HYDROGEOMORPHIC AND BOTANICAL ASSOCIATIONS OF BAJADA EPHEMERAL DRAINAGES IN THE WHITE TANK MOUNTAINS, SONORAN DESERT

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Ephemeral drainage plant communities of the Sonoran Desert compose a highly significant yet relatively unexplained portion of the ecosystem. Eighty-one percent of all southwestern and 94% of Arizona drainages are categorized as ephemeral drainages (Levick et al. 2008). Small but significant portions of the bajada environment are also composed of ephemeral drainages. These drainages carry out important landscape scale functions in water movement, groundwater recharge, nutrient movement and cycling, sediment transportation, geomorphology, plant habitat, seed disbursement, as well as wildlife habitat and corridors. In decades past, Sonoran Desert bajada research relating the physical earth sciences to ecology has focused on explaining upland plant community patterns along this landform (Yang and Lowe 1956, Phillips and MacMahan 1978, Key et al. 1984, McAuliffe 1994, Parker 1995, McAuliffe 1999). This body of research, however, has very little information pertaining to ephemeral drainages dissecting the upland bajada environment.

The bajada geomorphic environment is a composition of geomorphic surfaces of varying soil development proceeding away from a mountain (Peterson 1981, McAuliffe 1994). Each of these geomorphic surfaces is characterized by a unique lithology, slope, age and degree of argillic and caliche soil horizon development. Generally, geomorphic surfaces containing highly developed argillic or caliche soil horizons are found near the mountain while surfaces of undeveloped soils are furthest away from the mountain. Depending on the bajada, local geomorphic history, however, may result in different landscape scale patterns of geomorphic surfaces and soil development. This physical environment forms the template from which the ephemeral drainage develops its channel morphology, hydrology and botanical associations.

It was expected that the various geomorphic surfaces composing the bajada found at the study sites would determine the specific channel morphology, hydrology and plant community associations of the examined ephemeral drainage. The goal of this study was to explain (1) channel morphology, (2) hydrology or ephemeral flow patterns and (3) plant communities found along the ephemeral drainage. Plant communities of drainages were also compared to upland communities. These factors were then utilized to give an overall explanation for the distribution of hydrogeomorphic and botanical associations found along the bajada ephemeral drainage.

STUDY SITE

Three ephemeral drainage and bajada systems originating from the White Tank Mountains were examined for this study. The three study sites were located on the north, west, and east slopes of the mountain range. The White Tank Mountains are located approximately 40 km west of Phoenix, Arizona, in the Sonoran Desert portion of the Basin and Range Geological Province. The mountains are primarily a granite-gneiss metamorphic core complex. Study site elevations ranged from 600 m above sea level for sites found in the mountains to the lowest study sites found on the lower bajadas at 300 m above sea level. Rainfall followed a bimodal, summer monsoonal and winter rainy season pattern, which ranged from 138 mm annually on the western bajada site to 199 mm annually on the eastern bajada (nearest similar elevation rain gages, Ford Canyon Wash 5425 and Sun Valley Parkway at Northern 5300, Flood Control District of Maricopa County). July is the hottest month of the year with an average high of 40.6 °C and January the coldest month of the year with an average low of 2.3 °C (Western Regional Climate Center Wittmann, Arizona 029464).

METHODS

A total of 173, 0.1-hectare (ha) plots were located within three ephemeral drainage systems originating in the White Tank Mountains and descending down the adjacent bajadas. Plot shape varied based on the width of the channel reach sampled. For example, a channel reach that was 20 m wide was 50 m long, or a channel reach that was 25 m wide was 40 m long. Along each drainage system, geomorphic surfaces were identified according to Field and Pearthree (1991). Channel morphological features such as active channel width and maximum depth, entire riparian corridor width and maximum depth, channel slope, caliche development, percent of channel with bedrock, bank height ratio, and rocks >25 mm per m^2 were observed and recorded for each plot. Number of rills or smaller drainages entering each plot and 100

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m upstream were also counted. Plant species were also identified within each drainage plot and density of species determined or canopy cover estimated. An additional 115, 0.1-ha plots were placed in the uplands adjacent to drainage plots for vegetation sampling. In upland plots, plant species were identified and densities determined or canopy cover estimated.

