Geographic Information System Topographic Factor Maps for Wildlife Management

by

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(ABSTRACT)

A geographic information system (GIS) was used to create landform measurements and maps for elevation, slope, aspect, landform index, relative phenologic change, and slope position for 3 topographic quadrangles in Virginia. A set of known observation points of the Northern dusky flying squirrel (*Glaucomys sabrinus*) was used to build 3 models to delineate sites with landform characteristics equivalent to those known points. All models were built using squirrel observation points from 2 topographic quadrangles. The first model, called “exclusionary”, excluded those pixels with landform characteristics different from the known squirrel pixels based on histogram analyses. Logistic regression was used to create the other 2 models. Each model resulted in an image of pixels considered equivalent to the known squirrel pixels.

Each model excluded approximately 65% of the Highland study area, but the exclusionary model excluded the fewest known squirrel pixels (12.62%). Both logistic

regression models excluded approximately 10% more known squirrel pixels than the exclusionary approach.

The models were tested in the area of a third quadrangle with points known to be occupied by squirrels. After the model was applied to the third topographic quadrangle, the exclusionary model excluded the least amount of full-area pixels (79.30%) and only 14.81% of the known squirrel pixels. The second logistic regression excluded 81.16 % of the full area and no known squirrel pixels. All models proved useful in quickly delineating pixels equivalent to areas where wildlife were known to occur.

Acknowledgments

This project would not have been possible without the help of many people associated with and not associated with Virginia Polytechnic Institute and State University. My greatest thanks goes to my committee chair Dr. Robert Giles. Without his help I would not be here today. His help in bringing me to this school, pointing me in the right directions, inspiring me to continue, and patient editing of my writing is impossible to measure. I would like to thank my other committee members, Dr. Richard Oderwald and Dr. Gerald Cross for their time and guidance. Their guidance in the development of this thesis was much appreciated.

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Introduction and Objectives

Rowe (1969) asserted that “...landform constitutes the relatively stable base of the landscape ecosystem and is, therefore, its best taxonomic feature." A precise definition of landform has never been given. Researchers often define the term to fit the needs of their study. The term “landform” has been used in reference to drainage class (e.g., well-drained lower slope), topographic position (e.g., mid-slope, summit), slope position (e.g., ridge, plateau, saddle), slope shape (e.g., planar, convex, sloped), convexity or concavity of the land, and geomorphic units (Pregitzer and Ramm 1984). Many of these terms used to describe landform are amorphous themselves. The common denominator of the various uses of “landform” is that it is a general, non-scientific term that integrates information about local climate, soil formation and properties, forest composition, and forest productivity (Pregitzer and Ramm 1984).

Landform has been used to connote slope form, slope shape, topographic position, physiography, drainage class, geology, and parent material substrate. Rowe (1980) made the observation that one person’s “land element” may be another one’s “biogeocoenosis.” Landform was defined broadly to include physiography, geomorphology, terrain, and topography (Pregitzer and Ramm 1984). Howard and Mitchell (1985) stated that landforms were expressions of geomorphologic processes.

Landform descriptors are used in simple descriptive studies and in complex mathematical analyses and predictions. The most basic of these landform descriptors is elevation. Simple derivatives of elevation include slope steepness and aspect. More complex analyses can be performed to create variables including measures of the convexity or concavity of the land surface, slope position, roughness measures, forest site quality measures (Wathen 1977), slope erodability, probability of landslides (Gao and Lo 1995), and many others listed and discussed in Martin (1988). The potential for using abiotic landform descriptors as geographic information system (GIS) data layers in ecological studies has recently been recognized (Cibula and Nyquist 1987, Frank and Isard 1986). The Virginia Gap Analysis Project[1] has used the combination of Landsat imagery and ecological modeling to delineate forest cover types (Morton in prep., Klopfer 1997).

Every landform can have its own effect on local ecosystems. Hillsides vary in their slope, aspect, elevation, roughness, and many other factors, any one of which may determine local temperature and moisture regimes, and thus affect plants and animals. Ridges vary in shape (knob, saddle, etc.) and vulnerability to erosion (depending on slope type, parent material, etc.). Valleys undergo dramatic temperature and moisture changes in a 24-hour period. At night, cool, moist air settles in the valley floor. During the day the valley is exposed to the sun which warms and dries it. All of these factors influence local ecosystems and are factors determining which floral and faunal species inhabit the area.

