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

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Abstract

Grassy balds are important ecosystems within high-elevation areas of Roan Mountain massif in the southern Appalachian Mountains. These areas are dominated by native grasses and sedges, and contain endemic, endangered, and rare species. They are globally threatened by woody plant encroachment. Restoration efforts have been conducted on these balds for approximately 30 years by a number of agencies. In 1987–1988 Hamel and Somers conducted vegetation analyses on these balds to characterize plant communities before intensive management began. In summer 2020, we resurveyed the vegetative communities on Round, Jane, and part of Grassy Ridge Balds to compare current composition to that before management was initiated. Using similar methodology to Hamel and Somers, 11 transects and 226 one m^2 vegetative sampling plots were established across the balds. Percent coverage of vegetation type, percent slope, aspect, and soil depth were recorded at each plot. Management records were compiled to determine management history of individual plots. Percent cover data were sorted into the 21 most dominant vegetation types and subjected to principal components analysis (PCA), cluster analysis, and regression. PCA revealed plots separating along a gradient of blackberry and grass cover, as well as blackberry, grass, and fern cover. Cluster analysis revealed 12 plant community groups. Grass dominated four community groups consisting of 148 total plots. A significant positive relationship was seen between graminoid cover and management frequency and a negative relationship with the amount of time since management activity. Blackberry cover was shown to increase with higher frequency of certain management techniques. All of the relationships had low explanatory power suggesting that other factors might influence the plant community compositions on the Roan. 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.

1. Introduction

Temperate montane grasslands and meadows, often known as grass balds, are important and rare ecosystems. Characteristically, grass 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 considered to be some of the largest and most stable in temperate regions. 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[1]. The balds of the Roan Mountain Massif are considered to be some of the most diverse high mountain communities supporting rare species, such as Gray's lily (*Lilium grayi* S. Watson), Roan Mountain bluet (*Houtonia purpurea 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.)[1]. There is a global decline of these historically open and treeless expanses due to the encroachment of surrounding forests and woody plant species[2], 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[1, 3-6].

