Available online at http://scik.org
Environ. Ecol. Manage. 2014, 2014:1
ISSN 2051-2945

MICROCLIMATIC AND PEDOLOGICAL CONDITIONS OF ROCK SHELTERS CONTAINING SOLIDAGO ALBOPILOSA, RED RIVER GORGE, KENTUCKY

JEREMIAH J. NIEVES[1,*], AND C. ANDREW DAY[2]

[1]Department of Biostatistics, University of Kentucky, Lexington 40536, USA

[2]Department of Geography and Geosciences, University of Louisville, Louisville 40292, USA

Abstract: The Red River Gorge of Kentucky is the only known location of the threatened plant species *Solidago albopilosa*. We conducted a preliminary assessment of microclimatic and pedological variables within the rock shelters in which the species is endemic to determine which variables are significantly different from the surrounding environment and to estimate future viability of the sites. Significant differences found between the inside of the rock shelters and the surrounding environment suggests that *S. albopilosa* resides in Red River Gorge rock shelters that are significantly cooler and more humid. Furthermore, the distribution of the shelter aspects suggest that *S. albopilosa* prefers Easterly or Northerly facing shelters that receive minimal direct sunlight and only do so when the air temperature is close to its lowest point within a 24 hour period. No significant differences were found among the soil macronutrients that we tested and soil pH. We intend to conduct further long-term microclimate research of the shelters to determine what factors are involved in the presence or non-presence of *S. albopilosa*.

Keywords: *Solidago albopilosa*, microclimate, Kentucky, Red River

[*]Corresponding author

Received August 21, 2013

1. Introduction

The White-haired Goldenrod (*Solidago albopilosa* Braun), hereinafter *S. albopilosa* and seen in Figure 1, is distinctly set apart from other members of the genus *Solidago* by the dense covering of long white hairs on its slender stems. The leaves are very thin and their bottoms are covered with the same white hairs found on the stem of the plant (Braun, 1942). Around August, small yellow flowers bloom along the upper half of *S. albopilosa*. *S. albopilosa* is only found in the sandstone rock shelters of the Red River Gorge Geological area within the Daniel Boone National Forest of Kentucky, despite searches of similar habitats in surrounding areas.

Although the rock shelters are common within the Gorge, only a small proportion of them harbor *S. albopilosa*. *S. albopilosa* usually grows between the drip line and the back wall of the shelter in sand, on interior ledges, and cracks along the walls and is commonly seen growing in close proximity to the Round-leaved Catchfly (*Silene rotundifolia*) and Alumroot (*Heuchera parviflora*) (Currie, 1988). *S. albopilosa* is rhizomatous and has multiple stems per plant, making it difficult to accurately count the number of plants through above ground observation alone (White and Drozda, 2006).

The primary threat to *S. albopilosa* is the alteration and destruction of its habitat due to recreational activities that are common in the area, including hiking, rock climbing, camping, and building of fires near cliff lines and rock shelters. These activities have led to the local extirpation of some *S. albopilosa* sites (White and Drozda, 2006). Due to the threat to its habitat, the extensive use of the area for recreation, the inability to enforce regulations because of a lack of manpower, and the unique climate of the Red River Gorge, *S. albopilosa* was eventually designated a threatened species under the Endangered Species Act of 1973 in May of 1988 (Currie, 1988). Subsequent actions taken to protect the species and its habitat include the posting of informative signs, restriction of access to rock shelters, restrictions on fire building in proximity to rock shelters, fencing around selected *S. albopilosa* sites, and the rerouting of trails (U.S. Fish and Wildlife Service, 2009).

While little is known about *S. albopilosa* as a whole, there is a distinct dearth of literature on what localized microclimatic and pedological conditions are present in the rock shelters that harbor *S. albopilosa*. Microclimates generated by unique local biological or physiographical conditions are capable of playing a significant role towards controlling the distribution of certain plant species by modifying air and soil temperatures, humidity and light intensity, among other variables (Rosenburg et al., 1983; Arya 1988; Jones 1992). We approached this issue by taking measurements of key microclimatic variables, along with soil pH and macronutrients, an estimation of the present *S. albopilosa* plants at each site, and the aspect of the rock shelters at sites currently populated by *S. albopilosa*. While we would reasonably expect the air temperature to be lower and the relative humidity to be higher inside versus outside of the rock shelters, whether there is a significant difference between those temperatures and humidities is to be questioned.

We hypothesize that the air temperature inside the rock shelters, to be measured at both ground level and elevated 1m, will be significantly lower than the corresponding measurements outside and above the rock shelters. Additionally, we hypothesize that the relative humidity inside the rock shelters, to be measured at ground level and elevated 1m, will be significantly higher than the corresponding measurements outside and above the rock shelters. With regards to soil pH and macronutrient content, our hypothesis is that there will be a significant difference between measurements to be taken inside the rock shelters as compared to the measurements that will be taken outside and above the rock shelters.

By understanding what variables make the environment of the rock shelters unique perhaps the locations of previously undiscovered *S. albopilosa* sites will be easier to identify, allowing for earlier intervention and protection of *S. albopilosa*. Should this preliminary investigation indicate a significant difference between the shelters' climate and that of the surrounding environment, we intend to follow up with year round monitoring of the rock shelter microclimatological conditions.