Locations and extents of ephemeral flow events within the drainages were observed after large rainfall events for each of the bajadas. Rainfall events were monitored through accessing the Flood Control District of Maricopa County rain gauge network website (2014). All Flood Control District of Maricopa County rain gauges were, however, located outside of the examined watersheds but were within 5 km and were the closest similar elevation gauges. Evidence of flows was observed after rainfall events by walking drainages or by accessing channel along trails or roadways after rainfall events that took place between January and August 2014. Flow was determined to have taken place if alluvial sediments were found to be disturbed and organic materials removed by recent flows.

Data Analysis

Analyses of data collected from each of the bajada systems were carried out independent of one another. Non-metric multidimensional scaling (NMS) using Relative Sorenson's distance measure was utilized to group fluvial morphology into major channel categories and in determining major groupings of plant communities. NMS is an effective method for grouping ecological community data which may be non-normal or discontinuous (Bradfield and Kenkel 1986, Minchin 1987, McCune and Grace 2002). Each NMS was carried out in PC-ORD 5.10 software using 250 runs with real data and 250 runs with randomized data with a random starting configuration provided by the software (McCune and Mefford 2006). Major groups for both channel morphology and plant communities were determined from NMS two-dimensional ordinations. Linear regression of plant species richness versus distance from mountain was carried out for both drainage and upland plots.

Results

The following results are presented in summary form for the three bajada ephemeral drainage systems examined for this study. Results below are as they were presented at the 59th annual meeting of the Arizona-Nevada Academy of Science, April 18, 2015 at Arizona State University at the West campus, Glendale, Arizona.

Bajada Geomorphology

Utilizing Field and Pearthree (1991), four generalized geomorphic surfaces were found at the examined study sites, (1) the mountain defined by the presence of steep slopes, bedrock and poorly developed soils, (2) the upper bajada where soils were highly developed with stage III or greater caliche, (3) middle bajadas with moderately developed soils of stage II or less caliche and (4) the lower bajada, furthest away from the mountain and with undeveloped soils (Fig. 1). Each of the three bajadas examined had similar landscape scale patterns of soil progressing from highly developed soils on geomorphic surfaces near the mountain, to soil surfaces of progressively less development further away from the mountain.

Channel Morphology

Four generalized channel morphology types were also identified through non-metric multidimensional scaling (Figs. 1, 2). Clusters of channel reaches in the ordinations appeared to be largely dependent on geomorphic surface dissected by the drainage and therefore were grouped accordingly. Channel types were as follows, (1) bedrock constrained channels typically found on the mountain and with poorly developed soils, (2) strongly caliche constrained channels with deep incision found on the upper bajada, (3) weakly caliche constrained channels with moderate incision found on the middle bajada, and (4) geomorphically unconstrained channels found on the lower bajada where soils were undeveloped.

Ephemeral Flow Patterns

Rainfall events where ephemeral flow was observed to take place within the three drainage systems were as follows: 24 to 30 mm (precipitation amount depended on rain gauge) on 3/1/2014, 35 mm on 7/7/2014, and 36 mm on 7/31/2014. Each of these rainfall events was of large enough size to cover the entire bajada under examination. Evidence of flow was mapped for two rainfall events for each of the bajada drainage systems. The small sample size was a result of the low frequency of flow that occurred during the study period and limits the overall usefulness to the study. Flows for each of the drainages were largely discontinuous along channels. It was found that generally, geomorphic surfaces with a greater number of rills or smaller channels entering the main channel had a greater chance of a flow event occurring. The mountain drainage was observed as having discontinuous flow. Upper bajada channels had the most infrequent flows and the lowest number of small-rills or channels entering the main channel. Middle bajadas had the most frequent flows and also had

