Forage Assessment of the Lower Salt River Horse Recreation Area, Maricopa County, Arizona

Final Report

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BACKGROUND

The Salt River horse herd was established with AZ State Bill HB2340 and signed into law by Governor Doug Ducey on May 11, 2016. The bill established the Salt River horse herd as property under jurisdiction of the State. The Bill makes it illegal to harass, shoot, kill, or slaughter horses in the proposed Salt River horse zone established on the Tonto National Forest. The bill also states The Arizona department of agriculture shall enter into an agreement with the United States Forest Service (FS) pursuant to section 11-952, Arizona Revised Statutes, to implement title 3, chapter 11, article 11, Arizona Revised Statutes, as added by this act. B. Title 3, chapter 11, article 11, Arizona Revised Statutes, as added by this act, does not become effective unless the Arizona Department of Agriculture (ADA) and the FS enter into an agreement pursuant to subsection A of this section on or before December 31, 2017. This agreement was signed December 27, 2018.

Wild horses on public lands are protected under CFR 36 Subpart B 222.20-36 (Code of Federal Regulations) and subject to management actions which include provisions for sanctioned removal from FS lands. However, the Salt River horse population is not currently classified as *Wild* under the Wild Free-Roaming Horses and Burros Act of 1971 and as a result are not afforded protected status under the existing Federal statute. The introduction of Arizona HB2340 states Salt River horses are no longer considered stray under State law and therefore prohibited from removal. Arizona HB2340 limits the removal of the horses and other management options from the Tonto National Forest as feral or stray livestock.

The University of Arizona was commissioned by the Southwestern Region and Tonto National Forest to conduct forage availability analysis of the approximately 11,000-acre Salt River horse zone. Forage availability analysis provides a loose measure of seasonal vegetation production values that may be used in turn to estimate sustainable horse densities and overall carrying capacity by animal unit (AU) within the Salt River horse zone.

INTRODUCTION

Free-roaming are managed under protected status as "living symbols of the historic and pioneer spirit of the West" by The Wild Free-Roaming Horses and Burro Act (1971). Since its enactment, populations of free-roaming horses have become well established. For many people these horses are emblematic of America's unique heritage and provide a sense of enrichment and cultural fulfilment not distinct from that afforded by native wildlife. As a result, numerous advocacy groups have been established to facilitate and, in some cases, check the management approaches of both State and Federal agencies. This diverse confluence of viewpoints necessitates an informed dialogue that weighs the emotional enrichment afforded by these horses with the potential ecological impacts posed by the population. Such an approach is critical to ensuring horses have a sustainable role in the American West.

The introduction of free-roaming horses to an ecosystem may have implications for both interspecies competition and biodiversity (Berger 1985, Beever and Brussard 2000,2004, Otermann-Kelm et al. 2008, Hall et al. 2016,2018, Scasta et al 2016) as well as for the soils and vegetative communities on which they graze (Pavage et al. 2011, Porter et al. 2014, Boyed et al 2017). Horses are highly adaptable and were domesticated, in part, for their capacity to persist in a range of environments from lowland desert basins to sub alpine forests (Mills and McDonnell 2005). As a result, resource utilization may vary widely among horse populations, often necessitating management options that are both complex and case specific (Garrot and Oli 2013).

The content and quality of a nonmigratory herbivorous mammal's diet likely fluctuates in response to seasonal change and overall variation in forage availability. As a result, such herbivores may adopt a more dynamic forage strategy in an effort to meet nutritional demands during periods of limited accessible forage (Kutilek 1979, Scarnecchia et al. 1985). Variation in forage strategy is most commonly observed in resource limited systems where climatic and/or density dependent factors necessitate utilization of a range of plant species in order to meet basic nutritional demands (Marshall et al. 2004, Frank and McNaughton 1998).

Forage production can vary substantially from year to year or by season based on the timing and amount of precipitation received. In arid systems annual forage may be available only during years where precipitation is normal or above, conversely annual production may be significantly reduced in years with below average precipitation. Typically, the Forest Service does not include annual vegetation in forage production calculations (BLM 1996; Smith et al. 2005), however, for this study we chose to include annual vegetation when it was green and growing as it appeared to be a main source of forage for the Salt River horse population at the onset of this study. In general, the production of annual vegetation is highly dependent on the occurrence of seasonal precipitation events that, in an arid system, may vary significantly in both space and time. As a result, using early season metrics of precipitation are not always an accurate means of predicting annual forage production (Duncan and Woodmansee 1975). Over the course of this study we failed to document a single perennial grass plant within any of our study locations. It is possible that continued utilization combined with drought have suppressed the perennial grass component of this system though further study would be required to adequately address this hypothesis.

Estimating forage production on rangelands has long been an important element of grazing and rangeland management. Forage production is defined as the weight of forage that is produced within a designated period of time on a given area, often expressed as green, air-dry, or oven-dry weight. These measures may be classified as annual, current year's, or seasonal forage production (Vallentine 2000) and is typically restricted to above ground production (Gillen and Smith 1986; Despain et al. 1991; BLM 1996). Quantifying comparative yield has been a standard method for estimating total biomass or production on southwestern rangelands. Comparative yield provides a relatively rapid and simple method for documentation of yield estimates than visual estimations alone, and when combined with dry-weight rank (DWR) provides a measure of species composition by weight (Gillen and Smith 1986; Despain et al. 1991; BLM 1996).

The *greenness* or density of photosynthetic pigments (i.e. chlorophyll) within an individual plant correlates strongly with nutritional quality (Augustine and McNaughton 1998, Mehaffey et al. 2005, Christianson and Creel 2009). In general, nutritional quality of forage is highest during periods of production and declines as a plant species increases in lignin's or becomes senescent. Highest quality forage is typically selected preferentially to maximize nutritive value and may therefore dictate the spatiotemporal distribution of grazing species within an ecosystem (McNaughton 1985, Frank and McNaughton 1998). Horses may utilize a range of graze, browse and aquatic species in an effort to supplement nutritional requirements seasonally (Hanley 1982, Crane et al. 1997, Mills and McDonnell 2005, Schoenecker et al 2016). Measuring seasonal variation of forage quality and availability on diet is critical for understanding the way in which a species both interacts with its environment and for better understanding the underlying physiological responses that govern population health and dynamics. Fecal sampling of equids provides an informative, cost effective and non-invasive means by which to examine detailed dietary characteristics of free roaming horses (King et al 2018). Calculating the density of photosynthetic pigments via fecal chlorophyll analysis is, therefore an effective means by which to relate diet quality to seasonality and broader environmental changes within a given population (Christianson and Creel 2009). We examined forage production and metrics of diet quality of Salt River Horses to 1.) document forage availability by species by season 2.) examine general patterns of seasonal variation in diet quality 3.) relate diet quality to metrics of seasonal forage availability 4.) relate diet quality to diet content and 5.) to examine potential for changes in quality between spring season of 2017 to 2018 under normal precipitation and drought conditions, respectively.

STUDY AREA

The total defined study area encompasses roughly 6,500ha extending east/northeast from the confluence of the Verde and Salt Rivers between the Bush and Beeline Highway 87 until their intersection (Appendix 1). The riparian corridor and mesquite bosques occupy roughly 1,800ha with the remaining ~4,700ha comprised of Sonoran upland vegetation and decomposed volcanic soil type. Topography is relatively mild across the study area and is defined largely by the Salt River valley with rolling ridgelines, washes and small hills to the north of the Salt River. Elevation ranges from 400m at the confluence of the Verde and Salt Rivers to 895m at the summit of Stewart Mountain at the eastern extent of the study area. Average annual rainfall is 18-25cm though measured precipitation was slightly above average in during 2017 at 28.8cm at the nearest weather Station (Saguaro Lake; Gage ID 63500). Winter precipitation data beginning December 2017 have not been posted at the Saguaro Lake Weather Station, however, regional totals are well below 30-year average and have precipitated regional drought conditions throughout the Southwest.

METHODS

On most rangelands, aboveground plant biomass (standing crop) is best measured in late summer to early fall after most of the perennial grass has reached maturity and is referred to as 'peak standing crop' (Smith et al. 2005). However, due to the complexity and dynamics of rangeland ecosystems, repeated measurements throughout the season may be necessary to more accurately quantify annual forage production.

Production data were collected at both upland locations (*n*=8) (determined by distance from river and dominant plant species occupying each site) and mesquite bosque sites (*n*=3) within the study area (Appendix 1). Collection locations were established by University of Arizona Research Specialists and consisted of 2 parallel pace transects (*N*=11) of 50 quadrat placements (*N*=100). Initial transect direction was randomly selected. Transects were separated by a minimum of 4 paces between them. We considered annual plants in our surveys only when annuals were green and growing and were assumed to be a main source of forage for the horses in the Salt River area. Senescent annuals were not quantified in our analysis. Transects SRH07 and SRH08 were established but became largely inaccessible following the scheduled flow increase to the Salt River beginning in April 2017. Preliminary measurements from these transects were not included in our metrics of production data.

A list of all plant species present at each sampling location were recorded prior to production data being collected. Any species unknown to the observers were collected and brought to the University of Arizona Herbarium for identification.

Data were recorded using the Vegetation GIS Data System (VGS) version 4.0 software on University of Arizona tablet computers. VGS comparative yield data were computed manually in Microsoft® Excel® (Microsoft 2016).

Dry-Weight Rank (DWR)

At each quadrat placement, the three species with the highest yield on a dry weight basis were ranked. The highest yielding species was given a rank of 1, the next highest 2, and the third highest a 3. If there were less than three species present in the quadrat, multiple ranks were assigned to the species present. This method of DWR assumes that a rank of 1 corresponds to 70% composition, rank 2 to 20%, and rank 3 to 10%. Therefore, if only one species was present it was assigned ranks 1, 2 and 3 (or 100%). If two species were found, one was given ranks 1 and 2 (90%) ranks 1 and 3 (80%) or ranks 2 and 3 (30%) depending on the relative weight of the two species (Gillen and Smith 1986; Despain et al. 1991; BLM 1996).

The portion of a plant that contributed to dry weight includes any part of a plant that occurred within a vertical projection of the quadrat perimeter. For each species, the number of 1, 2, and 3 ranks were multiplied by 7, 2, and 1 respectively and were recorded under the appropriate weighting column. These values were then added and recorded under weighted species column. Individual species rates were established by taking the relative frequency of that species via the weighted column and dividing that species estimation by the total assessed biomass per site to assess relative species composition per site as a ratio.

Comparative Yield

Comparative Yield is a double sampling method for estimating available standing crop. Prior to sampling, five reference quadrats were established (Haydock and Shaw 1975; BLM 1996; Smith et al. 2005). Each reference quadrat was selected to represent the range in dry weight of the standing crop that was likely to be encountered during sampling. The quantity of new vegetative growth in quadrats 1 and 5 defined the spectrum of measured yield. Reference quadrat locations were located by first selecting a representative location of lowest yield (excluding bare or nearly bare quadrats) as quadrat 1 followed by selection of a highest comparative high yield site for quadrat 5 (excluding unusually dense patches of vegetation or situations that had a rare chance of being encountered during sampling). Reference quadrat 3 was located by selecting an area of relative density roughly half way between references 1 and 5 in terms of dry weight of plant material within the frame. Reference quadrats 2 and 4 were thus established in the same manner. Reference quadrats were then clipped and weighed to verify a linear distribution of vegetative weight. New reference quadrat sampling locations were established during each monthly collection interval to avoid re-sampling an area that had already been measured during previous sampling efforts.

Sampling was conducted in conjunction with dry weight rank. At each quadrat placement, the quadrat was mentally or directly compared to the references and given a rank corresponding to the appropriate reference. If a yield of a quadrat appeared to be greater than the references, a greater reference was given (i.e. 6, 10, etc.) appropriate to the level of additional vegetation found within the frame.

Vegetation in the reference quadrats was clipped and weighed following sampling. Clipped material was oven-dried at 60 degrees Celsius for 48 hours. Samples were then re-weighed and final dry weight of each sample was used in all calculations of comparative yield.

