Plant Functional Diversity - Species

In this section we discuss the three major forms of diversity. *Alpha-diversity* - or species richness, is simply the number of species in a space at a point in time. The scale at which we discuss $\alpha - diversity$ is usually up to a few football fields in size. This metric refers to areas which we are intimately familiar with and may traverse readily on foot. *Gamma-Diversity*, represents the richness of species in a larger area, generally a landscape. For example, we may readily discuss the $\gamma - diversity$ of the Dominguez-Escalente National Monument. In all instances the $\alpha - diversity$ of sites are nested within the gamma diversity of an area. $\gamma - diversities$ -in this case the number of species- exceed those of $\alpha - diversities$, both due to the relative uncommonness of many species, these uncommon species are often not present across the entirety of the landscape, and due to the large changes in the type of species supported by differing habitat types. These turnovers across the alpha diversity of sites, the difference in species present at sites, comprise *beta-diversity*. High rates of $\beta - diversity$, or dissimilarity of sites, foster high rates of gamma-diversity (Whittaker (1972)).

Evolution, the process largely mediating the maintenance of diversity, is survival of the fittest. However, the conditions of the test which may constitute the 'fittest' are nearly as numerous as the forms of diversity. Many species which exist in the same location in space, have distinct characteristics which allow for species persistence; dry years favor some species, while wet years favor others, some require more sun, while others thrive with less, and there are myriad permutations and combinations of these settings. The cover of these species ebb and flow with the usual weather and disturbances within the climate zone of the site (Hoover et al. (2014)). These trends are especially important for the production of forage and browse, over the life of most large animals, they will have to feed on what they have available. No single species is the fittest at a site on a time scale which the BLM manages land for, and having multiple species within the same functional groups in space is the only stable strategy for management.

While Ecological Site Descriptions do not provide true measures of $\alpha - diversity$ many of them do contain lists of taxa which may be considered *dominant* or *subordinate* at a site (Avolio et al. (2019), Grime (1998)). In general, it seems that the Shrubs, Trees, and Grasses at an Ecological Site would be considered *dominant*, and the forbs *subordinate*; keep in mind these terms refer to immediate ecosystem cycling effects, and the services offered by forbs to insects and then larger animals remain substantial (Avolio et al. (2019)). These species which have high amounts of biomass, and ground cover, may be thought of as a core groups of species which are essential for the functioning of an ecosystem (Grime (1998)), and each of the dominant species have been theorized to have conceptual effects as large as their cover. When dominant and subordinate species are lost from an area, it also has effects on the remaining species - most of which are relatively uncommon across the landscape (Grime (1998), Whittaker (1965)). Considerable research has shown that having a diverse suite of plant species allows areas to: 1) Produce more forage in both a single year, and across different weather scenarios (Vogel et al. (2012), Hoover et al. (2014)), 2) recover from disturbances such as fire, or compaction (Tilman & Downing (1994)) 3) and resist degradation such as from the encroachment of noxious weeds (Weisser et al. (2017), Avolio et al. (2019), Allan et al. (2011), Gaitan et al. (2014), Sheley & James (2010), Isbell et al. (2011), Oakley & Knox (2013), *and reviewed in* Maestre et al. (2016), Oliver et al. (2015)).

Information on production at Ecological Sites implies some superficial, yet essential, components of plant diversity. Here we determine what proportion of species identified in ESD production tables are present at each AIM plot, how many are missing, and whether any species are uniformly missing. We also combine plots by Ecological Site to determine $\gamma - diversity$ by site, and compare the relative turn over in species composition within each Ecological Site which has replicate plots.

Methods

In order to determine which, and how many, species are noted to be dominant members of the vegetation at an Ecological Site, all ESD's for which an AIM plot was verified to were checked. All conditions (e.g. all

State/Phase combinations which were present) from the reference tables were copied from these manually into spreadsheets, and data were cleaned using R. The USDA symbols utilized in these tables, were verified to match to the look up tables which were created for our project, to ensure that the same species between the two data sources could not be 'missed' due to using different abbreviation codes. Given that only two species (*Pinus edulis*, *Junipers osteosperma*) were ever considered to be true 'Trees' under both systems, this lifeform was dropped from all analyses to focus on the more variable groups.
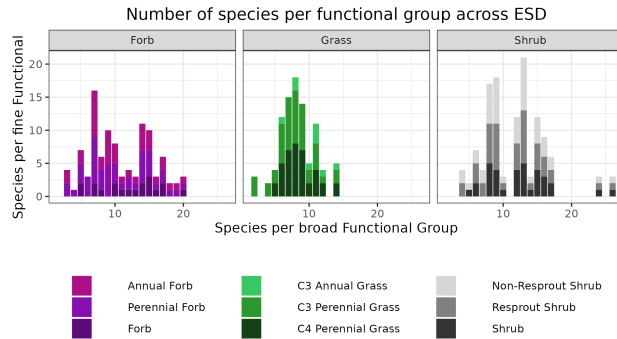

Figure 1: Number of Species Per Functional Groups

In order to be able to make comparisons across functional groups, for each species present in both the ESD's and our plot based data, we ensured that they drew from the same attribute table. This was especially important for situations where subshrubs are alternatively classified as forbs or shrubs depending on context. After performing this, we recovered both the 'coarse' functional groups used by the AIM team, which correspond largely to the botanical notion of 'lifeforms'. Subsequently, using the developed attribute tables finer functional groups, developed locally, which reflect the propensity of major groups of these lifeforms to respond to various disturbances, such as drought (e.g. C3 and C4 grasses), and fire (non-resprout and re-sprouting shrubs). In instances where more fine scale functional data were not available, such as was the case for sprouting potential of many shrub species, then species were left at this level rather than attempting to determine an appropriate group for them.