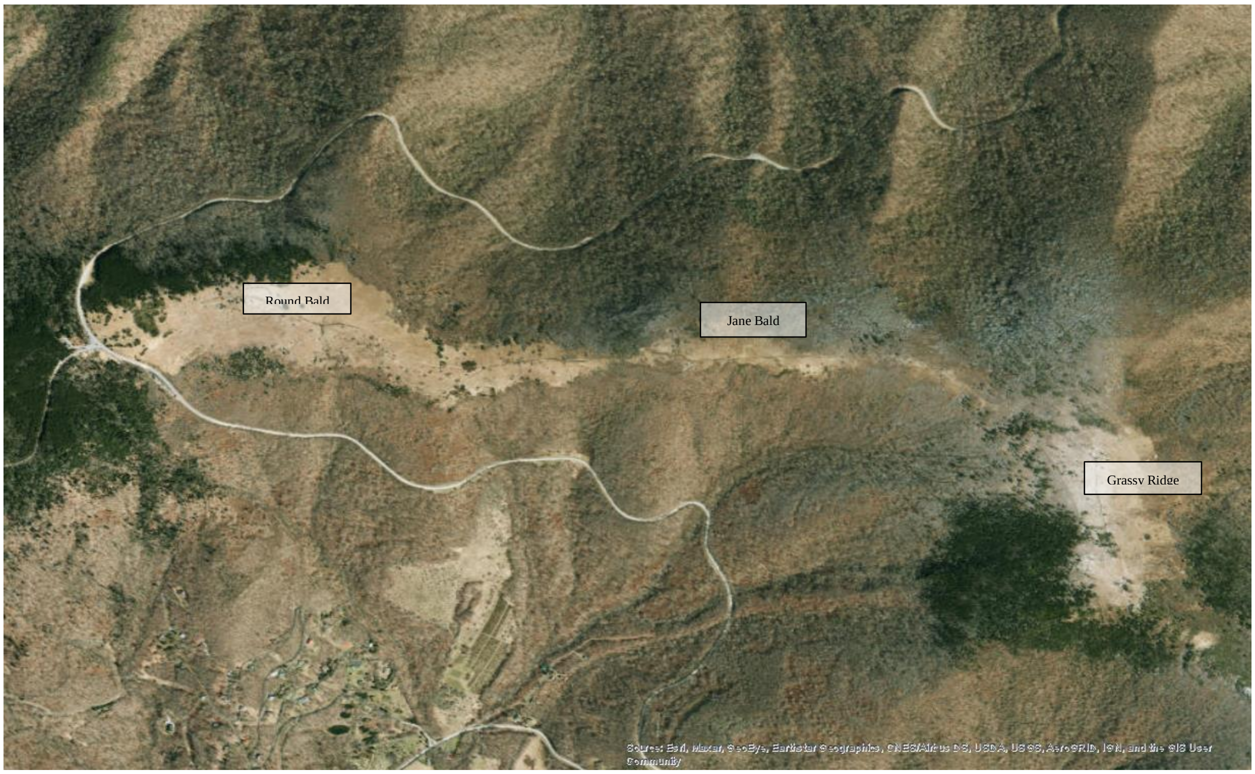

Figure 1. Map of Round, Jane, and Grassy Ridge Balds, 2021. Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Altius DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community.

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[3], effectively dismissing them as human artifacts. Weigle and Knowles[1] 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[1] which sustained the balds until they became locally extinct approximately 11,500 years ago. Native American management and European settlement have maintained the balds by 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 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[1]. Some of these species are members of the northern alpine and tundra floras while some may be relicts of flora associated with the late Pleistocene alpine period[7]. 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[7]. 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[8]. 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[9]. The further loss and fragmentation of temperate mountain grasslands may lead to a change in regional carbon storage[10], 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 non-profit and government organizations to work together for the past three decades to preserve and rehabilitate the area. The larger balds are owned by the National Park Service and the U.S. Forest Service, along with the Southern Appalachian Highlands Conservancy owning 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[1]. 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[11]. 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[8]. In the Pacific Northwest region of North America, grasslands and mountain meadows have declined significantly over the past century[2]. 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[2]. 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[12]. 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[13].

Currently, repeated 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 perennial shrub that uses vegetative growth from rootstocks as the principal method for colony development[13] 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[4]. Given the long, and somewhat vague maintenance history of the Roan balds previous to 1988 when official management by the U.S. Forest Service began, many management techniques have been considered including prescribed burns. Murdock[4] conducted an experiment examining the impacts of burning, cutting, and the combination of burning and cutting treatments on plant community composition within 20.23 hectares on the western side of Round Bald. The study did show an increase of mountain oats grass in response to fire that persists for at least two years after the last burn treatment. However, weather conditions on the Roan balds are often highly variable making it difficult to conduct prescribed burns.

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[11] in 1987 and 1988. 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[11], I resurveyed the vegetation on Round, Jane, and a small portion of Grassy Ridge balds in the summer of 2020. The goal was 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.

2. Methods and Materials

2.1 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 in the area 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 gap between each of them. Data collection started in June 2020 and extended until September 2020.

2.2 Field Work

2.2.1 transect and plot establishment

Transects were positioned 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 line. 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[8]. If an original Hamel and Somers[8] plot was encountered along a transect, the plot distance was adjusted so that these plots would be resampled.

2.2.2 data collection

Percent coverage of vegetation was determined using a 1 x 0.5 m^2 PVC quadrat divided into 50 equal sized squares. Plots were 1 x 1 m^2 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 center line of the transect. Every square was visually assigned a dominant type of vegetation which allowed a total of 100% coverage per plot (Figure 2). 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 laveis* Weigand), mountain ash (*Sorbus americana* Marshall*)*, American beech (*Fagus grandifolia* Ehrh.*)*, flame azalea (*Rhododendron calendulaceum* (Michx.) Torr.), and frasir 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." Plants that were considered to be "other woody" or "other forb" were further identified to species at the time of the survey or at a later point using photographs. Due to COVID-19 limitations, grasses, sedges, and ferns were not identified to species level. However, the categorical format aligns with other vegetation surveys done in the Roan Highlands in efforts to contribute to previous and future research.