Average yield was estimated by ratio estimate on an oven dry-weight basis (BLM 1996). The average rank of the 5 clipped quadrats (3.0) was multiplied by the mean weight of the clipped samples (g). The mean rank of all quadrats estimated in the sample was multiplied by the mean rank interval gives the estimate of the mean yield per quadrat for the sample. The mean yield per quadrat was multiplied by a conversion factor of 62.5 to convert from grams per quadrat to kilograms per hectare for a 40x40cm ($0.16m^2$) frame. The average yield (kg/ha) was then multiplied by a conversion factor of 0.9 to convert from kg/ha to lbs/ac.

Total vs. Accessible Forage Availability

Traditional methods of estimating forage production via DWR and Comparative Yield typically account for total vertical canopy cover. Our original field methods modeled these estimations and accounted for total vertical canopy cover during each site visit. However, this approach likely overestimates the relative quantity of forage actually accessible to horses. To mitigate potential effects of over estimation of forage availability we conducted a *post hoc* analysis to develop an adjusted metric of accessible forage across measured upland sites. Monitoring sites were first sorted by vegetation class with classifications determined by dominant vegetation groups (i.e. primarily tree and annual; shrub and annual; tree, shrub, annual; etc.). Two sites were subsequently remeasured using DWR and comparative yield. *Accessible forage* was defined as the estimation of the maximum height an average Salt River horse might reach on a tree or shrub without its front hooves leaving the ground. We established a maximum ~2.5m vertical height. All measured transect data was then adjusted based off relative site species composition and derived metrics of accessible forage to measure forage availability over time.

Image 1 Browse line observed near the Goldfield Recreation Area. Browse lines were common in dense sections of mesquite bosques where horses tended to congregate during the heat of the day, however, general browsing on mesquite was evident across the study area.

Diet Sampling and Fecal Chlorophyll Analysis

We collected Salt River Horse fecal samples opportunistically proximal to each established vegetation transect. We sampled horse feces from February-December 2017 (*n*=54) with a comparative set of fecal samples collected in March of 2018 (*n*=18). Fecal samples were used for both Next Generation DNA sequencing as well as to assay fecal chlorophyll content. Samples were collected concomitantly with our measures of DWR and comparative yield. This approach was used 1.) to examine potential variation in horse diet content and selection as it relates to seasonal forage availability and 2.) compare diet to real time utilization metrics (DWR and comparative yield). Collection of Class I-III samples (Appendix 7) were prioritized with three to five samples collected at each site at least once monthly with the exception of June and September of 2017 in which no collection occurred. The bulk of samples were collected proximal to the riparian corridor (Appendix 8) with remaining samples collected only infrequently in the upland sites given limited horse occupancy during the drier seasons. All fecal samples extracted were preferentially selected based on freshness to minimize the potential for degradation by continued bacterial decomposition, solar exposure and invertebrate consumption. When possible, samples were collected >20m apart to minimize potential for repeat sampling of the same individual. Samples were collected and stored in paper bags to minimize potential for damage via condensation derived from storage in plastic. Samples were put on ice for transport and stored at 1˚c until extraction.

Next Generation sequencing of Salt River horse fecal samples was performed by Jonah Ventures laboratory (Boulder, Colorado, USA). Batches were analyzed at an interval of three months and correspond roughly with broader seasonal changes. Outputs of the dietary analysis were returned by Jonah Ventures in the form of a consolidated species list via a Microsoft Excel spreadsheet. Dietary composition was then organized hierarchically off relative composition of plant species consumed/season. In instances where specific plant species were unidentifiable the plant genus was used as a classifier. Given the diversity of plant species detected, species that corresponded to <5.0% of total sample composition/season were omitted from our final analysis given the potential for incidental consumption rather than seasonal selection by individual.

Photosynthetic pigments were extracted by measuring approximately 0.2g of ground fecal matter from each sample into 50mL sample vial. Each vial and pellet were measured to record the initial weight. We added 30mL of ethanol to each vial and boiled all samples at 80˚c for 20 minutes to extract the pigment from the solid material into solution. After cooling, 20µl of supernatant from each sample was pipetted into a corresponding well plate and run for spectrophotometric analysis (Epoch Microplate Spectrophotometer). We measured light absorption at a single wavelength of 666nm optical density based on the established protocols developed by Christianson and Creel (2009) to measure concentration of photosynthetic pigment of each sample. Following spectrophotometry all sample vials with remaining ethanol solution were placed in a drying oven at a temperature of 75 ˚c for 24-48 hours. After drying, each sample tube and pellet were weighed again to relate total pellet size to measured concentration of photosynthetic pigment to develop our adjusted values of chlorophyll content per sample.

RESULTS

Vegetation production values across the established upland monitoring sites were highly variable over the 2017 collection season. Such high variability in seasonal production in the southwest is not uncommon, given the spotty spatiotemporal distribution of precipitation events. Winter rains in 2016 produced a flush of winter annual production, as shown by the February 2017 measurements and production steadily declined throughout the remainder of the year (Figure 1).

The initiation of this study during February 2017 coincided with the highest measured levels of winter annual vegetation production on the Salt River horse area. Peak (maximum) total forage production values for 2017 were measured in February and ranged from 129.0 lbs/acre to 2215.7 lbs/acre across the nine established sites while the lowest production values were measured in December 2017, ranging from (37.6 lbs/acre to 534.2 lbs/acre) (Appendix 11).

The site with lowest winter/spring productivity was SRH08 at 129.0 lbs/acre. The site was primarily dominated by low lying annual forb production. SRH05, located at the Blue Point recreation area, exhibited the greatest measured winter productivity at 2215.7 lbs/acre and was comprised entirely of annual forbs and mesquite foliage. Both sites SRH04 and SRH10 consistently had the lowest total productivity throughout the summer months.

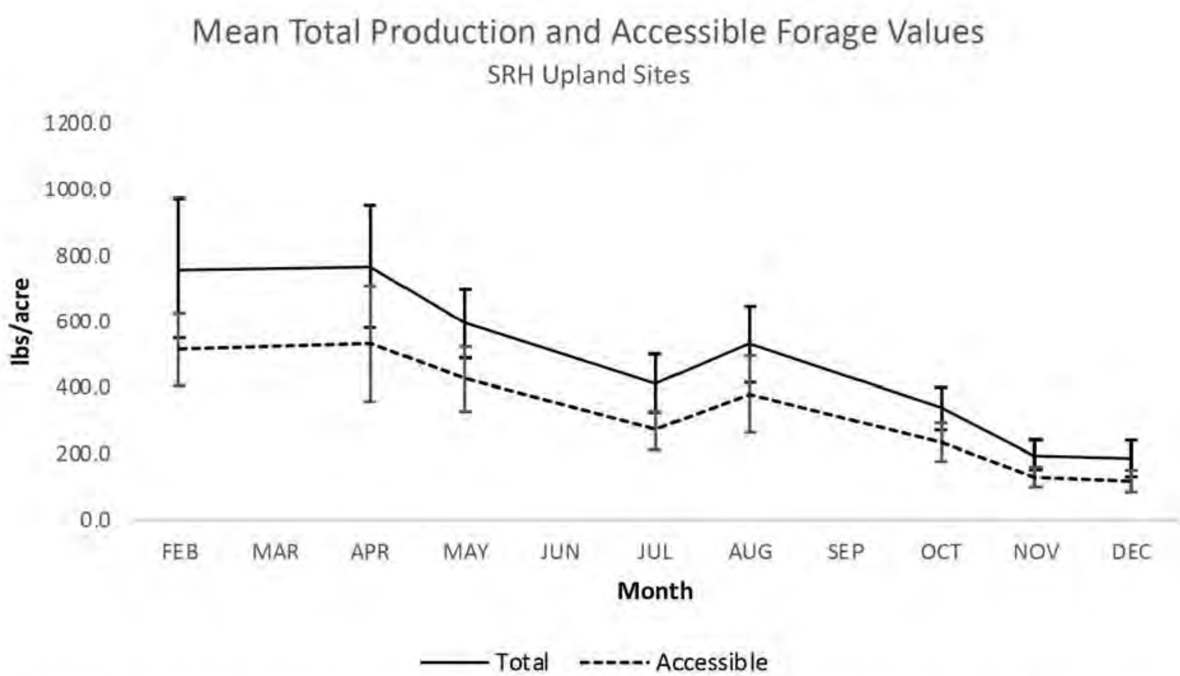

Figure 1 Graph compares the relationship between the mean total forage availability to only forage accessible to horses below an 2.5m height threshold per measured canopy.

Forage availability within the mesquite bosques appeared greatly reduced following peak spring annual production. Accessible production values ranged from 425 lbs/ac to 380 lbs/ac during the hottest months of the year. Direct observation of horses at the Usery Pass and Blue Point Recreation Areas shows a reliance on remaining spring annuals including species such as six-weeks fescue *(Vulpia octoflora)*, six-weeks needle grama *(Bouteloua aristidoides)*, and red brome *(Bromus rubens)* and a variety of mustards (*Brassica* spp.). Annuals, when consumed, were typically highly degraded often having been trampled and in the case of the mustards, broken into sections then eaten off the ground. Red brome was rarely consumed, if at all, on any of the upland site locations.

Species composition across the study area was comprised primarily of brittlebush (*Encelia farinosa*), mesquite (*Prosopis velutina*), and ironwood (*Olneya tesota*) with smaller shrubs such as bursage (*Ambrosia deltoideae*), creosote (*Larrea tridentata*), annual grasses and annual forbs occupying the understory (Figure 2). Field observations indicated little to no perennial grass at each of the initial sampling locations and cross-country travel between locations. Appendix 2 provides a comprehensive list of all documented plant species.

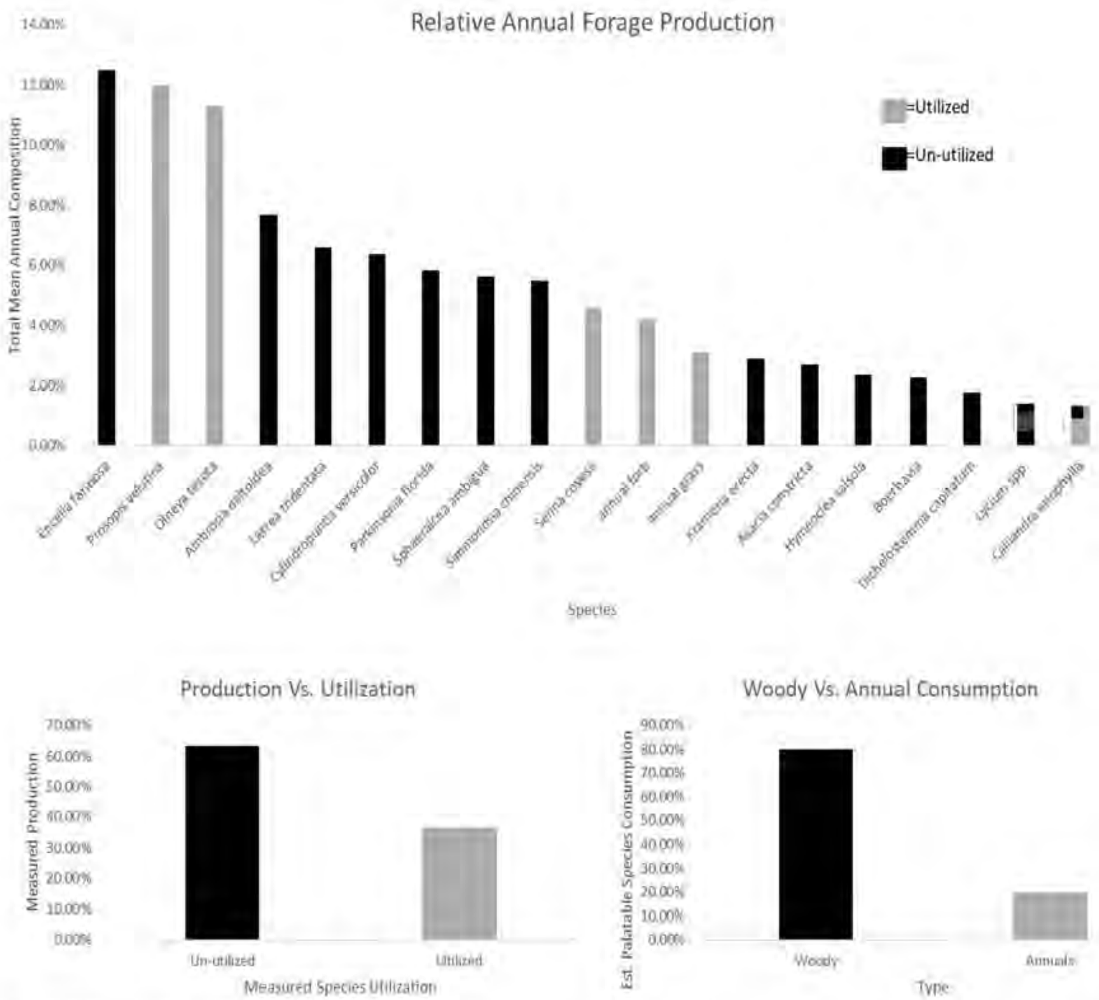

Figure 2 Mean forage production for all species measured ≥2.0% of production over 2017. Of available potential forage species few were actively selected by horses for consumption of which the majority were woody species and of inherently low diet quality.

