

DEMOGRAPHICS OF RIPARIAN LIZARDS IN THE CHIRICAHUA MOUNTAINS IN
RELATION TO WATER
AVAILABILITY AND EMERGING AQUATIC INSECTS AS A POTENTIAL FOOD
SOURCE

by

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Abstract

Severe drought driven by climate change and water use by humans are causing formerly perennial streams to flow intermittently, presenting an unprecedented level of disturbance. The loss of emerging aquatic insects as potential prey items could negatively impact riparian and terrestrial species, including lizards. Because lizards play important roles in riparian food webs (e.g. predators, nutrient cycling), it is crucial to understand the cascading effects of stream drying on lizard communities. We hypothesized that perennial streams provide aquatic subsidies to riparian lizards, reducing competition and opening niches. We predicted that lizard abundances would be greater, and that individuals within a species would grow larger and faster, along perennial streams compared to ephemeral streams. We studied three paired 100-meter perennial and ephemeral reaches with similar microhabitat but differing water availability in the Chiricahua Mountains of southeastern Arizona. We measured individual growth rates during a 2-month mark-recapture study of Yarrow's spiny lizards (*Sceloporus jarrovi*), striped plateau lizards (*Sceloporus virgatus*), and ornate tree lizards (*Urosaurus ornatus*). We used emergence traps to quantify the availability of aquatic prey. Aquatic insects were collected in high abundances, suggesting a potential food source for lizards along perennial streams that may be unavailable along ephemeral streams. When considering mass at first capture, we found that *S. jarrovi* were larger at perennial versus ephemeral reaches. However, this pattern did not hold true for *S. virgatus*. Additionally, we failed to detect differences in abundances between paired perennial and ephemeral reaches for either *S. jarrovi* or *S. virgatus*. Low sample sizes prevented us from performing any statistical analyses for *Urosaurus ornatus* and on the mark-recapture data for *S. jarrovi* and *S. virgatus*. Although more research is needed to confirm these results, they indicate that emerging aquatic insects may be an important resource to riparian lizard

species in arid environments. Future research should quantify trophic links between lizards and potential aquatic subsidies.

Introduction

Climate models predict a drying trend in the southwestern United States that will continue through the 21st century (Seager et al. 2007, Seager and Vecchi 2010). Reduced amount of precipitation will likely have extensive impacts on terrestrial and aquatic ecosystems (Ledger et al. 2012). Natural disturbances, such as drought, are vital processes in ecosystems and govern population abundances and patterns of community diversity (Lytle and Poff 2004). However, severe drought driven by climate change, coupled with water use by humans, is presenting a level of disturbance not documented historically in stream ecosystems. For example, record low flow conditions have been observed in some rivers and formerly perennial streams have become intermittent (Phillips and Thomas 2005, Bogan and Lytle 2011, Wilson et al. 2012). Although the ecological effects of stream drying have been studied in aquatic systems (Schriever and Lytle 2016), little research has been done on how these disturbances affect terrestrial species that live along streams.

Terrestrial organisms that rely on subsidies from perennial streams may be vulnerable to changes in flow regimes, particularly during drought. Emerging aquatic insects are one of the largest subsidies for terrestrial organisms (Ramey and Richardson 2017). Terrestrial consumers in the riparian zone, such as spiders, birds, bats, and lizards, may receive 25-100% of their carbon or energy from emerging aquatic insects (Baxter et al. 2005). Many of these consumers adjust their behavior, growth, and abundances to the short-term influx of emerging aquatic insects during the summer when emergence peaks (Baxter et al. 2005). Aquatic insects have strong effects on terrestrial consumer abundance. For example, in a Japanese forest, birds benefited greatly from emerging aquatic insects, while stream fishes were subsidized by terrestrial insects that accidentally fell into streams (Nakano and Murakami 2001). Additionally, aquatic insects comprised 50-90% of the monthly energy budget for half of the bird species

studied (Nakano and Murakami 2001). In addition to providing emerging aquatic insects as prey items to terrestrial species, perennial stream water may also be beneficial to terrestrial invertebrates. When water was experimentally introduced to a desert ecosystem through either cottonwood leaves (with high-water content) or freely available surface water, primary consumers responded positively to both treatments but terrestrial invertebrate predators only responded to surface water (Allen et al. 2014).

In the southwestern United States, many desert animals find relief from aridity by living close to riparian areas where temperatures are cooler and water may be available. This pattern may even be observed for taxa not primarily thought of as being associated with riparian vegetation, such as lizards. While it is known that streams transport resources, energy, detritus, and organisms (Sabo and Hagen 2012) to adjacent terrestrial environments, not as much is known about the effects of these resources on the fitness of terrestrial consumers (Sabo and Power 2002a). However, some surprising links between aquatic insects and lizards have been reported (Sabo and Power 2002a). Manipulative subsidy experiments with *Sceloporus occidentalis* (western fence lizard) at the Eel River in California, showed that individuals with access to aquatic insect prey grew larger and faster than those whose access was restricted (Sabo and Power 2002a). The experiment encompassed more than half of the growing season (May to October) along a river in northern California. In a separate subsidy experiment from June to September, *S. occidentalis* were found in higher abundances when there was an influx of aquatic prey items. Although aquatic insects were less frequently caught by lizards, they had similar total dry masses as compared to terrestrial or semi-aquatic prey (Sabo and Power 2002b). These findings suggest that aquatic insects could serve as important food sources for riparian lizards in the western United States.

Southern Arizona supports a diverse assemblage of lizard species, with more than 40 species found throughout the state (Brennen and Holycross 2009). While no previous studies in the region have addressed aquatic insect consumption by riparian lizards, some general prey selection studies have been done. *Sceloporus jarrovi* (Yarrow's spiny lizard) eat many types of terrestrial invertebrates, including flies, termites, leaf hoppers, cicada, and dusty wings; in times of low insect abundance *S. jarrovi* mostly fed on ants (Ballinger & Ballinger 1979). Despite this seemingly wide diet, individual lizards do not necessarily choose food items just based on their relative availability (Simon and Middendorf 1985). Optimal foraging theory may be the mechanism that explains this pattern, where animals can be choosier when presented with more options. In addition to choosing different prey items available in a given location, lizards also may change the location where they forage for food. Some studies have noted that the perch height of *S. jarrovi* varied by season, with some individuals moving to higher perch heights during the monsoon season (Simon and Middendorf 1985). Individuals closer to the ground tended to catch ground-dwelling insects while individuals with higher perch heights tended to catch flying insects (Simon and Middendorf 1985). *S. jarrovi* may have shifted their perch heights to access aerial food sources, to reduce competition, or for thermoregulation purposes.

Southern Arizona experiences long dry seasons followed by intense monsoon floods that would seem to limit aquatic insect production. Despite the limited abundance of aquatic insects emerging from streams, these insects may serve as important food resources for lizards. The region is known to have very diverse aquatic invertebrate communities, supporting over 500 species (Bogan 2012, Bogan et al. 2015). Some aquatic insects in the region have evolved life history adaptations to emerge from streams into their aerial adult stage right before the summer floods normally occur (Lytle 2002). This peak aquatic insect emergence during the hottest and

driest time of the year may provide a crucial resource for riparian lizards, as other insects may be less active during this time. However, this peak emergence right before the monsoon season could be disrupted by stream drying. In an unprecedented drying event of a desert spring in southeastern Arizona, six aquatic invertebrate species were extirpated and the abundances of other species decreased by nearly 40% (Bogan and Lytle 2011). It is unclear how these changes in aquatic insect communities caused by drought will affect riparian species, specifically lizards.

