of this study was to understand the aquatic invertebrate biodiversity and community composition across pools in the Wildhorse drainage located at Saguaro National Park using primarily volunteer community scientists. Pool richness in Wildhorse drainage is higher than what was seen in previous rock pool studies (Kubly, 1992; Washko, 2023). This is most likely because Wildhorse drainage extends into higher elevations, where higher rates of precipitation provide water to lower-elevation areas of the watershed (Pelletier et al., 2013; Zylstra et al., 2015), contributing to water permanence. Our data demonstrates that pools within Wildhorse Canyon had different aquatic invertebrate community compositions and different levels of taxa richness, which could be attributed to varying hydroperiod lengths. Differences in taxa composition are likely due to higher richness seen in longer-lasting pools, which are often larger pools (Washko, 2023). Larger, longer-lasting pools can accommodate a variety of taxa due to the reliability of the water for longer-lived species and habitat heterogeneity. Further, pools with longer hydroperiods are able to support more expansive food webs that include intermediate consumers and predators (Schriever et al., 2015). Indeed, pool 15c, the pool with the longest hydroperiod (National Park Service personal communication), often had much higher richness regardless of season (Figure 1A; Figure 1B). Due to its large size, pool 15c also had a higher diversity of microhabitats (inundated vegetation, shallow water, deep water, rock walls with undercuts, and gravel habitat; author personal observation). Furthermore, pool 15c was characterized by a number of indicator taxa that spanned many different functional feeding groups and life history traits (Table 1).

Another study from the region determined that the mean number of taxa present was positively correlated with pool volume and hydroperiod, but best explained by the distance upstream in the drainage (i.e. isolation; Kubly, 1992). Isolation was not a factor in this study due to all the sampled pools being in close proximity to each other within the canyon. All pools were within a 0.2 km stretch of canyon, there were more pools immediately upstream and downstream of the sampled pools, and the drainage near to other canyons containing tinajas.

We observed low richness during high flow events, which occurred during the months of January and February in 2023, as shown in Figure 2B. These were the only samples taken during periods when high stream flow connected all the pools. Benthic invertebrate diversity is often decreased during floods (Scrimgeour et al., 1988), and previous research suggests that colonization and dispersal is slow during the winter months due to low invertebrate activity levels (Tronstad et al., 2007). The combination of flooding and cold temperatures could explain the low richness found in January and February 2023.

Previous work in the Sonoran Desert found that tinaja water levels tend to be more consistent during the winter months, thus allowing a reliable environment for a variety of taxa (Washko, 2023). The spring and monsoon seasons are often marked by extreme flood events and fluctuating water levels due to unpredictable summer and spring drying events (Washko, 2023). Interestingly, we observed that extended winter flows allowed stream taxa, like Limnephilidae caddisflies, which were taxa indicative of winter conditions (Table 2), and Capniidae stoneflies to colonize the drainage. Stoneflies in particular have adapted to temporary flow events and can remain dormant and resistant to desiccation for months after stream drying, waiting for winter flow (Bogan, 2017). This may be why we did not detect stoneflies in any of our surveys prior to the intermittent winter flow event starting in January 2023. The differences between our findings and those of Washko (2023) are likely due to the extensive elevation change found in the Wildhorse Canyon watershed, whereas elevation change in Organ Pipe Cactus National Monument (where Washko collected data) is less pronounced and has no snowpack to provide flow. Based on these findings, we suggest that future research look into the effects that seasonal flow has on richness and community composition in Wildhorse Canyon.