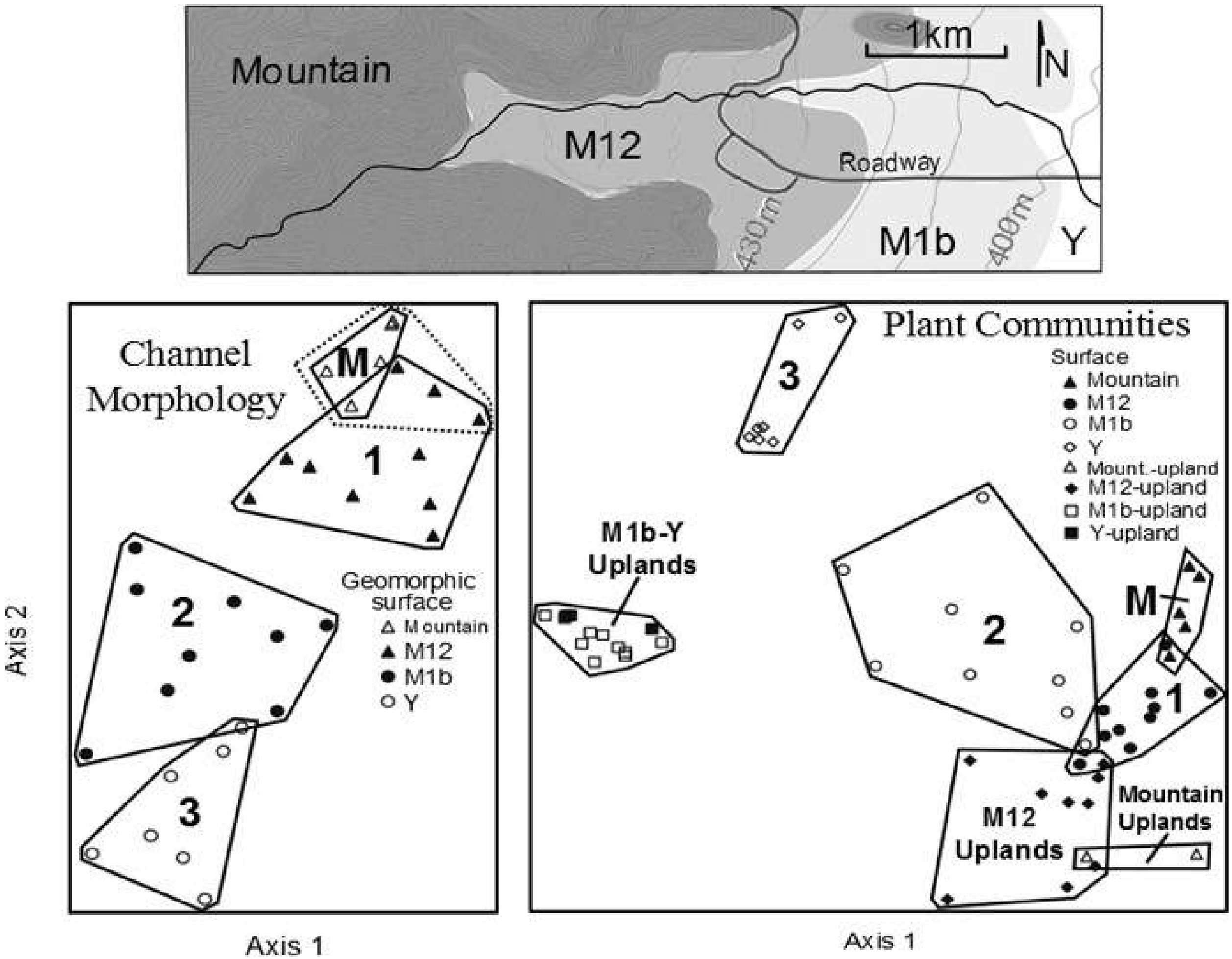

Figure 1. Results of the eastern bajada ephemeral drainage study site. Other bajadas study sites had similar results and are summarized within the results section but not presented within this figure. Top, geomorphic surface map of the eastern site according to Field and Pearthree (1991). Bottom left, Non-metric multidimensional scaling (NMS) plot of channel morphological characteristics. Solid overlay boxes represent major groupings of channel morphology types according to geomorphic surfaces. Dashed overlay box represents channel reaches strongly influenced by bedrock within the channel. Bottom right, NMS plot of plant communities, overlay boxes represent major groups according to geomorphic surfaces. Overlay boxes M, 1, 2 and 3 represent geomorphic surfaces and contain same channel reaches in both NMS plots. M in the ordination plot corresponds to the mountain geomorphic surface, 1 in the ordination plots corresponds to the upper bajada soil surface M12, 2 in the ordination plots corresponds to the middle bajada soil surface M1b, and 3 in the ordination plots corresponds to the lower bajada soil surface Y.

the greatest number of rills or channels entering the main channel. Flows in channels on lower bajadas were variable between the bajadas.