Swanson et al. (1988) described 4 classes of action, of landform effects:

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[1] Virginia Gap Analysis Project is part of the National Gap analysis Project. It is a multi-agency operation working towards assessing and protecting biodiversity. The Virginia branch is associated with Virginia Polytechnic Institute and State Universtiy located in Blacksburg, Virginia.

Class 1: Landforms influence local temperature (air and ground), moisture gradients, and nutrients available at sites within a landscape. This is caused by local slope, aspect, elevation, and parent material.

Class 2: Landforms change the flow of energy, water, seeds, organic, and inorganic material through a landscape.

Class 3: Landforms alter the timing, frequency, and locations of non-geomorphically induced disturbance by agents such as fire, wind, and grazing.

Class 4: Landforms change the spatial pattern and frequency of geomorphic processes that alter biotic features and processes.

All 4 classes of effects may be profound on the plant and animal composition in an area. The complex relations of these classes occur everywhere and can be demonstrated in a hypothetical mountain range in the eastern United States. On northeast-facing slopes at low elevations, land managers may likely find Rhododendron. This occurrence seems related to the cool moist local climate induced by the mountain reducing direct sun (Class 1 effect). At the same time, higher productivity may be found in valley bottoms, as compared to ridge tops, as a result of downslope movement of nutrients (Class 2 effect). A Class 3 effect may be found where the vegetation has been destroyed by snow avalanches following bedrock-defined paths. These bare sites may then be subject to surface erosion and sediment transport (Class 4 effect).

The complex nature of computing landform measures for large areas has often limited their use in ecological studies. Before the advent of the computer system, many landform measures such as elevation, slope, and aspect were computed from paper topographic maps. The process of extracting slope and aspect for large areas from these topographic maps was slow and often inaccurate. With the first computers, landform measures were still difficult and very expensive (in both dollars and time) to compute. With the ever-increasing power and availability of the personal computer, and digital elevation data, landform variables can now be computed for large areas in seconds for simple variables. More complex landform denotations, such as watershed and drainage delineation, can be performed (1997) in less than 0.5 hours for a complete 7.5 minute topographic quadrangle. Once computed, statistical analyses can be made on single landform variables, or on various combinations of variables for a selected area.

This thesis reports a study of several landform-related abiotic factors within a GIS in an area to determine their usefulness in ecological studies. It was hypothesized that the analysis of these abiotic factors would reveal ecological processes and interactions not yet realized through conventional analyses. It was also hypothesized that a methodology could be developed for improving the selection of areas in which a species may occur. By having many readily-produced factors that are expressions of landform throughout Virginia and other areas, it seemed likely that field observations could be augmented. Where a field person may have hundreds of wildlife observations and several possibly-related habitat variables at each point, the processes described herein are believed to suggest how several landform variables may be added as potential independent variables to studies in order to improve knowledge of wildlife and its relations to its total environment. The specific objectives of the study were:

1) To create several topographically-based GIS data layers and analyze their utility in environmental studies.

2) To use the created GIS data layers to develop models to delineate the abiotic habitat for a faunal species.

3) To test the models created in an area geographically distant from the model-building location.

Literature Review

Literature relevant to each abiotic factor will be reported in the "Methods" section to clarify the relevance of each factor in ecological studies and management. Abiotic factors studied included: elevation, slope, aspect, landform index, phenologic change, and slope position. The literature reviewed in this section was limited to:

1) Abiotic Landform Descriptors

2) Integration of GIS and Ecological Studies

Abiotic Landform Descriptors

Many definitions of landform have been given. Way (1973) stated that landforms are, "Terrain features formed by natural processes, which have a definable composition and range of physical and visual features." I have studied the features of elevation, slope, aspect, landform, phenologic change, and slope position.

Elevation and Slope

A base layer within many GISs is the data for elevation or units above a standardized sea level. The elevation layer is one from which many landform descriptors are derived. Elevation data for most locations are available in digital form called digital elevation models (DEM) through the United States Geological Survey (USGS), or on paper topographic maps. A DEM is "...any digital representation of the continuous variation of relief over space..." (Burrough 1986).

The first vertical derivative of elevation is slope (Evans 1972). Slope refers to the angle of inclination of a land surface above the horizontal. Slope steepness, measured as rise over run, can be calculated by geographic information systems through many mathematical formulae (Chang and Tsai 1991, Peucker et al. 1979, Green and Sibson 1978, McCullagh and Ross 1980, McKenna 1987, Scarlatos 1989). The accuracy of each method of slope calculation varies, and is dependent on the quality and scale of the base DEM. Chang and Tsai (1991) and Hammer et al. (1995) studied the effects of different scales of DEMs and slope calculation methods on slope accuracy. They found little differences existed between these methods. As DEM raster size increased, or scale increased, slope accuracy decreased. Walsh et al. (1987) attributed poor slope computation accuracy on low resolution DEMs (3 arc-second). Computed slope values, as expected, showed greater error in areas of high relief than areas with low relief (Chang and Tsai 1991).