The aspect, slope percent, and the average soil depth were measured for each plot. Soil depth was measured at the center point of each of the four sides using a metal flag. 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.

Figure 2. Overhead view of a survey plot showing placement of the quadrat in reference to the transect line and squares used to assign percent cover of vegetation.

2.3 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 analysis. This was to ensure that infrequent plants did not influence the results and to match the methods used by Hamel and Somers[11]. Bare ground cover, rock cover, and overstory species were excluded from analyses. To determine which factors explain variation in plot distribution, principal components analysis was conducted on the vegetation cover data using PC-ORD v6.08[15] with centered variance and covariance matrices within distanced-based biplot (Figure 2). Cluster analysis of the vegetation cover data was performed with PC-ORD using Ward's method with Euclidian distances and 75% information remaining[16] 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[17]. Clusters were separated on the resulting dendrogram (Figure 3). 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 subsequent order. A spatial join conducted using ArcGIS 10.6[18] 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[19].

3. Results

3.2 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 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 fern (-0.329), grass (0.430), and blackberry (0.790) (Figure 3).

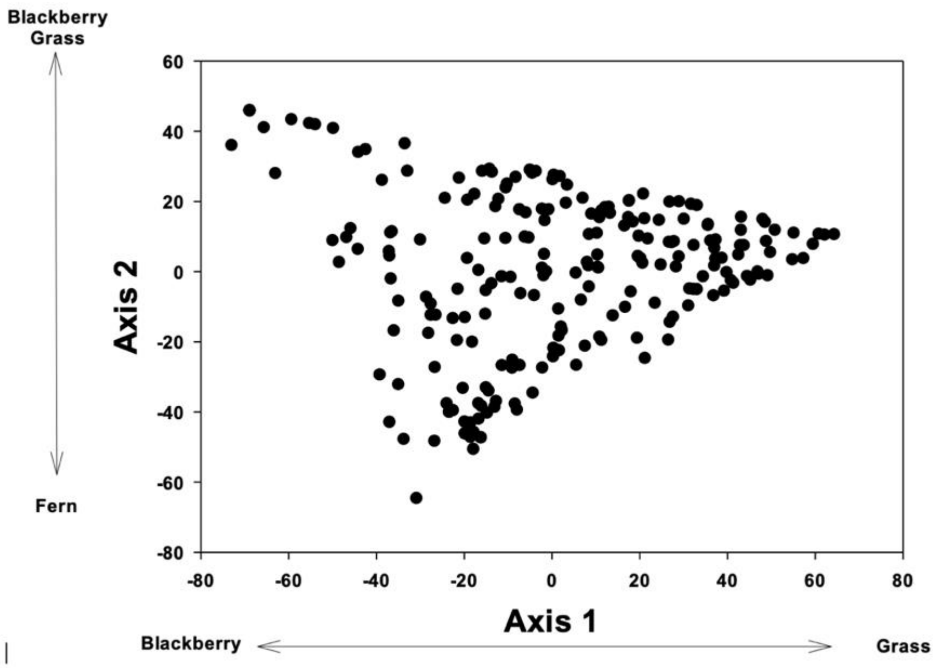

Figure 3. Principal component analysis of the vegetation cover data shows the plots separating along a gradient of high blackberry to high grass cover along Axis 1 (33.8% of the variance). Axis 2 (20.0% of the variance) demonstrates the plots separating along an axis of blackberry, grass, and fern cover. Each point represents a single plot.