Plant Communities

Four ephemeral drainage and three upland plant communities were identified through Non-metric multidimensional scaling (Figs. 1, 3). Clustering of sampled reaches appeared to be dependent on geomorphic surface or channel morphology and therefore reaches were grouped accordingly. Upland plant communities within the mountain were dominated primarily by *Encelia farinosa* (brittlebush), on the upper bajada *Ambrosia deltoidea* (triangle leaf bursage) was the dominant species, and on the middle to lower bajada *Larrea tridentata* (creosote bush) was dominant. Within mountain and upper bajada drainage reaches *Parkinsonia microphylla* (foothill palo verde) was the dominant species. However, species associated with *P. microphylla* differed between the mountain and upper bajada making them group as two different plant communities. Middle bajada channels were dominated by *L. tridentata* and lower bajada channels *P. florida* (blue palo verde). Both upland and drainage plant species richness decreased downslope away from the mountain with drainage species richness being greater overall (Fig. 4).

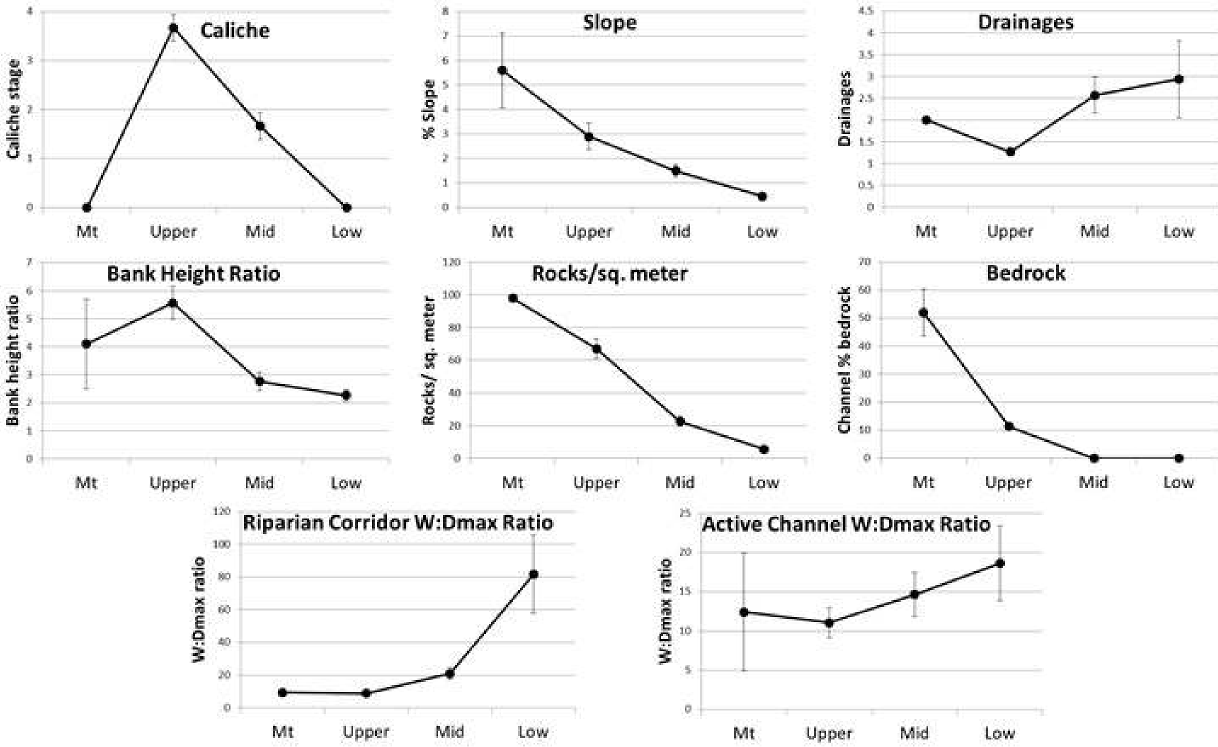

Figure 2. Channel morphology types characteristics. X-axis represents both generalized geomorphic surface channel morphology types found on, and major channel morphology type; Mt is mountain landform, Upper is upper bajada, Mid is middle bajada, and Low is lower bajada. Top left, Caliche graph shows stage (0, no caliche present to 4, highly developed caliche) of caliche development found in channel reach banks. Top middle, Slope graph showing mean channel type slope. Top right, Drainages, average number of low-order drainages or rills entering both channel reaches and 100m upstream. Middle left, Bank Height Ratio, low bank height/maximum depth bank full, a measure of incision. Middle, Rocks/sq. meter, number of rocks >25mm/m^2. Middle right, Bedrock, percent of channel with exposed bedrock. Bottom left, Riparian Corridor W:Dmax Ratio, width to maximum depth ratio for entire historical riparian corridor. Bottom right, Active Channel W:Dmax Ratio, width to maximum depth ratio for present day active channel.

