Ecological Effects of Stream Flow Permanence on Butterfly and Plant Communities of Sonoran Desert Streams

by

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A Thesis Presented in Partial Fulfillment
of the Requirements for the Degree
Master of Science

Approved June 2015 by the
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ARIZONA STATE UNIVERSITY

August 2015

ABSTRACT

Stream flow permanence plays a critical role in determining floristic composition, abundance, and diversity in the Sonoran Desert, but questions remain about the effects of stream flow permanence on butterfly composition, abundance, and diversity. Understanding the effects of flow permanence on butterflies and relevant subsets of butterflies (such as butterflies whose host plants are present) and comparing them to these same effects on plants and relevant subsets of plants (such as butterfly nectar plants and larval host plants) provided insight into pollinator and riparian conservation and restoration.

I surveyed four Sonoran desert stream sites, and found significant relationships between flow permanence and plant and butterfly species richness and abundance, as well as strong relationships between plant and butterfly abundance and between plant and butterfly species richness. Most notably, my results pointed to hosted butterflies as a break-out category of butterflies which may more clearly delineate ecological relationships between butterfly and plant abundance and diversity along Sonoran Desert streams; this can inform conservation decisions. Managing for hosted (resident) butterflies will necessarily entail managing for the presence of surface water, nectar forage, varying levels of canopy cover, and plant, nectar plant, and host plant diversity since the relationships between hosted butterfly species richness and/or abundance and all of these variables were significant, both statistically and ecologically.

DEDICATION

This Masters thesis is dedicated first to my family, especially my parents, Susan Ritchey and Scot Butler III, my uncle, Jim Ritchey, my late maternal grandmother, Mary Ann Ritchey, and my paternal grandmother, Joan Collet Butler, without whose moral support and financial assistance this thesis would not have come to be. Second, it is dedicated to Dr. Andrew Smith, who has taught me many incredible lessons about the field of conservation biology, to Amy Rabideau of the Disability Resource Center, who connected me to Vocational Rehabilitation Services, and to Wendi Simonson of the School of Life Sciences, who supported me with that tiny touch of humanity that made all the difference when my grandmother passed away as my final draft thesis came due. Finally, it's dedicated to my labmates and friends, who helped me through the many stages and life changes of graduate school: Margaret White, Natalie Case, Andrea Hazelton, Melanie Tluczek, Jackie Betsch, Danika Setaro, Amanda Suchy, Frankie Coburn, Dustin Wolkis, Robert Madera, Tyna Yost, and Brenton Scott.

ACKNOWLEDGEMENTS

I would like to thank my advisor, Dr. Julie Stromberg, for accepting me into her lab and allowing me to work for her, both as a research assistant and a teaching assistant. I am grateful for her considerable support and patience through the years of my program. Among many other things, my committee member Liz Makings helped me find resources to locate sites appropriate for my study, helped me field-pilot the study, and helped me identify my plants. She has been an invaluable professional associate and friend. I have been fortunate to both work for Dr. Dave Pearson as a teaching assistant and have him as a committee member. He has helped me solidify my understanding of what it means to creatively do science. Dr. Stephen Buchmann has taken time out of his busy life to weigh in on this Masters project as a committee member as well. He has worked on a national and international scale to develop pollinator conservation programs, and I thank him for bringing a unique and encouraging viewpoint to this project. Dr. May Boggess helped me format and analyze my data; as the most recent addition to my committee, she has been a crucial unifying and finalizing force for this project, and I humbly and sincerely thank her for the time, energy, and heart she has given to mentoring me. For site reconnaissance and selection assistance, I would like to thank Janet Grove, Grant Loomis and Lynn Mason of the United States Forest Service, as well as Dr. Meg White and Rich Bailowitz. For site permissions, I thank Kelly Kesssler, Louise Congdon, and Todd Willard of USFS, and Kevin Smith and Darci Kinsman of Spur Cross Ranch Conservation Area. I am grateful to have received various forms of financial assistance at critical times; specifically, I would like to thank Yvonne Rojas and Juergen Gadau for their help in obtaining School of Life Sciences Fellowships; Juergen Gadau and Osvaldo Sala for creating the Research and Training Initiatives field assistance fellowship; Bill Atteberry of Vocational Rehabilitation Services; and the Andrew and Florence Brown Scholarship Fund. Finally, my fieldwork partner, Brian Martin, deserves his own page; I could not have asked for a better field work partner.

TABLE OF CONTENTS

Page

APPENDIX Page

LIST OF TABLES

Table Page

LIST OF FIGURES

Figure Page

INTRODUCTION

Background

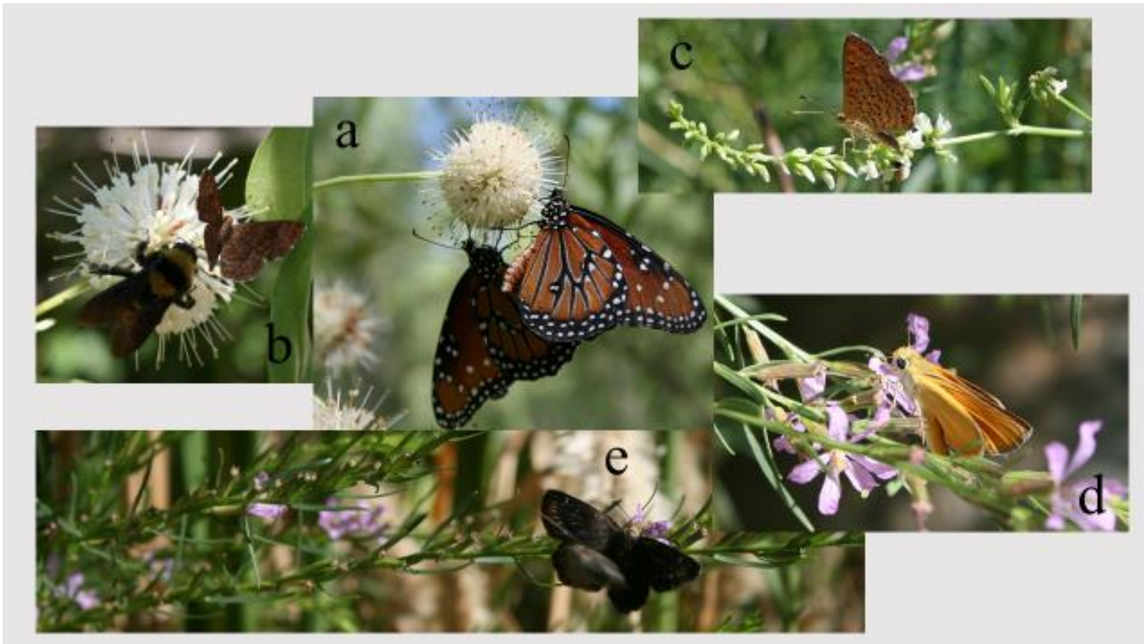
Stream flow permanence plays a critical role in determining floristic composition, abundance, and diversity in riparian areas of dryland regions (Katz et al. 2012; Levick et al. 2008; Stromberg et al. 2007), but questions remain about its influence on butterflies (Kerr et al. 1998). Water is an essential resource for sustaining both plant and animal life (including butterflies and many other pollinators) in arid regions (Brand et al. 2010; Dingle et al. 2005; Fleishman et al. 1999; Knopf et al. 1988; Levick et al. 2008; Stromberg et al. 2007). Stream flow permanence varies among desert streams from permanent (flowing year-round) to temporary (flowing for some portion of the year). Some temporary streams have surface flow most of the year, including some drought seasons, but the majority of desert drainages flow only after storms (Levick et al. 2008). Climate change in dryland areas, including the American Southwest, is expected to bring about declines in the length of stream segments with perennial flow (Seager et al. 2007). These physical changes will impact plant and animal populations including pollinators and breeding birds (Brand et al. 2010; Palmer et al. 2008)

Understanding the effects of changes in flow permanence on butterflies will yield insights for the purposes of pollinator and riparian conservation and restoration.
There is a pressing need for this information, as ongoing worldwide pollinator population declines adversely affect plant reproduction for the majority of angiosperm plants (Meffe 1998; National Research Council 2007; Potts et al. 2010). Wildland ecosystems and agroecosystems depend on pollinators for continuance; food supplies for people and wildlife are at stake (Meffe 1998; National Research Council 2007; Potts et al. 2010).

Butterflies are common insect pollinators of angiosperms plants as they move from flower to flower transferring pollen onto receptive stigmatic surfaces (Chittka and Thomson 2001; Mader et al. 2011; Nelson and Andersen 1999; Nelson and Andersen 1994; Nelson and Wydoski 2008; Waser and Ollerton 2006; Willmer 2011). They use nectar from flowers as their main energy source, and large butterflies with high wing load (such as monarchs (*Danaus plexippus*), queens (*Danaus gilippus*), and pipevine swallowtails (*Battus philenor*) (Figure 1a), as well as many other smaller butterflies (Figure 1b), drink nectar at buttonbush (*Cephalanthus occidentalis*). Small butterflies with low wingload, such as metalmarks (Figure 1c), sulphurs and yellows, skipperlings (Figure 1d) and duskywings (Figure 1e) drink nectar at smaller flowers such as California loosestrife (*Lythrum californicum*) (Figure 1d,e) and sweetclover (*Melilotus officinalis*) (Figure 1c).

Butterfly larvae depend on specific plant species as food sources until they metamorphose into the adult stage. Monarch butterfly larvae (*Danaus plexippus*) obligately consume plants in the dogbane family (Apocynaceae), specifically within the milkweed genus (*Asclepias*), for example. The dependence of butterfly species on plant resources for both larval and adult stages, in tandem with the dependence of many plant species' on pollinators for reproduction, is a mutualism which has evolved phylogenetically between plants and butterflies (Ehrlich and Raven 1964; Thomas et al. 2011).

Figure 1: (a) Danaus gilippus, (b, c) Calephelis nemesis, (d) Copaeodes aurantiaca, and (e)Erynnis funeralis nectaring at Cephalanthus occidentalis, Lythrum californicum, and Melilotus officinalis. Photo credit: Elizabeth Makings.



Butterfly abundance and diversity in riparian areas is sometimes used as an indicator of riparian habitat quality (Kremen 1992; Nelson and Andersen 1999; Nelson and Andersen 1994; Nelson and Wydoski 2008). Riparian ecosystems, especially in arid lands, function as critical habitat for pollinators and other wildlife across many taxa (Dingle et al. 2005; Levick et al. 2008). For butterflies, they provide water, shade, migration corridors, nectar, larval food plants, and sites for roosting, overwintering, ovipositioning, pupation, congregation, and mating (Dennis 2012). Monarchs (Danaus plexippus) have been shown to prefer riparian corridors as migratory routes (Dingle et al. 2005; Morris et al. 2015); other migratory species such as cloudless sulphurs (*Phoebis sennae*), gulf fritillaries (*Euptoieta claudia*), painted ladies (*Vanessa cardui*), red admirals (*Vanessa atalanta*), common buckeyes (*Junonia coenia*), mourning cloaks (*Nymphalis antiopa*), and queens (*Danaus gilippus*) also commonly seek riparian areas.

Agricultural areas near riparian ecosystems benefit from the pollinator populations these ecosystems foster (Kremen et al. 2004; Nabhan 2001).

Research Questions

1) How do butterfly and plant composition, species richness and abundance vary between adjacent permanent and temporary reaches of Sonoran desert streams?
2) How does stream flow permanence affect plant and butterfly species richness and abundance?
3) Is there a positive relationship between butterfly species richness and plant species richness? Butterfly abundance and plant abundance? If so, how do stream flow permanence, air temperature and shade affect these relationships?

My first research question treats stream flow permanence as a categorical variable; it's either permanent or temporary. This allows for a comparison of plant and butterfly composition between the reach types that would not otherwise be possible. In the second research question, stream flow permanence is a continuous variable; it's a measurement of how much of the length of each study reach was covered in surface water. Thus, the first two research questions require different forms of analysis. Regarding species richness and abundance, the results of analysis for one question will lend objectivity to the results of the other.

For plants, I analyzed all plants, plants in flower (nectar plants), and larval food plants (host plants). Similary, butterflies were analyzed as a whole and also as a subset which were observed in the same reach as their larval host plants (hosted butterflies).

In question 1 I compare the number and identity of migratory butterfly and hosted butterfly species between permanent and temporary transects. Plant composition is compared between reach types in terms of number and identity of plant species in the five categories of Wetland Indicator Status (www.plants.usda.gov).

Hypotheses and predictions

To minimize redundancy, predictions for the first and second research question have been elided (Table 1).

Table 1: Hypotheses and predictions for research questions.

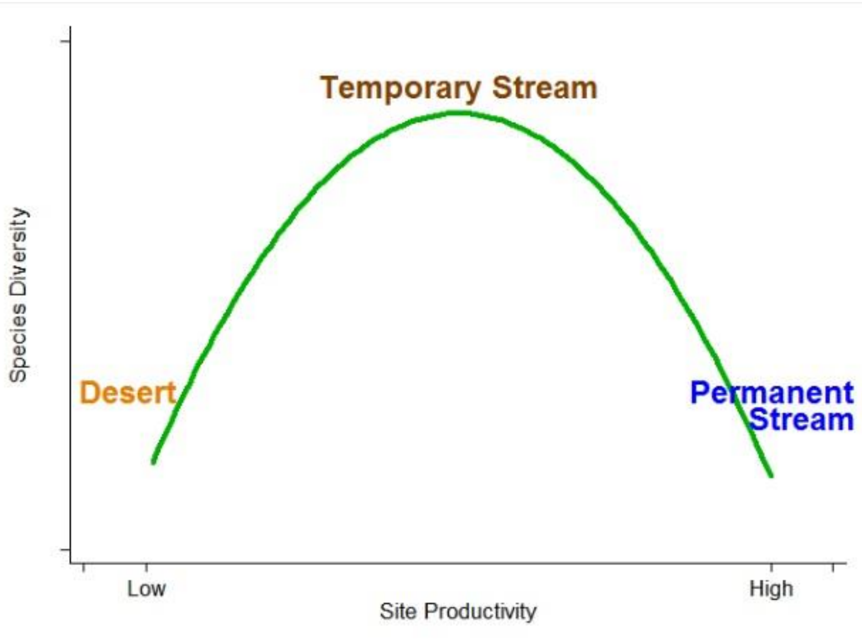
	Hypothesis	Prediction
Research Questions 1 and 2: Comparison between permanent and temporary reaches: overall effects of stream flow permanence		
Abundance		
Plants, including host plants	Productivity in riparian ecosystems, especially in arid regions, increases with surface water availability (Free et al. 2013; Fu and Burgher 2015; Zelnik and Čarni 2008)	Plant cover will increase with stream flow permanence.
Nectar plants	Narrowed blooming time based on sporadic water availability, lower percent shade, and higher temperature on temporary streams favors mass blooming in fall and spring (Willmer 2011).	Nectar plant cover will decrease with stream flow permanence in fall and spring but increase with stream flow permanence in summer.
Butterflies	Butterfly abundance increases with plant cover (Blair and Launer 1997) and is also strongly correlated with floral abundance (Holl 1995; Scriven et al. 2013).	Butterfly abundance will decrease with stream flow permanence in fall and spring but increase with stream flow permanence in summer.
Hosted Butterflies	Moisture regimes drive hosted butterfly abundance patterns via host plant resource availability (Thomas et al. 2011).	Hosted butterfly abundance will increase with stream flow permanence.
Species Richness		
Plants, including nectar and host plants	Intermediate productivity hypothesis (IPH): plant diversity is negatively correlated with increasing productivity in arid lands where water controls productivity (Figure 2) (Huston 2014)	Plant species richness will decrease with stream flow permanence.
Butterflies	Butterfly diversity increases with increasing plant diversity (Blair and Launer 1997; Nelson and Andersen 1994; Waltz and Wallace Covington 2004). Butterfly species richness correlates strongly with flowering plant diversity (Holl 1995; Scriven et al. 2013). Butterflies of all sizes and proboscis lengths feed at massed flowers, and larger, longer-tongued butterflies do so preferentially (Tiple et al. 2009).	Butterfly species richness will decrease with stream flow permanence.
Hosted Butterflies	Hosted butterfly diversity increases with host plant diversity (Dennis 2012; Thomas et al. 2011)	Hosted butterfly species richness will decrease with stream flow permanence.

	Hypothesis	**Prediction**
Composition		
Plants	Plant community composition varies along moisture gradients such that wetland plants are more likely to be found in saturated/perennial areas (Free et al. 2013; Fu and Burgher 2015; Levick et al. 2008; Stromberg et al. 2007; Zimmerman et al. 1999).	More obligate and facultative wetland species will be found on the permanent transects while more facultative upland and upland species will found on the temporary transects, and number of facultative species will be equal between transects. Species composition will overlap between the transects.
Butterflies	Butterfly community composition varies along resource use gradients. Migratory (non-resident) butterfly species and hosted (resident) butterfly species use riparian resources differently and are differently affected by stream flow permanence. Migrating butterflies may primarily use riparian corridors as flyways and resource banks for migration, while hosted butterflies may use them primarily as ovipositioning sites and resource banks for their larvae (Dennis 2012; Morris et al. 2015).	Migratory butterfly species composition will be the same between transects, and will overlap with hosted butterfly species composition. More hosted butterfly species (from species richness prediction) will be found on the temporary transects than the permanent transects; hosted butterfly species composition between transects will overlap.
Research Question 3: Relationships between plant species richness and butterfly species richness; relationships between plant abundance and butterfly abundance: effects of air temperature, shade and surface flow permanence on these relationships.		

