Effects of Grassy Bald Management on Plant Community Composition within The Roan Mountain Massif

Cecelia Stokes and Jonathan L. Horton*

Biology Department
The University of North Carolina Asheville
One University Heights
Asheville, North Carolina 28804 USA

* Corresponding author (jhorton@unca.edu)

Abstract
Within the Roan Mountain massif in the southern Appalachian Mountains, grassy balds are important, yet threatened ecosystems dominated by native graminoids with many endemic and endangered species. Restoration efforts have been conducted for 30 years by several agencies. In 1987–1988 a vegetation analyses was conducted on these balds to characterize plant communities before intensive management began. In summer 2020, we resurveyed the vegetation using similar methodologies on Round, Jane, and part of Grassy Ridge Balds to assess the impact of management activities. Percent coverage of vegetation type was recorded in 226 one m^2 plots along 11 transects. Management history was compiled for individual plots. Percent cover data were subjected to cluster analysis, principal components analysis (PCA), non-metric multidimensional scaling (NMS), and regression. Cluster analysis of sampled plots revealed 12 plant community groups. PCA revealed plots separating along a gradient of blackberry and grass cover, as well as blackberry, grass, and fern cover.

Results from NMS showed less separation of plots compared to PCA with most plots clustering in the center, except those with high bare ground coverage. A significant positive relationship was seen between graminoid cover and management frequency and a negative relationship with the amount of time since management activity. All of the relationships had low explanatory power suggesting that other factors might influence the plant populations. Our research shows there is a positive association with graminoid cover and increased management frequency, but more research involving other biotic and abiotic factors and management history should be explored.

Key Words

Grassy balds, land management, plant community composition, conservation, restoration

Introduction

Temperate montane grasslands and meadows, often known as grassy balds, are rare, but important, ecosystems. Characteristically, grassy balds are dominated by native grasses, sedges, and forbs, but also contain many endemic, endangered, and rare plant species. The grassy balds of the southern Appalachian Mountains are known for high biodiversity and their overall scenic beauty (Weigle and Knowles 2013). They occupy isolated peaks and ridges ranging from the Great Smoky Mountains through Virginia. These communities are surrounded by forests of red spruce (*Picea rubens* Sarg.), Fraser fir (*Abies fraseri* (Pursh) Poir.), beech (*Fagus grandifolia* Ehrh.), and yellow birch (*Betula alleghaniensis* Britton), along with a few other smaller tree species (Weigl and Knowles 2013). The balds of the Roan Mountain Massif support many rare species, such as Gray's lily (*Lilium grayi* S. Watson), Roan Mountain bluet (*Houstonia purpuea L. var. montana* (Small) Terrell), and Roan Mountain golden rod (*Solidago roanensis* Porter). Round, Jane, and Grassy Ridge Balds (Figure 1), all within the Roan Massif, are dominated by mountain oat grass (*Danthonia compressa*

Austin), Pennsylvania sedge (*Carex pensylvanica* Lam.), Catawba rhododendron (*Rhododendron catawbiense* Michx.), and green alder (*Alnus viridis* (Chaix) DC.; Weigl and Knowles 2013). There is a global decline of these historically open and treeless expanses due to the encroachment of surrounding forests and woody plant species (Zald 2009), but blackberry (*Rubus allegheniensis* Porter and *Rubus canadensis* L.) is the most pervasive threat to these communities in the southern Appalachians. The biological significance of the balds of the Roan Mountain Massif has led to much research to determine their origins and best management practices to preserve the unique plant community composition (Mark 1958; Gersmehl 1973, Murdock 1986; Weigl and Knowles 1999; Weigl and Knowles 2013).

Understanding the origin of the grassy bald communities has resulted in extensive debate. Over the course of the past several decades, some researchers have thought the balds were the result of Native American activities or agricultural practices of European settlers (Gersmehl 1973), effectively dismissing them as human artifacts. Weigl and Knowles (2013) proposed an alternative climate-herbivore hypothesis to explain the balds' origins and persistence through time. They theorized, while experiencing frequent human modification over the last 150 years, grassy balds are most likely a natural occurrence. They are thought to be the product of Pleistocene glacial advances displacing woody vegetation from mountain tops, coupled with the activities of mostly now extinct grazers on the resulting open habitats. The grass and sedge communities supported a large and diverse group of grazers, such as mammoth, mastodon, bison, moose, elk, and caribou (Weigl and Knowles 2013) which sustained the balds until they became locally extinct approximately 11,500 years ago. Native American management and European settlement have maintained the balds for livestock, hunting, and other pastoral tasks for much of their more recent history. Many graminoid-based ecosystems, dominated by grasses, sedges and rushes, thrive on disturbance (Yuan et al 2016) and the lack of adequate grazing has contributed to their decline. Despite their increasing scarcity, balds still support many rare, endemic, and disjunct plant species (Weigl and Knowles 2013). Some of these species are members of the northern alpine and tundra floras while some may be relics of flora associated with the late Pleistocene alpine period (Godt et al. 1996). During this period there would have been extensive open meadows and exposed rock outcrops across the mountaintops in this region. Many of these species that are highly light-dependent have had suitable conditions over a large enough area for sufficient time to speciate, to avoid the extinction effects of small population size, and to disperse along some of the ridges (Godt et al. 1996). However, these species' habitats have been steadily altered due to climatic changes, disruptions in disturbance regimes, and subsequent successional events. Grassy balds are defined by high biodiversity and numerous endemic species which means the loss of one bald represents the loss of an entire ecosystem that may not be present at any other place on the landscape (Copenheaver et al. 2009). They provide a source of food for fauna, soil erosion protection, water flow regulation, carbon sequestration, habitat for migratory species, as well as recreational and aesthetic values (Tokarczyk 2017). The further loss and fragmentation of temperate mountain grasslands may lead to a change in regional carbon storage (Knapp et al. 2008), loss of biodiversity, degrade unique plant communities, and negatively impact many species that require open spaces for survival.

