

Macroinvertebrates and Their Relationship to Water Availability and Streamflow in Middle Rincon Creek, Saguaro National Monument East



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Introduction

In arid regions, surface water is an invaluable resource to a huge variety of biological organisms. While many desert adapted organisms are well suited to their arid environments thanks to low water requirements, excellent physiological water retention and reabsorption systems, or access to sources of water not available to other organisms, a majority of the desert biota is dependent on surface water to some extent. Even tiny, ephemeral rain pools may be teeming with life, the organisms within astoundingly diverse and perfectly adapted to exploit the temporary environment they inhabit. Without occasional surface water availability, the diverse and comparatively lush deserts of the American southwest could not exist.

While water is necessary to the survival of many organisms, some are entirely dependent on relatively long-term water availability, including riparian plants, algae, fish, and aquatic herpetiles and macroinvertebrates. Without persistent or frequent influx of water, many of these organisms could not survive in arid regions. Nonetheless, even these organisms utilize specialized life history strategies that allow them to survive in the unpredictable and often ephemeral aquatic habitats found in deserts. For example, the spadefoot toad is able to defer development until there is sufficient rain to form the pools necessary for continued development. The giant water bug *Abedus herberti* and the hellgrammite *Corydalus* sp. are apparently able to sense rapid increases in stream flow and avoid flash floods by seeking shelter on land. Many other aquatic insects are able to determine when a local source of water has evaporated to the point continued survival is unlikely and migrate to fresh or larger sources of water, sometimes many miles from their original location. Indeed, insects are often the first organisms to colonize a new body of water in the desert.

Much research in aquatic systems has focused on indicator species, species that reveal something about the characteristics of the body of water under study. It is assumed that if a species is found within a body of water, it is physiologically adapted to the conditions of the water in the habitat. Fish are commonly used as bioindicators of many water quality parameters as they are dependent on and highly responsive to changes in their aquatic environment. They cannot move overland easily (typically on as eggs on the legs of birds), making them ideal indicator species: they are bound by the confines of the body of water they are born in and must be able to tolerate the range of conditions within to survive. There are also relatively few species of freshwater fish and they are large, so identification is easy. However, many bodies of water are unable to support fish. In such systems, scientists must turn to alternative indicator species such as the aquatic macroinvertebrates and algae.

Aquatic macroinvertebrate communities have long been recognized as important monitoring tools in aquatic systems, and for good reason. Invertebrates and algae are often the only macroorganisms within a body of water. In such cases, macroinvertebrates are superior to algae as study organisms as they are sentient beings and can choose to leave their habitat in search of new or better ones if conditions deteriorate. However, like fish, most stages of aquatic insects cannot leave

the water for extended periods and must be adapted to the conditions of their environment to survive. This makes them useful as bioindicators. Like fish, macroinvertebrates are responsive to their environments: if conditions are not sufficient for survival, the faunal dynamics shift as the less tolerant species die or migrate out of the system and are succeeded by the species better adapted to the conditions. Macroinvertebrates are particularly useful as bioindicators in arid regions where permanent sources of water, such as springs or large rivers, are scarce. In Arizona, intermittent and ephemeral streams vastly outnumber permanent streams and these systems are often unable to support fish, either because they do not contain a sufficient water volume or the stream periodically dries completely. Macroinvertebrates are useful bioindicators in Arizona because they are able to tolerate a wider range of conditions than fish and are more widespread.

Water in the arid west is an extreme environment. While permanent waters in mesic regions are relatively stable, buffered environments, desert water is unstable and unpredictable. Large pools may form during rains, but unless they persist for several days, they are largely useless to most aquatic organisms. Desert streams are subject to flash floods capable of destroying the majority of the organisms inhabiting them, significant daily shifts in conditions (i.e. temperature, oxygen levels), and high evaporation rates. It is likely that aquatic organisms in arid regions are more tolerant of extreme conditions and wild fluctuations in water quality parameters than those of more mesic regions because their habitats are much less stable.

Despite the great importance of surface waters in the American southwest, there has been surprisingly little research completed in the aquatic systems of the area. Compared to mesic regions, the waters of arid regions are poorly understood and many questions remain unanswered. For example, it is unknown whether permanent streams of desert regions undergo the same processes that permanent streams in mesic areas do. Do nutrients cycle the same way in mesic and arid region permanent streams? Intermittent streams? It is also unknown how important the hyporheic zone, the area of saturation between the base of a stream and the groundwater, is to aquatic organisms in desert regions. The hyporheic zone is widely accepted as a refuge for aquatic macroinvertebrates during times of low water availability in permanent streams in mesic regions, but do desert aquatic insects have access to this region in a rapidly drying stream? Relatively little is known about the faunal dynamics and nutrient cycling of intermittent streams and how these change when the stream transitions from a lotic to a lentic system. Much more research must be completed within arid regions before we can truly understand the dynamics of surface water resources within them.

The main objective of the current study is to classify the water needs of the aquatic invertebrates of Middle Rincon Creek in Saguaro National Monument East in support of the water rights claim made by the National Park Service for this stream in the state of Arizona. We also wish to determine how the transition of the stream from a lotic to a lentic affects macroinvertebrate diversity and community composition and whether the hyporheic zone is an important refuge as the stream dries. We hope to contribute to the body of knowledge about streams and their macroinvertebrate populations in the arid

western United States, particularly southern Arizona, so that we might better understand how these systems function and whether they are comparable to streams in mesic regions.

Methods

Location of Stream

Rincon Creek is located in southern Arizona east of Tucson and is part of the Santa Cruz River watershed. Its source is in the Rincon Mountains near Rincon Peak and the Happy Valley lookout and it flows across Saguaro National Monument before emptying into Pantano Wash, the Rillito River, and eventually the Santa Cruz (Figure 1). Several other small mountain streams and washes flow into Rincon Creek upstream of its confluence with Pantano.



Figure 1. Topographic map of the study region.

Stream Characteristics

Rincon Creek is an intermittent stream and experiences cyclic availability of water; it does not flow year round. In a typical year, the stream flows during the winter. The surface water evaporates rapidly as the temperature increases through spring and into summer such that several distinct, disconnected pools form. The stream usually flows again during late summer with the arrival of the monsoons. During this time, it is prone to both minor and major flash flooding. Distinct pools begin to form after the monsoons have passed and persist until the start of the winter rains when the winter flow begins again. This pattern of succession repeats the following year. In dry years, the number of available pools may decrease, and in severely dry years, the stream may dry completely. During wet years, the stream may flow throughout the year and never transition into a pooled system.

Rincon Creek is a bedrock dominated stream. In many portions of the stream, the bedrock is at the surface so that subterranean flow is impossible. In other regions, substrate lies on top of the bedrock. Substrates are largely silt/sand with some medium and small cobble interspersed. As the stream dries and transitions from a flowing to a pooled system, pools form in bedrock-lined low lying regions.

Rincon Creek is surrounded by a narrow riparian area dominated by cottonwoods, willows, and sycamores. The trees provide shade to a majority of the stream. During periods of drying, other vegetation may grow between pools, including grasses and aquatic macrophytes.

Sampling Sites

All study sites chosen for this study (Figure 2) were located downstream of the confluence of Chiminea Creek and Rincon Creek. Additionally, all sites were located downstream of the Rincon Water Company's pumping station.

Three sampling sites were selected for use throughout this study, all areas where water persists as discrete pools during periods of drying. Pool A (Figure 3) was located just below the confluence of Rincon and Chiminea Creeks. The site is also the location of the NPS bubbler gauge. Pool A was bedrock covered with small to medium cobble, gravel, and silt/sand.

Pool C (Figure 4) was located just downstream of the location where the old road to the Madrona Ranger Station crosses the creek. It is a bedrock lined pool partly covered by a thick layer of sand/silt with few medium cobbles. During periods of drying, the water shrinks to the lowest point, a bedrock lined pool with no other substrate covering it. This site was chosen because it is the site of one of the most persistent pools within the study reach.