Relationship		
Species Richness	a) Positive relationships exist between plant diversity (including host plant and nectar plant diversity) and butterfly diversity (including hosted butterfly diversity) (Dennis 2012; Holl 1995; Scriven et al. 2013; Thomas et al. 2011; Tiple et al. 2009; Willmer 2011)	Butterfly and hosted butterfly species richness will increase with plant, nectar plant, and host plant species richness.
Abundance	a) Positive relationships exist between plant abundance (including nectar plant and host plant abundance) and butterfly abundance (including hosted butterfly abundance (Dennis 2012; Holl 1995; Scriven et al. 2013; Thomas et al. 2011; Tiple et al. 2009; Willmer 2011).	Butterfly and hosted butterfly abundance will increase with plant, nectar plant and host plant abundance.
Effects		
Stream flow permanence, air temperature and percent shade	Butterflies are highly dependent on heat, light, and moisture, and their resource use is affected by changes in these variables (Dennis 2012; Thomas et al. 2011).	Higher temperatures, lower shade, and greater stream flow permanence will result in higher butterfly species richness values (within the increasing relationship between butterfly species richness and plant species richness) and higher butterfly abundance values (within the increasing relationship between butterfly abundance and plant abundance).

The Intermediate Productivity Hypothesis (IPH), first developed by Grime in 1973, is my working hypothesis regarding the relationship between plant species richness and stream flow permanence (Table 1, Figure 2) (Huston 2014). Primary productivity in arid environments like the Sonoran Desert is lowest in upland or desert, intermediate along temporary streams, and highest along permanent streams, but as productivity increases in permanent streams, plant species diversity declines (Levick et al. 2008; Stromberg et al. 2009).

Figure 2: Intermediate Productivity Hypothesis

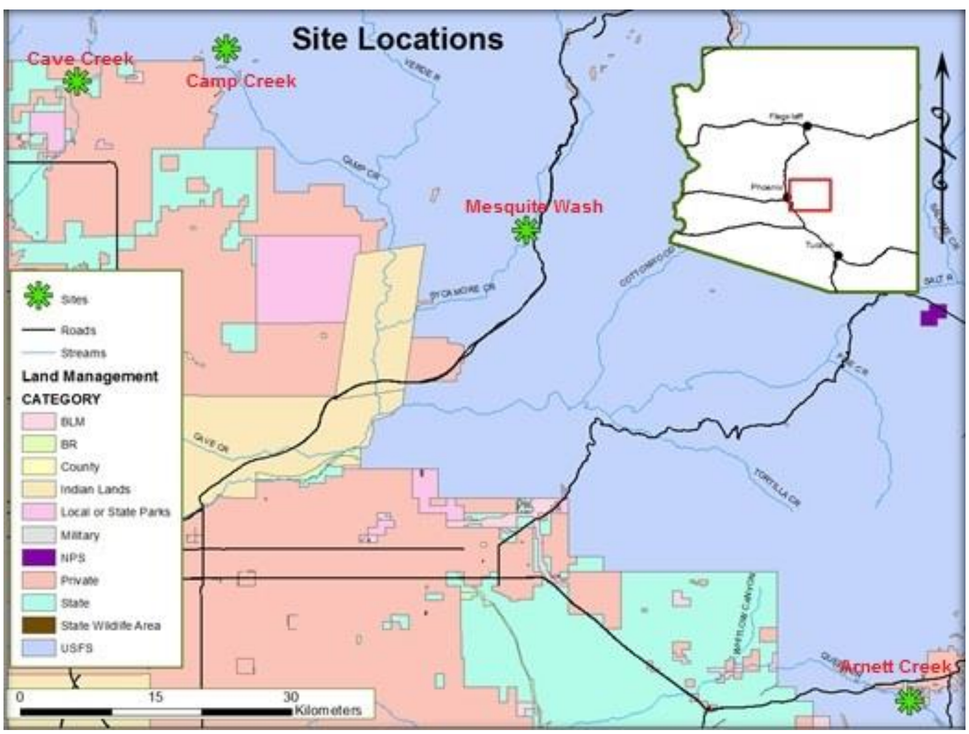


METHODOLOGY

Study design and site selection

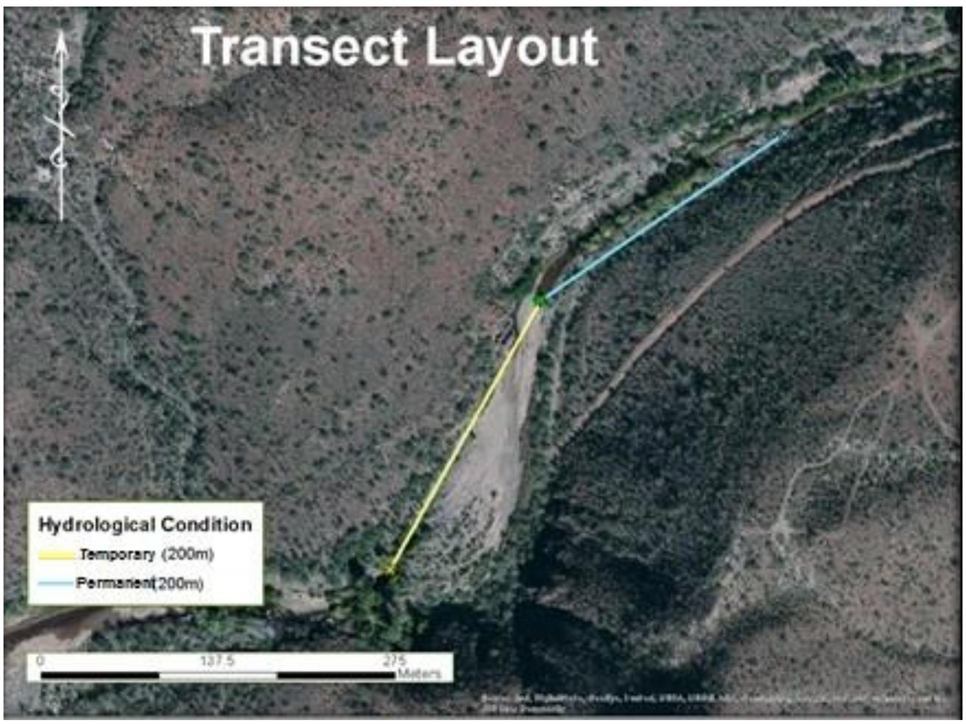
I investigated four Sonoran desert streams with permanently flowing segments adjacent to temporarily flowing segments. The temporary reaches had flow only after storms and in winter and early spring. Three sites (Arnett Creek, Camp Creek, and Mesquite Wash) are located within Tonto National Forest, and the fourth site (Cave Creek) is located within the Spur Cross Ranch Conservation Area within the town of Cave Creek, Arizona (Figure 3). All study areas are within 50 miles (change to km) of the Greater Phoenix Area and are located within the Arizona Upland subdivision of the Sonoran Desert (Brown 1982; Shreve and Wiggins 1951).

Figure 3: Locations of study sites along Sonoran desert streams.



At each site, a permanently flowing stream segment was located immediately contiguous (upstream or downstream) to a temporarily flowing segment (Figure 4). Two 200m transects were sampled, one along each segment, for butterflies and plants. Transects of this length were considered appropriate both for plant sampling and butterfly counts (Blumstein and Fernández-Juricic 2010; Pollard 1977). Each transect represents one sampling unit.

Figure 4: Example of study design at Cave Creek.



Sampling period

My study period spanned two years. Each site was sampled once a month for a period of 2-3 days from mid-August to early November of 2013, and again from late February to early June of 2014 for a total of six sampling months (with 8 field days per sampling month and a total of 48 field days. The sampling period for this study was selected to capture the months with both greatest plant productivity and flowering and greatest butterfly activity (post-monsoon, fall, spring, and early summer seasons).

Plant sampling

Plant cover by species was sampled in 20, 1 x 1 m2 plots randomly placed along each of the two transects (total of 40 plots per site). Cover was defined as a measure of the area covered by the above-ground parts of plants of a given species when viewed directly from above (or as they would appear if viewed directly from above, in the case of plants taller than the observer) (Sutherland and Krebs 1997). Cover included only plants up to 10m in height to account for sampling space consistency. Plant vouchers were identified to species when possible and deposited in the Arizona State Herbarium. The cover data were used to estimate the composition, abundance, and species richness of plants. Plant species' wetland indicator status was determined using USDA Plants database (www.plants.usda.gov).

Plots were randomized both longitudinally and perpendicular to the channel within the parafluvial zone. This zone was defined as a line perpendicular to the channel where plant growth began (i.e., midstream, or 10cm from the water's edge, etc.) and moved outward in a randomized direction (either left or right to an observer facing upstream) to the near edge of the riparian gallery tree trunks, upland (if the stream lacked a riparian forest at that point), or other barrier (such as boulders or rock wall) (Levick et al. 2008).

Many plant species at the study sites (e.g., *Lythrum californicum*, an important nectar plant) exhibit distinct clonal growth and patchy distribution, and therefore each individual plant in the study area did not have an equal and independent chance of being sampled (Sutherland and Krebs 1997; Whitlock and Schluter 2009). Thus, plots were randomized within each 10 meter segment of each transect (one plot per 10m) rather than within the 200m transect as a whole.

Species in the plots which had fresh, open flowers and were not anemophilous (wind-pollinated) or otherwise abiotically pollinated were considered nectar plants. Although not all flowering plants produce nectar, I chose this definition of nectar plants due to time and budget constraints; I considered measuring nectar within individual flowers and/or conducting a literature search for nectar quantity for all flowering plant species but ultimately found these actions to be beyond the scope of the study (Kearns and Inouye 1993). Host plants species and genera for all butterfly species identified in the study were determined using a field guide to butterflies in Arizona (Stewart et al. 2001). Plants seen within the study were designated as host plants if they were a host plant for any butterfly identified to species at any site at any time, and if they were identified to genus. If these same plant species and genera were seen within the study, they were designated as host plants.

Butterfly Sampling

Butterflies were sampled using the modified “Pollard Walk” model (Pollard 1977; Sutherland and Krebs 1997). Butterflies were recorded within a 10 meter cube with the transect in the center of the bottom horizontal plane, while walking at a slow and steady pace. Species were observed using close-focus binoculars and identified with the aid of butterfly guides and lists (Bailowitz 1991; Central Arizona Butterfly Association 2006;

Glassberg 2001; Stewart et al. 2001). Many photo-vouchers were taken both on-transect during counts and in the general area during non-count periods. No physical butterfly samples were taken.

Transect counts were timed to approximately half an hour and taken at 9:00am, 10:30am, and 12:00pm on one sampling day per sampling month at each site. Each count began at one end of the two contiguous 200m transects and ended at the bottom of the other. Sampling was restricted to non-rainy weather without heavy wind. If light to moderate wind occurred, conditions were recorded and the count proceeded. Counts were used to estimate butterfly composition, species richness and abundance. Hosted butterfly species richness and abundance were determined by matching butterfly species to identified host plants.

Sampling space consistency

Riparian zone widths were measured once per site at eight points along each transect (and also at the midpoint). These values were averaged in order to account for sampling space consistency between butterfly sampling and plant sampling: the sampling space for butterflies consisted of the width of the observer's ten-meter cube, multiplied by the length of the transect, and the plant sampling space consisted of the average riparian zone width times the length of the transect.

Flow permanence, temperature and shade measurements

Stream surface flow permanence and air temperature were measured once per month at each site. Flow permanence was measured by recording length of surface water, wetted ground, and dry ground along the transect lines. Temperature was measured using a Sper portable digital indoor/outdoor thermometer at the same four points at 50m intervals along each transect. Measurements were taken between the 10:30am and 12:00pm butterfly counts, with the thermometer positioned 0.61m (2 ft.) off the ground in shade.

Shade was measured once per season at each site (sampling months October-November 2013 and April and May 2014). Sampling months August-September 2013 and May 2014 constituted the summer season for this study, while September-October and October-November 2013 constituted fall, and March and April 2014 constituted spring. Shade was measured as percent tree canopy cover using a spherical densiometer at eight points at 25m intervals along each transect, with one measurement also taken at the midpoint.

Statistical analysis

Difference in means between the permanent and temporary transects were analyzed using paired-sample t-tests, and comparisons between seasons within transects were analyzed using analysis of variance (ANOVA) (Research Question 1). Linear regression models were used to evaluate relationships between continuous variables (Research Questions 2 and 3). The statistical analysis was performed using the software package Stata (StataCorp LP 2013). Significance was determined at the 5% level.

For means calculations and linear regression involving shade, the shade value from the observed month in each season was used for the unobserved month as well. For means calculations and linear regression involving temperature, Weather Underground data (www.wunderground.com) from the nearest stations to Arnett Creek (Superior Highlands) and Camp Creek (Cave Creek Airport) for all sampling dates at those sites were regressed with data taken during the study to approximate missing values.

RESULTS

Research Question 1: Comparison between permanent and temporary transects

Species richness and abundance

Inferential Summary

Nectar plant and butterfly species richness were greater on the temporary transects than the permanent transects in spring, as was butterfly species richness for the overall study period (Table 2, 3). Hosted butterfly species richness was also greater on the temporary transects in all seasons and overall. Plant abundance was greater on the permanent transects in fall and overall, and butterfly abundance was greater on the permanent transects in spring, while hosted butterfly abundance was greater on the temporary transects in spring and overall.

Table 2: Biotic variables which were significantly different between permanent and temporary transects

	Summer	**Fall**	**Spring**	**Study period**
Nectar plant species richness			Temporary	
Butterfly species richness			Temporary	Temporary
Hosted butterfly species richness	Temporary	Temporary	Temporary	Temporary
Plant cover		Permanent		Permanent
Butterfly abundance			Permanent	
Hosted butterfly abundance			Temporary	Temporary
Percent surface water	Permanent	Permanent	Permanent	Permanent
Percent shade	Permanent	Permanent	Permanent	Permanent

Within the permanent transects, butterfly abundance was greater in summer than fall, while within the temporary transects, plant and host plant species richness were greater in spring than fall (Table 3). Temperature was greater in summer than spring within both the permanent and temporary transects, and percent shade and surface water were greater on the permanent transects than the temporary transects in all seasons and overall, while percent dry ground was greater on the temporary transects in all seasons and overall.

Table 3: Means (and standard errors in parentheses) for all variables at all sites for both permanent and temporary transects, with means comparisons between transects within and across seasons, and within transects between seasons. Summer values are means of August-September and May mean values, fall values are means of September-October and October-November mean values, and spring values are means of March and April mean values.