Aspect

The first horizontal derivative of elevation is aspect (Evans 1972). Aspect is the compass direction a slope faces. Similar to slope, aspect can be computed through a variety of mathematical formulae (Chang and Tsai 1991, Peucker et al. 1979, Green and Sibson 1978, McCullagh and Ross 1980, McKenna 1987, Scarlatos 1989, Ritter 1987). Aspect calculation from digital data may also have inaccuracies that are dependent on the scale of the DEM and the relief of the terrain. As raster size increases or the terrain becomes more flat, errors associated with aspect calculation increase (Isaacson and Ripple 1990, Chang and Tsai 1991).

The variables elevation, slope, and aspect are 1-dimensional measures that each describe a feature of a site. Several authors have combined and transformed elevation, slope, and aspect to create new variables and mathematical formulae to describe landforms in more than 1-dimension. Mitchell (1995) described a windthrow triangle which rated the risk at a site to wind damage based on topographic exposure (slope and aspect). Gao and Lo (1995) created a linear polynomial regression equation using elevation, slope, aspect, and configuration to model locations with a high potential for landslides. Preliminary evaluation of the model indicated an accuracy of 83%. Peddle and Duguay (1995), similar to a study reported by Stage (1976), combined slope and aspect to create a topoclimatic index. The topoclimate index was used to describe the effects that steep-mountain-faces have on the distribution of snow fall. According to their index and within their area, steep, east-facing slopes received the greatest accumulation of snow, and thus received the highest topoclimatic index.

Shape

Several authors have used measures of convexity or concavity of the land surface as landform descriptors. All of these measures are based, in some way, on changes in elevation (often measured as slope) from a central point of interest to surrounding points at some given distance away. Grender (1976) created a computer program to classify each raster cell for an area into 1 of 6 basic topographic shapes. The program written by Grender (TOPO III) examined the elevation of 8 points at fixed distances away from the central point (1 point for each of the 8 compass directions). A topographic shape was assigned to the central point based on the number of the 8 points that were higher, lower, or at the same elevation as the central point. Pyatt (1969) created the Topex score as a measure of the shelter afforded a defined location by the surrounding topography. The Topex score was measured as the angle of elevation in degrees from a fixed point to the visible horizon for a predetermined number of compass points. Wilson (1984) devised a method to compute a Topex score from topographic maps, eliminating the need to visit the field. McNab (1987, 1993) built upon Wilson's work with the Terrain Shape Index (TSI) and Landform Index (LFI). Both the TSI (microscale land shape) and LFI (macroscale land shape) could be computer-generated from digital elevation data.

Martin (1988) listed over 100 landform measures which fell into 9 categories of land surface descriptors. The 9 categories listed by Martin were elevation, slope, aspect, relief, area, length, texture and roughness, pattern. Many of the 100 measures analyzed by Martin proved to be of limited use, difficult to compute, or very similar to other measures. Within the list compiled by Martin there were few indices or combinations of variables that had been used to describe landforms.

Integration of GIS and Ecological Studies

The relationships that exist between abiotic site factors and the distributions of flora and fauna have been studied for decades. The literature is replete with studies of the relationships between species and elevation (Whittaker 1956, Hack and Goodlett 1960, Swanson 1979, McGregor et al. 1981, Linzey 1968, Tiejte et al. 1990, Amman 1973, Randall 1971). Slope and aspect has been shown to affect the distributions of species as well (Shields and Grubb 1974, Dickinson 1976, Oosenbrug and Theberg 1980, Gionfriddo and Krausman 1986, Flather and Hoekstra 1985, Catling and Burt 1995). Landform descriptors have been used as base factors in site classification studies (Pielou 1979, Rowe 1980, Swanson et al. 1988, Swanson 1979, Flather and Hoekstra 1985, Coughenour 1991, Hills 1960, Jones 1991, Jones and Churchill 1987, Tuttle 1970, Steinbrenner 1975). Hills (1960) in the Ontario Site Classification System analyzed the vegetation-landform coincidences to create a subdivision of the macroclimate continuum. The level of an individual forest stand was defined by narrow ranges of physical and vegetational features (Hills and Pierpoint 1960). The timing of phenological events of flora and fauna based on abiotic site factor changes has been studied and reported as well (Hopkins 1938, Wang 1984, Bailey 1984, Beattie 1985, Howard and Wallace 1985, Keys et al. 1986). Slope position has been correlated to growth rate of vegetation (Auten 1945, Spurr 1952, Whittaker 1956, Fies 1983, Breimer et al. 1986) and soil water and nitrogen content of soil (Qureshi 1982). Low slope positions are often more favorable for many tree species than upper slopes (Weitzman and Trimble 1957, Munn and Vimmerstedt 1980, McNab 1985).