The unique vegetation, beautiful scenic landscapes, and historic importance of the Roan Mountain massif grassy balds have motivated several nonprofit and government organizations to work together for the past three decades to preserve and rehabilitate the area. The larger balds are managed by the

National Park Service and the U.S. Forest Service, along with the Southern Appalachian Highlands Conservancy managing surrounding smaller balds and large tracts of nearby forested areas. Most balds that are relatively stable and open are those that have been recently, or are still being, grazed by livestock, or that are maintained by frequent cutting and mowing (Weigl and Knowles 2013). Woody plant invasion onto the balds was recognized as a serious management problem at a special Balds Management Symposium convened by the Forest Service in 1986 (Hamel and Somers 1990). The decrease in grassy balds is a widespread conservation and ecological restoration concern. Grassy openings are at risk of closing completely in several regions in which frequent disturbance is needed to maintain graminoid dominance (Copenheaver et al. 2009). In the Pacific Northwest region of North America, grasslands and mountain meadows have declined significantly over the past century (Zald 2009). A study found that the five balds in the Oregon Coast Range had spatially decreased by 66% within 1948–1953 to 1993–2000 due to primarily forest encroachment (Zald 2009). In 1988, a vegetation survey of the bald, Judaculla Fields, of Black Balsam found that grass and mixed herb cover decreased by 25% and 21% respectively and woody shrub cover increased by 239% over a five-year period (Sullivan and Pittillo 1988). Additionally, dendrochronological analysis on Craggy Gardens, a grassy and heath bald in the Southern Appalachian Mountains, reconstructed 245 years of red oak (*Quercus rubra* L.) encroachment. In the absence of regular grazing, red oak establishment rapidly increased until ecological restoration projects began in 2001 (Crawford and Kennedy 2009).

Currently, repeated hand mowing and shrub cutting is being used in the Roan balds to reduce populations of blackberry and other encroaching woody plant species. The goals of management are to greatly reduce the amount of blackberry in the grass dominated areas without causing detrimental damage to the rare species and other important forbs. Mountain oat grass was the historically dominant grass species, but has been steadily outcompeted by thickets of blackberry. Blackberry is a perennial shrub that uses vegetative growth from rootstocks as the principal method for colony development (Crawford and Kennedy 2009) and can aggressively spread throughout open areas. These thickets progress very quickly and suppress grasses, sedges, and slower growing forbs. Other common woody species within the grassy balds, such as rhododendron and green alder are not as aggressive and expand very slowly in the absence of disturbance (Murdock 1986).

The threat of natural and anthropogenic factors to the persistence of these balds requires conservation efforts to be developed and guided by an understanding of the impacts of active management practices on plant community dynamics. Before current active management programs began, an intensive vegetative survey was conducted across the Roan Mountain Massif in 1987 and 1988 (Hamel and Somers 1990). This study detailed the relationships among the balds, the distribution of plant community types including the dominant species present, and the physical parameters of the bald ecosystem. Using a similar methodology to that of Hamel and Somers (1990), the vegetation on Round, Jane, and a small portion of Grassy Ridge balds was surveyed in the summer of 2020. The main objectives were to assess the effects of 30 years of management on plant community composition and distribution compared to those in the late 1980s before active management was implemented.

Materials and Methods

Study Site

The Roan Mountain massif is located within the Unaka Range of the southern Appalachian Mountains in the southeastern United States. The Cherokee and Pisgah National Forests merge near the peak of the highlands, with Roan

Mountain State Park positioned at the northern base of the Roan. The Appalachian Trail extends throughout most of the area. This study was conducted on the balds between Carver's Gap and the beginning portion of Grassy Ridge bald. Transects and vegetation plots were established on Round bald (1775 m), Jane bald (1769 m), and a small portion of Grassy Ridge bald (1879 m), as well as the gaps between each. Data collection started in June 2020 and extended until September 2020. In the time available, we were only able to resurvey a portion (Round, Jane, and a portion of Grassy Balds) of the Hamel and Somers (1990) study.

Field Methods

Transects were positioned along the Appalachian Trail at 150 m intervals starting from Carver's Gap (36.1065077°N, -82.1106785°W). In order to ensure a similar transect density as Hamel and Somers (1990), the route of the historic Appalachian Trail (AT; rerouted in 2008) was used as a central line until it converged with the current route. To aid in relocation of transects, a GPS point was taken where each transect bisected the current location of the AT. The distance from the trailhead at Carver's Gap (fence) to each transect was measured along the current AT. Transects were laid out perpendicular to the central line extending outward in northerly and southerly directions until the end of the grassy bald was reached. In order to maintain a consistent bearing throughout sampling, a 100 m tape was used to lay out the transect. The edge of the grassy bald occurred at the point in which heath shrubs or tree species presence became proportionally higher than grassy area. Heath balds and forested areas are not the intended area of focus for this study. If there was no grassy bald present at the corresponding 150 m interval, a GPS point was recorded, and the dominant types of vegetation were noted. The following transect was established at the next 150 m interval. This allowed for consistent transect location from bald to bald. Vegetation plots were sampled randomly at 8–12 m intervals along the entire transect to ensure a similar density to Hamel and Somers (1990). If an original plot was encountered along a transect, the plot distance was adjusted so that these plots would be resampled.

Data Collection

Percent coverage of vegetation was determined using a 1 x 0.5 m2 PVC quadrat divided into 50 equal sized squares. Plots were 1 x 1 m2 with the northern half of the plot being surveyed first then the southern half. The center aligned with the number on the meter tape corresponding with the distance of the plot from the centerline of the transect. Every square was visually assigned a dominant type of vegetation which allowed a total of 100% coverage per plot. Shrub (>1 m in height) and ground coverage (<1 m in height) were determined, as well as, the type of overstory, if present. The categories of shrub vegetation consisted of green alder, blackberry, blueberry (*Vaccinium* spp.), Catawba rhododendron, serviceberry (*Amelanchier laevis* Weigand), mountain ash (*Sorbus americana* Marshall), American beech (*Fagus grandifolia* Ehrh.), flame azalea (*Rhododendron calendulaceum* (Michx.) Torr.), and fraser fir. The categories of ground vegetation consisted of green alder, blackberry, blueberry, purple rhododendron, angelica (*Angelica triquinata* Michx.), grass, fern, sedge, grass, rock, bare, moss, lichen, "other woody," and "other forb." Some plants that were considered to be "other woody " or "other forb," such as Carolina bugbane (*Trautvetteria caroliniensis* (Walter) Vail), Roan Mountain rattlesnake root (*Prenanthes roanensis* (Chickering) Chickering), sheep's sorrel (*Rumex acetosella* L.), fringed loosestrife (*Lysimachia ciliata* L)., and whorled wood aster (*Oclemena acuminata* (Michx.) Greene), were further identified to species in the field when possible. Despite the ongoing Covid pandemic, we were granted a limited research permit from the U.S. Forest Service to collect vegetative data at Roan. The ongoing COVID pandemic resulted in restricted acces, therefore our sampling time was shorter than expected and we were not permitted to take collections for later herbarium and lab identification. As a result, we were unable to do a complete species inventory. Instead, we used a modified sampling protocol developed by Gary Kauffman, a botanist for the U.S. Forest Service, to survey vegetative composition at Roan Mountain with a focus on a few dominant species (e.g. blackberry, rhododendron, angelica) and main functional types (e.g. grass, sedge, etc.). GPS locations and photographs were recorded for every plot. In total, 12 transects were established and 226 vegetation plots surveyed within the distance of 3.36 km from the trailhead, however two plots were excluded from analysis because of incomplete data.