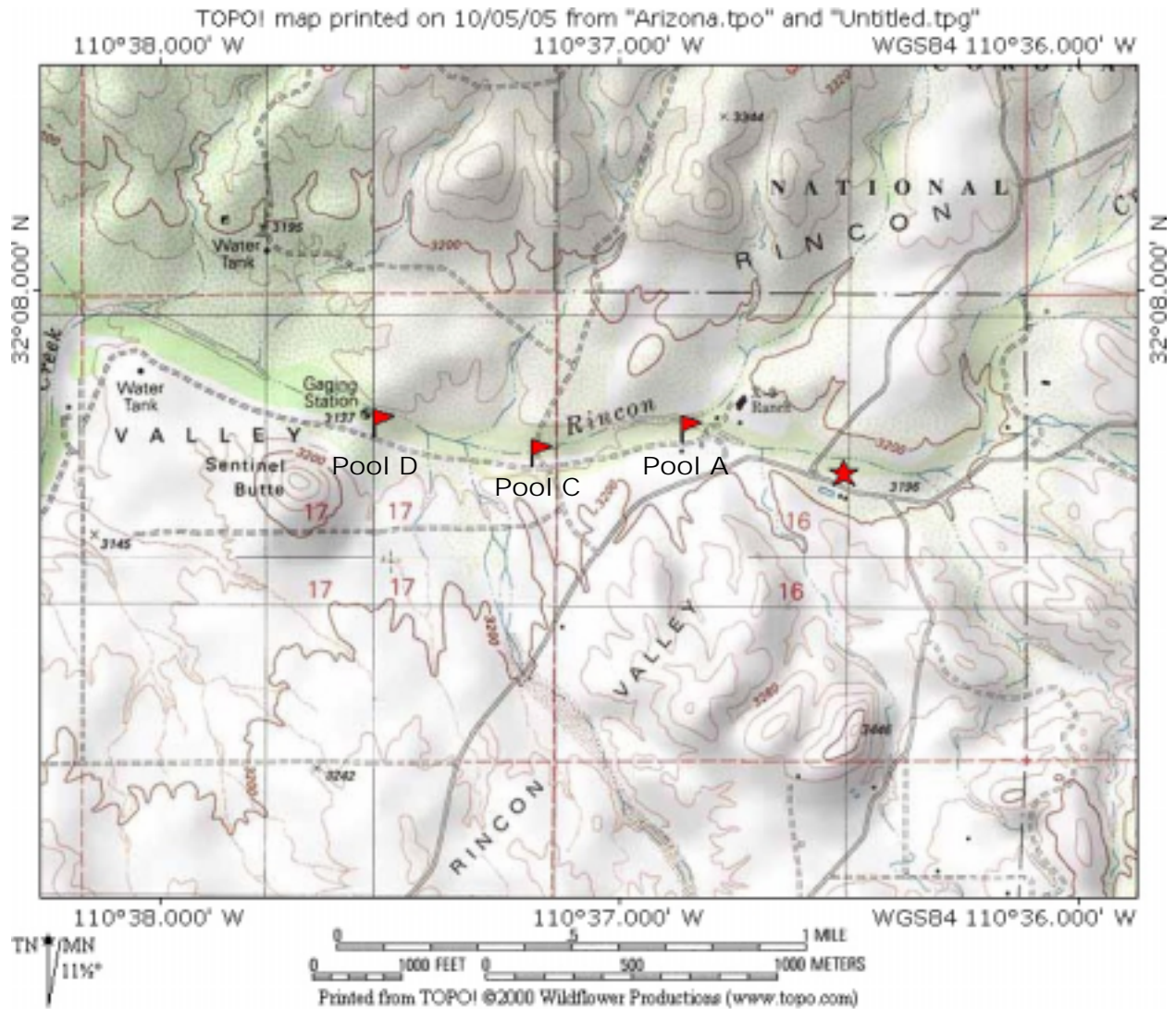


Figure 2. Topographic map depicting the study reach. Sampling sites are marked with flags. The Rincon Water Company pumping station is marked by the star.

Pool D (Figure 5) was located just upstream of the USGS stream gauge and downstream of the confluence of a large, unnamed wash and an additional smaller, unnamed wash. Pool D was bedrock covered by a thick layer of sand/silt and is apparently one of the depositional areas of the stream. This pool was prone to morphological changes as substrate was deposited or scoured out with changes in flow.



Figure 3. Pool A



Figure 4. Pool C



Figure 5. Pool D

Physico-chemical Sampling

We tested the water conditions every time we sampled as they, in addition to water availability and flow levels, might help explain the diversity and community structure we observed in the stream. On each sampling date, we measured water temperature, dissolved oxygen (DO), percent dissolved oxygen (DO%), specific conductivity, pH, oxidation-reduction potential (ORP), and turbidity using a Hydrolab. Hydrolab data were collected before sampling for macroinvertebrates so that the water would not be disturbed. The Hydrolab was positioned in the center of the pool or stream about 10cm below the surface of the water. We also measured the air temperature, wind speed and direction, and barometric pressure and noted the level of cloud cover and the presence of rain.

Additionally, we used the Hydrolab to take water quality measurements within the piezometers one time to determine what the conditions of the water within the hyporheic zone were during a period of drying. Hyporheic sampling is described below.

Surface Water Macroinvertebrate Sampling

To determine macroinvertebrate community structure and diversity, macroinvertebrate samples were taken at each site once a month when water was present from March 2004 through July 2006 (Appendix 1). Samples were taken with a 250 μ m kick net and consisted of either 3 one minute kicks (when the water was flowing) or 3 one minute sweeps (when the water was pooled). The collected material was then transferred to a bottle and preserved with ethyl alcohol for transport to the University of Arizona Environmental Research Laboratory (ERL) for processing.

At ERL, the samples were rinsed in a 90 μ m sieve and transferred to a Caton tray for subsorting. 1/10th of the sample was removed at random from the whole sample. The macroinvertebrates were carefully separated from the other materials in the subsample using a Wild stereo microscope. The macroinvertebrates in the subsample were identified to the genus level according to Merritt and Cummins (1996) and the total number of individuals of each taxa counted. Sludges worms (Haplotaxida) were identified only to the family level.

No samples were collected between March and May 2005 as the funding for the second year of the project had not been disbursed and work could not continue due to lack of funds. Sampling was conducted less than once a month after December 2005 due to the lack of surface water.

Hyporheic Zone Invertebrate Sampling

It was expected that the hyporheic zone of Rincon Creek would act as a habitat and/or a refuge for a variety of aquatic macroinvertebrates, so we sampled the hyporheic zone at each sampling site once a month from March 2004 through December 2005, regardless of whether there was water present or not. We designed two part recolonization samplers (Fig. 3) to collect samples from the hyporheic zone. The outer layer consisted of a 5 gallon plastic bucket with multiple 1 inch holes drilled into the sides and the bottom. This was buried in the substrate so that the upper edge was even with the surface. The inner layer of the sampler was made from a 1/2 meter long 1 1/2 inch diameter PVC pipe with several 1 inch holes cut from it. The inner surface of the pipe was lined with 1/4 inch wire mesh. A piece of threaded rebar ran through the center of the pipe and through caps on each end. The caps were held in place by wing nuts on both ends. The inner layer was filled with native substrate at each pool site, capped, and buried in the center of the bucket. The bucket was then filled with the soil displaced during sampler placement and the lid was placed over the top.



Figure 6. Hyporheic sampler.

The samplers were left undisturbed for a month, and then the inner portion of each sampler was removed and emptied into individual bottles. The contents were preserved with alcohol and transported to ERL for processing. The inner portion of the sampler was refilled with native soil, replaced in the bucket, and left to be recolonized over the next month.

During the first year, there was one hyporheic sampler at each site. Due to low macroinvertebrate yields, the sampling plan was altered the second year to rule out the possibility there was a problem with the design of our samplers. We installed an additional 3 samplers per site for a total of four per site. Two samples were collected monthly at each site. The contents of the other two samplers were collected quarterly to determine whether the reason we were collecting so few macroinvertebrates was because we were not allowing sufficient time for macroinvertebrate colonization of the samplers. There was no difference between the monthly and quarterly samples.