2. Materials and Methods

2.1. Study area

The Red River Gorge is designated by the U.S. Forestry Service (USFS) as a unique geological and archeological area within the Daniel Boone National Forest (U.S. Department of Agriculture, 2009). This area, lying within the Northern Forested Plateau Escarpment Ecoregion, is very rugged, with elevations ranging from 198m to 488m, and characterized by an abundance of ridges, rock shelters, cliff lines adjacent to rivers, and narrow valleys and ravines. The majority of these formations are composed of Pennsylvanian Sandstone, especially the ridges and many of the rock shelters, with Upper Mississippian Limestone and Lower Mississippian Siltstone composing many of the valley walls and inclines. The soil within the Red River Gorge is a mix of Ultisols, Inceptisols, and Alfisols (U.S. Environmental Protection Agency (EPA), 2012a & 2012b). Ultisols, which have a high incidence of iron oxides that give them a red-ish hue, are eroded and deposited into the Red River giving the river, and consequently the surrounding area, its name. The specific area of the Red River Gorge investigated in this study can be seen in Figure 2.

Mean annual precipitation in the area is approximately 114.3cm to 124.5cm with mean annual temperatures ranging from -6.7° to 7.8°C and 16.7° to 30°C, January's range and July's range respectively (U.S. EPA, 2012b). The Red River Gorge is covered by a mixed mesophytic forest with the slopes of the area dominated by mixed oak and oak-pine species (Küchler, 1964) with yellow-poplar, eastern hemlocks, and rhododendrons populating the footslopes, rock terraces, and well-drained hollows of the area (U.S. EPA, 2012b). Rhododendrons are also often found in great number in the area surrounding rock shelters (White and Drozda, 2006).

2.2. *Field methods*

We defined our sites as an area covered by *S. albopilosa* and separated from other *S. albopilosa* plants by no more than 2m. This distance was decided upon after preliminary investigations of the rock shelters. This means that we had the possibility for multiple sites within the same rock shelter, an example of which is in Figure 3. This point is important as environmental conditions can vary even across short distances within the same rock shelter. We selected our rock shelters based on physical accessibility from the last known occurrences of *S. albopilosa*, ignoring sites that were discovered to be extirpated, either from recreational activity or unknown causes, or were not found due to perceived instrument error in the initial recording of coordinates. We recorded the latitude and longitude coordinates of each sample site using a Trimble GeoXT 6000 and later post-processed the coordinates using Morehead, Kentucky as the accuracy base.

To determine the impact of recreational activities on habitat we used the scale seen in Table 1 which is based on the work of White and Drozda (2006). In order to get an estimate of the number of *S. albopilosa* stems at a site, we counted the stems of *S. albopilosa* within a $1m^2$ quadrat, estimated the area of the entire site, and then calculated a total stem estimate. We then rated the viability of a site based upon the estimated number of stems at a site, in relation to the mean of all sites sampled, taking into account the impact of recreation at each site. After standardizing the stem counts, assuming a normal distribution, the viability grade was calculated using the diagram in Figure 4 which takes into account a site's stem count as well as the evidence of recreational impacts at the site. For example, a site with a relatively high stem count with a "High" impact rating (Table 1) would receive a lower viability score than another site with the same stem count, but with an impact rating of "Low."

At each rock shelter, we recorded measurements inside the shelter, 5m outside the shelter, and directly above the shelter following a transect, a method commonly applied in other microclimate studies (Figure 3) (Godefroid, Rucquoij, and Koedam, 2006; Delgado et al., 2007; Brooks and Kyker-Snowman, 2009).We collected a single "Above" and "Outside" sample for each rock shelter containing *S. albopilosa* sites except the "Above" reading at the Rough Trail I shelter due to the physical inaccessibility of the area. Additionally, we had two outside readings at the Gray's Arch rock shelter since the shelter was partially divided by the arch's base. Measurements taken included: (1) aspect perpendicular to the rock shelter, (2) soil temperature, (3) air temperature at ground level and 1m above ground level, and (4) relative humidity at ground level and 1m above ground level. In addition, at each site, we collected surface soil samples to test for the pH, phosphate, nitrate, and potassium levels using a LaMotte soil testing kit. The precision of all instruments used can be seen in Table 2.

We documented all of our measurements within the time frame of 11:00 – 15:00 hours to limit the potential effects of a range of temperature change throughout a day similar to Godefroid, Rucquoij, and Koedam (2006). Data were collected on 23 and 26 June, 2012, on days displaying similar meteorological conditions.

2.3. Data analysis

We tested each variable and its respective groups for normality by creating probability plots using MiniTab 15 in order to determine if subsequent tests should be parametric or non-parametric. For variables whose groups were all normal in distribution, we performed a One-way ANOVA test using Tukey's method to determine which means, if any, were different. For variables whose groups were not all normal in distribution, we performed a Kruskall-Wallis test and followed up with Mann-Whitney tests, if the results from the Kruskall-Wallis test were statistically significant. All tests were analyzed at the 95% level of statistical significance.

3. Results

3.1. Microclimatic and pedological data

All microclimatic data was found to be normally distributed with the exception of the data corresponding to soil temperature, and air temperature (elevated).