In this study, we examined the differences in lizard populations along perennial and ephemeral streams in the Chiricahua Mountains of southeastern Arizona. We quantified the populations of three lizard species, *Sceloporus jarrovi* (Yarrow's spiny lizard), *Sceloporus virgatus* (striped plateau lizard), and *Urosaurus ornatus* (ornate tree lizard), across the early summer dry season and the beginning of the summer monsoon season. We hypothesized that perennial streams provide aquatic food subsidies to terrestrial species, which reduces competition and opens niches for riparian lizards. We predicted that lizard abundances would be greater, and that individuals within a species would grow larger and faster, along perennial streams compared to ephemeral streams. In addition to examining lizard abundance and growth, we also examined microhabitat use across the three lizard species, sampled terrestrial invertebrates at all sites, and quantified aquatic insect emergence at perennial sites.

Methods

Study Site

The Madrean Sky Island Region of southeastern Arizona, western New Mexico, and northwestern Mexico is a North American biodiversity hotspot with 28 different lizard species inhabiting the 20 different mountain ranges (Bezy and Cole 2014). Our research was based out of

the American Museum of Natural History's Southwestern Research Station (SWRS) in the Chiricahua Mountains of southeastern Arizona. The Chiricahua Mountains are an ideal study area because at least 18 species of lizards are found there, as well as many perennial and ephemeral streams with similar microhabitats for lizards

All study sites were located in the Coronado National Forest, and included South Fork Cave Creek above the trailhead (1635m elev., 2% slope, 10°N aspect), Cima Creek at the Basin Trail (1804 m elev., 8% slope, 100°SE aspect), and North Fork Cave Creek at Forest Road 42 (1602 m elev., 5% slope, 90°E aspect) (Fig. 1). The vegetation type at our sites is categorized as oak-pine woodland (Baynham 2012). At each of these three stream locations, we had paired 100-meter long perennial and ephemeral reaches (separated by 100 meters) that were similar in microhabitat, such as canopy cover and substrate type, but differed in water availability.

Lizard Capture

Over the course of eight weeks, from June 12th to August 7th, 2017, we surveyed lizards via a mark recapture study of three species commonly found throughout the range, *Sceloporus jarrovi*, *Sceloporus virgatus*, and *Urosaurus ornatus*. These lizards have a similar active season occurring from May to September. For the first four weeks (pre-monsoon season), each study site was surveyed twice per week. We captured lizards via noosing, with nooses constructed from braided fishing wire and retractable fishing rods. We began our study in early June, as insect abundance is typically low during this time (Simon and Middendorf 1985), in hopes of establishing a baseline for lizard mass across study sites. After the monsoon rains began, initiating a period of high insect abundance (Simon 1976), we surveyed each site once a week for four weeks.

At each 100-meter study reach, we surveyed lizards along the wet or dry stream channel, and out to 10 meters away from the stream channel (Fig. 2). To accomplish this, we established three transects at each reach. One person sought lizards while walking directly up the stream channel, while two additional people walked on either side of the stream, parallel to the stream channel surveyor. Each survey took approximately two hours, and all three surveyors made two passes along each transect. At North Fork Cave Creek, approximately 15% of the outermost 10m stretch of the wet reach was classified as road. This road is regularly used and we did not expect lizards to be using it as microhabitat, so this small portion of the North Fork Cave Creek wet reach was excluded from surveys. On any given day, we surveyed two paired sites, one in the morning, starting at 9am, and one in the afternoon, starting at 1 pm. Because we know that lizards overlap spatially but have different temporal usage (Simon and Middendorf 1985), we alternated which sites were surveyed in the morning versus the afternoon to make sure that we encountered all the lizards in each respective site. The survey order was randomly selected.

When a lizard was sighted, we recorded the microhabitat (bedrock, cobble, grass, rock wall, large boulders, medium boulders, small boulders, leaf litter, road, trail, trees, and woody debris) it occupied. After capturing each lizard, we took body measurements that included snout-vent length, tail length, regrown tail length, and mass. We also recorded the sex and general health conditions (e.g. if the animal was shedding or if it had worms) of each lizard. We also collected fecal samples when available. Each lizard was given a paint mark right above its tail to identify it across the field season. Lizards were also marked with unique toe-clippings (Perry et al. 2011) to identify individuals if paint markings failed, and to use across field seasons (i.e. for future studies). When we sighted a lizard, but were unable to capture it, we recorded the species as well as the microhabitat we saw it in but not any individual-specific information. We captured

35 lizards at South Fork however we saw but did not capture 6 lizards. We captured 22 lizards at North Fork at Cima Creek however we saw but did not capture 8 lizards. We captured 36 lizards at North Fork at the Basin Trail however we saw but did not capture 18 lizards. We did not include the individuals we sighted but did not capture in our analysis to avoid counting an individual more than once.

Invertebrate Abundance Survey

In order to quantify the abundance of aquatic prey that may be available to riparian lizards, we used aquatic insect emergence traps at our perennial sites. Our emergence trap design was modified from Cadmus et al (2016) to fit the small size of our study stream pools. We built 0.85 by 0.85 m emergence traps out of PVC piping and mesh netting and deployed two emergence traps in two randomly selected pools (that were large enough to fit the trap) in each 100m study reach. Emergence traps were deployed from the week of June 12th to July 3rd. During the first week of deployment, there were technical issues with the design so we were only able to collect samples for the second and third weeks. Preserved insects were collected from each trap once a week.

Terrestrial invertebrate assemblages along each 100m study reach were sampled through the use of beating sheets, constructed of light colored durable fabric and a t-shaped wooden frame. Samples were collected along the stream at 25, 50, and 75 meters. At each of these three longitudinal distances along the study reach, samples were collected in 5 x 5 meter grids away from the stream at 5, 10, and 15 meters on either side of the stream, for a total 21 sample grids in each of the paired perennial and ephemeral sites. Microhabitat was assessed at each sample site before insect sampling occurred. In grids that were primarily shrubs or trees, a branch was

selected and shaken for 15 seconds over the beating sheet. In grids that were primarily leaf litter, 20 ounces of leaf litter were collected by hand and shaken over the beating sheets. In the grids that were a mixture of vegetation and leaf litter, 10 ounces of leaf litter and the largest branch were shaken over the beating sheets. Visible invertebrates were then collected with forceps from beating sheet.

Once collected, all aquatic and terrestrial invertebrate samples were preserved in 70% ethanol and stored in the entomology laboratory at SWRS until they could be transported to the University of Arizona (UA). Once at UA, samples were processed and all invertebrates were identified to order and enumerated. Because terrestrial invertebrates were frequently found in aquatic emergence trap samples, each invertebrate collected was designated as being either aquatic or terrestrial (semi-aquatic invertebrates were counted as terrestrial).

Statistical Analysis

We tested for differences in lizard abundances between wet and dry reaches with a paired Wilcoxon rank-sum test for *S. jarrovi* and *S. virgatus*. We tested for differences in lizard mass at first capture between wet and dry reaches with a Wilcoxon rank-sum test for *S. jarrovi* and *S. virgatus*. We examined the available microhabitats within each 100m stream reach and performed a chi-squared analysis to determine if lizards were using the microhabitat present in proportion to its availability. We did not perform any statistical analyses with the mark-recapture data as sample sizes were insufficient. We were also unable to perform any statistical analyses for *U. ornatus* due to insufficient sample sizes. All analyses were performed in R Studio 1.1.423 using the package *stats* 3.4.1 (RStudio Team 2015).