At ERL, samples were rinsed in a 90 μ m sieve and all of the macroinvertebrates were removed using a Wild stereo microscope. Terrestrial organisms were not identified. Aquatic or semi-aquatic macroinvertebrates were identified and counted as in the surface samples.

We discontinued sampling the hyporheic zone in December 2005. We were no longer gaining useful data from the samples and concluded it was not worthwhile collecting more samples until the stream began to flow again. The project ended before there was sufficient flow to make collecting and processing additional hyporheic samples possible.

Upper Pools Macroinvertebrate Sampling

Because it had been so dry throughout the study period, in September 2005 we began collecting macroinvertebrate samples from the permanent pools upstream of the middle reach of Rincon Creek. We felt this was justified as most of the invertebrates found within the middle reach likely either drift downstream during periods of flow or migrate from the pools in the mountains to the pools within the reach. Additionally, due to the drought, we thought it worthwhile to determine what the macroinvertebrate community of the middle reach of Rincon Creek would most likely contain were it not dry.

Samples were collected, processed, and identified as in the surface samples.

Data Analysis

All statistical analyses were completed using JMP (SAS Institute Inc.). Graphs were created using JMP, Microsoft Excel (Microsoft Corporation), or Sigma Plot (SPSS Inc.).

Results

Stream Characteristics

During the period over which this study was completed, southern Arizona was in the midst of a severe drought. Little rain fell anywhere within the region, but even less fell in the Rincons. Flow was much lower during the study period than it had been in previous years. As a result, Rincon Creek was often dry on our monthly sampling dates. We visited the creek a total of 21 times during the period of study (Appendix A). Of those dates, there was water present in any part of the middle reach only 10 times, less than half of our total sampling dates. For the upstream (Pool A) and downstream (Pool D) sites, water was present only 6 times during the study.

During the summer months, minor floods occurred occasionally and caused disturbances in the stream. However, these floods usually had minor impact and did not significantly affect the data we collected. For example, the August 2005 sampling was completed a few days before a small flood. By the time we sampled again in September, the flood waters had already disappeared and there were no pools present within the middle reach of Rincon Creek.

Physico-Chemical Parameters and Macroinvertebrates

There was no significant relationship between any of the water quality parameters measured with the Hydrolab and the diversity of macroinvertebrates inhabiting the middle reach of Rincon Creek ($p < 0.10$ in all cases). Hydrolab data was not taken at Madrona or the Grotto on most visits, so it is uncertain whether the same trend occurred at these two sites.

The specific physico-chemical parameters measured and their values are listed in Appendix B.

Pool A

Pool A had water present during 6 of the 21 sampling trips (Appendix A). Of the three sites, it was the shallowest and the first to dry between rainy seasons. However, it also had the most consistent macroinvertebrate population. Overall, we collected 2755 individual macroinvertebrates from 78 different taxa (Appendix C). 20 taxa were found in samples from at least half of the sampling dates (Table 1) and could be considered permanent residents of the stream at this site.

Table 1. Most common macroinvertebrate taxa of Pool A

Order	Family	Genus	Frequency
Anomopoda	Daphniidae	Daphnia	83.3%
Diptera	Chironomidae	Cricotopus	83.3%
Haplotaenidia	Enchytraeidae		83.3%
Coleoptera	Dytiscidae	Oreodytes	66.7%
Coleoptera	Gyrinidae	Gyrinus	66.7%
Coleoptera	Hydrophilidae	Berosus	66.7%
Diptera	Chironomidae	Radotanypus	66.7%
Diptera	Chironomidae	Rheotanytarsus	66.7%
Ephemeroptera	Baetidae	Callibaetis	66.7%
Hemiptera	Corixidae	Graptocorixa	66.7%
Hemiptera	Notonectidae	Buenoa	66.7%
Limnephila	Physidae	Physella	66.7%
Calanoida	Temoridae	Epischura	50.0%
Coleoptera	Dytiscidae	Laccophilus	50.0%
Diptera	Ceratopogonidae	Mallocohelea	50.0%
Diptera	Chironomidae	Chironomus	50.0%
Diptera	Chironomidae	Tanytarsus	50.0%
Diptera	Chironomidae	Thiennemannimyia	50.0%
Diptera	Culicidae	Anopheles	50.0%
Hemiptera	Notonectidae	Notonecta	50.0%

Of the 20 common taxa, 14 are bound to the stream and are dependent on the presence of water for their survival. These taxa die when the stream dries. The remaining 6 taxa (*Gyrinus*, *Berosus*, *Graptocorixa*, *Buenoa*, *Laccophilus*, and *Notonecta*) are capable of leaving the stream in search of more permanent sources of water.

The relationship between monthly streamflow (cfs) and the diversity of Pool A is not significant ($p=0.14$). However, when the 15 months without any streamflow are removed from the analysis, the p value is much reduced ($p=0.06$). This suggests that the relationship could be significant were there more sampling dates occurring on days there was water present in the stream. Regardless, the greatest diversity occurred during periods of low flow (Figure 7). It should come as no surprise that the lowest diversity occurred during dry periods when most aquatic organisms are unable to survive in the streambed.

There is a significant relationship between the diversity of the stream and the type of water present in the stream ($p<0.001$, Figure 8). All water types but small pools and low flow are significantly different. The number of taxa present in the small pool, the water type with the greatest diversity, may represent an outlier. It is likely that because the pool was so small, we were more likely to capture the entire diversity of the pool during our sampling whereas it would be nearly impossible to capture the true diversity of a larger pool or flowing system.