Table 3 shows that air temperature (ground) was found to be significantly lower, with $p = 0.015$, in the rock shelters when compared to above the shelters. The mean air temperature (ground) for inside the shelter was 25.4 ℃ while the mean air temperature (ground) for above was 28.0 ℃. However, in Table 4, air temperature (elevated) was not found to be significantly different with $p = 0.100$.

Shown in Table 5, relative humidity (ground) was found to be significantly higher, with $p = 0.002$, in the rock shelters and outside the rock shelters when compared to above the rock shelters. The mean relative humidity (ground) above the shelters was 41.8 % whereas the mean relative humidities (ground) for outside the shelters and in the shelters were 52.2 % and 51.8 %, respectively. Additionally, in Table 6, relative humidity (elevated) was found to be significantly higher, with $p = 0.003$, in the rock shelters when compared to above the rock shelters. The mean relative humidities (elevated) for inside the shelters and above the shelters were 45.8% and 35.7%, respectively.

None of the soil data was found to be normally distributed. Furthermore, all soil variables were found to not be significantly different between the shelters, outside, and above, following Kruskall – Wallis analysis.

3.2. Condition and Estimated Future Viability of Sites

Of the sampled sites listed in Table 7, there were three sites with a viability grade (Figure 4) of “D,” eight sites with a grade of “C,” two sites with a grade of “B,” and one site with a grade of “A.” Recreational impacts were observed, to some degree, at all shelters except the Double Arch Trailhead shelter. No impacts due to recreational activities were evident within sites that had been fenced off by the U.S. Forestry Service.

4. Discussion

The significantly lower air temperature (ground) in the shelters (Table 3), compared to above the shelters, can be explained by the significantly higher relative humidity also experienced at ground level in the shelters (Table 5) as relative humidity has an inverse relationship with air temperature. Previous studies have shown that moisture in the soil or air has a dampening effect on the variability of temperatures in both mediums (Bennie et al., 2006; Lu et al., 2009; Ashcroft and Gollan, 2013). Ashcroft and Gollan (2013) showed in microrefugia, such as the rock shelters in the Red River Gorge, that while air temperature is strongly related to humidity, soil temperatures are more strongly dependent on the vapor pressure deficit (i.e. high temperatures and low humidity are necessary for soil temperature to increase its variation). The results of the tests seen in Table 3, Table 5, and Table 6 suggest that the rock shelters, in which *S. albopilosa* populations are found, have significantly cooler and more humid conditions than the surrounding environment. This would indicate that further, year round study of the microclimate of the shelters and the climate of the shelters' immediate surroundings should be conducted in order to determine the magnitude of the dampening of temperature variability in both the soil and air of the shelters.

The difference in air temperature (ground) is most likely the result of differing amounts of insolation between the different locations at each site. The first order controls of surface temperature are the elevation, aspect, and slope of a location with second order controls being other factors such as canopy cover (Ricotta and Avena, 1996; Bennie et al., 2006; Ashcroft and Gollan, 2013; Gutiérez-Jurado and Vivoni, 2013). Displayed graphically in Figure 5, of the 14 site aspects recorded (Table 7), ten had an easterly direction (0° - 180°), four had a westerly direction (180° - 360°), nine had a northerly direction (270° - 90°), and five had a southerly direction (90° - 270°). The average of these aspects was 31.7° (Figure 5). The distribution and the average of these aspects suggests that *S. albopilosa* prefers easterly and northerly facing shelters within the Red River Gorge. Such shelters receive less direct sunlight or receive less intense, direct sunlight during the pre-solar noon hours when air temperatures are at their lowest during a 24-hour cycle. Throughout the year, the sun's zenith never moves to latitudes outside of the range 23.5 ° N to 23.5 ° S, leading to lower insolation on North facing slopes in the Northern hemisphere (Rich, Hetrick, and Savings, 1995; Bennie et al., 2006; Gutiérrez-Jurado and Vivoni, 2013). The easterly facing shelters only receive direct sunlight, assuming that there is no obstruction from vegetation, in the morning hours when insolation from the sun strikes at an oblique angle, therefore less energy strikes the earth's surface (Ricotta and Avena, 1996). This is modeled by Lambert's Cosine Law (Equation 1) where illuminance on a surface, E_θ, is proportional to the light's angle of incidence, θ, on the surface. The angle of incidence θ is the absolute value of the difference between the observer's latitude β and the solar declination of the sun δ.

$$E_\theta = E_o \cos(\theta) \qquad (1)$$

$$\theta = | \beta - \delta |$$

Although no significant differences in the soil macronutrient content between sites were found, there were some interesting observations to note in Table 8. Two out of the three (GALower and GAFenced) shelter soil samples from the Gray's Arch shelter tested positive for high concentrations of nitrogen, a level not found in any of the other samples. In addition, one of the two samples that had "High" concentrations of nitrogen also tested positive for "Very High" concentrations of Potassium. The other of the two aforementioned samples also had elevated levels of Potassium in comparison to the remainder of the soil samples taken (Table 8).