Data Analysis

The vegetation plot data from 224 plots was used to determine the 21 most frequently recorded vegetation types (Table 1) then subjected to a series of analyses. This was to ensure that infrequent plants did not influence the results and to match the methods used by Hamel and Somers (1990). Rock cover and overstory species were excluded from these analyses. Cluster analysis of the vegetation cover data was performed with PC-ORD v6.08 (McCune and Mefford 2011) using Ward's method with Euclidian distances and 75% information remaining (Peck 2010) to determine plant community assemblages. Ward's method uses the total error sum of squares criterion with K-means partitioning and produces groups that minimize within-group variance (Murtagh 2014). Clusters were separated on the resulting dendrogram (Figure 2). Community groups were distinguished by the three most dominant vegetation types contributing more than an average of 14% total cover between included plots and named with the types in

Cluster Analysis

subsequent order. To determine which factors explain variation in plot distribution and to relate these results to the previous Hamel and Somers (1990) report, principal components analysis was conducted on the vegetation cover data using PC-ORD with centered variance and covariance matrices within distanced-based biplots. Plot distribution was visualized using the assigned cluster (or plant community) number from analyzed vegetative cover data. Additionally, we used non-metric multidimensional scaling (NMS) with Sorensen distance measures in PC-ORD, following protocols from Peck (2010), to further examine patterns of plot distribution. Joint plots were used to determine species vectors associated with the spatial separation of plots in the recommended 2D representation. A spatial join conducted using ArcGIS 10.6 (ESRI 2017) compiled the entirety of the management history from 1988 to 2020 including specific types, most recent activity, and frequency of management for each individual plot. The relationship between cover of vegetation of management concern (blackberry, grass, sedge, and combined graminoids (grass and sedge)) and management activities was assessed through linear regression. Linear models were constructed relating cover to 1) number of hand mowing (weed whacking), 2) shrub cutting, 3) track mowing (using a large riding mower), 4) goat grazing, 5) total number of all management treatments separately. Additionally, models were constructed relating cover to the time since last management activity. These analyses were done in SAS v9.4 (SAS Institute 2012).

PCA

NMS

ArcGis

Linear Regression

Results

Plant Community Composition

Clustering vegetation plot data of the most dominant vegetation (Table 1) described 12 clusters (Table 2, Figure 2). All of the groups were found on Round bald, whereas four groups were found on Jane, eight within Engine gap, and seven on Grassy Ridge. However, Grassy Ridge was not completely sampled because of time constraints. The grass community was found within 54 plots making it the most prevalent of the community types. It averaged 74% grass cover. The grass/blackberry community included 47 of the survey plots making it the second most frequent community type. It averaged 49% grass cover and 41% blackberry cover. The grass/blackberry/fern community consisted of 28 plots which averaged 31% grass, 27% blackberry, and 25% fern cover on average. The fourth community, blackberry, is a group made up of majority blackberry averaging 75% ground cover in 26 total plots. The grass/sedge/blackberry community averaged 41% grass, 15% sedge, and 14% blackberry cover and includes 19 plots. The sixth community, sedge/blackberry/grass, was similar to group five in the vegetation types, but differed in their cover dominance. The cover averaged 46% sedge, 24% blackberry, and 14% grass between 11 plots. The fern/blackberry community averaged 72% fern cover and 14% blackberry and included 10 plots. The moss/Carolina bugbane community averaged 23% moss cover and 14% Carolina bugbane cover. Two communities were described as rhododendron ground averaged 58% cover in the ground cover layer and rhododendron shrub with 100% shrub cover. These communities included 11 plots combined. The blueberry/grass community averaged 97% blueberry shrub cover and 19% grass cover between five plots. Lastly, the blueberry community averaged blueberry ground coverage of 83% and includes four plots.

grass community 1
grass/blackberry 2
grass/blackberry/fern 3
Blackberry 4
grass/sedge/Blackberry 5
Sedge/Blackberry/grass 6
Fern/Blackberry 7
moss/bugbane 8
rhodo ground 9
rhodo shrub 10
Blueberry/grass 11
Blueberry 12

Variation in Plot Distribution

The PCA on 224 of the plots detailed that 11 axes accounted for 94.5% of variability in distribution. Eigenvalues ± 0.3 were used to determine axis influence. The primary axis (Axis 1) explained 33.8% of the variance and plots separated along this axis by eigenvalues on a gradient of blackberry

(-0.538) and grass (0.821) cover. Additionally, Axis 2 explained 20.0% of variance in plot distribution and was driven by eigenvalues of fern (-0.329), grass (0.430), and blackberry (0.790) (Figure 3). Plots containing community type 1: grass (Table 2) were clustered along the right side of Axis 1 with plots of other community types with a high grass and blackberry components (2: grass/blackberry; 3: grass/blackberry/fern; 5: grass/sedge/blackberry) clustered more in the center of the graph. Plots dominated by blackberry (community type 4) were clustered in the upper left. Results from NMS showed less separation of plots, with a majority of plots clustered in the center of the graph (Figure 4A). Plots containing a high shrub component, either in the ground cover layer (community type 9: rhododendron in the ground cover layer; 10 rhododendron in the shrub layer; 11: blueberry in the shrub layer with grass ground cover; and 12: blueberry in the ground cover layer) were mostly outside the central grouping of plots. The "bare ground" vector points towards some of these plots. Looking at a close up of the central grouping of plots (Figure 4B), shows plots separating on the species vectors "grass" (community type 1: grass) and "blackberry" (community type 4: blackberry). Plots with a high component of both grass and blackberry (2: grass/blackberry) are clustered mostly between these two vectors.