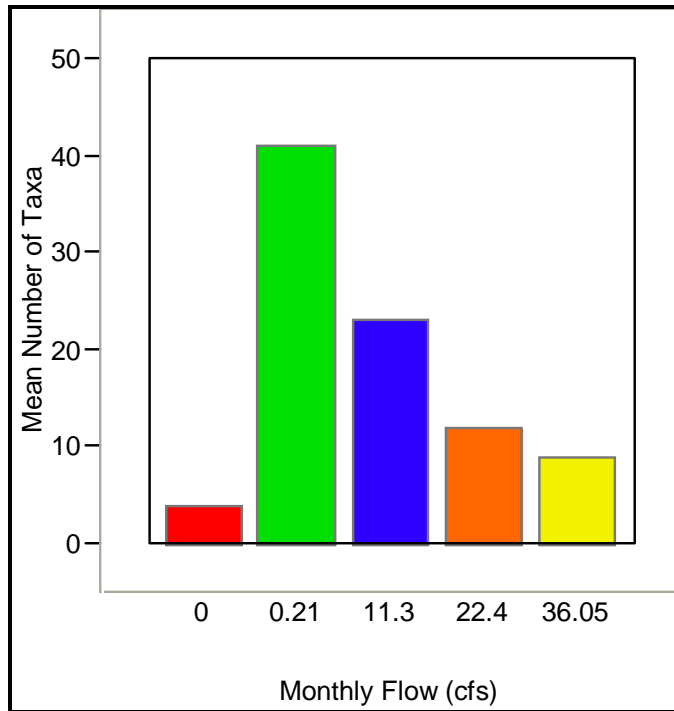


Figure 7. Number of taxa and monthly streamflow, Pool A

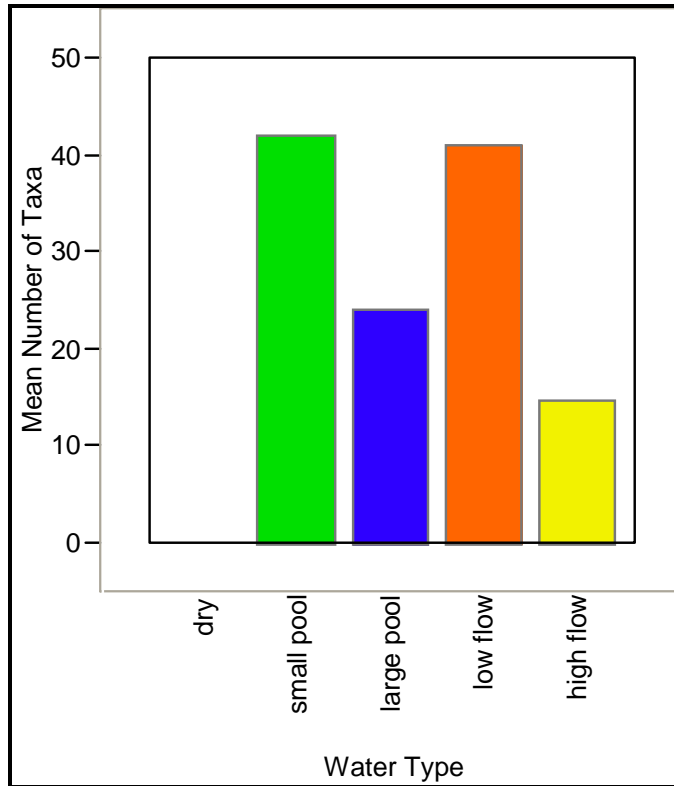


Figure 8. Number of taxa and type of water, Pool A

Pool C

Pool C had water present during 10 of the 21 sampling trips (Appendix A), the most of any site. Of the three sites, it was both the smallest in volume, but the last to dry between rainy seasons. It also had the greatest diversity. Overall, we collected 3714 individual macroinvertebrates from 80 different taxa (Appendix C). Only 5 taxa were found in samples from at least half of the sampling dates (Table 2) and could be considered permanent residents of the stream at this site.

Table 2. Most common macroinvertebrate taxa of Pool C

Order	Family	Genus	Frequency
Coleoptera	Hydrophilidae	Berosus	60.0%
Hemiptera	Corixidae	Graptocorixa	60.0%
Diptera	Ceratopogonidae	Mallocochelea	50.0%
Ephemeroptera	Baetidae	Callibaetis	50.0%
Limnephila	Physidae	Physella	50.0%

Of the 5 common taxa, 3 are bound to the stream and are dependent on the presence of water for their survival. The remaining 2 taxa (*Berosus* and *Graptocorixa*) are capable of leaving the stream when the conditions of Pool C deteriorate.

The relationship between monthly streamflow (cfs) and the diversity of Pool C is not significant ($p=0.58$). Unlike Pool A, the greatest diversity of this pool occurred during periods of moderate flow (Figure 9). As in Pool A, it is not surprising that the lowest diversity occurred during dry periods. However, the diversity is also low when the stream is flowing heavily.

There is a significant relationship between the diversity of the stream and the type of water present in the stream ($p=0.0045$, Figure 10). Interestingly, the diversity of small pools and the dry streambed are not significantly different. High and low flows are also not significantly different.

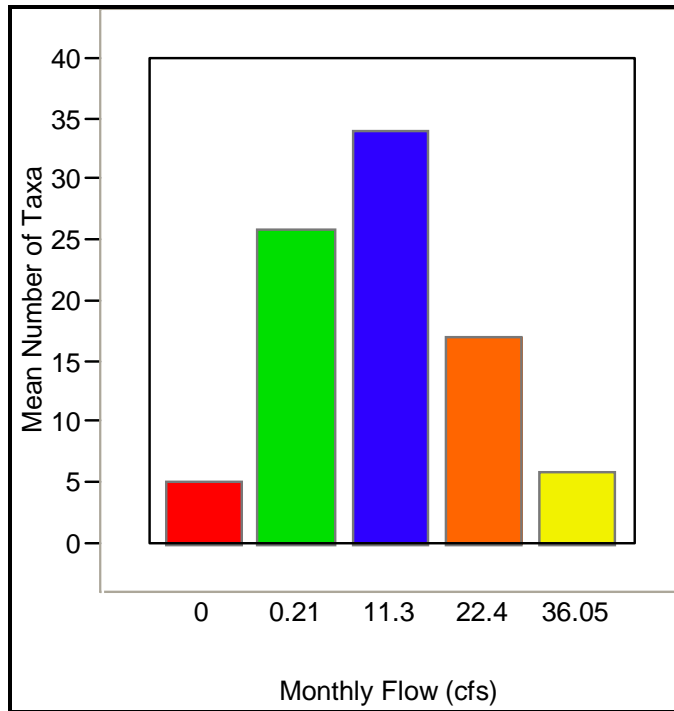


Figure 9. Number of taxa and monthly streamflow, Pool C

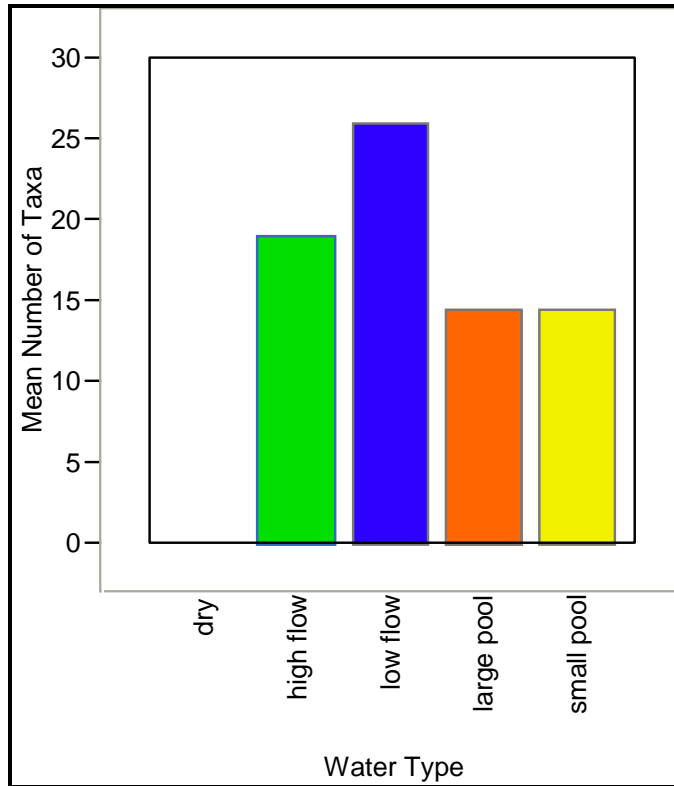


Figure 10. Number of taxa and type of water, Pool C

Pool D

Pool D had water present during only 6 of the 21 sampling trips (Appendix A). It had the greatest volume and depth of the 3 sites, but had the lowest diversity. Overall, we collected 3245 individuals from 63 different taxa (Appendix C). 11 taxa were found in samples from at least half of the sampling dates (Table 3) and could be considered permanent residents of the stream at this site.

Table 3. Common macroinvertebrate taxa of Pool D

Order	Family	Genus	Frequency
Anomopoda	Daphniidae	Daphnia	66.7%
Coleoptera	Dytiscidae	Rhantus	66.7%
Diptera	Chironomidae	Rheotanytarsus	66.7%
Coleoptera	Dytiscidae	Oreodytes	50.0%
Diptera	Ceratopogonidae	Mallocohelea	50.0%
Diptera	Chironomidae	Dicrotendipes	50.0%
Diptera	Culicidae	Anopheles	50.0%
Ephemeroptera	Baetidae	Callibaetis	50.0%
Haplotaxida	Enchytraeidae		50.0%
Hemiptera	Corixidae	Graptocorixa	50.0%
Limnephila	Physidae	Physella	50.0%

Of the 11 common taxa, 9 are bound to the stream and are dependent on the presence of water for their survival. The other taxa (*Rhantus* and *Graptocorixa*) are capable of leaving the stream.

The relationship between monthly streamflow (cfs) and the diversity of Pool D is nearly significant ($p=0.059$) when a second degree polynomial is fitted, which strongly suggests that the highest diversity occurs during periods of low flow and the lowest diversity during dry and high flow periods. As in Pool A, the greatest diversity of Pool D occurred during periods of low flow (Figure 11). Again, it is not surprising that the lowest diversity occurred during dry periods.

There is a strongly significant relationship between the diversity of the stream and the type of water present in the stream ($p<0.001$, Figure 12). As with the other sites, the greatest diversity occurs during periods of low flow. There is no significant difference between small pools and dry pools nor large pools and low flow.