Spring 2017-2018 Chlorophyll Assessment

We compared the mean relative concentration of chlorophyll pigment for fecal samples collected February to April of 2017 (n=4) to those collected in March of 2018 (n=18) to examine potential variation in diet quality between periods of normal/slightly above average and below normal winter precipitation (Figure 3). Fecal samples collected in 2018 were not sequenced for diet content nor were they related to metrics of forage production as was done with all 2017 samples. This analysis was intended only to establish a relative baseline in diet quality between average precipitation and drought conditions (Image 2). The 2017 sample size was comparatively low given fecal sampling protocols were still being developed at the time of collection, as a result this analysis is opportunistic and true chlorophyll values are likely to deviate somewhat from the given mean.

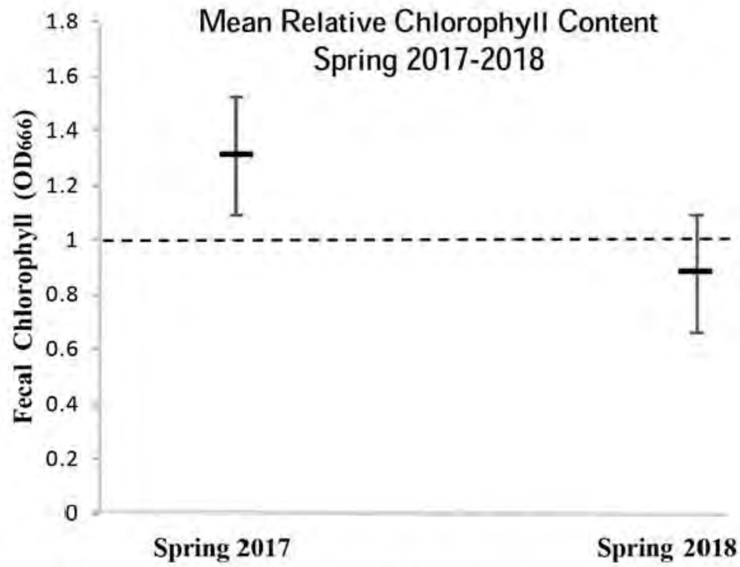

Figure 3 Mean chlorophyll concentration from periods of peak spring production from February-April 2017 and March of 2018. Hash line represents the average chlorophyll value from all extracted 2017 samples below which available forage likely fails to meet/exceed daily nutritional requirements.

Reductions in winter species associated with limited precipitation over the 2018 season have the potential to adversely impact the diet quality of Salt River horses given a strong selection preference for annual forbs and grasses. The mean value of photosynthetic pigment concentration was roughly 33% lower in samples collected during periods of peak production 2018 over those collected from the same period in 2017 with a relative concentration of chlorophyll in all 2018 samples below the cumulative average concentration for all samples collected in 2017 (February-December). While there is low statistical power derived from a reduced 2017 sample size, in general the variation between diet quality of spring 2017 and 2018 indicates horses likely lack that available forage needed to satisfy daily nutritional requirements.

Image 2 Comparison between available forage at the Blue Point transect (SRH05) February 2017[a] and early March 2018[b].

Diet Quality and Composition

We examined the relationship between monthly diet composition derived from Next Generation DNA sequencing of fecal samples and chlorophyll content. This approach allowed for a direct comparison of diet quality to seasonal variation in forage consumption. We selected samples (N=36) of highest quality (Appendix 7) from each collection interval (February-December 2017) from both bosque and upland sites. All samples were extracted using the aforementioned protocols. Variation in individual fecal sample content from the same collection interval is likely a result of forage selection preference and/or forage availability at a given location between horses. As a result, we considered the mean chlorophyll value for all samples extracted across the study area for each sampling period to examine general trends in diet quality across the population rather than individual level. Mean chlorophyll values from each sample interval were related to the mean composition of woody and herbaceous species content, aquatic/riparian species content and mesquite only utilization from each sampling interval via regression analysis.

The dietary characteristics of Salt River Horses relate closely to seasonal trends in forage availability (Fig. 4). In general, measures of elevated chlorophyll content relate to periods of annual forage production following periods of winter and monsoon precipitation. Regression analysis indicates a significant ($y = -1.0353x + 0.7856$; $R^2 = 0.7639$; $p<0.001$) inverse correlation between consumption of woody and herbaceous plant material (Fig. 5). Consumption of herbaceous material is positively correlated ($y = 0.7594x + 0.7532$; $R^2 = 0.1792$; $p=0.007$) with chlorophyll content and diet quality (Fig. 6) while increased consumption of woody plat material results in a significant reduction ($y = -0.4898x + 1.1977$; $R^2 = 0.1046$, $p=0.012$) in mean fecal chlorophyll content (Fig. 7). Mesquite was detected in all but two of the fecal samples extracted and often (52.0%) comprised the majority of plant matter per fecal sample. The abundance and disproportionate utilization of mesquite suggests a potential reliance on the species especially during periods of reduced forage availability. Despite increased utilization mesquite consumption was also negatively associated with fecal chlorophyll and diet quality ($y = -0.9827x + 1.1997$; $R^2 = 0.3508$; $p<0.001$) (Fig. 8). Peak consumption of aquatic or riparian obligate species occurred concomitantly with peak periods of spring time annual production and reduced with the onset of the dry season. Consumption of aquatic/ riparian obligate species correlates positively ($y = 1.5967x + 0.6367$; $R^2 = 0.2222$; $p=0.043$) with diet quality (Fig. 9) and comprises the bulk of herbaceous material per fecal sample from July-December 2017.

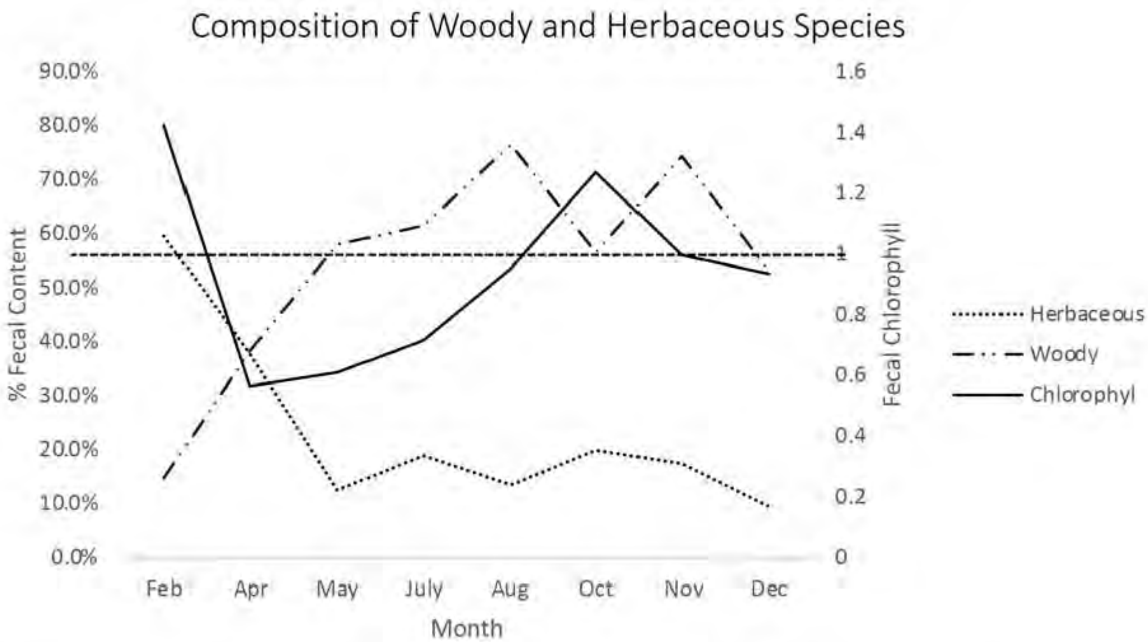

Figure 4 Relationship between forage species consumption and diet quality via fecal chlorophyll analysis from February-December 2017.

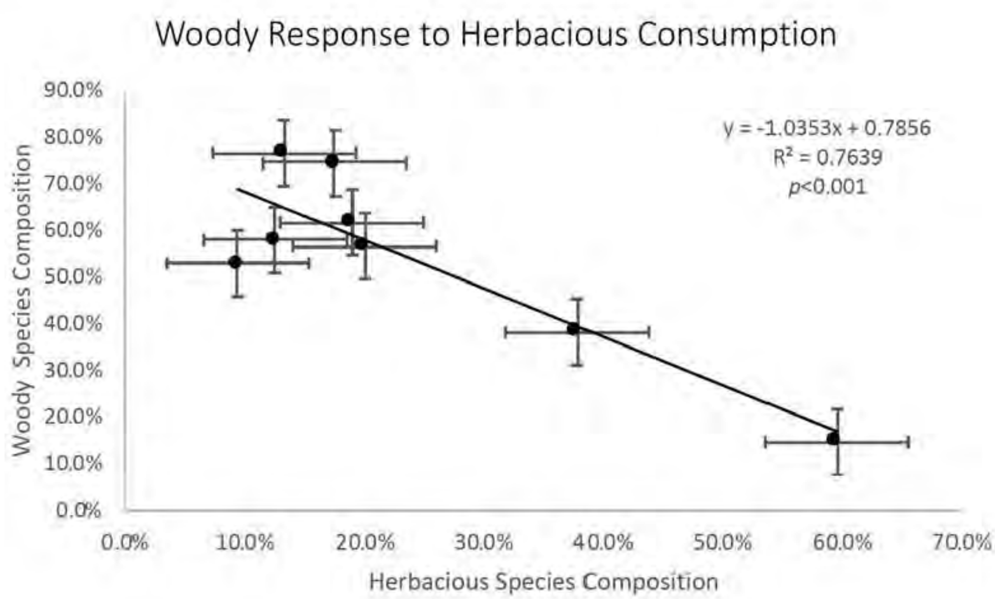

Figure 5 Regression of woody and herbaceous species consumed. Trend indicates a strong selection preference for herbaceous material over woody species.

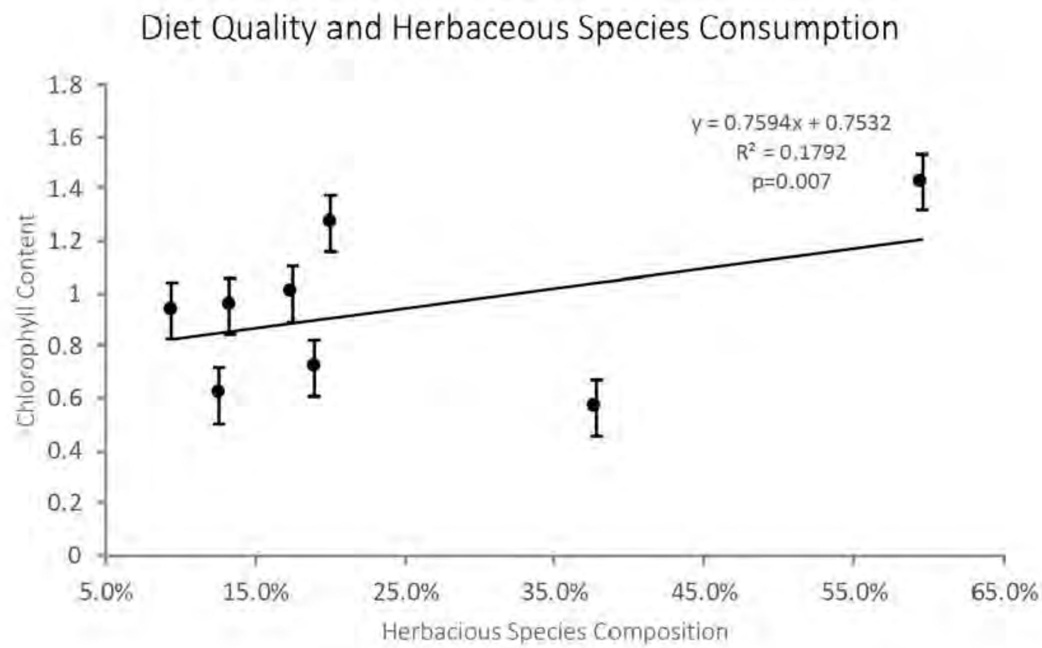

Figure 6 Relationship between mean chlorophyll pigment concentration and the consumption of herbaceous forage species.

