DISTRIBUTION PATTERNS IN APPALACHIAN TABLE MOUNTAIN PINE AND PITCH PINE STANDS

A Thesis

by

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MASTER OF SCIENCE

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Committee Members,	David Cairns
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ABSTRACT

Flammable pine stands are often located on the driest slopes of forested landscapes in the Appalachian Mountains, but there appears to be regional variation in the topographic distribution of these pines across the southern Appalachian forests. A matrix of stands dominated by oaks and other hardwood trees covers each landscape, with patches of pines embedded within the matrix. Disturbances, such as fire, and gradients of abiotic factors such as moisture availability have influenced these forest patterns.

This study uses Southeast GAP Analysis Project land cover data at twelve landscapes of 8 km by 8 km to explore the spatial distribution of pine stands in protected areas of the southern Appalachians. The distributions of the pine stands were analyzed with respect to topographic variables including heat load index, slope, elevation, incoming solar radiation, topographic wetness index, and topographic exposure index. These variables were derived from digital elevation models. Across the twelve landscapes, pine stands are consistently found on dry topographic positions. However, the pine stands vary in terms of the aspects they occupy. Pines primarily occupy the south- and southwest-facing slopes in the southern end of the Appalachian Mountains, while at the northern end of the study region, pines shift towards the west- and northwest-facing slopes. This regional shift in the aspects covered by pine stands likely reflects an interaction between regional climate, vegetation, fire regimes, and local terrain.

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This thesis work would not have been possible if it were not for the help, guidance, and support of many people. Dr. Charles Lafon's tireless efforts to guide, suggest, and edit are deeply appreciated. Dr. Cairns and Dr. Wu provided more technical, methodological, and statistical help than they know—thank you both for wonderful and engaging classes that I was able to use to shape this project.

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"I am grateful for my family" is a poor expression to convey my gratitude to my family. Thanks to my wonderful grandparents, Mary and Jerry Jordan, for their encouragement. My sister, Jordan, and brother, Andrew, have always pushed me to succeed, and have been there to cheer me on when I needed it most. My mother, Jill Jordan, is a titan among humans. Thanks for everything.

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Contributors

This work was supervised by a thesis committee consisting of Professor Charles Lafon and Professor Dave Cairns of the Department of Geography and Professor Ben Wu of the Department of Ecosystem Science and Management.

All work for the thesis was completed by the student, under the advisement of Professor Charles Lafon of the Department of Geography.

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CHAPTER I

INTRODUCTION AND LITERATURE REVIEW

Introduction

A forested landscape comprises discrete patches of different forest ecosystems, such as mesic hardwoods stands and xeric pine stands embedded in an oak-forest matrix (Forman 1995b). The overall mosaic contains three different types of components: the background ecosystem type, the patches of different ecosystems, and the corridors that connect similar patches to each other (Forman 1995a). The pattern of patches can be explained by understanding the processes that shape them (Kupfer 2011).

These processes operate at multiple spatial and temporal scales. Landscapes can be understood as hierarchical systems, where each spatial scale has autonomous processes nested within other spatial scales according to size (Peters, Bestelmeyer, and Turner 2007). Another understanding of landscapes opposes the hierarchical system, refuting that the processes in each spatial scale are autonomous. Cross scale interactions are processes that occur at one spatial and temporal scale and impact the patterns and processes at another spatial or temporal scale. As a result, local-scale processes can influence landscape-scale patterns, and landscape-scale processes can affect local-scale patterns (Peters, Bestelmeyer, and Turner 2007).

One example of a patchy matrix that lends itself to examining cross scale interactions is the eastern North-American temperate forest. Within this oak-dominated forest, there are stands of Table Mountain pine (*Pinus pungens)*, an endemic species of yellow pine in the Appalachian forests that are important to forest managers (Burns and

Honkala 1990). Table Mountain pine are important in watershed management and, to a lesser extent are harvested for timber and pulpwood (Burns and Honkala 1990). They range from northern Georgia to Pennsylvania, and stretch across several regions of the Appalachians including the Blue Ridge and the Ridge and Valley physiographic provinces (Little 1971). Despite the breadth of their range, patches of Table Mountain pines are dispersed unevenly throughout a mosaic of hardwood-dominated forests (Brose and Waldrop 2006). Stands of Table Mountain pine often include pitch pine (*Pinus rigida),* another yellow pine species that occurs in the Appalachians and extends in range to coastal Maine on the northeast and northern Georgia to the southwest (Burns and Honkala 1990; Little 1971). Within the watershed, pitch pines are important for soil stabilization and runoff reduction, especially within areas of exposed soils or rugged terrain (Burns and Honkala 1990).

Table Mountain pine—pitch pine stands occupy particular areas within the forest matrix. These pine species are shade-intolerant and require disturbances to create gaps in the canopy in which young saplings mature into trees. These disturbance events include ice storms, insect outbreaks, and fire (Grime 1988; Lafon 2006; Sauer 1950). Table Mountain pines reproduce through serotinous cones that release seeds after heating by a fire (Waldrop and Brose 1999). In addition to occupying disturbance-prone areas, Table Mountain pine—pitch pine stands also occupy slopes in the landscape that are drier compared to valley bottoms. Pines are able persist on dry slopes because they are more drought-tolerant than most hardwoods (Burns and Honkala 1990; Zobel 1969). It is rare to find pines in mesic areas, as mesophytic hardwood species outcompete pines in these places (Cottam, Nelson, and Clarke 1939).

Previous studies suggest that the topographic distribution of the Table Mountain pine and pitch pine stands varies across the Appalachian region (Whittaker 1956). The stands are generally categorized as occurring on steep, south- or southwest-facing slopes (Williams and Johnson 1992; Zobel 1969). In particular, mature pine stands are throughout most of the south- and southwest-facing slopes on the Tennessee side of the Great Smoky Mountains, and are surrounded by oak-dominated stands on the nearby slopes (Whittaker 1956).

Exceptions to the general pattern of pine stands has been noted in some locations, including Rocky Face, North Carolina and Linville Mountain, North Carolina, where the stands were located on north-facing and west-facing slopes, respectively. (Flatley et al. 2013). In Virginia, pines have been reported to cover west-, northwest-, or north-facing slopes (Aldrich et al. 2010).

If pines normally establish and persist in the driest parts of the forest matrix, then why would the aspect of the pines vary between the southern and central Appalachians? This study seeks to delineate the different patterns of aspects occupied by the Table Mountain pine and pitch pine stands located in the southern Appalachians. By systematically exploring the locations of these pine stands at different locations within the southern Appalachians, we can begin to examine the cross-scale interactions that lead to regional differences in pine distribution in the Southern Appalachians.

Research questions

1. Do Table Mountain pine and pitch pine stands occupy the drier locations within the forest matrix in southern Appalachian National Parks and National Forests?
2. What are the aspects most frequently occupied by pines, and how do they vary across the southern Appalachian forests?

Literature review

Plant distribution is related to environmental conditions such as temperature and precipitation (Von Humboldt and Bonpland 1807). Plants require water to grow, and the rate of growth is positively correlated with water intake (Woodward 1987). Plants have faced evolutionary trade-offs in their response to different ecological pressures, such as low moisture availability and high competition from other plants, and these tradeoffs are thought responsible for different plant strategies (Aerts 1999). Plants with high water requirements are located in areas with either relatively high precipitation or easy access to stored water (Smith and Huston 1990). Alternatively, plants that can tolerate stressful conditions with low water only persist in areas with low moisture availability, as they grow slowly and would be outcompeted in areas with high water accessibility (Smith and Huston 1990).

Plant species are also constrained by temperature (Von Humboldt and Bonpland 1807). Thresholds of minimum temperatures in both the air and soil must be met in order for a tree to grow new secondary wood (Rossi et al. 2007). However, there is a trade-off for surviving low winter temperatures: slow growth. Slow growth limits the southern range in boreal trees due to competition from faster growing species (Loehle 1998). The growth of tropical trees in each year is also inversely related to minimum temperatures (Clark et al. 2003). The distribution of temperate plants can also be limited by cold temperatures, which reduce plant reproduction and growth (Woodward, Fogg, and Heber 1990), Limiting temperatures affect plant distribution both across elevations in a forest and towards the poles across latitude (Woodward 1987). Temperature and precipitation influence range limits for each plant species, and other features in the range, such as soil and terrain, determine finer-scale distribution constraints.

Microclimate-level moisture differences can cause differences in vegetation on the local scale. Along a hill slope, soil moisture is related to both topography and soil properties such as depth and texture (Yeakley et al. 1998). The importance of soil properties becomes even more important when rainfall is irregular (Yeakley et al. 1998). The small differences in water availability created along a hill slope contribute to variations in vegetation structure or species composition within a functional group. For example, the forests in the southern Appalachians contain many tree species, and the dominant species shift from mesophytic yellow-poplars, hemlocks, birches, and other species to oaks as the moisture levels decrease (Day and Monk 1974). These local variations within one functional type, such as mesophytic to xerophytic trees, reflect broader differences in vegetation structure across a moisture gradient.

South-facing slopes are often the warmest and driest slopes in the northern hemisphere, as these slopes receive higher solar radiation than north-facing slopes or strictly east- and west-facing slopes (Geiger, Aron, and Todhunter 1969). Plants on south-facing slopes also experience longer growing seasons because the minimum temperature threshold is met earlier and extends longer on the south-facing slopes than the north-facing slopes (Rossi et al. 2007). These differences in solar radiation also influence vegetative community structure by reducing the soil moisture through evaporation. Differences in exposure to solar radiation also affect the daily range in temperature, which can limit the ability of species to establish (Stueve et al. 2009).

Disturbances constrain vegetation distribution. Plant communities observed in an area reflect not only the current climate and location, but also the past and present disturbance regime (Sauer 1950). Frequent disturbances prohibit slow-growing late successional plants, and instead allow for disturbance-adapted plants to persist over generations. The wind exposure and ice storms in New England conifer forests kill mature trees in a wave-like pattern across the landscape (Sprugel 1976). This wave pattern is a cyclical regeneration pattern that creates a new forest every 50 to 60 years, and occurs faster on windward slopes compared to leeward slopes (Sprugel 1976). The community structure in other locations depend entirely on the frequency of disturbance. For example, frequent fires prohibit a grasslands from transforming into woody shrub lands, and without these disturbances the community structure will change (Sauer 1950).

Disturbances such as fire affect the landscape on different spatial scales, and as a result is a cross-scale interaction (Peters, Bestelmeyer, and Turner 2007). On fine scales, the fire will spread depending on the characteristics of individual trees and local fuel loads between the trees, but at broad scales wildfire spreads depending on fuel loads of corridors and patches, as well as species composition within patches (Peters, Bestelmeyer, and Turner 2007). The broad-scale spatial distribution of wildfire is dependent on the fine scale processes, and the results of the wildfire impact species abundance patterns. These species abundance patterns create the patches within the forest matrix, which in turn influence the spread of fire.

The oak-dominated forests of the southern and central Appalachian Mountains provide an excellent case study in fire-induced cross-scale interactions. The oak-dominated mosaic, which includes patches of pine-dominated or mesophytic hardwood-dominated stands, reflect different ecological factors and site-specific disturbance histories. Oak-dominated forests in the Appalachians are thought to require frequent disturbances, especially by fire, to regenerate and to prevent their replacement by shade-tolerant hardwoods (Abrams 1992). This fire-oak hypothesis suggests that without regular burnings, the abundance of oak species will diminish in the eastern North American forests (Brose et al. 2013). However, the oaks will grow on the xeric sites where they can outcompete pines, except on the most extreme sites (Barden 2000). Prescribed burnings allow oak species to regenerate more than mesic hardwoods, and this process prohibits the dominant species in the forest from transitioning to mesic hardwood-dominance (Brose et al. 2013). Mesic hardwoods create conditions that are unfavorable to the spread of fire by forming dense leaf litter and moist understory microclimates (Nowacki and Abrams 2008). Therefore, once mesophitication occurs it is difficult to reinstitute a fire regime to return the dominant species type to oaks.

The current oak- and pine-dominated forests in eastern North America are a product of a frequent fire regime in previous years. Lightning-ignited fires and fires set by Native Americans likely worked in tandem to maintain the oak- and pine-dominated forests until European settlement in the mid-1700s (Brose et al. 2001; Abrams 1992). Between European settlement and industrial logging, the new settlers continued the fire regime. (Brose et al. 2001; Abrams 1992). Industrial logging came to the Appalachians in the 1880s, and in addition to the logging, the forests were subjected to further disturbances as a result of more frequent fires. These fires burned slash left by logging activities, and were ignited because of anthropogenic field-clearing fires or fly away sparks from the new railroads. Even-aged stands of oak and pines were created as a result of these disturbances (Brose et al. 2001).

The length of time between two successive fires, also known as the fire interval, along with soil conditions determined what types of species were able to persist in the area. According to dendroecological studies of fire-scarred trees, the fire interval in the southern Appalachians ranged from two years to 19.5 years, with a median interval of 5.4 years between successive fires (Lafon et al. 2017). Some landscapes in Virginia and North Carolina had mean fire intervals at about the same length as the regional average, such as Reddish Knob at a fire every 4.8 years, Mill Mountain every 5.4 years, Kelley Mountain every 3.9 years, and Linville Gorge every 4 years (Aldrich et al. 2010; Flatley et al. 2013; Lafon et al. 2017). Other locations in Virginia and some in Tennessee had shorter fire intervals, such as 2.2 years in Licklog, Tennessee, 2.6 years at House Mountain, and 2.9 years at Griffith Knob (DeWeese et al. 2010; Flatley et al. 2013;

Lafon et al. 2017). At each of these locations, however, the mean fire interval represented merely the average conditions, with several intervals longer or shorter in length between fire events, depending on historical conditions of land use or weather (Lafon et al. 2017).

After these periods of extensive burning, the United States government instituted a fire suppression policy at the turn of the century in an effort to allow the forests to grow mature trees (Brose et al. 2001). However these policies were not implemented effectively until the mid-1930s (Brose et al. 2001). Fire suppression created unintended consequences, and modified the landscape for over fifty years. Without fires to regenerate the oak-dominated forests and the pine stands, the community structure began to shift towards mesophytic hardwoods (Abrams and Nowacki 1992; Scholwater, Coulson, and Crossley 1981).

CHAPTER II

METHODS

Methods overview

To elucidate patterns in pine distribution, I picked twelve study landscapes across the southern and central Appalachians, each an 8 km by 8 km area. At each landscape, the elevation, slope, incoming solar radiation, topographic wetness index, topographic exposure index, and soil drainage abilities were calculated and examined to determine whether or not the pines occupied the driest sections in the landscape. To identify the regional variation in the aspects most frequently occupied by the pines, the percent of each aspect class covered by pine-dominated cells was calculated and compared between the landscapes. The raw number of cells in each category at each landscape is included in Appendix A. Lastly, the differences between the percent of each aspect class covered by pines was correlated to climatic variables to investigate whether or not the pattern is related to climate.

Study area

The Appalachians are a range of mountains dominated by forests in eastern North America, and commonly separated into four distinct regions. The Appalachian Highlands include two mountainous regions (the Ridge and Valley and the Blue Ridge) abutted by the Appalachian Plateau to the west and the Piedmont to the east. The Appalachian Plateau and Ridge and Valley are underlain by sedimentary rocks which have been dissected in some places to form rugged relief in the Plateau and parallel

ridges separated by valleys in the Ridge and Valley (Shankman and James 2002). The Blue Ridge is underlain by metaphormic rock, and the Piedmont is underlain by a combination of metamorphic and igneous rock (Shankman and James 2002).
Forests composition within these mountains varies spatially and temporally with both climate and disturbance regimes; historically, forest fires were one of the dominant disturbances in the Appalachian Ridge and Valley and the Blue Ridge (Lafon and Grissino-Mayer 2007). The Appalachian Plateau is dominated by mixed mesophytic forests in the south and transitions to northern hardwoods in the north (Lafon et al. 2017). An oak-dominated mixed mosaic forest covers most of the Ridge and Valley province and the Blue Ridge province, with mesic stands more common in the Blue Ridge (Lafon et al. 2017). Forested areas in the Piedmont are fairly mixed between oak stands, pine stands, and mixed hardwood stands (Lafon et al. 2017).

The climate of the southern Appalachians is humid with biannual peaks in highest precipitation (Whittaker 1956). The Appalachian Mountains have a wide range in elevation and topographic features. There are several different land uses within the Appalachians, ranging from protected areas such as National Parks and National Forests, to agricultural land and cities. Twelve locations were selected throughout this region in Georgia, Tennessee, North Carolina, and Virginia (Figure 1, Table 1). The Blue Ridge and the Ridge and Valley are the only two physiographic provinces included in this study, and the Blue Ridge has been divided into the Northern and Southern Blue Ridge (Table 1). The Southern Blue Ridge was further divided into eastern and western (Table 1).

Figure 1. Locations of the twelve study landscapes.

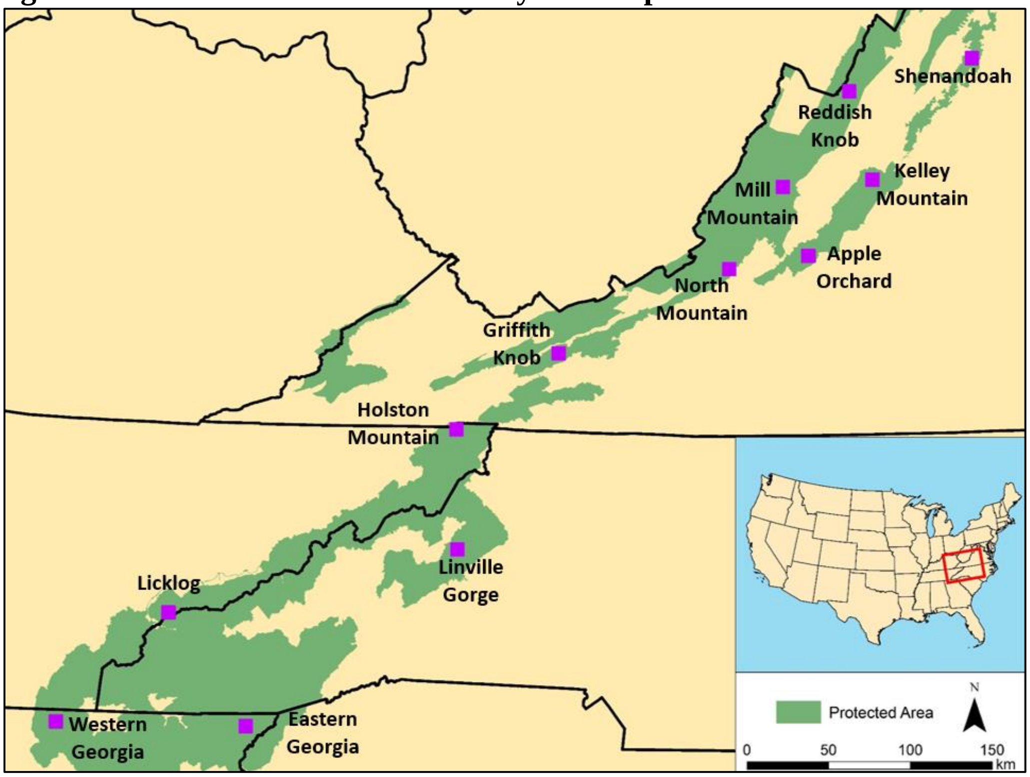


Table 1. Location descriptions of the twelve study landscapes.

Location	Latitude	Longitude	Physiographic Province	National Park or National Forest	Elevation Minimum (m)	Elevation Maximum (m)	Percent Occupied by Pine Stands
Western Georgia	34° 55' 19" N	84° 35' 21" W	Southern Blue Ridge-East	Chattahooche National Forest	424	1,264	2.3%
Eastern Geogria	34° 55' 36" N	83° 19' 8" W	Southern Blue Ridge-East	Chattahooche National Forest	498	1,396	2.0%
Licklog	35° 32' 32" N	79° 40' 20"W	Southern Blue Ridge-East	Great Smoky Mountains National Park	523	1,498	2.6%
Linville Gorge	35° 55' 9" N	81° 54' 46" W	Southern Blue Ridge-West	Pisgah National Forest	541	1,281	3.3%
Holston Mountain	36° 34' 51" N	81° 55' 40" W	Southern Blue Ridge-West	Cherokee National Forest	526	1,198	2.1%
Griffith Knob	37° 0' 12" N	81° 13' 46" W	Ridge and Valley	George Washington and Jefferson National Forest	687	1,184	2.9%
North Mountain	37° 27' 50" N	80° 3' 5" W	Ridge and Valley	George Washington and Jefferson National Forest	381	921	3.1%
Apple Orchard	37° 31' 52" N	79° 30' 11" W	Northern Blue Ridge	George Washington and Jefferson National Forest	301	1,283	1.8%
Mill Mountain	37° 54' 44" N	79° 40' 20" W	Ridge and Valley	George Washington and Jefferson National Forest	362	1,029	6.6%
Kelley Mountain	37° 56' 39" N	79° 2' 54" W	Northern Blue Ridge	George Washington and Jefferson National Forest	495	1,093	6.3%
Reddish Knob	38° 25' 59" N	79° 11' 50" W	Ridge and Valley	George Washington and Jefferson National Forest	536	1,339	12.4%
Shenandoah	38° 35’ 58’’ N	78° 19' 55" W	Northern Blue Ridge	Shenandoah National Park	257	1,220	3.7%

The weather at each landscape varied, but the temperature at every landscape was highest in the summer months and lowest in the winter months (Figures 2-13). Precipitation was unevenly distributed in the year at each landscape (Figures 2-13). Temperature and precipitation data at each location is taken from either the nearest Remote Automated Weather Station (RAW Station) or the nearest airport (Holston Mountain, Figure 6 and Apple Orchard, Figure 9), depending on which location was closer to the landscape. Data from the RAW Stations were downloaded at http://fam.nwcg.gov/fam-web/weatherfirecd/fire_files.htm, and data from the airports were downloaded at http://www.ncdc.noaa.gov/cdo-web/search. Precipitation data was averaged for each month, and the minimum and maximum temperature readings for each month were averaged, and the average of those values were also calculated (Figures 2-13). The degree to which each RAW Station or Airport represents the weather at the landscape probably differs between each location because of the distance between the weather station and the landscape (Table 2).

Table 2. Distance between each landscape and the representative RAW station or airport.

Site	Weather Station	Distance (km)
Western Georgia	Cohutta #1	2.38
Eastern Georgia	Tallulah #1	N/A, Inside landscape
Licklog	Indian Grave	4.98
Linville Gorge	North Cove Pinnacle	7.37
Holston Mountain	Tri Cities Airport	39.61
Griffith Knob	Stony Fork	0.54
North Mountain	Craig Valley	2.43
Apple Orchard	Lynchburg Airport	29.38
Mill Mountain	Lime Kiln	5.58
Kelley Mountain	Sawmill Ridge	23.29
Reddish Knob	Upper Tract	38.60
Shenandoah	Headquarters	2.35

While Western Georgia, Eastern Georgia, Griffith Knob, North Mountain and Shenandoah are all within 3 km or less of their RAW Station, some other landscapes such as Holston Mountain, Apple Orchard, Kelley Mountain, and Reddish Knob are over 20 km away from their weather data source (Table 2). These distances are small at the regional scale, but are large at the local scale.

Another limitation in the weather data is the length of records at each landscape. The record lengths for the climate data also vary across the RAW Station, with some as few as 5 full years (Griffith Knob, Figure 7) and others with 42 years for some months (Shenandoah, Figure 13). Only the TriCities Airport and the Lynchburg Airport have climate normal calculated to represent their study landscapes, Holston Mountain (Figure 6) and Apple Orchard (Figure 9), respectively.

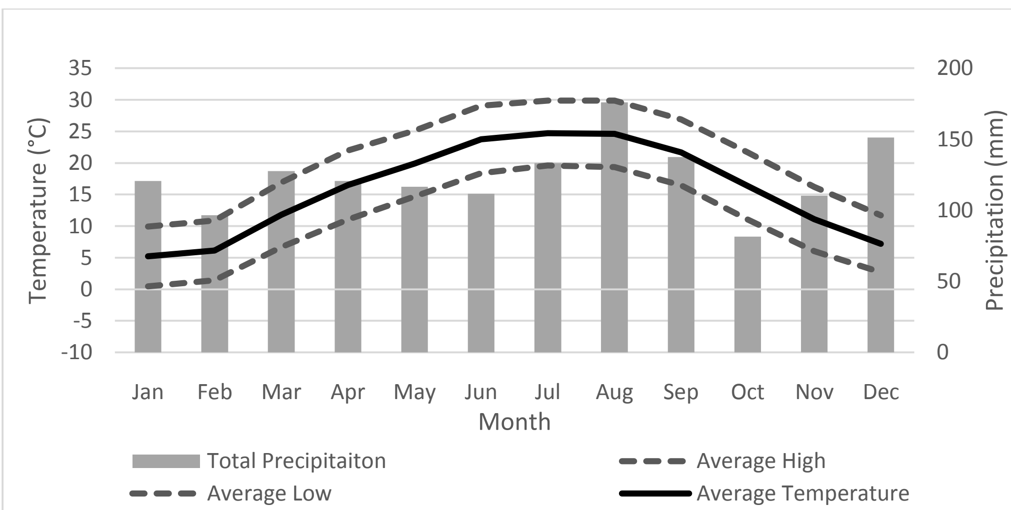


Figure 2. Monthly temperature and precipitation at Western Georgia. Records include October and November 2001, and January 2002-December 2015.

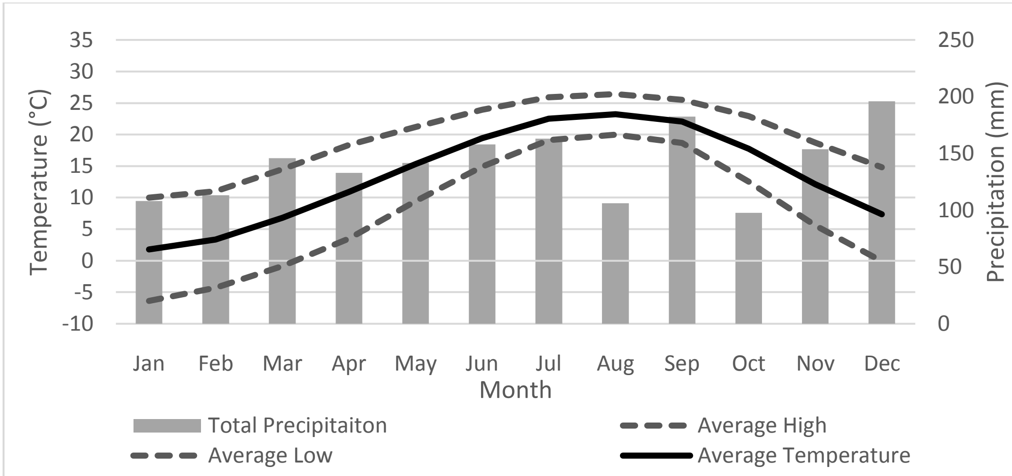


Figure 3. Monthly temperature and precipitation at Eastern Georgia. Records include October 2001 and April 2002-December 2015.

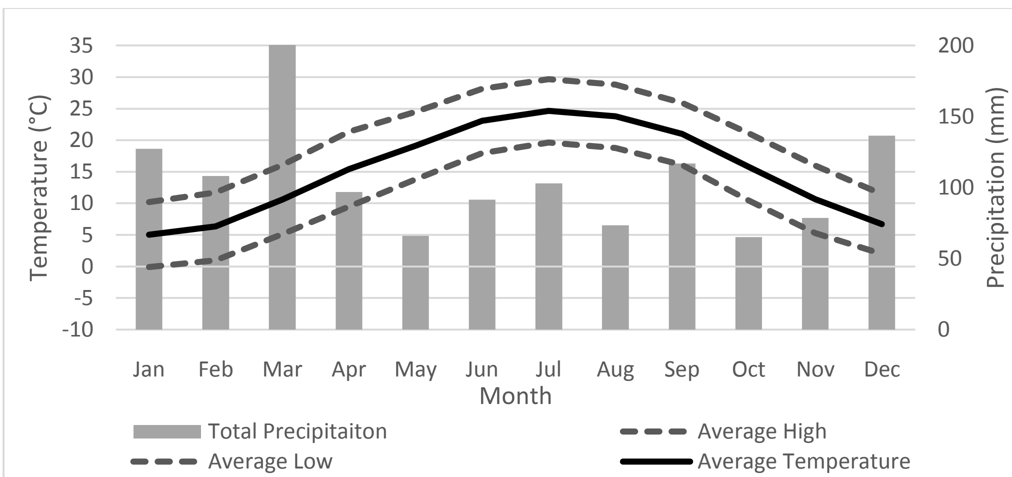


Figure 4. Monthly temperature and precipitation at Licklog. Records include January 1988, March –October 1988, January 1989-December 1994, October 1996, April and November 2002, May 2010-December 2015.

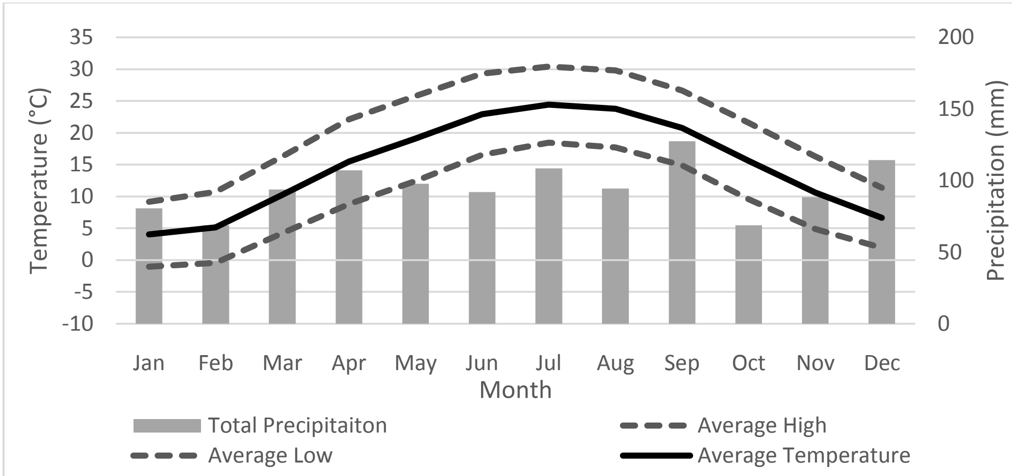


Figure 5. Monthly temperature and precipitation at Linville Gorge. Records include August 2001-January 2002, March 2002-August 2007, January 2008-December 2015.

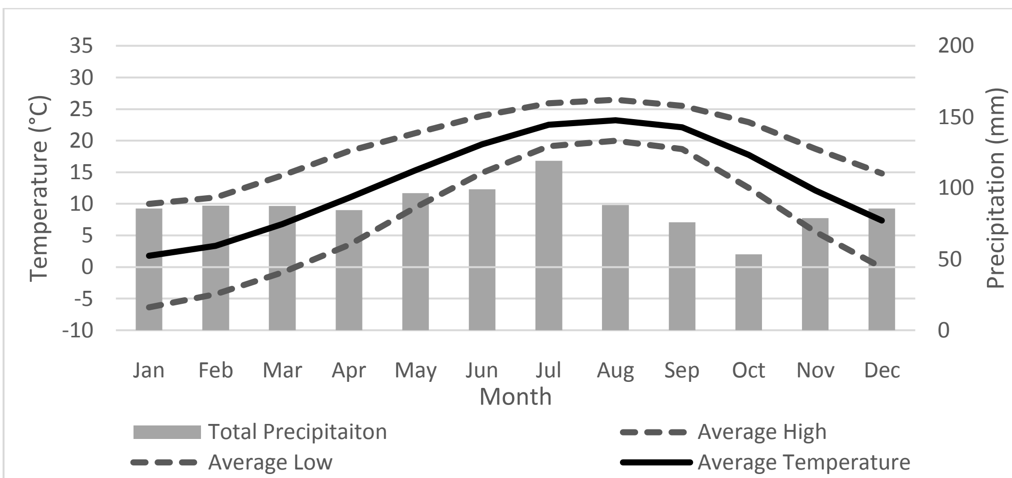


Figure 6. Monthly temperature and precipitation at Holston Mountain. Records are climate normals from 1980-2010.

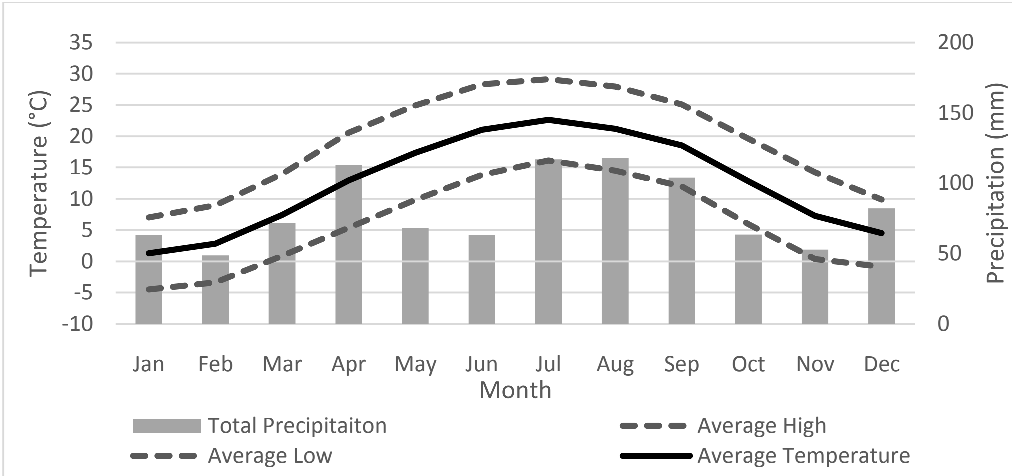


Figure 7. Monthly temperature and precipitation at Griffith Knob. Records include November 2005, March 2006, November 2007, February-May 2008, October 2009, July, November, and December 2010, and all months in 2011-2015.

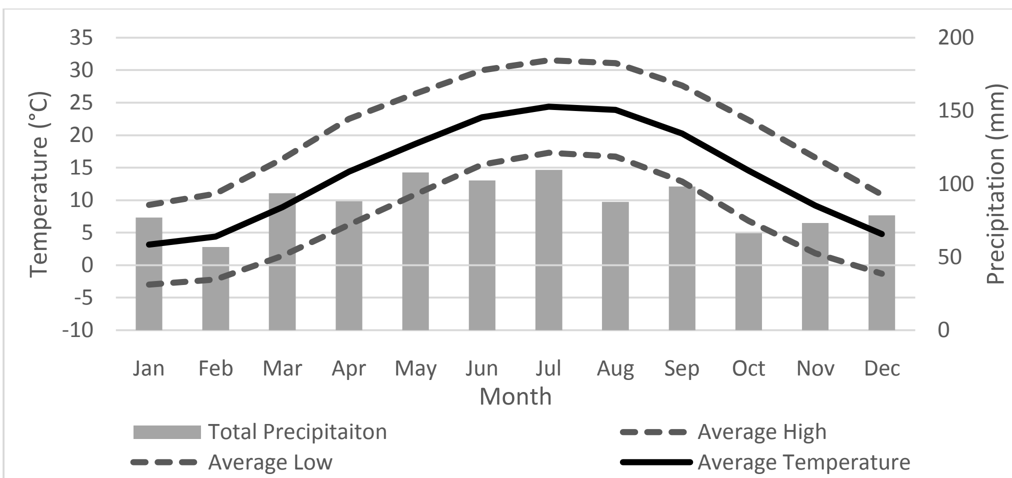


Figure 8. Monthly temperature and precipitation at North Mountain. Records extend from June 1994-December 2015.

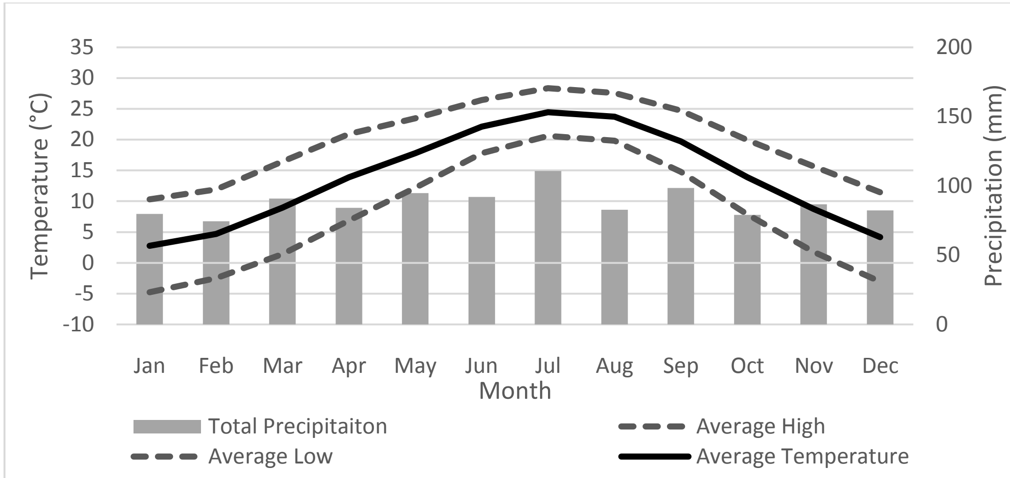


Figure 9. Monthly temperature and precipitation at Apple Orchard. Records are climate normals from 1980-2010.