At the Auxier Ridge site, we took two samples within the shelter: one on an upper ledge (ARLedge) and one from the floor of the shelter (ARFloor). On the floor of the shelter there was evidence of recent camp fires. When tested, the base floor sample had a pH of 8.0 in contrast to the pH readings of 4.0 from the upper ledge sample and

5.0 from the samples outside and above the shelter. In addition, the base floor sample tested positive for “Very High” concentrations of Potassium whereas all other samples from that site tested positive for “Low” or “Very Low” concentrations (Table 8). Lye (Potassium hydroxide; KOH) is created when wood ash reacts with water and forms an alkaline solution. We believe that the campfire(s) and this common chemical reaction are the cause of the alkaline shift in the sample’s pH and the increased amounts of Potassium.

All of the soil samples from the Double Arch Trailhead shelter (Table 8), when tested, began to bubble and produce a gas when the soil samples were combined with the Nitrogen, Phosphorus, and Potassium extraction reagents. The shelter sample produced fewer gas bubbles while the above sample reacted the most violently. The samples that were being tested for Phosphorus and Potassium also reacted more than the samples being tested for Nitrogen. None of the soil samples from other sites reacted in this way. The Double Arch Trailhead site is unique among our sampled sites because it is the only site located near to (approximately 22 meters downhill of) a road, specifically, a gravel road. Gravel roads are commonly constructed from crushed limestone and or dolomite (Hull, 2001). The Phosphorus and Potassium extraction reagents were primarily acetic acid (CH_3COOH) and the Nitrogen extraction reagent was a 0.75% Hydrochloric acid (HCl) solution. Limestone (Calcium Carbonate, $CaCO_3$) and dolomite (Calcium magnesium carbonate, $CaMg(CO_3)_2$) react with both of these reagents to produce Carbon dioxide (CO_2) as seen in Equations 2 – 5.

$$2\ CH_3COOH + CaCO_3 \rightarrow Ca(CH_3COO)_2 + CO_2 + H_2O \qquad (2)$$

$$2\ HCl + CaCO_3 \rightarrow CaCl_2 + CO_2 + H_2O \qquad (3)$$

CaMg(CO3)2 + 4 CH3OOH Ca(CH3OO)2 + Mg(CH3OO)2 + 2 CO2 +2 H2O (4)

$$CaMg(CO_3)_2 + 4\ HCl \rightarrow CaCl_2 + MgCl_2 + 2\ CO_2 + 2\ H_2O \qquad (5)$$

Additionally, the pH readings at this site for the shelter, outside, and above the shelter were 9.0, 8.5, and 9.5, respectively, which suggests a negative correlation between the sample distance from the gravel road and the pH of the sample (Table 8).

5. Conclusions

In this study, the test results suggest that the rock shelters in which *S. albopilosa* resides are significantly cooler in temperature and more humid than the environment surrounding the shelters. The distribution of the shelter aspects suggests that *S. albopilosa* prefers Easterly or Northerly facing shelters that receive minimal direct sunlight and only do so when air temperatures are close to their lowest point within a 24 hour period. While the soil samples taken from the various sites at the different shelters were not significantly different from each other's respective groups, it was found that there were chemical changes in the shelter soils surrounding campfires and near gravel roads.

Previous studies had only mentioned recreational activities as a threat to *S. albopilosa*, but further studies are recommended to determine the impact of the numerous gravel roads throughout the Red River Gorge on soil composition and pH in and about rock shelters. Other further studies involving shelter soils would include a broader analysis of the soil nutrients in the shelters, any significant composition differences between the shelter soils and the surrounding soils, and a study of the soil temperature fluctuations in and around the rock shelters within a year's time in conjunction with a germination study similar to Hidayati and Walck (2002). It is our intent to conduct further long-term research on the shelter microclimates. This issue will be approached by taking measurements of five key microclimatic variables: incoming solar radiation, air temperature, relative humidity, wind speed, and soil moisture. These measurements will be recorded using HOBO Micro Station loggers at 5 different sites, at ten second intervals simultaneously over the course of one year. The sites include a north and a south facing rock shelter that currently harbor *S. albopilosa*, a north and a south facing rock shelter that do not currently harbor *S. albopilosa*, and a further control site located on the grounds of the Gladie Learning Center within the Red River Gorge. The north and south facing shelter measurements will be used to compare the possible role of aspect on microclimate controls. Measurements at the three non *S. albopilosa* sites will seek to determine if other possible factors may be involved in the presence vs. non-presence of *S. albopilosa*.

Acknowledgements

Funding for this research was provided by the University of Louisville through their Summer Research Opportunity Program (SROP) and the Department of Geography and Geosciences at the University of Louisville. For assistance in the field, we thank D. J. Biddle and, in addition, Amy Ninneman who provided helpful feedback on the manuscript. We would also like to thank David Taylor, U.S. Forest Service Ranger Dave Manner of the Cumberland Ranger District, and Ranger Manner's team for their assistance in procuring locational data and permits.

Conflict of Interests

The author declares that there is no conflict of interests.

REFERENCES

[1] K. Deimling, Zeros of accretive operators, J. Math. Comput. Sci. 1 (2011), 1-18.

[2] C.K Chan, Integration of cultural awareness into Taiwanese elementary school activation English curriculum, Linguist. Cul. Educ. 2 (2012), 25-36.

[1] S. P. Arya. Introduction to Micrometeorology (1988), Academic Press.

[2] M. B. Ashcroft & Gollan, J. R. Moisture, thermal inertia, and the spatial distributions of near-surface soil and air temperatures: Understanding factors that promote microrefugia, Agr. Forest Meteorol. 176 (2013), 77– 89.