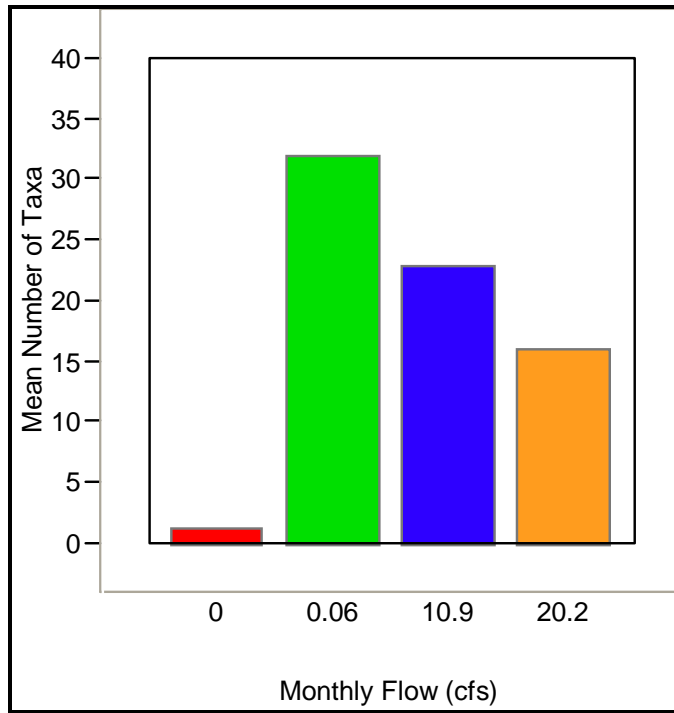


Figure 11. Number of taxa and monthly streamflow, Pool D

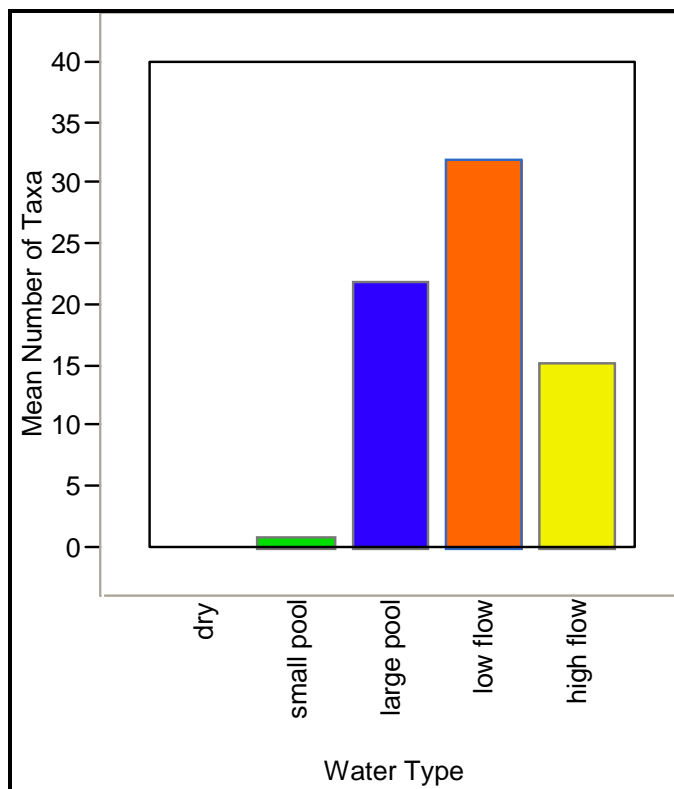


Figure 12. Number of taxa and type of water, Pool D

The Middle Reach of Rincon Creek

Overall, the creek only had water present during 10 of the 21 sampling trips (Appendix A). We collected 9714 individuals from 134 different taxa (Appendix C). Only 9 taxa were found in samples from at least half of the sampling dates (Table 4) and could be considered permanent residents of the stream as a whole.

Table 4. Common macroinvertebrate taxa of Middle Rincon Creek

Order	Family	Genus	Frequency
Anomopoda	Daphniidae	Daphnia	61.9%
Hemiptera	Corixidae	Graptocorixa	61.9%
Coleoptera	Hydrophilidae	Berosus	61.9%
Diptera	Chironomidae	Cricotopus	57.1%
Diptera	Chironomidae	Rheotanytarsus	57.1%
Ephemeroptera	Baetidae	Callibaetis	57.1%
Limnephila	Physidae	Physella	57.1%
Diptera	Ceratopogonidae	Mallocohelea	50.0%
Haplotaaxida	Enchytraeidae		50.0%

Of the 9 common taxa, 7 are bound to the stream and are dependent on the presence of water for their survival. The other taxa (*Berosus* and *Graptocorixa*) are capable of leaving the stream.

The relationship between monthly streamflow (cfs) and the diversity of macroinvertebrates in Middle Rincon Creek is significant ($p=0.0075$) when a second degree polynomial is fitted to the data (number of taxa = $5.59 + 1.62(\text{monthly flow}) - 0.05(\text{monthly flow} - 2.76)^2$). The relationship mirrors what we found in the individual pools; that the periods of low flow have the highest diversity (Figure 13) and the dry and high flow periods have the lowest diversity.

There is a strongly significant relationship between the diversity of the Middle Rincon Creek and the type of water present in the stream ($p<0.001$, Figure 14). As with the individual sites, low flow periods were significantly more diverse than the other water types. Dry pools have significantly less diversity than any other water type. There is no statistical difference between small pools, large pools, and high flow.