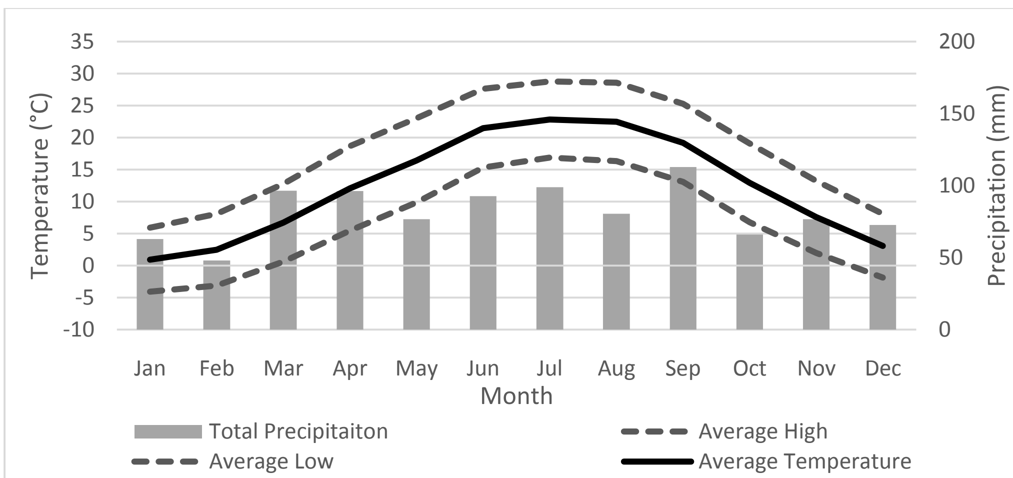


Figure 10. Monthly temperature and precipitation at Mill Mountain. Records at this location are scattered between April 1975- March 1998 (excluding almost every June-September), and include every month between March 1998-January 2006, and August 2006-December 2015.

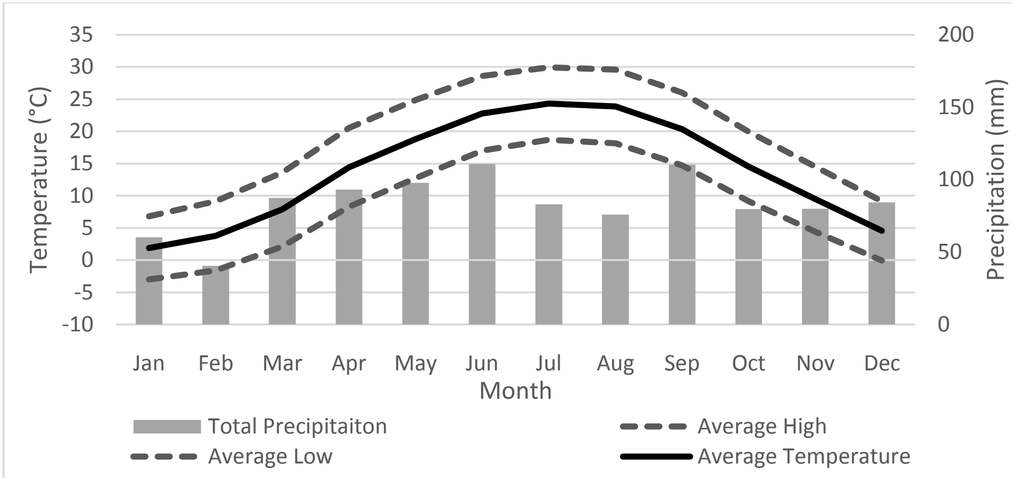


Figure 11. **Monthly temperature and precipitation at Kelley Mountain. Records include November 1998-May 2005, November 2007-December 2015.**

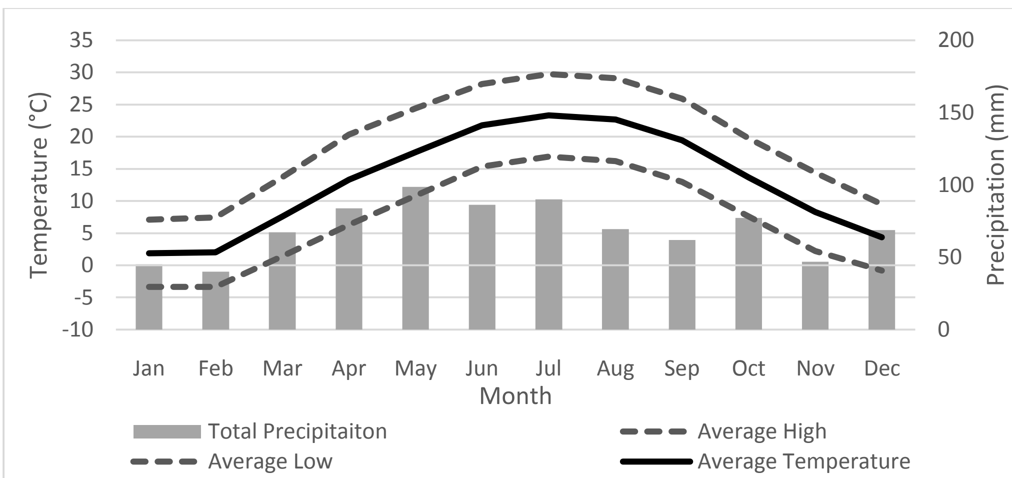


Figure 12. **Monthly temperature and precipitation at Reddish Knob. Records include September 2005-December 2015.**

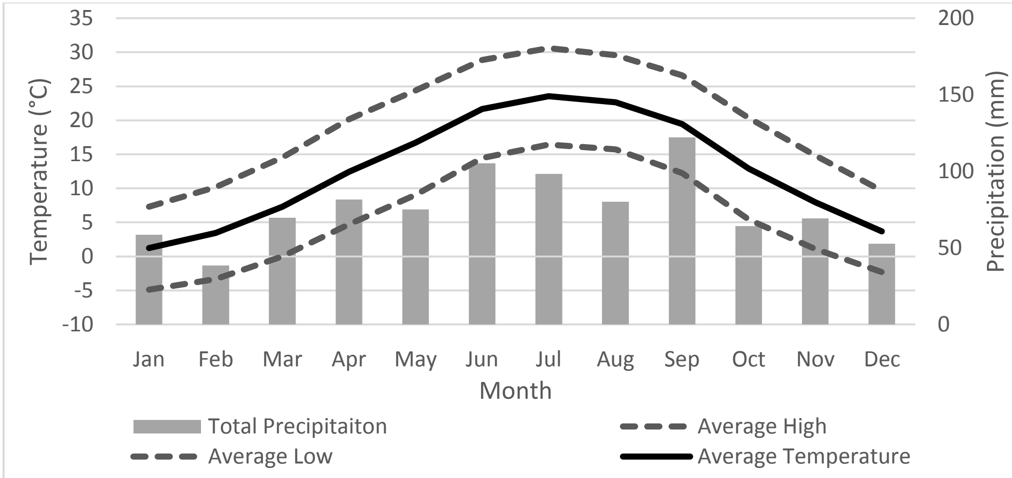


Figure 13. Monthly temperature and precipitation at Shenandoah. Records include October 1973-December 1993 (excluding most February, June-September months, and all of January Months), January 1994-May 2005, and September 2007-December 2015.

Wind speed and direction also vary among all twelve landscapes (Figure 14). Most landscapes have a fairly even spread of wind direction, but some like Apple Orchard had one main wind direction (Figure 14). Wind roses for each month at each landscape were also created (Appendix B).

Figure 14. Wind roses of the twelve landscapes, with wind speed shown in meters per second. Sites include A) Western Georgia, B) Eastern Georgia, C) Licklog, D) Linville Gorge, E) Holston Mountain, F) Griffith Knob, G) North Mountain, H) Apple Orchard, I) Mill Mountain, J) Kelley Mountain, K) Reddish Knob, and L) Shenandoah.

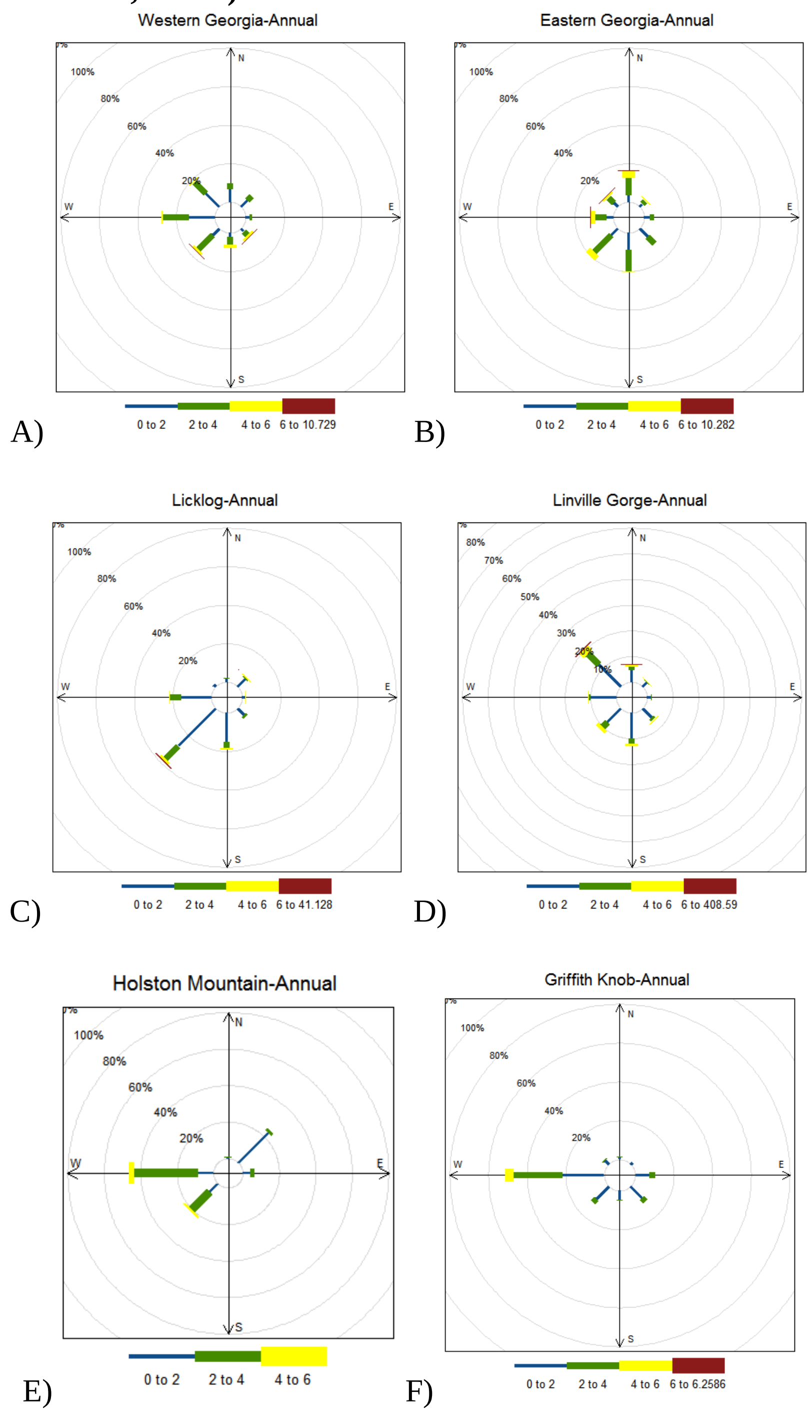
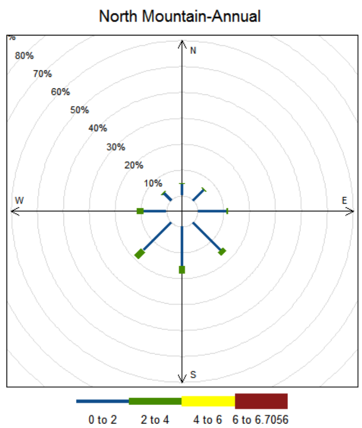


Figure 14 Continued.



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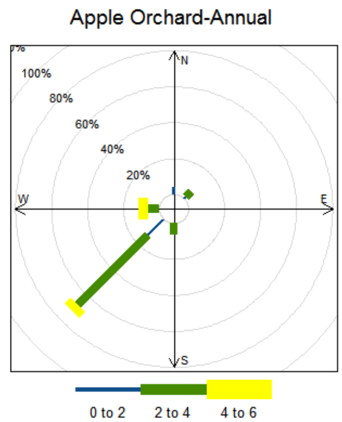

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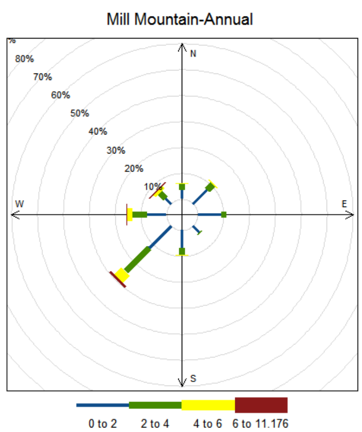
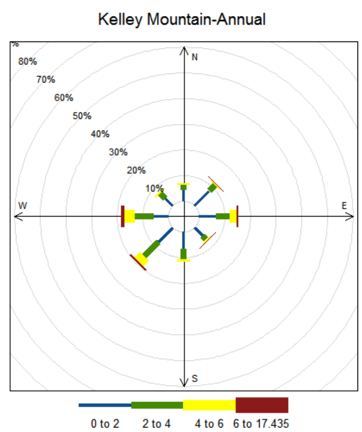


I)



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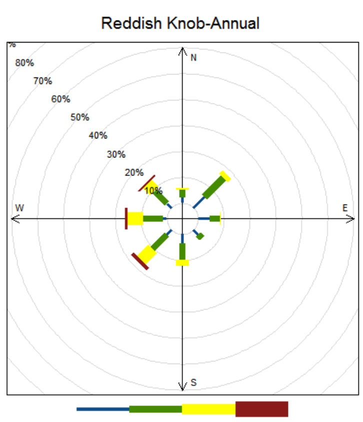
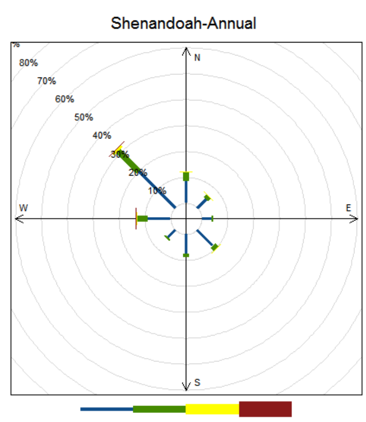


K)



L)

Data sources

Data for this project were downloaded from various government and government-affiliated websites. Georectified tiff images of 1:24,000 scale USGS topographic maps were downloaded from U.S. Geological Survey's National Geologic Map Database website, available at http://ngmdb.usgs.gov/maps/topoview/viewer/#11/34.8969/-83.3416. Digital Elevation Models (DEMs) were downloaded from the U.S. Geological Survey's website (http://viewer.nationalmap.gov/basic/). Each DEM spans 1° by 1°, and has a resolution of 30 meters by 30 meters (1 arc second). These DEMs were used to derive aspect, slope, radiation topographic evenness index, and topographic wetness index.

Maps throughout this thesis were created using ArcGIS® software and USGS topographic base maps (in Appendix B) by Esri. ArcGIS® and ArcMap™ are the intellectual property of Esri and are used herein under license. Copyright © Esri. All rights reserved. For more information about Esri® software, please visit www.esri.com. State boundaries were downloaded from https://www.census.gov/geo/maps-data/data/cbf/cbf_state.html at a scale of 1:5,000,000.

The location of pines was determined using land cover data from the Southeast GAP Analysis Project. This project was conducted by the U.S. Geological Survey's division Biological Resources Division, and the resulting rasters are available for download at http://www.basic.ncsu.edu/segap/. The resolution of the data is 30 meters by 30 meters. The most prominent land cover type for this analysis is the Southern Appalachian Montane Pine Forest and Woodland, with 50% or more of the canopy dominated by Table Mountain pines and pitch pine (Descriptions of Ecological Systems for Modeling of LANDFIRE Biophysical Settings 2007). Two other land cover types were used in this project, as the range of the Montane Pines did not extend into areas of Northern Virginia where such pines are known to exist (Aldrich et al. 2010; Hack and Goodlett 1960). These cover types are Northeastern Interior Dry-Mesic Oak Forest-Virginia/Pitch Pine Modifier, and the Southern Ridge and Valley Dry Calcareous Forest - Pine modifier. These two vegetative cover types were selected through a combination of their descriptions and their apparent match to previously published descriptions (Aldrich et al. 2010; DeWeese et al. 2010; Flatley et al. 2013). Data from the Southeast GAP Analysis Project covers Georgia, North Carolina, South Carolina, Tennessee, and Virginia, and therefore the study area for this project is confined to these states.

Soil data were downloaded from the National Resource Conservation Services (NRCS), available at https://gdg.sc.egov.usda.gov/GDGOrder.aspx. These data are downloaded in the GSSURGO raster files for each state. The soil name, dominant drainage class, and wettest drainage class were recorded for each landscape. The resolution of these raster files is 10 meters by 10 meters, and therefore had to be aggregated during analysis to 30 meters by 30 meters.

Climate data were downloaded from the two sources: National Oceanic and Atmospheric Administration (NOAA) and Remote Automated Weather Stations (RAW Station). For each study landscape, the nearest weather Station that records all data types was used to represent landscape conditions. The Remote Automated Weather Stations (RAW Station) data were downloaded as text files through the National Wildfire

Coordinating Group's Fire and Weather Data, available at http://fam.nwcg.gov/fam-web/weatherfirecd/fire_files.htm. RAW Station data includes records such as temperature, wind speed and direction, humidity, precipitation, and solar radiation. Each RAW Station has a different range of years recorded. The text files were converted into csv format and used to determine the average, maximum, and minimum temperatures for each weather condition per month. The data from NOAA specifically pertains to the Tri Cities, TN Airport to represent Holston Mountain landscape, and the Lynchburg, VA Airport to represent Apple Orchard landscape. RAW Station data were not used at these two landscapes as the nearest RAW Station was further away than their respective airports. The NOAA data was downloaded as csv files through their National Centers for Environmental Information, available at http://www.ncdc.noaa.gov/cdo-web/search. Temperature, precipitation, and snow data were downloaded for climate normal on a daily basis. Data on cloud cover, wind speed, and wind direction were downloaded for climate normal on an hourly basis. Both climate normals were determined using data from 1981-2010.

Landscape selection

Twelve landscapes were chosen based on different criteria. Six of the landscapes were previously surveyed in various fire history studies (Aldrich et al. 2010; DeWeese et al. 2010; Flatley et al. 2013). An additional six landscapes were chosen to fill the gaps in the pine distribution of landscapes across the region. Landscapes were chosen in the protected areas outlined in the 1:24,000 topographic maps GeoTIFFs. Within each landscape, the pine stands needed to cover a sizeable amount of the space. Each landscape needed to be near a RAW Station or airport in order to have local weather conditions recorded. The twelve landscapes were also chosen to represent the spectrum of the Appalachians across the states from Georgia to Virginia available in the Southeast Gap Analysis Project Data.

Landscape analysis

The DEM and Vegetation layers were projected and clipped to the 8 km by 8 km landscape boundary in the appropriate UTM zone. All of the landscapes except for Western Georgia were projected into UTM Zone 17, while Western Georgia was projected into UTM 16. Three of the landscapes Griffith Knob, Kelley Mountain, and North Mountain required merging of two DEM files to create a continuous DEM. For each landscape, the main DEM was placed first into the tool “mosaic to new raster” and then the smaller piece. By placing the main piece in first, the second, smaller piece would fit into the pattern of the first piece’s grid system. This process was also helpful in reducing the overlap of the two DEM files in Griffith Knob.

Six variables were calculated in ArcMap and are discussed below. Once each of these main variables were calculated for each landscape, the raster images were converted into TIFF files. The raster images also were clipped to the pine layers, and these were likewise converted to TIFF files. Each TIFF was brought into the statistical program R to extract the values for each 30x30m cell, along with the x and y coordinates. These values then were merged by location into 24 csv files containing the value for each of the six variables as well as the x and y UTM coordinates for both the whole landscape and the pine areas.

Aspect

For each landscape, the aspect was calculated using the standard Arc tool. The aspect value was then categorized into the equal sized aspect classes of the cardinal and primary intercardinal directions. The percent of each aspect class covered by pines was determined by dividing the number of pine-covered cells in each aspect class by the total number of cells in the class for each landscape. Chi squared analysis of the pines and areas not dominated by pines was performed to determine if the pines were occupying specific parts of the landscape in a nonrandom pattern.

Heat load index

The heat load index was calculated to determine the relative sun exposure for each part of the landscape. By converting the aspect into a heat load index, areas that receive similar sun exposure amounts can have similar values, despite being sorted into different aspect classes (Stoddard and Hayes 2005; Beers, Dress, and Wensel 1966). The heat load index can then compare points that have similar heat loads of incoming radiation but are separated by the eight classes for aspect. The formula used to generate the heat load index was

$$\text{Heat load index} = 1 - \cos(\theta - 45)/2$$

according to Beers et al. and utilized by Stoddard and Hayes (Stoddard and Hayes 2005). However, the originally published formula uses radians, and so the formula used for this study was adapted to use aspect in units of degrees:

$$\text{Heat Load Index} = 1 - \cos(\theta * \pi / 180\text{-}45))/2$$

This calculation was performed in R. Heat Load Index values range from 0 (northeast) to 1 (southwest) (Stoddard and Hayes 2005). For analysis, ten equal interval classes were created, with each class spanning one tenth of the index value (e.g. 0.00-0.09, 0.10-0.19, etc.). The percentages of each class covered by the pine stands was calculated by dividing the number of pine-covered cells in each heat load class by the total number of cells in the heat load class. The difference between observed pine distribution and expected distribution was examined using chi squared analysis.

Slope

The standard Arc Tool calculated slope for each landscape. Ten equal interval classes divided the slope values. Each class spanned 7° and ranged from 0° to 70° (eg. 0° to 6.9°, 7° to 13.9°). For analysis, the percent of each slope class occupied by pines was calculated by dividing the number of pine-dominated cells in each class by the total number of cells in the slope class per landscape. Comparing the expected random distribution of pines against the actual distribution was performed with the chi squared test.

Radiation

The ArcMap radiation tool was used to estimate radiation with the setting "Special Days" to find the trends in radiation for the extremes events in solar radiation: the winter solstice, the summer solstice, and an equinox. The radiation tool estimates the incoming solar radiation using a combination of direct and diffuse insolation, measured in Watts/m^2 (Fu and Rich 2002). Long wave radiation emitted by the atmosphere was therefore excluded from analysis, as was reflected light.

For analysis, the radiation values were split into ten equal interval classes of 200 W/m^2, ranging from 4,900 W/m^2 to 6,900 W/m^2. However, the lowest radiation class (4,900 to 5,099) did include a few cells whose values were lower than 4,900 that did not warrant extending the number of classes. The percent of pines within each radiation class was calculated by dividing the number of all pine cells within each class by the total number of cells in the class. Chi squared tests were run on each landscape to determine if the pines were occupying some radiation classes more than others.

Topographic wetness index

The ArcMap extension TauDEM was used to calculate the topographic wetness index (Tarboton 1997). This program included flow partitioning to multiple adjacent cells, which allowed for a more realistic representation of how the water flows through the landscape than if all flow is allocated to a single adjacent cell. TauDEM first removes any pits within the landscape and calculates slope before using flow partitioning to calculate flow direction. In this case, one cell can drain into more than one other cell in different relative frequencies, which is closer to the actual flow on a landscape. After calculating flow directions, the contributing area for each cell is calculated to see which other pixels feed into any one pixel. The slope and the contributing areas are then used to create the topographic wetness index (TWI). The formula used by TauDEM is

$$TWI = \ln (A/\tan(B))$$

where A is the contributing areas and tan(B) is the slope per cent (Naito and Cairns 2011); (Beven and Kirkby 1979). However, when areas had either a contributing area of zero or a slope of zero, a NA value was returned by the formulas. This indicates that the area is either on the most extreme part of the ridge that only receives precipitation and does not have any area that drains into it, or that the area is within a valley bottom with a lot of area draining into it. This index is created in an area equal to the size of each landscape plus a one kilometer area, and then clipped down to the landscape area.

TWI values were grouped into ten equal interval classes for analysis. Each group spanned 2.09 index values, and classes ranged from 2 to 23. Classes with low TWI values represent dry areas, while areas with high TWI values have large areas that drain into it (Wu and Archer 2005). In addition to the ten classes, there is an 11th category of NA values created as a result of the TWI equation, and these landscapes likely represent either the driest areas on the landscape or some of the wettest. Since it is not certain whether or not the NA values represent wet or dry areas in the landscape, they are excluded from analysis. The number of cells with NA values at each landscape ranged from 614 cells at Apple Orchard, representing 0.8% of the landscape, to 41,101 cells at

Holston Mountain, representing 36.2% of the landscape. Every other landscape, however, had the number of NA cells between 614 at Apple Orchard and 2,183 cells at Griffith Knob (representing 2.9% of the landscape), and Holston Mountain appears to be an outlier. The percent of each TWI class occupied by pines was calculated by dividing the number of pine cells in a class by the total number of cells in the class per landscape. Chi squared tests were used to determine if the pines were unequally distributed across the different TWI classes.

Topographic exposure index

The sheltering effect was determined using the Topographic Exposure Index (TEI), where the sheltering of some areas due to the surrounding terrain reduces the exposure to various weather conditions such as radiation, wind, and rain. TEI is created by calculating the average elevation of the surrounding area in a 250 meter radius for each cell using the focal statistics tool, and then subtracting this average from the elevation of the cell (Evans et al. 2014). This formula has been adapted from the Evans et al. 2014 paper to reduce the size of the surrounding area for the mean calculation.

Ten equal interval TEI classes were created to delineate the different values of exposure. TEI values began at -64, representing sheltered areas, and ran to 86, representing dry, exposed areas. Each TEI classes spanned 15 index values (eg. -64 to -50). However, the lowest and the highest TEI class contained values less than, or higher than, the stated range, respectively. These values were included in the first and last classes rather than creating many other classes because of the required minimum number of cells in each category. The percentage of pines in each TEI class was calculated as the number of pine cells in each class divided by the total number of cells in the class per landscape. Chi squared tests were performed on the number of pine cells and non-pine cells in each class to determine if the pines were occupying the classes differently.

Soil

The raster soil data were clipped to an area equal to the study landscape plus one kilometer of buffer and then aggregated to 30m by 30m resolution using the ArcMap tool “Aggregate” for the median value. The aggregated file was then projected into the correct UTM and clipped to the landscape boundary and to the pine locations. The GSSURGO describes the dominant drainage ability of each soil map unit, and stratifies the drainage ability into one of seven classes: “Very Poorly Drained, Poorly Drained, Somewhat Poorly Drained, Moderately Well Drained, Well Drained, Somewhat Excessively Drained and Excessively Drained” (Staff 1992). The number of cells in each category at each location was determined, along with the number of pine-dominated cells in each soil category for each landscape. However, the number of soil cells at each landscape is different than the number of cells at each landscape for the other variables. This is a result of the difference in location of the centroids of the cells between the soil data and the digital elevation model, which served as the basis for the other topographic variables. The percent of pines occupying each soil drainage class was calculated by dividing the number of pine cells in each drainage class at each landscape by the total number of cells in that particular class. The Western Georgia landscape was excluded from analysis because the majority of the study landscape appearing in an area without any soil data available. Chi squared analysis determined whether or not there was a significant distribution of the pines compared to a random distribution.

Fire history field sites

Six of the landscapes (Licklog, Linville Gorge, North Mountain, Kelley Mountain, Mill Mountain, and Reddish Knob) contained pine stands sampled in previous fire history studies (Aldrich et al. 2010; DeWeese et al. 2010; Flatley et al. 2013). To determine whether or not these previously sampled pine stands occur on different aspect classes throughout the region, I identified each stand on a Digital Orthophoto Quarter Quads (DOQQ), which was overlaid with a GeoTIFF topographic map from which I determined its aspect. Aspect was determined for three points in each stand- at the top, middle, and bottom of the stand. The percent of stands in each aspect class was calculated by dividing the total number of stand points in each aspect class by the total number of points sampled at that landscape (three per stand).Then the aspects of the stands at each landscape were compared to the aspect of the stands at other landscapes.

Statistical analysis

The relationships between the topographic and climatic variables were investigated using Pearson's correlations in R, version 3.0.1 and the VEGAN package (Oksanen et al. 2007).

To determine whether or not the pines were occupying classes unevenly within each topographic variable, chi square tests were performed. Chi square demonstrates if the pines are confined to certain parts of the landscape, rather than occupying the whole range of conditions in a relatively equal fashion. Chi squared analysis was performed using Microsoft Office Excel 2007, and followed the test procedures outlined by Zar 1999 (Zar 1999). For any test with one degree of freedom, Yates' correction for continuity was used to account for the lack of independence in the distribution.

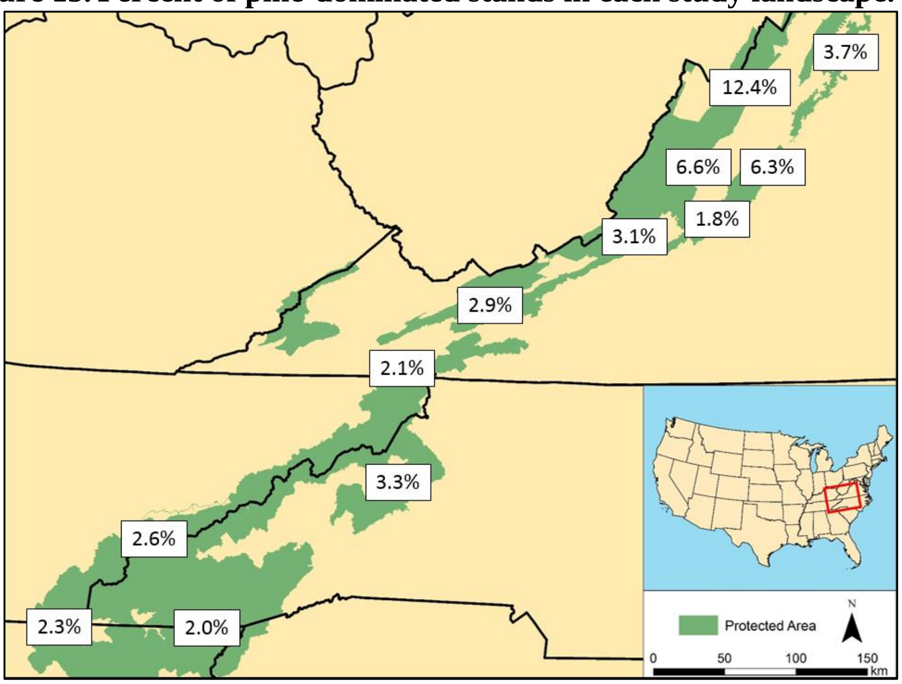
A threshold of 300 cells in one class type was required to be included in a chi squared test, and if one class type was under this threshold, then the values were included into the next closest class. 300 cells was the threshold value used, as chi square analyses work best when there is no predicted value under 5. The landscape with the smallest percent of pines covering the available landscape is Apple Orchard at 1.8%, meaning that 300 was the minimum value of total cells in a class to predict 5 cells as pine-dominated. In the soil analysis, three landscapes contained classes with less than 300 cells that were in between two other classes that met the threshold. In these cases, the classes that did not meet the threshold were excluded from analysis, rather than combining them with either class.

CHAPTER III

RESULTS

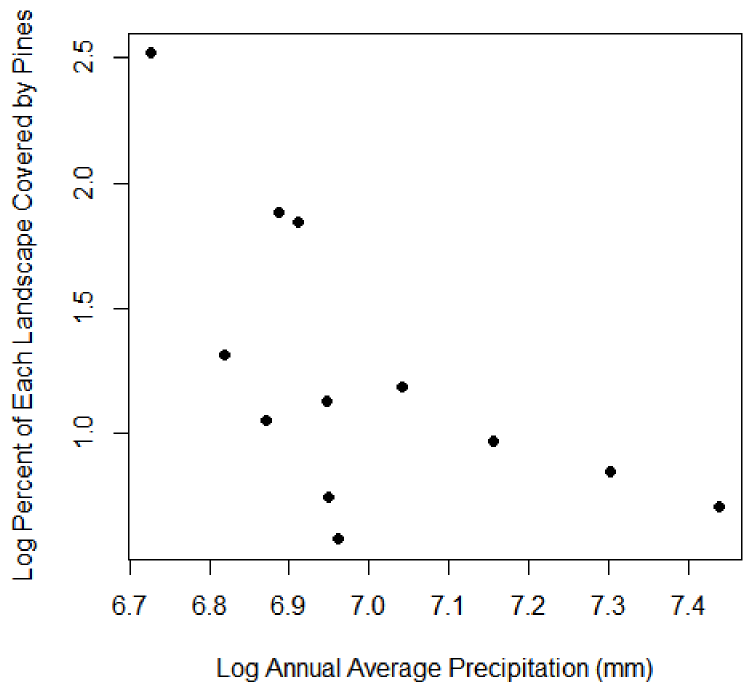
Do Table Mountain pine and pitch pine stands occupy the drier locations within the forest matrix in southern Appalachian National Parks and National Forests?

Figure 15. Percent of pine-dominated stands in each study landscape.



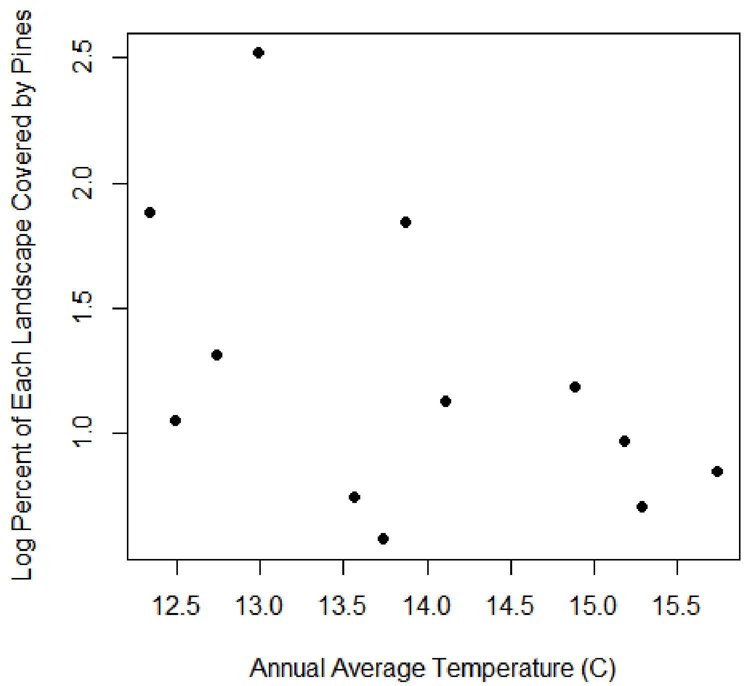
The percentage of each study landscape covered by pine stands varied across the twelve landscapes from 1.8% at Apple Orchard to 12.4% at Reddish Knob. However, the log percent of each landscape covered by pines did not change based on the distance from the southwestern most landscape, Western Georgia (R= 0.1739, p=0.589). Total annual precipitation is negatively related to the percent of each landscape occupied by pine-dominated stands (R= -0.618, p = 0.032) (Figure 16).

Figure 16. Percent of each landscape covered by pine stands with respect to annual precipitation in millimeters.



The percent of each landscape covered by pines is not related to average annual temperature (R= -0.491, p=0.105) (Figure 17).

Figure 17. Percent of each landscape covered by pines compared to annual average temperature.



Heat load index

Across ten of the twelve landscapes, there was an upward trend where the pines were occupying more of the available terrain in the higher heat load classes than in the lower heat load classes (Figures 18 and 19). Reddish Knob, however, has a peak of nearly the same percentages for the 0.9-1.0 category as the 0.3-0.39 category (Figure 19). Apple Orchard exhibited a different pattern, where it peaked in the 0.50-0.59 class (Figure 19).

When comparing the distribution of the pines to the areas without pines, there is significant clumping of the pines on areas of certain heat load ranges. Within each landscape, the pines are distributed neither randomly nor evenly across the areas of different heat load index values (Table 3).

Table 3. Site-specific chi squared analysis of stands occupying different heat load classes.