Variable	**Life Form**	**Transect**	**Summer**	**Fall**	**Spring**	**Overall**
Species Richness						
	Plant	Permanent	20.5 (2.1)	20.1 (1.5)	22.6 (1.6)	21.1 (1.0)
		Temporary	22.1 (2.7)	17.9 (1.5)	26.4 (2.7)	22.1 (1.5)†
	Nectar plant	Permanent	2.4 (0.5)	1.8 (0.6)	1.3 (0.6)	1.8 (0.3)
		Temporary	2.1 (1.2)	2.3 (0.8)	3.9 (0.9)°°	2.8 (0.5)
	Host plant	Permanent	7.9 (1.0)	7.8 (0.8)	8.4 (0.7)	8 (0.5)
		Temporary	8.9 (0.5)	7.5 (0.5)	10.4 (1.3)	8.9 (0.5)†
	Butterfly	Permanent	10.4 (1.7)	11.8 (1.5)	7.8 (1.3)	10 (0.9)
		Temporary	12 (1.5)	15 (2.6)	13.8 (1.7)°°	13.6 (1.1)**
	Hosted	Permanent	3.0 (0.8)	3.3 (0.8)	3 (0.8)	3.1 (0.4)
	Butterfly	Temporary	4.9 (0.9)°°	6.6 (0.8)°°	6.4 (0.9)°°	6.0 (0.5)**
Abundance						
	Plant	Permanent	47.5 (6.3)	44.4 (5.2)	39.4 (8.9)	43.8 (3.9)
		Temporary	36.4 (5.1)	33.5 (4.2)°°	26.9 (5.9)	32.3 (2.9)**
	Nectar plant	Permanent	5.3 (2.0)	1.4 (0.7)	9.5 (5.8)	5.4 (2.1)
		Temporary	1.8 (0.9)	1.6 (0.9)	3.6 (1.4)	2.3 (0.7)
	Host plant	Permanent	5.5 (2.6)	6.3 (2.4)	6.3 (1.7)	6 (1.3)
		Temporary	4.8 (1.2)	11.3 (4.1)	8 (1.5)	8.1 (1.6)
	Butterfly	Permanent	50.8 (18.3)	14.5 (2.7)	8.8 (2.9)	24.7 (7.1)‡
		Temporary	44.6 (18.1)	18.0 (4.5)	20.5 (5.0)°	27.7 (6.6)
	Hosted	Permanent	11.5 (5.3)	3.8 (1.4)	4.2 (1.6)	6.5 (2)
	Butterfly	Temporary	13.5 (4.9)	6.7 (1.9)	10.4 (2.9)°	10.2 (2)°
Temperature (C)		Permanent	32.1 (1.3)	25.8 (2)	21.4 (1.5)	26.5 (1.3)‡
		Temporary	34.1 (1.4)	26.2 (2)	22.7 (2)	27.9 (1.4)‡
Shade (%)		Permanent	87.2 (5)	73.6 (6)	78.2 (4.9)	79.7 (3.2)
		Temporary	46 (10.7)°°	36.2 (12.4)°°	36 (13.3)°°	39.4 (6.8)**
Surface Water (%)		Permanent	78.1 (10.8)	78.8 (9.8)	97.5 (2.5)	84.2 (5.2)
		Temporary	39.8 (17.7)°	20.8 (13.2)°°	61.9 (14.3)°°	39.9 (9.1)**
Wetted Ground (%)		Permanent	12.1 (6.8)	8.2 (2.6)	0.4 (0.4)	7.2 (2.6)
		Temporary	8.9 (6.2)	22.2 (12.5)	11.4 (6.6)	14.3 (5.2)
Dry Ground (%)		Permanent	9.8 (6.7)	13.1 (8.5)	2.1 (2.1)	8.6 (3.8)
		Temporary	51.3 (16.1)°°	57.1 (17.4)°°	26.7 (12.1)°	45.8**

*significant difference for entire study period between transects at 10% level.
**significant difference for entire study period between transects at the 5% level
°significant difference between transects within seasons at 10% level.
°°significant difference between transects within seasons at 5% level
†significant difference within transects (either P or E) between seasons at 10% level ‡significant difference within transects (either P or E) between seasons at 5% level.

In terms of analysis within sites, at Camp Creek, host plant, butterfly, and hosted butterfly species richness were greater on the temporary transect than the permanent transect while plant, host plant, butterfly, and hosted butterfly abundance were greater on the permanent transects (Table 4). At Cave Creek, plant abundance was similarly greater on the permanent transect, and at Mesquite Wash, butterfly and hosted butterfly species richness were similarly greater on the temporary transects while at Arnett Creek, although host plant species richness was greater on the temporary transects, hosted butterfly species richness was greater on the permanent transect.

Between sites, values for plant and host plant species richness, plant, nectar plant, and host plant abundance, and percent shade, surface water, wetted ground and dry ground on the permanent transects differed significantly between two or more sites (Table 4, Figure 5, Appendix B). On the temporary transects, values for butterfly species richness, plant abundance and host plant abundance, and percent shade, surface water, and dry ground also differed between one or more sites.

Figure 5: Percent surface water by site, transect and month. Abbreviations: MW=Mesquite Wash; AC=Arnett Creek; CvC=Cave Creek; CC=Camp Creek. P=Permanent transect; T=Temporary Transect

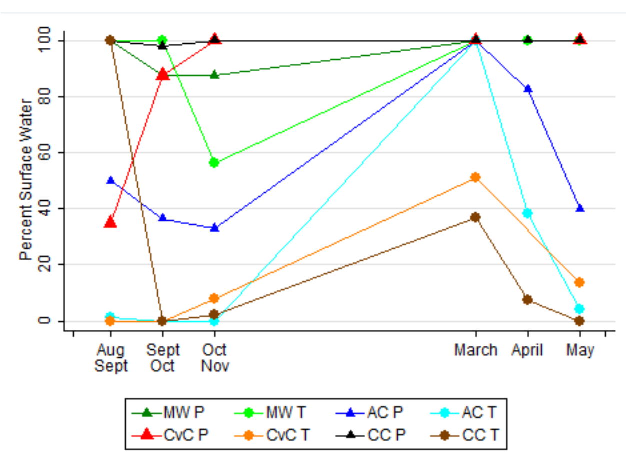


Table 4: Means (and standard errors in parentheses) for all variables at all sites for both permanent and temporary transects, with means comparisons between transects within and between sites.

Variable	Life Form	Transect	Mesquite Wash	Arnett Creek	Cave Creek	Camp Creek
Species Richness						
	Plant	Permanent	25.5 (1.4)	21.3 (2.7)	18.5 (1.4)	19.0 (1.0)‡
		Temporary	24.7 (3.1)	22.5 (4.1)	19.7 (3.0)	21.7 (1.9)
	Nectar plant	Permanent	2.3 (0.7)	0.8 (0.7)	1.7 (0.7)	2.3 (0.6)
		Temporary	3.8 (1.3)	2.5 (1.3)	2.2 (0.7)	2.5 (1.1)
	Host plant	Permanent	9.2 (0.7)	8 (1.1)	9 (1)	5.8 (0.2)‡
		Temporary	7.5 (1.0)	10.2 (1.1)°°	9.5 (0.9)	8.5 (1.1)°
	Butterfly	Permanent	9.7 (1.4)	10 (1.6)	12.8 (2.1)	7.3 (1.7)
		Temporary	14.5 (1)°°	9.2 (1.5)	12.2 (2.1)	18.5 (2.4)°°‡
	Hosted	Permanent	2.8 (0.7)	4.5 (1.2)	3.3 (0.8)	1.7 (0.5)
	Butterfly	Temporary	5.5 (0.8)°	3.5 (1.0)°°	2.3 (0.9)	3.7 (0.7)°°
Abundance						
	Plant	Permanent	51.4 (9.4)	23.8 (3.4)	46.7 (6.4)	53.2 (5.3)‡
		Temporary	49.1 (7.3)	28.9 (4.0)	22.5 (2.1)°°	28.4 (1.7)°°‡
	Nectar plant	Permanent	5.3 (2.0)	0.1 (0.1)	2.5 (0.9)	13.8 (7.3)†
		Temporary	2.5 (1.2)	0.2 (0.1)	4.1 (1.8)	2.4 (1.7)
	Host plant	Permanent	11.3 (1.6)	1.4 (0.6)	10 (2.7)	1.5 (1.3)‡
		Temporary	14.7 (4.7)	2.2 (0.7)	5.1 (1.6)	10.2 (0.7)°°‡
	Butterfly	Permanent	26.7 (13.3)	24.2 (11.9)	19.6 (6.1)	28.3 (23.9)
		Temporary	23.7 (5.8)	15.2 (7.6)	18.8 (6.4)	53.0 (22.3)°°
	Hosted	Permanent	9.3 (4.8)	11.4 (5.8)	3.7 (1.3)	1.7 (0.7)
	Butterfly	Temporary	6.3 (2.2)	9.6 (5.1)	9.9 (4.9)	15 (3.2)°°
Temperature (C)		Permanent	27.2 (2.3)	27.2 (3.1)	28.5 (2.7)	23.6 (2.7)
		Temporary	27.8 (2.4)	28.0 (3.4)	30.6 (3.0)	25.1 (3.0)
Shade (%)		Permanent	63.4 (1.6)	95.2 (1.1)	70 (5.2)	90.1 (3.6)‡
		Temporary	18.4 (3.4)°°	93.6 (0.5)	14 (3.4)°°	31.7 (2.1)°°‡
Surface Water (%)		Permanent	95.8 (2.6)	57.0 (11.3)	84.5 (12.6)	99.7 (0.3)‡
		Temporary	92.7 (7.3)	23.9 (16.4)	14.5 (9.5)°°	24.4 (16.2)°°‡
Wetted Ground (%)		Permanent	4.2 (2.6)	18.7 (7.9)	5.5 (3.4)	0 (0)‡
		Temporary	7.3 (7.3)	16.5 (9.6)	9.8 (6.7)	22.6 (15.7)
Dry Ground (%)		Permanent	0 (0)	24.4 (9.8)	10.0 (10.0)	0.3 (0.3)†
		Temporary	0 (0)	59.6 (17.8)	75.7 (10.5)°°	53.0 (19.3)°°‡

°significant difference between transects within seasons at 10% level.
°°significant difference between transects within seasons at 5% level
†significant difference within transects (either P or E) between seasons at 10% level
‡significant difference within transects (either P or E) between seasons at 5% level.

Descriptive Summary

Across sites, there were several consistent seasonal patterns in the descriptive data: first, at every site, plant species richness was greater (even if only slightly so in some cases) on the temporary transect than the permanent transect in at least one month of summer, nectar plant species richness was greater on the temporary transect in at least one month of spring, and butterfly species richness was greater on the temporary transect for the entire spring season (two months) (Figure 6). Second, host plant species richness was greater on the temporary transect in at least one month of summer (and always in August) at all four sites, and hosted butterfly species richness was also greater on the temporary transect in at least one month of fall, summer, and spring (Figure 7). Finally, plant abundance was greater on the permanent transect in both summer months and at least one month of fall at all four sites, as well as in at least one month of spring at three of the four sites. Nectar plant abundance was also greater on the permanent transect in at least one month of summer at three sites (Figure 8). No consistent seasonal patterns were found relating to host plant and hosted butterfly abundance (Figure 9).