Results

Lizard Capture

Over the course of the summer we collected a total of 93 lizards (39 *S. jarrovii*, 51 *S. virgatus*, and 3 *U. ornatus*) across the three study sites. We found *S. jarrovii* in cobble, large boulder, medium boulder, small boulder, leaf litter, trees, and woody debris microhabitats. *S. virgatus* was found in large boulder, small boulder, tree, and woody debris microhabitats. *U. ornatus* was found in cobble, leaf litter, tree, and woody debris microhabitats. Each of the six study reaches was missing no more than two of these microhabitat types, suggesting similar microhabitat distributions across the reaches. We found that lizards were using the microhabitats according to the proportion of their availability [South Fork wet $p = 0.23$, $\chi^2 = 18$ ($n = 24$ *S. jarrovii*), South Fork dry $p = 0.48$, $\chi^2 = 9.6$ ($n = 5$ *S. jarrovii*), North Fork wet $p = 0.20$, $\chi^2 = 19.2$ ($n = 18$ *S. virgatus*), North Fork dry $p = 0.38$, $\chi^2 = 19.2$ ($n = 10$ *S. virgatus*), Cima Creek wet $p = 0.19$, $\chi^2 = 19.6$ ($n = 15$ *S. virgatus*), and Cima Creek dry $p = 0.30$, $\chi^2 = 14$ ($n = 5$ *S. virgatus*)] (Fig 3). Because we experienced low sample sizes for some species in some reaches, we only ran the chi-squared test for species that had at least 5 individuals in a given reach.

Statistical tests failed to detect differences in lizard abundances between paired wet and dry sites ($p = 0.37$, $U = 3$ for *S. jarrovii*; $p = 0.5$, $U = 3$ for *S. virgatus*), but qualitative assessments suggest trends that may have emerged with larger sample sizes. At two of the study sites (North Fork and Cima Creek), abundances of *S. virgatus* were twice as high in the wet reaches than in the dry reaches. We only captured one individual of *S. virgatus* in the South Fork site, so we are unable to compare abundances between wet and dry reaches there. For *S. jarrovii*, patterns of abundances were more complex. At the South Fork site, abundances of *S. jarrovii* were nearly five times higher in the wet reach than in the dry reach. However, at North Fork and

Cima Creek, abundances of *S. jarrovii* were equal in the wet and dry reaches. We omitted *U. ornatus* from these analyses due to low sample sizes (Fig. 4).

When considering mass at first capture, we found that *S. jarrovii* were larger at wet versus dry reaches ($p = 0.0025$, $T = 310$). However, we did not find any differences in mass between wet and dry sites for *S. virgatus* ($p = 0.53$, $T = 119.5$). We only captured three *U. ornatus* across all sites, so we were not able to perform any statistical analyses for that species (Fig. 5).

Invertebrate Abundance Surveys

Our terrestrial invertebrate surveys detected 10 orders of insects and other invertebrates: Hymenoptera, Aranae, Hemiptera, Lepidoptera, Coleoptera, Orthoptera, scorpions, Isopoda, Neuroptera, and Diptera. Terrestrial invertebrate abundance and order richness was qualitatively higher in the wet reaches at all distances along the stream, and closer to the stream as opposed to further away from the stream, except for grids at 10 and 15m from the left of the stream. However, small sample sizes and high variation among sampling grids resulted in large standard deviations around these means (Figs. 6-7).

The invertebrate order richness we collected from the emergence traps was fairly similar across all three of the wet reaches (20 orders found at South Fork, 17 orders found at North Fork, and 19 orders found at Cima Creek) (Fig. 8). The emergence traps captured both terrestrial (Fig. 9) and aquatic invertebrates (Fig. 10). Orders captured include: Ephemeroptera, Trichoptera, Diptera, Ixodida, Hymenoptera, Coleoptera, Collembola, Thysanoptera, Lepidoptera, Hemiptera, Odonata, Orthoptera, and Araneae. Overall, total emergence trap invertebrate abundance seemed to increase as the season continued (Fig. 11). At South Fork and Cima Creek 86% and 75% of all

invertebrates collected from emergence traps in weeks 2 and 3, respectively, were aquatic insects (Fig. 12). However, at the North Fork site the pools began to dry up in week 3 of trap deployment. At this site, only 10% and 12% of the invertebrates in the emergence traps in weeks 2 and 3, respectively, were aquatic insects (Table 1).

Discussion

Our study focused on the populations of three sympatric lizards *Sceloporus jarrovi*, *S. virgatus*, and *Urosaurus ornatus* in the Chiricahua Mountains of southeastern Arizona. We were interested in examining how drought would impact the abundances and growth rate of these populations. Ephemeral streams reaches were used as a natural proxy for a drought-affected stream and compared to perennial stream reaches to illustrate how stream drying might affect riparian lizards in arid environments.

Mass at First Capture

Despite having relatively low sample sizes we were able to detect a difference in mass at first capture for *S. jarrovi* between perennial and ephemeral sites. Access to aquatic insect food resources, as reflected in the emergence trap data, may have driven this trend. Previous research from a river in California showed that lizards will first eat aquatic insects and then switch to terrestrial prey when aquatic prey items are unavailable (Sabo and Power 2002b). Lizards with access to aquatic insects grew 2.6x faster in length and 1.9x faster in body mass than those without the same access (Sabo and Power 2002b). High insect abundance can potentially lead to lizards selecting larger and more nutritious prey items, as opposed to prey items such as ants

which may be in high abundance but are smaller and yield less nutritional value (Ballinger 1979, Simon and Middendorf 1985). When aquatic prey items were experimentally removed from lizard enclosures, lizard densities decreased in plots lacking this food source, despite overall prey biomass (terrestrial plus aquatic) being equal in all plots (Sabo and Power 2002a). We propose that *S. jarrovi* are similarly benefiting from aquatic insect prey along Arizona streams, and hope to strengthen our conclusions in future studies with greater sample sizes.

In contrast to our findings with *S. jarrovi*, we did not detect differences in mass at first capture between perennial and ephemeral reaches for *S. virgatus*. From previous studies, we know that both species can have similar diets (Watter 2010). The lack of mass differences for *S. virgatus* could possibly be due to the fact that we captured far fewer individuals than we did for *S. jarrovi*. We also had to exclude 11 gravid females at our perennial reaches and six gravid females at our ephemeral reaches. We excluded these females from analyses because mark-recapture data for a small number of gravid females suggested high variability in egg mass; females lost between two and five grams in mass after laying eggs. Alternatively, it is possible that the larger *S. jarrovi* captures larger, more nutritious prey items than *S. virgatus*, including emerging aquatic insects like mayflies and caddisflies. In a previous study examining optimal foraging theory between *S. jarrovi* and *S. virgatus* at different life stages, adult *S. jarrovi* were found to have the highest diet profitability (Watter 2010). Accordingly, *S. jarrovi* may be eating more aquatic insects along perennial streams, and thus growing larger, while *S. virgatus* diet (and thus their relative size) remains similar between perennial and ephemeral reaches.

Abundances at Perennial vs Ephemeral Reaches

There was no difference in lizard abundances between perennial and ephemeral reaches for any of our species. We believe this is due in part to low sample sizes, as we only had three pairs of perennial and ephemeral reaches to compare. Abundances of *S. virgatus* were much higher along perennial reaches at two streams, but not at the third, and *S. jarrovii* exhibited similar patterns (Fig. 4). Perhaps with additional pairs of perennial and ephemeral reaches, these trends of higher abundances would have been statistically significant. There were a few individuals at each site that we detected visually but were unable to capture via noosing as they would dart into refugia (i.e. under large boulders or into agave) if approached. We hope that expanding our sampling methods will help increase our sample sizes by capturing animals that we were unable to capture via noosing.

Previous research suggests that, of our three focal species, at least *S. virgatus* is known to be closely associated with riparian areas in the Chiricahua Mountains (Vinegar 1975). *S. virgatus* were also found in higher densities closer to dry streambeds as opposed to the surrounding grassy woodland and rock outcrops (Abell 1999). So, this means that even with a larger sample size, we may not see a difference in abundance between perennial and ephemeral sites for *S. virgatus*. In fact, if *S. virgatus* have a strong affinity for dry streambeds we might even expect their abundances to be higher along dry stream reaches than perennial reaches, although the studies of Vinegar (1975) and Abell (1999) did not include perennial stream study sites.