Site	$\chi 2$ value	P value	df
Western Georgia	**903.12**	**<0.001**	**9**
Eastern Georgia	**1306.56**	**<0.001**	**9**
Licklog	**1077.05**	**<0.001**	**9**
Linville Gorge	**2332.84**	**<0.001**	**9**
Holston Mountain	**1724.67**	**<0.001**	**9**
Griffith Knob	**1434.62**	**<0.001**	**9**
North Mountain	**1773.59**	**<0.001**	**9**
Apple Orchard	**485.75**	**<0.001**	**9**
Mill Mountain	**2767.92**	**<0.001**	**9**
Kelley Mountain	**2189.11**	**<0.001**	**9**
Reddish Knob	**390.37**	**<0.001**	**9**
Shenandoah	**757.72**	**<0.001**	**9**

Figure 18. **The percent of each heat load index value class occupied by pines at the six southern landscapes. Sites include A) Western Georgia, B) Eastern Georgia, C) Licklog, D) Linville Gorge, E) Holston Mountain, and F) Griffith Knob.**

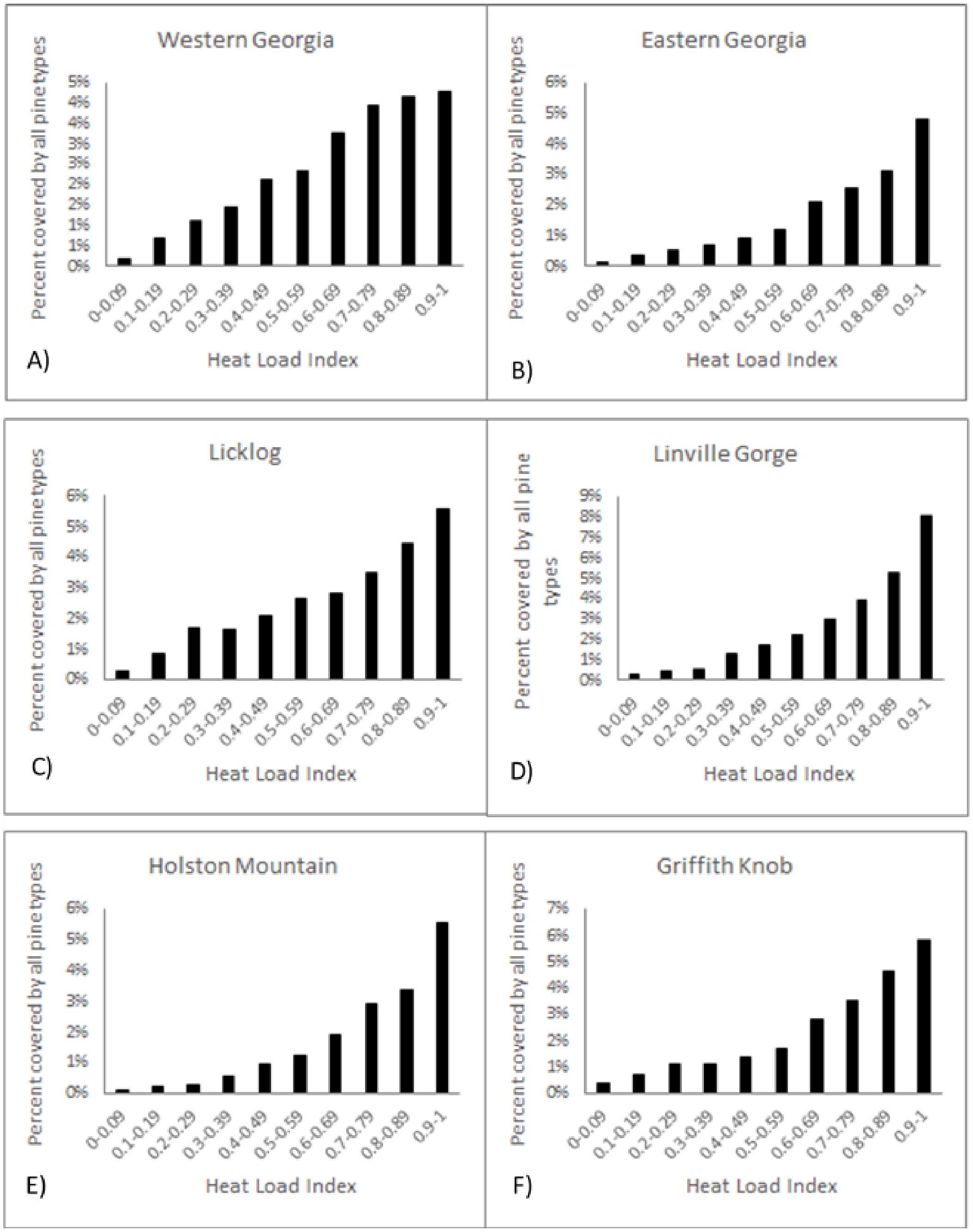
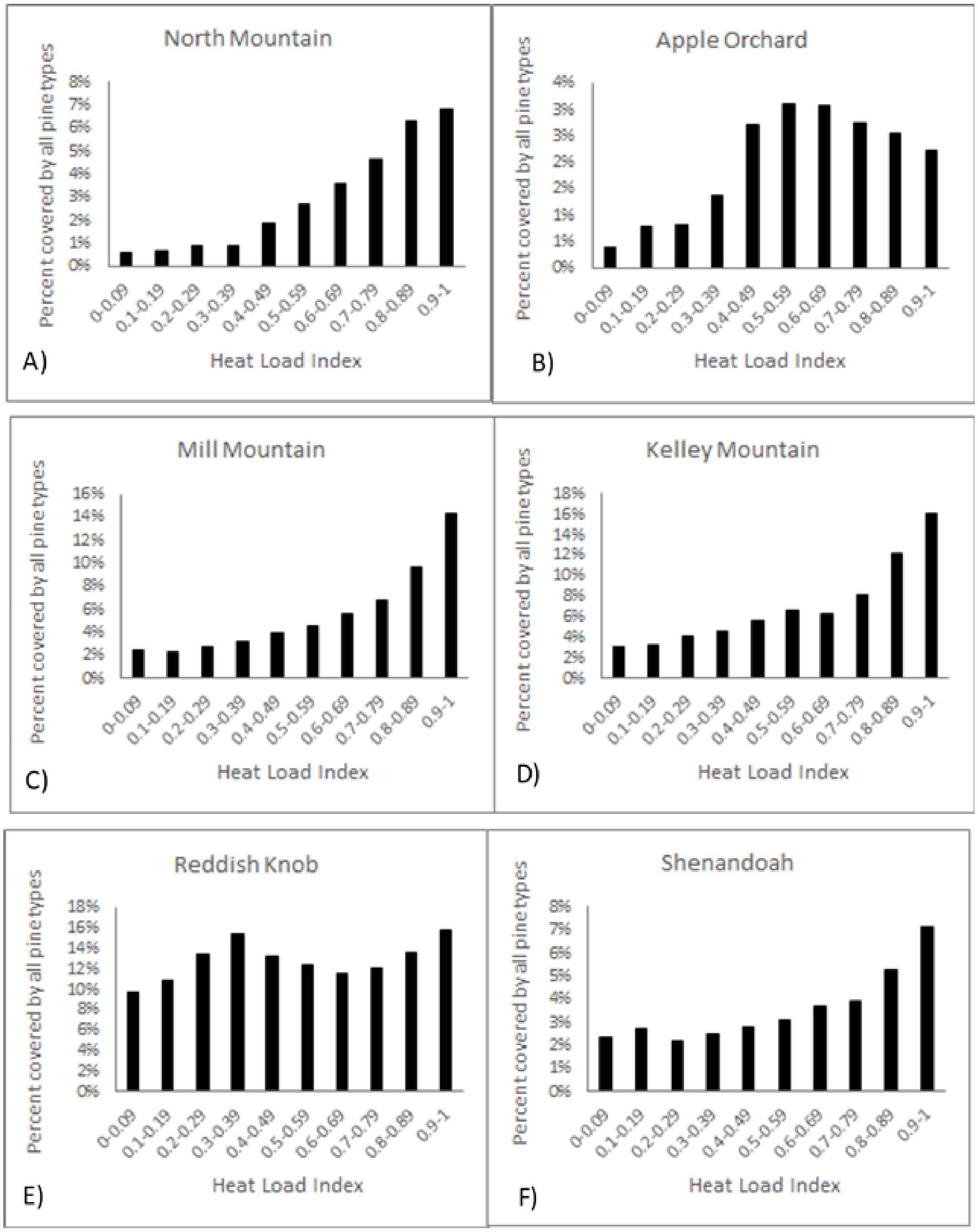


Figure 19. The percent of each heat load index value class occupied by pines at the six northern landscapes. Sites include A) North Mountain, B) Apple Orchard, C) Mill Mountain, D) Kelley Mountain, E) Reddish Knob, and F) Shenandoah.



Radiation

The percentage of pines occupying each radiation class varied by location, but generally pine stands occurred in areas with higher radiation (Figures 20 and 21). Apple Orchard's highest percent of pines in a radiation class was in the lowest class (4,900-5,099 W/m^2), while eight of the other landscapes peaked in the third highest class, 6,300-6,499 W/m^2 (Figures 20 and 21). Asterisks in the bar graphs indicate where there are zero cells in that category for the entire landscape, and it is therefore impossible for pine stands to occur in that category at the landscape.

Across all landscapes, the pines tended to increase in percent from the lowest radiation class to the 6,100 -6,299 W/m^2 class. The distribution of pines compared to the total terrain for each radiation class was different (Table 4). Pines occupied the various classes in different proportions compared to what was expected by chance (Table 4).

Table 4. Chi square results of the distribution of pine stands across the twelve landscapes among the radiation classes.

Site	$\chi 2$ value	P value	df
Western Georgia	**520.56**	**<0.001**	**9**
Eastern Georgia	**85.40**	**<0.001**	**8**
Licklog	**544.34**	**<0.001**	**9**
Linville Gorge	**438.15**	**<0.001**	**9**
Holston Mountain	**215.96**	**<0.001**	**9**
Griffith Knob	**142.52**	**<0.001**	**8**
North Mountain	**203.10**	**<0.001**	**9**
Apple Orchard	**1156.01**	**<0.001**	**7**
Mill Mountain	**250.53**	**<0.001**	**7**
Kelley Mountain	**283.29**	**<0.001**	**9**
Reddish Knob	**875.91**	**<0.001**	**8**
Shenandoah	**1996.08**	**<0.001**	**9**

Figure 20. **Percent of land occupied by pines in each radiation class in the six southern landscapes. Sites include A) Western Georgia, B) Eastern Georgia, C) Licklog, D) Linville Gorge, E) Holston Mountain, and F) Griffith Knob.**

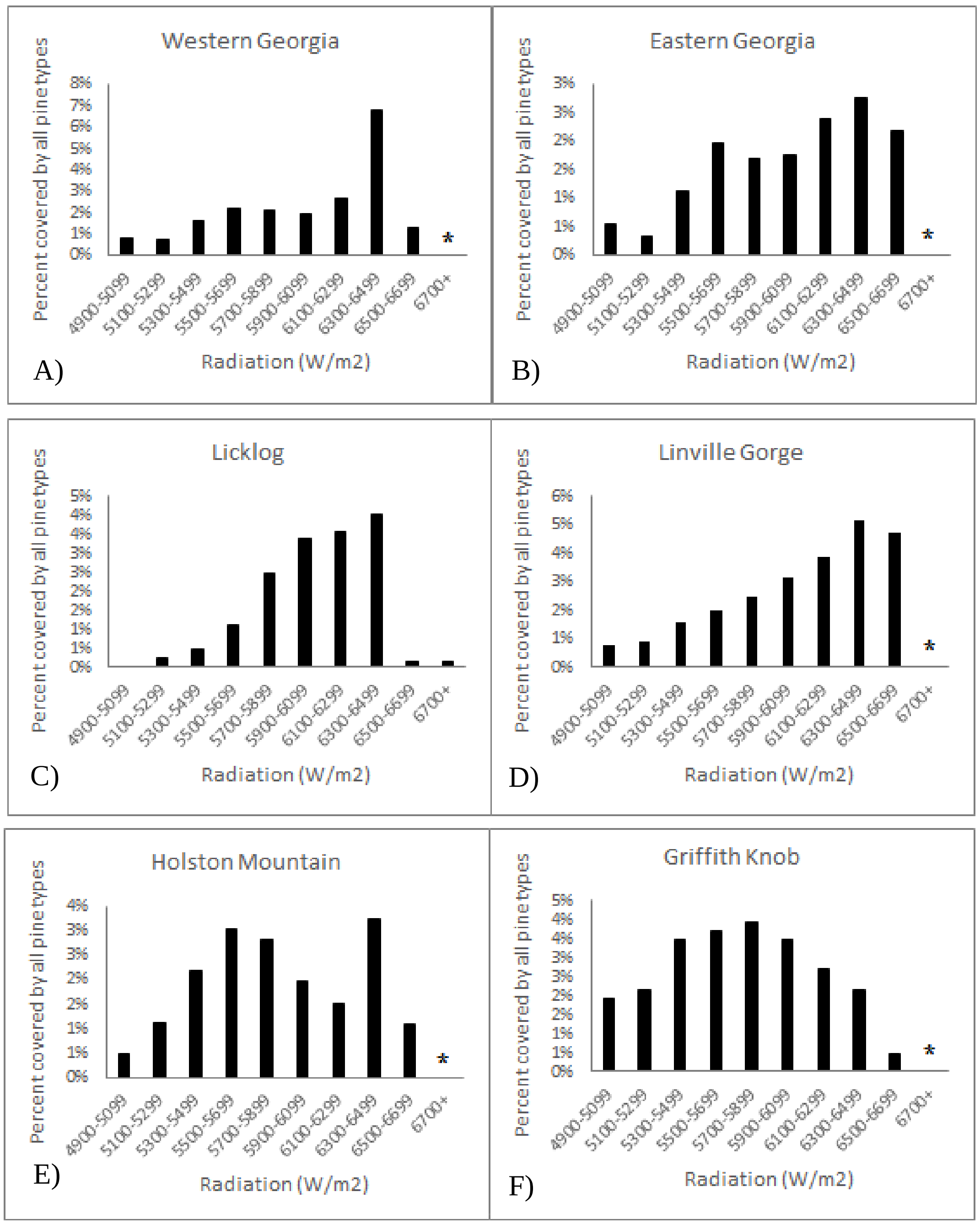
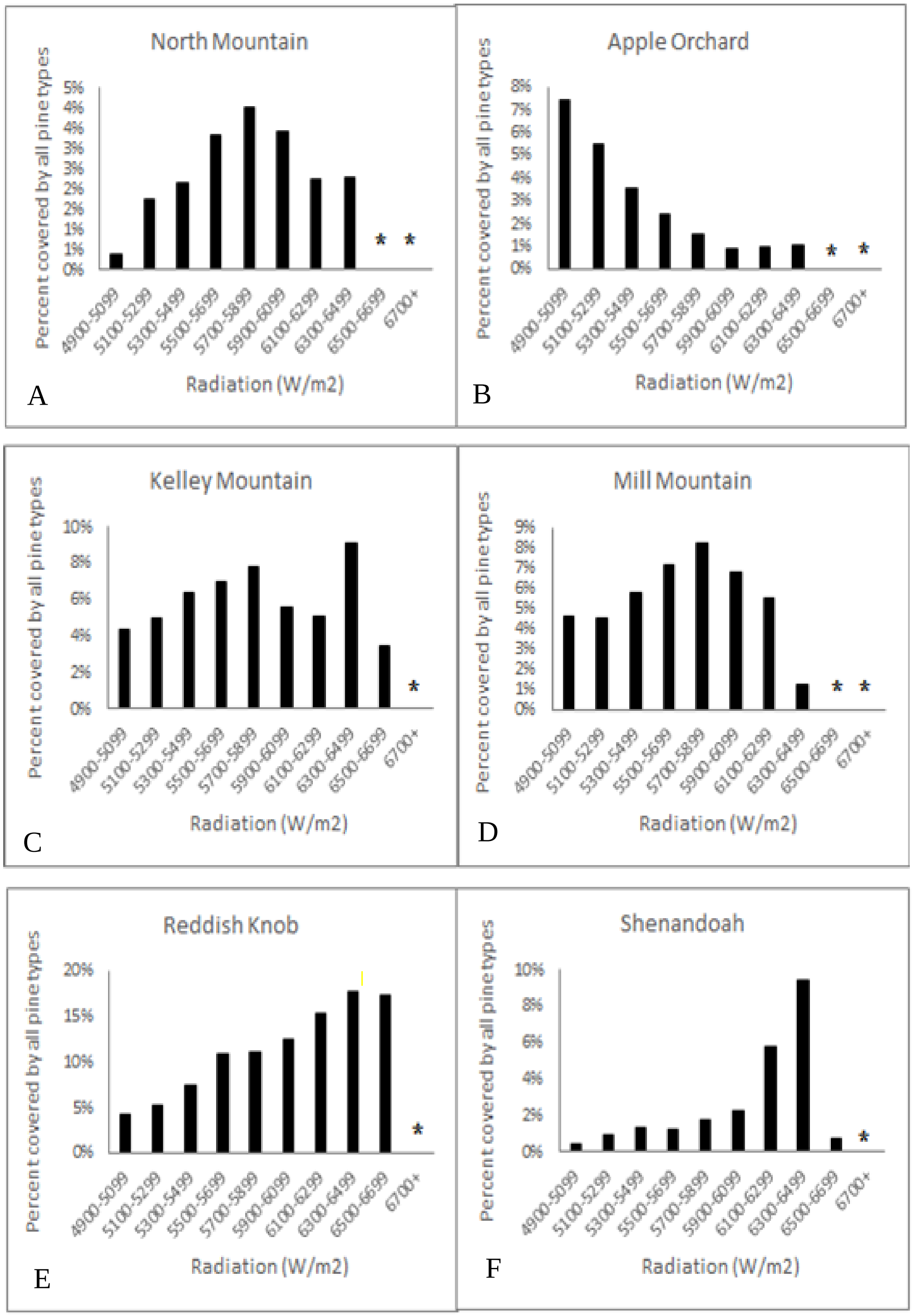


Figure 21. Percent of land occupied by pines in each radiation class in the six northern landscapes. Sites include A) North Mountain, B) Apple Orchard, C) Mill Mountain, D) Kelley Mountain, E) Reddish Knob, and F) Shenandoah.



Slope

Overall, the distribution of pine stands across the slope classes do not exhibit one cohesive pattern. Five of the landscapes (Eastern Georgia, Griffith Knob, Holston Mountain, Apple Orchard, and Kelley Mountain) tended to have higher percentages of pine stands covering the available terrain as the slope increased (Figures 22 and 23). Three other landscapes (Linville Gorge, Mill Mountain, and North Mountain) had the highest percent of pine stands covering the land in the middle value slopes, such as 14°-20.9° (Figures 22 and 23). The lowest six slope classes each have at least one landscape that has the highest percent of pines occupying that class (Figures 22 and 23). The classes 21°-27.9° and 28°-34.9° are the most common classes in which the percent of pine stands covering the land peaks. Across all landscapes, the pines occupy different slope classes than what is expected by random chance (Table 5). Asterisks in the bar graphs indicate where there are zero cells in that category for the entire landscape.

Table 5. Chi square results of pine distribution among the slope classes at each of the twelve landscapes.

Site	$\chi 2$ value	P value	df
Western Georgia	**190.18**	**<0.001**	**6**
Eastern Georgia	**61.63**	**<0.001**	**5**
Licklog	**129.31**	**<0.001**	**5**
Linville Gorge	**165.35**	**<0.001**	**7**
Holston Mountain	**717.28**	**<0.001**	**5**
Griffith Knob	**149.82**	**<0.001**	**5**
North Mountain	**310.82**	**<0.001**	**5**
Apple Orchard	**1503.15**	**<0.001**	**5**
Mill Mountain	**161.00**	**<0.001**	**6**
Kelley Mountain	**79.89**	**<0.001**	**5**
Reddish Knob	**1356.18**	**<0.001**	**5**
Shenandoah	**1790.56**	**<0.001**	**5**

Figure 22. The percent of land covered by pines within each slope class in the six southern landscapes. Sites include A) Western Georgia, B) Eastern Georgia, C) Licklog, D) Linville Gorge, E) Holston Mountain, and F) Griffith Knob.

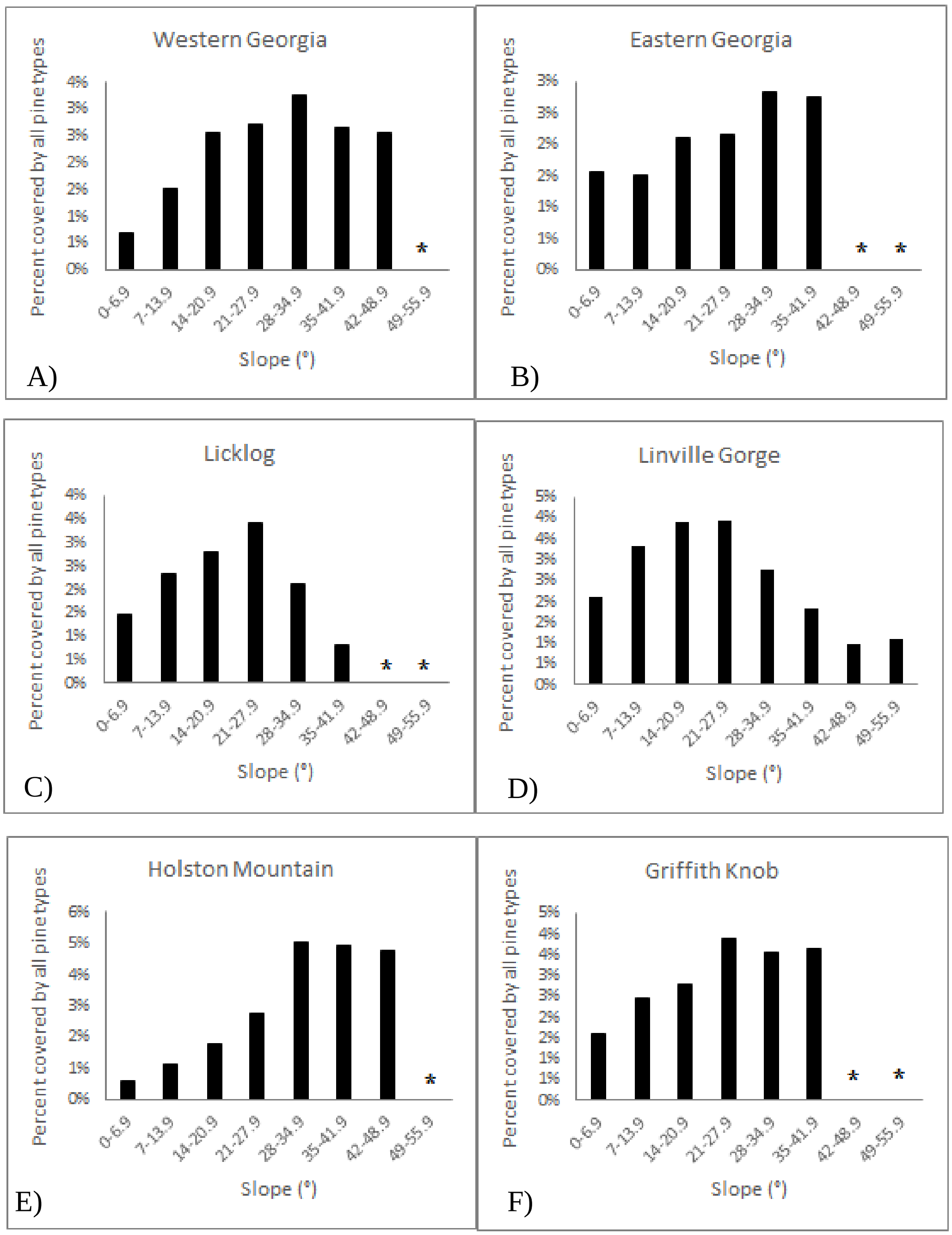
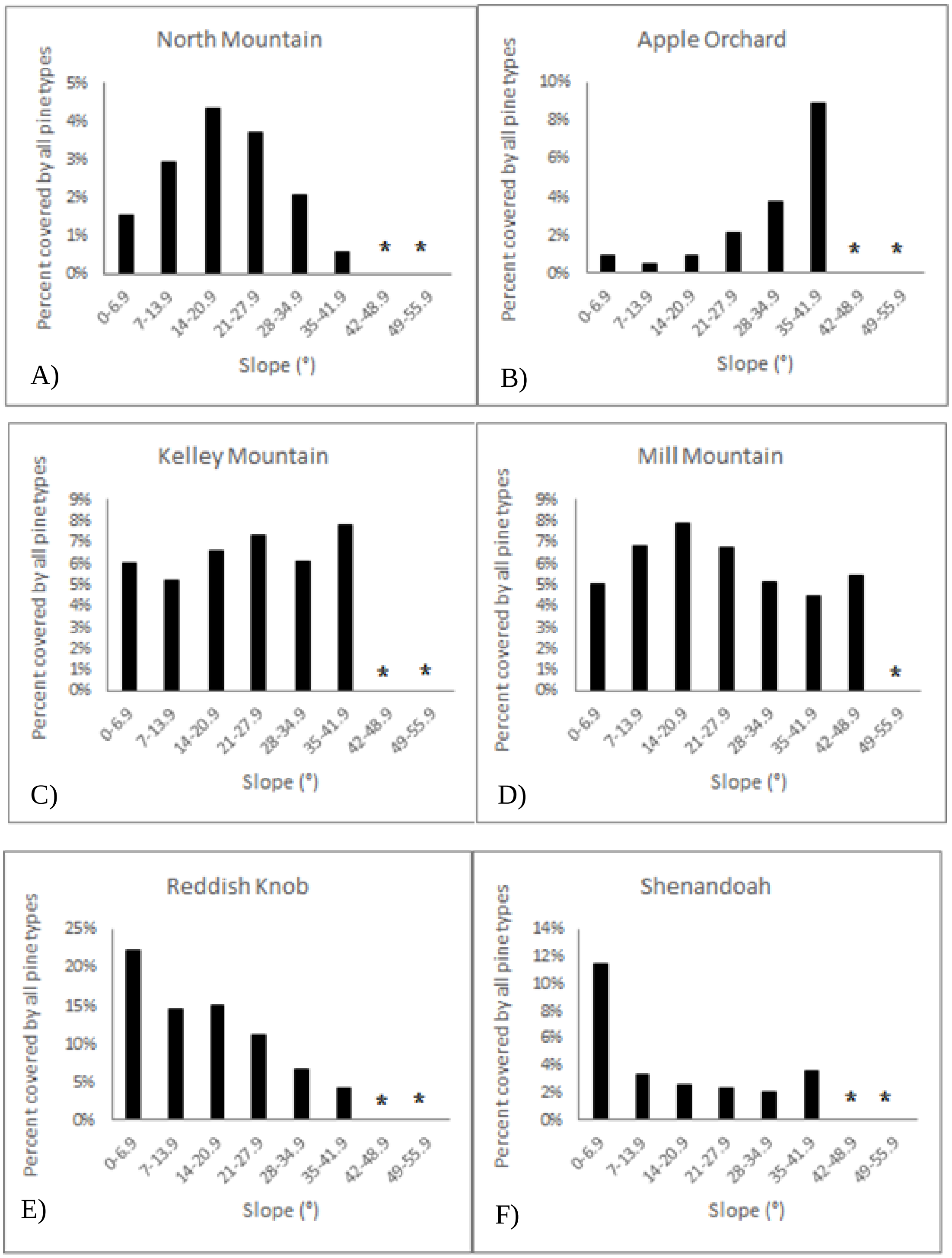


Figure 23. The percent of land covered by pines within each slope class in the six northern landscapes. Sites include A) North Mountain, B) Apple Orchard, C) Mill Mountain, D) Kelley Mountain, E) Reddish Knob, and F) Shenandoah.



Elevation

Of the land available in each elevation class, pine stands most commonly covered larger amounts in the mid-elevation ranges, 400 m to 900 m (Figures 24 and 25). Two landscapes (Mill Mountain and North Mountain) peaked in the 400 -499 m group, one landscape (Reddish Knob) peaked in the 500-599 m group, one landscape peaked in the 700-799 m group, and one landscape (Apple Orchard) peaked in the 900-999 m group (Figure 25). The remaining five landscapes are five out of the six most southern sites (Eastern Georgia, Western Georgia, Linville Gorge, Griffith Knob, and Holston Mountain), and peaked in the 800-899 m group, indicating that the pines are persisting in the higher end of middle elevations (Figure 24). At each landscape, the pines occupy the available elevations unequally, demonstrating a preference for some of the elevations rather than others, such as the extreme low and high elevations (Table 6). Asterisks in the bar graphs indicate where there are zero cells in that category.

Table 6. Chi squared results of pine distribution among the available elevation classes at each of the twelve landscapes.

Site	$\chi 2$ value	P value	df
Western Georgia	**1877.82**	**<0.001**	**8**
Eastern Georgia	**833.99**	**<0.001**	**7**
Licklog	**2617.39**	**<0.001**	**9**
Linville Gorge	**485.71**	**<0.001**	**7**
Holston Mountain	**1926.85**	**<0.001**	**6**
Griffith Knob	**427.12**	**<0.001**	**5**
North Mountain	**327.93**	**<0.001**	**5**
Apple Orchard	**1334.33**	**<0.001**	**8**
Mill Mountain	**2097.30**	**<0.001**	**6**
Kelley Mountain	**2724.01**	**<0.001**	**5**
Reddish Knob	**993.61**	**<0.001**	**7**
Shenandoah	**2931.21**	**<0.001**	**9**

Figure 24. Percent of each elevation group covered by pines at the six southern landscapes. Sites include A) Western Georgia, B) Eastern Georgia, C) Licklog, D) Linville Gorge, E) Holston Mountain, and F) Griffith Knob.

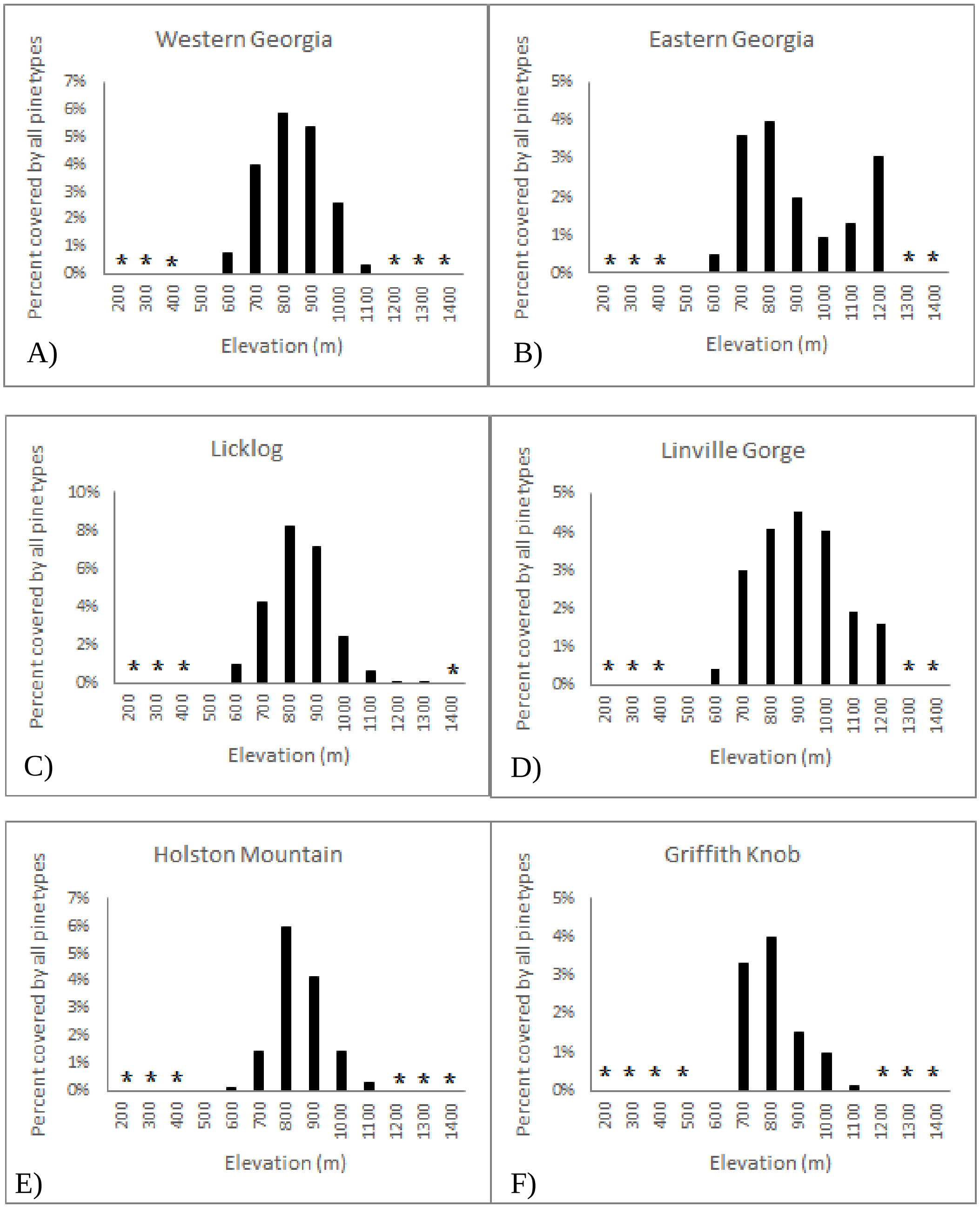
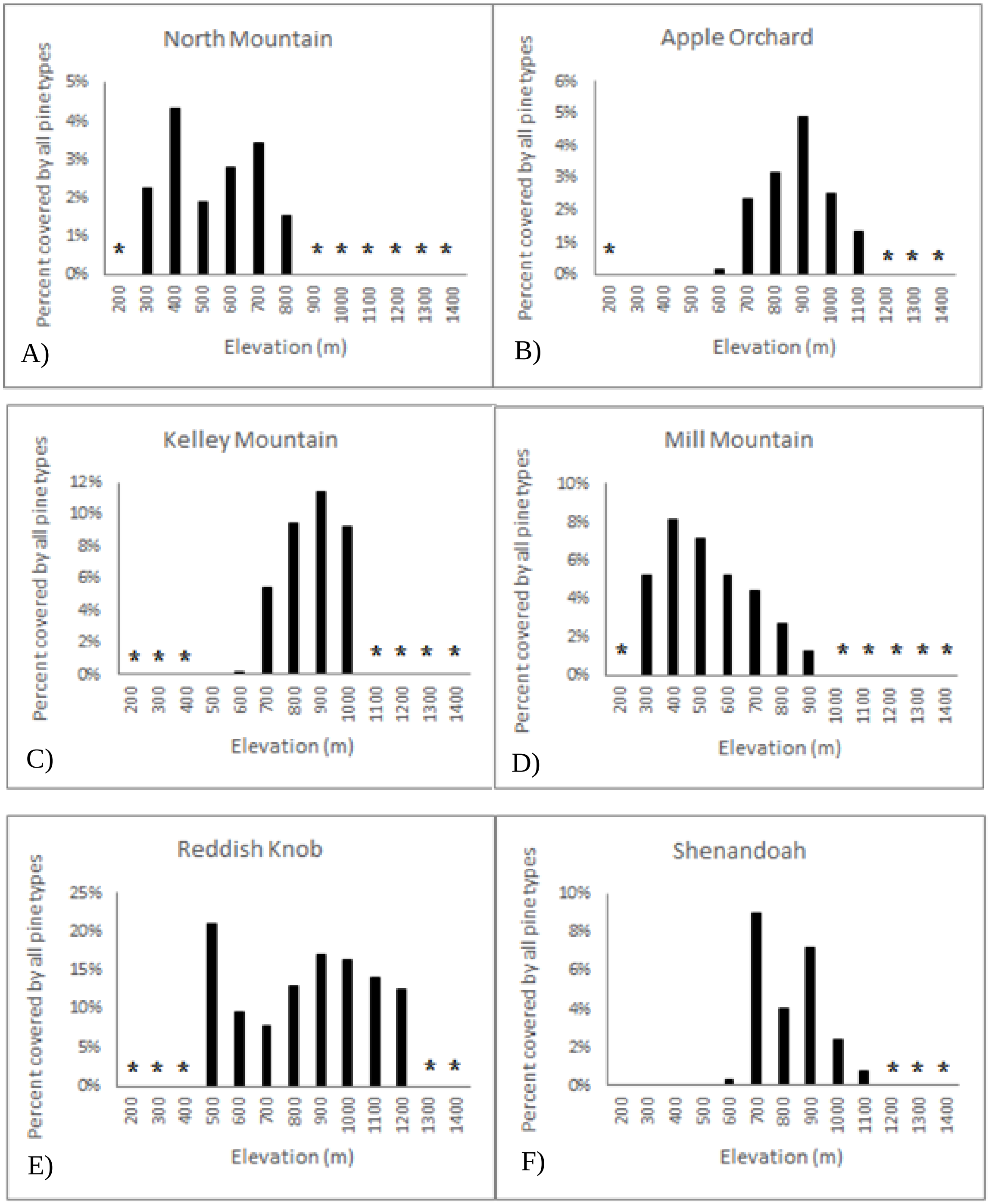


Figure 25. Percent of each elevation group covered by pines at the six northern landscapes. Sites include A) North Mountain, B) Apple Orchard, C) Mill Mountain, D) Kelley Mountain, E) Reddish Knob, and F) Shenandoah.