The calculation of all, previously mentioned, forms of diversity were not carried out for each individual plot. All plots had $\alpha - diversity$, the number of unique species per plot calculated. However, plots which lacked Ecological Sites, were unable to have $\gamma - diversity$, and subsequently $\beta - diversity$ calculated. Ecological Sites which lacked reference tables were able to have these calculations performed, as they are independent of the Descriptions. Calculations of $\beta - diversity$, wherein only plots belonging to the same Ecological Sites were compared, were performed using the 'vegdist' function from the package 'vegan', with standard defaults and as Sorenson-Dice dissimilarity (Oksanen et al. (2022), Sorensen (1948), Dice (1945)).

$$\text{Sorenson-Dice Index} = \frac{(2 \times \text{No. Species Site 1} \cap \text{Site 2})}{(\text{No. Species Site 1} + \text{No. Species Site 2})}$$

Wherein the number of species which are shared ("∩") between two sites are multiplied by 2, and divided by the total number of species at both sites.

The data collected by two distinct methods, Line-Point Intercept, and Species Richness, were both compared to the ESD reference data to determine which more closely reflected the benchmark values. After visual exploration of these data displayed in several plots (including Figure 2), it was determined that the Species Richness data more adequately reflected the Benchmarks values and it was used for all subsequent analyses.

In order to determine whether enough plots have been sampled to reliably estimate the number of species which are present per Ecological Site ($\gamma - diversity$), rarefaction and extrapolation curves from the iNEXT package were used with confidence intervals of 0.8, and 50 bootstrap replicates (Hsieh et al. (2022), Chao et al. (2014)).

Results & Discussion

Species richness data contained a total of 7525 records, which after removal of unidentified material left 6227 species records at 276 plots which were verified to Ecological Sites. 30 Ecological Sites had more than two AIM plots located in them, and had $\beta - diversity$ calculated for all plots 224 located in them.

While the species within any one reference table in an Ecological Site Descriptions are noted to represent the dominant species across a gradient which stratifies the Ecological Site, such as elevation, many of our plots contained an adequate number of these species per functional group. In fact, when considering the richness data, which we suspect is a more apt data set for comparing to the ESD taxa, many of our plots had the number of species expected in the reference table, for both the Forb and Shrub functional groups (Figure 2). For Shrubs it appears that the Ecological Sites which are meant to have the greatest number of shrub species do not reach these goals; and that perhaps only for these sites is the species representing the gradients of the Ecological Site utilized. Below we will make several comparisons of the number of species per plot to 3/4 of the number of species in each functional group in the production table. It appears unlikely that the production tables represent variables collected in a consistent manner; however they offer clear, and useful, insights.
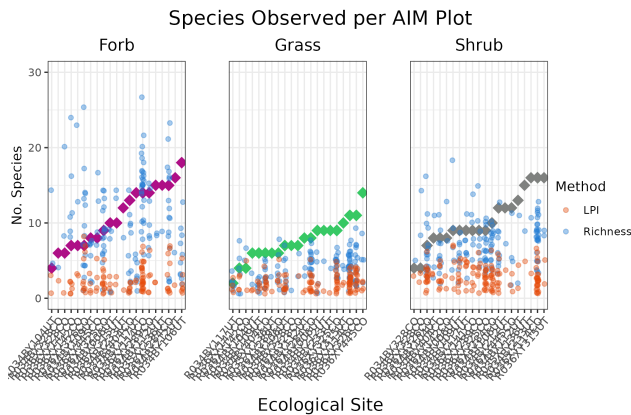

Figure 2: Number of Species Per Coarse Functional Groups

In regards to $\alpha - diversity$, the number of identified plant species varied widely by plot, from 2 - 54 (Med = 23). The 28 plots with the most species in them were in 10 Ecological Sites, this subset of plots had a minimum of 35 species per plot. Of the top 28 plot subset the Ecological Sites with the highest observed $\alpha - diversity$ were: R036XY114CO (plots = 7), R048AY238CO (plots = 3), R036XY326CO (plots = 3), R036XY113CO (plots = 2), R036XY141CO (plots = 2), R036XY284CO (plots = 2). The percent of all plots which had less than three-quarters the number of species noted, as were in the production table 43.5% , 86.5% , 62.9% for forbs, grasses, and shrubs respectively (Figure 2). The percent of all plots which had fewer than three-quarters the number of Annual and Perennial Forb species than in the production table were 38.6%, 42% (Figure 1). The percent of all plots which had fewer than three-quarters the number of Annual C3 Grasses, Perennial C3 Grasses, C4 Perennial Grasses species in the production table were 66.7%, 85.6%, 92.6%. The percent of plots with fewer than three-quarters Non-Resprouting Shrubs, Resprouting, and unclassified shrubs species as in the production table were 61.9%, 55.6%, 69.1%. As previously mentioned no benchmarks can be formed from the attribute tables, however the lack of grasses is concerning, and indicates that not only is there a lack of cover of this functional group (Section 11), but that this may be related to a lack of functional diversity brought on by a lack of species diversity.