3.2 Plant Community Composition

Clustering vegetation plot data of the most dominant vegetation (Table 1) described 12 clusters (Table 2, Figure 4). 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 consisted of 74% grass cover. The grass – blackberry community included 47 of the survey plots making it the second most frequent community type. It consisted of 49% grass cover and 41% blackberry cover. The grass – blackberry – fern community consisted of 28 plots which were made up of 31% grass, 27% blackberry, and 25% fern cover on average. The fourth community, blackberry, is a group made up of majority blackberry cover at 75% ground cover between 26 total plots. The grass – sedge – blackberry community consists of 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 consisted of 46% sedge, 24% blackberry, and 14% grass between 11 plots. The fern – blackberry community possessed a fern cover of 72% and blackberry at 14% and included 10 plots. The moss – Carolina bugbane community is categorized by 23% moss cover and 14% Carolina bugbane cover. However, these plants were not present in all of the 10 plots included in this group and were shown to be dominant due to high numbers within roughly half of them. Two communities were described as rhododendron ground with 58% cover and rhododendron shrub with 100% cover. These communities included 11 plots combined. The blueberry – grass community consisted of 97% blueberry shrub cover and 19% grass cover between five plots. Lastly, the blueberry community is categorized by blueberry ground coverage of 83% and includes four plots.

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 triquinta*
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