Topographic wetness index

Pine stands occupied the highest percent of available space in either the driest class or the second driest class (Figures 26 and 27). These two classes drain into other cells without too many other cells draining into them, so they are likely near ridge tops. While the percent of pines tended to decrease as the TWI value increased, there were noticeable other peaks at Kelley Mountain, Mill Mountain, and Shenandoah, suggesting that some of these pine stands were able to persist in areas receiving drained water (Figure 27). Across each landscape, the pines occupy certain TWI classes more than others (Table 7). Asterisks in the bar graphs indicate where there are zero cells in that category for the entire landscape.

Table 7. Chi square results of pine distribution among the TWI classes at each of the twelve landscapes.

Site	$\chi2$ value	P value	df
Western Georgia	**352.92**	**<0.001**	**6**
Eastern Georgia	**279.97**	**<0.001**	**6**
Licklog	**227.16**	**<0.001**	**5**
Linville Gorge	**385.79**	**<0.001**	**5**
Holston Mountain	**184.16**	**<0.001**	**5**
Griffith Knob	**845.95**	**<0.001**	**6**
North Mountain	**348.51**	**<0.001**	**6**
Apple Orchard	**313.79**	**<0.001**	**5**
Mill Mountain	**195.33**	**<0.001**	**6**
Kelley Mountain	**452.34**	**<0.001**	**6**
Reddish Knob	**660.31**	**<0.001**	**5**
Shenandoah	**308.46**	**<0.001**	**6**

Figure 26. The percentage of pines occupying each TWI classes in the six southern landscapes. Sites include A) Western Georgia, B) Eastern Georgia, C) Licklog, D) Linville Gorge, E) Holston Mountain, and F) Griffith Knob.

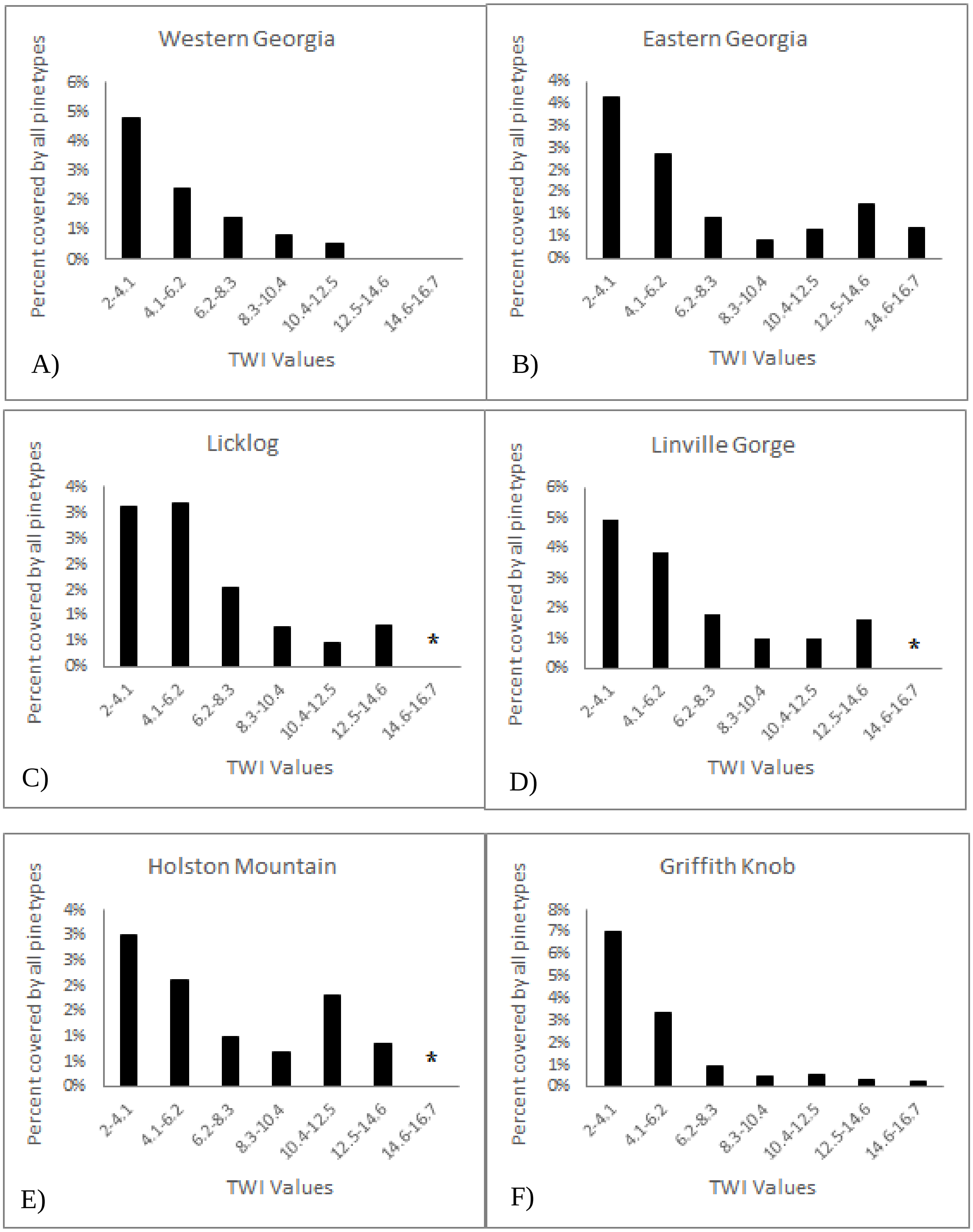
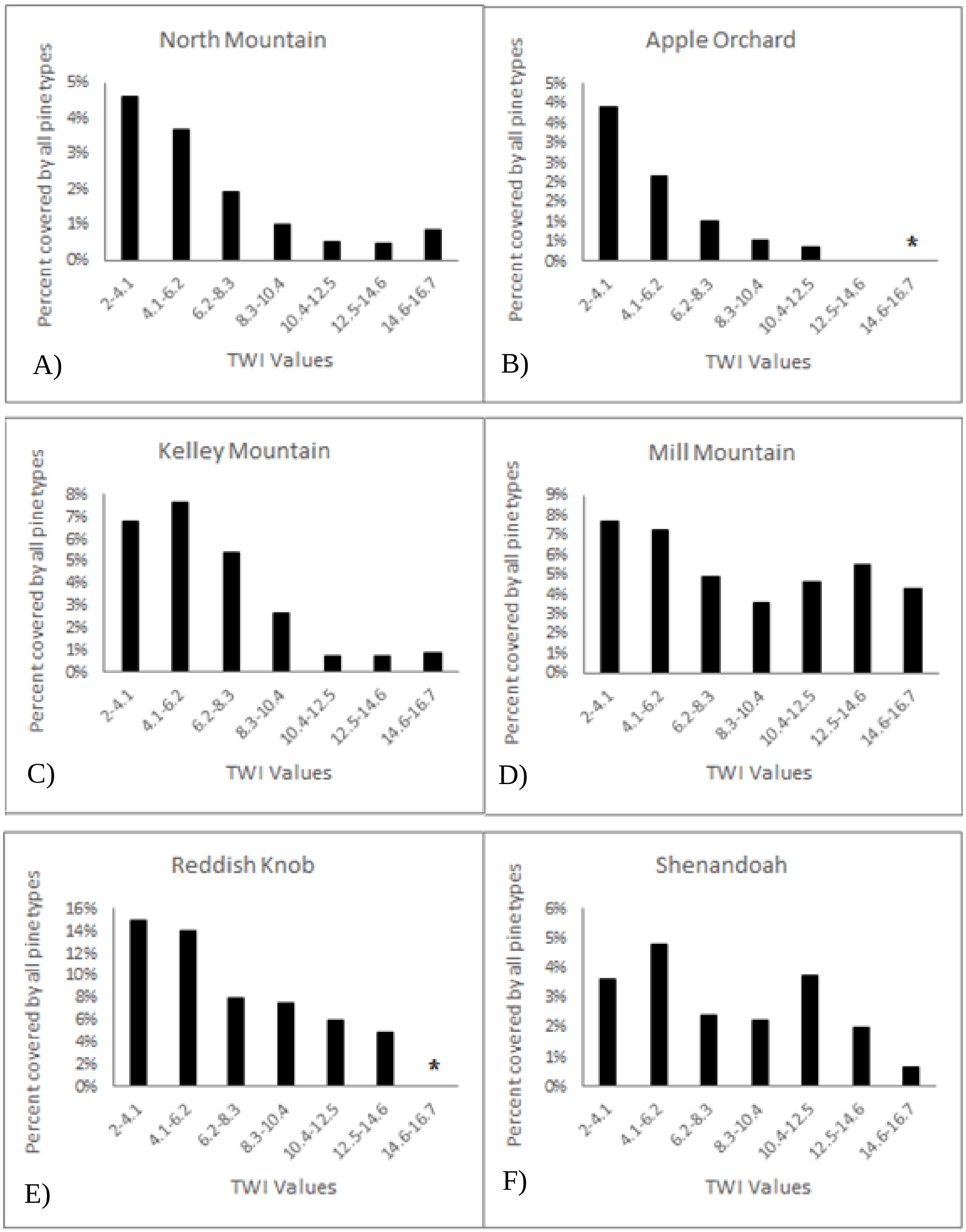


Figure 27. The percentage of pines occupying each TWI classes in the six northern landscapes. Sites include A) North Mountain, B) Apple Orchard, C) Mill Mountain, D) Kelley Mountain, E) Reddish Knob, and F) Shenandoah.



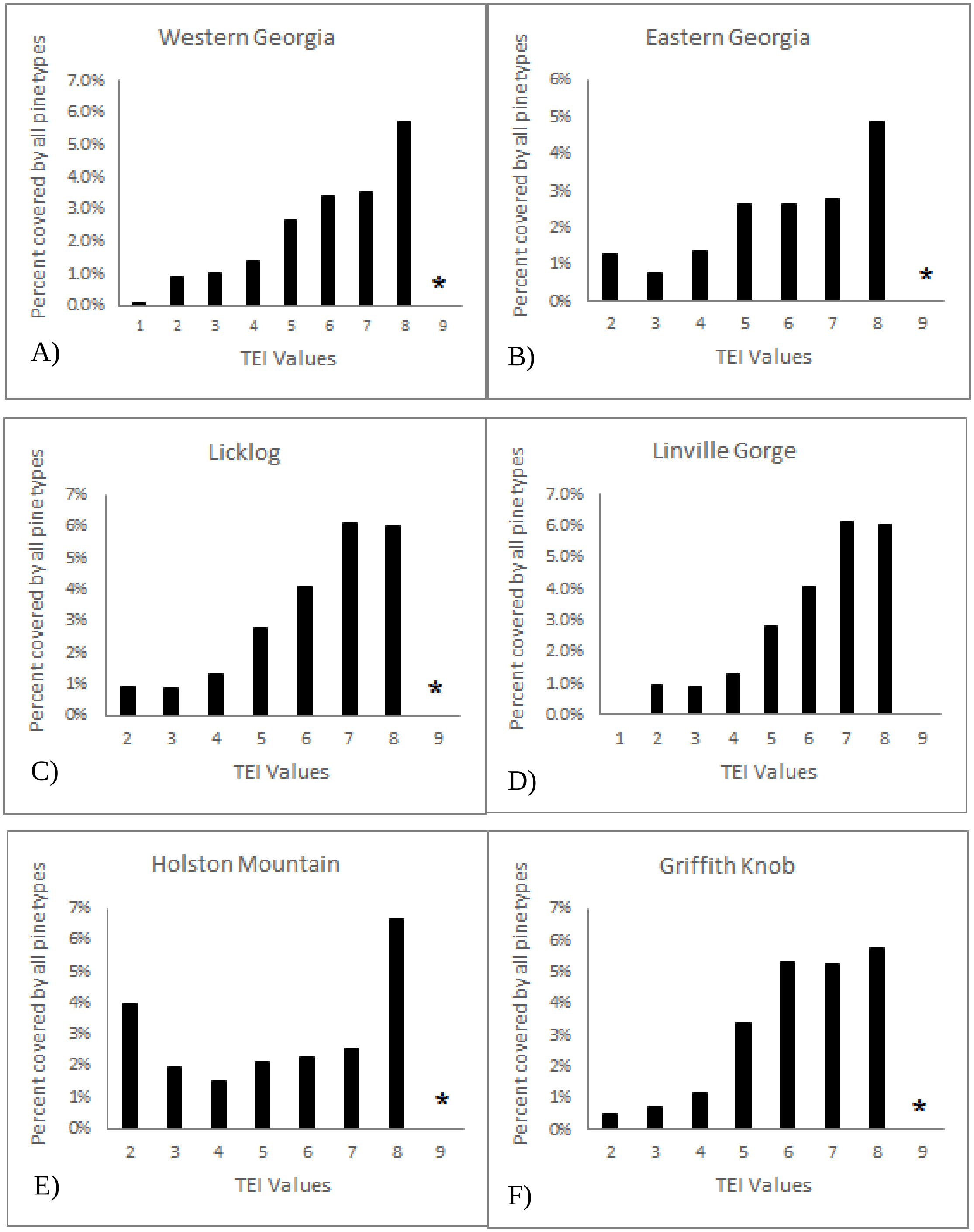
Topographic exposure index

The percent of land occupied by pines in each TEI class increases as the TEI value increases, indicating that pines are on the drier, more exposed slopes within the landscape (Figures 28 and 29). Every landscape had its highest percentage group in a class with positive values, indicating that they are more often on the landscapes with higher exposure (Figures 28 and 29). Over half of the landscapes peaked within the 41 to 55.99 class, and the 56 to 70.99 class, indicating a concentration of pines within the higher exposure classes (Figures 28 and 29). Across the twelve landscapes, the distribution of pines was different than what is expected by random chance (Table 8). Asterisks in the bar graphs indicate where there are zero cells in that category for the entire landscape.

Table 8. Chi square results of pine distribution among the TEI classes at each of the twelve landscapes.

Site	$\chi 2$ value	P value	df
Western Georgia	**401.85**	**<0.001**	**7**
Eastern Georgia	**275.42**	**<0.001**	**6**
Licklog	**738.36**	**<0.001**	**6**
Linville Gorge	**595.53**	**<0.001**	**8**
Holston Mountain	**212.37**	**<0.001**	**6**
Griffith Knob	**881.76**	**<0.001**	**6**
North Mountain	**820.59**	**<0.001**	**6**
Apple Orchard	**566.02**	**<0.001**	**6**
Mill Mountain	**378.16**	**<0.001**	**6**
Kelley Mountain	**2322.09**	**<0.001**	**6**
Reddish Knob	**3700.90**	**<0.001**	**7**
Shenandoah	**2777.26**	**<0.001**	**6**

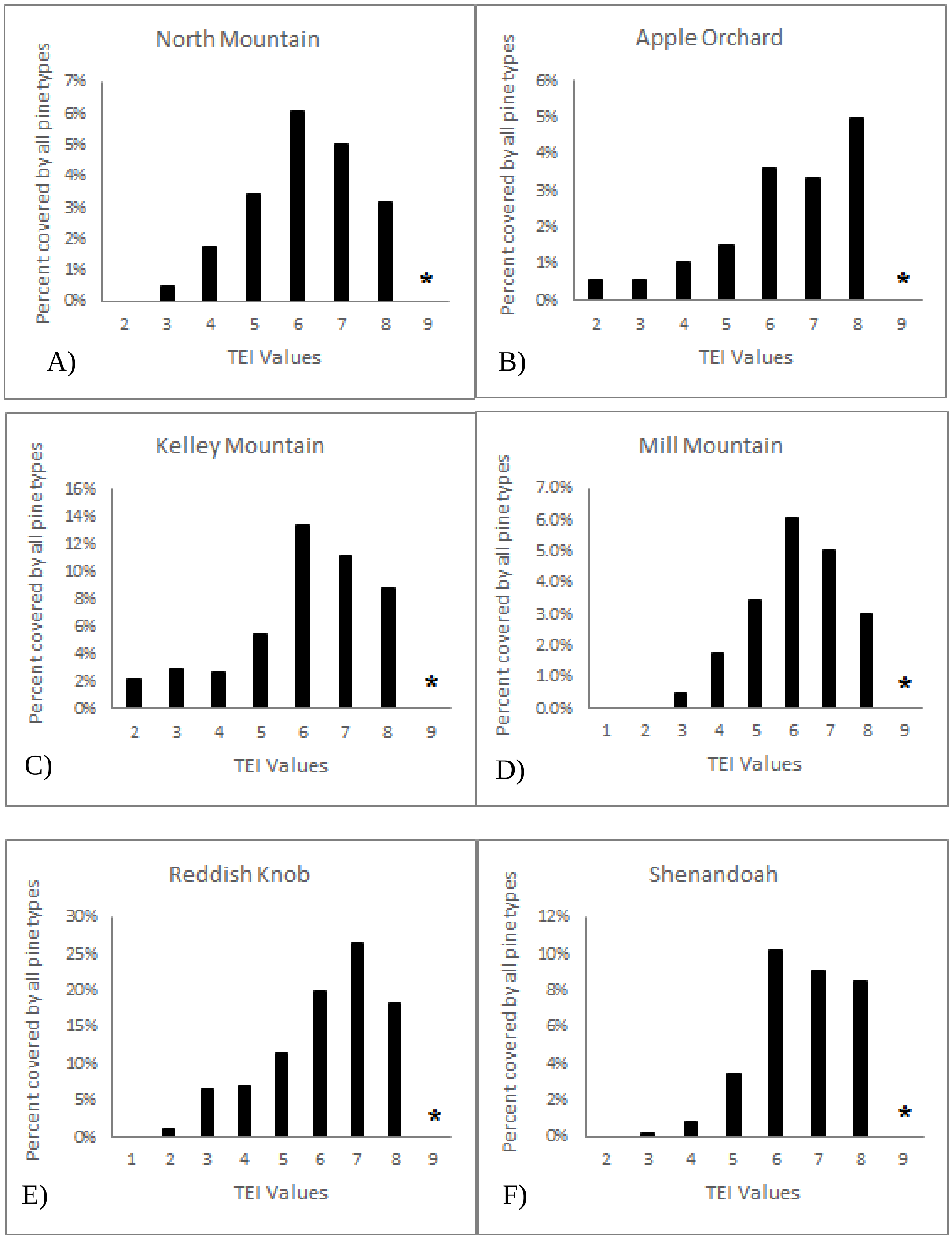
Figure 28. Percent of each TEI group occupied by pines in the six southern landscapes. Sites include A) Western Georgia, B) Eastern Georgia, C) Licklog, D) Linville Gorge, E) Holston Mountain, and F) Griffith Knob.



1: -64 to -50 3: -34 to - 20 5: -4 to 10.9 7: 26 to 40.9 9: 56 to 70.9

2: -49 to -35 4: -19 to -5 6: 11 to 25.9 8: 41 to 55.9

Figure 29. Percent of each TEI group occupied by pines in the six northern landscapes. Sites include A) North Mountain, B) Apple Orchard, C) Mill Mountain, D) Kelley Mountain, E) Reddish Knob, and F) Shenandoah.



1: -64 to -50   3: -34 to - 20   5: -4 to 10.9   7: 26 to 40.9   9: 56 to 70.9
2: -49 to -35   4: -19 to -5   6: 11 to 25.9   8: 41 to 55.9

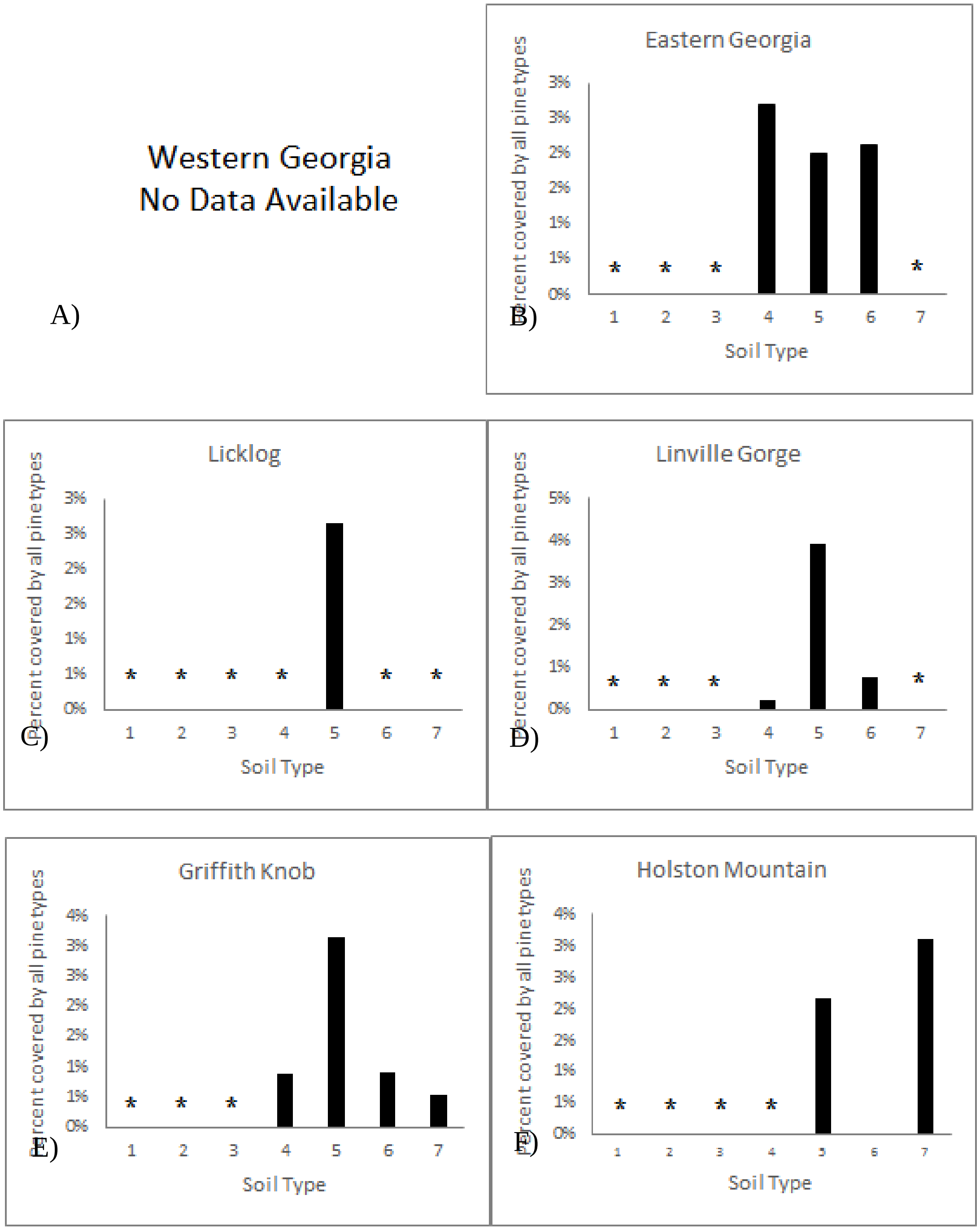
Soil

The pines are rarely present in the classes of very poorly drained to somewhat poorly drained, and instead occupy landscapes with good drainage abilities that infrequently hold water (Figures 30 and 31). Five of the landscapes have their highest percentages of pine coverage in the well drained class, indicating that while there is a range of dominant drainage soil conditions that the pines can tolerate, many of them are concentrated in soil that drains well but maintain soil moisture throughout most of the growing season (Figures 30 and 31) (Staff 1992). The Licklog landscape was excluded from Chi Squared analysis, as only one soil drainage class had over 300 cells, and therefore could not be compared against other soil types (Table 9). The pine stands at the Eastern Georgia landscape all occupy the soil types under a pattern expected at random, but the pine stands at the other landscapes do not (Table 9). Asterisks in the bar graphs indicate where there are zero cells in that category for the entire landscape.

Table 9. Chi square results of pine distribution distributions among the dominant drainage soil conditions at eleven of the landscapes.

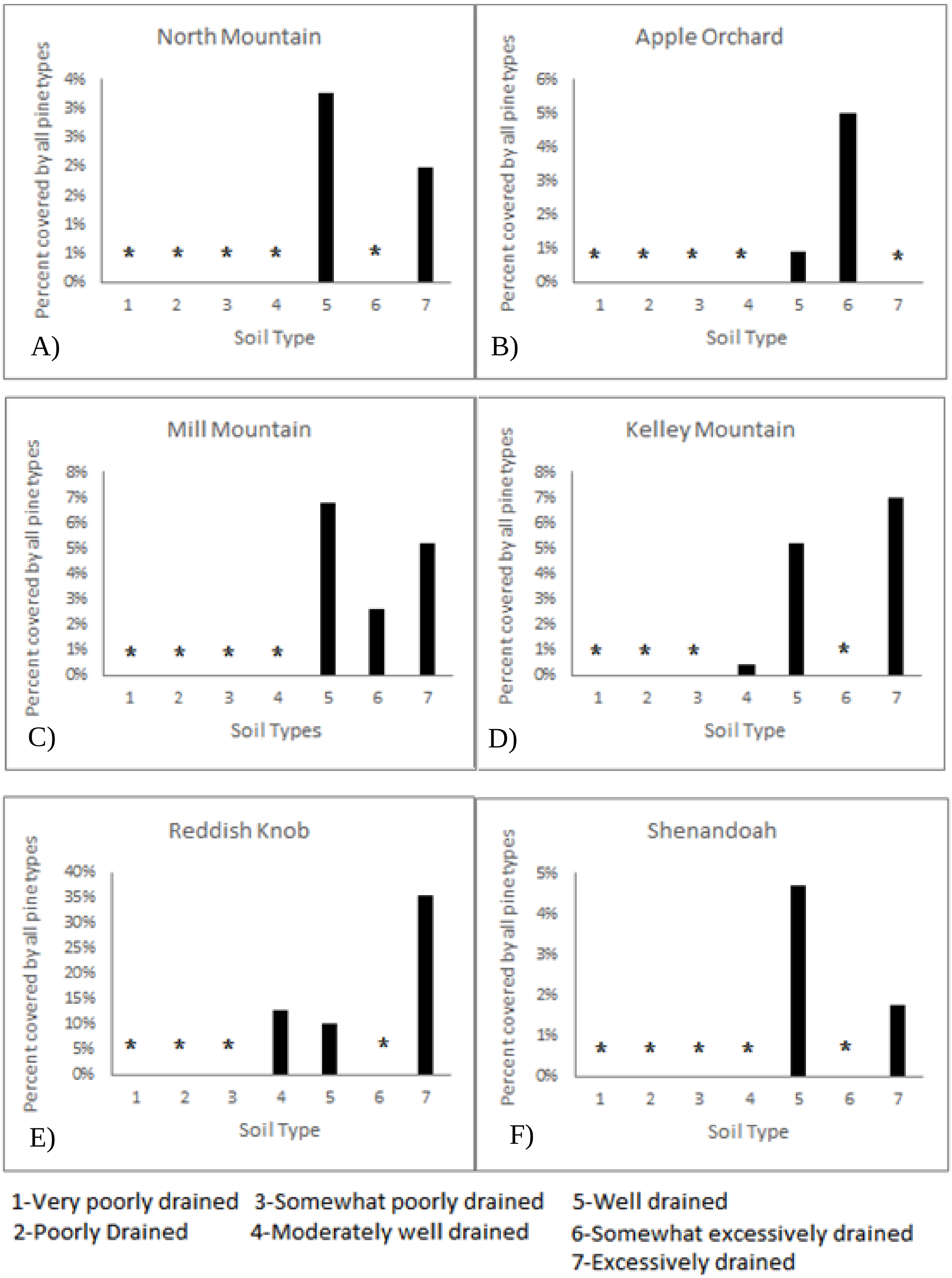
Site	$\chi 2$ value	P value	df
Eastern Georgia	1.37	0.50	2
Linville Gorge	**374.88**	**<0.001**	**2**
Holston Mountain	**114.29**	**<0.001**	**4**
Griffith Knob	**149.35**	**<0.001**	**3**
North Mountain	**37.58**	**<0.001**	**1**
Apple Orchard	**1122.51**	**<0.001**	**2**
Mill Mountain	**37.68**	**<0.001**	**2**
Kelley Mountain	**214.57**	**<0.001**	**2**
Reddish Knob	**2797.19**	**<0.001**	**2**
Shenandoah	**142.72**	**<0.001**	**1**

Figure 30. Percent of each dominant drainage class covered by pines in the five southern landscapes. Sites include A) Western Georgia, B) Eastern Georgia, C) Licklog, D) Linville Gorge, E) Holston Mountain, and F) Griffith Knob.



1-Very poorly drained 3-Somewhat poorly drained 5-Well drained
2-Poorly Drained 4-Moderately well drained 6-Somewhat excessively drained
7-Excessively drained

Figure 31. Percent of each dominant drainage class covered by pines in the six northern landscapes. Sites include A) North Mountain, B) Apple Orchard, C) Mill Mountain, D) Kelley Mountain, E) Reddish Knob, and F) Shenandoah.



What are the aspects most frequently occupied by pines, and how do they vary across the southern Appalachian forests?

Within each landscape, pines normally occupied the driest locations in the forest matrix: areas with high heat loads (Figures 18 and 19), high radiation (Figures 20 and 21), were exposed (Figures 28 and 29), drained into other areas (Figures 26 and 27), and contained soils that drained well (Figures 30 and 31). The aspect most occupied by pines should likewise be the driest aspect within the forest matrix, but the aspect that is most commonly occupied by pines varies across the region.

The pine stands in the five southernmost landscapes (Western Georgia, Eastern Georgia, Licklog, Linville Gorge, and Holston Mountain) primarily occupy the south- and southwest facing slopes (Figures 32 and 33). The pines in the middle five landscapes (Griffith Knob, North Mountain, Apple Orchard, Mill Mountain, and Kelley Mountain) primarily occupy the southwest-, west- and northwest-facing slopes (Figures 32-34). The pines at the northernmost landscapes (Reddish Knob and Shenandoah) primarily occupy the southwest-, west-, northwest-, and north-facing slopes (Figures 32 and 43). Only Reddish Knob contains pine stands on flat surfaces without an aspect; however the stands on the flat aspect only make up less than 0.01% of the total pine distribution (Figure 34).

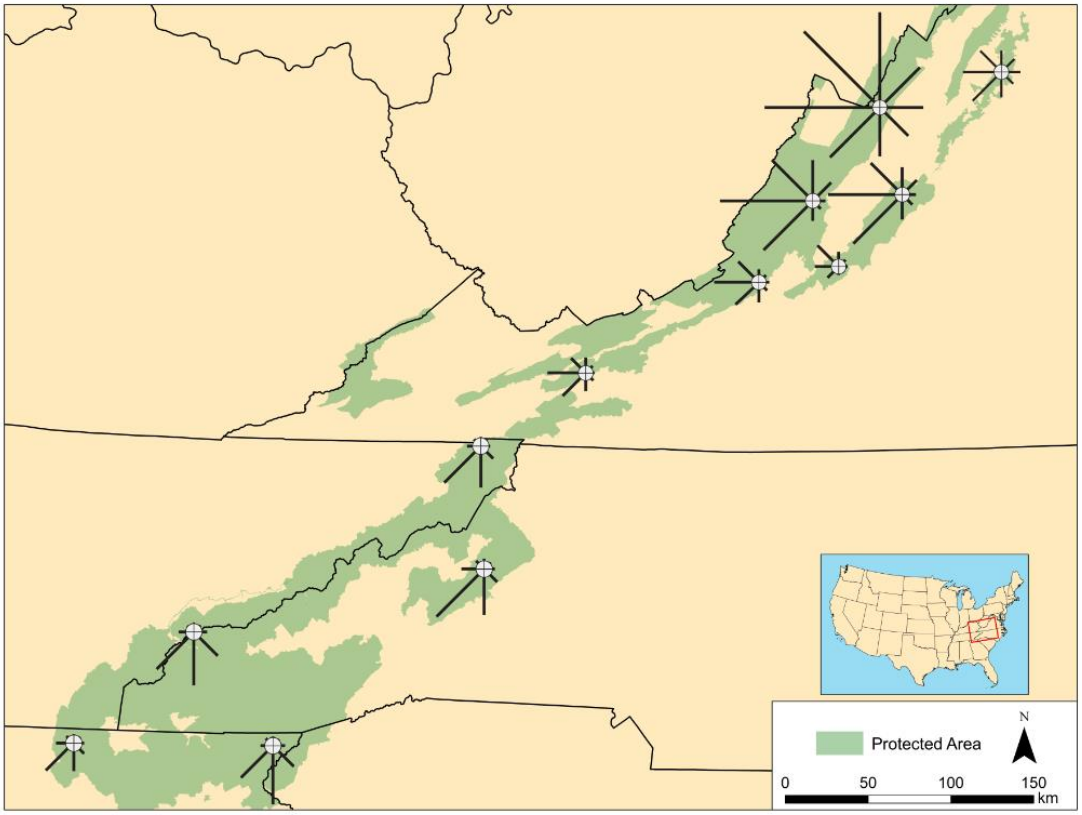


Figure 32. The relative amount each aspect class is occupied by pines all twelve study landscapes. The direction of each bar indicates the aspect class (north, south, etc.) and the bar length is proportional the percent of the cells occupied by pine stands in that aspect class.

The percent of pines on each aspect class demonstrate clear trends in occupying distinct portions of the landscape (Figures 32, 33, and 34). At each landscape, the pines are distributed unequally across the landscape compared to the aspect classes available (Table 10).

Figure 33. Percent of each aspect class covered by pines at the six southern landscapes. Sites include A) Western Georgia, B) Eastern Georgia, C) Licklog, D) Linville Gorge, E) Holston Mountain, and F) Griffith Knob.

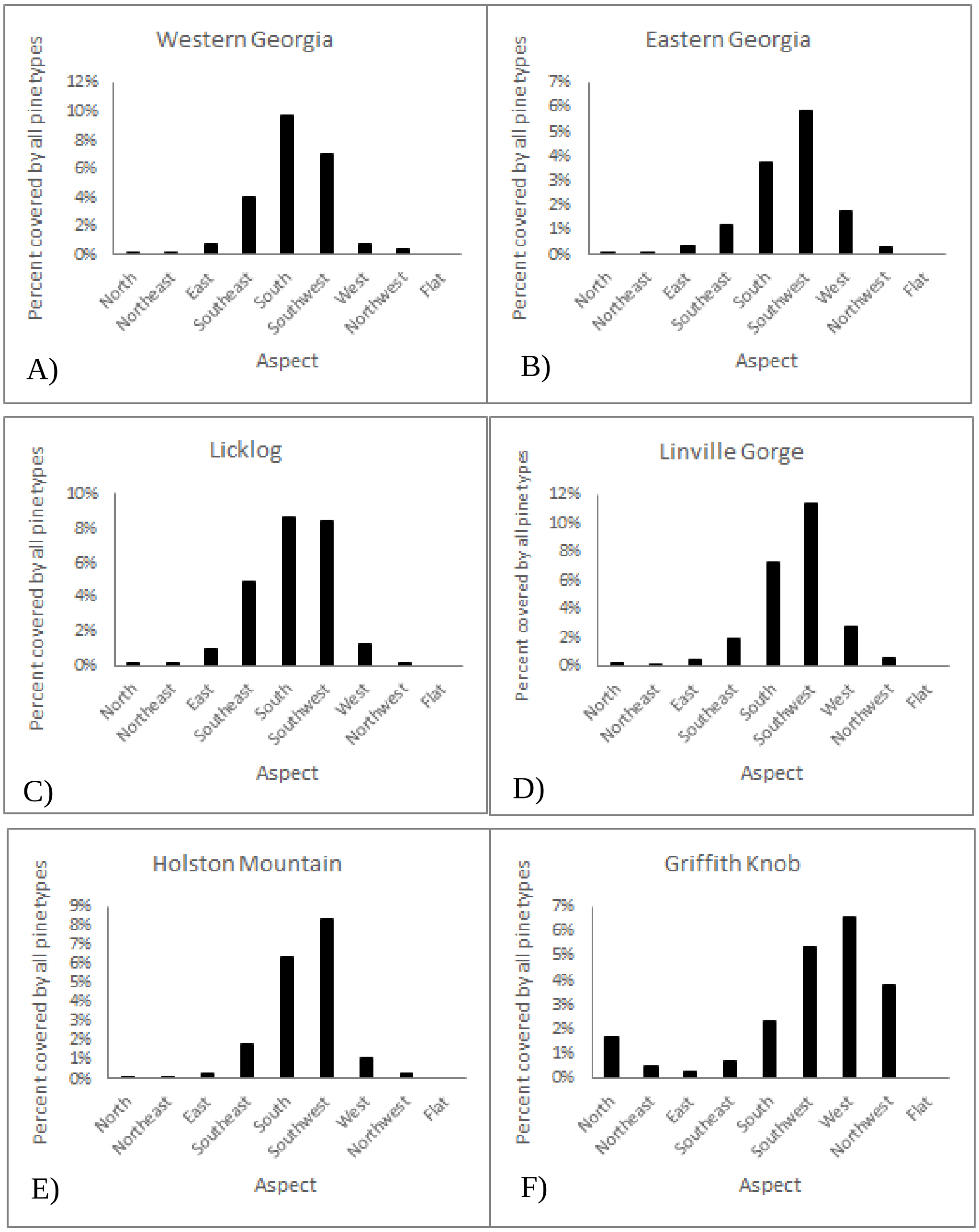


Figure 34. Percent of each aspect class covered by pines at the six northern landscapes. Sites include A) North Mountain, B) Apple Orchard, C) Mill Mountain, D) Kelley Mountain, E) Reddish Knob, and F) Shenandoah.