Discussion

Hydrogeomorphic and botanical associations found along the bajada ephemeral drainages examined within this study were determined to be strongly influenced by the geomorphic surface dissected by the drainage. Each geomorphic surface dissected by a drainage influenced channel morphology, ephemeral flow patterns and plant community associations. In a given geomorphic surface, the presence of bedrock and degree of caliche development appeared to have the strongest influence on these associations.

Four major hydrogeomorphic-botanical associations were identified, (1) bedrock constrained channels within mountain landforms, typically with discontinuous flow patterns and *Parkinsonia microphylla* (foothill palo verde) plant communities, (2) upper bajadas with strongly caliche constrained channels that were deeply incised, had low flow frequencies and containing *P. microphylla* plant communities, (3) middle bajadas with weakly caliche constrained channels of moderate incision with higher frequencies of flow and containing a *Larrea tridentata* (creosote bush) plant community and (4) lower bajadas with geomorphically unconstrained channels of moderate to no incision with variable flow patterns and a *P. florida* (blue palo verde) plant communities. These ephemeral drainage associations typically had an associated upland plant community adjacent to the channel. As seen in other studies, upland plant communities, similar to drainage communities, were strongly influenced by geomorphic surface soil development (McAuliffe 1994, 1999).

Caliche development of geomorphic surfaces was determined from this study to have a strong influence on the development of a channel morphology types. This is possibly due to the strongly cohesive, almost bedrock-like properties of highly developed caliche. Channel sediment cohesiveness has been demonstrated elsewhere as having a strong influence on channel morphology (Murphey et al. 1972, Bull 1997, Wohl and Achyuthan 2002). In addition to caliche development, each geomorphic surface of a bajada has a different lithological composition which will result in different channel morphologies (Leopold 1992).