Management History

Blackberry cover increased significantly with the number of shrub cutting treatments ($y = 5.2x +24.4$, $p = 0.0014$, $r2 = 0.046$) and goat grazing ($y = 5.8x + 29.6$, $p = 0.001$, $r2 = 0.049$). Blackberry cover was not significantly related to any other treatment or time since last treatment (all $p > 0.05$). Grass cover increased significantly with the total number of management activities ($y = 1.6x + 27.39$, $p = 0.002$, $r2 = 0.046$), and track mowing ($y = 1.4x +35.0$, $p = 0.040$, $r2 = 0.019$), and it decreased with increasing time since last management ($y = -0.9x + 43.4$, p

= 0.0002, $r2 = 0.061$). Sedge cover decreased significantly with increasing time since last treatment ($y = -0.3x + 8.0$, $p = 0.004$, $r2 = 0.038$). Sedge cover did not have a significant relationship to the total number of treatments ($p > 0.054$). Combined graminoid cover was shown to significantly increase as management treatments increased ($y = 2.0x + 30.6$, $p < 0.0001$, $r2 = 0.066$) and decreased as time since the last treatment increased ($y = -1.2x + 51.5$, $p < 0.0001$, $r2 = 0.093$) (Table 3).

Discussion

Plant Community Composition

Grassy balds are known for their high biodiversity and unique plant communities because of their association with northern alpine and relict floras. The percent cover data collected among the three balds consisted of roughly 59 different vegetation types, genera, and species, an underestimate, to be sure, because of our inability to conduct a complete floristic inventory. However, many of these were infrequent, appearing in few plots. While these were excluded from data analysis, their presence indicates the high biological diversity present in these communities. Hamel and Somers (1990) and found six community types present among the six balds: green alder/blackberry, oat grass/cinquefoil, blackberry/sedge, sedge, cinquefoil, and unresolved. Cinquefoil and blackberry/sedge communities were the most common found in the 1980s study, whereas in this study twelve community types were found with the grass and grass/blackberry groups being the two dominant community types. These differences may be attributed to multiple factors. First, our only study sampled three out of the six balds that were included in the original Hamel and Somers (1990) survey. Specifically, the exclusion of Yellow Mountain which contained 112 plots associated with the cinquefoil dominated community may have caused the lower frequency of cinquefoil seen in this study. In addition, the exclusion of Mt.

Hump and Bradley Gap may explain the difference in sedge dominance between studies. In the 2020 survey, sedge was found to be the dominant vegetation in the sedge/blackberry/grass community and the secondary component in the grass/sedge/blackberry community which were both found only on Round Bald and consisted of 30 total plots combined. However, Mt. Hump and Bradley Gap were found to have the highest frequency of community groups associated with sedge by Hamel and Somers (1990), therefore comparisons of sedge populations before and after management should be made with caution. Lastly, the methods of cluster analysis and interpretation of community types from dominant vegetation cover within plots used by Hamel and Somers (1990) differed from the methods outlined in this study. After determining the 21 most frequent vegetation types, they sought out cluster groupings that had a reasonable number of groups and were inferred as biologically interpretable. They chose to define the six clusters (listed in the previous paragraph) as the most meaningful and assigned each plot to a group based on its individual vegetation cover data. This difference in methodology could explain the higher number of community types described in our results. Furthermore, we established a 14% threshold to uniformly determine dominant vegetation cover across plot clusters to interpret community types (Table 2), whereas Hamel and Somers (1990) assigned importance values to each vegetation type to determine dominance and relative percent cover was not listed for all community groups. Without utilizing the same statistical methods it can be difficult to draw comparisons between studies. However, important ecological conclusions can still be made from our results. We outlined the current plant communities and compositions on Round bald, Jane bald, and a portion of Grassy Ridge bald which can be used to inform crucial on-going and future management strategies.

The consistent disturbance regime introduced after 1988 through active management can be interpreted as one of the main contributing factors to the change in dominant community types. Disturbance through active management has been shown to maintain biodiversity and increase grass species richness in grasslands (Wilson and Clark 2001, Fynn et al 2004, Smith et al 2008). Management treatments have increased substantially on the Roan Mountain Massif within the past 30 years and our results outlined the increase in frequency had a significantly positive relationship on graminoid cover (Table 3). Four of the community groups which consisted of 148 total plots (63.3% of total plots) were dominated by grass , whereas grass was the dominant component in one community group defined by Hamel and Somers (1990). Blackberry made up the dominant vegetation type of the blackberry community, the secondary component within the grass/blackberry, grass/blackberry/fern, sedge/blackberry/grass, and fern/blackberry communities, as well as the third component of the grass/sedge/blackberry community type. The current dominant plant communities of grass and grass – blackberry are suggestive of successful management treatments over the past few decades, but the high frequency of blackberry throughout the communities cannot be ignored for determining future management and should continue to be a restoration concern. Although not addressed in our study, non-native, invasive plants are an additional rehabilitation concern on the balds of the Roan. Hamel and Somers (1990) found *Rumex acetosella* to be the dominant non-native invasive species on all of the balds except Hump Mountain and Bradley Gap. This species was encountered in our sampling, but further research is needed to examine if its range has expanded or decreased with active management. Data on the ranges of other exotic invasive species, such as Timothy grass (*Phleum pratense* L.), Coltsfoot (*Tussilago farfara* L.), and garlic mustard (*Alliaria petiolata* (M. Bieb.) Cavara & Grande) would be valuable to incorporate into future vegetation surveys within the Roan

Highlands as well.

Variation in Plot Distribution

Principal components analysis of the twenty-one most dominant vegetation types described relationships between vegetation and variance of plot separation similar to that of Hamel and Somers (1990). Their results described 11 axes that accounted for 95% of variation within the entire dataset compared to the 11 axes found by our analyses that accounted for 94.5% of variance. The first major axes in the Hamel and Somers (1990) study accounted for 36% of variance and was driven by the contrast between blackberry and grass cover. Their second axis was driven by blackberry and sedge cover. Our main axis with the highest explanatory power (Axis 1) of 33.8%, also had plots separating along a gradient of blackberry and grass cover. Assigned community numbers (Table 2) were used as points to show the distribution of community types along the gradients described by both axes (Fig. 3). The plots within the grass (1) and blackberry (4) communities are clustered on opposite ends of Axis 1 suggesting as blackberry cover increases, grass cover decreases. Because blackberry is the main encroachment threat within these communities, the density and frequency of blackberry thickets on the balds should continue to be the central factor in deciding where, when, and what type of management treatment is executed within a given plant community. The Hamel and Somers' (1990) study was much larger with a total of 897 plots across six balds than this study, suggesting caution when drawing relationships between these two studies. However, the strong contrasting relationship between blackberry and grass cover found in both studies illustrates the importance in continuous management of woody plants to encourage graminoid and forb growth and inhibit further encroachment. The second main axis (Axis 2) describes the plots separating along a combined gradient of high

Fig. 3

blackberry and grass, and high fern cover. This is suggestive that areas with high fern cover will have less blackberry and grass cover. Of the twelve community groups described, ferns did not make up their own community, but it was the dominant cover type in the fern – blackberry, and grass – blackberry – fern communities. Hay-scented ferns form thick, tall clusters and were observed on all the balds surveyed in 2020. Potentially, future research could be necessary to assess fern populations and their potential impact on graminoid and forb dominated communities. Management techniques, such as mowing, have been shown to reduce fern frond size (Crétaz and Kelty 2006) and should be assessed for efficacy on the Roan Mountain Massif if a threat is determined.

