Rare Species

> *"Rarity is one of those concepts that suffuses our culture: it defies precise definition and when used by the scientist it is often given a spurious accuracy to satisfy our need for precision."*
>
> — V.H. Heywood 1988

In general, a connotation where rare species are synonymous with legal protections exists in popular culture (Kruckeberg & Rabinowitz (1985), Gaston (1994)). However, rarity is the normal condition under which a vast multitude of species in all kingdoms of life exist, and only a subset of these species are at risk of extinction (Enquist et al. (2019), Flather & Sieg (2007)). Rare species are inherently organisms which are difficult to detect in nature relative to other 'common' species (Rabinowitz (1981)), but see Kondratyeva et al. (2019) for elaborations on rarity. One of the most consistently supported, both empirically and theoretically, observations in ecology is that the majority of species in any one location are represented by only a few individuals (Preston (1948), Stohlgren et al. (2005), Manzitto-Tripp et al. (2022)).

Rare species encode enormous amounts of functional diversity to an area and have been shown in multiple cases to imbue an ability to respond to disturbance (Isbell et al. (2011), Leitao et al. (2016), Mouillot et al. (2013), Oliver et al. (2015)). While we focus on large functional groups in SECTION XX, each of these groups has enormous variation within them, and due to the sheet number of rare species, they comprise most of the variation within these groups (Kondratyeva et al. (2019), Mouillot et al. (2013)). Rare species are also capable of reducing the possibility and severity of biological invasions (Lyons & Schwartz (2001), Oakley & Knox (2013)).

A popular conceptual framework to discuss these species may be considered which contains three dimensions, 1) the geographic expanse of the species, 2) their relative restriction to particular habitats, 3) and the number of individuals per population 'size' (Rabinowitz (1981)). Collectively the interaction between these traits can result in a matrix with eight cells along these axises (Table 1), seven of these cells being rare species, six of which occur more frequently (Rabinowitz (1981)). The rare species which receive most of the attention, are those which are restricted to particular habitats across narrow geographical extents, *'narrow (local) endemics'* (Table 1 & 2) (Kruckeberg & Rabinowitz (1985)). In general narrow endemics tend to be the species which require special legal protection to ensure their habitats undergo minimal alterations (Harnik et al. (2012), AND AND). However, the remaining types of rarity still call for documentation by land management agencies.

Seven Forms of Rarity From Rabinowitz 1981				
Geo. Range:	Large		Small	
Habitat:	Wide	Narrow	Wide	Narrow
Population Size				
Large, dominant somewhere	Locally abundant over large range in several habitats	Locally abundant over large range in a specific habitat	Locally abundant in several habitats but restricted geographically	Locally abundant in a specific habitat but restricted geographically
Small, non-dominant	Constantly sparse over large range in several habitats	Consistently sparse in a specific habitat but over a large range	Constantly sparse and geographically restricted in several habitats	Constantly sparse and geographically restricted in a specific habitat

A typology of rare species based on three characteristics: geographic range, habitat specificity, and local population size.

> *"Many species are abundant in portions of their range, but uncommon in others Brown et al. (1995), Ter Steege et al. (2016)"*
>
> — Enquist et al. 2021

Using the conceptual model in Figure 1 we see that a majority of species in the UFO field office which would be considered rare are likely to have 'Large' Geographic Ranges (left two columns, note the upper left most entry represents common species). These three cells of rare species are less likely to be have federal protections, although at the edges of their ranges may have state protections, as they fundamentally at lower risk of extinction (Figure 2) (Flather & Sieg (2007)). Biologically, these taxa may have interesting properties, relating to their relative positions in the range of the species distribution. As the land which the UFO administers represents only a subset of the range of variation which exists in Western Colorado. An obvious example is that we lack both alpine, and many types of forests. Accordingly, species which may be common on Forest Service Land, may be rare on UFO land. Naturally these species are not of concern for identifying lands which need enhanced protections as would be offered under regulatory protocols, but they provide opportunities for distributing reproductive material to adjacent sites.