Microhabitat Use and Prey Availability

Lizards choose microhabitats for a variety of reasons including prey availability, thermoregulatory needs, and access to refuges from predators (Simon and Mittermeier 1985). We know that both *S. jarrovii* and *S. virgatus* are saxicolous (i.e. rock dwelling) lizards (Simon and

Middendorf 1985). Previous studies have shown that *S. jarrovii* is less likely to use rock substrate as lizard abundances increase because territoriality means they are forced away from preferred rocks (Vinegar 1975, Middendorf 1984). These findings could explain why in our South Fork perennial reach, where we observed the highest densities of *S. jarrovii* (24 individuals in a single 100m reach), we did not detect a preference for rock substrate. Instead, individuals of *S. jarrovii* used various microhabitats in proportion to their availability. However, our lower sample sizes for *S. virgatus* and *U. ornatus* may prevent definitive conclusions about microhabitat preferences. For example, we know that due to our method of capture we did not catch all the individuals in a given area, especially for *U. ornatus* as many escaped capture by running high into the trees. Due to the abundance of suitable microhabitat types at each site, we believe that there was no strong habitat limitation, which may explain why we did not see a significant difference in microhabitat use.

We found aquatic insects in relatively high abundances at two of our three perennial reaches (Table 1). However, previous studies of prey availability for *S. jarrovii* and *S. virgatus* (Ballinger and Ballinger 1979, Simon and Middendorf 1985, Watter 2010) did not consider aquatic insects as potential food sources. As such, these studies may have underestimated the prey breadth available along perennial reaches. In other systems, research has shown that emerging aquatic insects are one of the biggest food sources for some terrestrial consumers (Ramey and Richardson 2017), including lizards. It is possible that the larger mass at first capture for *S. jarrovii* along perennial versus ephemeral reaches was due to the availability of large aquatic insects (e.g. mayflies, caddisflies) as prey items. The fluxes of invertebrates to and from streams are important to riparian areas (Baxter et al. 2005). Unfortunately, we were unable

to explicitly link lizards to the aquatic insects we observed in the area. In the future we hope do this through visual observation, fecal matter analysis, and stable isotope analysis.

Overall, we did not observe strong trends in terrestrial invertebrate order richness or abundance given our small sample sizes and the limitations of our collection methods. We expected to see greater order richness and abundances in perennial reaches than ephemeral ones, and closer to the stream as opposed to further away from the stream. This lack of pattern may suggest that terrestrial insect abundance and order richness was not limiting at any of our sites, whether or not there was surface water available in the streams. Riparian areas along intermittent and ephemeral streams supported arthropod diversity similar to perennial streams in southeastern Arizona (Moody and Sabo 2017) . However, community composition was dissimilar between the different stream types. Perennial and ephemeral reaches were most dissimilar during monsoon season if both stream types were flowing at some point throughout the summer (Moody and Sabo 2017) . We collected samples right before the beginning of the monsoon season and did not compare community composition quantitatively, so we cannot compare directly with Moody and Sabo's (2017) data. However, at two of our three sites we observed similar terrestrial insect order richness and abundance between perennial and ephemeral reaches. In the future, we plan to take more samples in order to make solid conclusions about terrestrial prey availability.

Study Limitations and Future Plans

This study had many limitations, including: (1) not being able to use sticky traps to survey both aquatic and terrestrial insects, (2) a limited number of sample sites, and (3) limited lizard capture methods. Unfortunately, we were unable to use sticky traps for invertebrates as there was concern that small vertebrates would accidentally be caught in these traps. We were

looking for study reaches that had similar microhabitats but differing water availability that were not too far away from each other so that we could have matched pairs. These restrictions limited sampling sites, and an additional pair of potential sites was not available for study due to other permitting restrictions. Additional restrictions on site choices were caused by ongoing drought conditions. Many reaches that historically had water were dry in 2017, or would not have had adequate flow throughout the field season. Finally, malfunctioning emergence traps resulted in us being unable to quantify aquatic insect abundances for the first week. In the future, we plan to improve our emergence trap design as well as include more terrestrial insect samples.

The design for this study was descriptive, not experimental. Because of this we were unable to make quantitative links between lizards and prey selection. To better assess which prey items lizards are selecting and how prey affects lizard abundances and growth rates, we hope to do manipulative subsidy experiments similar to Sabo and Power (2002a and 2002b) to see if lizard abundances change within a stream reach based on aquatic insect prey availability. We also hope to use stable isotope analysis to make concrete trophic connections between lizards and emerging aquatic insects.

Conclusions

Riparian areas provide habitats and food resources to many species (Sabo et al. 2005). And yet there are relatively few studies that show the impacts of inputs from streams to terrestrial ecosystems, and how those processes might be altered by climate change and water withdrawal (Baxter et al. 2005, Sabo and Hagen 2012). In our study, we found that *S. jarrovii* seem to grow larger along perennial streams than ephemeral streams, likely benefiting from emerging aquatic insects as an additional prey source. Given regional climate change models that

predict that the Southwestern US will become more arid in the 21st century (Wilson et al. 2012) we expect to see shifts in population distribution, foraging behavior, and performance for riparian lizards like *S. jarrovi* as streams dry (Beal et al. 2014). Furthermore, this study only focused on three lizard species, but there are numerous other riparian species that rely on aquatic insects, such as bats, birds, and spiders (Baxter et al. 2005). As we continue to lose these perennial habitats due to stream drying, it is crucial to understand how these species will be affected. Further study will inform these knowledge gaps and guide future management and conservation methods.

Figures and Tables

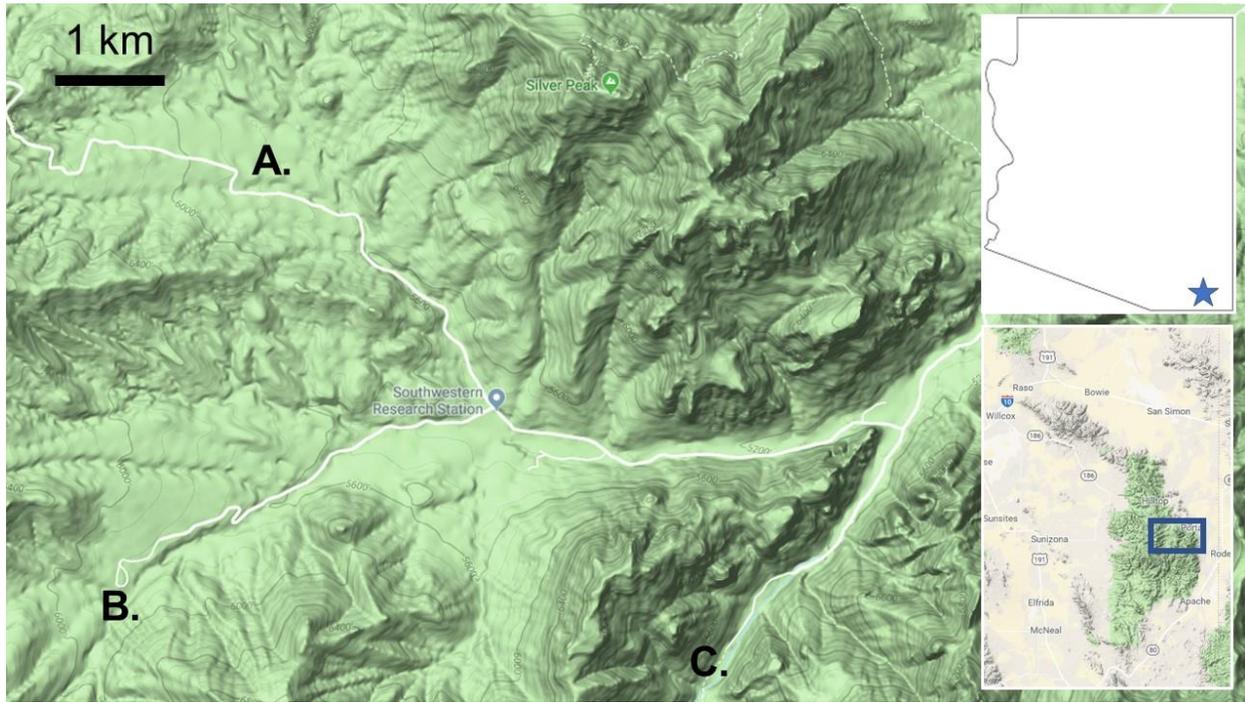


Figure 1. Map of study locations in the Chiricahua Mountains, southeastern Arizona: A) South Fork Cave Creek, B) Cima Creek, and C) North Fork Cave Creek. Imagery from Google Maps.