[3] J. Bennie, Hill, M. O., Baxter, R. & Huntley, B. Influence of slope and aspect on long-term vegetation change in British chalk grasslands, J. Ecol. 94 (2006), 355–368.

[4] E. L. Braun. A new species and a new variety of Solidago from Kentucky, Rhodora 44 (1942),

1-4.

[5] R. T. Brooks & Kyker-Snowman, T. D. Forest-floor temperatures and soil moisture across riparian zones on first- to third-order headwater streams in southern New England, USA, Forest Ecol. Manag. 258 (2009), 2117–2126.

[6] R. R. Currie. *Endangered and Threatened Wildlife and Plants; Determination of Threatened Status for Solidago albopilosa (White-haired Goldenrod)*. Asheville, NC: U.S. FWS Federal Register Vol. 53 No. 67 (1988), 11612-11615.

[7] J. D. Delgado, Arroyo, N. L., Arévalo, J. R., et al. Edge effects of roads on temperature, light, canopy cover, and canopy height in laurel and pine forests (Tenerife, Canary Islands), Landscape Urban Plan. 81 (2007), 328–340.

[8] S. Godefroid, Rucquoij, S. & Koedam, N. Spatial variability of summer microclimates and plant species response along transects within clearcuts in a beech forest, Plant Ecol. 185 (2006), 107-121.

[9] H. A. Gutiérrez-Jurado & Vivoni, E. R. Ecogeomorphic expressions of an aspect-controlled semiarid basin: II. Topographic and vegetation controls on solar irradiance, Ecohydrology 6 (2013), 24–37.

[10] S. N. Hidayati & Walck, J. L. Contrasting seed germination patterns for intracontinental disjuncts of Heuchera (Saxifragaceae) in North America: the eastern temperate H. parviflora and western montane H. cylindrical, Can. J. Botany 80 (2002), 1185–1192.

[11] D. N. Hull. *Sand and Gravel*. State of Ohio: Ohio Department of Natural Resources – Division of Geological Survey, GeoFacts No. 19 (2001), Retrieved July 25th, 2012 from the Ohio Department of Natural Resources website at
http://www.dnr.state.oh.us/Portals/10/pdf/GeoFacts/geof19.pdf

[12] H. G. Jones. Plants and Microclimate (1992), Cambridge, UK: Cambridge University Press.

[13] A. W. Küchler. Potential natural vegetation of the conterminous United States (map and manual). (1964), *American Geographic Society*, Special Publication 36.

[14] S. Lu, Ju, Z., Ren, T. et al. A general approach to estimate soil water content from thermal inertia, Agr. Forest Meteorol.149 (2009), 1693–1698.

[15] P. M. Rich, Hetrick, W. A. & Savings, S. C. Modelling topographical influences on solar radiation: manual for the SOLARFLUX model. LA-12989-M (1995), Los Alamos National Laboratories: Los Alamos; 33.

[16] C. Ricotta & Avena, G. C. The influence of meteorological conditions and topographic parameters on the beech forest microclimate of Simbruini Mountains, central Italy, Int. J. Remote Sens. 18 (1996), 505 – 516.

[17] N. J. Rosenberg, Blad, B. L. & Verma, S. B. *Microclimate: The Biological Environment* (1983), New York, NY: Wiley-Interscience.

[18] U.S. Department of Agriculture – Forest Service. Special Places: Red River Gorge Geological Area (2009), Retrieved June 5th, 2012 from the U.S. Forest Service website at http://www.fs.usda.gov/detail/dbnf/specialplaces/?cid=stelprdb5345319.

[19] U.S. Environmental Protection Agency – Western Ecological Division. Level III and Level IV Ecoregions of Kentucky (2012a), Retrieved June 5th, 2012 from the EPA website at ftp://ftp.epa.gov/wed/ecoregions/ky/ky_eco_lg.pdf.

[20] U.S. Environmental Protection Agency – Western Ecological Division. Level IV Ecoregions of Kentucky—poster backside (2012b). Retrieved June 5th, 2012 from the EPA website at ftp://ftp.epa.gov/wed/ecoregions/ky/ky_back.pdf.

[21] U.S. Fish and Wildlife Service. White-haired Goldenrod recovery action plan (2009), Retrieved June 6th from the U.S. FWS website at http://www.fws.gov/ecos/ajax/docs/action_plans/doc3114.pdf.

[22] D. L. White & Drozda, N. C. Status of *Solidago albopilosa* Braun (White-haired goldenrod) [Asteraceae], a Kentucky endemic, Castanea 71 (2006), 124 -128.

Table 1. Recreation impact scale.

Threat of Recreational Impact	High	Medium	Low
Definition [a]	Impact persistent and or severe; >30% of the habitat is altered or damaged by recreation and there is evidence of direct and lasting damage to plants of *S. albopilosa*, such as bare soil areas and disruption of vegetation.	Similar habitat damage as the "High" category but < 30% of available habitat and plants of S. albopilosa are affected.	Habitat for S. albopilosa has been disturbed by trampling or other recreational use, but has not resulted in compacted bare soil in vegetated areas or there is little/minor discernible impact from recreational use.