In particular, they may be species which are at the edges of their distributions, populations of species at the edges of distributions - either geographically or climatically - these populations often have notably different genetic constitutions than populations near the centers (Hampe & Petit (2005), Oldfather et al. (2020), reviewed in Pecl et al. (2017)). Populations which are expanding into new geographic ranges, largely following shifts in climates are termed *leading edges*, and those populations persisting at the edge of the extent geographic ranges are noted as *trailing edges*. Conserving trailing edge populations at the local level is important as they may contain many forms of genes which are pre-disposed to adapting to climate change associated variables (Hampe & Petit (2005)). Further these populations may end up being essential for adaption on up-slope Forest Service Lands, where our border with them faces alterations associated with severe fires and which may require immediate seed sourcing to recover a stable state (Parks et al. (2019)). Theoretically the lowlands of the UFO are capable of receiving migrants to them from a *leading edge*, however the up slope travel required to enter the basins (e.g. Paradox), slows steady-state dispersal, reducing the chances of immigrants to relatively infrequent events, such as seeds being stuck to muddy bird feet (Nathan et al. (2008), Jordano (2017)). While these events have largely shaped the global distribution of biodiversity, their infrequent occurrence generally means they occur on timescales outside of land management (Nathan et al. (2008)).

Recently approaches to develop a consensus index of Rabinowitzs sense of rarity exist (Maciel & Arlé (2020), Maciel (2021)). Here we attempt to leverage this index, along with another more traditional metric - which defines rarity as records under teh 25th quantile (Gaston (1994)), to identify plants which are locally rare within the Field Offices administrative areas.

Seven Forms of Rarity				
From Rabinowitz 1981 - Species modified to Field Office				
	Large		Small	
Geo. Range: Habitat: Population Size	Wide	Narrow	Wide	Narrow
Large, dominant somewhere	Common	Camissonia eastwoodiae	Sclerocactus glaucus	Penstemon retorsus
Small, non-dominant	Draba oligosperma	Cypripedium calceolus ssp. parviflorum		Eriogonum pelinophilum

A typology of rare species based on three characteristics: geographic range, habitat specificity, and local population size.

The other half of the table in Figure 1, the two right columns with 'Small' Geographic Ranges represents species which are very well tracked by multiple tiers of government and are generally of conservation concern. Species with 'Small' Geographic Ranges and 'Wide' Habitat Specificity (column 3) would be expected to be encountered at numerous AIM plots. These taxa are almost always generally noted as rare by the State, and BLM, and may be considered threatened or endangered by the United States Fish and Wildlife Service (USFWS), the agency which administers the *Endangered Species Act* (Figure 2); but tend to be quite abundant across the landscape within which they reside. Finally the column at right represents the species at the fundamental core of our notions of 'rarity'. These taxa are generally warranted legal protections as human modification of their habitats has the possibility to result in catastrophic declines of populations and subsequently the species. We will utilize pre-compiled tracking lists to address the species which aggregate in this end of the table.
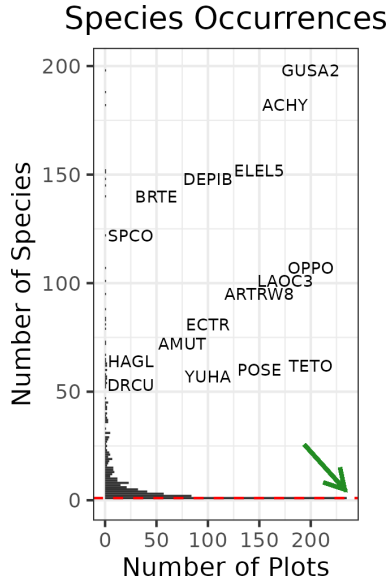
Methods

Species Occurrences

Figure 1: The Commonness of Rarity; This plot shows the number of times which a species was encountered at an AIM Plot. Both the 'singletons' and Gastons Quintile are on the red line. A randomly selected subset of more abundant species are selected to contextualize the few abundant species

Rare Species of Known Conservation Concern

To identify species which are rare, and are species of conservation concern, the Colorado Natural Heritage Program (CNHP) registry of rare plants was downloaded directly from the website in Winter of 2023. Using the list of C-values, also from the CNHP website, which contained an entry for nearly every species in the state (less *Mentzelia paradoxensis*), we determined the appropriate mapping between the plant species symbol used in the AIM database, and the official USDA codes used in all CNHP work. The CNHP registry of rare plants was then subset and used as the definitive source for each organizations tracked species.

Rare but untracked Species

The number of plots which a species was recorded at were counted. This list was filtered for species which only occurred at a single plot, our ecological version of the botanical 'singletons' collection. This list also had the 25th quantile calculated on it using the 'quantile' function from base R.

Rabinowitz Thought Experiment

To identify rare plants via the conceptual Rabinowitz framework the concepts of the Rare7 package were used, but implemented entirely separately.