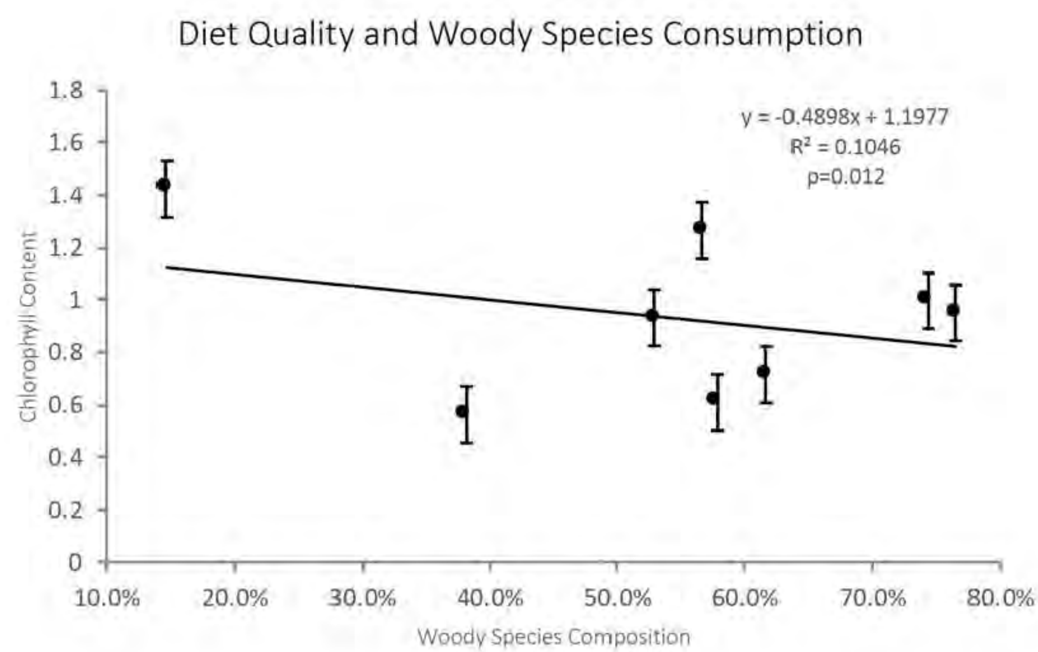

Figure 7 Relationship between mean chlorophyll pigment concentration and the consumption of woody forage species.

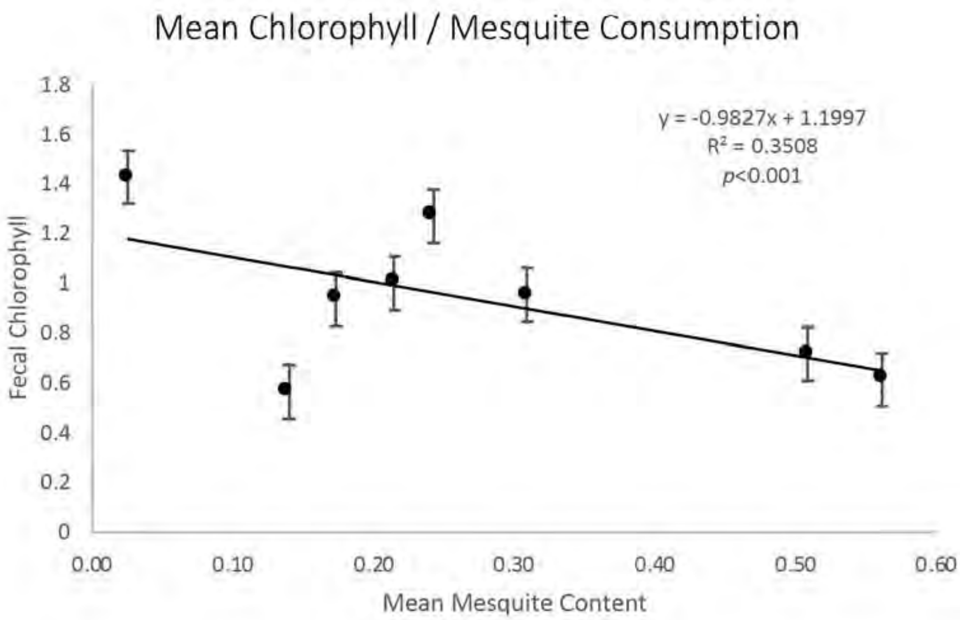

Figure 8 Relationship between mean chlorophyll concentration and the consumption of mesquite only. Mesquite was the most common species consumed by Salt River horses and most often comprised the bulk of the diet.

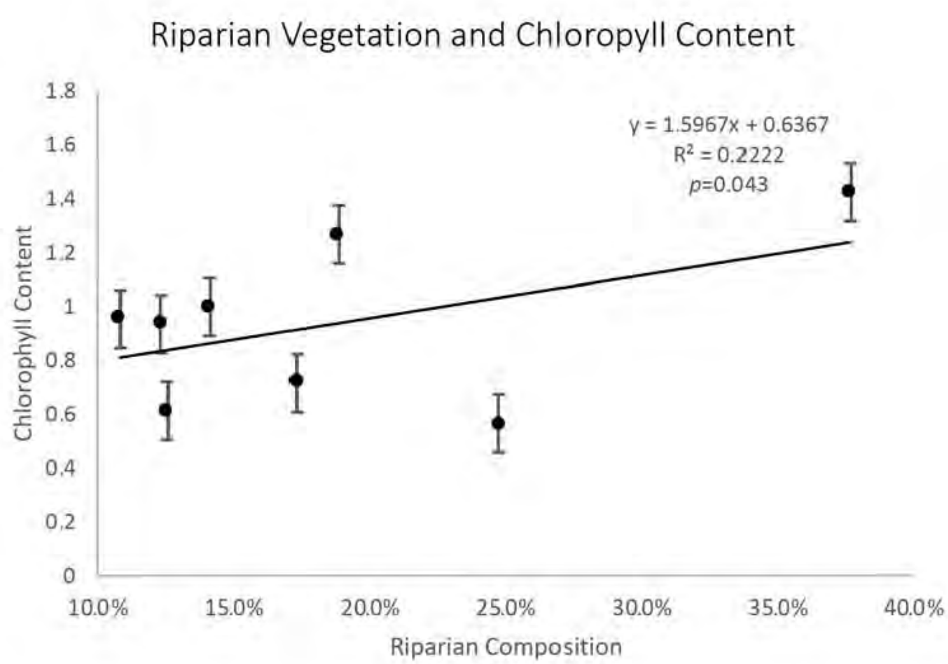

Figure 9 Relationship between mean chlorophyll concentration and the consumption of riparian obligate forage species. Riparian obligate species were consumed consistently over the study, however, the quantity of woody vegetation consumed by Salt River horses likely means utilization of riparian obligate species is only supplementary for much of the year.

DISCUSSION

The diet quality and quantity of the Salt River Horse herd appears strongly linked to seasonal precipitation events and associated production of annual vegetation. We detected a substantial reduction in nutritional quality of available forage in spring 2018 as a likely result of diminished annual forage production under drought conditions. This reduction in diet quality comes at a period when horses would otherwise maximize the nutritional value of available annual vegetation and likely develop energy reserves needed to sustain an individual though the dry season. The contrast in forage quality between spring 2017 and 2018 highlights both the Salt River horses dependence on the production of annual vegetation as well as the inherent lack of available forage alternatives needed to otherwise sustain a population.

When available, horses select for herbaceous plant material almost exclusively, including forbs and grasses, over woody species. Some woody species such as desert fairy duster (*Calliandra eriophylla*) are selected for only seasonally during periods of peak production but are otherwise avoided. As the availability of herbaceous matter is reduced horses increase their consumption of woody browse species including mesquite and ironwood to compensate. Variation in forage availability relates strongly to overall diet quality. Herbaceous forage correlates positively with increased fecal chlorophyll concentration while consumption of woody species exhibits a strong inverse correlation. This trend is especially pronounced when mesquite comprises ≥50% of fecal content. Riparian obligate species were utilized consistently (~10-20% fecal content) from May-December of 2017 with a spike in utilization coinciding only with a peak annual production from February-April 2017. Consumption of riparian obligate forage species correlates positively with increased diet quality; however, high concomitant utilization of woody species suggests consumption of riparian obligate forage alone is not enough to support daily horse nutritional requirements.

Our metrics of seasonal production included overall forage availability of both annual and perennial species including herbs, forbs, grasses, shrubs and trees. Our objective was to develop a comprehensive overview of all *potential* forage species available to the Salt River Horses by season. Analysis of diet content via NextGen fecal DNA sequencing, however, indicates that a majority (~64%) of potential forage species measured across all sample sites were not actively consumed by horses. As a result, estimates of available biomass outside the immediate Salt River riparian corridor likely heavily overestimate actual forage availability given horse selection preference. Upland areas beyond the immediate Salt River riparian corridor are typically lacking in desired forage and therefore likely to be occupied only during periods of peak annual production thus relegating the majority of horse activity and utilization to the mesquite bosque's and river corridor itself. Of the measured species consumed by horses, the majority (~80%) were trees and shrubs and of inherently low nutritive quality. The remainder (~20%) was comprised of annual forbs and grasses and were available almost exclusively during spring 2017.

We measured forage availability only outside of the riparian corridor of the Salt River itself, thus our metrics do not fully account for utilization of riparian obligate species. Data derived from fecal content analysis, however, suggests that the majority of riparian obligate species consumed are reeds, cattails and willows with only trace amounts of bermuda grass (*Cynodon dactylon*) no detection of *Zosteracae spp.* (eelgrass) in any of the fecal contents sequenced. Horses were observed in the Salt River repeatedly over the course of the study but only once did we observe a horse with head submerged and could not confirm consumption of aquatic forage although such instances have been reported anecdotally. More information is needed to validate the selection preference of riparian obligate forage species but our preliminary results suggest Salt River horses likely do not utilize sub-surface aquatic vegetation to the extent previously considered.

In a natural system the capacity of a landscape to provide the resources needed to support a given population operates on a continuum. As the availability of resources change so too will the dynamics of the population over time. This principal holds for both the stocking rate of livestock and the carrying capacity of wildlife (Appendix 6). Carrying capacity is an estimate of the average number of livestock or wildlife which can be sustained on a management unit compatible with achieving objectives for the unit (Society for Range Management 1999). While management efforts may struggle to control all extrinsic factors that may influence a population, density dependent variables may be adjusted to meet the cumulative long-term requirements needed to support a population while also maintaining or enhancing the integrity of that unit. Estimates of carrying capacity are general approximations that must be tempered with other information, experience and judgment (Smith et al. 2007), however, such levels are typically set well below a projected maximum utilization rate so as to allow for seasonal regeneration of grazed areas and to limit the possibility for ecological degradation.