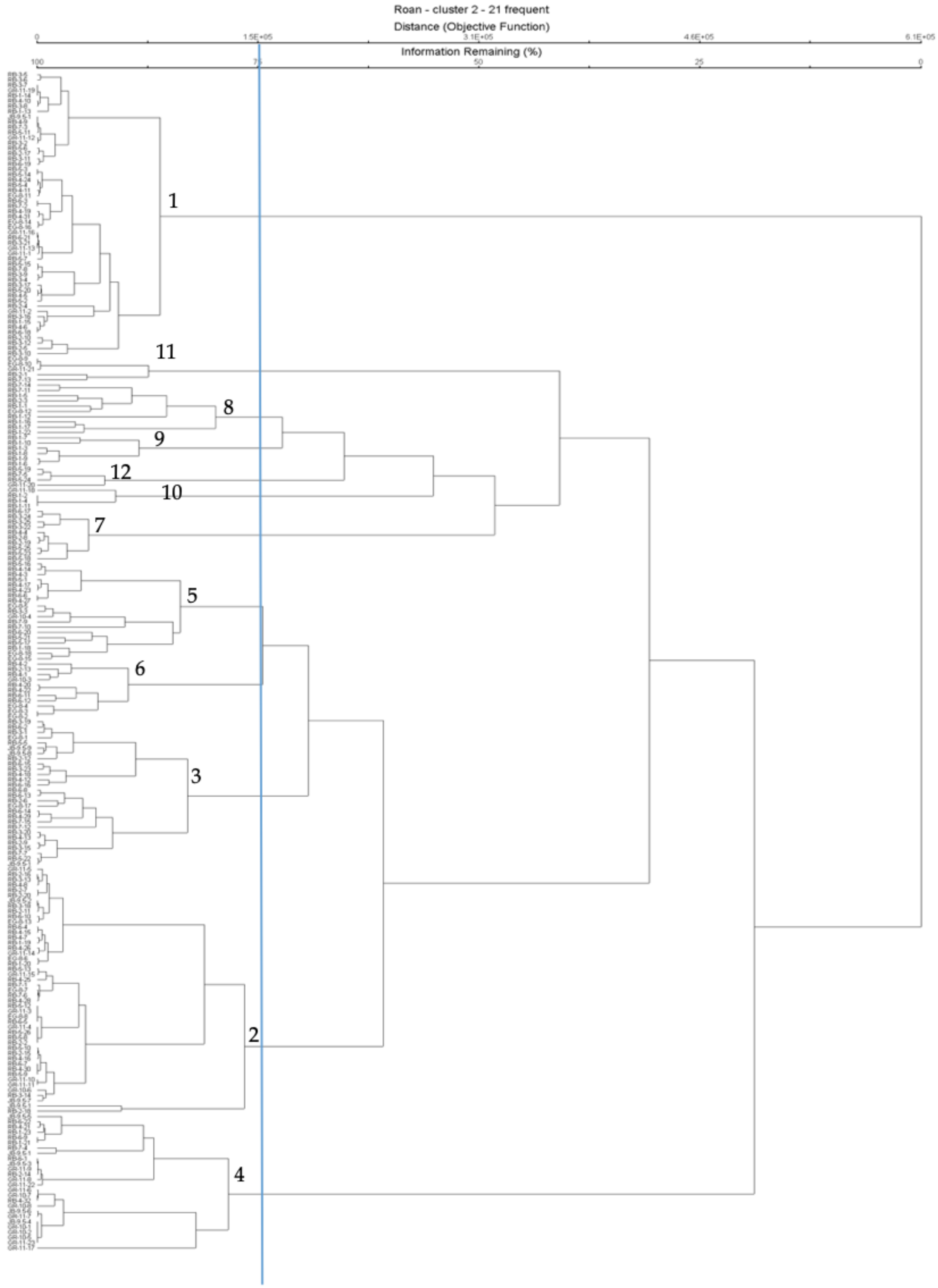

Figure 4. Dendrogram table of cluster analysis of the vegetation cover data performed with PC-ORD (McCune and Mefford 2011) using Ward's method with Euclidian distances. Twelve community types are shown with 75% information remaining (Peck 2010) represented by the blue line. Clusters are labeled with the corresponding plant community name (Table 2).

3.3 Management History

Blackberry cover increased significantly with the number of shrub cutting treatments (y = 5.2x +24.4, p = 0.0014, r^2 = 0.046) and goat grazing (y = 5.8x + 29.6, p = 0.001, r^2 = 0.049). Black berry 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, r^2 = 0.046), and track mowing (y = 1.4x +35.0, p = 0.040, r^2 = 0.019), and it decreased with increasing time since last management (y = -0.9x + 43.4, p = 0.0002, r^2 = 0.061). Sedge cover decreased significantly with increasing time since last treatment (y = -0.3x + 8.0, p = 0.004, r^2 = 0.038). Sedge cover did not have a significant relationship to 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, r^2 = 0.066) and decreased as time since the last treatment increased (y = -1.2x + 51.5, p < 0.0001, r^2 = 0.093) (Table 3).

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 Treatment**
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 = -0.3x+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

4. Discussion

4.1 Vegetation Patterns

Principle 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[11]. 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. However, the plots did not separate into defined clusters on the distance-based biplot (Figure 3) indicating a low confidence in the clustering algorithms. Hamel and Somers' major axis accounted for 36% of variance and was driven by the contrast between blackberry and grass cover. The second axis was driven by blackberry and sedge cover. Hamel and Somers' study was much larger with a total of 897 plots across six balds which should be taken into consideration when drawing relationships between these two studies. Our main axis with the highest explanatory power (Axis 1) of 33.8%, illustrated plots separating along a gradient of high blackberry to high grass cover. Suggesting that as blackberry cover increases, grass cover decreases. Because blackberry is the main encroachment threat within the Roan, 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. Originally, bare ground was found to be a major driving force of plot distribution, but it was largely associated with high rhododendron or blueberry shrub cover which is indicative of the impacts of dense shrubs on graminoid presence. However, these genera spread at a much slower rate[11] compared to blackberry. The second main axis (Axis 2) describes the plots separating along a combined gradient of high 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 is the dominant cover type in the fern – blackberry, and grass – blackberry – fern communities. Observationally, these were possibly the three most dominant vegetation types recorded within the survey plots. The Roan has had a long history of disturbance regimes spanning from ancient herbivores and anthropogenic activities, such as hunting, livestock grazing, and other pastural work. 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. The strong contrasting relationship between blackberry and grass cover found in Hamel and Somers[11] and the current study illustrates the importance in continuous management of woody plants to encourage graminoid and forb growth and inhibit further encroachment.