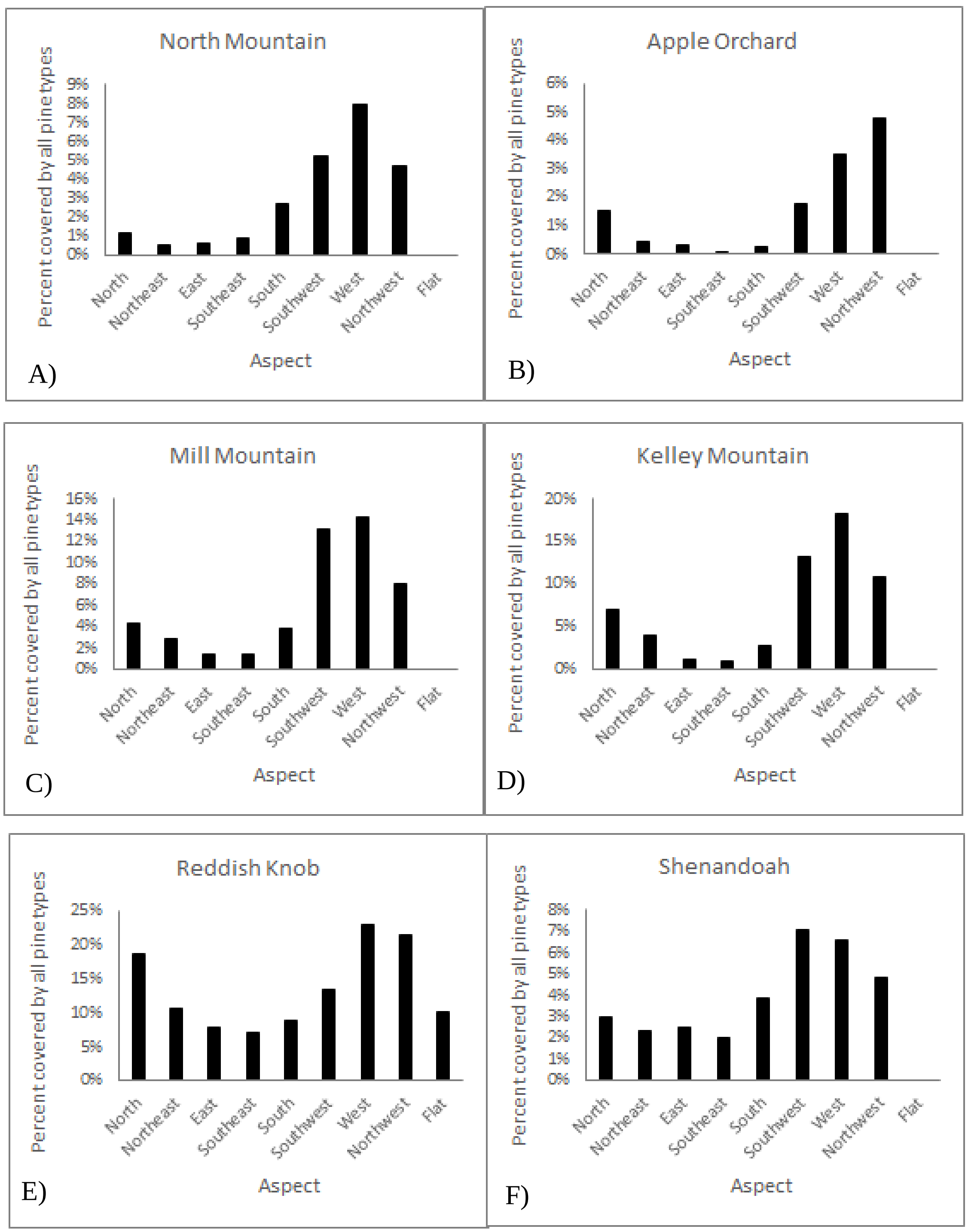


Table 10. Chi square analysis of pines among the aspect classes at each of the twelve landscapes.

Site	$\chi 2$ value	P value	df
Western Georgia	**3479.13**	**<0.001**	**7**
Eastern Georgia	**1733.58**	**<0.001**	**7**
Licklog	**3343.50**	**<0.001**	**7**
Linville Gorge	**3627.23**	**<0.001**	**7**
Holston Mountain	**3564.25**	**<0.001**	**7**
Griffith Knob	**1623.03**	**<0.001**	**7**
North Mountain	**2103.25**	**<0.001**	**7**
Apple Orchard	**1395.47**	**<0.001**	**7**
Mill Mountain	**3199.52**	**<0.001**	**7**
Kelley Mountain	**3952.42**	**<0.001**	**8**
Reddish Knob	**2126.59**	**<0.001**	**8**
Shenandoah	**753.10**	**<0.001**	**7**

Another way to address how the primary aspect classes occupied by pines changes across the region is by examining pine-dominated stands previously sampled in fire history studies. The overall pattern of the previously sampled pine stands indicate a change in primary aspect classes occupied from the south- and southeast-facing slopes in the south to predominantly west- and northwest-facing slopes in the middle landscapes (Figure 35). The primary aspects occupied changes again from the middle landscapes to the northern landscapes, where they are on southwest-, west- and northwest- facing slopes (Figure 35).

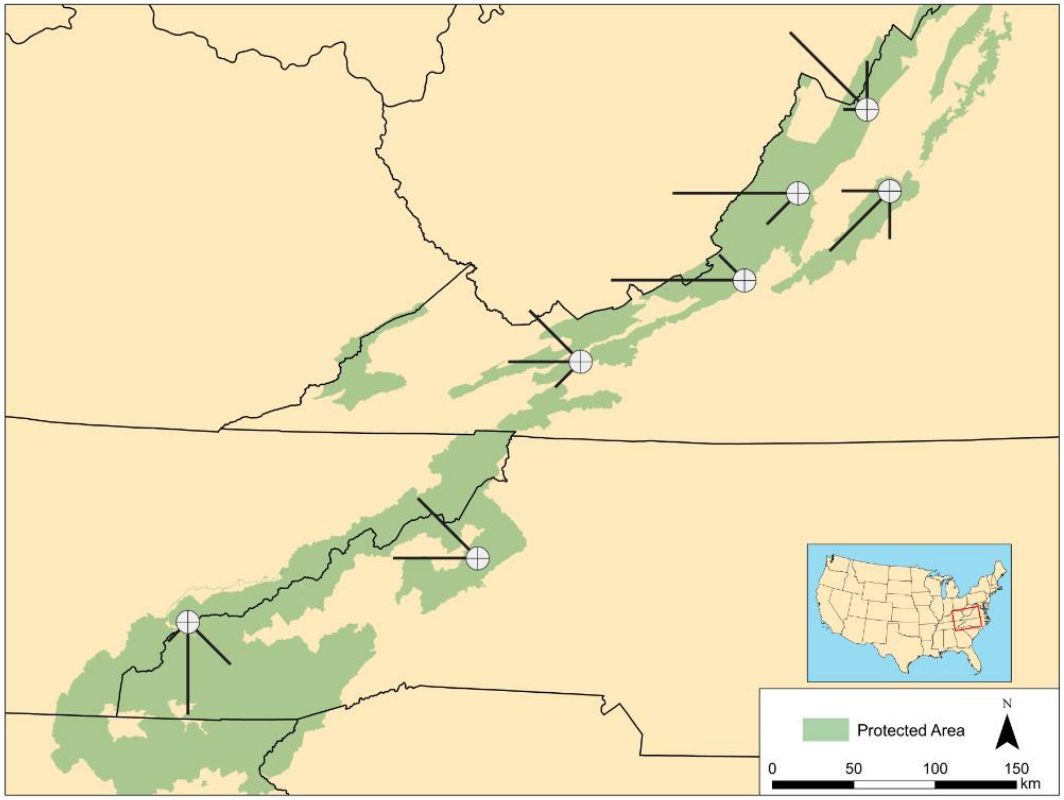


Figure 35. Aspect comparisons between the overall landscapes and the previously sampled pine stands in Licklog, Linville Gorge, Griffith Knob, North Mountain, Mill Mountain, Kelley Mountain, and Reddish Knob.

CHAPTER IV

DISCUSSION

Do Table Mountain pine and pitch pine stands occupy the drier locations within the forest matrix in southern Appalachian National Parks and National Forests?

The decline in the extent of pine-dominated stands with increasing annual precipitation is consistent with the general understanding that Table Mountain pine and pitch pine are favored in the driest environments of the Appalachian Mountains (Whittaker 1956; Williams and Johnson 1992; Zobel 1969). Further evidence that the pine stands are occupying the driest locations within each landscape include their presence on the parts of the landscape with higher heat loads and solar radiation, which reduce soil moisture. Additionally, they occur on areas with increases in sun and wind exposure that dry out the soils faster than sheltered areas and drain into other areas, rather than receiving the water runoff. Within every variable studied, there were exceptions to these trends, but overall these findings support the commonly-held characterization that pines occupy xeric slopes within the greater oak-forest matrix (Burns and Honkala 1990; Whittaker 1956; Williams and Johnson 1992; Zobel 1969).

Table Mountain pine stands occupy the middle elevations which receive less precipitation than the high elevations, and also drain away much of the water, resulting in the middle elevations becoming the driest topographic elevation group. Areas with high slope values are likewise dry because of the water runoff on the steep terrain, but pine-dominated stands generally failed to occupy areas with high slope values. Other than tapering off in occupation of steep slopes, the pine stands lacked a pattern of slope preference, which opposes the traditional observation of Table Mountain pine and pitch pine on steep slopes (Zobel 1969).

The dominant drainage ability of the soil upon which pines grew was often in the moderately well drained to excessively well drained categories. The moderately well drained soils drain slowly, so the water available to plants during the growing season is present for a short amount of time, but mesophytic plants can still grow (Staff 1992). Well drained soils likely drain the soil quickly, but still provides water to plants during much of the growing season (Staff 1992). Soils with somewhat excessive drainage and excessive drainage abilities are often coarse, and the water percolates deep into the ground, if it is present at all (Staff 1992). The growth of Table Mountain pine and pitch pine stands on soils that are well drained to excessively well drained at these twelve landscapes match the findings by Zobel (1969). However, the landscapes do not overall contain soils that drain poorly, indicating that the soil is not an important constraint on the distribution of pines.

What are the aspects most frequently occupied by pines, and how do they vary across the southern Appalachian forests?

Pine-dominated stands occupy the eight aspect classes differently at each landscape. The pines occupy the southeast-, south-, and southwest-facing slopes more at the southern locations, which is expected for xerophytic vegetation in the northern hemisphere because the highest insolation is at noon. At the northern loactions, the pattern changes and the pines occupy the west- and northwest slopes more than the other aspects, and the exceptions to the aspect trend noted by Zobel (1969) no longer appear to be exceptions, but rather part of the rule.

Three previous fire history studies examined individual pine stands at seven of the twelve landscapes (Aldrich et al. 2010; DeWeese et al. 2010; Flatley et al. 2013). The southwest-facing slopes are fairly evenly occupied by pines across the entire region, but the previous fire history studies show pines on that aspect infrequently. This lack of pine stands on southwest slopes in the previous studies is also contrary to previous publications describing the pines on this aspect class, as it receives higher radiation as a result of the afternoon sun and downwelling long wave radiation, making the locations drier compared to other aspect classes (Schwartz et al. 2016; Whittaker 1956). All of the previous studies conducted their sampling across a few spurs near each other, and if they had the time and resources to sample more than four stands at each location, it is possible that there would be an increased number of aspects sampled at each landscape.

Wind is a possible explaination for the increased presence on west-and northwest-facing slopes by pines at the northern locations, which is contrary to the typical pattern of xeric plants. The direction of wind can impact the health of conifer species, where windward, dry slopes have trees with desiccated needles more than leeward slopes (Hadley and Smith 1983). When comparing the wind roses based on annual measurements, the wind roses do not resemble the pattern of pine stands occupying each landscape, termed “pine roses.” However, when comparing the wind roses for each month to the pine rose for the landscape, there are some similarities. The dominance of west winds in every month is similar to the percent of western slopes occupied by pine stands at Griffith Knob. Much of the wind in June through September at Kelley Mountain is from the west and southwest, which dries the slopes to allow pine stands to grow.

The landscapes at North Mountain and Apple Orchard and have no discernable pattern between wind and pine distribution. The distance between the weather station, Lynchburg Airport, and the actual landscape at Apple Orchard is so large that it is possible the weather record does not reflect the weather at the landscape. North Mountain, however, is located near its RAW Station, and so it is difficult to understand what drives the pattern of pine distribution at that landscape. At landscapes with a concentration of northwest and west winds, these winds could dry out the northern slopes to offset the moisture difference between north- and south-facing slopes. As a result, the windier, drier slopes with afternoon sun become the west- and northwest-facing slopes which pines occupy in the northern landscapes Holston Mountain, Mill Mountain, Reddish Knob, and Shenandoah.

The role of fire

Site-specific fire history likely influences the patterns of pine distribution in terms of aspect. Appalachian fire events are more intense on the drier areas within a forest matrix, supporting pine stand growth over mesophytic hardwoods (Lafon et al. 2017;(Flatley, Lafon, and Grissino-Mayer 2011). The distribution of pines in landscapes of this study indicates that the pines are likely occupying the slopes that experience more intense fire disturbances compared to the more mesic slopes.

Fire affects forest structure and species composition in a cross scale process (Peters, Bestelmeyer, and Turner 2007). The ability of fire to spread between trees is different than its ability to spread between patches (Peters, Bestelmeyer, and Turner 2007). If there are patches of mesophyic species adapted to limiting fire spread around the pine stands, then the fire will spread differently than if it were simply an oak-forest with only stands of xeric pines. The frequency and severity of fires can also impact vegetation structure and community composition, especially in wetter areas (Flatley, Lafon, and Grissino-Mayer 2011). Of the landscapes in this study with published fire history reports, each landscape has a unique fire history (Aldrich et al. 2010; DeWeese et al. 2010; Flatley et al. 2013). These fire histories demonstrate that disturbances are important to the landscape for influencing the landscape-level distribution of species.

The two driest landscapes (Reddish Knob and Shenandoah) had some of the widest distribution of pine stands across the different aspect classes, while the pine stands at the two wettest landscapes (Eastern Georgia and Western Georgia) were confined onto a few of the aspect classes. These difference in pine distribution between these two pairs of landscapes is supported by previous findings. Wetter forests are more likely to have variations in fire distribution along topographic lines than drier, more flammable forests (Flatley, Lafon, and Grissino-Mayer 2011).

Application

Table Mountain pine and pitch pine are important fire-associated species in the Appalachian forests (Burns and Honkala 1990). The regional variation in distribution pattern for this species is central to discussions on the frequency and intensity of fires required to maintain stand diversity and landscape heterogeneity. As forest managers make decisions on the ideal species composition in stands, such as fire-intolerant hardwoods or fire-associated pines, they need to know what conditions are suitable to the pines. By including the aspect, location, and the other factors outlined above, forest managers can effectively plan the distribution of these species. This conversation is especially pertinent after decades of fire suppression comes to an end, and fire regimes are implemented to manage the biodiversity of eastern North American forests.

CHAPTER V

CONCLUSION

There is regional variation in the primary aspect classes most occupied by Table Mountain pine and pitch pine in the southern Appalachians. Though the pine stands are common on middle-elevation slopes that drain well, receive higher radiation and heat load, and are exposed to the weather, the driest slopes in the landscape appear to change between the different landscapes. Local conditions such as wind could influence the extent to which plants dry out on different aspects, and combined with the temperature differences between southwest- and northeast-facing slopes, the location of the driest slope could be changed.

At the southern end of the Appalachians, the pines primarily occupy the south- and southwest-facing slopes, but farther to the northeast, the pines primarily occupy the west- and northwest-facing slopes. Only the southwest-facing slopes are fairly evenly occupied between the northern and southern landscapes, and this is likely a result of the afternoon sun heating of the soil. The northerly winds drying the soil and vegetation and the western afternoon sun work in tandem to increase the presence of pines on northwest-facing slopes. Some of the landscapes, such as North Mountain and Apple Orchard, defy explanation for the specifics of their distribution across the aspect classes. The fire history of these landscapes could be more important than other landscapes, as the intensity of fires could create drier slopes that will later burn more intensely, creating a pattern of fire history, terrain, and weather work together to constrain the distribution of Table Mountain pine and pitch pine.

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APPENDIX A

Cell numbers in each category per landscape

Western Georgia-Cell number per TEI class			
TEI	Total	Not Pine	Pine
-64 to -50	851	850	1
-49 to -35	3413	3382	31
-34 to 20	9580	9482	98
-19 to -5	18996	18728	268
-4 to 10.9	21261	20696	565
11 to 25.9	15403	14876	527
26 to 40.9	6781	6542	239
41 to 55.9	1409	1336	73
56 to 70.9	144	128	16
71 to 86	3	3	0
Total	77841	76023	1818

Eastern Georgia-Cell number per TEI class			
TEI	Total	Not Pine	Pine
-64 to -50	62	61	1
-49 to -35	1265	1249	16
-34 to 20	9907	9832	75
-19 to -5	23008	22698	310
-4 to 10.9	22943	22345	598
11 to 25.9	13444	13089	355
26 to 40.9	5504	5352	152
41 to 55.9	1335	1268	67
56 to 70.9	85	82	3
71 to 86	9	9	0
Total	77562	75985	1577

Western Georgia-Cell number per elevation class			
Elevation	Total	Not Pine	Pine
200-299	0	0	0
300-399	0	0	0
400-499	3861	3861	0
500-599	18610	18610	0
600-699	14228	14120	108
700-799	8537	8198	339
800-899	11361	10693	668
900-999	9383	8881	502
1000-1099	7451	7261	190
1100-1199	3773	3762	11
1200-1299	637	637	0
1300-1399	0	0	0
1400-1499	0	0	0
Total	77841	76023	1818

Eastern Georgia-Cell number per elevation class			
Elevation	Total	Not Pine	Pine
200-299	0	0	0
300-399	0	0	0
400-499	32	32	0
500-599	7366	7366	0
600-699	14314	14248	66
700-799	13687	13195	492
800-899	14055	13500	555
900-999	15294	14994	300
1000-1099	8464	8385	79
1100-1199	3151	3110	41
1200-1299	1024	993	31
1300-1399	175	162	13
1400-1499	0	0	0
Total	77562	75985	1577

Western Georgia-Cell number per radiation class			
Radiation	Total	Not Pine	Pine
4900-5099	3467	3437	30
5100-5299	3332	3308	24
5300-5499	5657	5565	92
5500-5699	9228	9027	201
5700-5899	13490	13209	281
5900-6099	18934	18562	372
6100-6299	18178	17686	492
6300-6499	4608	4294	314
6500-6699	947	935	12
6700+	0	0	0
Total	77841	76023	1818

Eastern Georgia-Cell number per radiation class			
Radiation	Total	Not Pine	Pine
4900-5099	486	484	2
5100-5299	926	923	3
5300-5499	2525	2497	28
5500-5699	5771	5657	114
5700-5899	12354	12144	210
5900-6099	21318	20945	373
6100-6299	23551	22989	562
6300-6499	9387	9129	258
6500-6699	1228	1208	20
6700+	16	9	7
Total	77562	75985	1577

Western Georgia-Cell number per TWI class			
TWI	Total	Not Pine	Pine
2-4.1	8449	8045	404
4.1-6.2	49574	48369	1205
6.2-8.3	11224	11064	160
8.3-10.4	4040	4006	34
10.4-12.5	1832	1822	10
12.5-14.6	859	859	0
14.6-16.7	330	330	0
16.7-18.8	40	40	0
18.8-20.9	7	7	0
20.9-23	0	0	0
NAs	1486		5
Total	77841	74542	1818

Eastern Georgia-Cell number per TWI class			
TWI	Total	Not Pine	Pine
2-4.1	7069	6811	258
4.1-6.2	49102	47947	1155
6.2-8.3	12332	12218	114
8.3-10.4	4812	4793	19
10.4-12.5	1840	1828	12
12.5-14.6	823	813	10
14.6-16.7	349	346	3
16.7-18.8	79	79	0
18.8-20.9	9	9	0
20.9-23	3	3	0
NAs	1144	1138	6
Total	77562	75985	1577

Western Georgia-Cell number per slope class			
Slope	Total	Not Pine	Pine
0-6.9	6661	6616	45
7-13.9	15594	15359	235
14-20.9	20056	19543	513
21-27.9	18844	18333	511
28-34.9	11750	11366	384
35-41.9	4192	4081	111
42-48.9	666	649	17
49-55.9	78	76	2
56-62.9	0		0
63-70	0		0
Total	77841	76023	1818

Eastern Georgia-Cell number per slope class			
Slope	Total	Not Pine	Pine
0-6.9	5419	5334	85
7-13.9	17099	16840	259
14-20.9	25668	25131	537
21-27.9	20022	19592	430
28-34.9	7644	7428	216
35-41.9	1513	1466	47
42-48.9	194	191	3
49-55.9	3	3	0
56-62.9	0		0
63-70	0		0
Total	77562	75985	1577

Western Georgia-Cell number per aspect class			
Aspect	Total	Not Pine	Pine
North	11111	11098	13
Northeast	8622	8620	2
East	10081	10005	76
Southeast	7736	7420	316
South	7144	6454	690
Southwest	8121	7546	575
West	12218	12120	98
Northwest	12808	12760	48
Flat	0	0	0
Total	77841	76023	1818

Eastern Georgia-Cell number per aspect class			
Aspect	Total	Not Pine	Pine
North	6854	6851	3
Northeast	9272	9269	3
East	10819	10778	41
Southeast	10781	10651	130
South	12537	12071	466
Southwest	12889	12130	759
West	8820	8663	157
Northwest	5590	5572	18
Flat	0	0	0
Total	77562	75985	1577

Western Georgia-Cell number per heat load class			
Linearized Aspect	Total	Not Pine	Pine
0-0.09	15259	15233	26
0.1-0.19	7281	7230	51
0.2-0.29	5851	5787	64
0.3-0.39	5151	5076	75
0.4-0.49	5100	4991	109
0.5-0.59	5051	4933	118
0.6-0.69	5302	5129	173
0.7-0.79	6009	5772	237
0.8-0.89	7534	7223	311
0.9-1	15303	14649	654
Total	77,841.00	76023	1818

Eastern Georgia-Cell number per heat load class			
Linearized Aspect	Total	Not Pine	Pine
0-0.09	15959	15940	19
0.1-0.19	6834	6810	24
0.2-0.29	5107	5081	26
0.3-0.39	4386	4355	31
0.4-0.49	4156	4119	37
0.5-0.59	4332	4279	53
0.6-0.69	4668	4570	98
0.7-0.79	5480	5341	139
0.8-0.89	7371	7140	231
0.9-1	19269	18350	919
Total	77562	75985	1577

Western Georgia-Cell number per soil type			
Dominant Drainage Ability	Total	Not Pine	Pine
No Data Available			

Eastern Georgia-Cell number per soil type			
Dominant Drainage Ability	Total	Not Pine	Pine
Very poorly drained	148	138	10
Poorly Drained	17	17	0
Somewhat poorly drained	0	0	0
Moderately well drained	205	205	0
Well drained	57992	56829	1163
Somewhat excessively drained	12102	11847	255
Excessively drained	0	0	0
Total	70464	69036	1428

Licklog-Cell number per TEI class			
TEI	Total	Not Pine	Pine
-64 to -50	743	722	21
-49 to -35	2658	2595	63
-34 to 20	8418	8284	134
-19 to -5	23096	22727	369
-4 to 10.9	25117	24154	963
11 to 25.9	14292	13608	684
26 to 40.9	5345	5037	308
41 to 55.9	1560	1453	107
56 to 70.9	437	410	27
71 to 86	130	123	7
Total	81796	79113	2683

Linville Gorge-Cell number per TEI class			
TEI	Total	Not Pine	Pine
-64 to -50	94	94	0
-49 to -35	1920	1901	19
-34 to 20	10225	10136	89
-19 to -5	20863	20595	268
-4 to 10.9	22664	22029	635
11 to 25.9	15701	15062	639
26 to 40.9	5574	5232	342
41 to 55.9	1000	938	62
56 to 70.9	79	76	3
71 to 86	0	0	0
Total	78120	76063	2057

Licklog-Cell number per elevation class			
Elevation	Total	Not Pine	Pine
200-299	0	0	0
300-399	0	0	0
400-499	0	0	0
500-599	2263	2263	0
600-699	7097	7068	29
700-799	10271	9966	305
800-899	15337	14711	626
900-999	17814	17009	805
1000-1099	17608	16901	707
1100-1199	8963	8791	172
1200-1299	2443	2404	39
1300-1399	0	0	0
1400-1499	0	0	0
Total	81796	79113	2683

Linville Gorge-Cell number per elevation class			
Elevation	Total	Not Pine	Pine
200-299	0	0	0
300-399	0	0	0
400-499	0	0	0
500-599	4330	4330	0
600-699	16327	16171	156
700-799	8178	7835	343
800-899	8965	8232	733
900-999	7875	7312	563
1000-1099	8248	8047	201
1100-1199	8276	8226	50
1200-1299	8527	8519	8
1300-1399	5592	5589	3
1400-1499	1802	1802	0
Total	78120	76063	2057

Licklog-Cell number per radiation class			
Radiation	Total	Not Pine	Pine
4900-5099	4627	4588	39
5100-5299	2931	2904	27
5300-5499	4387	4319	68
5500-5699	6547	6417	130
5700-5899	9765	9522	243
5900-6099	14898	14434	464
6100-6299	19632	18874	758
6300-6499	14728	13976	752
6500-6699	4280	4078	202
6700+	1	1	0
Total	81796	79113	2683

Linville Gorge-Cell number per radiation class			
Radiation	Total	Not Pine	Pine
4900-5099	1845	1843	2
5100-5299	2548	2542	6
5300-5499	4142	4123	19
5500-5699	6812	6736	76
5700-5899	10846	10581	265
5900-6099	16793	16224	569
6100-6299	20679	19941	738
6300-6499	9334	8959	375
6500-6699	4413	4407	6
6700+	708	707	1
Total	78120	76063	2057

Licklog-Cell number per TWI class			
TWI	Total	Not Pine	Pine
2-4.1	10844	10308	536
4.1-6.2	45518	43774	1744
6.2-8.3	15132	14865	267
8.3-10.4	5716	5660	56
10.4-12.5	2331	2308	23
12.5-14.6	523	515	8
14.6-16.7	43	42	1
16.7-18.8	2	2	0
18.8-20.9	1	1	0
20.9-23	0	0	0
NAs	1686	1638	48
Total	81796	79113	2683

Linville Gorge-Cell number per TWI class			
TWI	Total	Not Pine	Pine
2-4.1	9192	8906	286
4.1-6.2	47736	46222	1514
6.2-8.3	12219	12031	188
8.3-10.4	4579	4544	35
10.4-12.5	1863	1854	9
12.5-14.6	819	810	9
14.6-16.7	263	263	0
16.7-18.8	27	27	0
18.8-20.9	4	4	0
20.9-23	1	1	0
NAs	1417	1401	16
Total	78120	76063	2057

Licklog-Cell number per slope class			
Slope	Total	Not Pine	Pine
0-6.9	6543	6406	137
7-13.9	18200	17593	607
14-20.9	21557	20713	844
21-27.9	17466	16776	690
28-34.9	10567	10277	290
35-41.9	5036	4945	91
42-48.9	1774	1757	17
49-55.9	537	530	7
56-62.9	100	100	0
63-70	16	16	0
Total	81796	79113	2683

Linville Gorge-Cell number per slope class			
Slope	Total	Not Pine	Pine
0-6.9	4906	4835	71
7-13.9	15555	15193	362
14-20.9	23605	22940	665
21-27.9	20945	20230	715
28-34.9	10419	10198	221
35-41.9	2458	2436	22
42-48.9	228	227	1
49-55.9	4	4	0
56-62.9	0		0
63-70	0		0
Total	78120	76063	2057

Licklog-Cell number per aspect class			
Aspect	Total	Not Pine	Pine
North	6374	6355	19
Northeast	8276	8263	13
East	12669	12610	59
Southeast	12923	12666	257
South	10590	9828	762
Southwest	10369	9196	1173
West	12582	12231	351
Northwest	8013	7964	49
Flat	0	0	0
Total	81796	79113	2683

Linville Gorge-Cell number per aspect class			
Aspect	Total	Not Pine	Pine
North	11760	11745	15
Northeast	9745	9726	19
East	8617	8533	84
Southeast	8260	7854	406
South	7752	7080	672
Southwest	8213	7518	695
West	11169	11021	148
Northwest	12604	12586	18
Flat	0	0	0
Total	78120	76063	2057

Licklog-Cell number per heat load class			
Linearized Aspect	Total	Not Pine	Pine
0-0.09	16008	15965	43
0.1-0.19	7227	7195	32
0.2-0.29	5713	5680	33
0.3-0.39	5116	5048	68
0.4-0.49	4965	4879	86
0.5-0.59	4988	4877	111
0.6-0.69	5121	4966	155
0.7-0.79	6197	5955	242
0.8-0.89	7968	7546	422
0.9-1	18493	17002	1491
Total	81796	79113	2683

Linville Gorge-Cell number per heat load class			
Linearized Aspect	Total	Not Pine	Pine
0-0.09	15294	15249	45
0.1-0.19	7066	7005	61
0.2-0.29	6162	6059	103
0.3-0.39	5574	5484	90
0.4-0.49	5279	5170	109
0.5-0.59	5334	5192	142
0.6-0.69	5514	5360	154
0.7-0.79	5834	5630	204
0.8-0.89	7075	6762	313
0.9-1	14988	14152	836
Total	78120	76063	2057

Licklog-Cell number per soil type			
Dominant Drainage Ability	Total	Not Pine	Pine
Very poorly drained	189	187	2
Poorly Drained	0	0	0
Somewhat poorly drained	0	0	0
Moderately well drained	777	777	0
Well drained	56458	54240	2218
Somewhat excessively drained	13390	13290	100
Excessively drained	0	0	0
Total	70814	68494	2320

Linville Gorge-Cell number per soil type			
Dominant Drainage Ability	Total	Not Pine	Pine
Very poorly drained	0	0	0
Poorly Drained	0	0	0
Somewhat poorly drained	0	0	0
Moderately well drained	138	138	0
Well drained	70401	68534	1867
Somewhat excessively drained	0	0	0
Excessively drained	99	99	0
Total	70638	68771	1867

Holston Mountain-Cell number per TEI class			
TEI	Total	Not Pine	Pine
-64 to -50	208	199	9
-49 to -35	2124	2040	84
-34 to 20	8456	8289	167
-19 to -5	23664	23304	360
-4 to 10.9	27195	26623	572
11 to 25.9	14504	14173	331
26 to 40.9	5259	5126	133
41 to 55.9	1165	1094	71
56 to 70.9	80	69	11
71 to 86	1	0	1
Total	82656	80917	1739

Griffith Knob-Cell number per TEI class			
TEI	Total	Not Pine	Pine
-64 to -50	68	67	1
-49 to -35	1815	1807	8
-34 to 20	7303	7249	54
-19 to -5	25479	25188	291
-4 to 10.9	29021	28038	983
11 to 25.9	14251	13498	753
26 to 40.9	4799	4546	253
41 to 55.9	731	687	44
56 to 70.9	54	53	1
71 to 86	0	0	0
Total	83521	81133	2388

Holston Mountain-Cell number per elevation class			
Elevation	Total	Not Pine	Pine
200-299	0	0	0
300-399	0	0	0
400-499	0	0	0
500-599	7673	7673	0
600-699	22095	22066	29
700-799	11242	11079	163
800-899	13626	12813	813
900-999	13599	13042	557
1000-1099	11516	11350	166
1100-1199	2905	2896	9
1200-1299	0	0	0
1300-1399	0	0	0
1400-1499	0	0	0
Total	82656	80919	1737

Griffith Knob-Cell number per elevation class			
Elevation	Total	Not Pine	Pine
200-299	0	0	0
300-399	0	0	0
400-499	0	0	0
500-599	0	0	0
600-699	466	466	0
700-799	29560	28578	982
800-899	27170	26089	1081
900-999	16719	16465	254
1000-1099	7167	7099	68
1100-1199	2439	2436	3
1200-1299	0	0	0
1300-1399	0	0	0
1400-1499	0	0	0
Total	83521	81133	2388

Holston Mountain-Cell number per radiation class			
Radiation	Total	Not Pine	Pine
4900-5099	2040	2034	6
5100-5299	2249	2224	25
5300-5499	4036	3948	88
5500-5699	6820	6614	206
5700-5899	10842	10539	303
5900-6099	18297	17939	358
6100-6299	26720	26318	402
6300-6499	10445	10107	338
6500-6699	1207	1194	13
6700+	0	0	0
Total	82656	80917	1739

Griffith Knob-Cell number per radiation class			
Radiation	Total	Not Pine	Pine
4900-5099	1351	1325	26
5100-5299	1689	1653	36
5300-5499	3044	2939	105
5500-5699	5204	5012	192
5700-5899	8709	8367	342
5900-6099	14165	13672	493
6100-6299	28684	27913	771
6300-6499	19573	19155	418
6500-6699	1102	1097	5
6700+	0	0	0
Total	83521	81133	2388

Holston Mountain-Cell number per TWI class			
TWI	Total	Not Pine	Pine
2-4.1	0	0	0
4.1-6.2	21338	20701	637
6.2-8.3	43201	42283	918
8.3-10.4	10277	10177	100
10.4-12.5	3533	3509	24
12.5-14.6	1717	1686	31
14.6-16.7	692	686	6
16.7-18.8	111	110	1
18.8-20.9	4	4	0
20.9-23	1	1	0
NAs	1782	1760	22
Total	82656	80917	1739

Griffith Knob-Cell number per TWI class			
TWI	Total	Not Pine	Pine
2-4.1	7330	6816	514
4.1-6.2	50774	49091	1683
6.2-8.3	14126	13991	135
8.3-10.4	4977	4952	25
10.4-12.5	2517	2504	13
12.5-14.6	1243	1239	4
14.6-16.7	284	283	1
16.7-18.8	70	70	0
18.8-20.9	13	13	0
20.9-23	4	4	0
NAs	2183	2170	13
Total	83521	81133	2388

Holston Mountain-Cell number per slope class			
Slope	Total	Not Pine	Pine
0-6.9	11207	11138	69
7-13.9	20613	20383	230
14-20.9	21980	21590	390
21-27.9	17671	17179	492
28-34.9	8696	8259	437
35-41.9	2345	2229	116
42-48.9	144	141	3
49-55.9	0	0	0
56-62.9	0		0
63-70	0		0
Total	82656	80919	1737

Griffith Knob-Cell number per slope class			
Slope	Total	Not Pine	Pine
0-6.9	10258	10092	166
7-13.9	22047	21502	545
14-20.9	25667	24956	711
21-27.9	16461	15820	641
28-34.9	7184	6928	256
35-41.9	1709	1641	68
42-48.9	190	189	1
49-55.9	5	5	0
56-62.9	0		0
63-70	0		0
Total	83521	81133	2388

Holston Mountain-Cell number per aspect class			
Aspect	Total	Not Pine	Pine
North	12049	12045	4
Northeast	9791	9789	2
East	8003	7984	19
Southeast	7764	7625	139
South	8806	8246	560
Southwest	10176	9331	845
West	12254	12122	132
Northwest	13813	13777	36
Flat	0	0	0
Total	82656	80919	1737

Griffith Knob-Cell number per aspect class			
Aspect	Total	Not Pine	Pine
North	6522	6413	109
Northeast	6566	6535	31
East	12025	11987	38
Southeast	12985	12891	94
South	11028	10775	253
Southwest	13286	12578	708
West	12612	11782	830
Northwest	8497	8172	325
Flat	0	0	0
Total	83521	81133	2388

Holston Mountain-Cell number per heat load class			
Linearized Aspect	Total	Not Pine	Pine
0-0.09	15321	15311	10
0.1-0.19	6615	6603	12
0.2-0.29	5634	5618	16
0.3-0.39	5541	5512	29
0.4-0.49	5475	5424	51
0.5-0.59	5726	5655	71
0.6-0.69	6140	6024	116
0.7-0.79	6556	6365	191
0.8-0.89	8103	7831	272
0.9-1	17545	16576	969
Total	82656	80919	1737

Griffith Knob-Cell number per heat load class			
Linearized Aspect	Total	Not Pine	Pine
0-0.09	13597	13548	49
0.1-0.19	6942	6895	47
0.2-0.29	5774	5713	61
0.3-0.39	5554	5494	60
0.4-0.49	5378	5304	74
0.5-0.59	5237	5149	88
0.6-0.69	5342	5193	149
0.7-0.79	5816	5611	205
0.8-0.89	7639	7283	356
0.9-1	22242	20943	1299
Total	83521	81133	2388