In the case of the Salt River horse herd such a strong dependence on annual forage production likely exacerbates the potential effects of climatic variation on overall population heath and long-term stability. General climate models predict a continued trend of warming and aridification of the Southwest that may result in increased occurrence of drought events (Blacklund et al 2008, IPCC 2013) with broad implications for regional ecohydrology (Wilcox 2010) and vegetation composition (Breshears et al 2008). High dependence on woody vegetation in the diet, especially in years of average to slightly above average precipitation and production as measured in 2017, suggests that the current system likely lacks the capacity to meet the long term nutritional requirements of the herd at the given density. We repeatedly observed horses consuming broken stems of mustard (*Brassica spp.*) off the ground at the Coon Bluff Recreation Area beginning as early as July 2017. We also documented the contrast between total consumption of annual forage species versus overall available dry matter within a fenced exclosure to which horses had no access (Appendix 10). Additionally, neither palo verde (*Parkinsonia spp*) nor brittle bush (*Encelia farinosa*) registered beyond trace amounts in any of the fecal content sequenced, however, by December 2017 we observed at least two individuals actively stripping and consuming branches from a palo verde and documented multiple individuals foraging on the stems of senescent brittle bush with indications of further browsing on multiple brittle bush plants around the transect (SRH03). Though anecdotal, these observations further suggest that horses continually select for lower quality forage only after preferred forage has been consumed to near entirety. The seasonal relegation of horses to the riparian corridor is likely to exacerbate density dependent factors such as overutilization of plant species and increased potential for agonistic interactions between conspecifics. Horses are generally territorial and thus as resources become limited competition is more likely to increase. Individuals unable to maintain an active home range proximal to the riparian corridor may be relegated to the marginal upland habitat and may roam beyond the bounds of established management area. As a result, horses outside the riparian corridor will need to travel further and more often to water which in turn increases the potential for human/ horse interaction and vehicular collisions. Given the potential for impact posed not only to the Salt River horses but also to the resources on which they depend the need to understand the ecological interactions of the herd is critical to developing a management and conservation strategy that balances the needs of ecosystem with the long-term health and sustainability of the population. Such an approach necessitates informed dialogue and decision making that encompasses the breadth of viewpoints on this subject to ensure a management approach that is both comprehensive and well-rounded that will in turn allow for the continued support of the diversity of the greater Salt River ecosystem.

NEXT STEPS

While our measures of Salt River horse forage availability and diet suggests the potential for continued nutritional costs on a broad scale the following next steps are recommended to fill in remaining gaps pertaining to both ecology and management:

- Continued photographic documentation of established vegetation monitoring sites to examine fine scale long term seasonal changes including incorporation of NDVI/EVI to measure annual production
- Riparian corridor vegetation monitoring potentially including some MIM methods on woody species use coupled with continued browse monitoring in both upland and riparian zones.
- Examination of seasonal variation in horse behavior and spatiotemporal distribution as it relates to resource availability
- Development of long term climate model to predict expected outcomes of forage availability
- Collaboration with Brigham Young University on their riparian corridor monitoring study.

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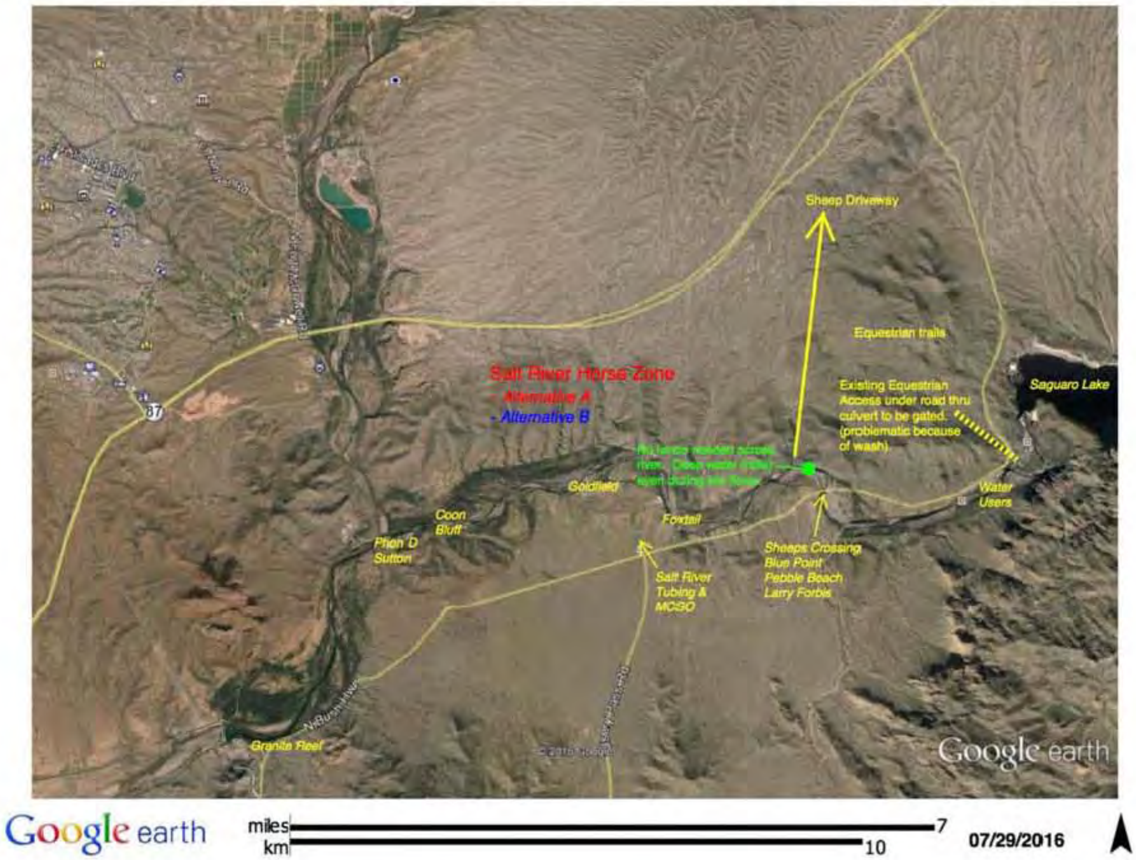
APPENDIX 1: MAP OF SALT RIVER HORSE ASSESSMENT AREA



Map provided by USDA Forest Service Tonto National Forest.

APPENDIX 2: SPECIES LIST OF PLANTS ENCOUNTERED

Plant Code	Latin Name	Common Name	Annual/ Perennial
ACMA	*Acmispon maritimus*	coastal bird's foot trefoil	P
AMDE4	*Ambrosia deltoidea*	triangle leaf bursage	P
ARIS	*Aristida*	three-awn grass	A/P
ARLA	*Argythamnia lanceolata*	narrowleaf silverbush	P
ASSU	*Asclepias subulata*	desert milkweed	P
ASTRA	*Astragalus*	locoweed	A/P
BRASS2	*Brassica*	mustard	A
BRRU2	*Bromus rubens*	red brome	A
CAER	*Calliandra eriophylla*	false mesquite	P
CAGI10	*Carnegia gigantea*	saguaro	P
CIRSI	*Cirsium*	thistle	A/P
CYBI9	*Cylindropuntia biglovii*	teddy bear cholla	P
CYVE3	*Cylindropuntia versicolor*	staghorn cholla	P
DICAC5	*Dichelostemma capitatum*	bluedicks	P
ESCA2	*Eschscholzia californica*	California poppy	A
ECHINO	*Echinocereus*	hedgehog cactus	P
ENFA	*Encelia farinosa*	brittlebush	P
EPHED	*Ephedra*	mormon tea	P
ERODI	*Erodium*	filaree	A
FEWI	*Ferocactus wislizeni*	barrel cactus	P
GAMO	*Galium mollugo*	false bedstraw	P
HORDE	*Hordeum*	barley	A/P
KAGR	*Kallstroemia grandiflora*	Arizona poppy	A
KRER	*Krameria erecta*	ratany	P
LATR2	*Larrea tridentata*	creosote	P
LUPIN	*Lupinus*	lupine	A/P
LYCIU	*Lycium sp.*	wolfberry	P
MAMMI	*Mammillaria*	globe cactus	P
MILA6	*Mirabilis laevis*	four o'clock	P
OLTE	*Olneya tesota*	ironwood	P
PAFL6	*Parkinsonia florida*	blue palo verde	P
PAMI5	*Parkinsonia microphylla*	little leaf palo verde	P
PHACE	*Phacelia*	phacelia	A/P
PHORA	*Phoradendron*	mistletoe	P
PLPA2	*Plantago patagonica*	woolly plantain	A
PRIMU	*Primula*	primrose	A/P
PRVE	*Prosopis velutina*	velvet mesquite	P
SICH	*Simmondsia chinensis*	jojoba	P
SPAM	*Sphaeralcea ambigua*	globemallow	P
SPCO2	*Sphaeralcea coulteri*	annual globemallow	A
VAVE	*Vachellia vernicosa*	whitethorn acacia	P

APPENDIX 3: EXAMPLE OF VGS DATA SUMMARIES

All summaries available in Box upon request.

Composition by Weight (Dry-Weight-Rank)

Site Class: Salt River

Site ID: SRH01

Date: 2/20/2017

Dry-Weight-Rank Composition				Sample Size = ?	
Species	Rank (#Hits)			Wtd. Sum	% Composition*
	1	2	3		
Annual forb(s)	8	28	42	154	15.40
Annual grass(es)	13	23	24	161	16.10
Ambrosia deltoidea	17	2	2	125	12.50
Argythamnia lanceolata-silver leaf		1		2	0.20
Aristida purpurea			1	1	0.10
Asclepias subulata-green stick	1			7	0.70
Dichelostemma capitatum ssp. capitatum	3	16	7	60	6.00
Encelia farinosa	55	24	20	453	45.30
Lycium	1			7	0.70
Unknown 2-lotus	2	6	4	30	3.00
Weighted Sums:	700	200	100	1000	100.00

* Number of decimal places does not imply level of precision

Notes:

Page: 1/1

Vegetation/GIS DataSystem - University of Arizona

APPENDIX 4:EXAMPLE OF MONITORING SITE PHOTOGRAPHS

All digital photographs are available in Box upon request.

Figure 10. Overall site photograph of monitoring site SRH07.

Figure 2. North view of site SRH07.

Figure 3. East view of site SRH07.

Figure 4. South view of site SRH07.

Figure 5. West view of site SRH07.

APPENDIX 5: ALLOTMENT STOCKING INFORMATION

The Goldfield, Bartlett, St. Clair, and Sunflower allotments are most similar in vegetation, soil, and topography to the Salt River horse zone. The Goldfield allotment was originally the Blue Point allotment that extended west to the Forest boundary and was last permitted for 50 cattle year-round. The Goldfield allotment currently runs in the Salt River horse zone, from Granite Reef to Saguaro Lake, north and south of the Salt River.

The Bartlett allotment is permitted for 317 adult cattle for year-long grazing and 188 yearling cattle from 01/01 – 05/31.

The St. Clair allotment was permitted for 300 yearlings from 01/15 – 05/15.

The Sunflower Allotment encompasses approximately 158,000 acres northeast of Fountain Hills, Arizona extending from the Salt River and Saguaro Lake up along Four Peaks, ending just south of Sunflower, Arizona.

Table 1: Estimated livestock numbers for Goldfield, Bartlett, St. Clair, and Sunflower Allotments.

Unit Name	Acres	Season of Use	Estimated Permitted Number	AUMs	Acres/AUM
Goldfield	56549	01/01 – 12/31	50	600	94
Bartlett	48325	01/01 – 12/31	317	3804	13
St. Clair	68105	01/01 – 12/31	300	3600	19
Sunflower	158000	01/01 – 12/31	835	10020	16

Allotment information provided by USDA Forest Service Tonto National Forest.