The results from NMS showed less separation of plots compared to the PCA with the majority clustering within the center of the graph (Figure 4A) except for plots that correspond to communities with high levels of woody vegetation cover, such as rhododendron and blueberry. These outlying plots are separated along a vector driven by bare ground cover. Bare ground was largely associated with high rhododendron or blueberry shrub cover due to the inability of understory vegetation to grow underneath the thick canopy created by these woody plants. Community groups dominated by rhododendron and blueberry consisted of only 20 plots out of the 226 total and these genera spread at a much slower rate (Hamel and Somers 1990) compared to blackberry which is not suggestive of a crucial management concern currently. When looking more closely at the center cluster (Figure 4B), the plots are separating along two separate vectors driven by high grass and blackberry cover which is similar to the driving gradients found by the PCA ordination. The high stress value (23.7) found by the NMS ordination is indicative of a poor representation in the data of plant community composition variance. The lack of distinct grouping of community types suggests overlap of composition of these community types which may be attributed to our limitations in sampling detail of the vegetation to functional type or genus. It is possible that higher degrees of variance would be supported with species level identification of all vegetation encountered. Our results demonstrate the need for future research consisting of more complete vegetation sampling throughout the Roan Mountain Massif to fully assess the plant community types and their compositions.

Management History

The Roan has had a long history of disturbance regimes spanning from ancient herbivores and anthropogenic activities, such as hunting, livestock grazing, and other pastoral work (Weigle and Knowles 2013). However, many of the balds had been largely lacking the level of disturbance needed to impede woody plant encroachment since the cessation of livestock grazing and until mowing techniques were introduced in the late 1980's. Since 1988, the Roan has been actively managed with a combination of hand mowing, shrub cutting, track mowing, and goat grazing. Effectively managing ecosystems for specific outcomes, such as decreasing blackberry encroachment, can be difficult due to the complex relationships between flora and fauna that occur within it. Invasive species control is usually difficult and expensive as the risk of impacting non-target species limits management technique and timing options, so on-going research assessing the effectiveness and practicality of strategies is crucial.

Our results indicated a positive relationship between blackberry cover and the total number shrub cutting or goat grazing treatments. In contrast, Murdock (1986) found blackberry cover decreasing after cutting. The different responses of blackberry cover to cutting treatments could be attributed to the short-term nature of Murdock's sampling along with the study area being restricted to a portion of Round Bald.

Cutting treatments are not the most prevalent treatment used against blackberry thickets on the balds which suggests external factors influencing their increase in frequency. Due to the time and labor intensive nature of implementing shrub cutting across all six balds and the positive relationship outlined in the results, this method is not proposed as an effective management strategy. Furthermore, Murdock (1986) examined the impacts of burning and the combination of burning and cutting treatments on plant community composition. The study demonstrated a significant increase of mountain oats grass in response to fire that persisted for at least two years after the last burn treatment. Prescribed burns have been shown to increase forb and grass cover (Brockway et al 2002). However, much of our knowledge pertaining to grasslands and prescribed burns includes prairies, savannas, and other low elevation grasslands (Pendergrass et al 2002, Brockway et al 2002, Novak et al 2021). Little is known of the effects on woody encroachment, graminoid cover, and forb biodiversity within high-elevation grassy bald systems. Additional research would be needed to determine costs and benefits of introducing a fire regime to the Roan.

Goat grazing in the Roan began on Jane Bald in 2010 and ceased in 2015. Blackberry cover was shown to increase significantly with the frequency of grazing treatment, but only a small number of plots (12) underwent the treatment a maximum of six times. Grazing has not occurred in recent years which leaves space for other possible factors influencing blackberry cover. In the Great Smoky Mountains, the US Forest Service introduced herbivores in an attempt to maintain forest openings and found goats would eat the targeted woody plants, but consumed rare forbs and other non-target species as well (Johnson 1992). Because grasslands have historically been maintained by herbivory, it is a potentially viable option to maintain certain grassy areas. However, the non-selectiveness of goat consumption may negatively affect the rare and endemic species on the balds of the Roan Mountain Massif.

Hand mowing and track mowing have been the most frequent techniques used in the Roan Highlands because they allow for some selectiveness in which areas and plants are cut avoiding non-target and rare species. Our research describes a positive relationship between graminoid cover and the total number of times an area has received management. Additionally, graminoid cover had a significantly negative relationship with the increasing time since the last management treatment. Suggesting, frequent and active mowing, increases grass and sedge coverage, but as the time increases without management, graminoid cover decreases. Considering the significantly positive relationship of mowing treatments and grass cover and the separation gradient of the plots between high blackberry and high grass cover, the current management efforts on the grassy balds seems to be effective in maintaining important graminoid populations. There is a substantial visual difference between ground cover in photograph comparisons of the late 1980's and 2020 (Figure 5). The graminoid cover appears to be much more expansive in the present day and suggests a shift in plant community composition away from blackberry. Mowing has been described as a moderately effective management technique against blackberry cover (Ingham 2014 and Ensley 2015), but our results did not show a significant relationship between the two. It is possible the intensity and frequency of mowing on the balds are maintaining blackberry populations without reducing their range. Blackberry species are able to rapidly expand growth through the roots and shoots, grow vegetatively, flower early, and produce seeds at a high rate (Renteria et al 2021). Their reproductive success and rapid growth create challenges in the reduction of populations once they have invaded a habitat (Crawford and Kennedy 2009). Even though we did not see a decrease in blackberry cover associated with a management type or frequency, mowing seems to be the most effective treatment to increase graminoid cover and possibly inhibit blackberry populations from further increasing their range on the balds. Continual and frequent blackberry range assessments should be implemented going forward.