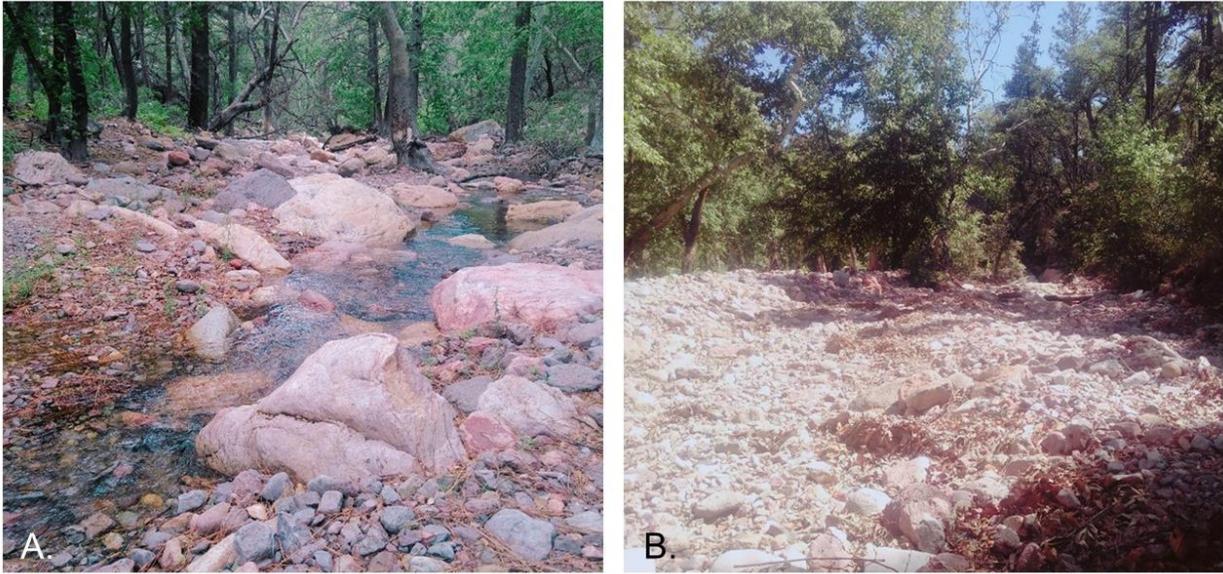


Figure 2. An example of the conditions in the paired 100-m perennial and 100-m ephemeral stream reaches at each site: A) perennial reach at the South Fork site, B) ephemeral reach at the South Fork site.

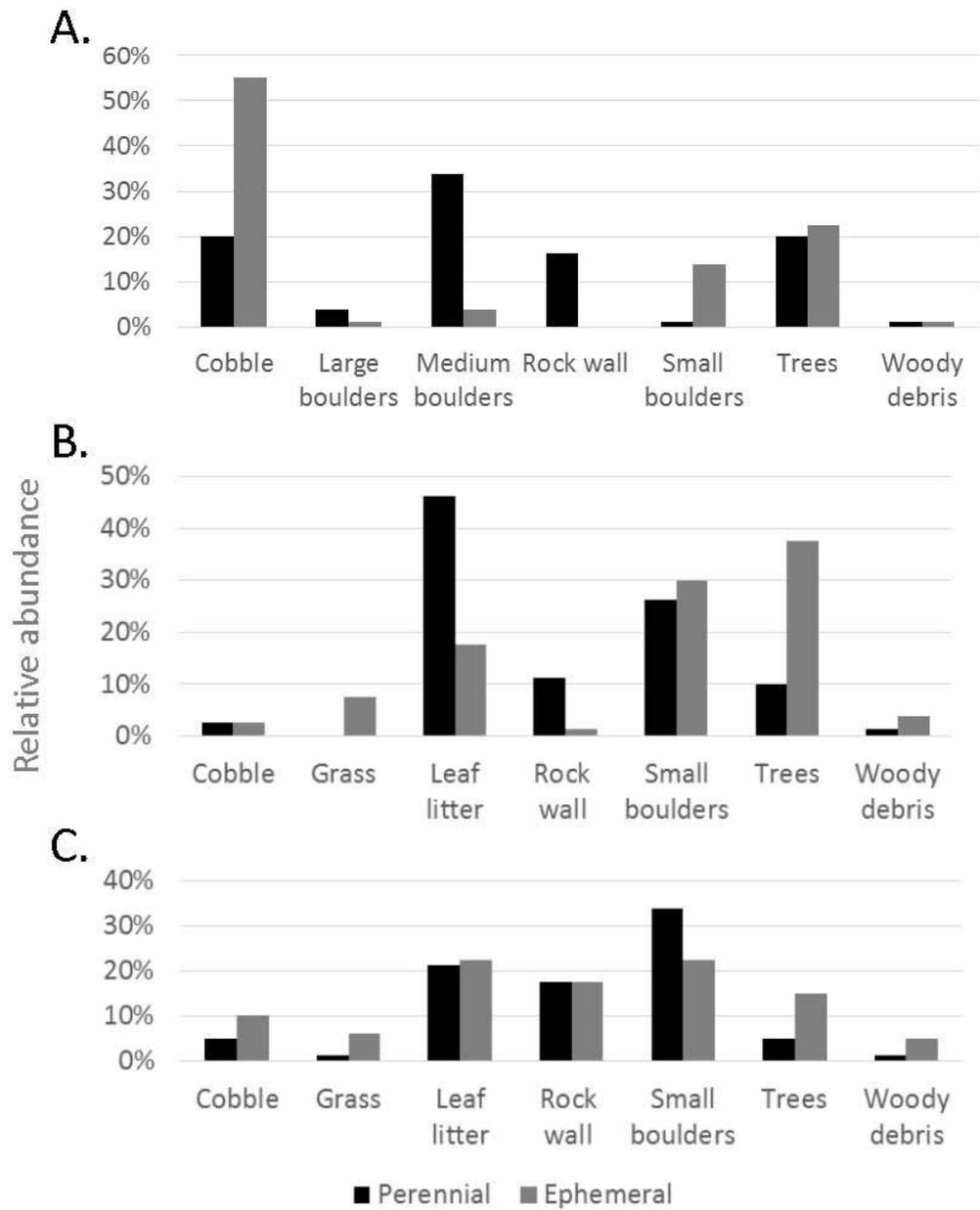


Figure 3. Relative abundances of microhabitat types at each of the three sites: A) South Fork, B) North Fork, and C) Cima Creek.