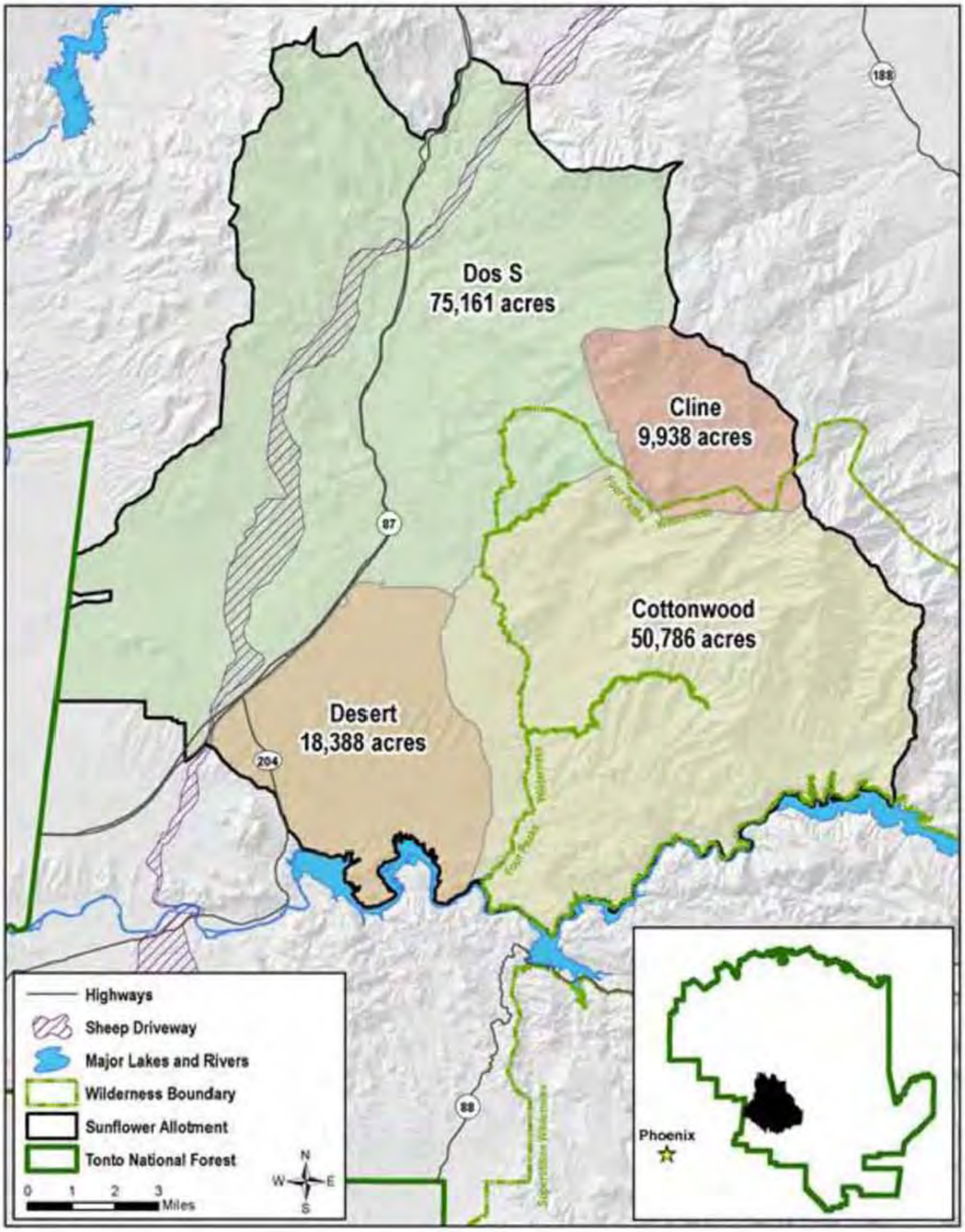


Figure 1. Map of the Sunflower allotment and units within. Provided by USDA Forest Service Tonto National Forest.

APPENDIX 6: Using forage production data to estimate proper stocking levels

Introduction

It is fairly common practice for range managers to try to estimate "proper" stocking rates by measuring (estimating) forage production per acre and "allocating" a percentage of the forage for livestock use. This approach can be reasonable on pastures of uniform soils and plant composition, small area, and high production, but it often provides highly variable estimates of stocking rates on arid/semiarid rangeland units. The points below summarize the major reasons why this is so.

Sampling Variability

Plant "production" is generally clipped and weighed, or estimated, in small plots (approx. 1-meter square or less). Each plot has an error associated with it due to technique or bias of the observer, e.g. clipping height, edge effects, etc., but these are probably less important than the effects of spatial variability in forage production. Spatial variability is due to differences in total production in the population of plots being sampled and to differences in composition (species or growth forms) of the plants occurring in different plots. Thus, even to estimate production with reasonable precision in a relatively uniform stand of vegetation (with uniform soil, slope, etc.) may require measurement of 10-30 individual plots. The more variability in plant types and spacing the more plots required. Over a large pasture this problem is compounded by the variation in the landscape due to soils, slopes, aspect, management history and other factors. Even on a given date, it is laborious to collect enough samples to arrive at a reasonable estimate of forage production.

Seasonal Variability

Production is usually considered to be only the amount of plant material produced by a plant during one growing season. Production by this definition can only be measured when the annual growth is completed. Unfortunately, there are two problems that make this practically impossible. Every plant species has a growth pattern in response to temperature and moisture conditions. New growth starts to accumulate when conditions are favorable and continues until frost, lack of water, and/or plant maturity result in no further net gain of biomass. The point at which the total amount of current year' growth reaches a peak is called "peak standing crop." This does not represent total growth for the year, because there is both gain and loss occurring throughout the year (e.g. flowers, fruits, older leaves may have been lost by the time growth stops). It is the best estimate of total growth that can be obtained with a one-point-in-time measurement, but always underestimates the total growth. After the point of peak standing crop, the weight of standing crop declines due to detachment, decomposition, leaching, herbivory, etc. The rate of decline may be substantial even in the absence of appreciable herbivory.

Every plant species has a somewhat different growth pattern, i.e. they reach peak standing crop at different times. This is most obvious when the vegetation consists of a mixture of cool-season and warm-season plants. There is no single time of year when a reasonable estimate of total production may be obtained. The best we can do is to measure an "index" at a particular point in time, but that has little to do with the total forage available to animals through the year.

Animal Distribution

It is well-known that animals do not grazed uniformly because of topography, distance from water sources, attractiveness of certain plant communities, presence of biting insects or predators, etc. Some of these, i.e. distance from water and slope, have been taken into account by use of formulas or models. These cannot provide reliable estimates on a site-specific basis because many important factors are not accounted for. Season of year, breed or age of livestock, origin of livestock, and intensity of management.

Proper Use Levels

Total production is often adjusted to a proper use level based on the following considerations. Physiological tolerance among forage plants for grazing is variable. The tolerance level depends on the species of plants (some more tolerant than others), the season of utilization, the frequency of utilization (or length of rest periods between grazing), and weather conditions.
Additionally, relative preference of plant species varies seasonally. It is commonly assumed that when certain species are properly used the associated less palatable species will generally be used even less. This may be a useful concept in measuring utilization, but the amount of forage available depends on knowing how much use will occur on associated species and whether that relationship of use on key species and associated species is constant. Such is not the case as animal preferences change throughout the year base on changing plant species phenological stages.

Animal Intake

Once the amount of forage production per acre is estimated the pounds of forage are converted to a stocking rate by dividing the pounds of available forage per acre by the pounds of forage consumed by an animal unit (1000-pound animal) per day or month (AUM). The rule of thumb is that ruminant animals will eat about 2% of their body weight per day, or about 20 pounds of dry forage for a 1000# animal. But this figure varies widely. The relatively few research studies on arid/semiarid rangelands report figures from 1 % to over 3% of body weight. The intake depends greatly on the abundance, palatability, and digestibility of the forage available; factors that are dependent on season of year, weather conditions, type and origin of livestock, use of supplemental feed, type of forage plants being used, etc. The importance of this figure is that the stocking rate calculated is directly proportional to the figure used for intake. For example, if there is estimated to be 500 pounds of available forage per acre, using an intake of 20 pounds per day gives a stocking rate of 4 days per acre, or about 7 acres per AUM. But if actual intake is only 10 pounds per day, the actual proper stocking rate is twice as high, a substantial difference based on a factor that cannot be accurately determined or validated for specific situations.

Conclusion

Use of production data to estimate proper stocking levels is based on calculations involving a number of factors. Each of these factors either can only be crudely estimated in the field or is incapable of being measured in the field and is instead based on assumptions from experience and/or the scientific literature. This approach to carrying capacity estimation can be useful for broad-scale modeling or for comparing the estimated capacity of two pastures, where relative values will suffice. But for establishing allowable or recommended stocking rates for a given ranch, allotment, or pasture, they are not suitable. It is preferable to use professional experience based on local knowledge (which is clearly identified as such) than to give the impression of scientific validity by using formulas based on imprecise factors and assumptions.

APPENDIX 7: FECAL SAMPLE COLLECTION SCALE

The following scale may be used to prioritize and categorize fecal sample collection. Sample quality, content and extent of degradation will vary seasonally as a result of changes in temperature, precipitation and available forage. The following provides general guidelines and techniques to ensure the collection of viable fecal samples for genetic sequencing and content analysis regardless of seasonal variation. This Class distinction also allows for priority selection of samples to run i.e. samples of lower quality may omitted from sequencing as needed.

Class I - Sample still visibly moist on exterior and obviously deposited recently, typically lighter in coloration light brown to olive depending on diet and season. Class I samples are a priority for collection, however, given the higher moisture content such samples should be frozen or refrigerated within several hours of collection to avoid bacterial/fungal decomposition. Samples should be stored in a paper bag, avoid use of plastic storage containers. Class I samples can be taken from anywhere in the pile, however, care should be given to minimize amount of soil and debris attached to each sample.

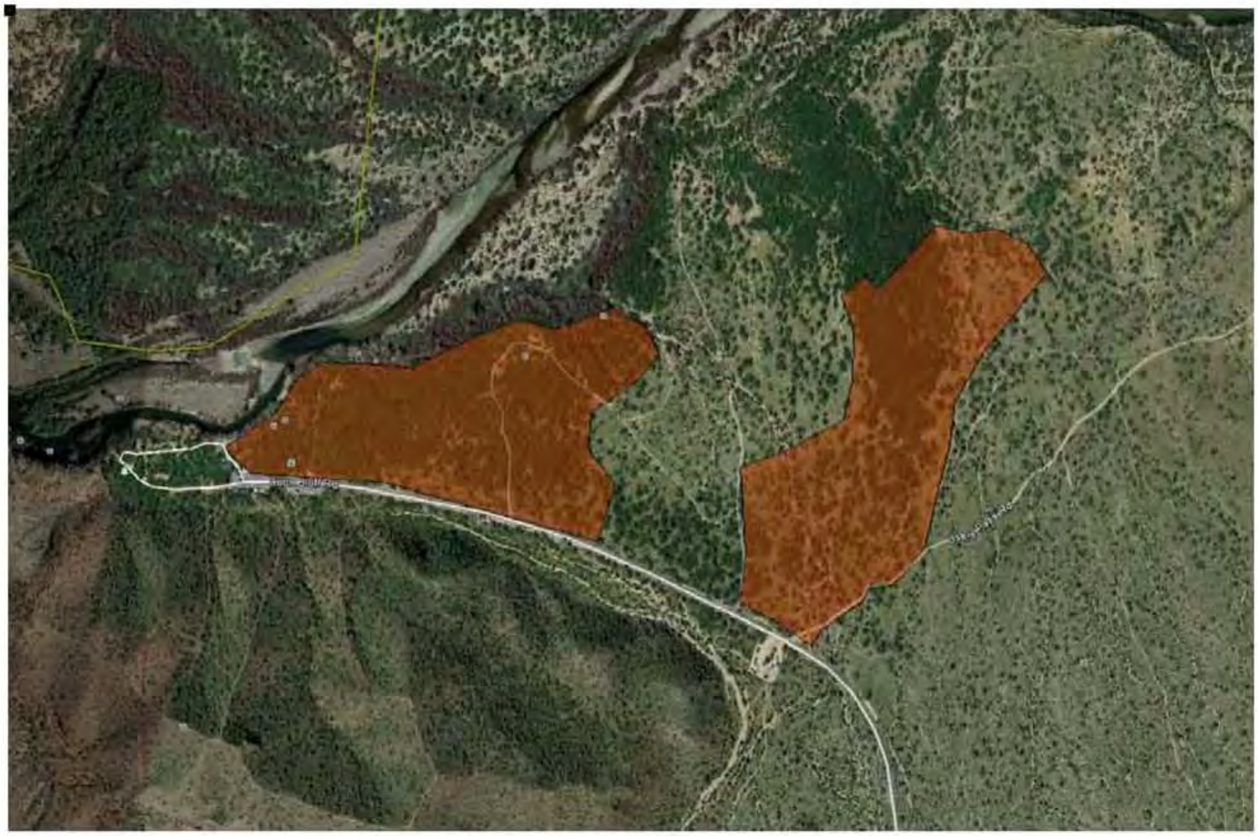
Class II - Sample dry to touch on exterior but still retains moisture on interior. Exterior likely lacking in cracks though will be darker than Class I samples. Be careful not to confuse internal moisture content with dew or precipitation that may accumulate in older and more degraded samples. Class II samples may retain moisture for ~1-5 days depending on season. Given viability of sample Class II samples can be taken from anywhere in the pile, however, as with Class I soil and debris should be kept to a minimum.