Holston Mountain-Cell number per soil type			
Dominant Drainage Ability	Total	Not Pine	Pine
Very poorly drained	0	0	0
Poorly Drained	321	321	0
Somewhat poorly drained	4	4	0
Moderately well drained	323	323	0
Well drained	60482	59184	1298
Somewhat excessively drained	3198	3198	0
Excessively drained	6491	6289	202
Total	70819	69319	1500

Griffith Knob-Cell number per soil type			
Dominant Drainage Ability	Total	Not Pine	Pine
Very poorly drained	0	0	0
Poorly Drained	25	25	0
Somewhat poorly drained	0	0	0
Moderately well drained	2040	2022	18
Well drained	62938	60965	1973
Somewhat excessively drained	1089	1079	10
Excessively drained	4551	4527	24
Total	70643	68618	2025

North Mountain-Cell number per TEI class			
TEI	Total	Not Pine	Pine
-64 to -50	64	64	0
-49 to -35	912	912	0
-34 to 20	7256	7221	35
-19 to -5	26886	26415	471
-4 to 10.9	29721	28694	1027
11 to 25.9	13397	12581	816
26 to 40.9	4155	3947	208
41 to 55.9	1073	1039	34
56 to 70.9	57	57	0
71 to 86	0	0	0
Total	83521	80930	2591

Apple Orchard-Cell number per TEI class			
TEI	Total	Not Pine	Pine
-64 to -50	52	52	0
-49 to -35	966	960	6
-34 to 20	7821	7777	44
-19 to -5	24329	24078	251
-4 to 10.9	28838	28401	437
11 to 25.9	14326	13804	522
26 to 40.9	4519	4368	151
41 to 55.9	893	849	44
56 to 70.9	52	49	3
71 to 86	0	0	0
Total	81796	80338	1458

North Mountain-Cell number per elevation class			
Elevation	Total	Not Pine	Pine
200-299	0	0	0
300-399	532	520	12
400-499	33236	31805	1431
500-599	26713	26211	502
600-699	12725	12371	354
700-799	7052	6810	242
800-899	3208	3160	48
900-999	55	53	2
1000-1099	0	0	0
1100-1199	0	0	0
1200-1299	0	0	0
1300-1399	0	0	0
1400-1499	0	0	0
Total	83521	80930	2591

Apple Orchard-Cell number per elevation class			
Elevation	Total	Not Pine	Pine
200-299	0	0	0
300-399	5718	5718	0
400-499	7810	7810	0
500-599	9444	9444	0
600-699	10277	10264	13
700-799	11359	11092	267
800-899	11481	11116	365
900-999	10421	9915	506
1000-1099	9969	9721	248
1100-1199	4341	4284	57
1200-1299	976	976	0
1300-1399	0	0	0
1400-1499	0	0	0
Total	81796	80340	1456

North Mountain-Cell number per radiation class			
Radiation	Total	Not Pine	Pine
4900-5099	2792	2786	6
5100-5299	2456	2413	43
5300-5499	4782	4679	103
5500-5699	9513	9195	318
5700-5899	17947	17226	721
5900-6099	31508	30435	1073
6100-6299	13999	13684	315
6300-6499	524	512	12
6500-6699	0	0	0
6700+	0	0	0
Total	83521	80930	2591

Apple Orchard-Cell number per radiation class			
Radiation	Total	Not Pine	Pine
4900-5099	3500	3240	260
5100-5299	2850	2694	156
5300-5499	4682	4515	167
5500-5699	7892	7704	188
5700-5899	14658	14435	223
5900-6099	24619	24394	225
6100-6299	13255	13129	126
6300-6499	7497	7415	82
6500-6699	2835	2806	29
6700+	8	8	0
Total	81796	80340	1456

North Mountain-Cell number per TWI class			
TWI	Total	Not Pine	Pine
2-4.1	9193	8772	421
4.1-6.2	49101	47292	1809
6.2-8.3	13893	13623	270
8.3-10.4	5487	5433	54
10.4-12.5	2810	2796	14
12.5-14.6	839	835	4
14.6-16.7	245	243	2
16.7-18.8	88	87	1
18.8-20.9	19	19	0
20.9-23	3	3	0
NAs	1843	1827	16
Total	83521	80930	2591

Apple Orchard-Cell number per TWI class			
TWI	Total	Not Pine	Pine
2-4.1	4254	4088	166
4.1-6.2	49025	47962	1063
6.2-8.3	18570	18383	187
8.3-10.4	5888	5857	31
10.4-12.5	2298	2290	8
12.5-14.6	867	867	0
14.6-16.7	242	242	0
16.7-18.8	34	34	0
18.8-20.9	3	3	0
20.9-23	1	1	0
NAs	614	611	3
Total	81796	80338	1458

North Mountain-Cell number per slope class			
Slope	Total	Not Pine	Pine
0-6.9	11493	11318	175
7-13.9	22658	21999	659
14-20.9	21379	20448	931
21-27.9	17227	16588	639
28-34.9	8478	8304	174
35-41.9	2126	2113	13
42-48.9	160	160	0
49-55.9	0	0	0
56-62.9	0		0
63-70	0		0
Total	83521	80930	2591

Apple Orchard-Cell number per slope class			
Slope	Total	Not Pine	Pine
0-6.9	6288	6231	57
7-13.9	19270	19177	93
14-20.9	23127	22911	216
21-27.9	19737	19321	416
28-34.9	10030	9652	378
35-41.9	2922	2654	268
42-48.9	398	370	28
49-55.9	23	23	0
56-62.9	1	1	0
63-70	0		0
Total	81796	80340	1456

North Mountain-Cell number per aspect class			
Aspect	Total	Not Pine	Pine
North	9883	9772	111
Northeast	8674	8628	46
East	10799	10730	69
Southeast	13399	13278	121
South	7757	7546	211
Southwest	8052	7629	423
West	13661	12576	1085
Northwest	11296	10771	525
Flat	0	0	0
Total	83521	80930	2591

Apple Orchard-Cell number per aspect class			
Aspect	Total	Not Pine	Pine
North	13973	13760	213
Northeast	9533	9491	42
East	9502	9473	29
Southeast	8776	8768	8
South	8982	8962	20
Southwest	7322	7194	128
West	9548	9213	335
Northwest	14160	13479	681
Flat	0	0	0
Total	81796	80340	1456

North Mountain-Cell number per heat load class			
Linearized Aspect	Total	Not Pine	Pine
0-0.09	15081	14995	86
0.1-0.19	7560	7508	52
0.2-0.29	6883	6821	62
0.3-0.39	6518	6460	58
0.4-0.49	6225	6110	115
0.5-0.59	5945	5784	161
0.6-0.69	5604	5404	200
0.7-0.79	6081	5797	284
0.8-0.89	7148	6699	449
0.9-1	16476	15352	1124
Total	83521	80930	2591

Apple Orchard-Cell number per heat load class			
Linearized Aspect	Total	Not Pine	Pine
0-0.09	15670	15610	60
0.1-0.19	7445	7387	58
0.2-0.29	6924	6869	55
0.3-0.39	6803	6711	92
0.4-0.49	6399	6226	173
0.5-0.59	6060	5872	188
0.6-0.69	6232	6041	191
0.7-0.79	6440	6263	177
0.8-0.89	6981	6803	178
0.9-1	12842	12558	284
Total	81796	80340	1456

North Mountain-Cell number per soil type			
Dominant Drainage Ability	Total	Not Pine	Pine
Very poorly drained	0	0	0
Poorly Drained	0	0	0
Somewhat poorly drained	44	44	0
Moderately well drained	197	197	0
Well drained	62001	59983	2018
Somewhat excessively drained	129	124	5
Excessively drained	8207	8043	164
Total	70578	68391	2187

Apple Orchard-Cell number per soil type			
Dominant Drainage Ability	Total	Not Pine	Pine
Very poorly drained	0	0	0
Poorly Drained	0	0	0
Somewhat poorly drained	0	0	0
Moderately well drained	81	81	0
Well drained	52052	51587	465
Somewhat excessively drained	15635	14852	783
Excessively drained	0	0	0
Total	67768	66520	1248

Mill Mountain-Cell number per TEI class			
TEI	Total	Not Pine	Pine
-64 to -50	265	265	0
-49 to -35	1828	1817	11
-34 to 20	10287	9919	368
-19 to -5	23870	22383	1487
-4 to 10.9	23634	21871	1763
11 to 25.9	14559	13385	1174
26 to 40.9	5839	5385	454
41 to 55.9	1569	1449	120
56 to 70.9	228	217	11
71 to 86	3	3	0
Total	82082	76694	5388

Kelley Mountain-Cell number per TEI class			
TEI	Total	Not Pine	Pine
-64 to -50	240	240	0
-49 to -35	2680	2618	62
-34 to 20	9036	8777	259
-19 to -5	18403	17921	482
-4 to 10.9	29938	28317	1621
11 to 25.9	16508	14288	2220
26 to 40.9	4378	3892	486
41 to 55.9	589	535	54
56 to 70.9	24	20	4
71 to 86	0	0	0
Total	81796	76608	5188

Mill Mountain-Cell number per elevation class			
Elevation	Total	Not Pine	Pine
200-299	0	0	0
300-399	2931	2779	152
400-499	25938	23835	2103
500-599	28516	26484	2032
600-699	13280	12583	697
700-799	6914	6610	304
800-899	2974	2893	81
900-999	1445	1426	19
1000-1099	84	84	0
1100-1199	0	0	0
1200-1299	0	0	0
1300-1399	0	0	0
1400-1499	0	0	0
Total	82082	76694	5388

Kelley Mountain-Cell number per elevation class			
Elevation	Total	Not Pine	Pine
200-299	0	0	0
300-399	0	0	0
400-499	76	76	0
500-599	6651	6651	0
600-699	16585	16569	16
700-799	18040	17051	989
800-899	17826	16132	1694
900-999	18313	16223	2090
1000-1099	4305	3906	399
1100-1199	0	0	0
1200-1299	0	0	0
1300-1399	0	0	0
1400-1499	0	0	0
Total	81796	76608	5188

Mill Mountain-Cell number per radiation class			
Radiation	Total	Not Pine	Pine
4900-5099	5542	5354	188
5100-5299	3830	3656	174
5300-5499	6510	6132	378
5500-5699	11286	10479	807
5700-5899	17674	16217	1457
5900-6099	27226	25376	1850
6100-6299	9543	9015	528
6300-6499	466	460	6
6500-6699	5	5	0
6700+	0	0	0
Total	82082	76694	5388

Kelley Mountain-Cell number per radiation class			
Radiation	Total	Not Pine	Pine
4900-5099	1494	1429	65
5100-5299	2617	2486	131
5300-5499	4461	4174	287
5500-5699	7123	6626	497
5700-5899	13056	12037	1019
5900-6099	21383	20186	1197
6100-6299	20994	19923	1071
6300-6499	9765	8875	890
6500-6699	903	872	31
6700+	0	0	0
Total	81796	76608	5188

Mill Mountain-Cell number per TWI class			
TWI	Total	Not Pine	Pine
2-4.1	12884	11891	993
4.1-6.2	46825	43447	3378
6.2-8.3	11646	11072	574
8.3-10.4	4710	4542	168
10.4-12.5	2613	2492	121
12.5-14.6	1039	982	57
14.6-16.7	229	216	13
16.7-18.8	69	65	4
18.8-20.9	6	6	0
20.9-23	1	1	0
NAs	2060	1980	80
Total	82082	76694	5388

Kelley Mountain-Cell number per TWI class			
TWI	Total	Not Pine	Pine
2-4.1	3602	3357	245
4.1-6.2	48153	44491	3662
6.2-8.3	20359	19260	1099
8.3-10.4	5453	5306	147
10.4-12.5	1813	1800	13
12.5-14.6	882	876	6
14.6-16.7	511	509	2
16.7-18.8	66	63	3
18.8-20.9	7	7	0
20.9-23	0	0	0
NAs	950	75669	11
Total	81796	151338	5188

Mill Mountain-Cell number per slope class			
Slope	Total	Not Pine	Pine
0-6.9	8361	7941	420
7-13.9	17113	15949	1164
14-20.9	21597	19894	1703
21-27.9	19639	18306	1333
28-34.9	11420	10831	589
35-41.9	3620	3459	161
42-48.9	322	305	17
49-55.9	10	9	1
56-62.9	0		0
63-70	0		0
Total	82082	76694	5388

Kelley Mountain-Cell number per slope class			
Slope	Total	Not Pine	Pine
0-6.9	10385	9762	623
7-13.9	18264	17316	948
14-20.9	21794	20355	1439
21-27.9	20230	18752	1478
28-34.9	9869	9267	602
35-41.9	1198	1107	91
42-48.9	56	49	7
49-55.9	0	0	0
56-62.9	0		0
63-70	0		0
Total	81796	76608	5188

Mill Mountain-Cell number per aspect class			
Aspect	Total	Not Pine	Pine
North	10455	10010	445
Northeast	8967	8719	248
East	8310	8200	110
Southeast	10034	9889	145
South	9509	9155	354
Southwest	9369	8139	1230
West	13286	11394	1892
Northwest	12152	11188	964
Flat	0	0	0
Total	82082	76694	5388

Kelley Mountain-Cell number per aspect class			
Aspect	Total	Not Pine	Pine
North	15096	14034	1062
Northeast	9204	8843	361
East	10417	10300	117
Southeast	14695	14574	121
South	7156	6965	191
Southwest	4355	3780	575
West	7014	5737	1277
Northwest	13827	12343	1484
Flat	32	32	0
Total	81796	76608	5188

Mill Mountain-Cell number per heat load class			
Linearized Aspect	Total	Not Pine	Pine
0-0.09	13869	13537	332
0.1-0.19	7119	6954	165
0.2-0.29	6133	5961	172
0.3-0.39	5431	5262	169
0.4-0.49	5429	5214	215
0.5-0.59	5382	5136	246
0.6-0.69	6124	5784	340
0.7-0.79	6758	6304	454
0.8-0.89	8393	7586	807
0.9-1	17444	14956	2488
Total	82082	76694	5388

Kelley Mountain-Cell number per heat load class			
Linearized Aspect	Total	Not Pine	Pine
0-0.09	14955	14492	463
0.1-0.19	9331	9025	306
0.2-0.29	9282	8910	372
0.3-0.39	8740	8344	396
0.4-0.49	8105	7649	456
0.5-0.59	7048	6586	462
0.6-0.69	5828	5458	370
0.7-0.79	5260	4834	426
0.8-0.89	4908	4311	597
0.9-1	8339	6999	1340
Total	81796	76608	5188

Mill Mountain-Cell number per soil type			
Dominant Drainage Ability	Total	Not Pine	Pine
Very poorly drained	0	0	0
Poorly Drained	0	0	0
Somewhat poorly drained	0	0	0
Moderately well drained	254	251	3
Well drained	66373	61879	4494
Somewhat excessively drained	993	967	26
Excessively drained	2964	2810	154
Total	70584	65907	4677

Kelley Mountain-Cell number per soil type			
Dominant Drainage Ability	Total	Not Pine	Pine
Very poorly drained	0	0	0
Poorly Drained	0	0	0
Somewhat poorly drained	0	0	0
Moderately well drained	2355	2345	10
Well drained	17354	16449	905
Somewhat excessively drained	0	0	0
Excessively drained	50744	47183	3561
Total	70453	65977	4476

Reddish Knob-Cell number per TEI class			
TEI	Total	Not Pine	Pine
-64 to -50	402	402	0
-49 to -35	3982	3934	48
-34 to 20	13063	12217	846
-19 to -5	17497	16268	1229
-4 to 10.9	21200	18783	2417
11 to 25.9	18005	14416	3589
26 to 40.9	7101	5220	1881
41 to 55.9	1362	1114	248
56 to 70.9	44	35	9
71 to 86	0	0	0
Total	82656	72389	10267

Shenandoah-Cell number per TEI class			
TEI	Total	Not Pine	Pine
-64 to -50	15	15	0
-49 to -35	652	652	0
-34 to 20	6750	6736	14
-19 to -5	26716	26486	230
-4 to 10.9	29155	28147	1008
11 to 25.9	12967	11647	1320
26 to 40.9	4315	3922	393
41 to 55.9	635	579	56
56 to 70.9	20	20	0
71 to 86	0	0	0
Total	81225	78204	3021

Reddish Knob-Cell number per elevation class			
Elevation	Total	Not Pine	Pine
200-299	0	0	0
300-399	0	0	0
400-499	0	0	0
500-599	1686	1334	352
600-699	10977	9924	1053
700-799	21079	19423	1656
800-899	20942	18252	2690
900-999	14825	12318	2507
1000-1099	8558	7171	1387
1100-1199	3457	2975	482
1200-1299	1034	894	140
1300-1399	98	98	0
1400-1499	0	0	0
Total	82656	72389	10267

Shenandoah-Cell number per elevation class			
Elevation	Total	Not Pine	Pine
200-299	1019	1019	0
300-399	4054	4054	0
400-499	6787	6787	0
500-599	8075	8075	0
600-699	12379	12344	35
700-799	16836	15331	1505
800-899	12208	11720	488
900-999	11698	10862	836
1000-1099	5792	5654	138
1100-1199	2307	2288	19
1200-1299	70	70	0
1300-1399	0	0	0
1400-1499	0	0	0
Total	81225	78204	3021

Reddish Knob-Cell number per radiation class			
Radiation	Total	Not Pine	Pine
4900-5099	2355	2264	91
5100-5299	3254	3082	172
5300-5499	6234	5765	469
5500-5699	9721	8657	1064
5700-5899	13908	12374	1534
5900-6099	18451	16131	2320
6100-6299	19535	16542	2993
6300-6499	7610	6260	1350
6500-6699	1575	1301	274
6700+	13	13	0
Total	82656	72389	10267

Shenandoah-Cell number per radiation class			
Radiation	Total	Not Pine	Pine
4900-5099	1983	1956	27
5100-5299	2693	2669	24
5300-5499	4422	4364	58
5500-5699	7494	7401	93
5700-5899	13866	13619	247
5900-6099	19771	19336	435
6100-6299	15521	14618	903
6300-6499	12851	11637	1214
6500-6699	2624	2604	20
6700+	0	0	0
Total	81225	78204	3021

Reddish Knob-Cell number per TWI class			
TWI	Total	Not Pine	Pine
2-4.1	7431	6315	1116
4.1-6.2	51247	44014	7233
6.2-8.3	15149	13936	1213
8.3-10.4	4087	3781	306
10.4-12.5	1802	1695	107
12.5-14.6	752	713	39
14.6-16.7	147	141	6
16.7-18.8	12	12	0
18.8-20.9	2	2	0
20.9-23	0	0	0
NAs	2027	70609	247
Total	82656	141218	10267

Shenandoah-Cell number per TWI class			
TWI	Total	Not Pine	Pine
2-4.1	3761	3624	137
4.1-6.2	42979	40913	2066
6.2-8.3	23168	22610	558
8.3-10.4	7010	6854	156
10.4-12.5	2201	2119	82
12.5-14.6	808	792	16
14.6-16.7	254	252	2
16.7-18.8	55	55	0
18.8-20.9	4	4	0
20.9-23	1	1	0
NAs	984	980	4
Total	81225	78204	3021

Reddish Knob-Cell number per slope class			
Slope	Total	Not Pine	Pine
0-6.9	5756	4473	1283
7-13.9	14281	12206	2075
14-20.9	20580	17502	3078
21-27.9	24194	21488	2706
28-34.9	15053	14046	1007
35-41.9	2603	2495	108
42-48.9	189	179	10
49-55.9	0	0	0
56-62.9	0		0
63-70	0		0
Total	82656	72389	10267

Shenandoah-Cell number per slope class			
Slope	Total	Not Pine	Pine
0-6.9	9266	8205	1061
7-13.9	22950	22187	763
14-20.9	21435	20887	548
21-27.9	17611	17197	414
28-34.9	8120	7951	169
35-41.9	1777	1717	60
42-48.9	65	59	6
49-55.9	1	1	0
56-62.9	0		0
63-70	0		0
Total	81225	78204	3021

Reddish Knob-Cell number per aspect class			
Aspect	Total	Not Pine	Pine
North	10353	8422	1931
Northeast	13242	11859	1383
East	13275	12251	1024
Southeast	9594	8925	669
South	13232	12063	1169
Southwest	11167	9669	1498
West	5480	4221	1259
Northwest	6223	4898	1325
Flat	90	81	9
Total	82656	72389	10267

Shenandoah-Cell number per aspect class			
Aspect	Total	Not Pine	Pine
North	8615	8363	252
Northeast	11288	11027	261
East	15105	14736	369
Southeast	11928	11694	234
South	10219	9829	390
Southwest	9350	8690	660
West	8273	7727	546
Northwest	6447	6138	309
Flat	0	0	0
Total	81225	78204	3021

Reddish Knob-Cell number per heat load class			
Linearized Aspect	Total	Not Pine	Pine
0-0.09	22205	20070	2135
0.1-0.19	8955	7984	971
0.2-0.29	5958	5161	797
0.3-0.39	4696	3971	725
0.4-0.49	4303	3733	570
0.5-0.59	4064	3558	506
0.6-0.69	4529	4007	522
0.7-0.79	5183	4554	629
0.8-0.89	7585	6554	1031
0.9-1	15178	12797	2381
Total	82656	72389	10267

Shenandoah-Cell number per heat load class			
Linearized Aspect	Total	Not Pine	Pine
0-0.09	20719	20238	481
0.1-0.19	9032	8786	246
0.2-0.29	6438	6299	139
0.3-0.39	5404	5271	133
0.4-0.49	4630	4500	130
0.5-0.59	4379	4243	136
0.6-0.69	4585	4416	169
0.7-0.79	4904	4713	191
0.8-0.89	6057	5740	317
0.9-1	15077	13998	1079
Total	81225	78204	3021

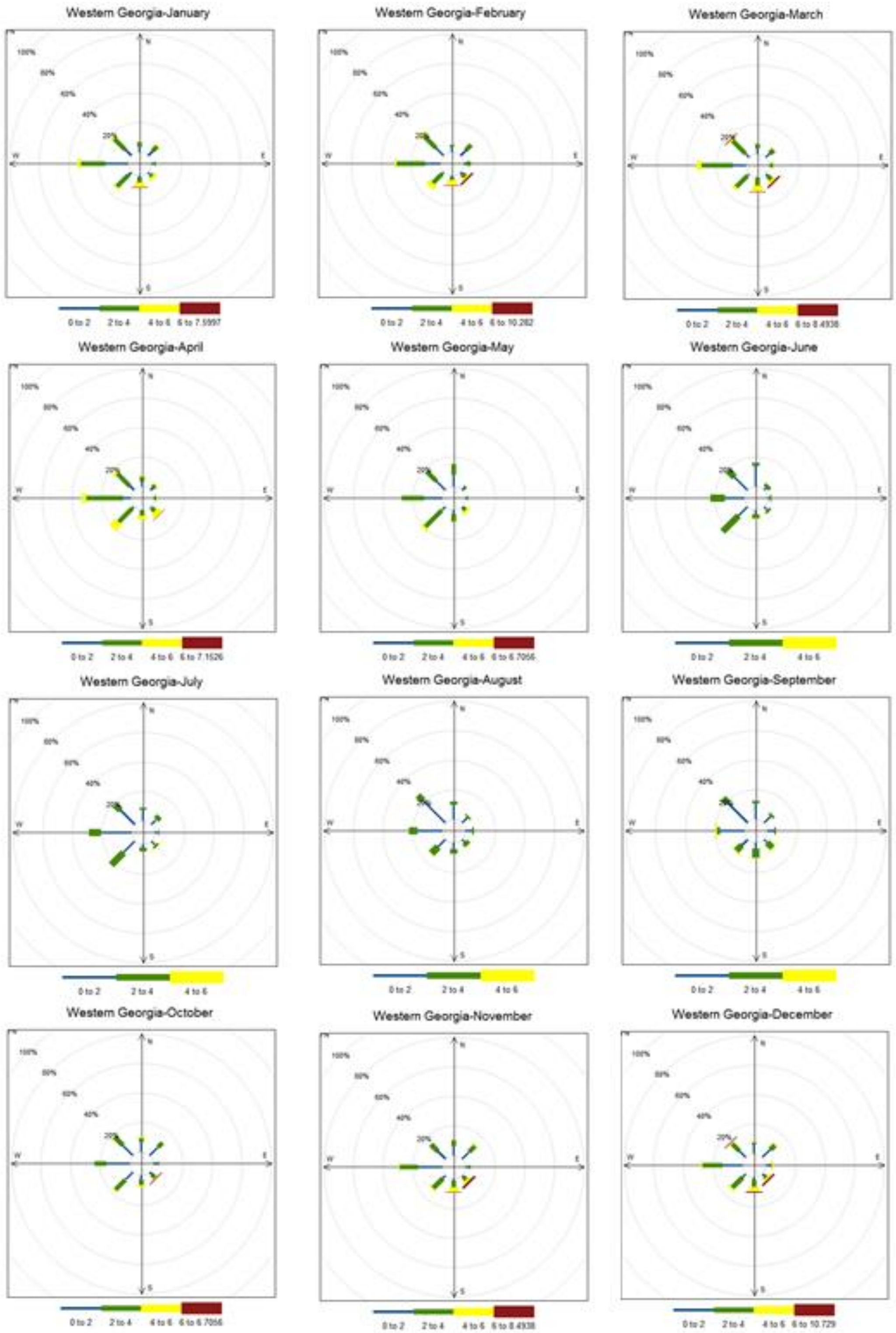
Reddish Knob-Cell number per soil type			
Dominant Drainage Ability	Total	Not Pine	Pine
Very poorly drained	0	0	0
Poorly Drained	0	0	0
Somewhat poorly drained	0	0	0
Moderately well drained	363	317	46
Well drained	62900	56512	6388
Somewhat excessively drained	18	17	1
Excessively drained	5019	3243	1776
Total	68300	60089	8211

Shenandoah-Cell number per soil type			
Dominant Drainage Ability	Total	Not Pine	Pine
Very poorly drained	0	0	0
Poorly Drained	159	151	8
Somewhat poorly drained	0	0	0
Moderately well drained	39	39	0
Well drained	22172	21127	1045
Somewhat excessively drained	8523	8373	150
Excessively drained	39	39	0
Total	30932	29729	1203

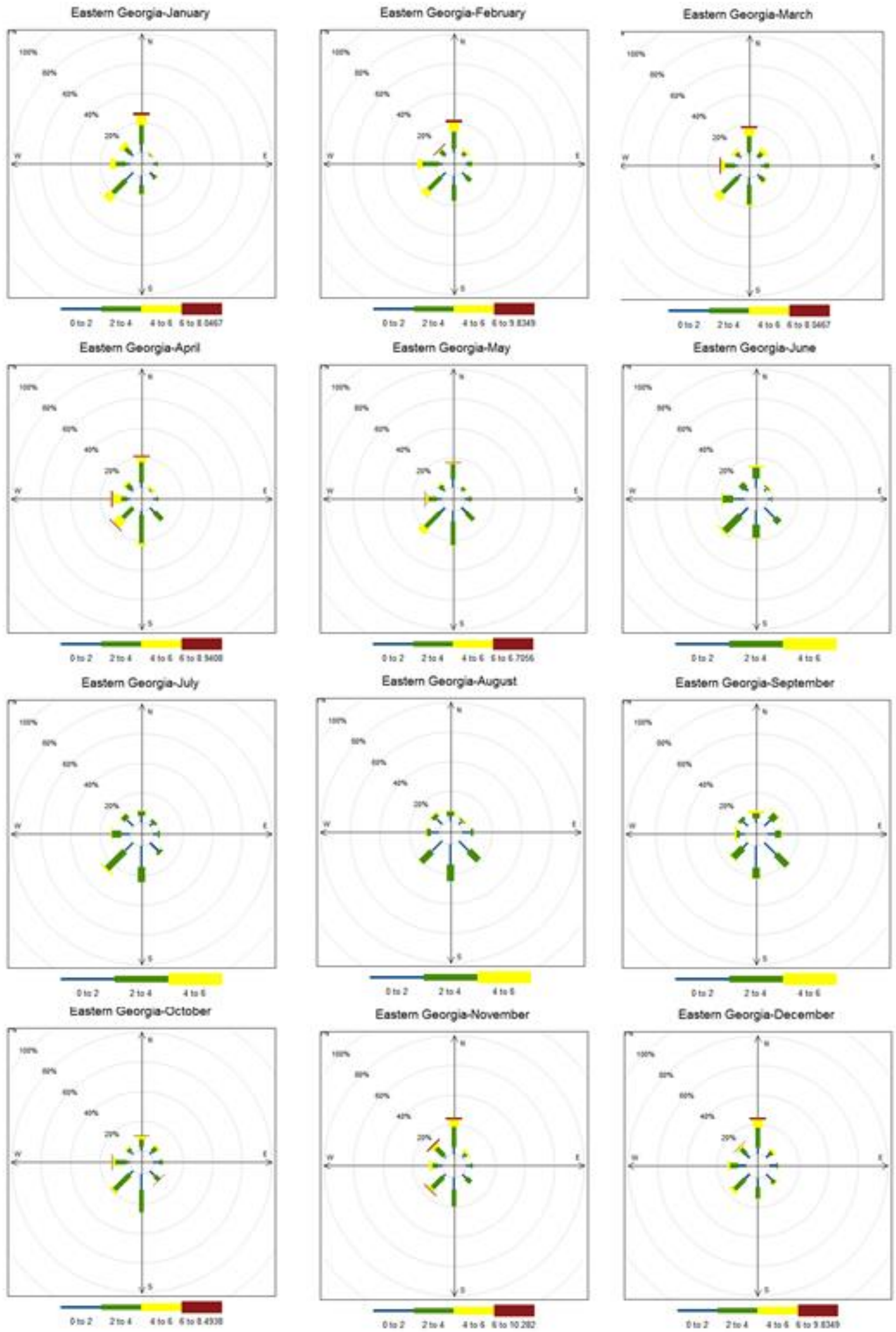
APPENDIX B

Monthly wind roses

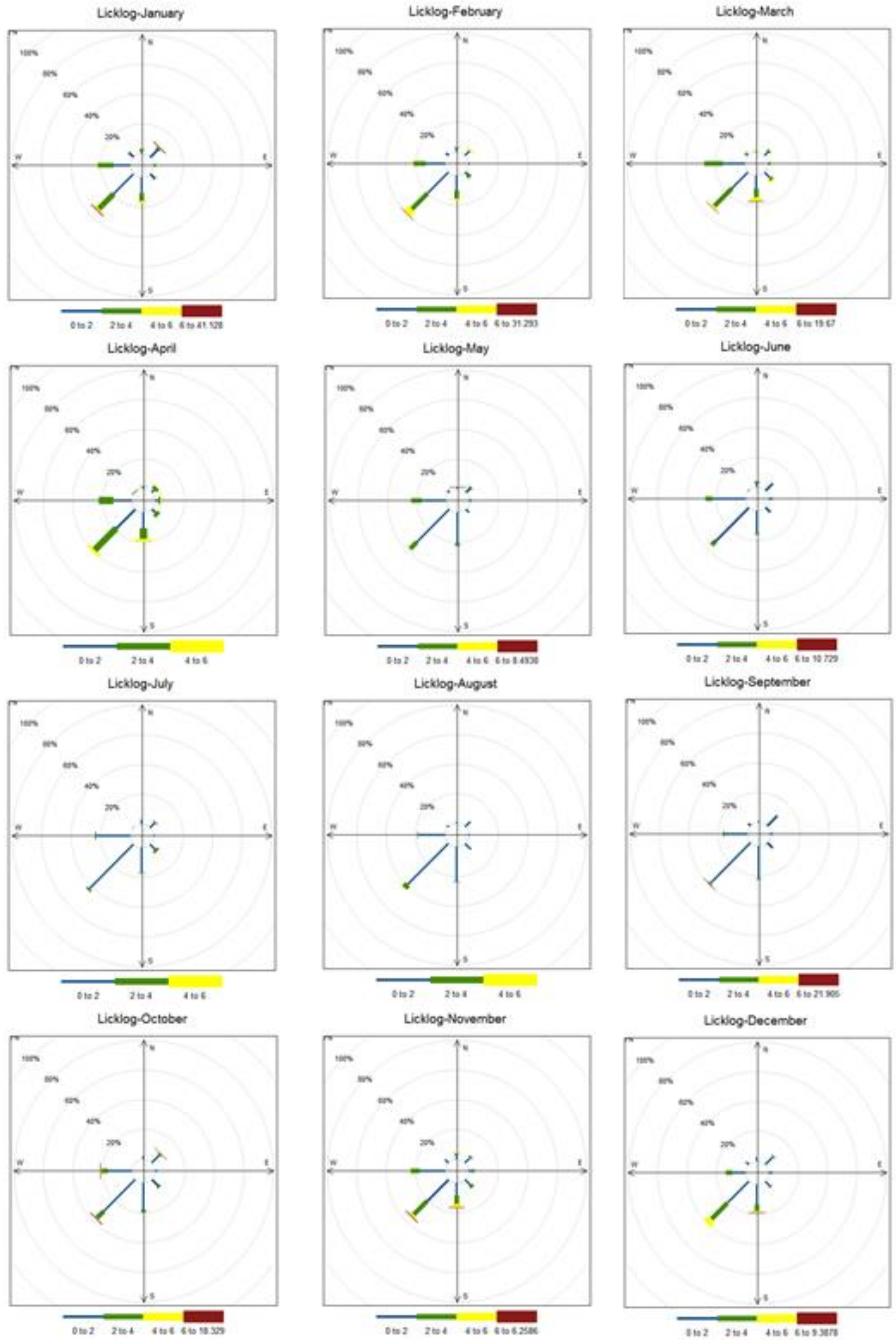
Monthly wind roses at Western Georgia. Wind speed shown in meters/second.



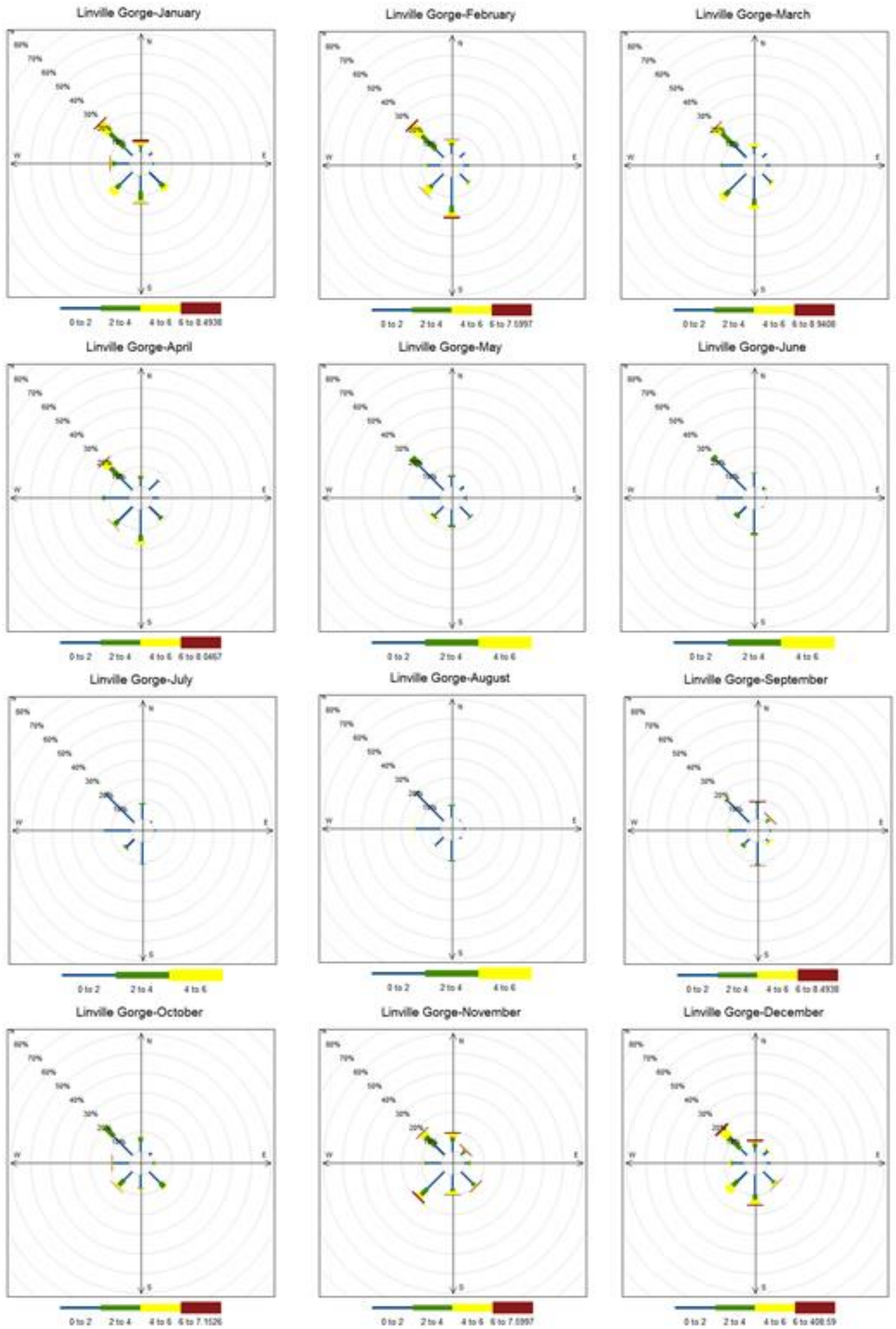
Monthly wind roses at Eastern Georgia. Wind speed shown in meters/second.