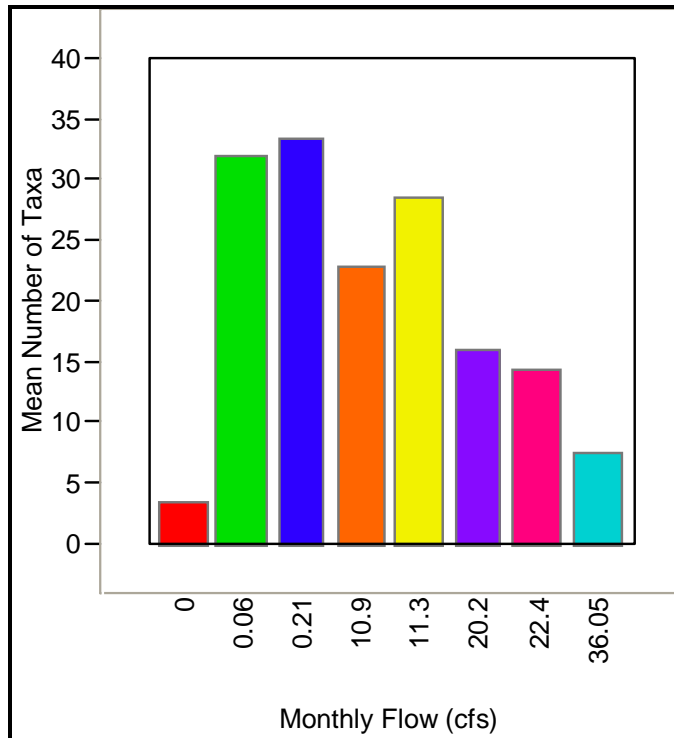


Figure 13. Rincon Creek monthly flow and macroinvertebrate diversity

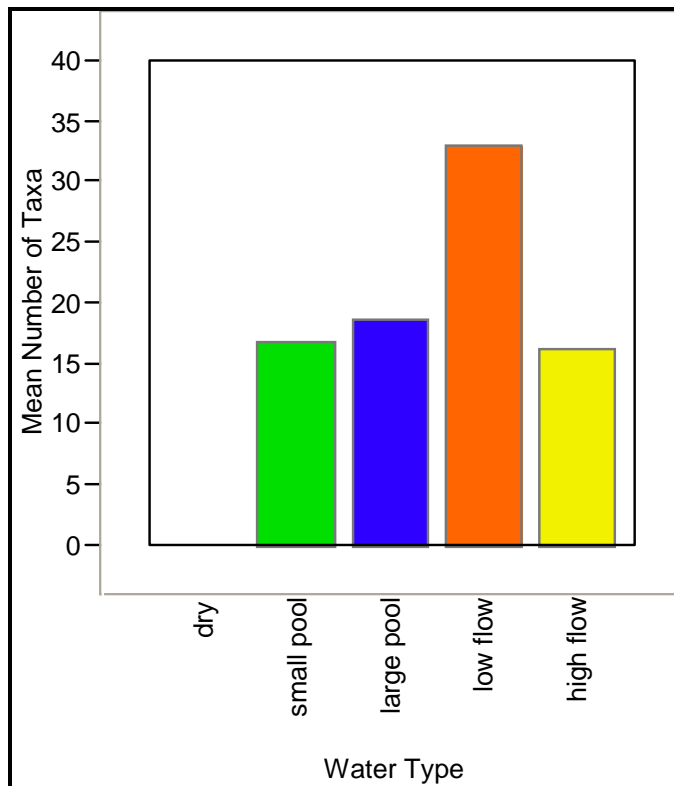


Figure 14. Rincon Creek water type and macroinvertebrate diversity

The Hyporheic Zone of Rincon Creek

The hyporheic zone of the middle reach was very unproductive. Our samplers captured very few macroinvertebrates within the study period. We ruled out sampler error during the second year when we changed the sampling design – there simply were not macroinvertebrates in the hyporheic zone. Overall, we discovered only 13 individuals in 4 taxa (Appendix D). None of the taxa were found often enough to be considered common. The hyporheic zone of Middle Rincon Creek is obviously not important as a refuge or a habitat.

Hydrolab readings taken from the wells suggest that there is no oxygen within in the hyporheic zone of Rincon Creek, even just below the surface. As the majority of macroinvertebrates living within the hyporheic zone are aerobic and obtain their oxygen from the water, it is unlikely that any macroinvertebrates can successfully colonize the hyporheic zone of this stream.

Drought Effects

The drought was more pronounced the second year than the first. Water persisted less and flow was generally lower the second year compared to the first. The diversity of the pools also decreased between the first and second years.

Upper Pools

Due to the extended drought conditions, we began sampling in the Madrona pools and The Grotto to see what the stream would most likely contain had persistence of water increased. At Madrona, we sampled a total of 6 dates and found 1891 individuals in 54 taxa (Appendix C). Of these, almost half of the taxa (24) were present in at least 50% of the samples and can be considered permanent residents.

Table 2. Common macroinvertebrates of Madrona

Order	Family	Genus	Frequency
Coleoptera	Gyrinidae	Gyrinus	100.0%
Coleoptera	Hydrophilidae	Berosus	100.0%
Anomopoda	Daphniidae	Daphnia*	83.3%
Calanoida	Temoridae	Epischura*	83.3%
Coleoptera	Dytiscidae	Derovatellus	83.3%
Coleoptera	Dytiscidae	Desmopachria	83.3%
Coleoptera	Dytiscidae	Hydrovatus	83.3%
Coleoptera	Dytiscidae	Laccophilus	83.3%
Coleoptera	Hydrophilidae	Hydrochus	83.3%
Diptera	Chironomidae	Chironomus*	83.3%
Ephemeroptera	Baetidae	Callibaetis*	83.3%
Ephemeroptera	Caenidae	Caenis*	83.3%
Haptotaxida	Enchytraeidae*		83.3%
Hemiptera	Corixidae	Graptocorixa	83.3%

Hemiptera	Naucoridae	Ambrysus	83.3%
Coloptera	Dytiscidae	Oerodytes	66.7%
Coloptera	Dytiscidae	Thermonectus	66.7%
Diptera	Chironomidae	Procladius*	66.7%
Hemiptera	Notonectidae	Buenoa	66.7%
Hemiptera	Notonectidae	Notonecta	66.7%
Hydrachnida	Hydrachnidae	Hydrachna*	66.7%
Limnephila	Physidae	Physella*	66.7%
Coleoptera	Gyrinidae	Dineutus	50.0%
Diptera	Chironomidae	Stempellinella*	50.0%

Of the 24 common taxa, 10 (marked with an *) are bound to the stream and are dependent on the presence of water for their survival. The other taxa are capable of leaving the stream.

The Madrona Pools, while less diverse than any of the pools in the middle reach of Rincon Creek, were very stable. There were many more permanent species in this pool than in Rincon Creek and it was the only pool studied that had species found on 100% of the sampling trips.

The Grotto was only sampled once during the study period. In it, we found 88 individuals in 12 taxa (Appendix C). As we only sampled one time, we cannot say for certain that these can be considered permanent species, but it is safe to assume they are. There had been little flow between the Grotto and the rest of the watershed for many months when we sampled.

Interestingly, there is a rather rare species of beetle found in both the Madrona pools the the Grotto, *Hydrochus stephanii*. This beetle has only been discovered in a few locations in southern Arizona and has never been recorded in the Rincon Mountains.

Discussion

It is clear from this study that the best conditions for macroinvertebrates in the middle reach of Rincon Creek is a state of low flow, probably about 0.5 to 1 cfs. This may be because it is a transitional state between lotic and lentic systems and has characteristics of both types of water. Invertebrates that thrive in pools experience low enough flow that they are able to flourish without their food or themselves being swept downstream, while invertebrates that require flow have sufficient flow to allow them to survive.

It is surprising that the physico-chemical parameters measured were not significantly related to the diversity of the macroinvertebrates of Rincon Creek. Countless other studies have shown significant relationships between physico-chemical parameters and macroinvertebrate diversity. Oxygen availability seems to be particularly important in determining species composition within a body of water, but it was not significantly associated with the composition of the pools here. This suggests that

macroinvertebrates inhabiting Rincon Creek are especially well adapted to a wide range of water conditions and that the presence of water is the most important factor determining the composition of species and the diversity of this stream. Whether this applies to other intermittent streams in the area is uncertain, but likely.

There were fewer “permanent” species within Rincon Creek than we expected. It is likely that some species are underrepresented in the samples (i.e. those that swim well enough to escape the approach of the net, such as the giant water bug *Lethocerus*) or are widely distributed enough that they were simply not collected each time we sampled. Other species, especially territorial species, would be less commonly collected than species where many individuals are spread evenly throughout the system. The taxa we list as permanent were typically collected in large quantities every time we found them in our samples and probably had more individuals and were more closely spaced than other taxa in the stream.

There were also far fewer macroinvertebrates in the hyporheic zone of Rincon Creek than we expected. There are several reasons why this zone might not be an acceptable habitat for aquatic macroinvertebrates within this stream. First, the hyporheic zone in all three pools was silt/sand dominated. Many macroinvertebrates, especially the large ones, are not equipped for burrowing through sand and probably could not move through the substrate well enough to be protected. Second, the hyporheic zone was anaerobic. During periods of flow, there may be sufficient oxygen passing through the substrate to allow the survival of invertebrates, but there certainly was not enough to support aerobic life during the pooled periods. Even if an animal was capable of burrowing into the substrate, it likely would not survive due to hypoxia. Third, it is uncertain whether there is a true hyporheic zone in this stream. A vast majority of the studies on hyporheic zone invertebrates have been completed in mesic areas and/or permanent streams. It is possible that the hyporheic zones of intermittent streams work differently or may not exist at all. During the dry seasons and because the bedrock was so close to the surface, there were long reaches where Rincon Creek dried completely down to the bedrock. In those areas, there is no real hyporheic zone as there is no portion of the substrate that is wetted. It is likely that the stream either has no functional hyporheic zone or it behaves significantly differently from those of permanent streams. Regardless, the substrate of Rincon Creek was a poor habitat for most macroinvertebrates in the stream and was rarely colonized.