Class III - Exterior of sample may show beginning signs of degradation. Small cracks may be apparent on the surface and the color is often lighter than Class II samples. Interior, though dry, should still retain a higher degree of greenness (use available forage as a guide for expected greenness i.e. will likely be lighter in dry season etc...). Overall pile structure is still likely consolidated and lacks conspicuous signs of degradation. This is likely the most often collected sample type. Given the age of the sample focus on the collection of pellets from the center of the pile or those most protected from UV radiation or precipitation, the core of the sample should be fairly protected as is but the les degraded the better.

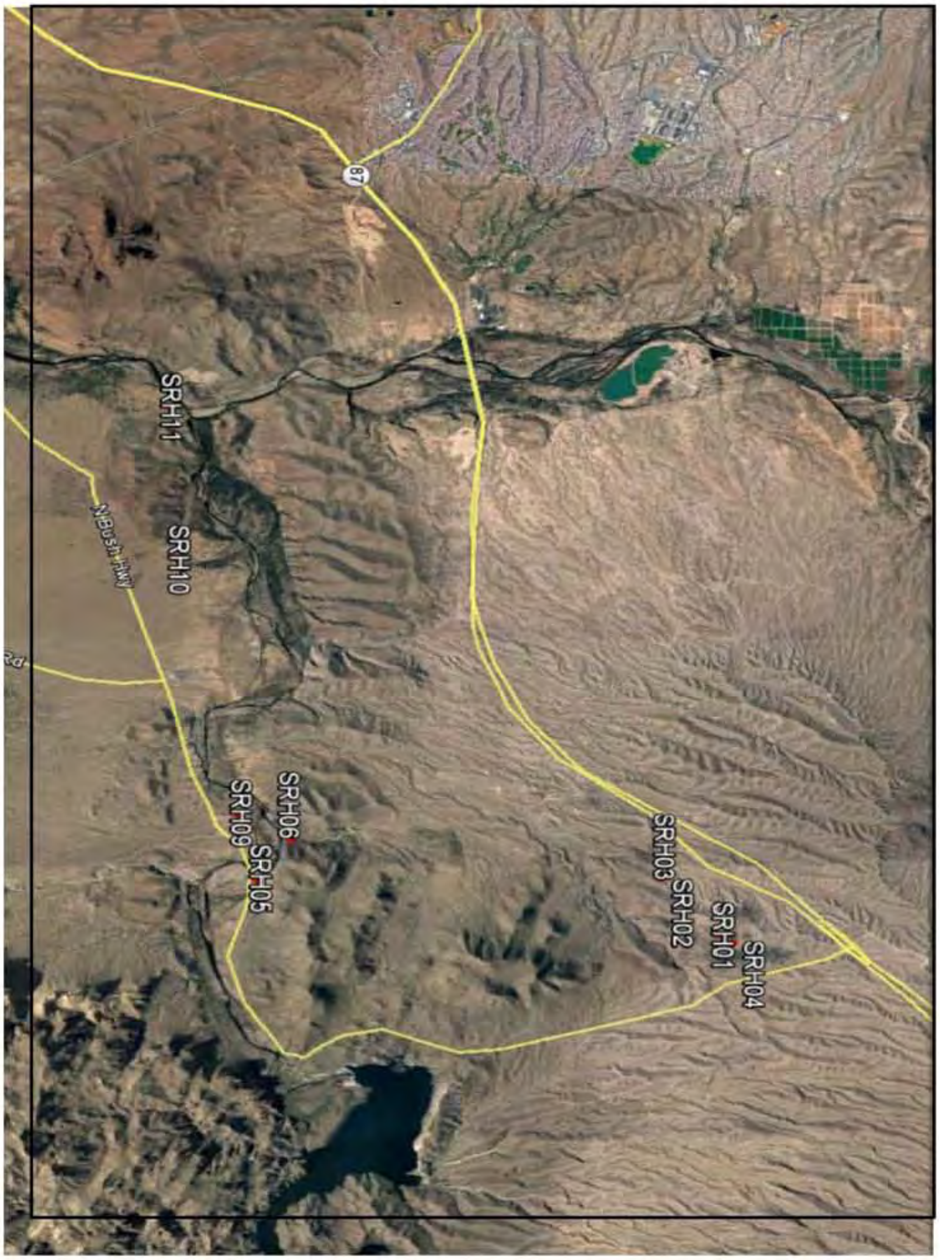
Class IV - Class IV show obvious signs of degradation often with conspicuous cracks on exterior. Interior coloration will likely be lighter than that of Class III. The pile may be more dispersed given trampling and insect use. Better preserved Class IV samples should be collected only when a thorough search for samples of higher quality yield no results. Selectively choose samples that are clumped near the center of the pile *but* avoid collecting samples from the bottom of the pile where it contacts the soil given the potential for elevated microbial degradation. Remember running these samples is expensive and it is better to omit a sample than it is to run a non-viable sample.

Class V - This Class of sample should never be collected for sequencing. Obviously degraded and sun-bleached fading into white. Piles often dispersed and crumpling.

APPENDIX 8: PRIMARY FECAL SAMPLE COLLECTION



9: AERIAL OVERVIEW OF STUDY AREA AND ASSOCIATED TRANSECTS




SRH09
SRH06
SRH05
N Bush Hwy


87
SRH03
SRH02
SRH01
SRH04


SRH11
SRH10

Image Close up aerial imagery of SRH10 (Coon Bluff) during January 2018[a] and February 2017[b]. Images highlight the extent of annual production and the overall lack of alternative forage when annual production is reduced.

APPENDIX 10: FENCE LINE CONTRAST AND BROWSE LINES ON WOODY SPECIES

Image The above highlights the contrast in remaining annual forage[ab] between areas accessible to horses and those where horses are excluded (July 2017) with the final series image taken 180˚ from image a. to highlight the full extent of utilization.


b.

Image Series[abc] further highlight extent of annual utilization via fence line contrast taken April 2018. Annual vegetation present in all photos is likely remnant of winter 2016-17 production.

APPENDIX 11: TABLUAR SUMMARY OF TOTAL PRODUCTION ON THE SALT RIVER STUDY AREA

	Est. TOTAL Production (lbs/ac)													
Site	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**MEAN**	**SD**	**SE**
1	1230.0	-	705.6	815.7	-	108.6	215.8	-	184.8	86.6	91.6	429.9	432.0	152.7
2	851.2	-	932.3	374.4	-	292.6	210.5	-	253.0	141.1	106.6	395.2	318.4	112.6
3	516.4	-	1919.5	504.0	-	301.3	458.2	-	154.8	133.3	62.6	506.2	597.8	211.3
4	386.5	-	926.6	37.8	-	97.2	211.1	-	96.7	48.8	37.6	230.3	305.2	107.9
5	2215.7	-	1224.6	665.0	-	665.9	925.1	-	603.8	441.7	230.6	871.5	619.5	219.0
6	623.1	-	273.0	-	-	276.8	204.5	-	211.2	316.0	181.4	298.0	151.1	57.1
7	266.9	-	-	-	-	-	-	-	-	-	-	266.9	-	-
8	129.0	-	-	-	-	-	-	-	-	-	-	129.0	-	-
9	637.1	-	150.9	805.6	-	583.2	909.0	-	504.6	65.6	77.6	466.7	330.9	117.0
10	-	-	358.3	982.8	-	896.4	612.0	-	463.0	279.5	534.2	589.5	263.9	99.8
11	-	-	421.2	572.8	-	492.8	1034.8	-	545.1	263.2	349.5	525.6	249.6	94.3
MEAN	761.8		768.0	594.8		412.8	531.2		335.2	197.3	185.7			
SD	634.6		559.5	296.7		267.1	349.1		192.2	134.1	163.6			
SE	211.5		186.5	104.9		89.0	116.4		64.1	44.7	54.5			

- indicates no data was recorded

	Est. ACCESSIBLE Production (lbs/ac)													
Site	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**MEAN**	**SD**	**SE**
1	1140.2	-	654.1	756.2	-	100.7	200.1	-	171.3	80.3	84.9	398.5	400.5	141.6
2	789.1	-	864.2	347.1	-	271.3	195.1	-	234.5	130.8	98.8	366.4	295.1	104.3
3	478.7	-	1779.4	467.2	-	279.3	424.7	-	143.5	123.6	58.0	469.3	554.1	195.9
4	104.3	--	250.2	10.2	-	26.2	57.0	-	26.1	13.2	10.2	62.2	82.4	29.1
5	598.2	-	330.7	179.5	-	179.8	249.8	-	163.0	119.3	62.3	235.3	167.3	59.1
6	577.6	-	253.0	-	-	256.6	189.5	-	195.8	293.0	168.1	276.2	140.1	52.9
7	247.5	-	-	-	-	-	-	-	-	-	-	247.5	-	-
8	119.6	-	-	-	-	-	-	-	-	-	-	119.6	-	-
9	590.6	-	150.9	805.6	-	583.2	909.0	-	504.6	65.6	77.6	460.9	327.9	115.9
10	-	-	96.7	265.4	-	242.0	165.2	-	125.0	75.5	144.2	159.2	71.3	26.9
11	-	-	421.2	572.8	-	492.8	1034.8	-	545.1	263.2	349.5	525.6	249.6	94.3
MEAN	516.2		533.4	425.5		270.2	380.6		234.3	129.4	117.1			
SD	331.7		527.5	278.3		175.0	350.1		174.5	92.0	98.9			
SE	110.6		175.8	98.4		58.3	116.7		58.2	30.7	33.0			

- indicates no data was recorded

APPENDIX 12: TABLUAR SUMMARY OF SPEICES COMPOSITION BY SITE

Site 1

Species	February	March	April	May	June	July	August	September	October	November	December	MEAN
annual grass	16.2		38.6	0.0		0.0	1.9		0.0	0.0	0.0	7.1
annual forb	15.3		32.4	0.0		0.0	0.0		0.0	0.0	0.0	6.0
Ambrosia deltoidea	12.5		4.3	14.4		9.6	6.2		8.4	5.7	7.3	8.5
Argythamnia lanceolata	0.2		0.0	0.0		0.0	0.0		0.0	0.0	0.0	0.0
Aristida purpurea	0.1		0.0	0.0		0.0	0.0		0.0	0.0	0.0	0.0
Asclepias subulata	0.7		0.0	0.0		3.6	0.0		0.0	1.8	1.7	1.0
Dichelostemma capitatum	6.0		0.4	0.0		0.0	0.0		0.0	0.0	0.0	0.8
Encelia farinosa	45.3		23.9	79.7		72.5	34.6		42.1	43.5	53.7	49.4
Lycium spp.	0.7		0.4	0.8		14.3	3.5		2.1	1.8	9.8	4.2
lotus	3.0		0.0	0.0		0.0	0.0		0.0	0.0	0.0	0.4
Senna covesii	0.0		0.0	5.1		0.0	53.9		47.4	47.3	27.6	22.7
SUM	100.0	0.0	100.0	100.0	0.0	100.0	100.0	0.0	100.0	100.0	100.0	100.0

Site 2

Species	February	March	April	May	June	July	August	September	October	November	December	MEAN
annual grass	2.3		7.1	0.0		0.0	0.2		0.0	0.0	0.0	1.2
annual forb	20.5		41.9	0.0		0.0	0.0		0.0	0.0	0.0	7.8
Acacia constricta	0.0		0.0	0.0		0.0	2.1		0.0	0.0	0.0	0.3
Ambrosia deltoidea	7.2		12.0	24.2		34.6	23.0		12.2	27.4	39.0	22.4
Asclepias subulata	0.7		0.0	0.0		0.0	0.0		0.1	0.0	0.0	0.1
aster	0.7		0.0	0.0		0.0	0.0		0.0	0.0	0.0	0.1
Boerhavia	0.0		0.0	0.0		0.0	0.0		53.7	0.0	0.0	6.7