Geographic Range - In order to produce an estimate of the geographic ranges which species occurred over in the New World, 750 (26.6%) of the 2860 native species present in the Flora of Colorado were randomly sampled. To acquire geographic information on each of these species they were submitted to the 'Botanical Information and Ecology Network' (BIEN) database. All downloaded records from North America from the year 1900 onward were maintained for subsequent analyses.

To estimate the total geographic range which the species covers, minimum convex hulls were produced for each individual species using 500 *jacknife resampling* events; this approach was utilized to reduce the effects a single widely *disjunct* mis-identified record could have on results. The median of all re-sampling events was then used as the geographic range estimate.

Occupancy - To determine how often species occurred across these geographic ranges, a minimum convex hull of the full occurrence data set was 'rasterfied' i.e. turned into a gridded dataset, at a 4km^2 resolution. This raster dataset was overlaid with two other datasets to remove areas which specifically precluded the occurrence of plants records. Grid cells which contained $> 75\%$ large bodies of water, agriculture, or land which has been developed into urban areas (or a combination thereof) (EarthEnv Tuanmu & Jetz 2014), underwent 'focal operations' to unite cells into unsuitable habitat. The cells of unsuitable habitat were then removed from the range maps. The number of occupied 4km^2 cells within the geographic range were then counted. These values were then re-scaled to maximize the variance between 0-1, so that species across more habitats had values closer to 1, while species in fewer habitats had scores closer to 0.

Population Size - To create a broad binomial estimation of population size the BIEN data were split into two constituent portions. The first being records which were contributed from herbaria, and the other being records collected via survey based monitoring work. Raster cells were made more coarse, to 16km^2, to avoid having many 0 records. All plot based records from across all species were combined, and each raster cell which contained the presence of a plot was used for future analyses. For each species, if a plot based record was located in a cell, it was classified as having a high population, if only an herbarium collection was present it was classified as having a low population. The total number of $

Habitat Range - To produce a local spectrum of the range of habitats which a species occurs in all records had Omernik level 4 regions extracted to the them, and the proportion of habitats were calculated. $ NumberHabitats/NumberPoints $ these were then rescaled to maximize the variance between 0-1, so that species across more habitats had values closer to 1, while species in fewer habitats had scores closer to 0.

To better understand the relationship between habitat range both in Colorado and abroad, the values of habitat range were multiplied by the values of occupancy. The consensus values were used for further analyses.

Results

The original AIM Species Richness data set contained 7525 plot based observations from 276 plots. After removing 113 morphotypes which were not identified (1.5% of all records), dropping the 16 records which were not identified beyond genus (0.21% of all records), and removing 37 synonymous taxa at the same plot (0.5%), 7375 records were left. These records represented 676 distinct terminal taxa, i.e. final taxonomic units - species were not double-counted with infra species, which are more or less in accord with the states most current Floristic treatments, and the USDA.

The CNHP rankings include many species which are considered rare by agencies with different focuses and intentions from the BLM. While their initial list is comprised of 540, different organizations and agencies have different criteria for interpreting and classifying susceptibility of a species to extinction and loss of populations. The most rigorous and selective conditions are enforced the United States Fish and Wildlife Service (USFWS), whom maintain the only official registries and implement the evaluation procedures for 'Threatened' and 'Endangered' species. These categories represent species of the highest concern regarding their continued existence, with Endangered Species being the more severe category of the two. Colorado contains 15 species tracked by the USFWS, 8 of these species are threatened with extinction, and 6 are immediately endangered. Of the species tracked under the Endangered Species Act 5 species, Sclerocactus glaucus, was found at 5 plots.

The Bureau of Land Management officially tracks plants which are of conservation concern on their lands, and which may be petitioned to be elevated to the more stringent categories implemented by the Fish and Wildlife Service, but which are mostly undergoing further assessment. As the BLM is contained within the government, these tracked taxa do not contain any redundancies with the Endangered Species Act list. BLM Colorado has 65 sensitive species. Of the BLM sensitive species 5, Astragalus musiniensis, Astragalus rafaelensis, Pediomelum aromaticum, Lomatium concinnum, Camissonia eastwoodiae, were found at a total of 6 plots.