[a] Definitions based on White and Drozda (2006, p 125)

Table 2. Precision of recording instruments.

Instrument	Unit of Measure	Precision
Digital Thermometer (air)	Degrees Celsius (°)	± 0.1 °
Digital Thermometer (probe)	Degrees Celsius (°)	± 0.1 °
Capacitive Humidity Sensor	% Relative Humidity	± 0.1 %
Compass	Degrees (°)	± 1.0 °

Table 3. Results of one-way ANOVA test of air temperature (ground) data.

	df	SS	MS	F	*p*	S	R-sq. (%)	R-sq. adj. (%)
Location	2	478.1	239	7.97	0.002	5.477	39.91	34.9
Error	24	719.9	30					
Total	26	1198						

Individual 95% Confidence Intervals for Mean (Based on Pooled StdDev)

Location	n	Mean	StdDev
Above	6	41.833	7.199
Outside	7	52.2	4.808
Inside	14	51.821	4.977

Tukey 95% Confidence Interval: All Pairwise Comparisons Among Levels of Location

Location [a]	Lower	Center	Upper	Outside [b]	Lower	Center	Upper
Outside	2.761	10.367	17.972	Inside	-6.707	-0.379	5.95
Inside	3.317	9.988	16.659				

[a] Location - Above

[b] Outside - Location

Table 4. Results of Kruskall-Wallis test of air temperature (elevated) data.

	df	SS	MS	F	*p*	S	R-sq. (%)	R-sq. adj. (%)
Location	2	27.31	13.65	4.99	0.015	1.655	29.36	23.47
Error	24	65.7	2.74					
Total	26	93.01						

Individual 95% Confidence Intervals for Mean (Based on Pooled StdDev)

Location	n	Mean	StdDev
Above	6	27.95	1.822
Outside	7	25.843	1.744
Inside	14	25.429	1.54

Tukey 95% Confidence Interval: All Pairwise Comparisons Among Levels of Location

Location [a]	Lower	Center	Upper	Location [b]	Lower	Center	Upper
Outside	-4.405	-2.107	0.191	Inside	-2.326	-0.414	1.497
Inside	-4.537	-2.521	-0.506				

[a] Location - Above

[b] Outside - Location

Table 5. Results of one-way ANOVA test of relative humidity (ground) data.

Location	n	Median	Avg. Rank	Z	df	H	H adj.	*p*	*p* adj.
Above	6	27.65	18.8	1.69	2	4.62	4.62	0.1	0.1
Outside	7	27.6	15.9	0.72					
Inside	14	25.1	11	-2.04					
Overall	27		14						

Table 6. Results of one-way ANOVA test of relative humidity (elevated) data.

	df	SS	MS	F	*p*	S	R-sq. (%)	R-sq. adj. (%)
Location	2	430.7	215.4	7.49	0.003	5.364	38.42	33.29
Error	24	690.4	28.8					
Total	26	1121.1						

Individual 95% Confidence Intervals for Mean (Based on Pooled StdDev)

Location	n	Mean	StdDev
Above	6	35.667	4.268
Outside	7	42.843	6.451
Inside	14	45.793	5.186

Tukey 95% Confidence Interval: All Pairwise Comparisons Among Levels of Location

Location [a]	Lower	Center	Upper	Outside [b]	Lower	Center	Upper
Outside	-0.272	7.176	14.625	Inside	-3.247	2.95	9.147
Inside	3.594	10.126	16.659				

[a] Location - Above

[b] Outside - Location

Table 7. Location and condition of sampled *S. albopilosa* sites.

Shelter Name	Site Name	Coordinates [a]	Stem Count	Std. Count	Impact	Est. Viability	Aspect (°)	Notes
Auxier Ridge	AR Ledge	37.831443, -83.67621	6	-1.2	Low	D	45	---
	AR Floor	37.831443, -83.67621	3	-1.3	High	D	45	Evidence of Fire and Compaction
Double Arch	DA Edge	37.831321, -83.686171	24	-0.6	High	D	350	Evidence of Fire and Compaction
	DA Middle	37.831321, -83.686171	54	0.4	Med	C	350	Some Compaction
	DA Fenced	37.831321, -83.686171	48	0.2	Low	C	300	Fenced Off by U.S. FS
Double Arch Trailhead	DAT	37.820027, -83.683238	14	-0.9	Low	C	203	---
Gray's Arch	GA Lower	37.817264, -83.658532	33	-0.3	High	C	83	Heavy, Persistent Recreational Hiking
	GA Fenced	37.816746, -83.658262	89	1.5	Low	A	73	Fenced Off by U.S. FS
	GA South	37.816681, -83.658302	47	0.1	Med	C	73	Some Compaction
Rush Ridge	RR West	37.814506, -83.648860	27	-0.5	Low	C	100	---
	RR Middle	37.814583, -83.648886	79	1.1	Med	B	100	Some Compaction
	RR East	37.146450, -83.648868	67	0.8	High	C	100	Evidence of Fire and Compaction
Rough Trail I	RT I	37.818305, -83.645673	100	1.8	High	B	138	Trail Runs Through Shelter; Severe Compaction in Suitable Habitat
Rough Trail II	RT II	37.818047, -83.645155	8	-1.1	Low	C	66	---

[a] Coordinates in decimal degrees with respect to WGS 1984

Table 8. Results of soil sample analysis.