Figure 6: Plant, nectar plant and butterfly species richness at all sites

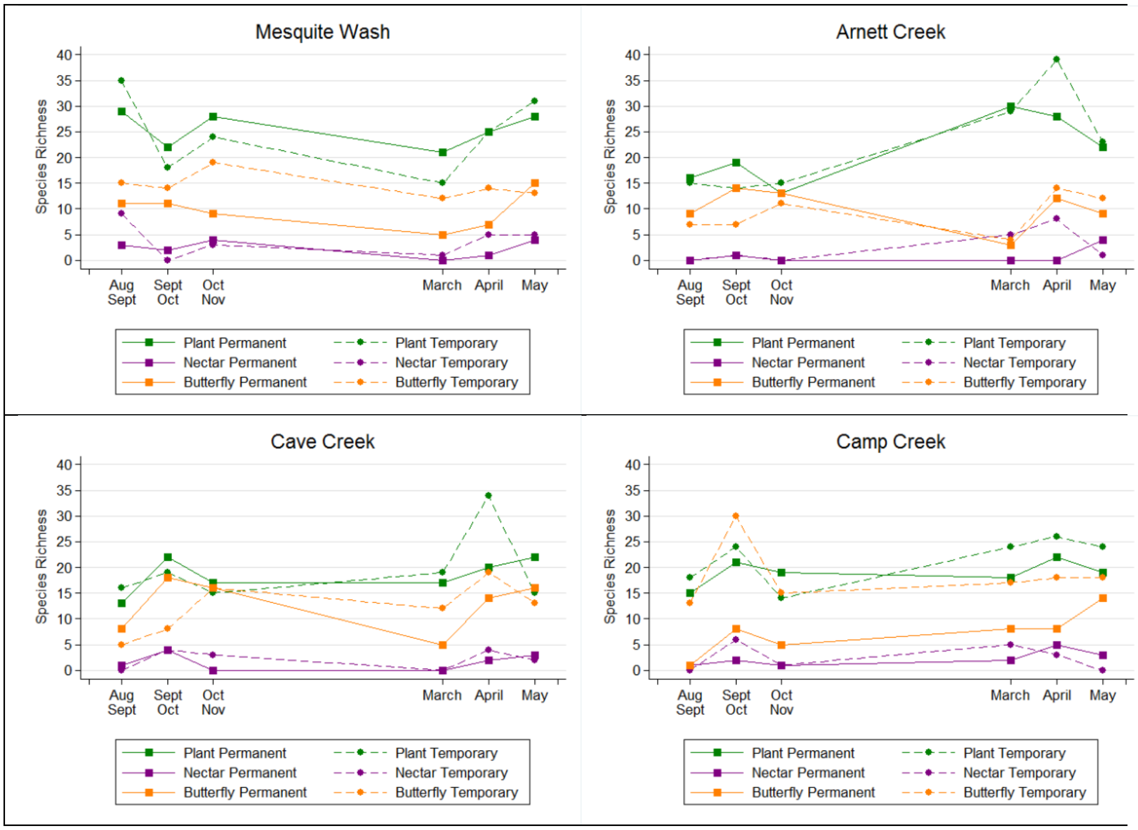


Figure 7: Host plant and hosted butterfly species richness at all sites

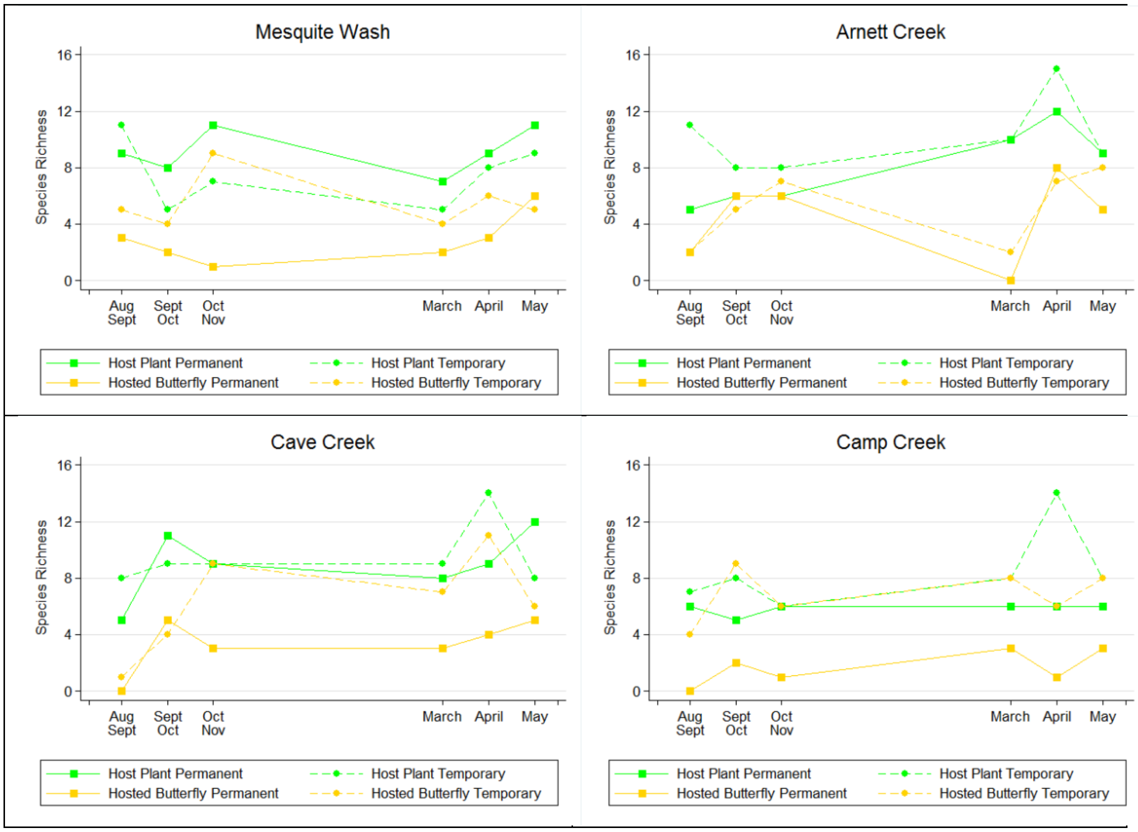


Figure 8: Plant, nectar plant, and butterfly abundance at all sites

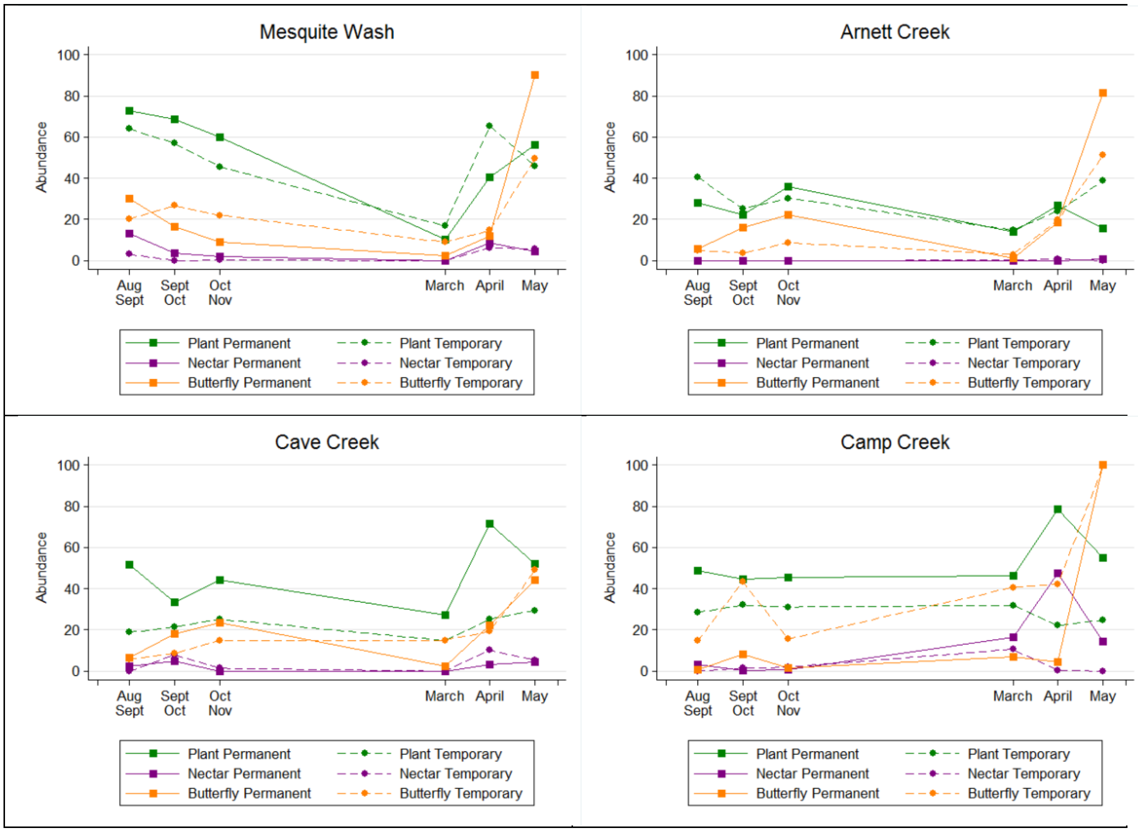
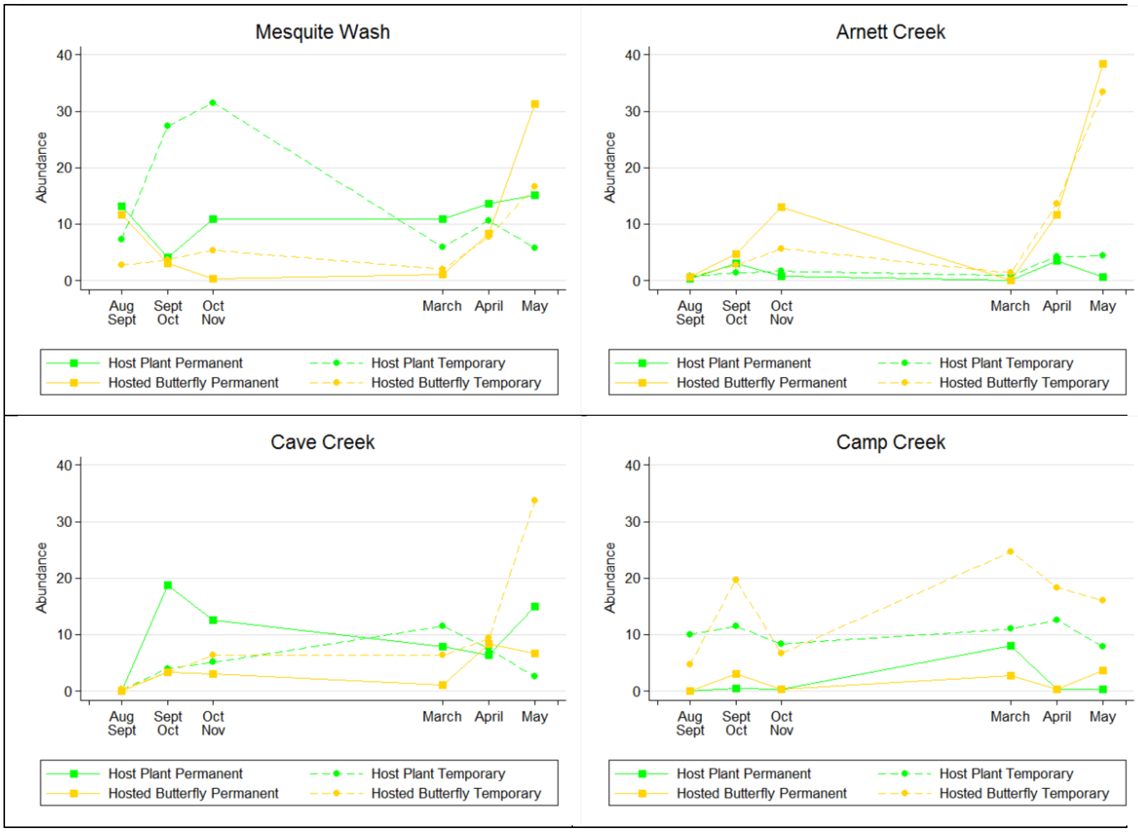


Figure 9: Host plant and hosted butterfly abundance at all sites



Composition

Plants

Total and mean number of obligate wetland plant species were greater on permanent transects, while total and mean number of facultative, facultative upland, and upland plants were greater on the temporary transects. Facultative wetland plants had equal totals and means between transect types (Table 5).

Numbers of obligate wetland and facultative wetland plant species were higher on the permanent transects of Arnett Creek and Cave Creek than on the temporary transects but lower on the permanent transect at Mesquite Wash for both categories, as well as lower on this transect at Camp Creek for facultative wetland plants and nearly equal (within one species) between transects for obligate wetland plants (Table 5, Appendix D). Facultative plant species numbers were also nearly equal between transects at Mesquite Wash and Cave Creek but were higher on the temporary transects of Arnett Creek and Camp Creek. Number of facultative upland plant species was higher on the temporary transects of Mesquite Wash, Cave Creek and Camp Creek but nearly equal between transects at Arnett Creek. In all cases, number of upland plant species was greater on the temporary transects.

Table 5: Plant species by United States Department of Agriculture (USDA) Wetland Indicator Status (from USDA Plants Database) at all sites on all transects.

USDA Wetland Indicator Status	Total Plant Species	Mesquite Wash		Arnett Creek		Cave Creek		Camp Creek		Mean (Standard Error)	
		P	T	P	T	P	T	P	T	P	T
1: OBL (Obligate Wetland)	14	8	10	6	3	6	3	6	7	6.5(0.5)	5.8(1.7)
2: FACW (Facultative Wetland)	17	9	11	4	2	5	3	5	7	5.8(1.1)	5.8(2.1)
3: FAC (Facultative)	30	10	11	11	18	8	7	8	17	9.3(0.8)	13.3(2.6)
4: FACU (Facultative Upland)	36	10	12	15	14	10	16	8	14	10.8(1.5)	14(0.8)
5: U (Upland)	55	5	10	15	21	3	20	3	13	6.5(2.9)	16(2.7)*

*Significant at the 10% level

Butterflies

There were no significant differences in mean number of migratory or hosted butterfly species between the permanent and temporary transects (Table 6). 72.7% (eight of eleven) of migratory butterfly species were also hosted butterfly species. 18.2% (two of eleven) of the migratory butterfly species, *Agraulis vanillae* and *Atalopedes campestris*, and 23.8% (ten of 42) of the hosted butterfly species (*Agraulis vanillae, Anthocharis sara, Apodemia mormo, Apodemia palmeri, Atalopedes campestris, Atrytonopsis edwardsi, Atrytonopsis lunus, Celotes nessus, Chlosyne lacinia, Pontia protodice*, and *Texola elada*) were observed solely on the temporary transects (Figure 10). 9.1% (one) of the migratory species (*Vanessa atalanta*) and 9.5% (four) of the hosted species (*Asterocampa celtis, Pontia sisymbrii, Satyrium sylvinus,* and *Vanessa atalanta*) were observed solely on the permanent transects. Migratory butterfly species composition overlap and hosted butterfly species composition overlap between the transects were 72.7% and 66.7%, respectively.

Table 6: Migratory and hosted butterfly species. Species with asterisk (*) occur in both categories.

Two categories of composition	Total Butterfly Species	Mesquite Wash		Arnett Creek		Cave Creek		Camp Creek		Mean (Standard Error)	
Migratory butterfly species	11	6	6	7	8	6	4	3	8	5.5 (0.9)	6.5 (1)
Abaeis nicippe		P	T	P	T	P	T		T		
Agraulis vanilla									T		
*Atalopedes campestris**				T							
*Danaus gilippus**		P	T	P	T	P	T	P	T		
*Danaus plexippus**		P			T	P			T		
*Euptoieta claudia**			T	P					T		
*Junonia coenia**		P	T	P	T	P	T		T		
*Nymphalis antiopa**				P	T						
Phoebis sennae		P	T		T	P		P	T		
*Vanessa atalanta**				P							
*Vanessa cardui**		P	T	P	T	P	T	P	T		
Hosted butterfly species	42	19	23	18	16	21	22	10	26	17 (2.4)	21.8 (2.1)
Anthocharis sara			T								
Apodemia mormo							T				
Apodemia palmeri			T								
Asterocampa celtis						P					
Asterocampa leilia		P	T	P	T	P	T				
*Atalopedes campestris**					T						
Atrytonopsis edwardsi									T		
Atrytonopsis lunus									T		
Calephelis nemesis		P	T				T				
Celastrina ladon		P	T	P	T	P	T	P	T		
Celotes nessus							T				
Chlosyne californica			T			P	T				
Chlosyne lacinia			T								
Colias eurytheme			T			P			T		
Colias philodice		P	T	P	T	P	T		T		
Copaeodes aurantiaca		P	T			P			T		
*Danaus gilippus**		P	T	P	T	P	T	P	T		
*Danaus plexippus**		P			T	P			T		
Echinargus Isola		P	T	P	T	P	T	P	T		
Euphilotes battoides		P	T			P	T		T		
Euphydryas chalcedona			T	P			T		T		
*Euptoieta claudia**			T	P					T		

Heliopetes ericetorum			T			P	T	P	T		
Hosted butterfly species	42	19	23	18	16	21	22	10	26	17 (2.4)	21.8 (2.1)
Hemiargus ceraunus				P	T		T		T		
*Junonia coenia**		P	T	P	T	P	T		T		
Leptotes marina		P	T	P	T	P	T	P	T		
Libytheana carinenta		P	T	P	T	P	T		T		
Limenitis archippus		P	T			P	T				
Limenitis arthemis		P	T	P	T	P	T	P	T		
*Nymphalis antiopa**				P	T						
Papilio multicaudata						P			T		
Pieris rapae		P					T	P	T		
Polydryas Arachne									T		
Pontia protodice			T		T						
Pontia sisymbrii		P		P							
Pyrgus communis						P	T	P	T		
Satyrium sylvinus		P									
Staphylus ceos		P		P	T				T		
Strymon melinus				P		P	T	P	T		
Texola elada									T		
*Vanessa atalanta**				P							
*Vanessa cardui**		P	T	P	T	P	T	P	T		

Figure 10: Permanent transect butterflies: (a) Sylvan Hairstreak (Satyrium sylvinus)*, (b) Red Admiral* (Vanessa atalanta)*; Temporary transect butterflies: (c) Sara Orangetip* (Anthocharis sara)*, (d) Gulf Fritillary* (Agraulis vanillae)*, (e) Sachem* (Atalopedes campestris)*, (f) Common*

Streaky Skipper (Celotes nessus). *Photos taken from* (*www.butterfliesofamerica.com*) *and Google Images.*

Research Question 2: Effects of stream flow permanence

Summary

Plant cover and butterfly abundance increased with surface water in summer and fall (Table 7). Plant, host plant, and butterfly species richness decreased with increasing surface water in spring, as did butterfly abundance, while hosted butterfly species richness increased. Plant cover increased with surface water for the study period overall.

Table 7: Biotic variables which increased or decreased significantly with increasing surface water at at least three study sites.

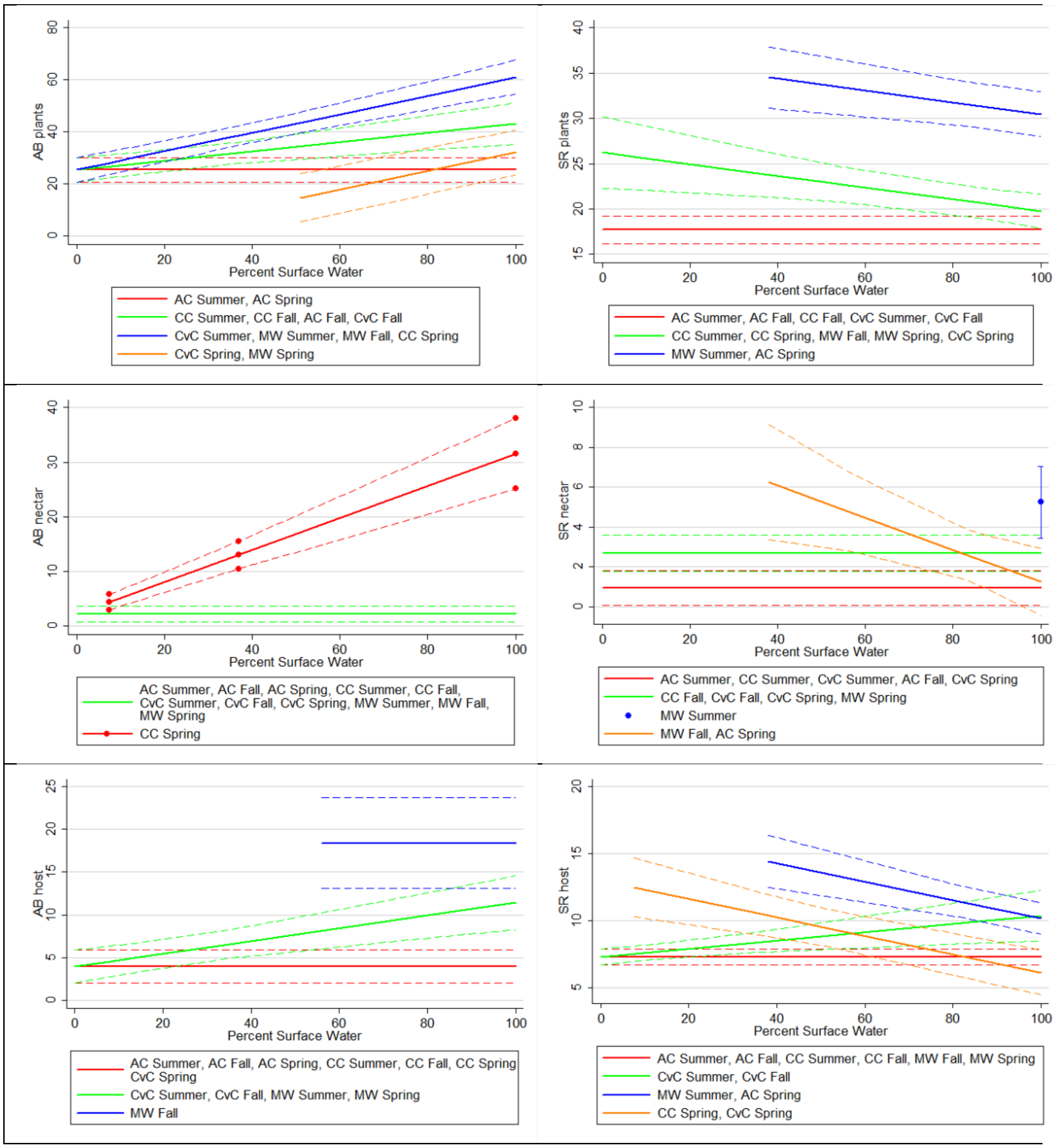
	Summer	Fall	Spring	Study period
Plant cover	Increase	Increase	Increase	Increase
Plant species richness			Decrease	
Host plant species richness			Decrease	
Butterfly abundance	Increase	Increase	Decrease	
Hosted butterfly abundance			Decrease	
Butterfly species richness			Decrease	
Hosted butterfly species richness			Increase	

Plants

Plant cover increased with surface water availability at all sites in all seasons, with the exception of one site in summer and spring (Figure 11). Nectar plant cover showed no effect of surface water increase at all sites in summer and fall; at one site in spring it showed an increase. Host plant cover remained constant with increasing surface water availability except at two sites in summer, one in spring and one in fall; in these cases host plant cover increased with surface water.

Plant species richness decreased with surface water availability at all sites in spring, two sites in summer, and one site in fall, but there was no effect at three sites in fall and two sites in summer (Figure 11). No effects of surface water on nectar plant species richness were observed in any site in any season, except at one site in fall and one in spring. Host plant species richness decreased with surface water at three sites in spring and one in summer. It showed no response to increasing surface water at three sites in fall, two in summer and one in spring; it increased at one site in spring and one in summer.