Monthly wind roses at Licklog. Wind speed shown in meters/second.

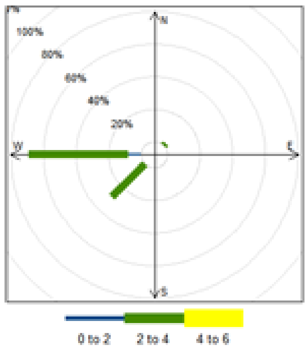


Monthly wind roses at Linville Gorge. Wind speed shown in meters/second.

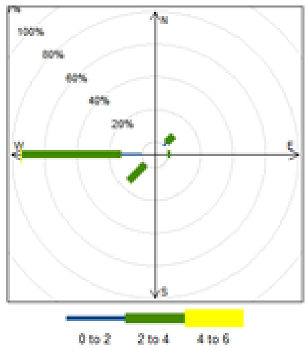


Monthly wind roses at Holston Mountain. Wind speed shown in meters/second.

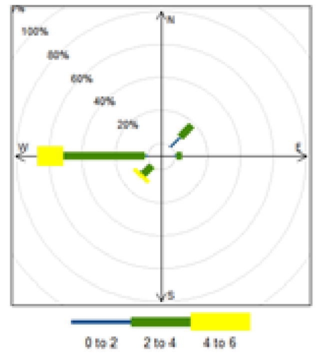
Holston Mountain-January



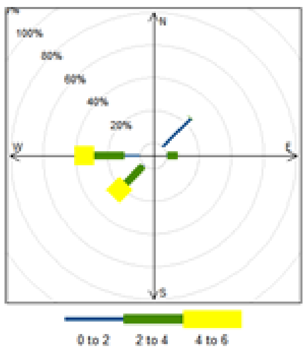
Holston Mountain-February



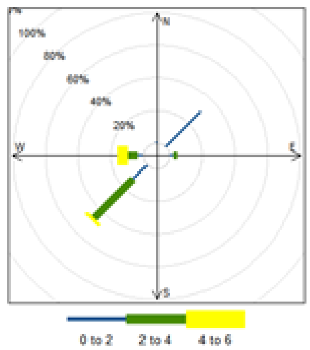
Holston Mountain-March



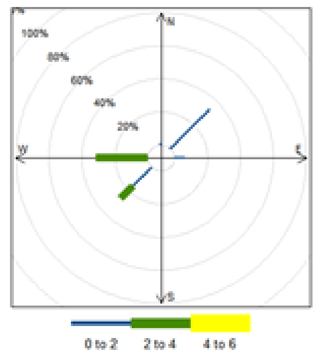
Holston Mountain-April



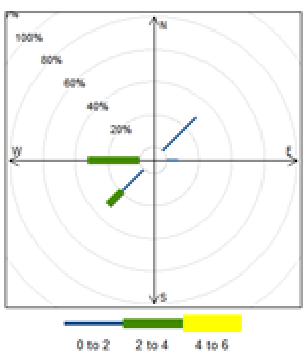
Holston Mountain-May



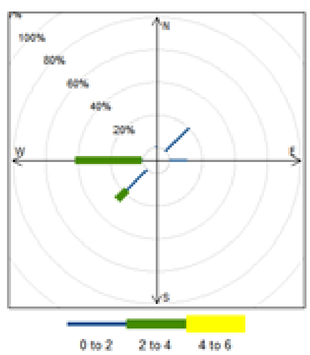
Holston Mountain-June



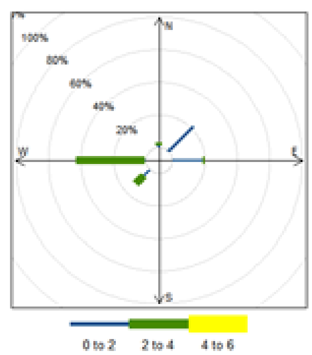
Holston Mountain-July



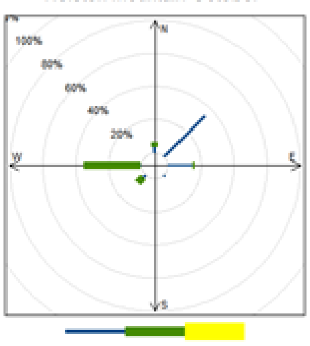
Holston Mountain-August



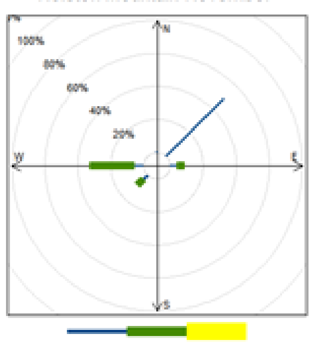
Holston Mountain-September



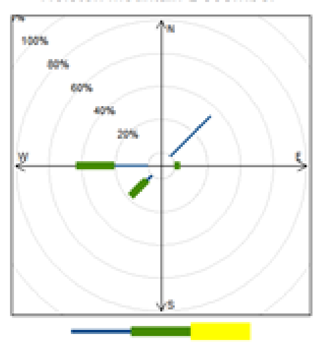
Holston Mountain-October



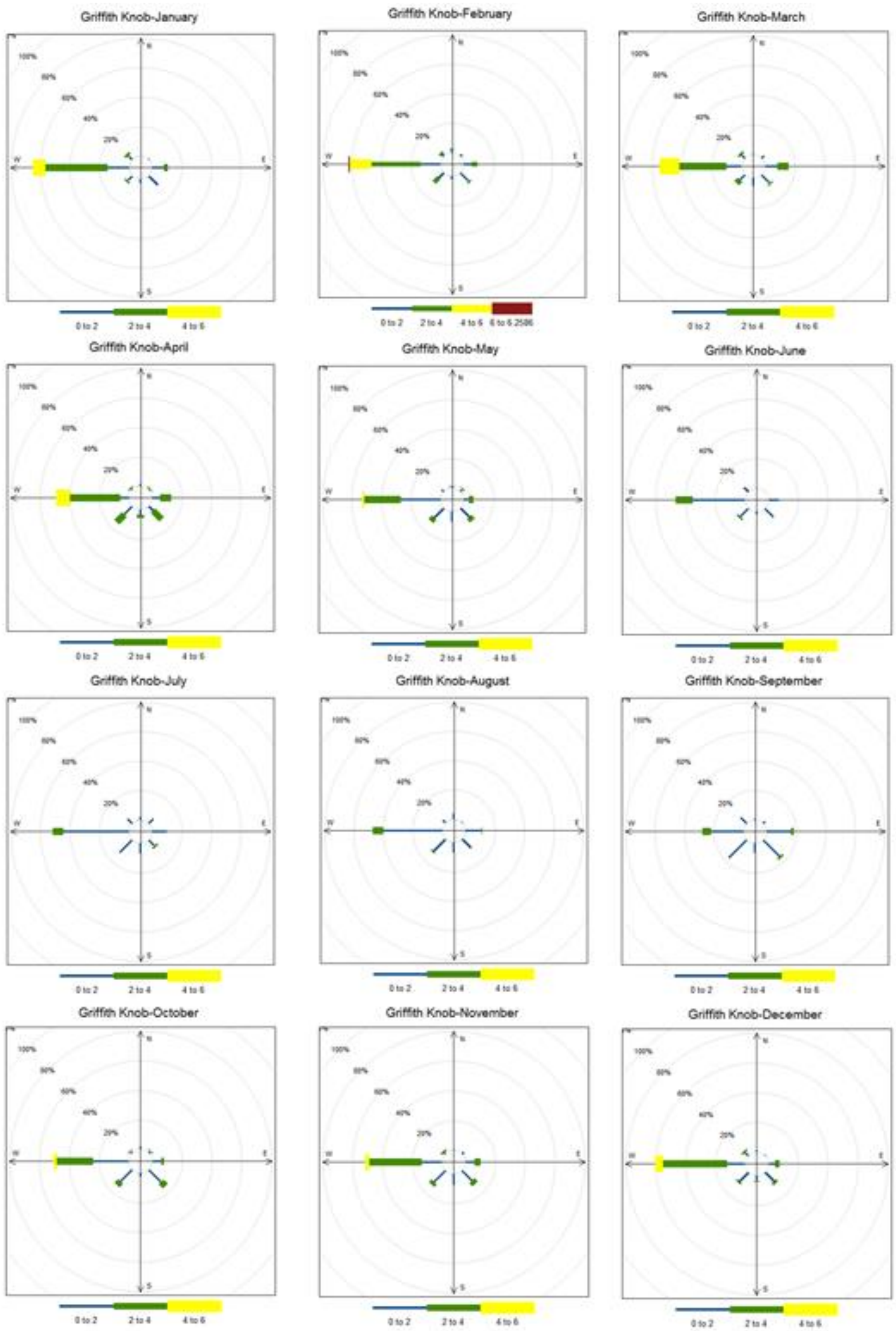
Holston Mountain-November



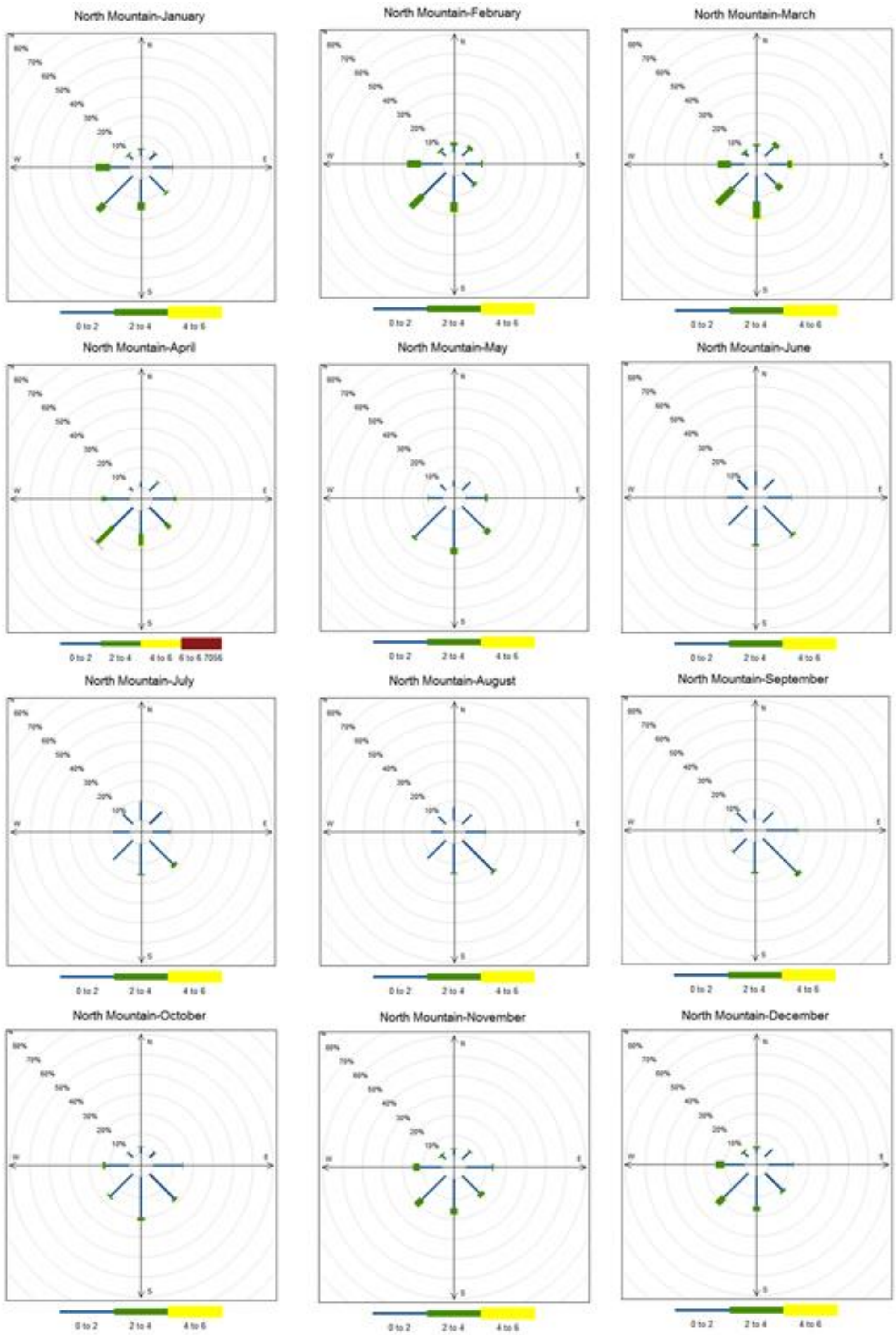
Holston Mountain-December



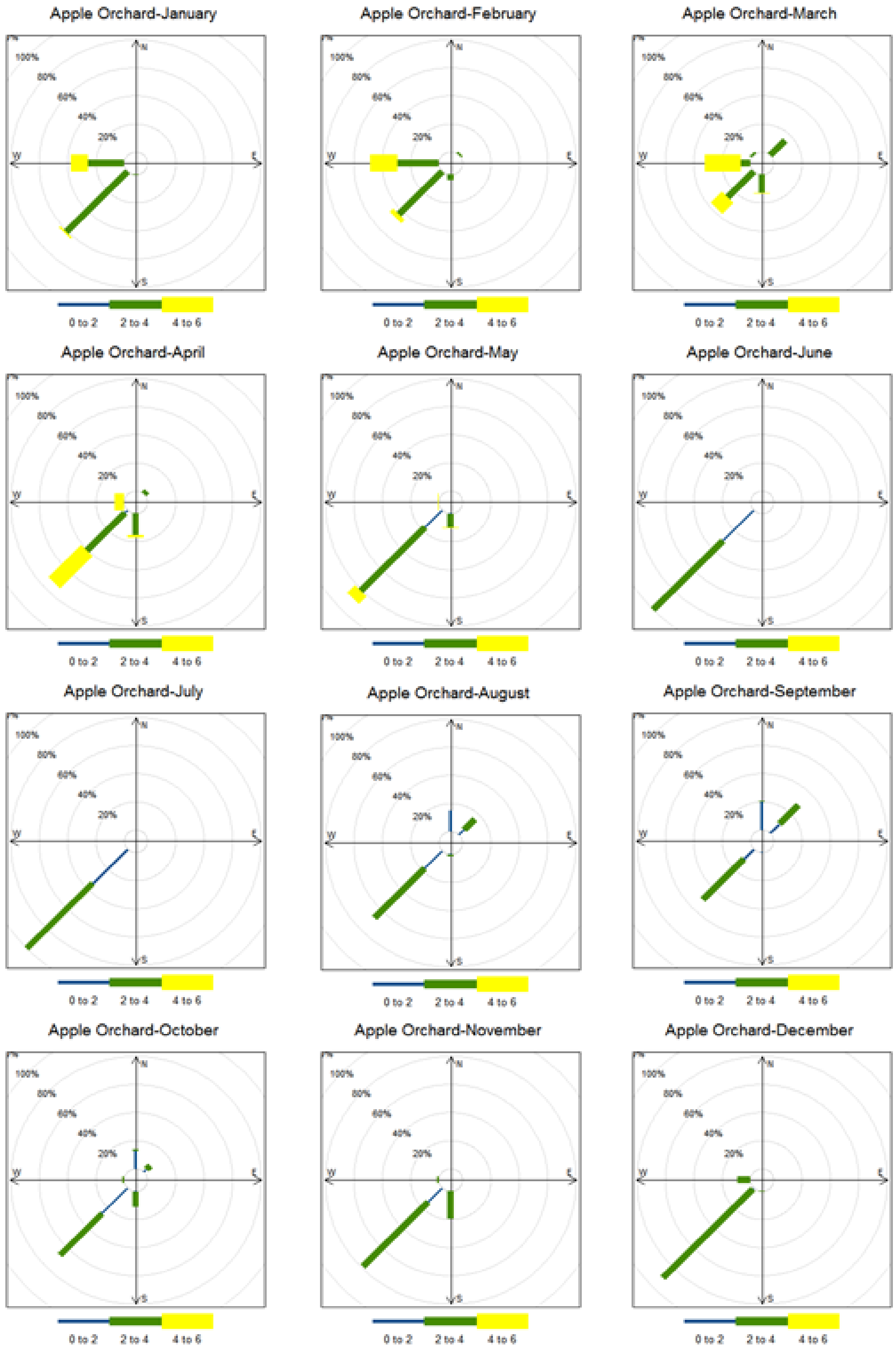
Monthly wind rose at Griffith Knob. Wind speed shown in meters/second.



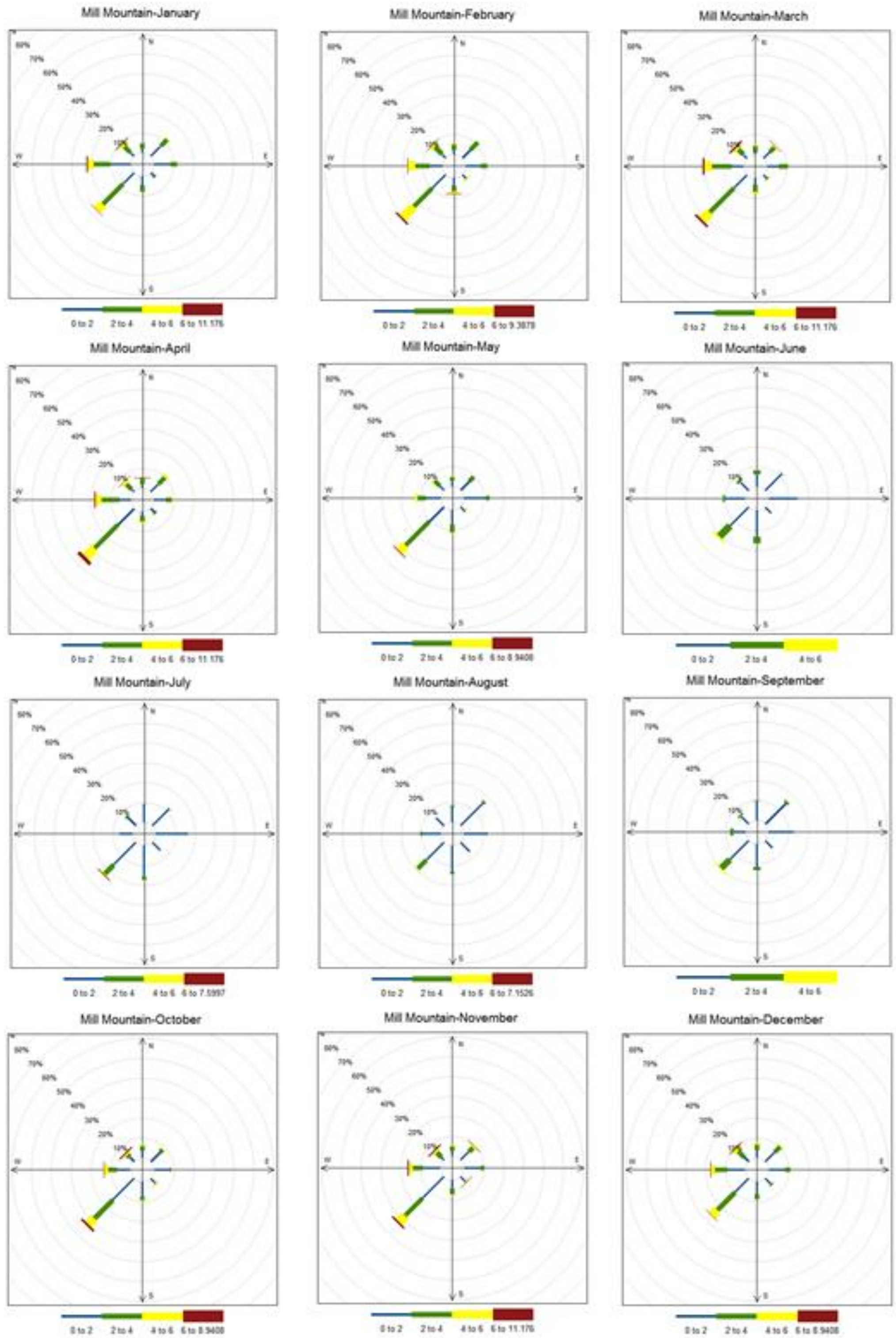
Monthly wind roses at North Mountain. Wind speed shown in meters/second.



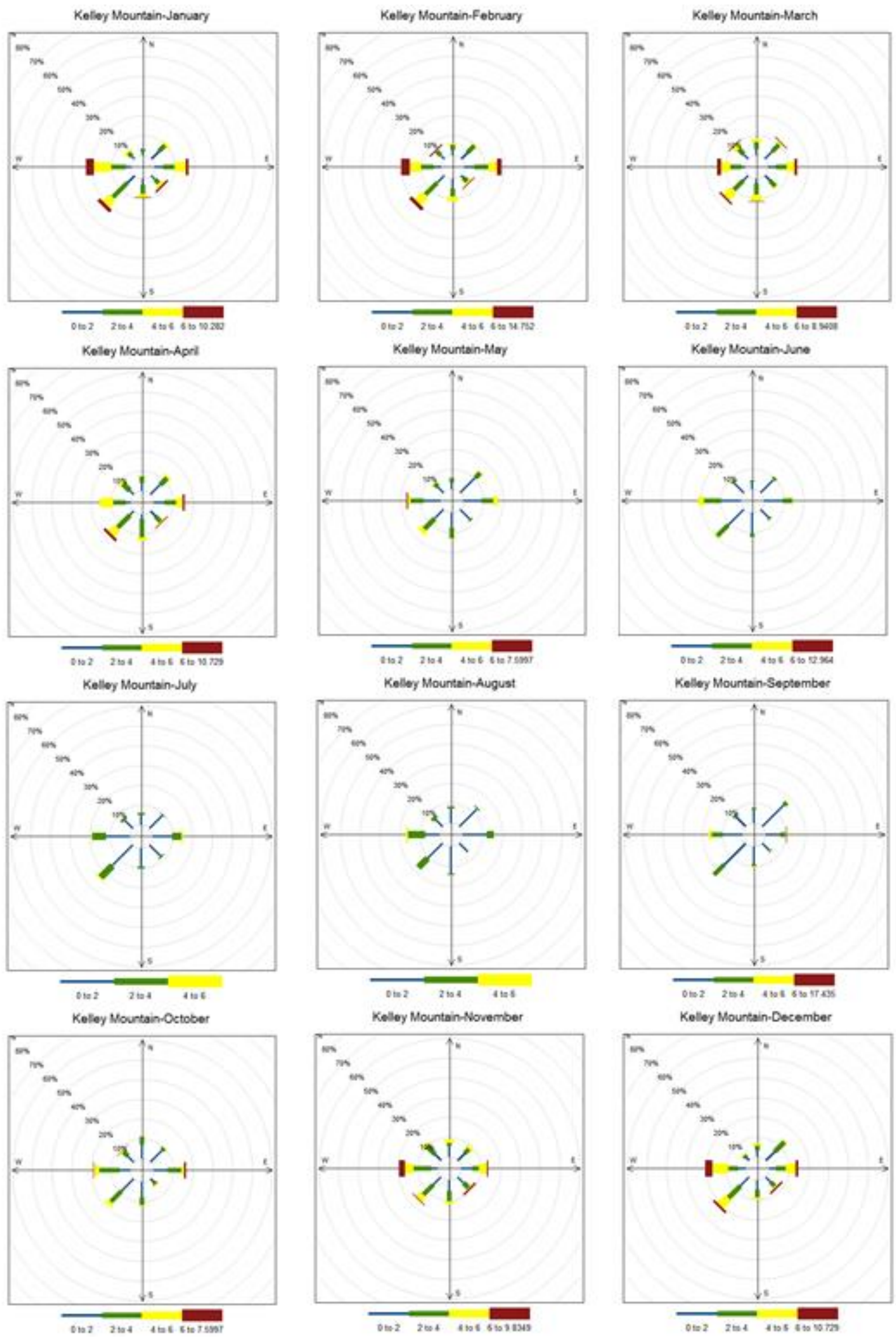
Monthly wind roses at Apple Orchard. Wind speed shown in meters/second.



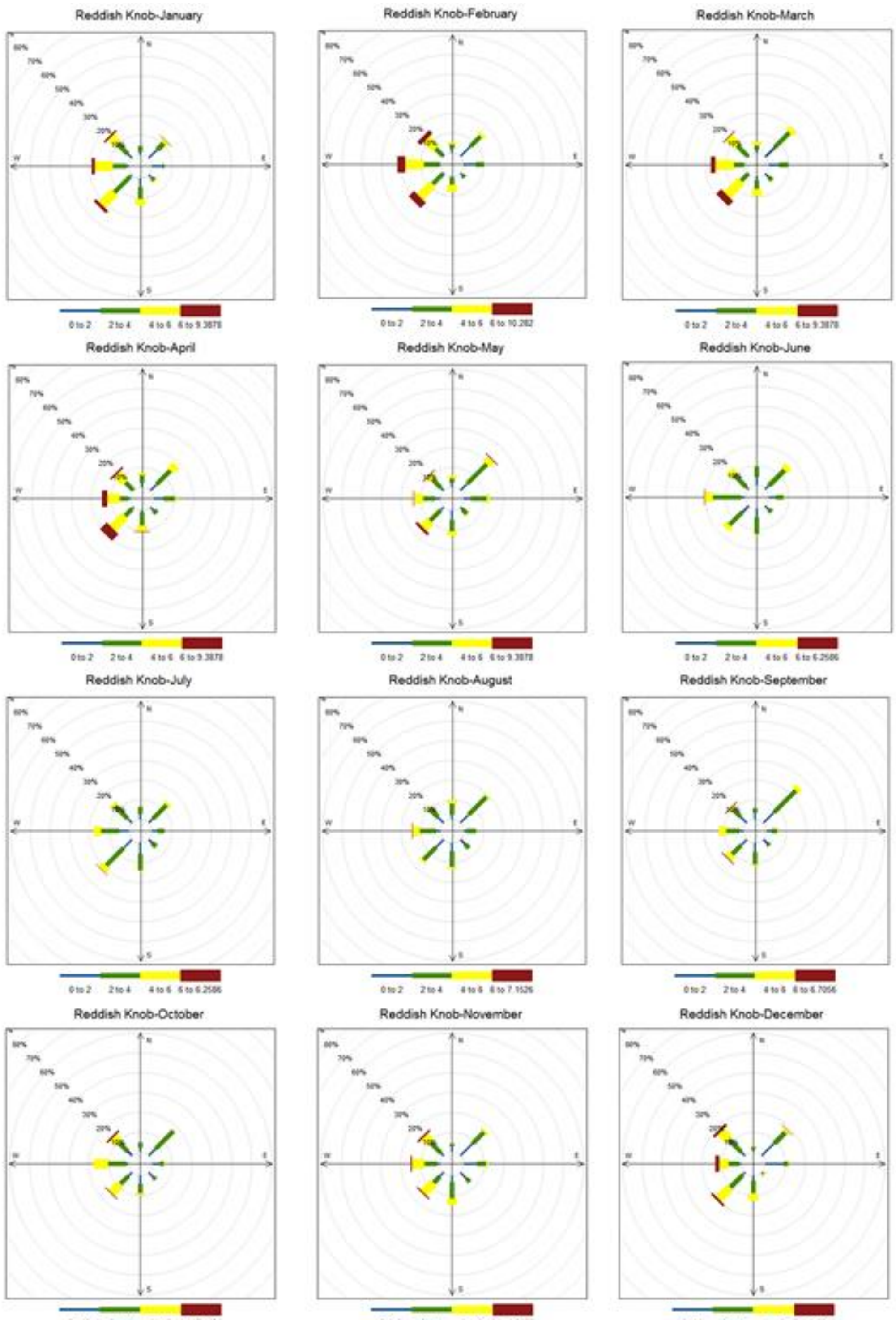
Monthly wind roses at Mill Mountain. Wind speed shown in meters/second.



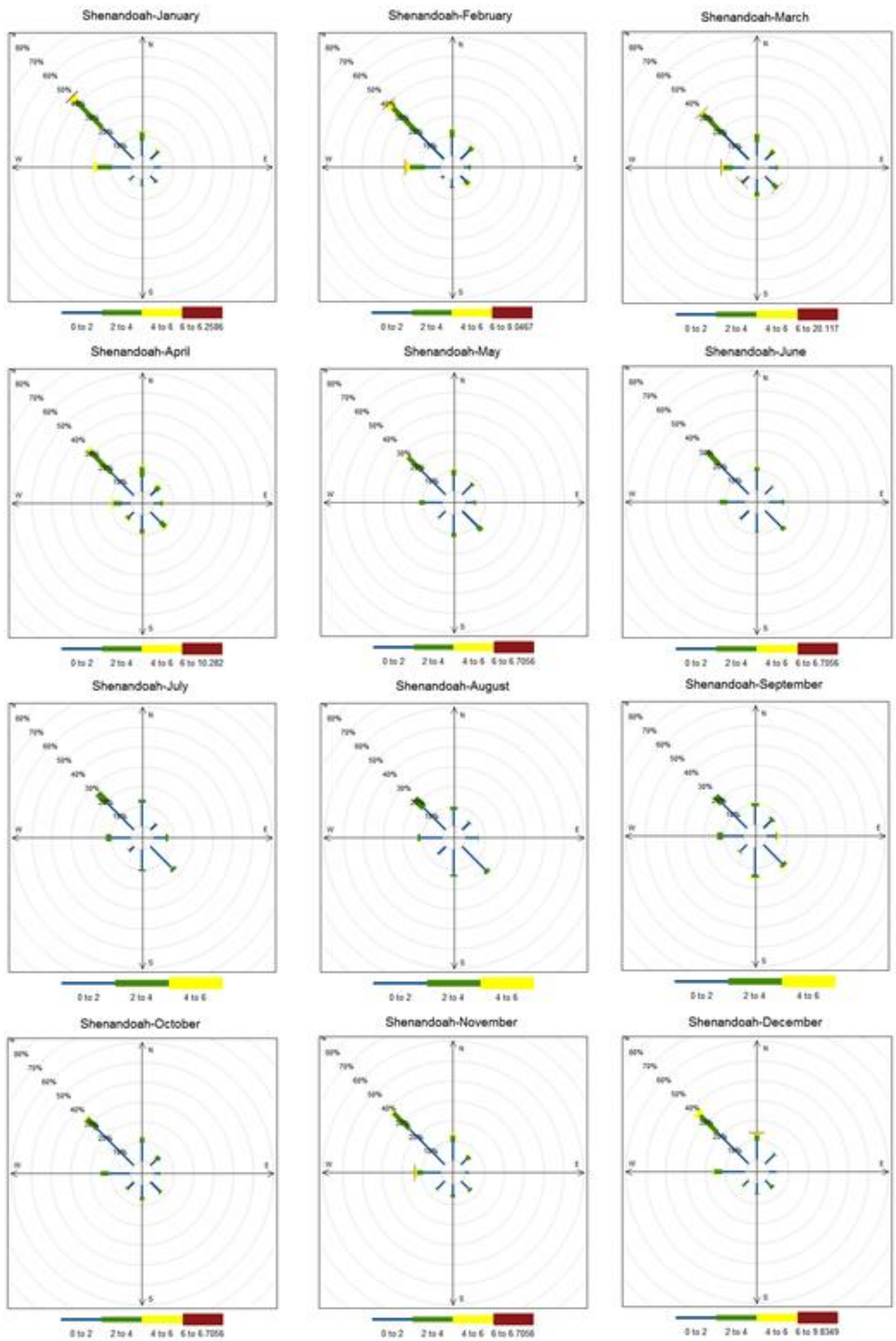
Monthly wind rose at Kelley Mountain. Wind speed shown in meters/second.



Monthly wind rose at Reddish Knob. Wind speed shown in meters/second.



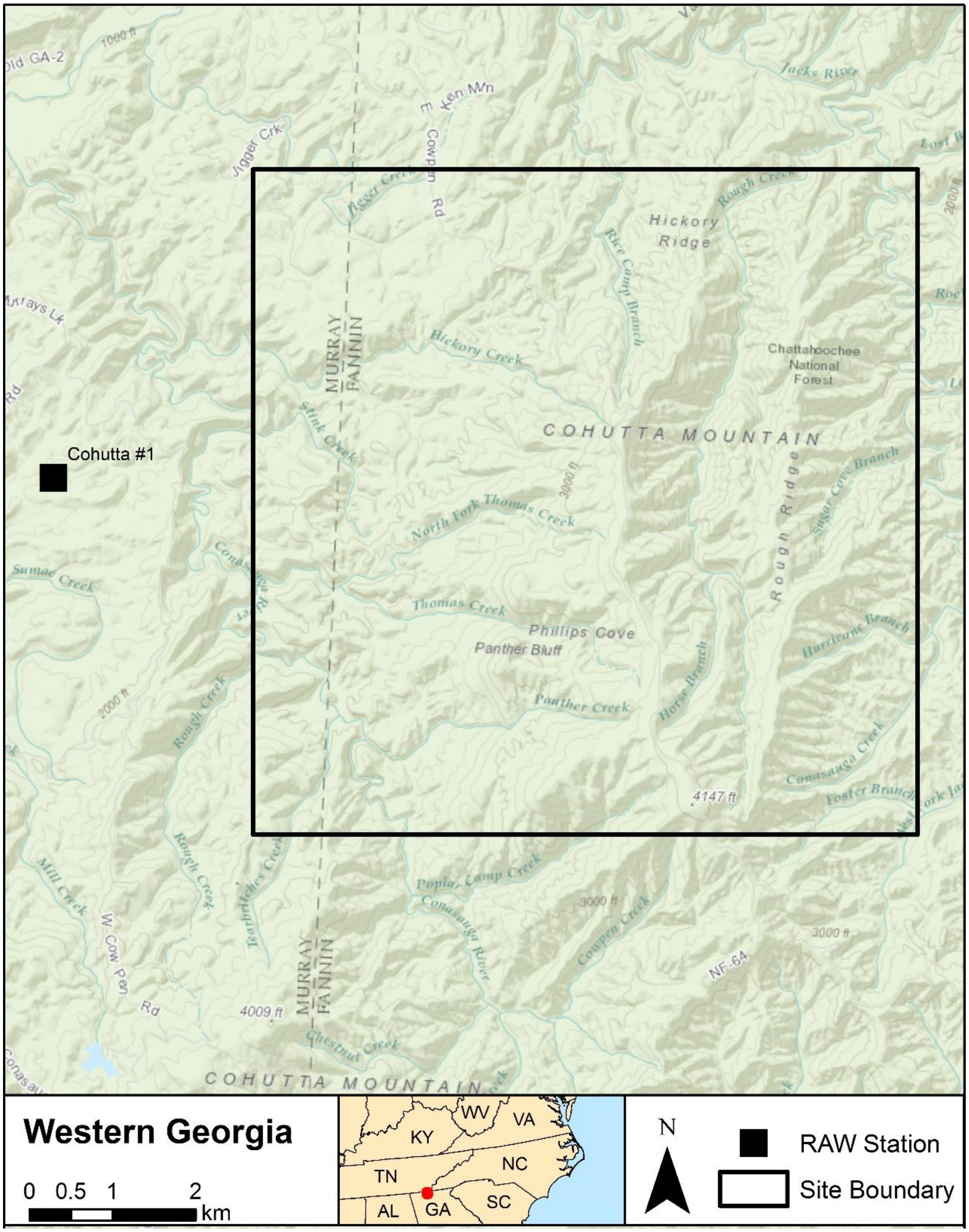
Monthly wind rose at Shenandoah. Wind speed shown in meters/second.