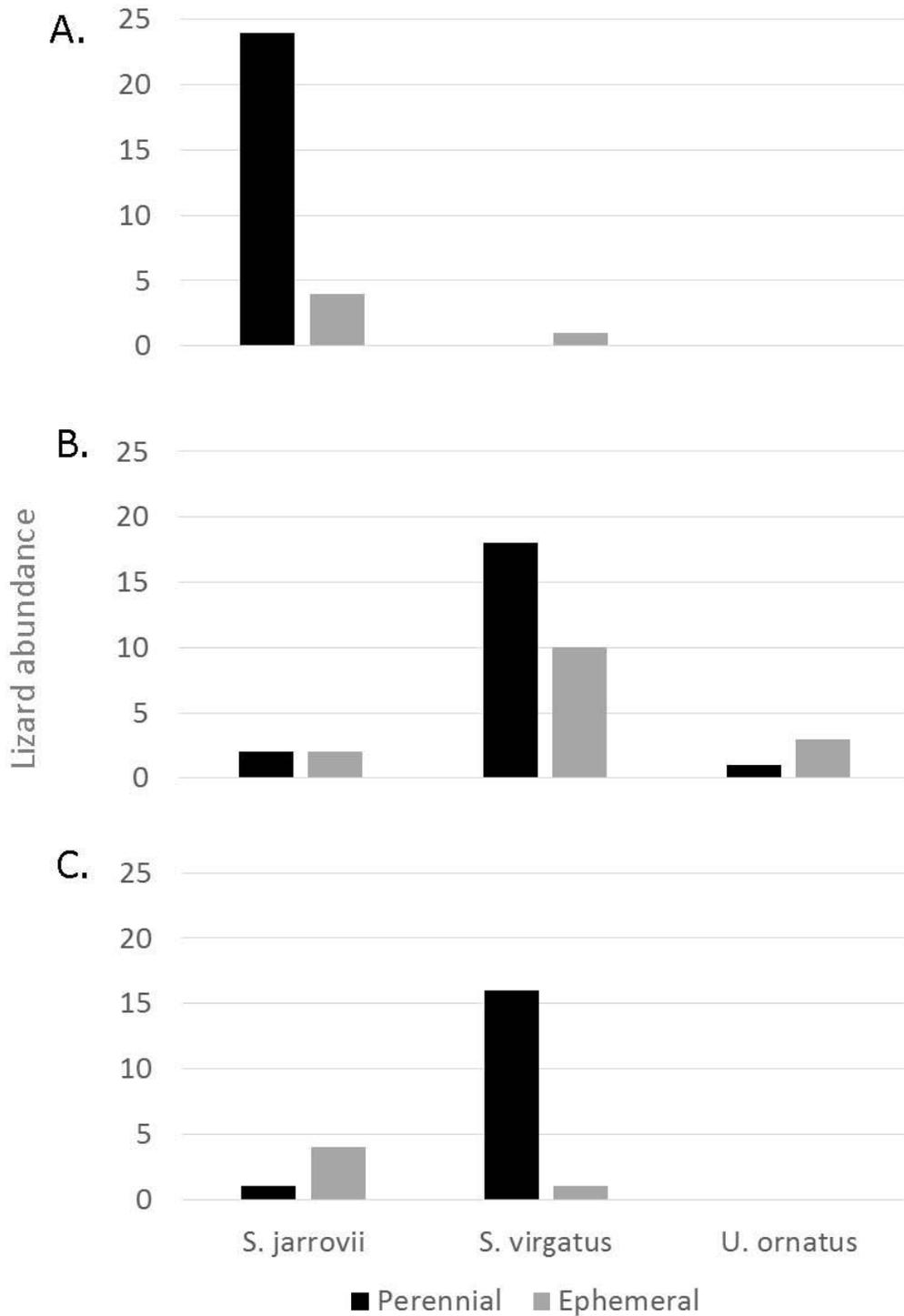


Figure 4. Lizard abundances for each of our three focal species at each of the three sites: A) South Fork, B) North Fork, and C) Cima Creek. We did not detect any differences in abundance between paired perennial and ephemeral reaches.

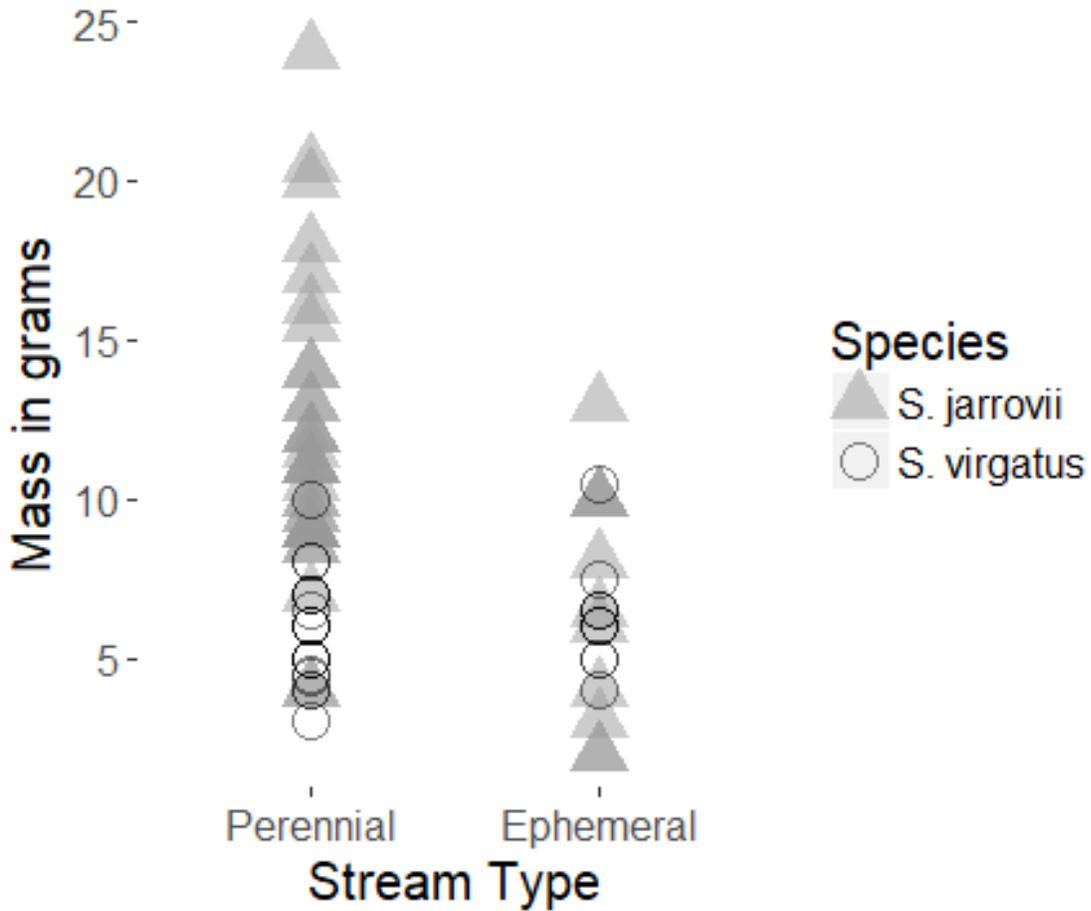


Figure 5. Mass at first capture for all individuals of *S. jarrovii* and *S. virgatus* measured at all perennial and ephemeral reaches. Mass at first capture for *S. jarrovii* was significantly higher along perennial versus ephemeral reaches, but no differences in mass were found for *S. virgatus*.