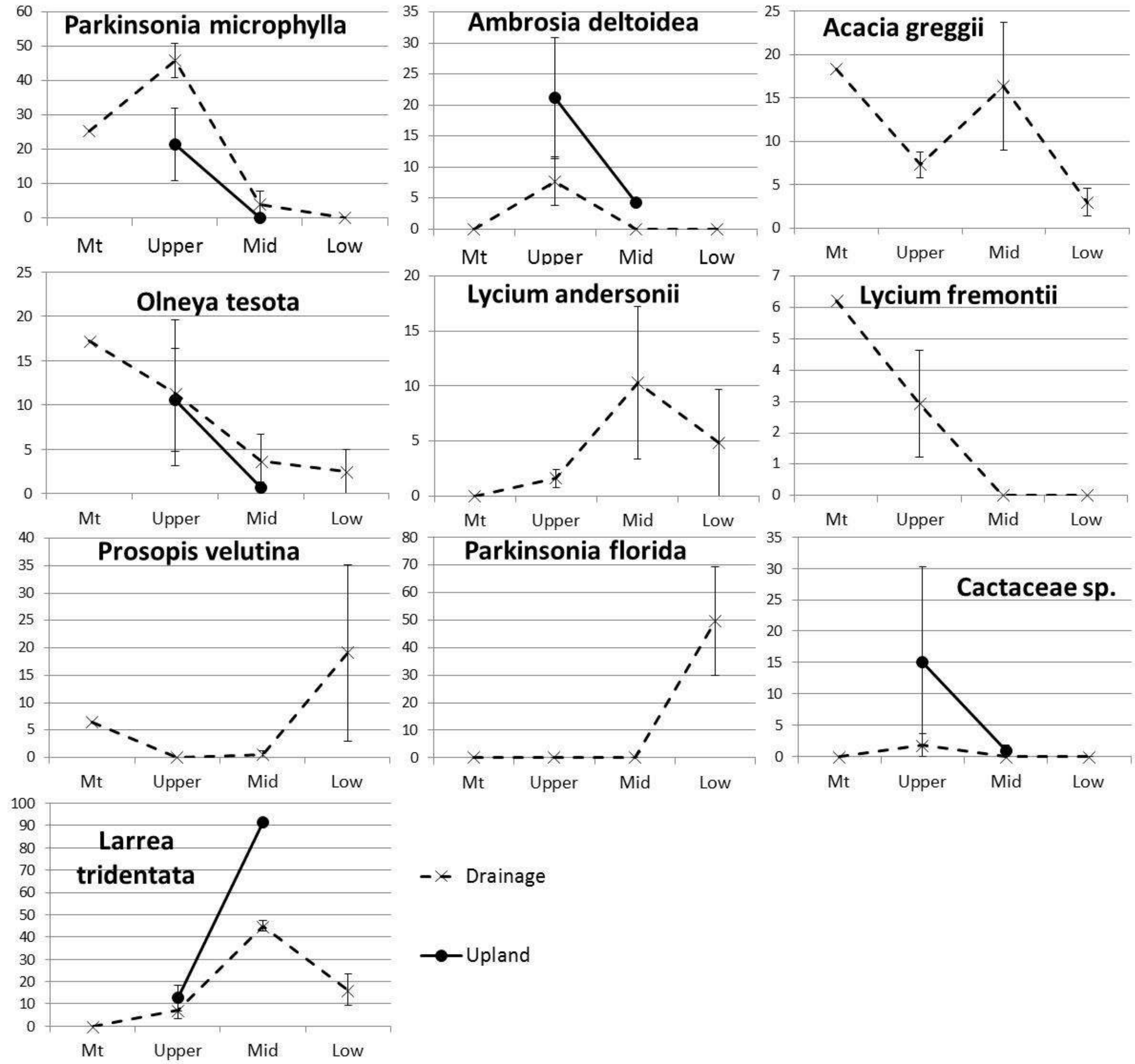

Figure 3. Combined data for both uplands and ephemeral channels of relative cover for similar geomorphic surfaces and channel types for each of the study sites. X-axis represents generalized geomorphic surface or channel type. Mt is mountain, Upper is upper bajada, Mid is middle bajada and Low is lower bajada. Y-axis is percent relative cover. Mountain landform upland communities were not sufficiently sampled and so are not included in these graphs. Lower bajada upland communities were grouped with middle bajada upland plant communities due to Non-metric multidimensional scaling plot results (Fig.1). *Parkinsonia microphylla* is foothill palo verde, *Ambrosia deltoidea* is triangle leaf bursage, *Acacia greggii* is catclaw acacia, *Olneya tesota* is ironwood, *Lycium andersonii* and *L. fremontii* are both wolfberry, *Prosopis velutina* is velvet mesquite, *Parkinsonia florida* is blue palo verde, Cactaceae sp. is cactus species and *Larrea tridentata* is creosote bush.

The discontinuous nature of flow through the observed ephemeral drainages also appeared to be strongly influenced by properties of the various geomorphic surfaces dissected. Two factors are considered possible influences on frequency of flow within channel reaches, (1) the ability of channel sediments to carry flow and limit transmission losses, and (2) the ability of a geomorphic surface and channel to convert upland sheet flow into channel flow. Channel reaches with a greater number of rills and smaller channels entering the drainage had more frequent flows. Within mountain channels, flow entered in many locations but was lost to transmission losses within a short distance of initiation, possibly due to deep and coarse channel sediments. Upper bajadas were deeply incised and had the lowest number of smaller channels entering sampled channel reaches. These factors were possibly why upper bajada channels had the lowest frequency of flows compared to other landscape positions. Deep incision of upper bajadas possibly prevented efficient conversion of upland sheet flow