Concerns regarding the species composition of shrubs and grasses may be related to the prevalence of *Guiterrhiza sarothae* (Section 13 Figure 1). Empirical evidence supports a theory that *Guiterrhiza sarothae* recruits when surplus resources become available, and that this resource availability is spurred by a lack of resource utilization by species which exploit similar niches, such as Grasses and Shrubs (Davis et al. (2000), Ralphs & McDaniel (2011)). The decline in these other species are likely due to disturbances (Ralphs & McDaniel (2011)). However, once established at moderate densities *Guiterrhiza sarothae* has a competitive advantage and inhibits recruitment of other grasses and shrubs (Ralphs & McDaniel (2011)).

The mean $\beta - diversity$, that is the dissimilarity between plots varied from 0.54 - 0.88, with lower values indicating greater differences between plots; and where the Ecological site with the most dissimilar plots, on average, contained just over half (0.54) of the same species as each other. The range of Sorenson-Dice values for the 25 most dissimilar plots were from 0.45 - 0.6. The 25 most dissimilar plots were in 9 Ecological Sites, with the following having the most plots in them: R036XY113CO (1), R036XY141CO (1), R036XY284CO (1), R036XY315UT (2), F048AY918CO (3), R034XY401CO (3). The median of beta-diversity of the major functional groups varied from forb (0.82), grass (0.55), shrub (0.62), indicating that turnover in forbs is much greater than for the other two groups. This is to be expected given that there are a greater number

of forb species than grasses and shrubs. Given the low amounts of $\alpha - diversity$ observed for grasses, these results may indicate that the same few grass species are being observed across plots. The turnover in species composition for the minor functional groups was not analyzed as more replicates appear to be required.

The $\gamma - diversity$ of Ecological Sites varied widely in the number. However, the accuracy of the current estimates of $\gamma - diversity$ are limited by the number of replicates per Ecological Site. The estimated Sample coverage per Ecological Site ranged from 23.44 to 91.62 with a median of 65.82, 80% confidence interval; in general it appears only 3-4 plots are required to gain Sample coverage estimates about 50%. In other words, we do not yet have enough replicates per Ecological Site to make definitive statements regarding the species richness of each site, but clear trends have emerged. The Ecological Sites with the greatest number of species are R036XY114CO (spp. = 201), R036XY113CO (spp. = 187), R036XY284CO (spp. = 143), R036XY326CO (spp. = 131), R048AY238CO (spp. = 131). The predicted estimates of the number of species which are to be expected, in the UFO, at these sites with further sampling are: R036XY114CO (spp pred. = 267, LCL = 226, UCL = 307), R036XY113CO (spp pred. = 280, LCL = 228, UCL = 332), R036XY284CO (spp pred. = 249, LCL = 201, UCL = 298), R036XY326CO (spp pred. = 228, LCL = 173, UCL = 283), R048AY238CO (spp pred. = 240, LCL = 188, UCL = 293) (80% confidence intervals). It appears that the high rates of $\gamma - diversity$ observed at two Ecological sites: R036XY114CO, R036XY326CO, are likely to relate to the large geographic expanses of them, rather than high rates of $\beta - diversity$. While for the other sites, as expected $\beta - diversity$, is the primary factor fostering high rates of $\gamma - diversity$.

The Ecological Sites above, which have the greatest net number of species have forb (74-126 med. = 90), grass (15-20 med. = 19), shrub (26-50 med. = 39) species per functional group. The number of forbs at these ecological sites range from annual-forb (12-27 med. = 24), perennial-forb (50-100 med. = 74). The number of grasses at these sites range from c3-annual-grass (1-1 med. = 1), c3-perennial-grass (9-15 med. = 14), c4-perennial-grass (3-5 med. = 5). The number of shrubs vary from non-resprout-shrub (7-15 med. = 13), resprout-shrub (8-16 med. = 10), shrub (9-21 med. = 16), (Figure 1).

In summary, it appears that grass functional and taxonomic diversity are much lower than expected. It also appears that shrub diversity is wanting. Monitoring of forb diversity should be followed up several years post drought to determine if it rebounds. Returning to grasses, the number of species, in only a handful of plots, meets or exceeds the numbers of grass species noted present in reference conditions in all ESD's. Observations suggest that the grass species which appear to be missing from expanses of the field office include two species of *Sporobolus* (*S. airoides*, and *S. cryptandrus*), *Koeleria macrantha*, with noted declines in *Hesperostipa comata* and *Aristidia purpurea* in areas as well.

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