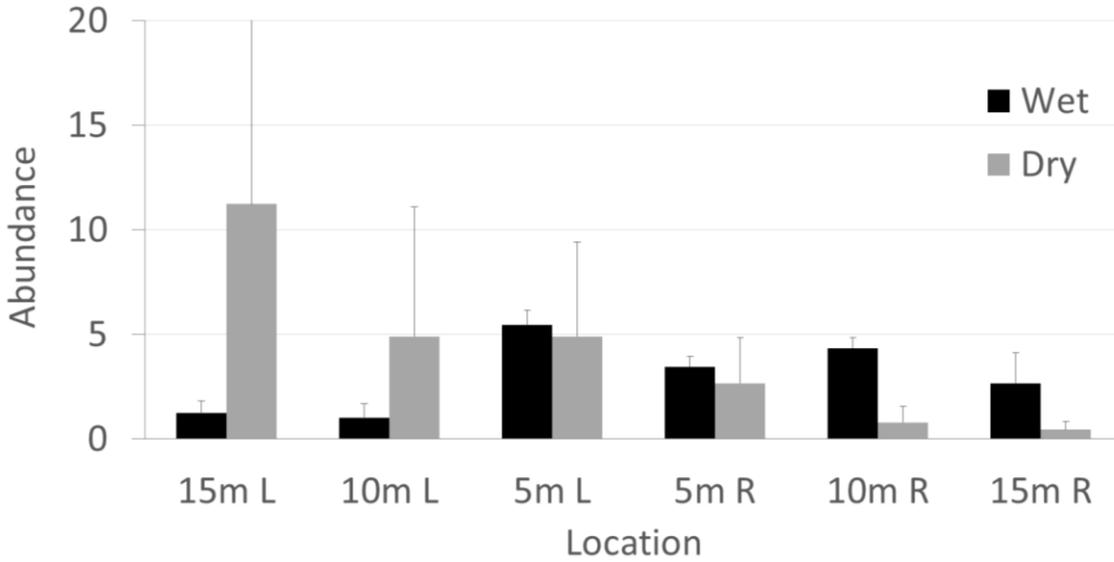


Figure 6. Average terrestrial invertebrate abundances at perennial and ephemeral reaches at three distances from the streambed (5m, 10m, 15m) across all three sites. Error bars represent one standard deviation.

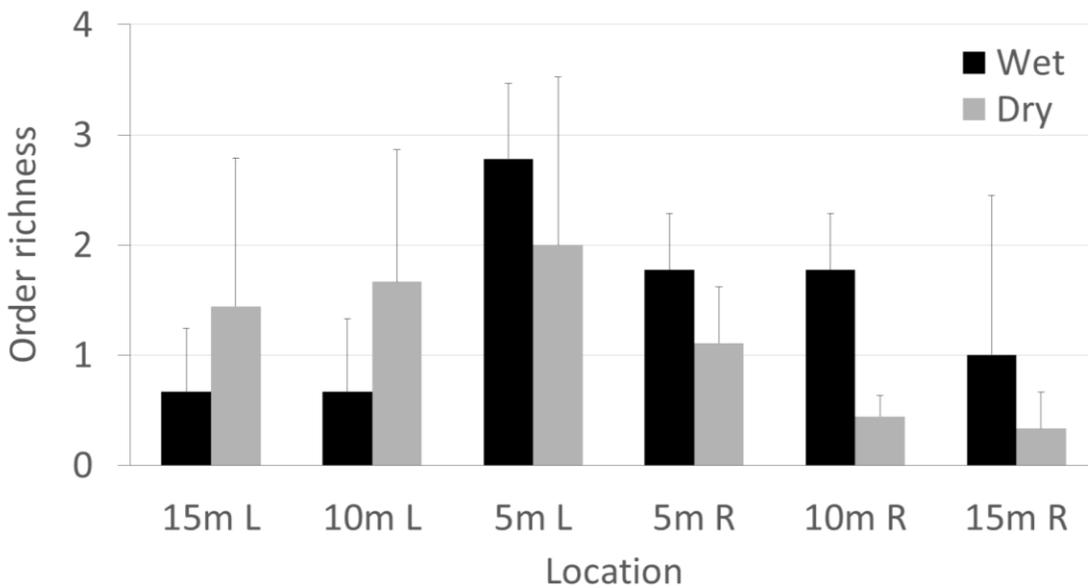


Figure 7. Average terrestrial invertebrate order richness at perennial and ephemeral reaches at three distances from the streambed (5m, 10m, 15m). Error bars represent one standard deviation.

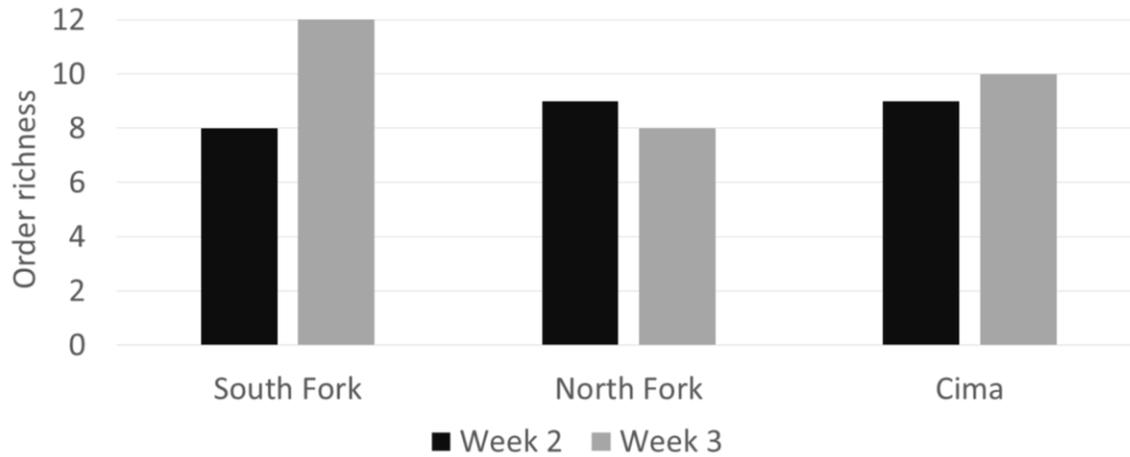


Figure 8. Invertebrate order richness from the emergence traps collected at each of the perennial reaches in weeks 2 and 3 of trap deployment.

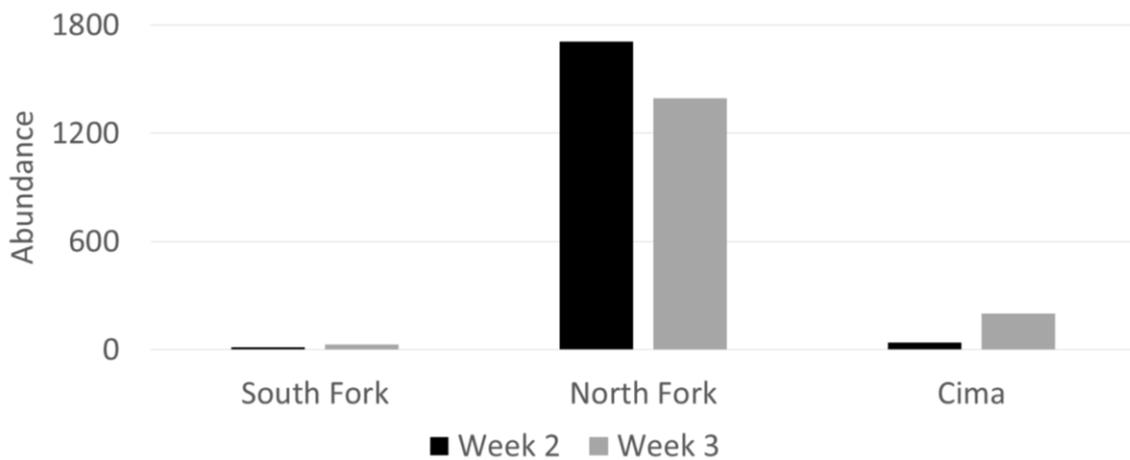


Figure 9. Terrestrial invertebrate abundance from the emergence traps collected at each of the perennial reaches in weeks 2 and 3 of trap deployment.