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. 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[11] 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 the grass and grass-blackberry groups were the two dominant community types in the 2020 survey. This difference could be attributed to the exclusion of Yellow Mountain from our study which contained 112 plots associated with the cinquefoil dominated community. 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. The PCA results suggest a low confidence in the clustering algorithms which may be why there are more plant community groups compared to the six found by Hamel and Somers analysis. Additionally, our incomplete survey of Grassy Ridge could be contributing to the inconsistent results of sedge population frequency which contained the second highest number of plots associated with the blackberry – sedge community after Round bald. However, the consistent disturbance regime introduced after 1988 through active management is possibly the main contributing factor to the change in dominant community types. Increased frequency of management has a significantly positive relationship with graminoid cover and treatments have increased substantially in the past 30 years. Four of the community groups which consisted of 148 total plots were dominated by grass (63.3% of total plots). 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 classification of the 4 least frequent communities (rhododendron (ground), rhododendron (shrub), blueberry (shrub) – grass, and blueberry (ground)) is possibly due to the lack of any other taxa. The plots included within these groups consist of mainly shrub cover which differentiates them from other communities that did not include plots with 100% shrub cover. The differing dominant plant communities of grass and grass – blackberry are suggestive of successful management treatments over the past 30 years. However, the frequency of blackberry throughout the communities cannot be ignored for determining future management and should continue to be a restoration concern.

4.2 Management History and Plant Communities

Effectively managing an ecosystem for a specific purpose, 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. The Roan has been actively managed since 1988 with a combination of hand mowing, shrub cutting, track mowing, and goat grazing. Blackberry cover's positive relationship with the total number of times a plot had undergone shrub cutting and goat grazing suggests its increases along with certain types of management. In contrast, the Murdock[4] study examining the impacts of burning and cutting treatments in the vegetation on Round Bald described 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 and the restriction to only a portion of Round Bald. Goat grazing in the Roan occurred on Jane Bald and ceased in the year 2015. The 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 influencing factors on blackberry cover. In the 1980's, the vegetation composition variations between the western balds (Round, Jane, and Grassy) and the eastern balds (Hump Mt, Bradley Gap, Little Hump, and Yellow) were found to be considerably distinct due to differing management histories. For example, Big Yellow Bald, has experienced a much longer period of continued grazing which has largely inhibited the expansive growth of blackberry and encouraged the presence of graminoids[11]. In the Great Smoky Mountains, the US Forest Service introduced herbivores in 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[20]. Because grasslands have historically been maintained by herbivory, it is a possible viable option to maintain certain grassy areas. However, the non-selectiveness of what plants the goats eat may cause larger problems for the rare and endemic species that occur 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 times an area has been managed. Additionally, graminoid cover had a significantly negative relationship with the increasing of 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 decrease. Mowing has been described as an effective management technique against blackberry cover[21], but our results did not show a significant relationship between the two. Although, 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. Furthermore, there is a substantial visual difference between ground cover in photograph comparisons of the late 1980's and 2020 (Figure 4). The graminoid cover appears to be much more expansive in present day and suggests a shift in plant community composition away from blackberry.

Figure 4. The southern side of Round bald from the 1980's (left) and 2020 (right) showing visual differences in blackberry cover.

4.3 Future Management and Research

Even though management treatments have varying consequences, 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. Management efforts focused on preservation of grassy balds incorporate disturbance regimes in order to sustain the ecosystem's open framework[5] and need to be based in understanding of plant community dynamics in relation to management history. The statistically significant relationships listed previously possessed fairly low explanatory powers that did not exceed 10%. Several additional factors could be contributing to the populations of blackberry and graminoids, such as chemical properties of the soil, precipitation levels, soil depth, slope, and interactions with co-occurring native flora, as well as exotic species. Based on the findings of this study, it is suggested that 1) a long-term monitoring program be implemented to periodically evaluate the methods (frequency and intensity) and results (plant community composition) of blackberry control treatments, 2) continue to frequently and actively mow areas of the balds that are dominated by high blackberry cover, and 3) incorporate comparative studies between the Roan and other ecologically important grassy balds in different regions, and 4) include other possible biotic and abiotic factors that could be influencing the graminoid and blackberry populations into future grassy bald plant community research.

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