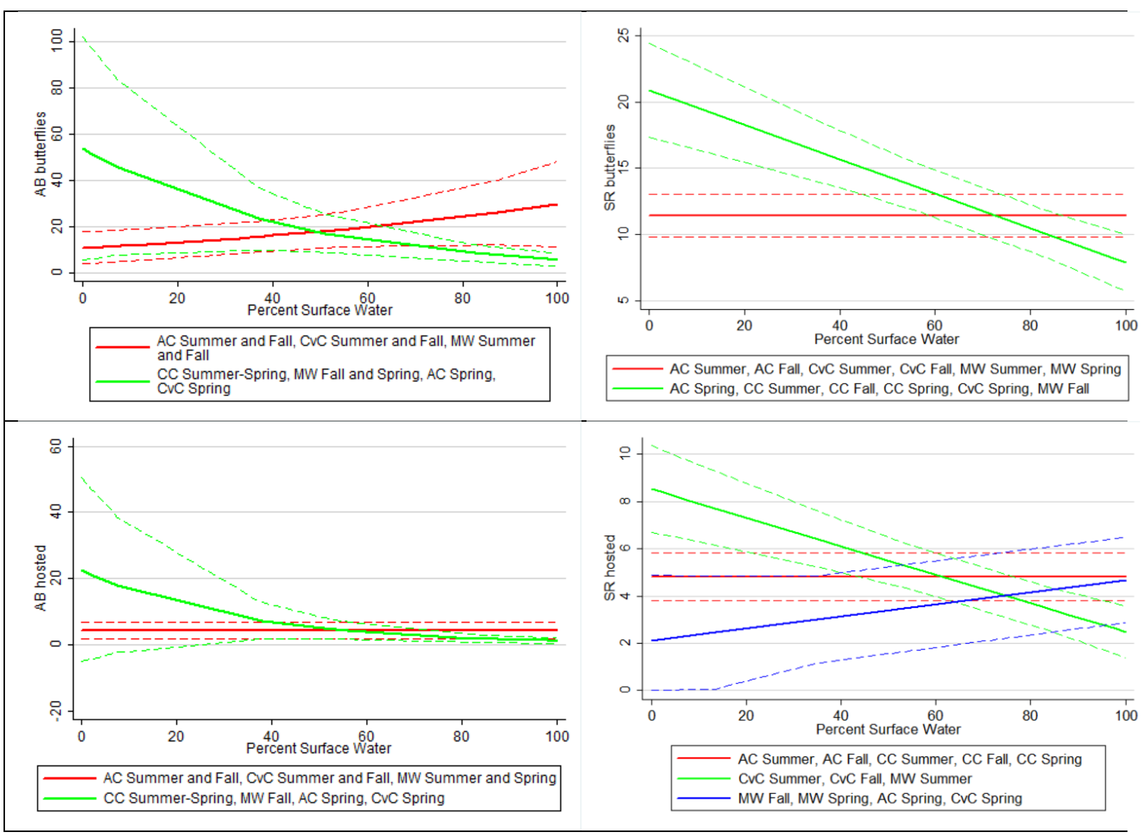
Figure 11: Linear regression of plant abundance, plant species richness, nectar plant abundance, nectar plant species richness, host plant abundance, host plant species richness, and percent surface water at all sites in all seasons. Abbreviations: AB=abundance; SR=species richness; AC=Arnett Creek; CC=Camp Creek; CvC=Cave Creek; MW=Mesquite Wash.



Butterflies

Butterfly abundance decreased with increasing surface water at all sites in spring, two in fall and one in summer; it increased with surface water at three sites in both summer and fall (Figure 12). Hosted butterfly abundance decreased at three sites in spring, two in fall, and one in summer; otherwise it remained constant—butterfly species richness also followed this pattern. Species richness of hosted butterflies increased with surface water at three sites in spring and one in fall, showed no effect of increasing surface water at two sites in summer and fall and one in spring, and decreased with increasing surface water at two sites in summer and one in fall.

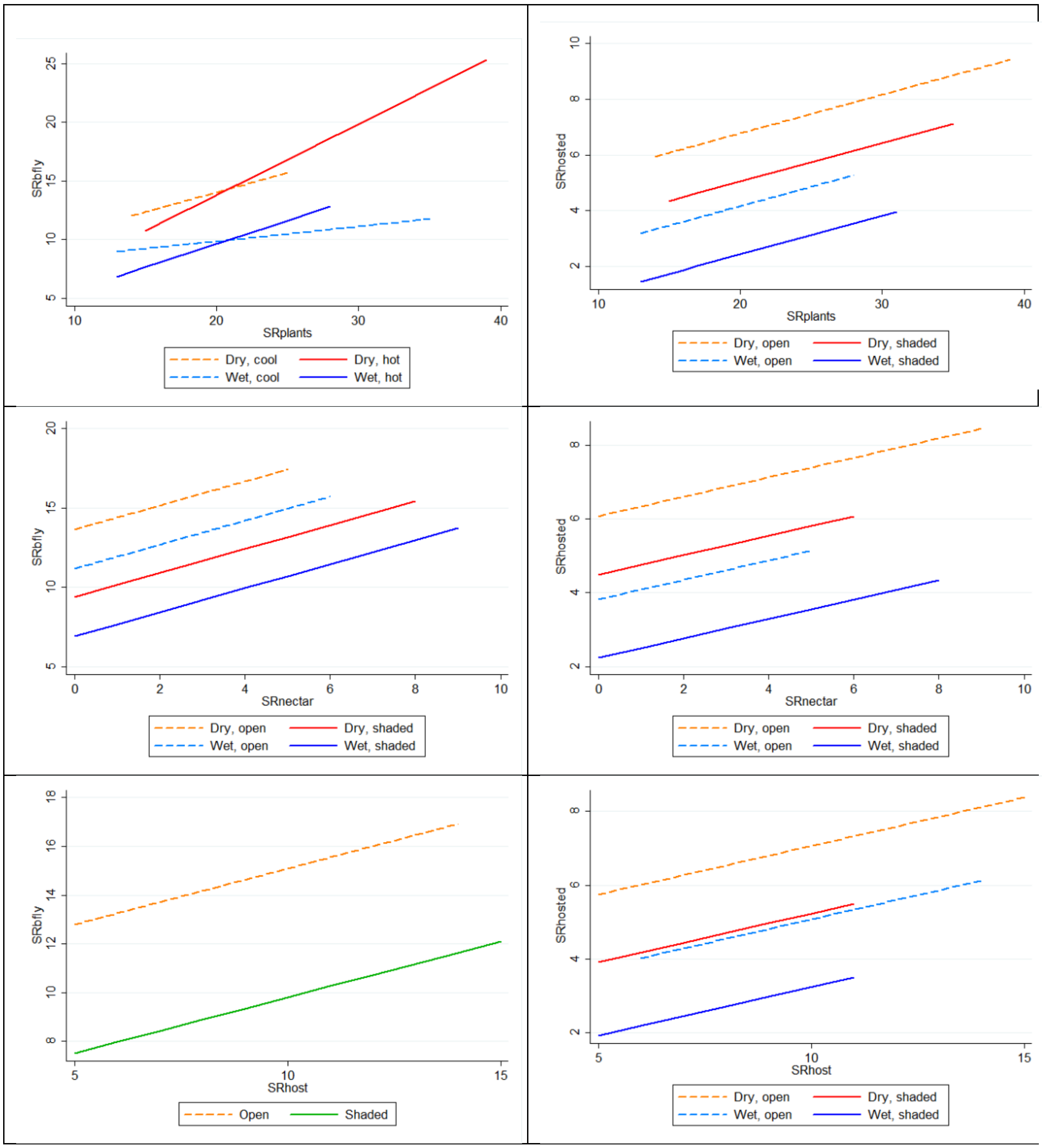
Figure 12: Linear regression of butterfly abundance, butterfly species richness, hosted butterfly abundance, hosted butterfly species richness, and percent surface water at all sites in all seasons.



Research Question 3: Relationships between plant and butterfly species richness and plant and butterfly abundance; effects of air temperature and shade on relationship

Both butterfly and hosted butterfly species richness increase with plant, nectar plant, and host plant species richness (Figure 13). Butterfly species richness increases most sharply with plant species richness at higher temperatures; its highest values occur with low percent surface water. Butterfly species richness increases with nectar plant species richness with highest values occurring with low percent shade, and within shade categories, its highest values occur with low percent surface water. It increases with host plant species richness with highest values again occurring at low percent shade. Hosted butterfly species richness increases with all three plant categories' species richness in a consistent pattern: values are highest at low percent surface water, and within surface water categories, they are highest at low percent shade.

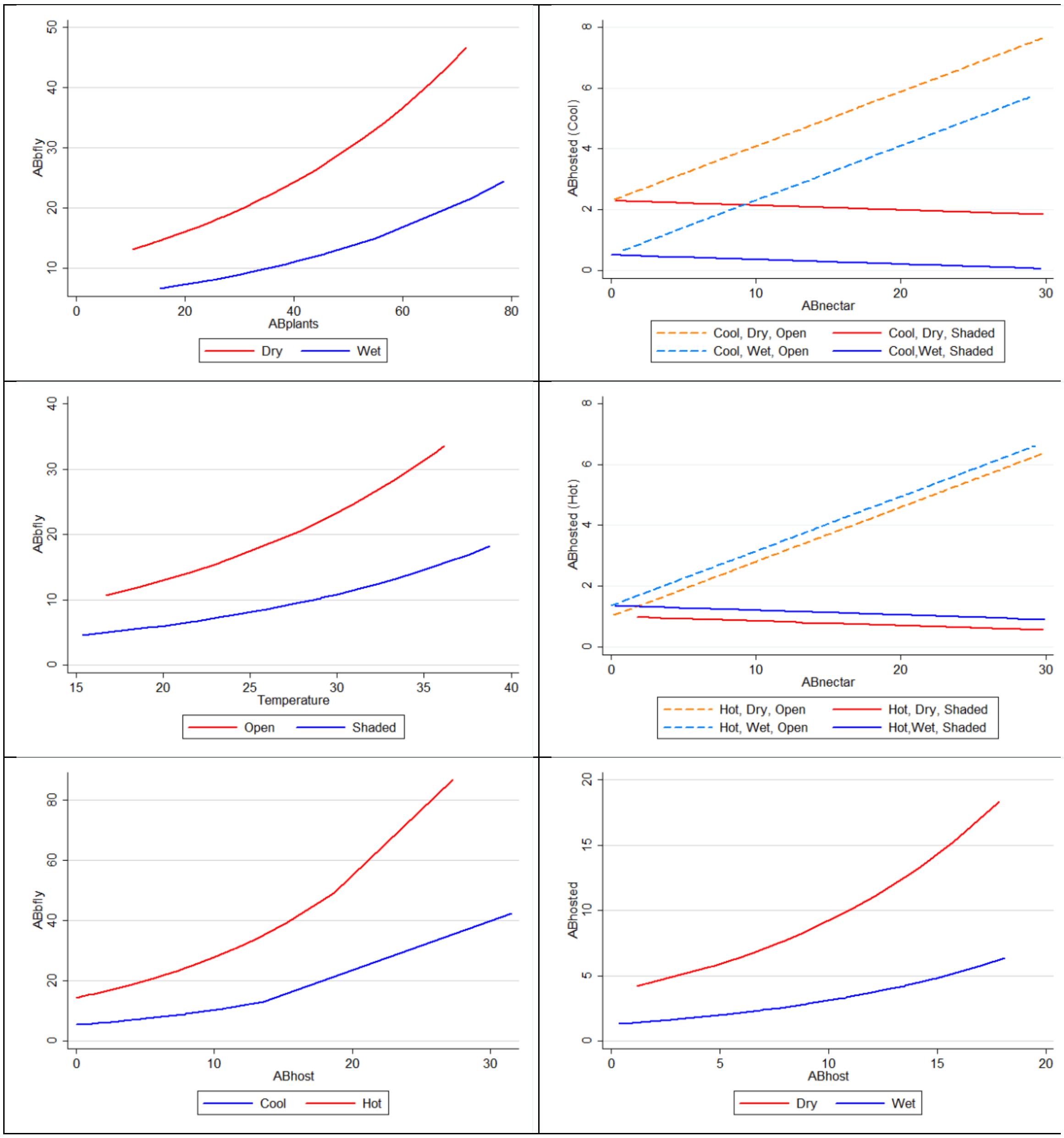
Figure 13: Linear regression of butterfly and hosted butterfly species richness and plant, nectar plant and host plant species richness with temperature, shade, and percent surface water. Temperature is plotted at 20˚C (cool) and 35˚C (Hot); surface water is plotted at 10% (dry) and 90% (wet); shade is plotted at 25% (open) and 95% (shaded).



Butterfly abundance increases with plant abundance with highest values occurring at low percent surface water (Figure 14). It also increases with host plant abundance, with highest values occurring at high temperatures; it is not related to nectar plant abundance but increased with temperature, with highest values occurring at low percent shade.

Hosted butterfly abundance increases with nectar plant abundance at low percent shade but decreases slightly (insignificantly) with nectar plant abundance at high percent shade (Figure 14). This split relationship remains the same regardless of temperature (although y-intercepts do shift); however, at cool temperatures and within each shade category, hosted butterfly abundance values are relatively higher at low percent surface water, while at warm temperatures within each shade category, they are relatively higher at high percent surface water. Hosted butterfly abundance also increases with host plant abundance, with highest values at low percent shade. It is not related to plant abundance, but decreases with surface water in the model (not pictured).

Figure 14: Linear regression of butterfly and hosted butterfly abundance and plant, nectar plant, and host plant abundance with temperature, shade, and percent surface water. Temperature is plotted at 20˚C (cool) and 35˚C (hot); surface water is plotted at 10% (dry) and 90% (wet); shade is plotted at 25% (open) and 95% (shaded).



DISCUSSION

Research Questions 1 and 2: Effects of stream flow permanence on plant, nectar plant, host plant, butterfly, and hosted butterfly species richness and abundance.

Synthesis

The spring season demonstrated significant results for all eight biotic variables, while the summer and fall seasons and the study period overall demonstrated results for three, three, and five variables, respectively (Table 8). This raises the possibility of a seasonal effect of stream flow permanence on plant and butterfly species richness and abundance occurring along Sonoran Desert streams in spring. Alternatively, the effects of disturbance or other ecological processes may be masking the effects of stream flow permanence in seasons other than spring. For example, late summer floods may uproot and sweep away many small or shallowly rooted plants, changing patterns of plant, nectar plant, and host plant species richness (and therefore butterfly species richness) such that no effect of stream flow permanence is detectable in late summer and fall.

In 52.6% (ten of nineteen) of all cases in which results of analysis for Research Questions 1 and 2 were significant, hypotheses were not rejected. Five of these cases were observed in spring. In 21.1% (four of nineteen) of all cases (hosted butterfly species richness for summer, fall, and the study period overall; butterfly species richness for the study period overall) predictions were met, but the underlying hypotheses for these predictions depended on the predictions for plant/nectar plant/host plant species richness (according to the intermediate productivity hypothesis) being met. Because they were not met, the rejection of the hypotheses posited to govern butterfly and hosted butterfly species richness cannot be ruled out—another potential indicator of a masking of the effects of stream flow permanence in seasons other than spring.

In 10.5% (two of nineteen) of all cases (butterfly abundance and hosted butterfly species richness in spring) the hypotheses were not rejected outright, but discrepancies between the two forms of analysis occurred—hypotheses were only rejected by one of the two forms in each case. This may be an artifact of the scale at which plant sampling occurred, indicating that more intensive sampling within the 200m transects would be needed to gain conclusive results. Finally, in 15% (three of nineteen) of all cases (butterfly abundance in fall and hosted butterfly abundance in spring and overall) hypotheses were rejected outright.

Table 8: Comparison of results from Research Questions 1 and 2. Results are reported if at least three sites demonstrated the effect. Asterisks (*) indicate a result that rejects or partially rejects the related hypothesis. Plus signs (+) indicate a result that meets prediction, but does not rule out rejection of the related hypothesis because it depends on another hypothesis whose prediction was not met. Lack of symbols indicates a result that does not reject the related hypothesis.

	Summer	**Fall**	**Spring**	**Study period**
Plant cover	Increase	Increase (P)	Increase	Increase (P)
Nectar plant species richness			(T)	(T)
Plant species richness			Decrease	
Host plant species richness			Decrease	
Butterfly abundance	Increase	*Increase	Decrease*(P)	
Hosted butterfly abundance			*Decrease*(T)	*(T)
Butterfly species richness			Decrease (T)	+(T)
Hosted butterfly species richness	+(T)	+(T)	*Increase(T)	+(T)

Species richness and abundance

In all cases in which flow permanence effects were found to be significant, all plant species richness variables (plant, nectar plant, and host plant) decreased with flow permanence, supporting the intermediate productivity hypothesis (Huston 2014). Butterfly species richness variables (butterfly and hosted butterfly) followed this same predicted pattern, aside from the discrepancy between Research Question 1 and Research Question 2 results in spring for hosted butterfly richness. Similarly, plant abundance increased with surface water availability, supporting the hypothesis of increasing productivity with stream flow permanence in arid riparian systems (Free et al. 2013; Fu and Burgher 2015; Zelnik and Čarni 2008).