Shelter Name	Site Name	pH	Phosphorus	Nitrogen	Potassium
Auxier Ridge	AR Ledge	4.0	Trace	Trace	Low
	AR Floor	8.0	Trace - Low	Trace	Very High
	AR Outside	5.0	Trace	Trace - Low	Very Low
	AR Above	5.0	Trace	Trace	Very Low
Double Arch	DA Edge	6.5	Trace	Low	Low
	DA Middle	5.5	Trace	Trace - Low	Very Low
	DA Fenced	5.0	Trace	Trace	Low
	DA Outside	8.5	Low	Trace	Very Low
	DA Above	4.5	Low - Med	Trace	Very Low
Double Arch Trailhead	DAT	9.0	Trace - Low	Trace	Low
	DAT Outside	8.5	Trace	Trace	Very Low
	DAT Above	9.5	Trace	Trace	Low
Gray's Arch	GA Lower	6.5	Low - Med	High	Very High
	GA Fenced	7.0	High	High	Med - High
	GA South	4.0	Trace	Trace	Low
	GA Lower Outside	6.5	Low	Trace - Low	Low
	GA Fenced Outside	4.5	Trace	Trace	Low - Med
	GA Above	4.0	Trace	Trace	Very Low
Rush Ridge	RR West	4.5	Trace - Low	Trace	Very Low
	RR Middle	4.0	Low	Trace	Low - Med
	RR East	5.0	Trace	Trace	Low
	RR Outside	4.0	Trace	Trace	Low
	RR Above	5.5	Trace - Low	Trace	Low
Rough Trail I	RT I	4.5	Trace	Trace - Low	Very Low
Rough Trail II	RT II	5.5	Trace - Low	Med - High	Low
	RT II Outside	5.0	Trace	Trace - Low	Very Low
	RT II Above	5.0	Trace	Trace	Low

Figure 1. Example specimen of a non-flowering *S. albopilosa*.

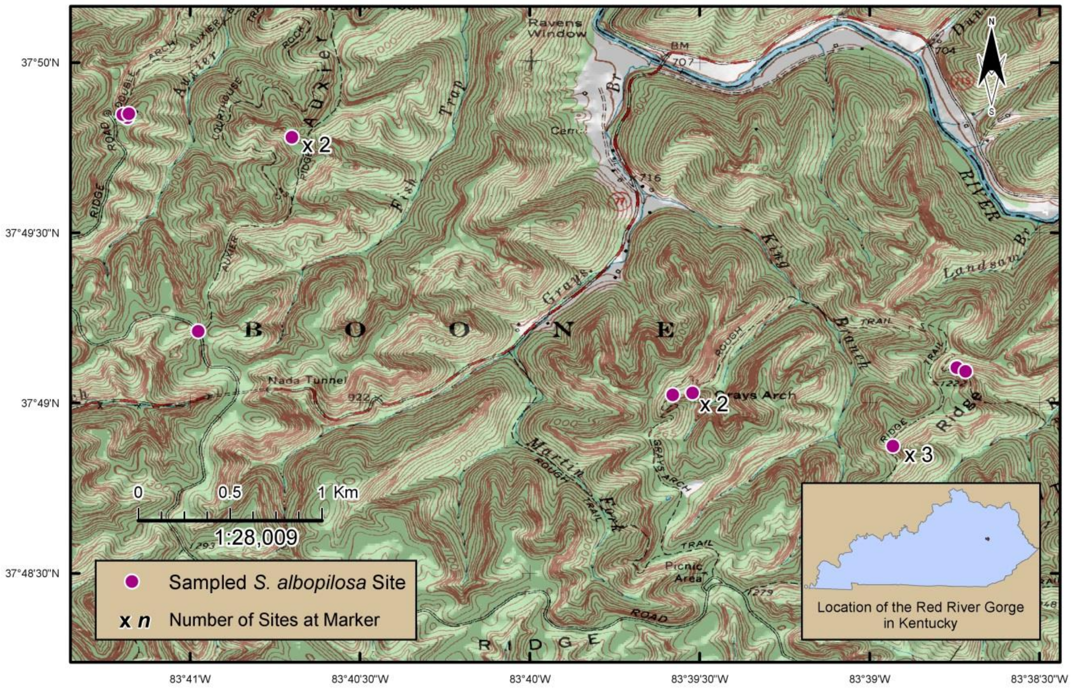

Figure 2. Map of the Red River Gorge study area and sample sites.