Aquatic Invertebrate Monitoring as a Citizen Science Effort

A main component of this project was citizen science involvement. Through our aquatic invertebrate surveys, we were able to engage a variety of volunteers in field science. Volunteer effort was useful because it allowed us to accomplish extensive aquatic invertebrate surveys each month, despite low National Park Service staff capacity. However, there were constraints to using volunteers to complete data collection. We observed that smaller aquatic invertebrates, such as Chironomidae and Cladocera, were often missed by volunteers, but noticed by the survey leaders. These taxa are often difficult to see during visual surveys, even for some experience in aquatic invertebrate identification, potentially leading to underrepresentation of smaller taxa in field surveys. This type of surveying can also be exclusionary to elderly volunteers who may not have the ability to see smaller aquatic invertebrates or the capacity to sit on the ground hunched over a small bin of invertebrates for long periods of time. To aid in counting large numbers of small aquatic invertebrates, we began bringing clicker counters (Appendix 1) into the field to make enumeration easier and more accurate for volunteers. Identifying to family level was also easier due to the lack of equipment and in-depth field guides. Other citizen science projects have cited that identification often has high error for volunteers (Pinto et al., 2020), but having experienced leaders in the field can help alleviate this. Data collected by volunteers can be high quality given enough support and experience (Storey et al., 2016).

Citizen science efforts in past projects have shown that data collected through these methods are accurate when the sampling protocol is standardized (Pinto et al., 2020). We are working to ensure that the Wildhorse tinaja survey protocol is understandable and accomplishable for volunteers, regardless of their experience levels. One next step we plan to pursue is to create a comprehensible visual guide of local aquatic invertebrates, as well as a map of the survey pools. Guides and maps would be useful for both finding the pools and ensuring correct identifications. This could also decrease the need to have knowledgeable leaders working in the field alongside volunteers. Community science projects are critical forms of communication that can provide the public with the chance to interact with scientists and field science, which has been cited by volunteers as motivating them to participate in community science and local decision-making (Pinto et al., 2020; Storey et al., 2016).

Conclusions

In the Wildhorse drainage, pool 15c is unique due to its large size, long hydroperiod, and diversity of habitats within the larger pool system. These factors have resulted in high species richness, but community composition and richness can be altered by high flow events. Future work should focus on understanding changes in aquatic invertebrate communities through different flow scenarios. Volunteers from the community aided in data collection, and through these repeated tinaja surveys, we have noted some constraints and made recommendations for best practices in community science monitoring of these pools, notably that concise survey protocols and accurate field guides are two materials that can help increase accuracy of data collection and volunteer enjoyment. Success of community science monitoring will contribute to an expanded understanding of this system to inform management decisions within the park.

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Appendices

Appendix #1. Sampling gear used in field surveys including white plastic tub, smaller containers, and short field guide.

Acari	Sanfilippodytes	Tropisternus_affinis	Tipulidae
Cladocera	Stictotarsus_corvinus	Tropisternus_lateralis	Unidentified_Diptera
Hydroporus	Thermonectus_marmoratus	Unidentified_hydrophilid (Helophorus?)	Caenidae_Caenis
Laccophilus_fasciatus	Thermonectus_sibleyi	unidentified_Dytiscidae	Callibaetis_sp.
Laccophilus_horni	Thermonectus_nigrofasciatus	Dytiscidae_larvae	Ameletidae_sp.
Laccophilus_pictus	Dineutus_sublineatus	Hydrophilidae_larvae	Abetus
Laccophilus_maculosus	Gyrinus	Gyrinidae_larvae	Lethocerus_sp.
Liodessus	Berosus_larger	Neoclypeodytes_chia	Graptocorixa_abdominalis
Neoclypeodytes	Berosus_smaller	Haliplidae_Desmopachria_mexicanus	Gerridae
Rhantus_gutticollis	Enochrus	Hydraenidae	Naucoridae
Progomphus_borealis	Physidae	Buenoa_arizonis	
Archilestes_grandis	Planorbidae	Buenoa_arida	
Oligochaeta	Limnephilidae	Notonecta_lobata	
Ostracoda	Marilia.caddis	Notonectadae_juvenile	
Platyhelminthes	Mesocapnia.arizonensis	Notonecta_kirbyi	
Ranatra	Dixidae	Copepoda	
Microvelia_sp.	Simuliidae	Ceratopogonidae	
Megaloptera	Stratiomyidae	Chaoboridae	
Aeshnidae	Limoniidae	Chironomidae	
Libellulidae	Tabanidae	Culicidae	

Appendix #2. List of all taxa found across surveys.

Appendix #3. Volunteers in the field counting aquatic invertebrates.