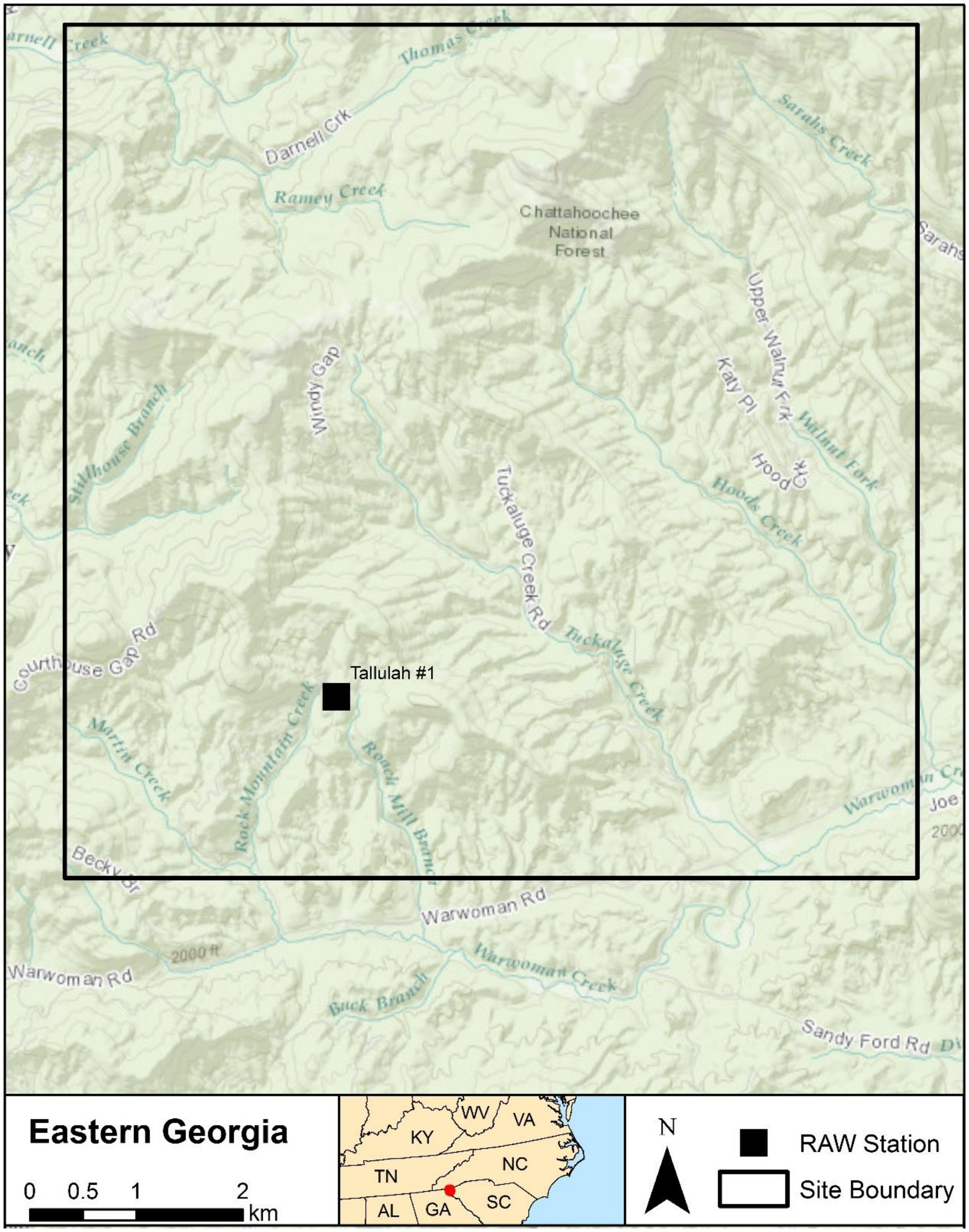
APPENDIX C

Landscape maps

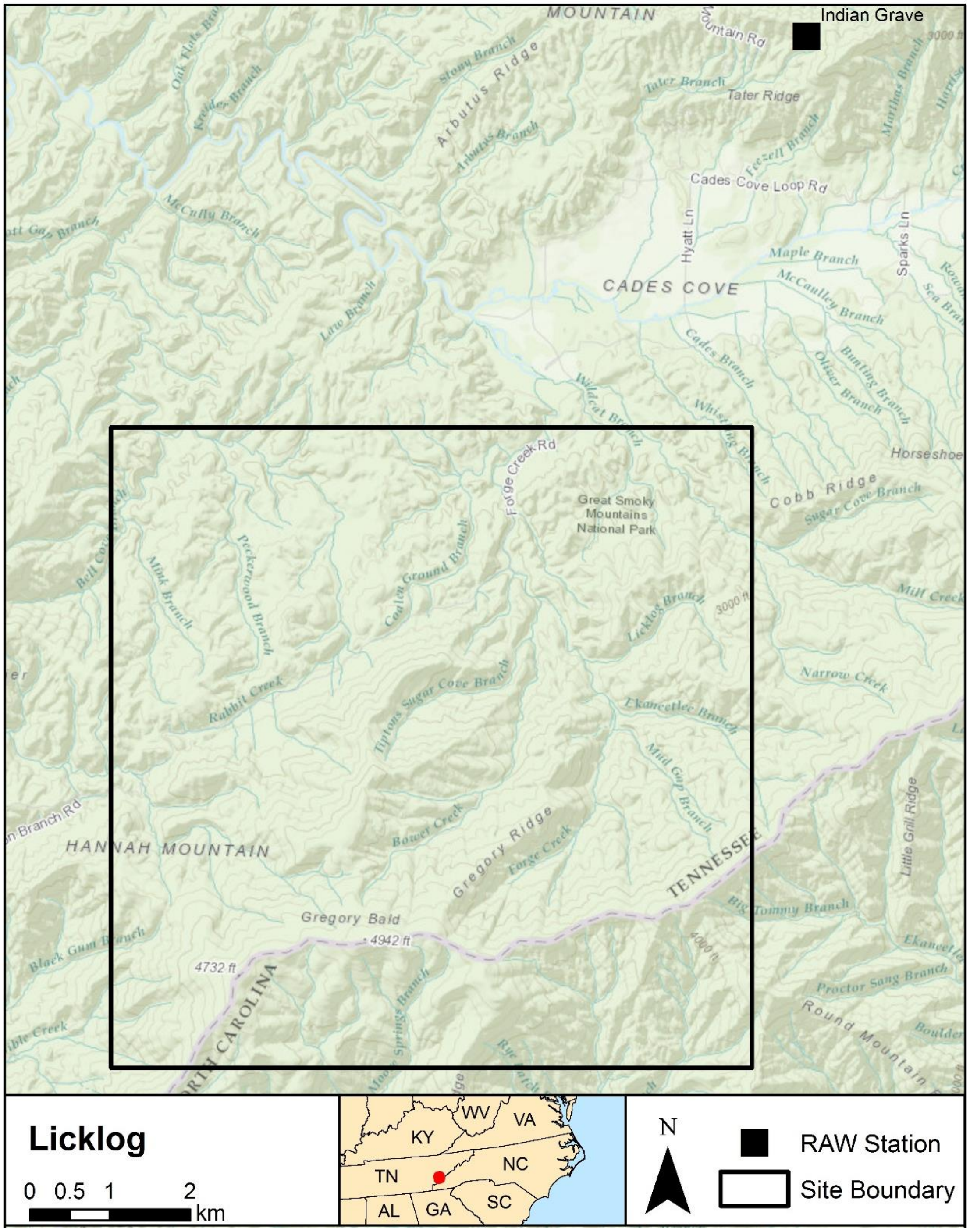
Landscape map for Western Georgia. Basemaps reprinted from ESRI Basemaps.



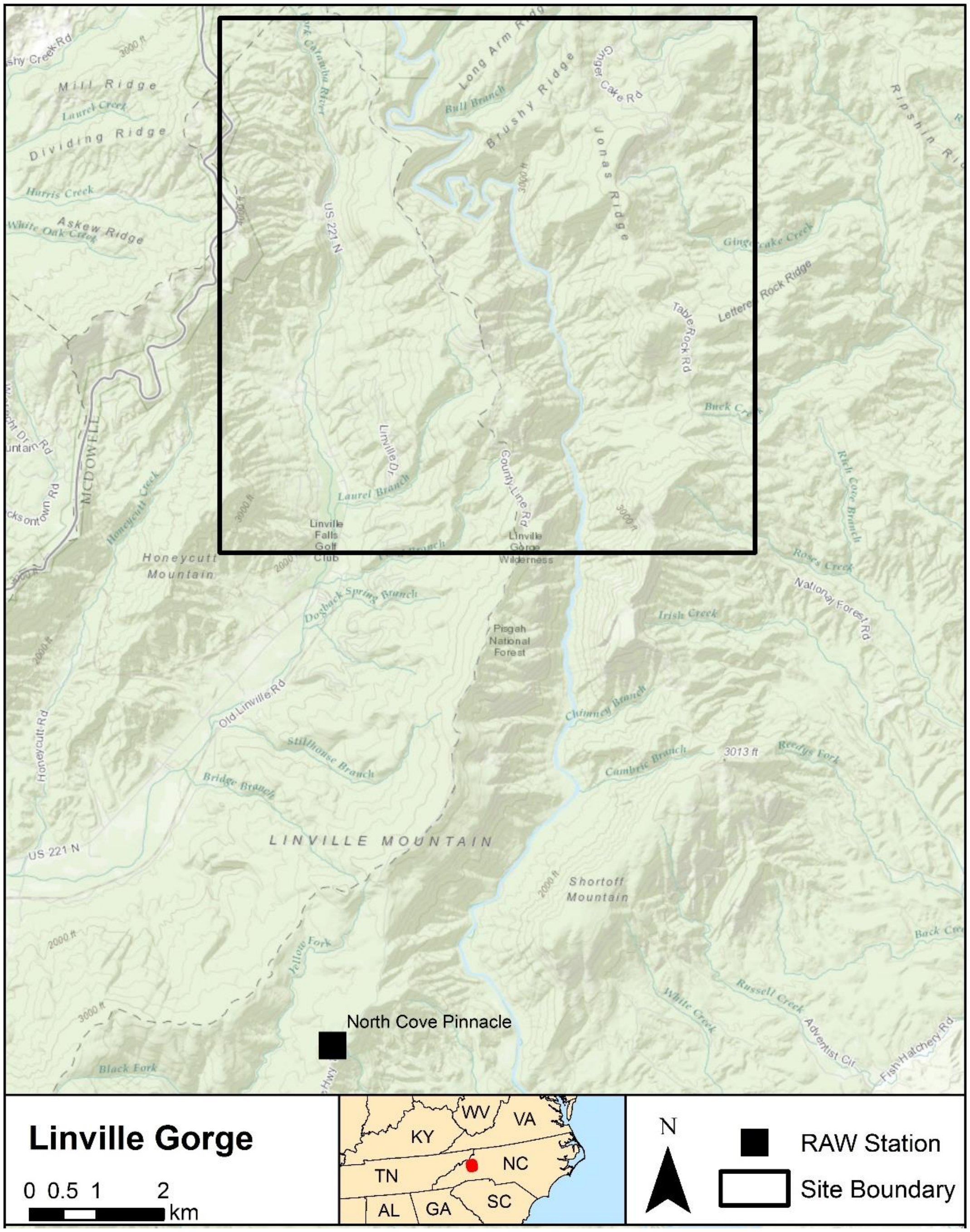
Landscape map for Eastern Georgia. Basemaps reprinted from ESRI Basemaps.



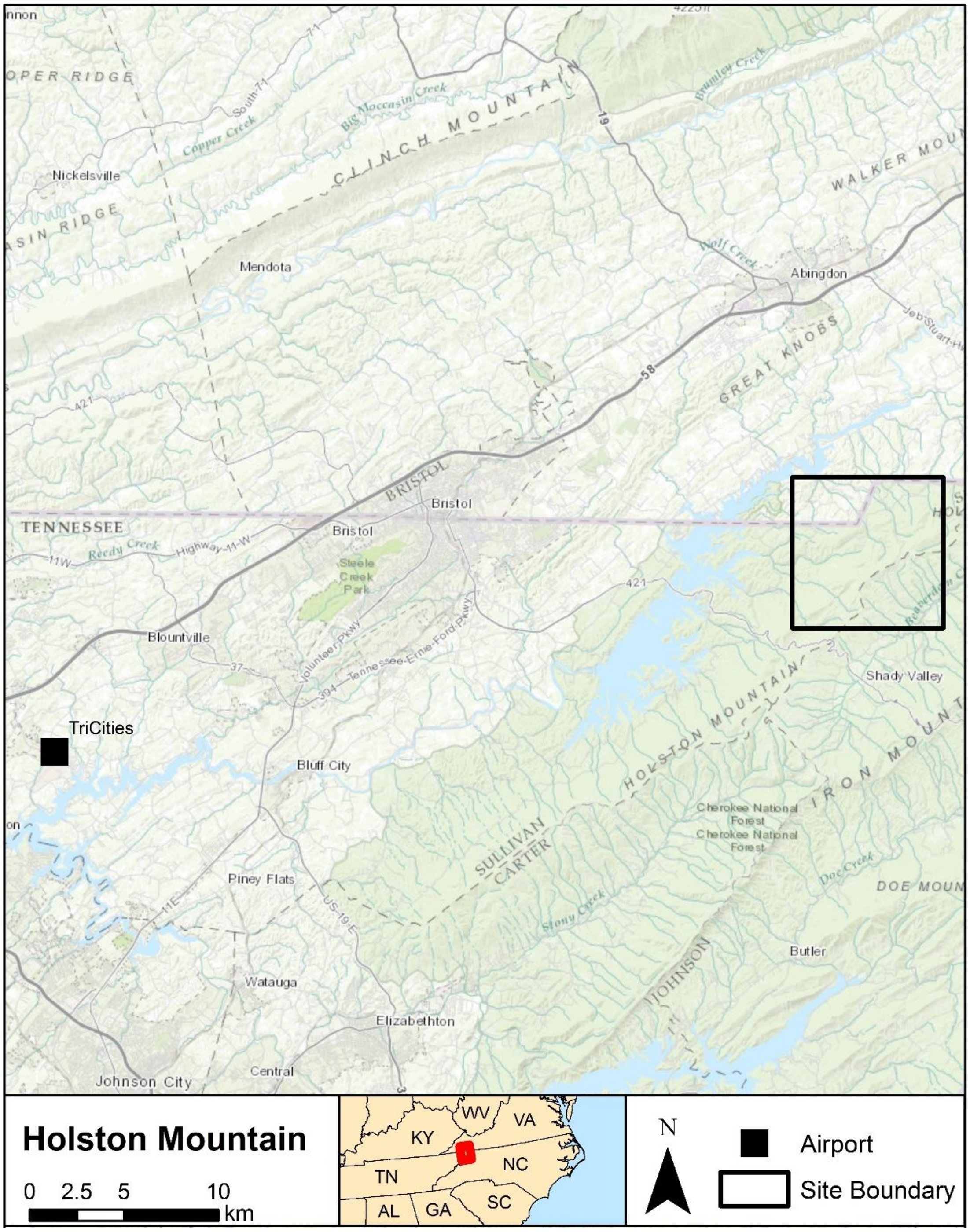
Landscape map for Licklog. Basemaps reprinted from ESRI Basemaps.



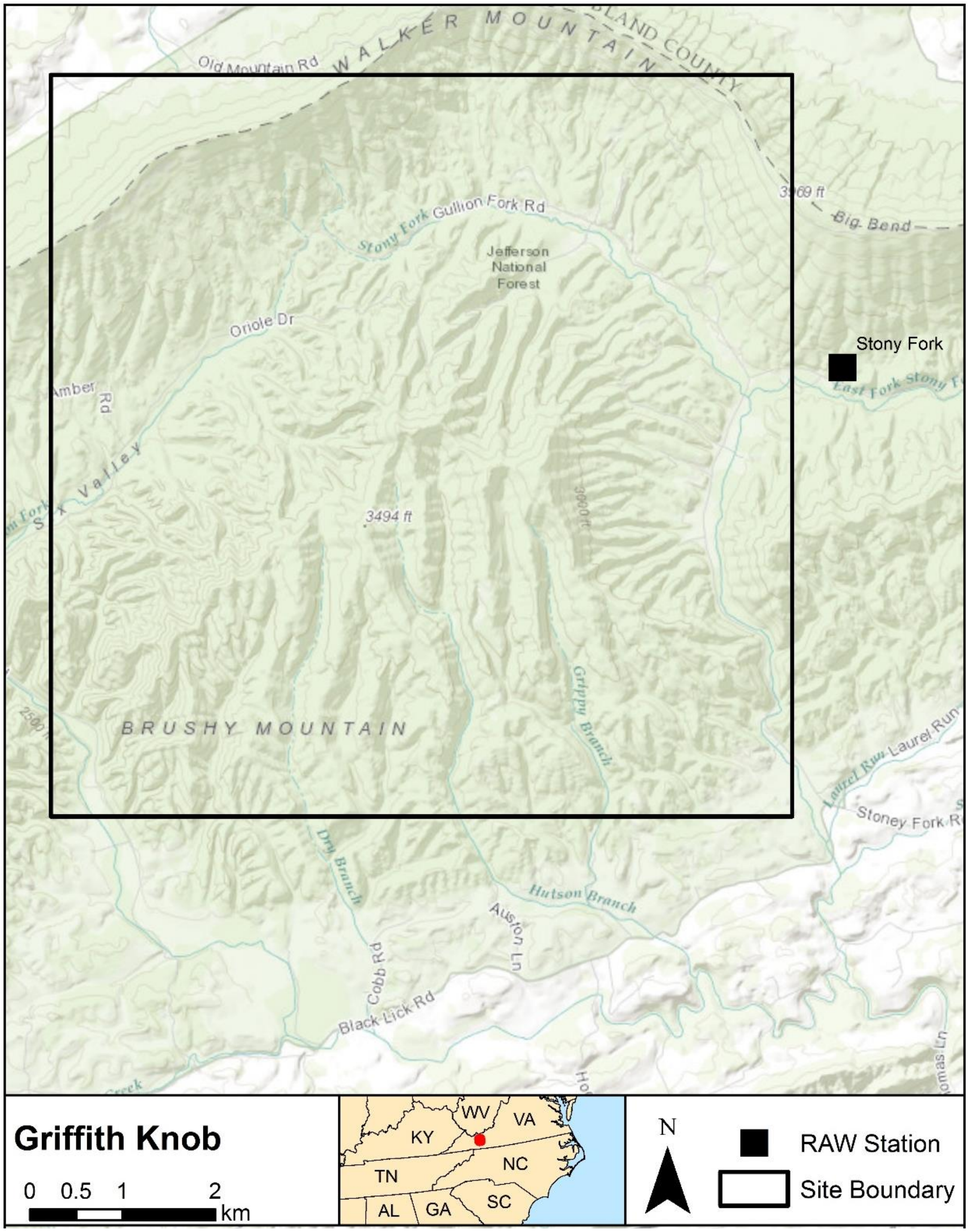
Landscape map for Linville Gorge. Basemaps reprinted from ESRI Basemaps.



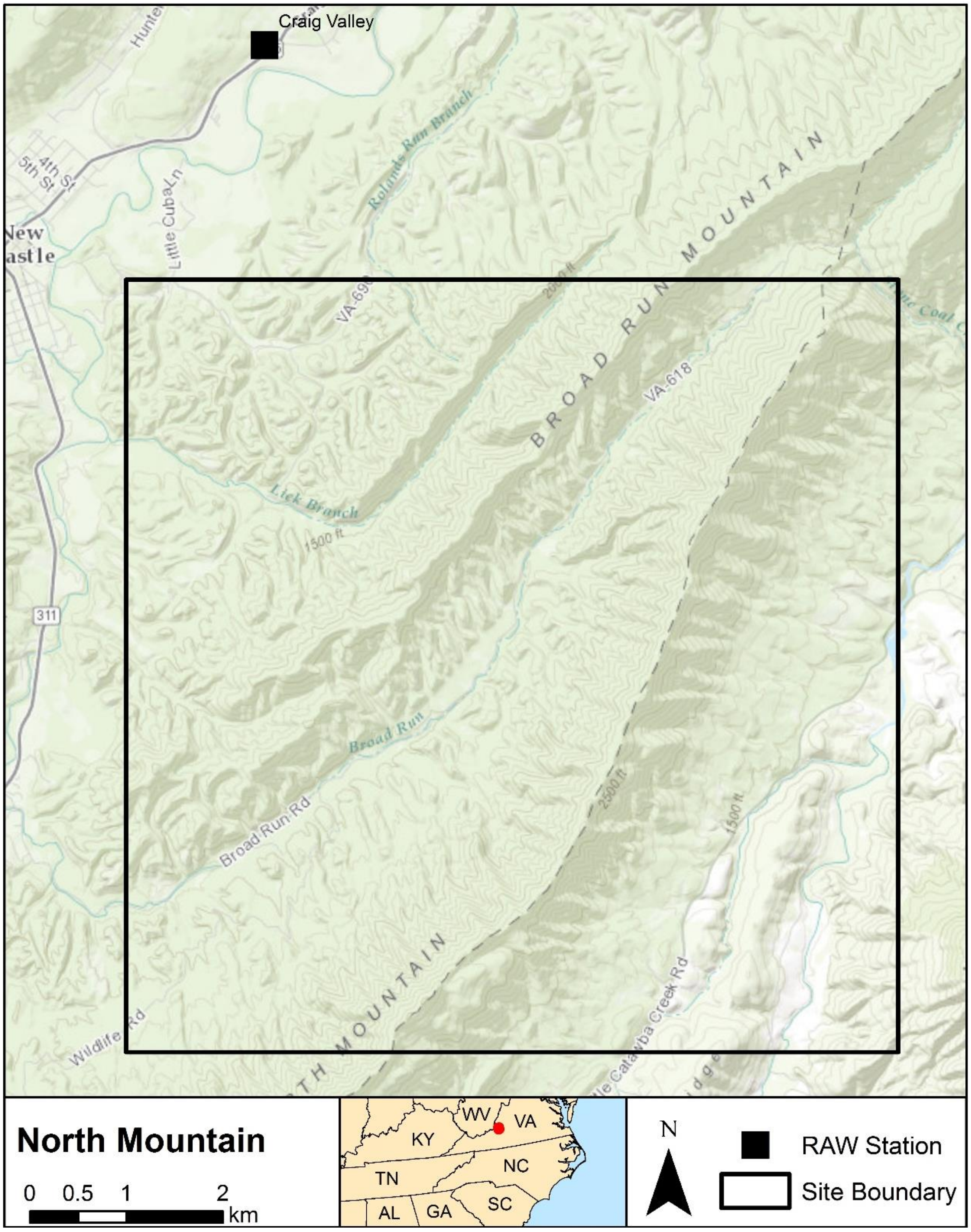
Landscape map for Holston Mountain. Basemaps reprinted from ESRI Basemaps.



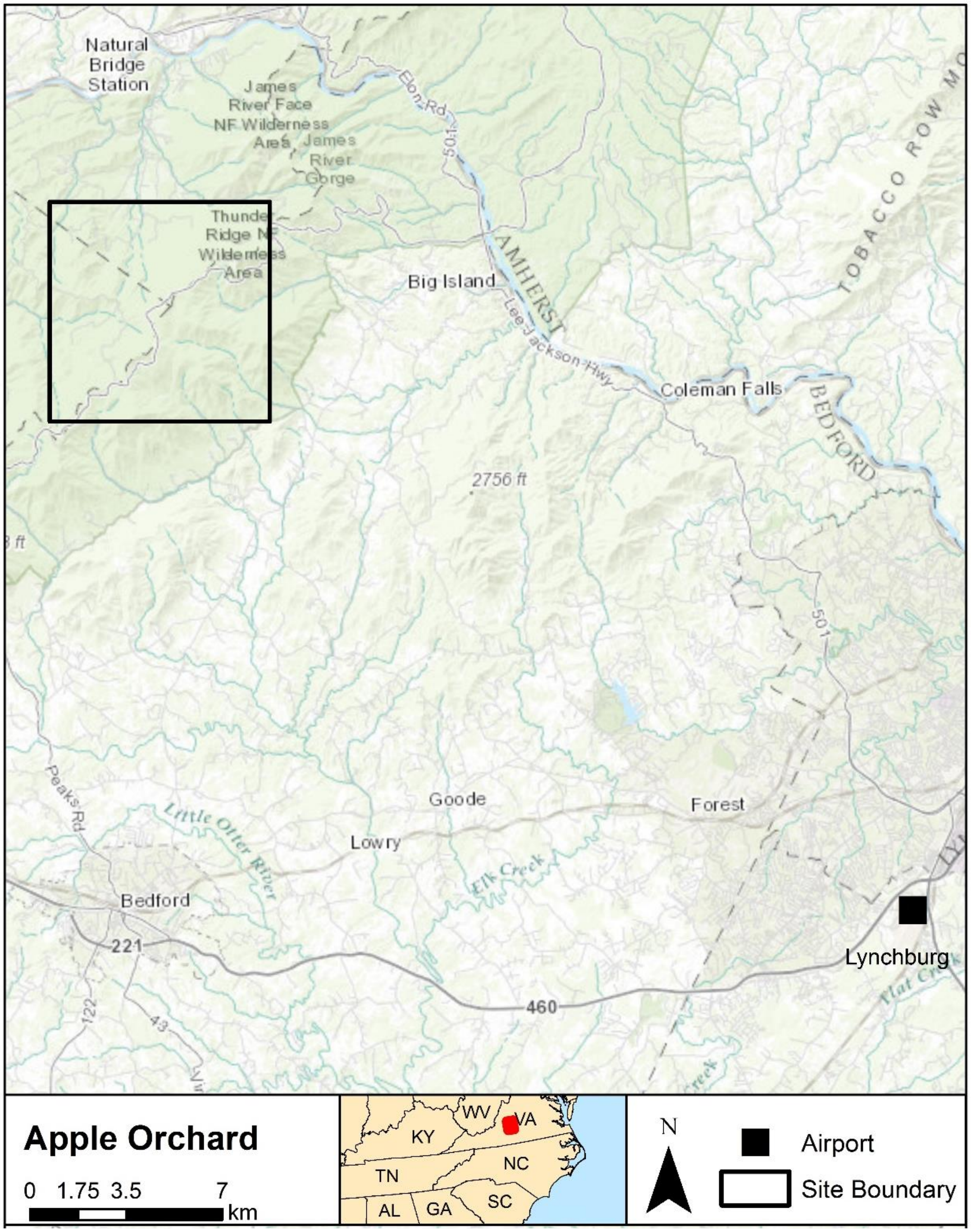
Landscape map for Griffith Knob. Basemaps reprinted from ESRI Basemaps.



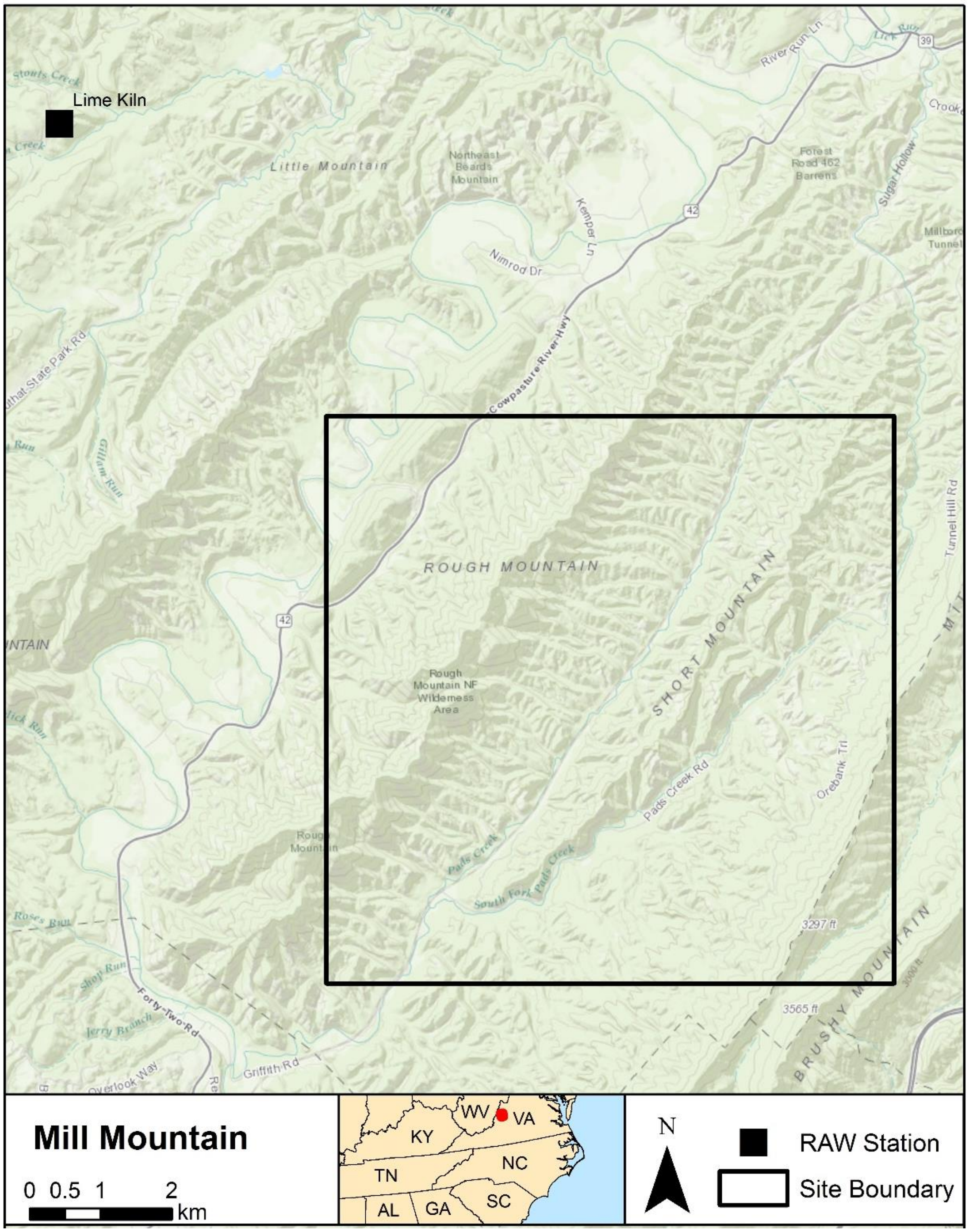
Landscape map for North Mountain. Basemaps reprinted from ESRI Basemaps.



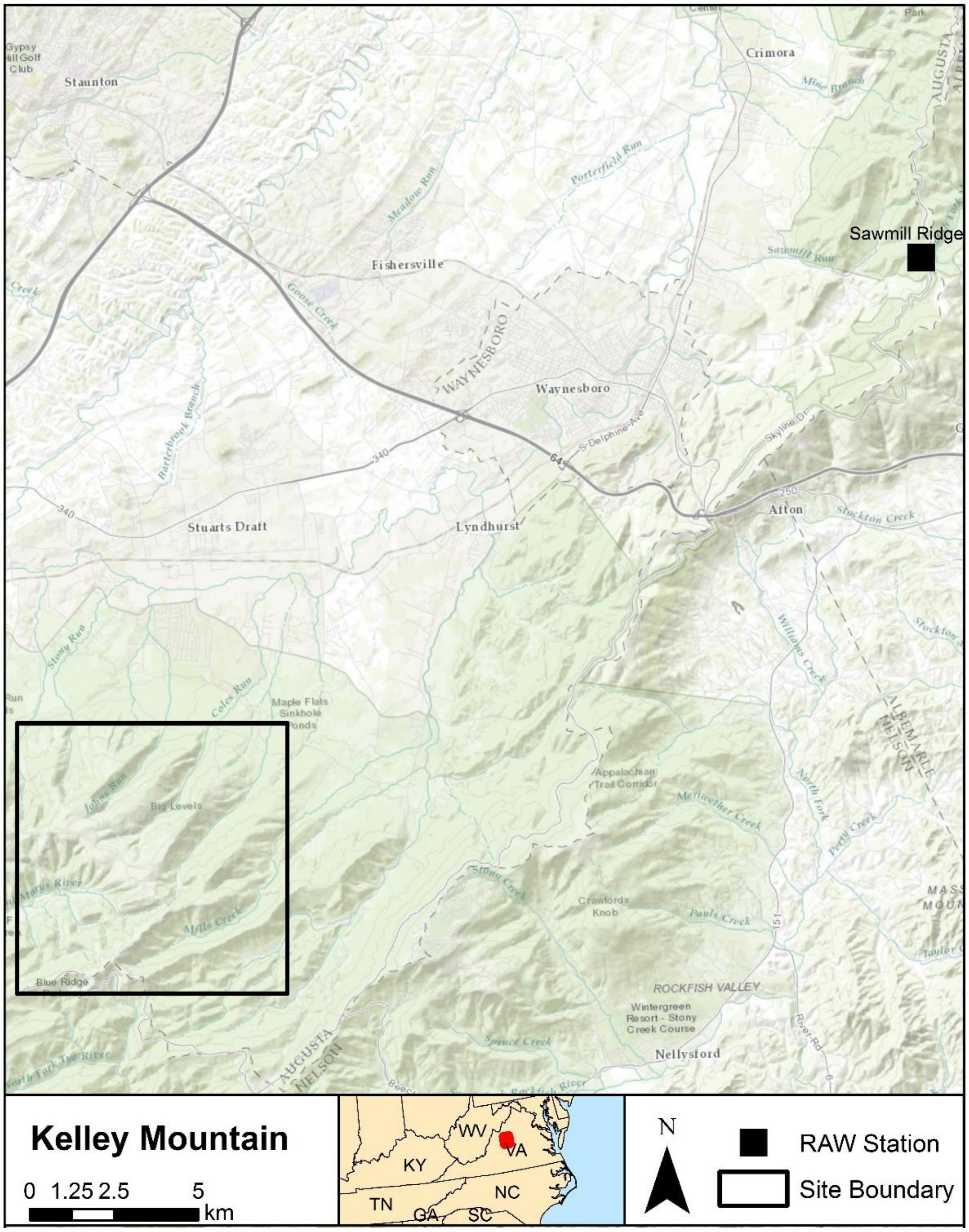
Landscape map for Apple Orchard. Basemaps reprinted from ESRI Basemaps.



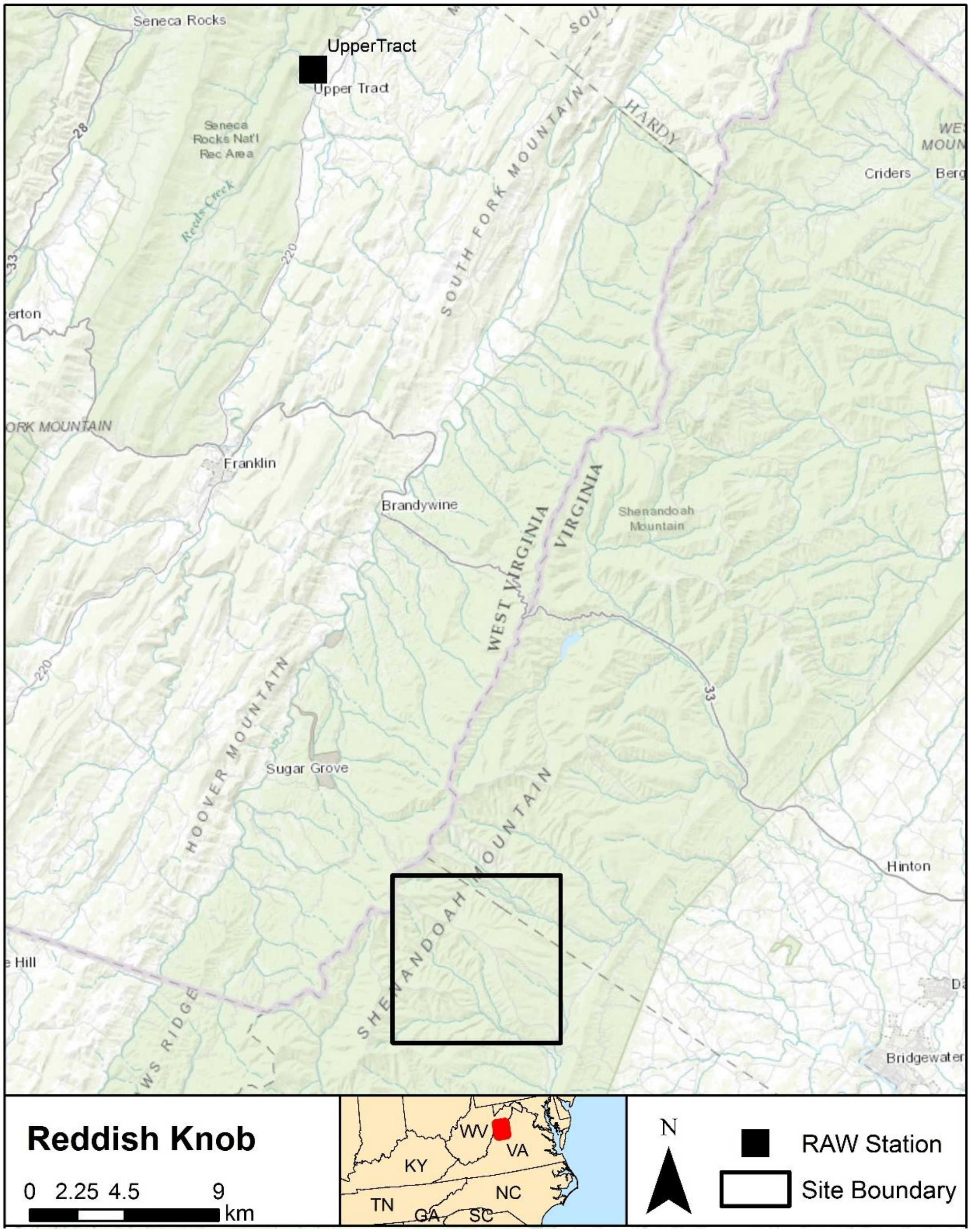
Landscape map for Mill Mountain. Basemaps reprinted from ESRI Basemaps.



Landscape map for Kelley Mountain. Basemaps reprinted from ESRI Basemaps.



Landscape Map for Reddish Knob. Basemaps reprinted from ESRI Basemaps.



Landscape map for Shenandoah. Basemaps reprinted from ESRI Basemaps.