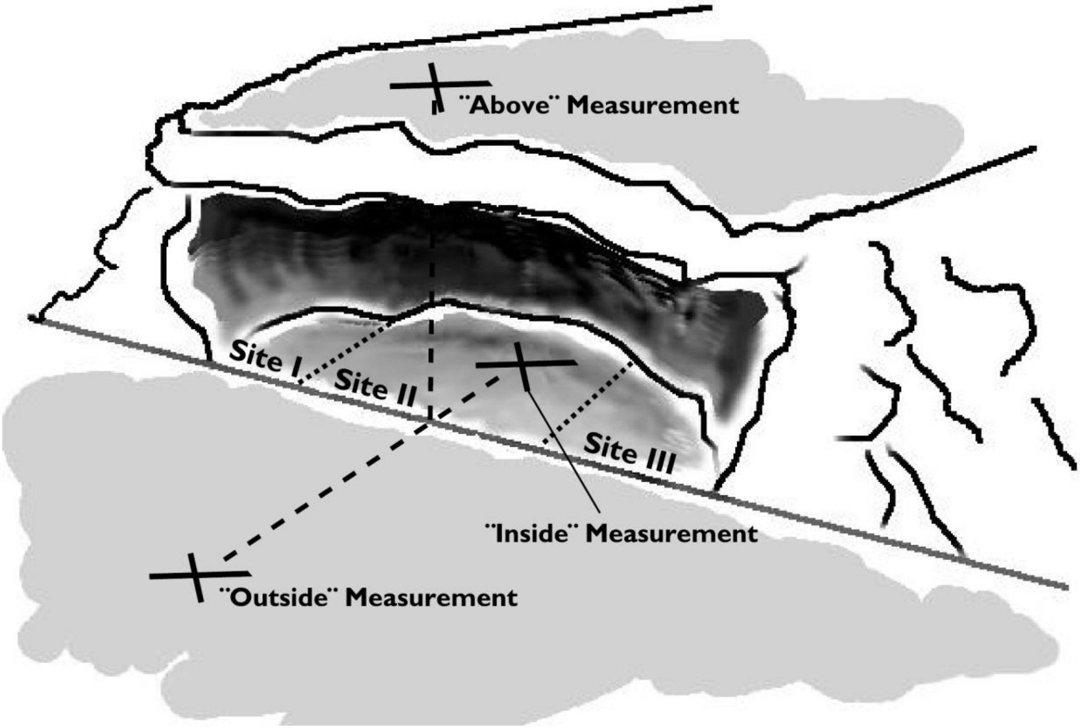

Figure 3. Sample site locations relative to rock shelters.

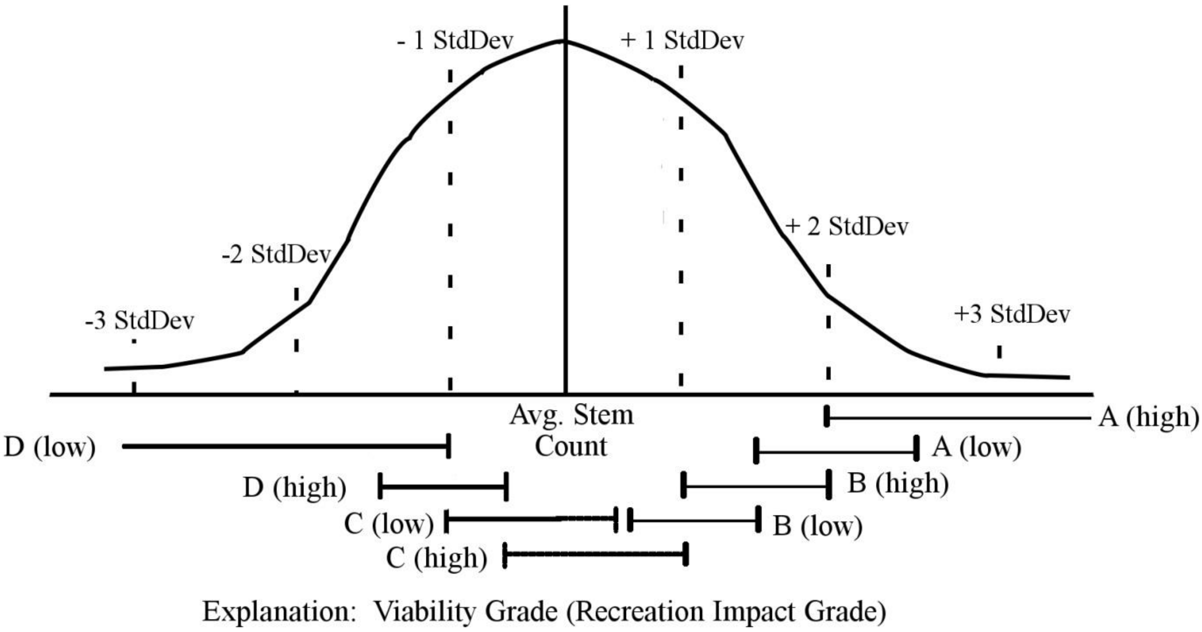

Figure 4. Estimation of *S. albopilosa* site viability.

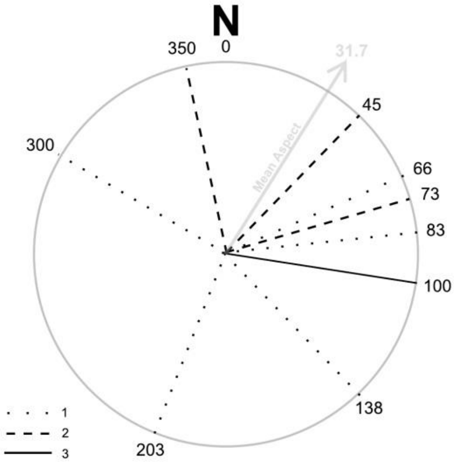

Figure 5. Distribution of rock shelter aspects containing *S. albopilosa*, including larger shelters that had multiple sites with different aspects (1-3).