Future Management and Research

Even though management treatments have several considerations, such as financial costs, labor intensity, and weather or recreational use conflicts, the absence of active management will eventually result in the loss of grassy balds in the Roan Mountain Massif. Management efforts focused on preservation of grassy balds incorporate disturbance regimes in order to sustain the ecosystem's open framework (Weigl and Knowles 1999) and need to be based in understanding of plant community dynamics in relation to management history. The linear relationships in response to management activities found in this study possessed fairly low explanatory power and variation in composition between plant communities was not sufficiently supported. Several additional factors could be contributing to the populations of blackberry, graminoids, and other plant species, such as chemical properties of the soil, precipitation patterns, soil microbial community composition, and interactions with co-occurring native and non-native flora. Based on the findings of this study, it is suggested that 1) a more intensive survey of current vegetation to a species level identification is conducted, 2) a long-term monitoring program be implemented to periodically evaluate the methods (frequency and intensity) and results (plant community composition) of blackberry control treatments, 3) continue to frequently and actively mow areas of the balds that are dominated by high blackberry cover, 4) incorporate comparative studies between grassy balds at Roan and other ecologically important grassy balds in different regions, and 5) include other possible biotic and abiotic factors that could be influencing the graminoid and blackberry populations into future grassy bald plant community research.

Acknowledgements

The authors wish to express their appreciation to Rachel Crabtree, Makenna Gazaille, and Nick Izzo for assisting in field surveys, as well as, Jamey Donaldson and Alan Smith for consultation. Thank you to Marquette Crockett for support and guidance and Mark Endries for GIS help. This research was funded by the Undergraduate Research Program of University of North Carolina Asheville, Appalachian Trail Conservancy, and Southern Appalachian Highlands Conservancy.

pilot 2 program 5 fire 4 balds 9 mowing 4 grazing 3 invasive 3

Literature Cited

1. Brockway, D. G., R. G. Gatewood, and R. B. Paris. 2002. Restoring fire as an ecological process in shortgrass prairie ecosystems: initial effects of prescribed burning during the dormant and growing seasons. Journal of Environmental Management. 65(2): 135-152.

2. Copenheaver, C. A., S. A. Predmore, and D. N. Askamit. 2009. Conservation of rare grassy openings to forest: have these areas lost their conservation value?. Nat. Areas J. 29:133-139.

3. Crawford, J. C. and L. M. Kennedy. 2009. Spatial and temporal patterns of tree encroachment into a southern Appalachian grass/heath bald using tree rings. Nat. Areas J. 29:367-375.

4. Crétaz, A. L. and M. L. Kelty. 2006. Control of hay-scented fern by mowing. North. J. Appl. For. 23(3): 149-154.

5. ESRI 2017. ArcGIS Desktop v10.6. Redlands, CA: Environmental Systems Research Institute.

6. Fynn, R. W. S., C. D. Morris, and T. J. Edwards. 2004. Effect of burning and mowing on grass and forb diversity in a long-term grass experiment. Appl. Veg. Sci. 7(1): 1-10.

7. Gersmehl, P. 1973. Pseudo-timberline: The southern Appalachian grassy balds. Artic Alpine Res. 5:A137-A138.

8. Godt, M. J. W., B. R. Johnson, and J. L. Hamrick. 1996. Genetic diversity and population size in four rare southern Appalachian plant species. Conservation Biol. 10:796-805.

9. Hamel, P. and P. Somers. 1990. Vegetation Analysis Report (draft): Roan Mountain Grassy Balds. Challenge Cost Share Project. 25 pp.

10. Ingham, C. S. 2014. Himalaya Blackberry (Rubus armeniacus) Response to Goat Browsing and Mowing. Invasive Pl. Sci. Managem. 7:532-539.

11. Johnson, R. 1992. Will "mountain goats" help save the southern balds? Appalachia 25: 16-21.

12. Knapp, A. K. J. M. Briggs, S. L. Collins, S. R. Archers, M. S. Bret-harte, B. E. Ewers, D. P. Peters, D. R. Young, G. R. Shaver, E. Pendall, and M. B. Cleary. 2008. Shrub encroachment in North American grasslands: shifts in growth form dominance rapidly alters control of ecosytem carbon inputs. Global Change Biol. 14:615-623.

13. Mark, A. F. 1958. The ecology of the southern Appalachian grass balds. Ecol. Monogr. 28:293-336.

14. McCune, B. and M. J. Mefford. 2011. PC-ORD: Multivariate Analysis of Ecological Data v6.08, MjM Software, Fleneden Beach, Oregon, USA.

15. Murdock N. A. 1986. Evaluation of Management Techniques on a Southern Appalachian Bald. Unpublished M.S. Thesis. Western Carolina University. 62 pp.

16. Murtagh, F. 2014. Ward's hierarchical agglomerative clustering method: which algorithms implement Ward's criterion? J. Classific. 31:274-295.

17. Novak, E. N., M. Bertelsen, D. Davis, D. M. Grobert, K. G. Lyons, J. P. Martina, W. M. McCaw, M. O'Toole, J. W. Veldman. 2021. Season of prescribed fire determines grassland restoration outcomes after fire exclusion and

overgrazing. Ecosphere. 19(2): e03730.

18. Peck, J. L. 2010. Multivariate Analysis for Community Ecologist: Step-By-Step. MJM Software Design, Gleneden Beach OR. 192 pp.

19. Pendergrass, K. L., P. M. Miller, and J. B. Kauffman. 2002. Prescribed fire and the response of woody species in Willamette Valley wetland prairies. Restor. Ecol. 6(3): 303-311.

20. Renteria, J. L., R. Atkinson, C. Crespo, M. R. Gardener, and E. D. Grosholz. 2021. Challenges for the management of the invasive blackberry (Rubus niveus) in the restoration of the Scalesia forest in the Galapagos Islands. Invasive Plant Sci. Manag. 14(1): 20-28.

21. SAS v9.4. 2012. SAS Institute Inc., Cary, NC, USA.

22. Smith, A. L., R. L. Barrett, and R. N. C. Milner. 2018. Annual mowing maintains plant diversity in threatened temperate grasslands. Appl. Veg. Sci. 21(2): 207-218.

23. Sullivan, J. H. and J. D. Pittillp. 1988. Succession of woody plants into a high elevation grassy bald of the Balsam Mountians. Castanea. 53: 245-251.

24. Tokarczyk, N. 2017. Forest encroachment on temperate mountain meadows – scales, drivers, and current research directions. Geographia Polanica. 90: 463-480.

25. Weigl, P. D. and T. W. Knowles. 1999. Antiquity of southern Appalachians grass balds: the role of megaherbivores. Growth and Change. 26: 365-382.

26. Weigl, P. D. and T. W. Knowles. 2013. Temperate mountain grasslands: a climate-herbivore hypothesis for origins and persistence. Biol. Rev. 89:466-76.

27. Wilson, M. V. and D. L. Clark. 2001. Controlling invasive Arrhenatherum elatius and promoting native prairie grasses through mowing. Appl. Veg. Sci. 4(1): 129-138.