Butterfly abundance increased with stream flow permanence in summer and spring, and results were divided between increase and decrease for spring. In the absence of significant effects of stream flow permanence on nectar plant cover, the default hypothesis for butterfly abundance is that it will increase with surface water availability alongside plant abundance, so these results don't reject this default hypothesis. It is likely that the scale at which nectar plant cover was measured within the study was inadequate for the detection of differences in this spatially small but ecologically critical subset of plant cover, masking any potential connection between nectar plant abundance and butterfly abundance.

Hosted butterfly abundance was predicted to increase with stream flow permanence, alongside host plant abundance (Thomas et al. 2011). No effects of stream flow permanence on host plant abundance were observed, however, and hosted butterfly abundance decreased with increasing surface water availability in spring and for the study period overall. Again, the effects of stream flow permanence on host plant abundance may be undetectable due to the scale of plant sampling. More spatially intensive sampling might yield significant information regarding a relationship between stream flow permanence and host plant cover/abundance.

Both hosted butterfly species richness and abundance were both negatively correlated with an increase in surface water. Hosted butterflies may function as a breakout group from butterflies in that the main driver for both their abundance and their diversity may be plant diversity, which consistently decreased with surface water availability in the study (Dennis 2012; Dennis et al. 2004; Dennis et al. 2006).

Research Question 3: Relationships between plant species richness and butterfly species richness; relationships between plant abundance and butterfly abundance: effects of air temperature, shade and surface flow permanence on these relationships.

<u>Summary</u>

In all cases, the hypothesis that plant, nectar plant, and host plant species richness and butterfly and hosted butterfly species richness are correlated was supported. In all ten cases of significant positive relationship, at least one of the three abiotic variables (flow permanence, temperature, and shade) affected the relationship; in one case, both flow permanence and temperature affected it, and in another, all three variables affected it (Table 9).   The hypothesis that butterflies depend on light and heat for their activities was supported by their preference in this study for warm sunny conditions (Dennis 2012). In this study, however, they don’t depend on moisture. The hypothesis that positive relationships exist between plant, nectar plant, and host plant abundance and butterfly and hosted butterfly abundance was rejected in only two cases: no relationship was found between butterfly abundance and nectar plant abundance, nor between hosted butterfly abundance and plant abundance.

Table 9: Summary of abiotic effects on plant-butterfly abundance and plant-butterfly species richness relationships. Flow permanence, temperature and shade refer to the level at which butterfly abundance or species richness had highest values. Temperature is plotted at 20˚C (Cool) and 35˚C (Hot); surface water is plotted at 10% (Dry) and 90% (Wet); shade is plotted at 25% (Open) and 95% (Shaded).

Relationship	Flow Permanence	Temperature	Shade
Butterfly-plant abundance	Dry		
Butterfly-host plant abundance		Warm	
Hosted butterfly-nectar plant abundance	Dry (Cool)/Wet (Warm)		Open
Hosted butterfly-host plant abundance			Open
Butterfly-plant species richness	Dry	Warm	
Butterfly-nectar plant species richness	Dry		Open
Butterfly-host plant species richness			Open
Hosted butterfly-plant/nectar plant/host plant species richness	Dry		Open

Noteworthy relationships

The relationship between hosted butterfly abundance and nectar plant abundance was highly significant, and was affected by all three abiotic variables (Table 9). This finding reflects the relationship between butterfly thermoregulatory requirements for (and limitations on) flight and butterfly water and food requirements. Without adequate heat for activity, foraging flight is not possible, but where heat/sunlight is more readily available, hosted butterflies are found in greater numbers where there are more open flowers, while in less-insolated areas, their numbers do not vary based on floral abundance. Yet regardless of foraging activity level, water in a desert environment becomes more important as a resource when temperatures are high, and under these conditions, hosted butterflies within both shaded and open environments are found in relatively larger numbers in wet areas than in dry areas, perhaps providing a true compass to the importance of permanent stream segments within the Sonoran Desert.

The consistent pattern of shade and surface water effects, within the relationships of hosted butterfly diversity increasing with plant, nectar plant, and host plant diversity, is a last indicator of the ecological pertinence of hosted butterflies as a break-out group. The consistent pattern of highest hosted butterfly diversity within low flow permanence situations and highest diversity in low shade scenarios within each flow permanence category lends support to the intermediate productivity hypothesis. Butterflies tended to prefer sites with intermediate productivity. Although productivity in this study was only estimated within the parafluvial zone via plant cover by species for plants up to 10m in height, it is clear from these diversity relationships that the productivity represented by shade (canopy cover) is also significant to hosted butterfly diversity, which was not the case for butterfly diversity at large.

Do those butterflies, then, which are found in close proximity to their host plants (within 200m in this study) reflect a biological difference from the overall group pertaining to life history as it affects their physiological and habitat needs (light/heat, water, nutrition (nectar) for themselves and for eggs, habitat for ovipositioning/food for larvae)? Are they in some way better indicators of butterfly habitat needs as a whole, based on more clearly delineable ecological relationships? I propose that hosted butterflies are a significant ecological breakout group from butterflies in general (Dennis 2012), and should be the focus of further study for pollinator habitat conservation and restoration modeling.

Synthesis of Research Questions 1,2, and 3

One main finding of this study was that that several indicators of butterfly communities—richness of butterflies, richness of hosted butterflies, and number of hosted butterflies—*decreased* with stream flow permanence. This patterns is likely explained by the idea that the butterflies were responding to changes in plant communities, given that nectar plant and host plant species richness also decreased with flow permanence.

Conservation and restoration applications

Hosted butterflies are resident species —they have the potential to lay eggs on-site, and therefore if eggs are laid, larvae must necessarily hatch, go through various instars, pupate, eclose, and spend some fraction of their adult lives on-site. This study, like others, demonstrates the importance of maintaining adequate nectar forage to maintain hosted,resident butterfly populations. Applying this to riparian conservation and restoration planning, efforts should be made to survey nectar plants on-site and augment nectar forage with plantings, if needed. Nectar plant conservation and/or restoration is likely to augment the abundance and the diversity of other pollinator populations, as well, (Mader et al. 2014; Mader et al. 2011; Meffe 1998; Memmott 1999; Nabhan 2001; Potts et al. 2010) which can provide pollinator services for Sonoran Desert stream ecosytems and nearby agroecosystems. Research into the natural flood cycle of the restoration target stream can help determine what nectar plant species are appropriate and best serve all restoration goals—for example, *Lythrum californicum*, which is clonal and flood-tolerant (and nectar-rich), may stabilize banks and therefore also stabilize the critical presence of surface water.

Results of this study suggest that in times of high temperature, surface water is more important to hosted butterflies than is nectar forage. Actions taken to preserve and/or restore permanent flows will be necessary for the conservation of resident butterfly populations. Conservation and/or restoration of plant species diversity, with an emphasis on nectar plant and host plant diversity, will also be necessary to maintain on-site hosted butterfly diversity. Conserving Sonoran Desert streams with both permanent and temporary reaches should maintain the overall highest hosted butterfly diversity,. Finally, the creation and/or maintenance of unshaded areas will be important to hosted butterfly diversity, and speaks to the importance of maintaining scouring floods as part of the natural flow regime (Poff et al. 1997).

Conclusions

The spring season demonstrated the greatest number of significant flow permanence effects on plant, nectar plant, host plant, butterfly, and hosted butterfly species richness, as well as plant, butterfly, and hosted butterfly abundance, raising the possibility of a seasonal effect of stream flow permanence along Sonoran Desert streams; alternatively, the effects of disturbance (such as flooding) or other ecological processes may be masking the effects of stream flow permanence in seasons other than spring. Plant abundance increased consistently with flow permanence, and butterfly abundance increased with it in two seasons; these findings are supported by the increase of butterfly abundance with plant abundance. Butterfly abundance also increased with host plant abundance. Plant, nectar plant, and host plant species richness decreased with flow permanence, supporting the intermediate productivity hypothesis. Butterfly and hosted butterfly species richness also decreased with flow permanence, supporting the hypothesis that their species richness depends on plant species richness. The consistent relationships of both butterfly categories' species richness increasing with all three plant categories' species richness confirm and strengthen this support. More spatially intensive sampling is needed to adequately explore the potential relationships between stream flow permanence and host plant and nectar plant abundance.

Hosted butterflies may function as an ecological breakout group from butterflies: both their abundance and diversity decreased with stream flow permanence, suggesting that the driver for both variables is plant diversity; their abundance increased with nectar plant abundance; and the relationship of their diversity increasing with the diversity of all categories of plants follows a tight model revolving around the intermediate productivity hypothesis at a grander scale than the scale of the study, prompting further research involving productivity estimates that include canopy cover more explicitly.

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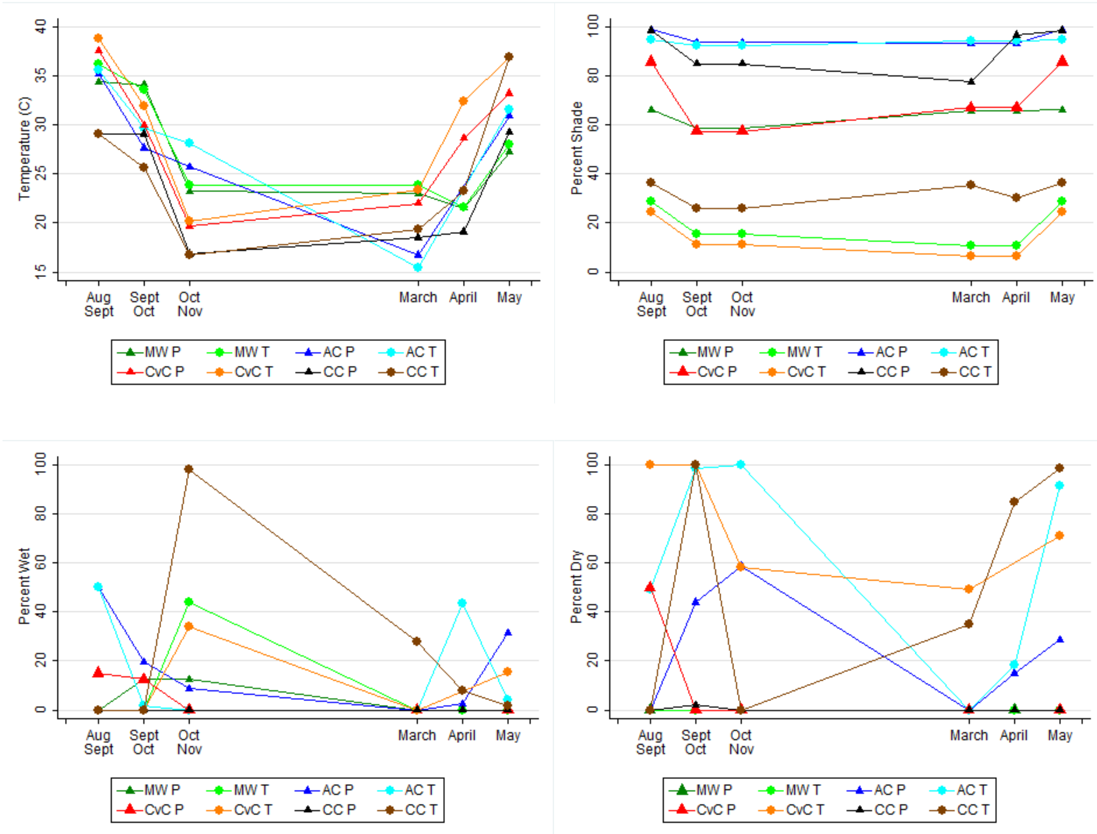
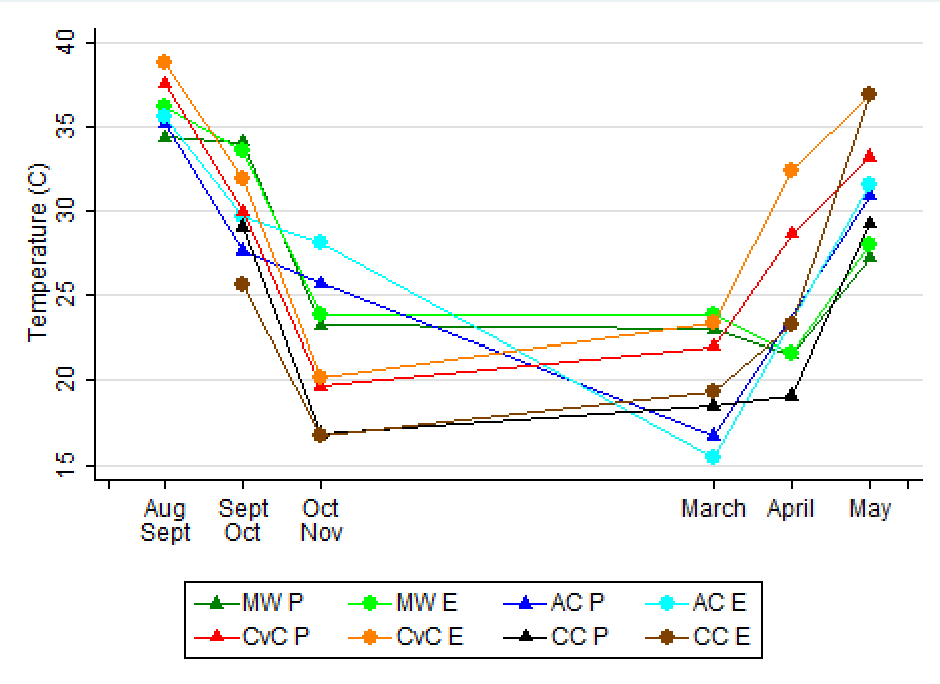
APPENDIX A

DESCRIPTIVE FIGURES FOR ALL SITES

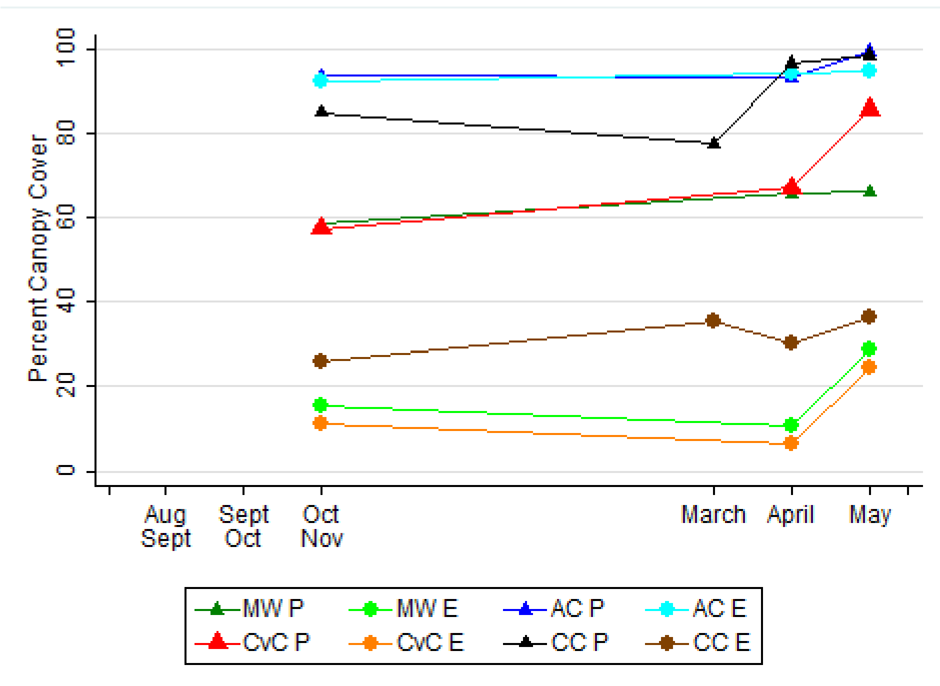
Air temperature, percent shade, percent wetted ground and percent dry ground at all sites.