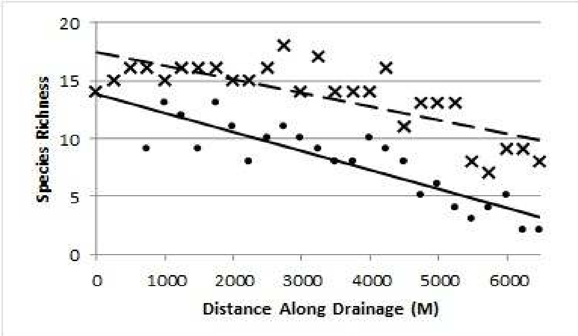

Figure 4. Eastern bajada species richness for uplands and channel reaches versus distance along drainage. X's represent channel reach plant species richness and the dashed-line represents channel reaches species richness regression. Dots represent upland plot plant species richness and the solid-line represents upland species richness regression.

to channel flow. Steep upper bajada slopes, running parallel to the ephemeral drainage, also caused sheet and small channel flow to run parallel to the main channel rather than merging with it and causing flow. Many of these smaller order channels on the upper bajada, however, converged with the main channel on the middle bajada where flow was found to be most frequent across all of the study sites. Channel flow patterns along lower bajadas were variable from site to site. In general however, smaller channels had more frequent flows than larger channels. This variability between sites possibly was a result of increasing channel sediment bed load volumes as channel size increased. Increased channel bedload possibly resulted in increased ability to absorb transmission losses.

The discontinuous nature of ephemeral flows observed within this study suggests that moisture does not increase downslope in ephemeral streams as has been demonstrated elsewhere (Goodrich et al. 1997). Therefore, plant communities are not responding to increased moisture downslope. Possibly, plant communities associated with the various channel morphologies and ephemeral flow patterns were a result of adaptations to soil properties and geomorphic processes taking place within various channel reaches. Channel properties and processes, as demonstrated above, were likely determined by the geomorphic surface dissected by the drainage. Within uplands, Sonoran Desert plant community structure is a result of soil development and the resulting distribution of moisture within the soil profile (Hamerlynck et al. 2002). Highly developed soils with strongly developed caliche and argillic horizons accumulate moisture above the caliche and impede root penetration deep into soils, therefore plant communities are characterized by shallow rooted plants such as *Ambrosia deltoidea* (triangle leaf bursage). Undeveloped soils lacking argillic and caliche soil horizons are characterized by deep infiltration of moisture and therefore deep rooted plants such as *Larrea tridentata* (creosote bush). It is expected that similar geomorphic associations are taking place within ephemeral drainages. For example, *L. tridentata* was most abundant in weakly caliche constrained and geomorphically unconstrained channels. This most likely is due to the lack of a caliche horizon which would impede moisture and root penetration deep into sediments. *L. tridentata* was, however, in very low abundance or completely absent in bedrock and strongly caliche constrained channels. Other species such as *Parkinsonia florida* (blue palo verde) and *Prosopis velutina* (velvet mesquite) also appear to be limited by the presence of caliche. Based on its abundance in strongly caliche constrained channels, *Parkinsonia microphylla* (foothill palo verde) appears to be highly adapted to the presence of caliche within channels as well as the process of channel incision.

CONCLUSION

Similar to upland plant communities within the Sonoran Desert, ephemeral drainage plant communities are strongly influenced by geomorphic surface dissected by the drainage. While it is known that the presence and degree of argillic and caliche soil horizon development influence upland plant communities by determining locations of moisture infiltration and limiting root penetration into soil, the exact nature of how geomorphic surface soil development determines plant communities within ephemeral drainages is not known. Channel morphology and ephemeral flow patterns also were determined to be strongly influenced by soil development of geomorphic surface dissected. These factors also possibly have a strong influence on plant community, but again, the exact nature of how this might affect plants is not known. Plant adaptations to geomorphic surface soil development within uplands can be simplified to vertical distribution of moisture and penetration of roots (Hamerlynck et al. 2002). Drainage plant adaptions are possibly far more complex having to deal with a wider range of conditions related to moisture and geomorphic processes such as flash floods, deposition and erosion. Further research is needed on the hydrological and geomorphic adaptations ephemeral wash plant species have that might make them adapted to certain channel morphologies.

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