28. Yuan, Z. Y., Y. H. Li, and R. L. Kallenbach. 2016. Anthropogenic disturbances are key to maintaining the

biodiversity of grasslands. Sci. Rep. 6 (22132): 1-8.
29. Zald, H. S. J. 2009. Extent and spatial patterns of grass bald land cover change (1948-2000), Oregon Coast Range, USA. Pl. Ecol. 201:517-529.

Table 1. The most dominant plant types recorded from the survey plots with their common and scientific names. Blueberry and Catawba rhododendron are included as shrub and ground cover separately in the analyses.

Common Name	**Scientific Name**
Green alder	*Alnus viridis*
Blueberry	*Vaccinium* spp.
Catawba rhododendron	*Rhododendron catawbiense*
Blackberry	*Rubus canadensis*
Fern	Multiple species
Angelica	*Angelica triquinata*
Grass	Multiple species
Sedge	Multiple species
Moss	Multiple species
Lichen	Multiple species
Frasir fir	*Abies fraseri*
Golden rod	*Solidago* spp.
Cinquefoil	*Potentilla* spp.
Carolina bugbane	*Trautvetteria caroliniensis* (Walter) Vail
Rattlesnake root	*Prenanthes roanensis* (Chickering) Chickering
Common sheep sorrel	*Rumex acetosella* L.
Fringed loosestrife	*Lysimachia ciliata* L.
Whorled wood aster	*Oclemena acuminata* (Michx.) Greene

Table 2. The 12 different plant communities derived from cluster analysis of vegetation cover data with 75% information remaining. The total number and total percent of plots within each group are shown, as well as, the balds the communities were found on. Groups are numbered in order of decreasing prevalence.

	Plant Community	**Number of Plots (Percent Total)**	**Bald**
1	Grass	54 (24.1%)	Round, Jane, Engine Gap, Grassy Ridge
2	Grass – Blackberry	47 (20.9%)	Round, Jane, Engine Gap, Grassy
3	Grass – Blackberry – Fern	28 (12.5%)	Round, Jane, Engine Gap
4	Blackberry	26 (11.6%)	Round, Jane, Engine Gap, Grassy

5	Grass – Sedge - Blackberry	19 (8.5%)	Round, Engine Gap
6	Sedge – Blackberry - Grass	11 (4.9%)	Round, Engine Gap, Grassy
7	Fern – Blackberry	10 (4.5%)	Round
8	Moss – Carolina Bugbane	10 (4.5%)	Round, Engine Gap
9	Rhododendron (ground)	6 (2.7%)	Round
10	Rhododendron (shrub)	5 (2.2%)	Round, Grassy
11	Blueberry (shrub) - Grass	5 (2.2%)	Round, Engine Gap, Grassy
12	Blueberry (ground)	4 (1.78%)	Round, Grassy

Table 3. Summary table of linear regressions results showing insignificant and significant relationships between cover type and management treatments.

Cover Type	**Treatment**					
	Hand Mowing	**Track Mowing**	**Shrub Cutting**	**Goat Grazing**	**Total # of Treatments**	**Time Since Last Management**
Blackberry	$p > 0.05$	$p > 0.05$	$y = 5.2x+24.4$ $p = 0.0014$ $r^2 = 0.0046$	$y = 5.8x+29.6$ $p = 0.001$ $r^2 = 0.049$	$p > 0.05$	$p > 0.05$
Grass	$p > 0.05$	$y = 1.4x+35.0$ $p = 0.040$ $r^2 = 0.019$	$p > 0.05$	$p > 0.05$	$y = 1.6x+27.39$ $p = 0.002$ $r^2 = 0.046$	$y = -0.9x+43.4$ $p = 0.0002$ $r^2 = 0.038$
Sedge	$p > 0.05$	$p > 0.05$	$p > 0.05$	$p > 0.05$	$p > 0.05$	$y = -.03x+8.0$ $p = 0.004$ $r^2 = 0.038$
Graminoid	$p > 0.05$	$p > 0.05$	$p > 0.05$	$p > 0.05$	$y = 2.0x+30.6$ $p < 0.0001$ $r^2 = 0.066$	$y = -1.2x+51.5$ $p < 0.0001$ $r^2 = 0.093$

Figure Captions

Figure 1. Map of Round, Jane, and Grassy Ridge Balds. Map was created using ArcGIS® Desktop v10.6 software by Esri.
Figure 2. Dendrogram table of cluster analysis of the vegetation cover data performed with PC-ORD (McCune and Mefford 2011) using Ward's method with Euclidian distances. Twelve community types are shown with 75% information remaining (Peck 2010) represented by the blue line. Clusters are labeled with the corresponding plant community name (Table 2).

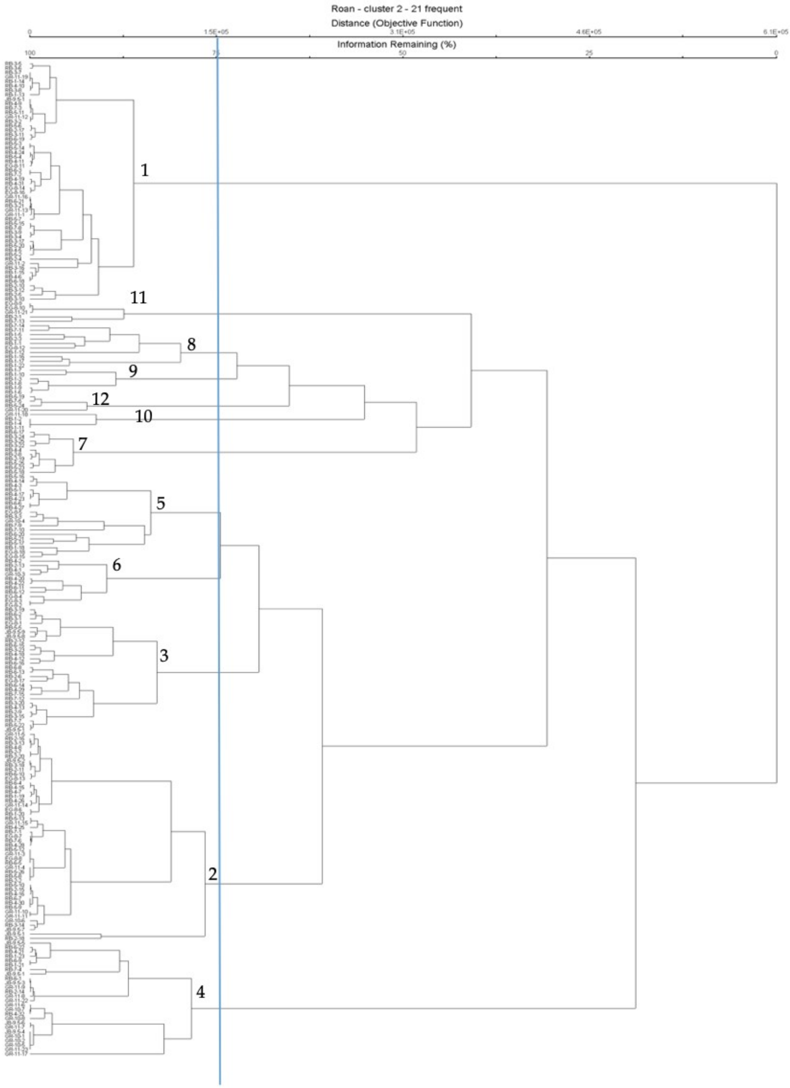
Figure 3. Principal component analysis of the vegetation cover data shows the plots separating along a gradient of high blackberry to high grass cover along Axis 1 (33.8% of the variance). Axis 2 (20.0% of the variance) demonstrates the plots separating along an axis of blackberry, grass, and fern cover. Plots are coded by vegetative community resulting from cluster analysis (listed in Table 2).