Despite the high loads of dead organic matter and small pool volumes in the Madrona pools, they were teeming with a diverse assemblage of macroinvertebrates. These pools were also very consistently diverse compared to the pools in Middle Rincon Creek, suggesting these pools offer more stability than do pools in the Middle Reach of Rincon Creek. Because they do not dry during the summer, species are able to survive year-round. These pools likely provide an important refuge for macroinvertebrates in the Rincon Creek watershed during the summer. The species found in Madrona pools are very similar to those found in the middle reach of Rincon Creek. Macroinvertebrates from Madrona are likely important in re-populating Rincon Creek when water becomes available and species escaping poor conditions of the creek probably find their way to

the pools. It is probable that persistence of the Madrona pools is essential for maintaining the diversity of macroinvertebrates within Middle Rincon Creek.

Finally, we discovered two rare taxa within Rincon Creek worthy of mention. The water scavenger beetle, *Hydrochus stephanii*, has already been mentioned. This beetle is rarely encountered elsewhere in Arizona, but was common in the Madrona pools and the Grotto. Additionally, during winter flows, large populations of capniid stoneflies (*Paracapnia*) were common in the stream. Stoneflies are incredibly rare at low elevations in Arizona, so it was surprising to find them in Rincon Creek. The presence of these two rare invertebrate taxa suggests that Rincon Creek is a unique and special system that should be protected.

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Appendix A

Sampling Dates

Sample Date	Pool A	Pool C	Pool D	Madrona	Grotto
3/31/2004	X	X	X		
4/27/2004	X	X	X		
5/31/2004	X	X	X		
6/30/2004	X	X	H		
7/30/2004	H	X	H		
8/30/2004	H	H	H		
9/29/2004	H	H	H		
10/29/2004	H	H	H		
11/29/2004	H	H	H		
12/23/2004	H	H	H		
2/1/2005	X	X	X		
(Gap in Data)					
6/2/2005	X	X	X		
7/8/2005	H	X	H		
8/4/2005	H	X	X		
9/21/2005	H	H	H	S	S
10/18/2005	H	H	H	S	
11/23/2005	H	H	H	S	
12/30/2005	H	H	H	S	
2/14/2006	O	O	O	S	
3/25/2006	O	O	O	S	
7/20/2006	O	S	S	S	
<p>X= Surface and hyporheic samples collected H= Hyporheic sample taken S= Surface sample taken O= No sample collected, but stream observed</p>					

Appendix B

Physico-Chemical Data

The physico-chemical data collected for all sites and dates are listed below.

Date	Site	Temp	DO	DO%	Sp Cond	pH	ORP	Air Temp
3/31/2004	Pool A	19.98	3.2	35	174.1	6.98	-140	68
	Pool C	21.8	3.68	41.8	183.1	7.09	-129	89
	Pool D	21.78	3.75	42	214.9	7.24	-134	71
4/27/2004	Pool A	19.39	4.72	51.7	162.5	7.27	148	75
	Pool C	17.96	4.61	48.2	169.3	7.17	169	75
	Pool D	19.98	5.41	59.6	188.1	7.37	157	75
5/31/2004	Pool A	22.48	4.07	46.6	241.2	10.63	2	94
	Pool C	24.3	6.87	81.1	251.9	9.69	18	94
	Pool D	23.76	5.25	62.3	289	6.58	290	92
6/30/2004	Pool A	22.06	3.09	43	227.1	6.31	81	87
	Pool C	22.98	7.16	101.6	391.6	7.95	108	89
7/30/2004	Pool C	30.01	7.18	93.4	293.9	7.04	101	92
2/1/2005	Pool A	13.23	4.14	48.1	90	6.74	255	68
	Pool C	13	4.3	50.1	93.4	6.83	250	62
	Pool D	12.88	4.29	49.3	95.4	6.91	246	62
6/2/2005	Pool A	19.71	3.1	41	203	6.28	269	82
	Pool C	22.92	5.15	73.5	300.8	7.14	260	84
	Pool D	20.63	3.9	53.2	359	7.12	256	78
7/8/2005	Pool C	29.3	5.65	89.9	414	7.7	163	93
8/4/2005	Pool C	Insufficient Water		82
	Pool D	33	3.83	64.3	370.7	8.93	-9	90
9/23/2005	Grotto	x	x	x	x	x	x	97
	Madrona	x	x	x	x	x	x	98
10/26/2005	Madrona	x	x	x	x	x	x	72
11/23/2005	Madrona	x	x	x	x	x	x	73
12/30/2005	Madrona	13.92	8.14	82.9	287.3	9.67	-133	80
2/14/2006	Madrona	13.12	5.42	53.3	489.4	8.15	104	77
3/25/2006	Madrona	17.32	10.65	113	225.3	9.03	-10	75
7/20/2006	Pool C	38.8	1.6	24.1	381.1	7.46	.	98

Key: (Temp) Water temperature °C, (DO) Dissolved oxygen mg/L, (DO%) Percent saturation of dissolved oxygen, (Sp Cond) Specific conductivity mS/cm², (ORP) Oxidation-reduction potential, (Air Temp) Air temperature °F. A value of X indicates that no Hydrolab data was collected at the site on that date.

Appendix C

Surface Macroinvertebrate Taxa of Rincon Creek

The following macroinvertebrates taxa were collected from the surface waters of Middle Rincon Creek during the course of this study.

Order	Family	Genus	FFG	TOL	A	C	D	M	G
Anomopoda	Daphniidae	Daphnia	CG	8		x	x	x	
Arhynchobdellida	Erpobdellidae	Erpobdella	PR	10				x	
Calanoida	Temoridae	Epischura	CG	8	x	x	x	x	
Calanoida	Temoridae	Heterocope	CG	8			x		
Coleoptera	Carabidae		PR		x			x	
Coleoptera	Dryopidae	Postelichus	SH	5		x			
Coleoptera	Dytiscidae	Agabus	PR	7	x	x			
Coleoptera	Dytiscidae	Celina	PR	7		x		x	
Coleoptera	Dytiscidae	Derovatellus	PR	7			x	x	
Coleoptera	Dytiscidae	Desmopachria	PR	7	x		x	x	
Coleoptera	Dytiscidae	Dytiscus	PR	7		x			
Coleoptera	Dytiscidae	Enochrus	PR	7		x			
Coleoptera	Dytiscidae	Hydrovatus	PR	7	x	x	x	x	x
Coleoptera	Dytiscidae	Laccodytes	PR	7	x				
Coleoptera	Dytiscidae	Laccophilus	PR	7	x	x	x	x	
Coleoptera	Dytiscidae	Liodesus	PR	7	x				
Coleoptera	Dytiscidae	Nebrioporus/ Stictotarsus	PR	7			x		
Coleoptera	Dytiscidae	Oerodytes	PR	7	x	x	x	x	
Coleoptera	Dytiscidae	Rhantus	PR	7	x	x	x		
Coleoptera	Dytiscidae	Thermonectus	PR	7		x		x	
Coleoptera	Dytiscidae	Uvarus	PR	7		x			
Coleoptera	Dytiscidae		PR	7		x			
Coleoptera	Gyrinidae	Dineutus	PR	8	x			x	
Coleoptera	Gyrinidae	Gyrinus	PR	8	x	x	x	x	
Coleoptera	Hydrophilidae	Ametor	PR	8			x		
Coleoptera	Hydrophilidae	Berosus	PR	8	x	x	x	x	x
Coleoptera	Hydrophilidae	Cymbiodyta	PR	7	x				
Coleoptera	Hydrophilidae	Enochrus	PR	7			x		
Coleoptera	Hydrophilidae	Hydrochus	SH					x	x
Coleoptera	Hydrophilidae	Paracymus	PR	7	x				
Coleoptera	Hydrophilidae	Tropisternus	PR	7	x	x	x	x	
Diptera	Ceratopogonidae	Dasyhelea	CG	7	x	x	x	x	
Diptera	Ceratopogonidae	Leptoconops	PR	7		x			
Diptera	Ceratopogonidae	Mallocohelea	PR	7	x	x	x	x	
Diptera	Ceratopogonidae				x	x	x		
Diptera	Chironomidae	Ablabesmyia	CG	8		x			
Diptera	Chironomidae	Chironomus	CG	10	x	x	x	x	
Diptera	Chironomidae	Corynoneura	CG	7	x		x		
Diptera	Chironomidae	Cricotopus	SH	3	x	x	x	x	