Several Non-Governmental Organizations (NGO's) also maintain their own information on species of concern, utilizing different methods and assessments than Government Agencies. A large portion of there goals are to form networks which are global in scale, rather than restricted to state actors, allowing for more comprehensive views of biological ranges and processes. Accordingly, they have a more integrated global perspective on species, and then make assessments of susceptibility to extinction at administrative units to assist local planners. One such agency is NatureServe. NatureServe uses a tiered ranking system, from 5-1, with lower values indicating susceptibility of a taxon to extinction at a either a Global or State level. Values '3' and below are taxa that warrant conservation considerations. The number of low value species, are greater at lower administrative levels, oftentimes due to species ranges crossing multiple administrative

units. The number of S3 ('S' short for 'State') or lower (S2, S1) species in Colorado is 519, and the subset of these which are globally tracked species with G3 ('G' short for 'Global') or lower ranks is 219. These two lists are not independent of the government data, for example the State list contains 15 of 15 FWS species, while the global list contains 14 of them. In addition, the state list contains 64 or the 65 BLM Sensitive Species, while the global list contains 53. We subtract these species from these two lists and end up with a total of 440 species on the state and 152 species on the global lists to avoid confusion in reporting. We further remove the species present in the state list from the global list reducing the state list to 291, which maintains the global list at 152. Of the state species 21, were found at a total of 47 plots, for a total of 50 records. Of the state species 13, were found at a total of 37 plots, for a total of 40 records.

A fascinating rare plant recorded on the AIM plots was *Mentzelia paradoxensis* J. J. Schenk & L. Hufford, a taxon described as new to science in 2010. This was found at a single plot, in the Paradox Valley, the locality from which it was collected in by prolific Intermountain West botanists Noel and Patricia Holmgren. This species hypothesis is so new, relatively little testing of it has been carried out, and to date the Colorado Natural Heritage Program has not evaluated the conservation status of it. Botanical collectors have determined it to be present in both the Paradox and the nearby Big Gypsum Valley, in both instances growing on stream terraces with elevated gypsum content. This species was requested to be added to the AIM database by both the Lead State Botanist, whom is also the BLM Rare Plant Lead, and the offices Ecologist. However, the AIM team refused to do so. We think it is important that other project leads maintain active lists of oddities which they come across to include in their analyses as needed and that they should not trust the NOC to adequately track biological resources.

In regards to species which are rare within the UFO field office, but not of conservation concern, two methods 'singletons' and 'Gastons Quantile', returned identical results. Both methods suggest that there are 235 rare species. The convergence of values implicates two methodological limitations. In regards to singletons, these records generally come from floristic inventories, wherein a well trained botanist is unconstrained by the dimensions of plots, and is able to roam a large area using their knowledge of an area and intuition. In the case of a field office wide inventory, they would be able to allocate considerable less time to certain Ecological Sites with very few species, in lieu of spending it in areas with many species. We do feel after several more AIM sample frames this will start to deliver quite effective results. Regarding Gastons Quintile, or the lower 25% of records, this may indicate an inconsistency in goals of survey work. Many ecologists in the era in which this metric was derived were oftentimes explicitly surveying for species diversity and abundance metrics, whereas AIM serves to characterize landscape units, as delimited by geomorphology. Accordingly, the ecologist of yesteryear strove to maximize variation between plots, while the rangeland ecologist of today seeks to maximize statistical inference across landscapes. That such a significant number of species only occurred at a single plot, may in part reflect that a single Sample Frame of AIM data is not enough to start to gather information on the biotic composition of this field office. However, we see no reasons that future results for Gaston's Index would be significantly different than the species composition presented here, and believe that many of the singleton's identified here, would be singleton's again after combing these data with those in the next sample frame.

Of the 235species identified by Gaston's and the Singleton method 19 overlap with the 27species of conservation concern which were found on plots. It is expected that these approaches would give different results, given that rare species tend to be abundant in portions of their ranges.

___When we remove these **r** known and documented, by CNHP, rare species from the subsequent analyses of rarity, the use of the composite Rabinowitzs Index identifies **r** taxa as rare. To determine whether this metric was capable of detecting species which have been identified as rare by the CNHP, the list of species . . . was compared to the output from the function . . . and chi-square results SAY . . . Indicating that. . .

Of these species **r** are known from the general area of the UFO, and **r** have been documented on UFO administered land. AIM crews observed the presence of **r** of these taxa, at **r** AIM sites. **r** of these sightings served as revisits to known *elemental occurrences* (EO's) and serve to document that the taxon was still extent in an established EO. **r** of these sightings, for **r** taxa, qualified as new *EOs* - or at least finally provide the essential official written documentation of a population. For the first time ever, AIM crews documented the existence of **r** species on UFO BLM administered lands.___

Discussion

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