Figure 4. Non-metric multidimensional scaling two axis solution of plant cover data. This solution had a final stress of 23.7. Important vegetative group vectors from joint plots are overlaid. Graph A shows the entire ordination, while graph B shows an inset of main clusters of plots. Individual plots are coded by vegetative community resulting from cluster analysis (listed in Table 2).

Figure 5. The southern side of Round bald from the 1980's (left) and 2020 (right) showing visual differences in blackberry cover.

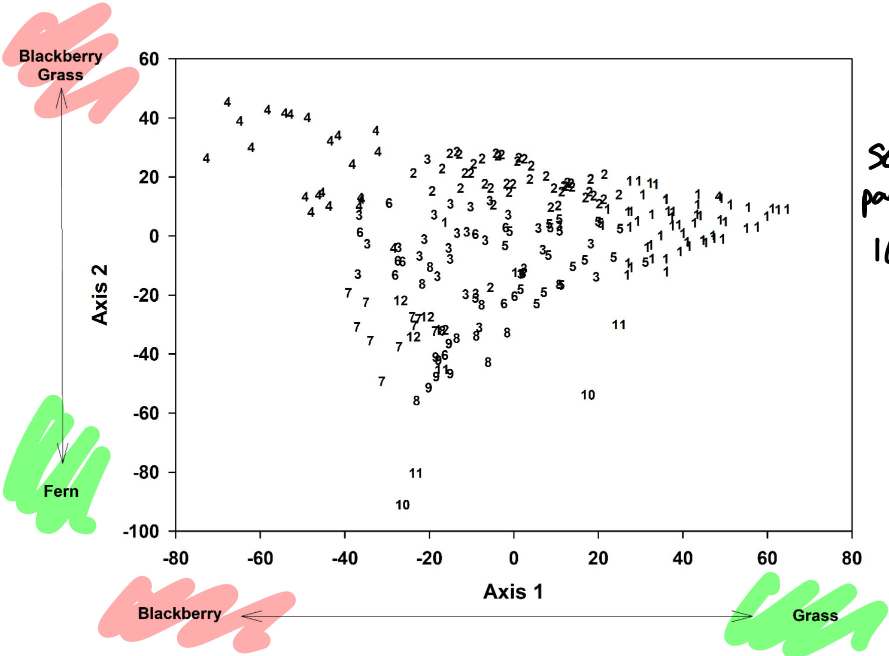
1

2



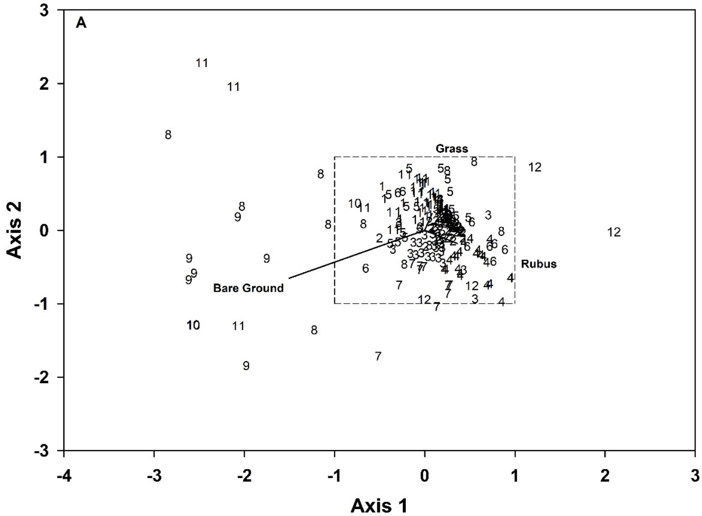
Roan - cluster 2 - 21 frequent
Distance (Objective Function)
0
1.5E+05
3.1E+05
4.6E+05
6.1E+05
Information Remaining (%)
100
75
50
25
0
1
11
8
9
12
10
7
5
6
3
2
4

3

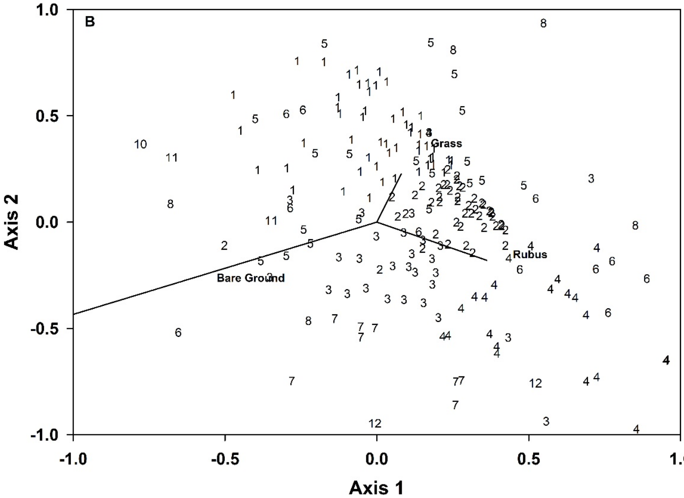


see page 16 & 17

4A



4B


B
Grass
Rubus
Bare Ground
Axis 1
Axis 2
1.0
0.5
0.0
-0.5
-1.0
-1.0
-0.5
0.0
0.5
1.0

5