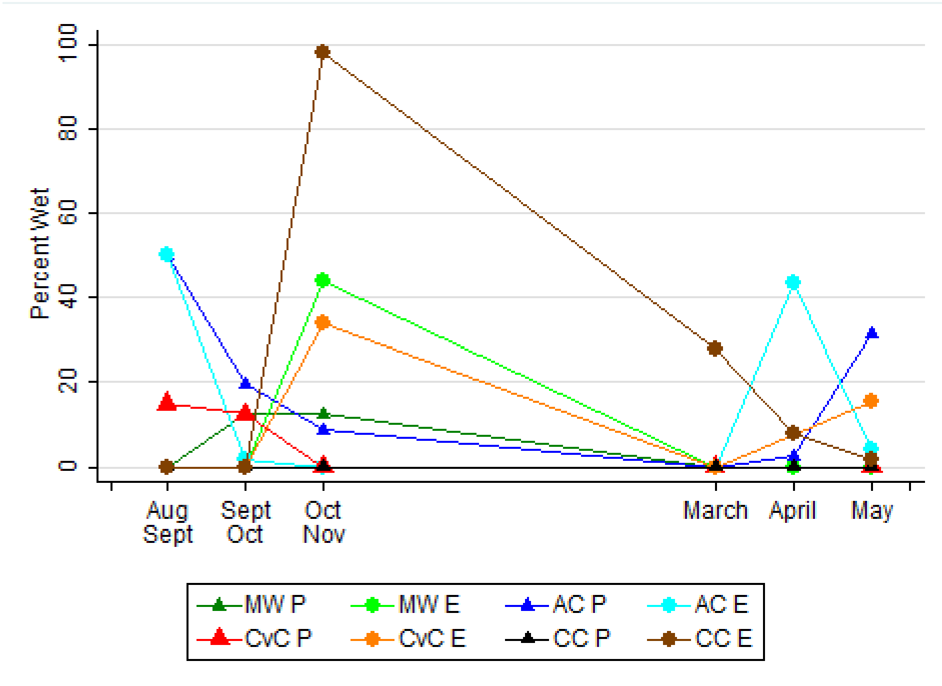
Temperature by site, transect and month



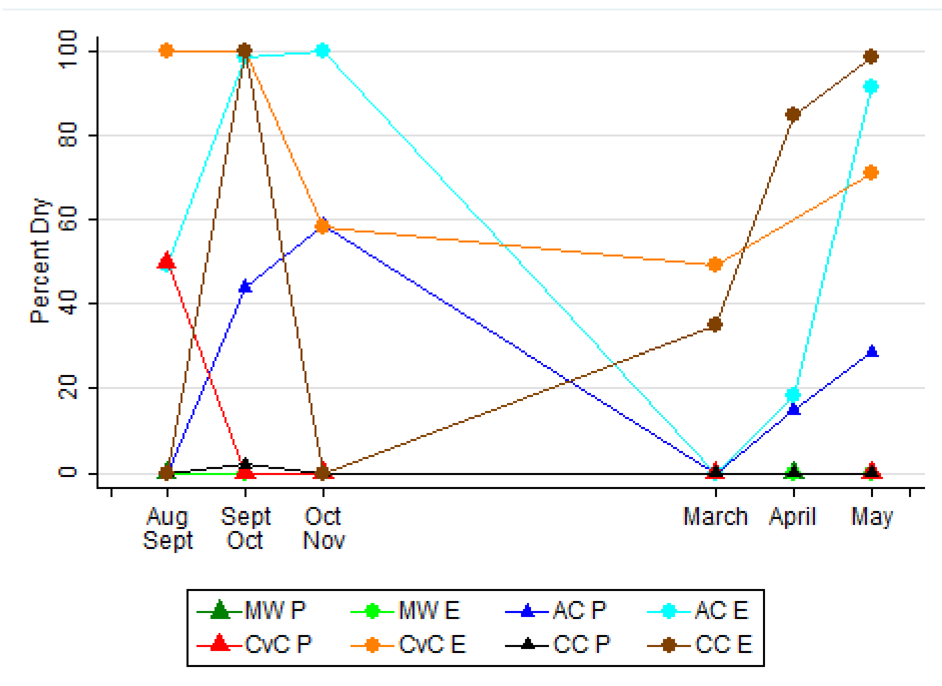
Percent shade by site, transect, and month



Percent wetted ground by site, transect and month



Percent dry ground by site, transect and month



APPENDIX B

DESCRIPTIVE SUMMARY BY SITE

Species richness values for plants and butterflies are simple counts. Plant abundance values are means of the aggregate plant cover (percentage) of the 20 plots per transect. Butterfly abundance values are means of the sum of three counts of individuals each sampling day (one sampling day per month). Hosted butterflies and nectar and host plants are break-outs from these groups.

Mesquite Wash

Biotic Summary

	Transect	Aug-Sept 2013	Sept-Oct 2013	Oct-Nov 2013	March 2014	April 2014	May 2014	Total	Mean
Species Richness									
Plants	Permanent	29	22	28	21	25	28	153	26
	Temporary	35	18	24	15	25	31	148	25
Nectar plants	Permanent	3	2	4	0	1	4	14	2
	Temporary	9	0	3	1	5	5	23	4
Host plants	Permanent	9	8	11	7	9	11	55	9
	Temporary	11	5	7	5	8	9	45	8
Butterflies	Permanent	11	11	9	5	7	15	58	10
	Temporary	15	14	19	12	14	13	87	15
Hosted butterflies	Permanent	3	2	1	2	3	6	17	3
	Temporary	5	4	9	4	6	5	33	6
Abundance									
Plants	Permanent	72.6	68.6	60	10.4	40.4	56.3	308	51.4
	Temporary	64.1	56.9	45.6	16.9	65.4	46	295	49.1
Nectar plants	Permanent	13.3	3.5	1.8	0	8.7	4.3	31.6	5.3
	Temporary	3.1	0	0.2	0	6.2	5.6	15.2	2.5
Host plants	Permanent	13.1	4	10.8	10.8	13.5	15.2	67.5	11.3
	Temporary	7.3	27.3	31.5	5.8	10.6	5.8	88.3	14.7
Butterflies	Permanent	30	16.7	9	2.3	12	90.3	160	26.7
	Temporary	20.3	26.7	22	9	14.7	49.7	142	23.7
Hosted butterflies	Permanent	11.7	3	0.3	1	8.3	31.3	55.7	9.3
	Temporary	2.7	3.7	5.3	2	7.7	16.7	38	6.3

Abiotic Summary

	Transect	Aug-Sept	Sept-Oct	Oct-Nov	March	April	May
Temperature (C)	Permanent	34.4	34.1	23.2	23	21.5	27.2
	Temporary	36.1	33.5	23.9	23.8	21.6	27.9
Flow Permanence							
% Surface Water	Permanent	100	87.5	87.5	100	100	100
% Wetted Ground		0	12.5	12.5	0	0	0
% Dry Ground		0	0	0	0	0	0
% Surface Water	Temporary	100	100	56	100	100	100
% Wetted Ground		0	0	44	0	0	0
% Dry Ground		0	0	0	0	0	0
% Shade	Permanent	.	.	58.4	.	65.6	66.1
	Temporary	.	.	15.6	.	10.9	28.8

Arnett Creek

Biotic Summary

	Transect	Aug-Sept 2013	Sept-Oct 2013	Oct-Nov 2013	March 2014	April 2014	May 2014	Total	Mean
Species Richness									
Plants	Permanent	16	19	13	30	28	22	128	21
	Temporary	15	14	15	29	39	23	135	23
Nectar plants	Permanent	0	1	0	0	0	4	5	1
	Temporary	0	1	0	5	8	1	15	3
Host plants	Permanent	5	6	6	10	12	9	48	8
	Temporary	11	8	8	10	15	9	61	10
Butterflies	Permanent	9	14	13	3	12	9	60	10
	Temporary	7	7	11	4	14	12	55	9
Hosted butterflies	Permanent	2	6	6	0	8	5	27	5
	Temporary	2	5	7	2	7	8	31	5
Abundance									
Plants	Permanent	28.1	22.5	36	13.9	26.6	15.5	142.7	23.8
	Temporary	40.5	25.1	30.3	14.8	24.1	38.7	173.5	28.9
Nectar plants	Permanent	0	0.1	0	0	0	0.6	0.6	0.1
	Temporary	0	0.1	0	0.2	0.8	0	1.1	0.2
Host plants	Permanent	0.3	3.1	0.7	0	3.5	0.6	8.1	1.4
	Temporary	5	3.7	8.7	3	19.7	51.3	91.3	15.2
Butterflies	Permanent	5.7	16	22.3	1	18.7	81.3	145	24.2
	Temporary	5	3.7	8.7	3	19.7	51.3	91.3	15.2
Hosted butterflies	Permanent	0.7	4.7	13	0	11.7	38.3	68.3	11.4
	Temporary	0.7	2.7	5.7	1.3	13.7	33.3	57.3	9.6

Arnett Creek

Abiotic Summary

	Transect	Aug-Sept	Sept-Oct	Oct-Nov	March	April	May
Temperature (C)	Permanent	35.2	27.7	25.7	16.8	.	30.9
	Temporary	35.5	29.6	28.1	15.4	.	31.5
Flow Permanence							
% Surface Water	Permanent	50	36.5	33	100	82.5	40
% Wetted Ground		50	19.5	8.8	0	2.5	31.5
% Dry Ground		0	44	58.8	0	15	28.5
% Surface Water	Temporary	1	0	0	100	38	4.3
% Wetted Ground		50	1.5	0	0	43.5	4.3
% Dry Ground		49	98.5	100	0	18.5	91.5
% Shade	Permanent	.	.	93.6	.	93.2	99.4
	Temporary	.	.	92.1	.	94.3	94.4

Cave Creek

Biotic Summary

	Transect	Aug-Sept 2013	Sept-Oct 2013	Oct-Nov 2013	March 2014	April 2014	May 2014	Total	Mean
Species Richness									
Plants	Permanent	13	22	17	17	20	22	111	19
	Temporary	16	19	15	19	34	15	118	20
Nectar plants	Permanent	1	4	0	0	2	3	10	2
	Temporary	0	4	3	0	4	2	13	2
Host plants	Permanent	5	11	9	8	9	12	54	9
	Temporary	8	9	9	9	14	8	57	10
Butterflies	Permanent	8	18	16	5	14	16	77	13
	Temporary	5	8	16	12	19	13	73	12
Hosted butterflies	Permanent	0	5	3	3	4	5	20	3
	Temporary	1	4	9	7	11	6	38	6
Abundance									
Plants	Permanent	51.7	33.3	44.2	27.3	71.7	52.2	280.3	46.7
	Temporary	18.8	21.4	25.2	14.9	25.3	29.5	135.1	22.5
Nectar plants	Permanent	2.2	5	0	0	3.3	4.3	14.8	2.5
	Temporary	0	7.8	1.4	0	10.3	5.3	24.8	4.1
Host plants	Permanent	0	18.7	12.5	7.9	6.3	14.9	60.2	10
	Temporary	0.2	4	5.1	11.5	7.4	2.5	30.7	5.1
Butterflies	Permanent	6.7	18.3	23.3	2.3	22.3	44.3	117.3	19.6
	Temporary	5.7	8.7	15	15	19.3	49	112.7	18.8
Hosted butterflies	Permanent	0	3.3	3	1	8.3	6.7	22.3	3.7
	Temporary	0.3	3.3	6.3	6.3	9.3	33.7	59.3	9.9

Cave Creek

Abiotic Summary

	Transect	Aug-Sept	Sept-Oct	Oct-Nov	March	April	May
Temperature (C)	Permanent	37.6	30	19.7	22	28.6	33.2
	Temporary	38.8	31.9	20.1	23.4	32.4	36.9
Flow Permanence							
% Surface Water	Permanent	35	87.5	100	100	.	100
% Wetted Ground		15	12.5	0	0	.	0
% Dry Ground		50	0	0	0	.	0
% Surface Water	Temporary	0	0	8	51	.	13.5
% Wetted Ground		0	0	33.8	0	.	15.5
% Dry Ground		100	100	58.3	49	.	71
% Shade	Permanent	.	.	57.4	.	67.1	85.6
	Temporary	.	.	11.3	.	6.3	24.2

Camp Creek

Biotic Summary

	Transect	Aug-Sept 2013	Sept-Oct 2013	Oct-Nov 2013	March 2014	April 2014	May 2014	Total	Mean
Species Richness									
Plants	Permanent	15	21	19	18	22	19	114	19
	Temporary	18	24	14	24	26	24	130	22
Nectar plants	Permanent	1	2	1	2	5	3	14	2
	Temporary	0	6	1	5	3	0	15	3
Host plants	Permanent	6	5	6	6	6	6	35	6
	Temporary	7	8	6	8	14	8	51	9
Butterflies	Permanent	1	8	5	8	8	14	44	7
	Temporary	13	30	15	17	18	18	111	19
Hosted butterflies	Permanent	0	2	1	3	1	3	10	2
	Temporary	4	9	6	8	6	8	41	7
Abundance									
Plants	Permanent	48.8	44.7	45.6	46.1	78.7	55	319	53.2
	Temporary	28.6	32	31.1	32	22.1	24.8	171	28.4
Nectar plants	Permanent	3.1	0.5	0.7	16.6	47.6	14.3	82.9	13.8
	Temporary	0	1.4	2	10.6	0.4	0	14.4	2.4
Host plants	Permanent	0	0.4	0.3	8	0.3	0.3	9.2	1.5
	Temporary	10	11.5	8.3	11	12.6	7.9	61.2	10.2
Butterflies	Permanent	0.7	8.3	1.7	7	4.3	148	170	28.3
	Temporary	14.7	43.3	15.7	40.7	42.3	161	318	53
Hosted butterflies	Permanent	0	3	0.3	2.7	0.3	3.7	10	1.7
	Temporary	4.7	19.7	6.7	24.7	18.3	16	90	15

Camp Creek

Abiotic Summary

	Transect	Aug-Sept 2013	Sept-Oct 2013	Oct-Nov 2013	March 2014	April 2014	May 2014
Temperature (C)	Permanent	.	29.1	16.9	18.5	19.1	29.3
	Temporary	.	25.6	16.7	19.3	23.2	36.9
Flow Permanence							
% Surface Water	Permanent	100	98	100	100	100	100
% Wetted Ground		0	0	0	0	0	0
% Dry Ground		0	2	0	0	0	0
% Surface Water	Temporary	100	0	2	37	7.5	0
% Wetted Ground		0	0	98	28	8	1.5
% Dry Ground		0	100	0	35	84.5	98.5
% Canopy Cover	Permanent	.	.	84.9	77.5	96.6	98.4
	Temporary	.	.	25.9	35.4	30	36.4

APPENDIX C

MINIMA AND MAXIMA FOR ALL VARIABLES ON ALL TRANSECTS AT ALL SITES

This table uses the approximations of values for shade and temperature for missing dates (see Methods: Statistical Analysis).

Variable	Life Form	Transect	Minimum/Maximum			
			Mesquite Wash	*Arnett Creek*	*Cave Creek*	*Camp Creek*
Species Richness						
	Plants	Permanent	21/29	13/30	13/22	15/22
		Temporary	15/35	14/39	15/34	14/26
	Nectar plants	Permanent	0/4	0/4	0/4	1/5
		Temporary	0/9	0/8	0/4	0/6
	Host plants	Permanent	7/11	5/12	5/12	5/6
		Temporary	5/11	8/15	8/14	6/14
	Butterflies	Permanent	5/15	3/14	5/18	1/14
		Temporary	12/19	4/14	5/19	13/30
	Hosted butterflies	Permanent	1/6	0/8	0/5	0/3
		Temporary	4/9	2/8	1/11	4/9
Abundance						
	Plants	Permanent	10/73	14/36	27/72	45/79
		Temporary	17/65	15/41	15/30	22/32
	Nectar plants	Permanent	0/13	0/1	0/5	1/48
		Temporary	0/6	0/1	0/10	0/11
	Host plants	Permanent	4/15	0/3	0/19	0/8
		Temporary	6/31	1/4	0/12	8/13
	Butterflies	Permanent	2/90	1/81	2/44	1/148
		Temporary	9/50	3/51	6/49	15/161
	Hosted butterflies	Permanent	0/31	0/38	0/8	0/4
		Temporary	2/17	1/33	0/34	5/25
Air Temperature ℃		Permanent	22/34	17/35	20/38	17/29
		Temporary	22/36	15/36	20/39	17/37
Tree Canopy Cover		Permanent	58/66	93/99	57/86	78/98
		Temporary	11/29	92/94	6/24	26/36
Percent Surface Water		Permanent	88/100	33/100	35/100	98/100
		Temporary	56/100	0/100	0/51	0/100
Percent Wetted Ground		Permanent	0/13	0/50	0/15	0/0
		Temporary	0/44	0/50	0/34	0/98
Percent Dry Ground		Permanent	0/0	0/59	0/50	0/2
		Temporary	0/0	0/100	49/100	0/100

APPENDIX D

PLANT SPECIES BY WETLAND INDICATOR STATUS, SITE AND TRANSECT

Indicator statuses include Obligate (1), Facultative Wetland (2), Facultative (3), Facultative Upland (4), and Upland (5).