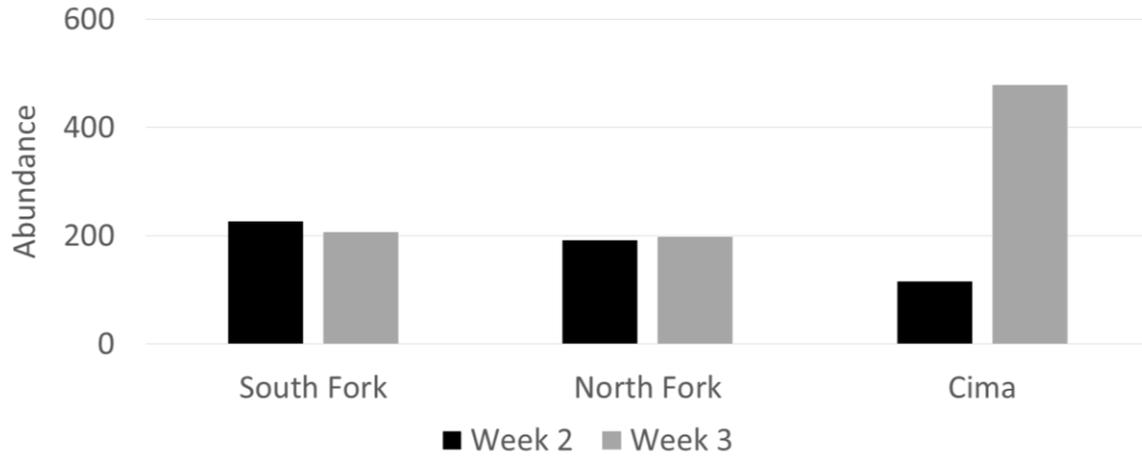


Figure 10. Aquatic insect abundance from the emergence traps collected at each of the perennial reaches in weeks 2 and 3 of trap deployment.

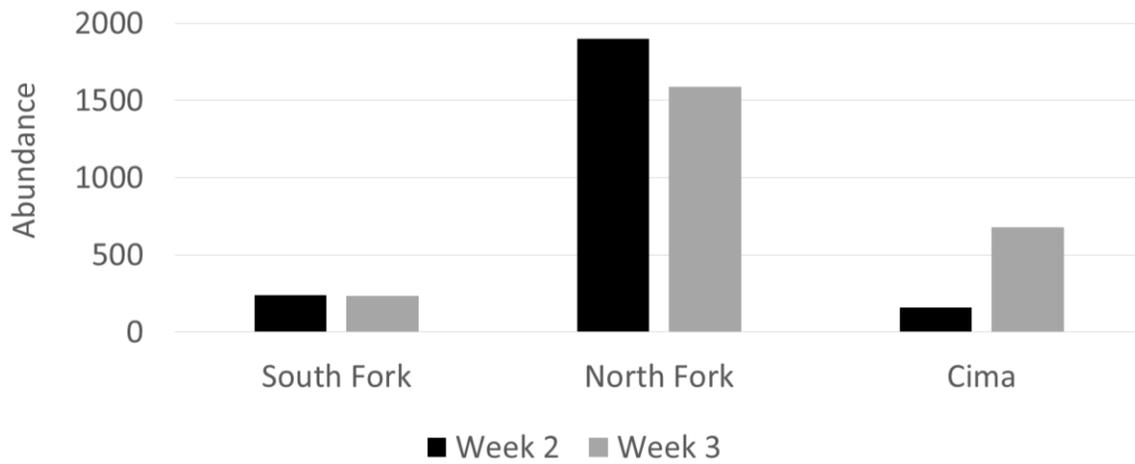


Figure 11. Total invertebrate abundance from the emergence traps collected at each of the perennial reaches in weeks 2 and 3 of trap deployment.

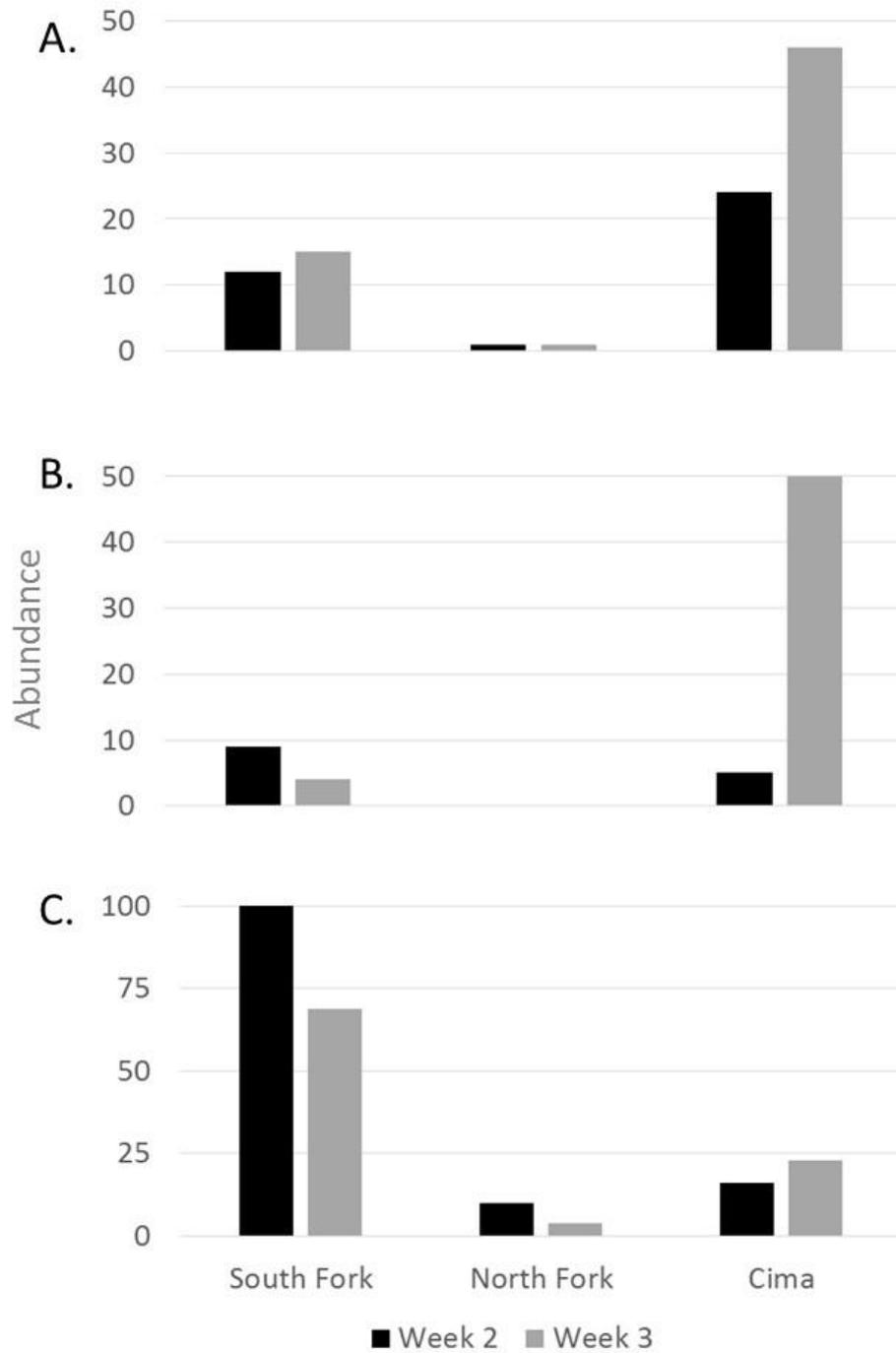


Figure 12. Aquatic insect emergence patterns for three of the most common taxa collected: A) caddisflies (Trichoptera), B) mayflies (Ephemeroptera), and C) midges (Diptera: Chironomidae).

Table 1. Ratios of aquatic insect adults to terrestrial invertebrates collected in the emergence traps. At the South Fork and Cima Creek perennial reaches we caught more aquatic insects than terrestrial invertebrates, however the North Fork perennial reach had many more terrestrial invertebrates in the trap because the stream pools were drying up during the 3-week trap deployment.

Aquatic vs Terrestrial Insect Abundance Ratio			
	South Fork	North Fork	Cima Creek
Week 2	18 : 1	0.1 : 1	3 : 1
Week 3	8 : 1	0.1 : 1	2 : 1

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