Order	Family	Genus	FFG	TOL	A	C	D	M	G
Diptera	Chironomidae	Dicrotendipes	CG	8	x	x	x	x	
Diptera	Chironomidae	Eukiefferiella	CG	8		x		x	
Diptera	Chironomidae	Glyptotendipes	CG	10				x	
Diptera	Chironomidae	Larsia	PR	6		x	x		
Diptera	Chironomidae	Macropelopia	PR	6		x			
Diptera	Chironomidae	Micropsectra	CG	7	x		x		
Diptera	Chironomidae	Orthocladus	CG	6	x	x			
Diptera	Chironomidae	Paramerina	PR	6		x	x		
Diptera	Chironomidae	Parapsectra	UK		x				
Diptera	Chironomidae	Paratanytarsus	UK	6	x				
Diptera	Chironomidae	Pentaneura	PR	6	x	x			
Diptera	Chironomidae	Polypedilum	SH	6			x		
Diptera	Chironomidae	Procladius	PR	9		x		x	
Diptera	Chironomidae	Psectrocladius	CG	6	x		x		
Diptera	Chironomidae	Pseudochironomus	CG	5	x	x		x	
Diptera	Chironomidae	Radotanypus	UK	11	x	x	x	x	x
Diptera	Chironomidae	Rheotanytarsus	CF	6	x	x	x	x	x
Diptera	Chironomidae	Stempellinella	UK	4				x	
Diptera	Chironomidae	Sublettea	UK	4		x			
Diptera	Chironomidae	Synendotendipes	UK		x				
Diptera	Chironomidae	Synorthocladus	CG	2				x	
Diptera	Chironomidae	Tanypus	PR	10		x	x		
Diptera	Chironomidae	Tanytarsus	CF	6	x	x		x	
Diptera	Chironomidae	Telmatopelopia	UK		x	x	x		
Diptera	Chironomidae	Thienemanniella	CG	6		x			
Diptera	Chironomidae	Thienemannimyia	CG	6	x	x	x	x	
Diptera	Chironomidae				x	x	x		
Diptera	Culicidae	Anopheles	CF	8	x	x	x		
Diptera	Culicidae	Culex	CF	8	x	x			
Diptera	Culicidae		CF	8			x		
Diptera	Empididae	Hemerodromia	PR	6		x			
Diptera	Ephydriidae	Brachydeutera	CG	9			x		
Diptera	Ephydriidae	Ephydra	SH	9	x	x	x		
Diptera	Ephydriidae		CG	9	x				
Diptera	Psychodidae		CG	5		x			
Diptera	Simuliidae	Prosimulium	CF	6	x				
Diptera	Simuliidae	Simulium	CF	6	x	x			
Diptera	Stratiomyidae	Oxycera	CG	8		x			
Diptera	Tabanidae	Chrysops	PR	7	x		x		
Diptera	Tipulidae	Ormosia	CG		x				
Diptera	Tipulidae	Pedicia	PR	6			x		
Diptera	Tipulidae	Tipula	SH	6	x				
Dorylaimida	Dorylaimidae	Dorylaimus	PR	5	x		x		
Ephemeroptera	Baetidae	Callibaetis	CG	9	x	x	x	x	
Ephemeroptera	Baetidae	Dipheter	CG	5		x			
Ephemeroptera	Baetidae	Fallceon	CG	4	x	x			
Ephemeroptera	Baetidae	Paracloeodes	SC	4	x		x		

Order	Family	Genus	FFG	TOL	A	C	D	M	G
Ephemeroptera	Baetidae	Procleon	CG	4			x	x	
Ephemeroptera	Baetidae		CG	4	x				
Ephemeroptera	Caenidae	Brachycerus	CG				x		
Ephemeroptera	Caenidae	Caenis	CG	7	x	x	x	x	
Ephemeroptera	Tricorythidae	Leptohyphes	CG	7	x				
Ephemeroptera	Tricorythidae	Tricorythodes	CG	7	x	x			
Haplotoxida	Enchytraeidae		CG	8	x	x	x	x	x
Hemiptera	Belostomatidae	Abedus	PR	8			x	x	
Hemiptera	Belostomatidae	Belostoma	PR	10	x				
Hemiptera	Belostomatidae	Lethocerus	PR	10		x	x	x	
Hemiptera	Corixidae	Graptocorixa	PR	8	x	x	x	x	x
Hemiptera	Corixidae		PR	8			x		
Hemiptera	Gerridae	Aquarius	PR		x				
Hemiptera	Gerridae	Metrobates	PR		x	x		x	
Hemiptera	Gerridae	Trepobates	PR			x			x
Hemiptera	Naucoridae	Ambrysus	PR	7				x	
Hemiptera	Nepidae	Ranatra	PR	11	x	x	x	x	
Hemiptera	Notonectidae	Buenoa	PR	7	x	x	x	x	x
Hemiptera	Notonectidae	Notonecta	PR	7	x	x	x	x	x
Hemiptera	Veliidae	Microvelia	PR		x	x			x
Hemiptera	Veliidae	Rhagovelia	PR			x			
Hydrachnida	Hydrachnidae	Hydrachna	PR	5	x			x	
Hydrachnida	Omartacaridae	Omartacarus	PR	5	x	x		x	
Hydrachnida	Sperchontidae	Sperchon	PR	5			x		
Hydroida	Hydridae	Hydra	PR	5			x		
Limnephila	Physidae	Physella	CG	8	x	x	x	x	
Lumbriculida	Lumbriculidae		CG	8	x	x			
Megaloptera	Corydalidae	Neohermes	PR	4		x			
Odonata	Aeshnidae	Aeshna	PR	5		x			
Odonata	Aeshnidae	Anax	PR	8		x		x	
Odonata	Coenagrionidae	Acanthagrion	PR			x			
Odonata	Coenagrionidae	Argia	PR	7	x	x		x	
Odonata	Coenagrionidae	Enallagma	PR	9	x	x	x		
Odonata	Coenagrionidae		PR		x				
Odonata	Gomphidae	Progomphus	PR	4	x		x		
Odonata	Lestidae	Archilestes	PR	9	x		x	x	x
Odonata	Lestidae	Lestes	PR	9		x			
Odonata	Libellulidae	Erythemis	PR	9	x				
Odonata	Libellulidae	Libellula	PR	9				x	
Odonata	Libellulidae	Palothemis	PR	9	x				
Odonata	Libellulidae	Pseudoleon	PR	9	x	x	x	x	
Odonata	Libellulidae	Sympetrum	PR	9		x			
Odonata	Libellulidae		PR			x			
Plecoptera	Capniidae	Paracapnia	SH	3	x	x	x		
Podocopida	Candoniidae	Candona	CG	8	x	x	x		
Podocopida	Cypridae	Eucypris	CG	8	x	x	x	x	
Trichoptera	Lepidostomatidae	Lepidostoma	SH	4				x	

Order	Family	Genus	FFG	TOL	A	C	D	M	G
Trichoptera	Limnephilidae	Eocosmoecus	SH	4				x	

Key: (FFG) Functional Feeding Group, (TOL) Pollution Tolerance Value, (A) Pool A, (C) Pool C, (D) Pool D, (M) Madrona, (G) The Grotto

Appendix D

Hyporheic Macroinvertebrate Taxa of Rincon Creek

The following macroinvertebrate taxa were collected in the hyporheic zone of Middle Rincon Creek during the course of this study.

Order	Family	Genus	FFG	TOL	A-H	C-H	D-H
Diptera	Ceratopogonidae	Dasyhelea	CG	7		x	
Diptera	Ceratopogonidae	Mallocohelea	PR	7		x	
Haptotaxida	Enchytraeidae		CG	8	x	x	x
Hydrachnida	Hydrachnidae	Hydrachna	PR	5	x		

Key: (FFG) Functional Feeding Group, (TOL) Pollution Tolerance Value, (A-H) Pool A hyporheic sample, (C-H) Pool C hyporheic sample, (D-H) Pool D hyporheic sample