Plant Species	Mesquite Wash		Arnett Creek		Cave Creek		Camp Creek	
Wetland Indicator Status 1 (OBL)	P	T	P	T	P	T	P	T
Centaurium calycosum	+	+						
Cephalanthus occidentalis	+	+						
Eleocharis montana			+	+				
Juncus ziphioides								+
Lythrum californicum	+	+			+	+		
Mentha spicata			+				+	+
Mimulus guttatus	+	+	+	+	+	+	+	+
Nasturtium officinale	+	+	+				+	+
Schoenoplectus americanus	+	+			+			
Stemodia durantifolia		+			+			
Symphyotrichum expansum		+			+		+	+
Typha domingensis	+	+			+	+	+	+
Veronica anagallis-aquatica	+	+	+				+	+
Total: 14	8	10	6	3	6	3	6	7
Wetland Indicator Status 2 (FACW)								
Anagallis arvensis		+						
Arundo donax					+			
Calibrachoa parviflora	+	+						
Cyperus eragrostis			+	+				
Cyperus odoratus		+						
Equisetum laevigatum	+		+					
Juncus torreyi	+	+			+			+
Oenothera elata	+							
Platanus wrightii	+	+					+	+
Polygonum aviculare		+						
Polygonum pensylvanicum	+	+						
Polypogon monspeliensis	+	+	+		+	+	+	+
Polypogon viridis	+						+	+
Populus fremontii		+			+	+		+
Rumex dentatus		+						
Salix gooddingii	+	+	+	+	+	+	+	+
Salix lasiocarpa							+	+
Total: 17	9	11	4	2	5	3	5	7

Plant Species	Mesquite Wash		Arnett Creek		Cave Creek		Camp Creek	
Wetland Indicator Status 3 (FAC)								
Aquilegia chrysantha							+	+
Artemisia dracunculus				+				+
Baccharis salicifolia	+	+	+	+	+	+		
Bromus diandrus	+	+	+	+		+	+	+
Carex thurberi							+	+
Celtis reticulate				+				+
Claytonia perfoliata			+	+				
Conyza Canadensis	+	+			+			+
Eclipta prostrata	+	+						
Epilobium canum							+	+
Euphorbia spathulata				+				
Fraxinus velutina	+		+	+	+	+		+
Galium microphyllum			+	+	+			
Hordeum murinum ssp. *Glaucum*			+	+				
Ipomoea coccinea						+		+
Juncus interior				+				
Lamium amplexicaule			+	+				
Lolium perenne		+		+				+
Muhlenbergia rigens	+	+	+	+	+	+	+	+
Nerium oleander			+	+				
Oenothera flava								+
Piptatherum miliaceum	+	+	+	+				
Rumex crispus	+	+			+		+	
Rumex hymenosepalus		+						+
Scutellaria potosina				+				
Sonchus asper							+	+
Tamarix ramossissima	+	+		+	+	+		+
Ulmus parvifolia								+
Vinca major							+	+
Xanthium strumarium	+	+	+	+	+	+		
Total: 30	10	11	11	18	8	7	8	17

Plant Species	Mesquite Wash		Arnett Creek		Cave Creek		Camp Creek	
Wetland Indicator Status 4 (FACU)								
Amaranthus palmeri						+		
Ambrosia ambrosioides	+				+	+		
Artemisia ludoviciana							+	+
Baccharis emoryi					+			
Baccharis sarothroides				+	+	+		
Baccharis sergiloides		+	+	+		+	+	+
Boerhavia erecta						+		
Bothriochloa barbinodis								+
Bowlesia incana		+	+	+				
Cynodon dactylon	+	+	+	+	+	+	+	+
Dodonaea viscosa			+	+				
Elymus glaucus			+				+	+
Eragrostis cilianensis								+
Ficus carica								+
Galium aparine	+		+	+				
Hedera canariensis							+	+
Helianthus annuus		+			+	+		
Heterotheca subaxillaris	+	+				+		
Lactua serriola	+	+	+	+	+	+	+	+
Lepidium virginicum			+	+				
Melilotus indicus		+	+	+	+	+		
Melilotus officinalis	+	+	+	+	+			+
Morus alba								+
Nicotiana obtusifolia						+		
Oenothera caespitosa								+
Oncosiphon piluliferum						+		
Panicum capillare	+	+						
Parietaria hespera			+					
Polanisia dodecandra	+	+				+		
Prosopis velutina	+	+	+	+	+	+		
Sarcostemma cynanchoides			+	+		+		
Senecio vulgare				+				
Sorghum halepense	+	+			+	+	+	+
Spermolepis echinata			+					
Stellaria media				+				
Vitis arizonica			+				+	+
total 36	10	12	15	14	10	16	8	14

Plant Species	Mesquite Wash		Arnett Creek		Cave Creek		Camp Creek	
Wetland Indicator Status 5 (U)								
Ambrosia monogyra			+			+		
Anisacanthus thurberi			+					
Aristida purpurea		+						
Avena fatua		+		+		+		
Bebbia juncea						+		+
Bouteloua curtipendula				+				
Brassica tournefortii				+		+		
Bromus rubens	+	+	+	+	+	+		+
Cirsium neomexicanum		+						+
Cryptantha barbigera				+	+	+		
Cryptantha decipiens		+				+		
Datura wrightii	+							
Daucus pusillus			+	+				
Descurainia pinnata			+					
Encelia farinosa						+		
Eriogonum deflexum						+		
Erigeron divergens								+
Erodium cicutarium			+	+		+		+
Euphorbia arizonica						+		
Euphorbia melanadenia			+	+		+		
Euphorbia setiloba			+					+
Gallium proliferum				+				
Gilia flavocincta								+
Gilia stellate				+				+
Glandularia gooddingii		+						
Gutierrezia sarothrae		+				+		
Herniara cinerea				+				
Hibiscus coulteri			+					
Ipomoea costellata								+
Isocoma tenuisecta								+
Lepidium lasiocarpum								+
Lepidium montana						+		
Lesquerella gordonii				+				
Linum lewisii				+				
Linum puberulum				+				
Lotus rigidus						+		
Lupinus sparsiflorus			+	+		+		
Maurandya antirrhiniflora							+	
Mimosa biuncifera								+
Penstemon pseudospectabilis							+	
Pennisetum setaceum	+	+						
Phacielia distans			+	+				
Phlox gracilis				+				+
Phlox tenuisecta	+				+			
Plantago patagonica				+		+		
Pterostigia drymarioides			+	+				
Silene antirrhina		+						
Simmondsia chinensis			+					
Sisymbrium irio				+		+		

Solidago velutina							+	
Wetland Indicator Status 5 (U)								
Sphaeralcea ambigua						+		
Stephanomeria pauciflora		+				+		
Thysanocarpus curvipes	+		+	+				
Uropappus lindleyi			+					
Ziziphus obtusifolia			+					
total 55	5	10	15	21	3	20	3	13

APPENDIX E

BUTTERFLY SPECIES BY HABITAT TYPE

Habitat Type	Mesquite Wash		Arnett Creek		Cave Creek		Camp Creek	
Surface Water Present	P	T	P	T	P	T	P	T
Agathymus aryxna	+		+		+		+	+
Anthocharis sara		+						
Asterocampa celtis					+			
Asterocampa leilia	+	+	+	+	+	+		
Calephelis nemesis	+	+				+		
Celastrina ladon	+	+	+	+	+	+	+	+
Copaeodes aurantiaca	+	+			+			+
Danaus gilippus	+	+	+	+	+	+	+	+
Danaus plexippus	+			+	+			+
Echinargus isola	+	+	+	+	+	+	+	+
Heliopyrgus domicella					+		+	
Limenitis archippus	+	+			+	+		
Nymphalis antiopa			+	+				
Papilio cresphontes							+	+
Papilio multicaudata					+			+
Satyrium sylvinus	+							
Total: 17	10	8	7	6	11	6	6	9
Wetted Ground Present								
Limenitis archippus	+	+			+	+		
Limenitis arthemis	+	+	+	+	+	+	+	+
Papilio multicaudata					+			+
Pyrgus philetas						+		
Vanessa atalanta			+					
Total: 5	2	2	2	1	3	3	1	2
Woodland								
Abaeis nicippe	+	+	+	+	+	+		+
Adelpha eulalia			+					+
Agathymus aryxna	+		+		+		+	+
Agraulis vanillae								+
Anthocharis sara		+						
Apodemia palmeri		+						
Asterocampa celtis					+			
Asterocampa leilia	+	+	+	+	+	+		
Atrytonopsis edwardsi								+
Atrytonopsis lunus								+
Battus philenor	+	+	+	+	+		+	+
Celastrina ladon	+	+	+	+	+	+	+	+
Celotes nessus						+		
Chlosyne lacinia		+						
Cogia hippalus							+	+
Danaus plexippus	+			+	+			+
Dymasia dymas								+
Erynnis tristis					+	+		+
Euphilotes battoides	+	+			+	+		+
Euphydryas chalcedona		+	+			+		+
Heliopetes ericetorum		+			+	+	+	+
Heliopyrgus domicella					+		+	
Hemiargus ceraunus			+	+		+		+
Leptotes marina	+	+	+	+	+	+	+	+
Libytheana carinenta	+	+	+	+	+	+		+

Woodland, continued	Mesquite Wash		Arnett Creek		Cave Creek		Camp Creek	
Limenitis archippus	+	+			+	+		
Limenitis arthemis	+	+	+	+	+	+	+	+
Nymphalis antiopa			+	+				
Papilio cresphontes							+	+
Papilio multicaudata					+			+
Polydryas arachne								+
Pontia sisymbrii	+		+					
Pyrgus philetas						+		
Satyrium sylvinus	+							
Systasea zampa			+		+	+		+
Texola elada								+
Zerene cesonia		+	+	+	+			+
Total: 37	13	15	15	11	18	15	9	25
Montane								
Adelpha eulalia			+					+
Atrytonopsis lunus								+
Heliopetes ericetorum		+			+	+	+	+
Polydryas arachne								+
Total: 4	0	1	1	0	1	1	1	4
Alpine								
Euphilotes battoides	+	+			+	+		+
Total: 1	1	1	0	0	1	1	0	1
Grassland								
Agathymus aryxna	+		+		+		+	+
Atrytonopsis edwardsi								+
Atrytonopsis lunus								+
Cogia hippalus							+	+
Colias eurytheme		+			+			+
Colias philodice	+	+	+	+	+	+		+
Copaeodes aurantiaca	+	+			+			+
Echinargus isola	+	+	+	+	+	+	+	+
Euphilotes battoides	+	+			+	+		+
Euphydryas chalcedona		+	+			+		+
Euptoieta claudia		+	+					+
Nathalis iole	+	+	+		+	+		+
Polydryas arachne								+
Pyrgus communis					+	+	+	+
Zerene cesonia		+	+	+	+			+
Total: 15	6	9	7	3	9	6	4	15

Desert	Mesquite Wash		Arnett Creek		Cave Creek		Camp Creek	
Abaeis nicippe	+	+	+	+	+	+		+
Apodemia mormo						+		
Apodemia palmeri		+						
Asterocampa leilia	+	+	+	+	+	+		
Atrytonopsis lunus								+
Celotes nessus						+		
Chlosyne californica		+			+	+		
Chlosyne lacinia		+						
Cogia hippalus							+	+
Danaus gilippus	+	+	+	+	+	+	+	+
Dymasia dymas								+
Echinargus isola	+	+	+	+	+	+	+	+
Erynnis funeralis			+		+	+		
Euphilotes battoides	+	+			+	+		+
Euphydryas chalcedona		+	+			+		+
Heliopetes ericetorum		+			+	+	+	+
Heliopyrgus domicella					+		+	
Hemiargus ceraunus			+	+		+		+
Leptotes marina	+	+	+	+	+	+	+	+
Nathalis iole	+	+	+		+	+		+
Papilio cresphontes							+	+
Polydryas arachne								+
Pontia protodice		+		+				
Pontia sisymbrii	+		+					
Pyrgus philetas						+		
Staphylus ceos	+		+	+				+
Systasea zampa			+		+	+		+
Zerene cesonia		+	+	+	+			+
Total: 28	9	14	13	9	13	16	7	17
Open								
Abaeis nicippe	+	+	+	+	+	+		+
Agathymus aryxna	+		+		+		+	+
Agraulis vanillae								+
Anthocharis sara		+						
Apodemia mormo						+		
Asterocampa celtis					+			
Atalopedes campestris				+				
Atrytonopsis edwardsi								+
Atrytonopsis lunus								+
Battus philenor	+	+	+	+	+		+	+
Calephelis nemesis	+	+				+		
Celastrina ladon	+	+	+	+	+	+	+	+
Celotes nessus						+		
Chlosyne californica		+			+	+		
Chlosyne lacinia		+						
Colias eurytheme		+			+			+
Colias philodice	+	+	+	+	+	+		+
Danaus gilippus	+	+	+	+	+	+	+	+
Danaus plexippus	+			+	+			+
Echinargus isola	+	+	+	+	+	+	+	+
Erynnis funeralis			+		+	+		
Euphilotes battoides	+	+			+	+		+
Euphydryas chalcedona		+	+			+		+
Euptoieta claudia		+	+					+

Open, continued	Mesquite Wash	Mesquite Wash (cont.)	Arnett Creek	Arnett Creek (cont.)	Cave Creek	Cave Creek (cont.)	Camp Creek	Camp Creek (cont.)
Eurema mexicana	+	+			+			+
Heliopetes ericetorum		+			+	+	+	+
Heliopyrgus domicella					+		+	
Hemiargus ceraunus			+	+		+		+
Junonia coenia	+	+	+	+	+	+		+
Leptotes marina	+	+	+	+	+	+	+	+
Libytheana carinenta	+	+	+	+	+	+		+
Limenitis archippus	+	+			+	+		
Nathalis iole	+	+	+		+	+		+
Nymphalis antiopa			+	+				
Papilio multicaudata					+			+
Phoebis sennae	+	+		+	+		+	+
Pieris rapae	+					+	+	+
Polydryas arachne								+
Pontia protodice		+		+				
Pontia sisymbrii	+		+					
Pyrgus communis					+	+	+	+
Pyrgus philetas						+		
Satyrium sylvinus	+							
Strymon melinus			+		+	+	+	+
Systasea zampa			+		+	+		+
Vanessa cardui	+	+	+	+	+	+	+	+
Zerene cesonia		+	+	+	+			+
Total: 47	21	25	21	17	28	25	13	31
Agricultural/Post-agricultural								
Abaeis nicippe	+	+	+	+	+	+		+
Agraulis vanillae								+
Anthocharis sara		+						
Atalopedes campestris				+				
Celastrina ladon	+	+	+	+	+	+	+	+
Chlosyne lacinia		+						
Colias eurytheme		+			+			+
Colias philodice	+	+	+	+	+	+		+
Copaeodes aurantiaca	+	+			+			+
Danaus gilippus	+	+	+	+	+	+	+	+
Danaus plexippus	+			+	+			+
Echinargus isola	+	+	+	+	+	+	+	+
Euphydryas chalcedona		+	+			+		+
Euptoieta claudia		+	+					+
Hemiargus ceraunus			+	+		+		+
Leptotes marina	+	+	+	+	+	+	+	+
Libytheana carinenta	+	+	+	+	+	+		+
Nathalis iole	+	+	+		+	+		+
Papilio cresphontes							+	+
Phoebis sennae	+	+		+	+		+	+
Pontia protodice		+		+				
Pyrgus communis					+	+	+	+
Vanessa cardui	+	+	+	+	+	+	+	+
Total: 23	12	17	12	13	14	12	8	19

Urban								
Abaeis nicippe	+	+	+	+	+	+		+
Agraulis vanillae								+
Asterocampa celtis					+			
Atalopedes campestris				+				
Celotes nessus						+		
Colias eurytheme		+			+			+
Colias philodice	+	+	+	+	+	+		+
Leptotes marina	+	+	+	+	+	+	+	+
Nymphalis antiopa			+	+				
Papilio cresphontes							+	+
Papilio multicaudata					+			+
Phoebis sennae	+	+		+	+		+	+
Pyrgus communis					+	+	+	+
Vanessa atalanta			+					
Vanessa cardui	+	+	+	+	+	+	+	+
Total: 15	5	6	6	7	9	6	5	10
Valley								
Dymasia dymas								+
Limenitis archippus	+	+			+	+		
Limenitis arthemis	+	+	+	+	+	+	+	+
Papilio multicaudata					+			+
Staphylus ceos	+		+	+				+
Total: 5	3	2	2	2	3	2	1	4
Canyon								
Adelpha eulalia			+					+
Agathymus aryxna	+		+		+		+	+
Anthocharis sara		+						
Asterocampa leilia	+	+	+	+	+	+		
Callophrys xami				+				
Celotes nessus						+		
Chlosyne californica		+			+	+		
Cogia hippalus							+	+
Papilio multicaudata					+			+
Pontia sisymbrii	+		+					
Staphylus ceos	+		+	+				+
Systasea zampa			+		+	+		+
Total 12	4	3	6	3	5	4	2	6
Cosmopolitan								
Nymphalis antiopa			+	+				
Vanessa atalanta			+					
Vanessa cardui	+	+	+	+	+	+	+	+
Total: 3	1	1	3	2	1	1	1	1
Migratory								
Abaeis nicippe	+	+	+	+	+	+		+
Agraulis vanilla								+
Atalopedes campestris				+				
Danaus gilippus	+	+	+	+	+	+	+	+
Danaus plexippus	+			+	+			+
Euptoieta claudia		+	+					+
Junonia coenia	+	+	+	+	+	+		+

Migratory, continued								
Nymphalis antiopa			+	+				
Phoebis sennae	+	+		+	+		+	+
Vanessa atalanta			+					
Vanessa cardui	+	+	+	+	+	+	+	+
Total: 11	6	6	7	8	6	4	3	8