Calliandra eriophylla	1.2		0.8	2.9		6.5	3.6		6.5	5.9	4.6	4.0
Dichelostemma capitatum	30.2		11.4	0.2		0.0	0.0		0.0	0.0	0.0	5.2
Ditaxis lanceolaa	0.0		0.0	1.5		0.0	0.0		0.0	0.0	0.0	0.2
Encelia farinosa	34.6		25.9	69.8		57.5	60.4		25.0	58.4	50.8	47.8
Ephedra trifurca						1.5				0.0	1.4	1.0
Krameria erecta	0.0		0.0	0.0		0.0	2.1		0.0	2.0	0.0	0.5
lotus	0.1		0.0	0.0		0.0	0.0		0.0	0.0	0.0	0.0
Lycium spp.	1.6		0.7	1.5		0.0	2.1		0.0	2.0	0.0	1.0
Mirabilis laevis	0.9		0.2	0.0		0.0	1.9		0.7	2.0	2.0	1.0
Senna covesii	0.0		0.0	0.0		0.0	4.5		0.0	2.2	2.2	1.1
unknown - three lobe	0.0		0.0	0.0		0.0	0.0		1.1	0.0	0.0	0.1
SUM	100.0	0.0	100.0	100.0	0.0	100.0	100.0	0.0	99.3	100.0	100.0	100.5

Site 3

Species	February	March	April	May	June	July	August	September	October	November	December	MEAN
annual grass	27.3		54.1	0.0		0.0	1.3		0.0	0.0	0.0	10.3
annual forb	32.3		33.1	0.0		0.0	69.0		0.0		0.0	19.2
Acacia constricta	0.9		0.4	18.3		18.1	4.8		11.9	27.1	8.0	11.2
Ambrosia deltoidea	4.3		1.0	11.4		13.1	1.8		22.7	20.8	12.0	10.9
aster	0.1		0.0	0.0		0.0	0.0		0.0	0.0	0.0	0.0
Dichelostemma capitatum	6.2		0.3	0.0		0.0	0.0		0.0	0.0	0.0	0.8
Encelia farinosa	20.5		6.0	12.9		17.5	2.2		15.8	10.0	24.4	13.7
Ephedra trifurca	0.0		0.0	2.9		0.0	0.0		0.0	0.0	0.0	0.4
Krameria erecta	0.9		0.9	17.7		16.3	6.1		22.7	3.8	20.0	11.0
Larrea tridentata	0.0		1.6	11.4		15.6	5.2		0.0	8.3	20.0	7.8
Lycium spp.	0.7		0.0	5.7		0.0	0.0		0.0	0.0	0.0	0.8
Mirabilis laevis	0.7		0.0	0.0		0.0	0.0		0.0	0.0	0.0	0.1
Simmondsia chinensis	6.1		2.6	19.7		19.4	9.6		26.9	30.0	15.6	16.2

SUM	100.0	0.0	100.0	100.0	0.0	100.0	100.0	0.0	100.0	100.0	100.0	102.4

Site 4

Species	February	March	April	May	June	July	August	September	October	November	December	MEAN
annual grass	49.7		73.0	0.0		0.0	0.0		0.0	0.0	0.0	15.3
annual forb	42.9		24.3	0.0		0.0	0.0		0.0	0.0	0.0	8.4
Ambrosia	0.0		0.2	0.0		0.0	0.0		0.0	0.0	0.0	0.0
Acacia constricta	0.0		0.0	16.7		0.0	5.9		7.1	0.0	8.3	4.8
Krameria erecta						0.0				10.0	8.3	6.1
Prosopis velutina	2.3		1.8	66.7		66.7	47.1		50.0	70.0	66.7	46.4
Sphaeralcea ambigua	0.7		0.7	16.7		33.3	23.5		21.4	20.0	16.7	16.6
Lycium spp.	0.0		0.0	0.0		0.0	0.0		7.1	0.0	0.0	0.9
lotus	4.4		0.0	0.0		0.0	0.0		0.0	0.0	0.0	0.6
Senna covesii	0.0		0.0	0.0		0.0	23.5		14.3	0.0	0.0	4.7
SUM	100.0	0.0	100.0	100.0	0.0	100.0	100.0	0.0	100.0	100.0	100.0	103.8

Site 5

Species	February	March	April	May	June	July	August	September	October	November	December	MEAN
annual grass	40.2		47.8	3.2		0.0	0.5		0.0		0.0	13.1
annual forb	39.9		25.0	0.0		0.0	64.7		41.9	0.0	0.0	21.4
Asclepias subulata	0.0		0.7	0.0		0.0	0.0		0.0	0.0	0.0	0.1
Larrea tridentata	0.0		0.0	0.0		0.0	1.8		0.0	0.0	0.0	0.2
Janusia gracilis	0.0		0.0	0.0		0.6	0.0		0.1	0.0	1.5	0.3
Lycium spp.	0.0		0.4	0.0		0.0	1.4		0.0	0.2	0.0	0.3
Parkinsonia florida	0.0		5.9	0.0		0.0	0.2		0.3	0.0	0.0	0.8
Phoradendron	4.4		1.1	3.6		4.7	2.0		0.6	5.2	3.2	3.1
Prosopis velutina	15.5		19.2	93.2		94.7	29.4		57.1	94.6	95.3	62.4

SUM	100.0	0.0	100.0	100.0	0.0	100.0	100.0	0.0	100.0	100.0	100.0	101.6

Site 6

Species	February	March	April	May	June	July	August	September	October	November	December	MEAN
annual grass	24.0		23.8			0.0	0.0		0.0	0.0	0.0	6.8
annual forb	45.9		37.0			0.0	0.0		0.0	0.0	0.0	11.8
Ambrosia deltoidea	17.5		21.0			70.9	43.7		53.8	41.8	62.7	44.5
aster						0.0				0.0	2.0	0.7
Cylindropunctia versicolor	7.0		12.8			29.1	42.9		34.2	42.5	23.9	27.5
Dichelostemma capitatum	0.9		0.0			0.0	0.0		0.0	0.0	0.0	0.1
Echinocereus						0.0				0.0	1.4	0.5
Encelia farinosa						0.0				1.4	0.0	0.5
Ephedra trifurca						0.0				0.2	0.0	0.1
Krameria erecta	0.0		1.0			0.0	0.0		0.0	0.0	0.0	0.1
Larrea tridentata	4.5		4.4			0.0	13.5		8.5	8.4	10.0	7.0
Lycium spp.						0.0				1.4	0.0	0.5
lotus	0.2		0.0			0.0	0.0		0.0	0.0	0.0	0.0
Parkinsonia microhylla	0.0		0.0			0.0	0.0		1.7	1.8	0.0	0.5
Simmondsia chinensis						0.0				0.4	0.0	0.1
unknown - hairy leaf						0.0			1.9	2.0	0.0	1.0
SUM	100.0	0.0	100.0	0.0	0.0	100.0	100.0	0.0	100.0	100.0	100.0	101.7

Site 7

Species	February	March	April	May	June	July	August	September	October	November	December
annual grass	5.9	0	0	0	0	0	0	0	0	0	0
annual forb	50	0	0	0	0	0	0	0	0	0	0
Ambrosia deltoidea	10.9	0	0	0	0	0	0	0	0	0	0

Cylindropuntia bigelovii	0.7	0	0	0	0	0	0	0	0	0	0
Cylindropuntia versicolor	7	0	0	0	0	0	0	0	0	0	0
Dichelostemma capitatum	12.8	0	0	0	0	0	0	0	0	0	0
Echinocactus	0.7	0	0	0	0	0	0	0	0	0	0
Encelia farinosa	3.5	0	0	0	0	0	0	0	0	0	0
Krameria erecta	0.9	0	0	0	0	0	0	0	0	0	0
Larrea tridentata	2.3	0	0	0	0	0	0	0	0	0	0
Parkinsonia microphylla	5.1	0	0	0	0	0	0	0	0	0	0
lotus	0.2	0	0	0	0	0	0	0	0	0	0
SUM	100	0	0	0	0	0	0	0	0	0	0

Site 8

Species	February	March	April	May	June	July	August	September	October	November	December
annual grass	14.8	0	0	0	0	0	0	0	0	0	0
annual forb	56.6	0	0	0	0	0	0	0	0	0	0
Ambrosia deltoidea	12.9	0	0	0	0	0	0	0	0	0	0
Cylindropuntia versicolor	2.1	0	0	0	0	0	0	0	0	0	0
Ferocactus wislizeni	0.2	0	0	0	0	0	0	0	0	0	0
Larrea tridentata	13.4	0	0	0	0	0	0	0	0	0	0
SUM	200.2	0	0	0	0	0	0	0	0	0	0

Site 9

Species	February	March	April	May	June	July	August	September	October	November	December	MEAN
annual grass	50.2		48.6	0.0		0.0	7.0		0.0	0.0	0.0	13.2
annual forb	37.0		28.2	0.0		0.0	56.2		30.7	0.0	0.0	19.0
Baileya multiradiata	0.0		0.0	3.0		0.0	0.0		0.0	7.7	0.0	1.3
Hymenoclea salsola	1.4		2.3	8.2		14.0	6.9		11.8	8.9	21.3	9.3

Janusia gracilis	0.0		0.0	0.0		0.0	0.9		0.4	0.0	0.0	0.2
Larrea tridentata	6.3		10.8	30.3		37.4	17.4		40.2	56.5	49.6	31.1
Parkinsonia florida	2.1		8.0	33.3		42.9	10.7		17.0	11.5	12.5	17.2
Phoradendron	0.2		0.0	2.1		0.0	0.0		0.0	0.0	0.0	0.3
Prosopis velutina	2.8		2.1	22.1		5.7	1.0		0.0	15.4	12.5	7.7
Senna covesii						0.0				0.0	4.2	1.4
unknown - knapweed	0.0		0.0	0.9		0.0	0.0		0.0	0.0	0.0	0.1
SUM	300.2	0.0	100.0	100.0	0.0	100.0	100.0	0.0	100.0	100.0	100.0	100.9

Site 10

Species	February	March	April	May	June	July	August	September	October	November	December	MEAN
annual grass			76.2	0.0		0.0	2.6		0.0	0.0	0.0	11.2
annual forb			6.7	0.0		0.0	61.0		0.0	0.0	0.0	9.7
Ambrosia deltoidea			0.7	2.9		0.0	1.0		2.9	2.9	3.0	1.9
Chamaesyce			0.0	2.9		0.0	0.0		0.0	0.0	0.0	0.4
Cylindropuntia versicolor			1.6	5.7		3.1	1.0		5.6	2.9	0.3	2.9
Hymeoclea salsola			1.4	5.7		6.6	2.0		5.6	11.1	0.0	4.6
Larrea tridentata			0.0	8.6		9.4	4.0		11.8	11.4	8.1	7.6
Lycium spp.			0.6	1.7		10.6	1.2		11.5	1.4	0.3	3.9
Olneya tesota			9.6	40.0		42.8	15.2		24.4	38.3	36.2	29.5
Parkinsonia microphylla						0.0				0.3	0.0	0.1
Phoradendron			0.0	4.9		1.3	1.8		4.1	3.7	2.7	2.6
Prosopis velutina			3.2	26.9		26.3	10.3		34.1	28.0	49.5	25.5
Sphaeralcea ambigua			0.0	0.9		0.0	0.0		0.0	0.0	0.0	0.1
SUM	0	0	100.0	100.0	0.0	100.0	100.0	0.0	100.0	100.0	100.0	100.1

Site 11

Species	February	March	April	May	June	July	August	September	October	November	December	MEAN
annual grass			30.3	0.0		0.0	0.0		0.0	0.0	0.0	4.3
annual forb			24.0	0.0		0.0	36.2		0.0	0.0	0.0	8.6
Ambrosia deltoidea			20.4	30.2		30.6	18.2		24.0	36.4	32.8	27.5
Cylindropuntia versicolor			5.1	8.3		21.9	12.9		5.2	13.2	5.1	10.2
Larrea tridentata			19.3	58.1		41.1	28.5		63.1	46.0	52.6	44.1
Lycium spp.			0.2	3.5		2.1	1.7		3.9	0.2	3.8	2.2
Prosopis velutina			0.7	0.0		4.3	2.4		3.9	4.3	5.7	3.0
SUM	0	0	100.0	100.0	0.0	100.0	100.0	0.0	100.0	100.0	100.0	100.0

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