As shown above, the premise that abiotic site factors influence numerous ecological phenomena has been well established in the literature. The next logical step seems to attempt to integrate many of these abiotic factors into a computer system for use in a GIS. Once integrated into a GIS it would then seem to be possible to verify and further analyze the abiotic factors (singly and in combinations) that may be influencing a species. The use of computers has been successfully demonstrated in population and habitat analyses, ecological, physiological, nutritional studies, simulations, and trends projections (Giles 1978). The computer now has demonstrable usefulness in wildlife management for education, resource inventory, planning, law enforcement, research, and decision making. Aspinall (1993) used Landsat thematic imagery and DEMs to model bird distribution and probability of occurrence. To predict hollow-bearing trees for wildlife in an area using a computer, Lindenmayer et al. (1991) used slope angle, topographic position, and various other landform measures. Hoar (1980) used several biotic and abiotic factors in a GIS to delineate sites with the same features. Schreiber et al. (1974) proposed the use of a computer based system to analyze the ecological factors (climate, soil, topography) and human activity (regional development, pollution) influencing species within a region.

Methods

The methods used to achieve the objectives will be discussed under the headings of elevation (including data from which other landform values are derived); slope; aspect; landform; herein defined in a particular way, the index K; a phenologic layer; and slope position.

The uses of the GIS layers or single-factor maps are then analyzed for the Northern dusky flying squirrel (*Glaucomys sabrinus)* in 2 topographic quadrangle maps in western Virginia.

Elevation

Overview

Elevation changes can have large effects on local climate and other ecological variables. Climate may alter the habitat that can be used by flora and fauna. At low elevations, conditions may be warm and sunny, but at high elevations there may be snow and 20§ F. This temperature difference, which has been quantified (Olgyay 1973, Cox and Moore 1980), is about 0.6§ C decrease for every 100 meter increase in elevation. Changes in temperature thus affect a variety of ecological factors as well (e.g., relative humidity, growing season, evapotranspiration). Hopkins (1938) studied the timing of various phenological events as related to changes in elevation, latitude, and longitude. Hopkins' results indicated that for every increase in elevation of 122 m (400 feet), phenological events were delayed by 4 days.

Elevation changes also have effects that are not so easily seen. The golden mouse (*Ochrotomys nuttalli*) was found to be restricted to elevations less than 823m (2700 feet) probably due to changes in over and understory floral composition (Linzey 1968). The distribution of the mountain pine beetle has been studied by Amman (1973) and McGregor et al. (1981). Both studies linked the presence of this beetle to changes in elevation and latitude. A similar study by Randall (1971) found that spider speciation occurred in the Great Smoky Mountain National Park along altitudinal gradients. Most dense pygmy salamander populations were found at high elevations in the southern Appalachian Mountains. None were found below 838 m (2750 feet) (Tilley and Harrison 1969).

The base layer of data used in deriving the majority of layers in this study was that for elevation. In the past, elevation data for an area were most commonly attained from paper topographic sheets. There are several problems associated with paper topographic maps including accurately locating specific sites on paper maps, correctly interpolating between contour lines, and consistently using information gained over large areas. The maps may deteriorate over time or be damaged by repeated use. Unless the maps are made of modern stable materials, they may shrink or swell with changes in local temperature and moisture conditions. The advantages of paper topographic maps are their availability, portability, and ease of use in the field.

With computer technology, elevation data are now available for most of the United States in digital form at several levels of resolution and data quality. Digital elevation data, or digital elevation models (DEM) are currently available at the 1:250,000 scale as public domain on the Internet. For this study, portions of DEMs corresponding to 7.5 minute topographic quadrangles (1:24,000) were used.   Digital elevation models of the study areas were attained from the United States Geological Survey (USGS, Reston, Virginia 22092) on compact disc. The DEMs had to be input to a GIS before any analyses could be performed. For this study 2 main GIS and image processing packages were used, TNT-MIPS (201 North 8th St., Lincoln, Nebraska 69508) and PCI (1925 North Lynn St., Arlington, Virginia 22209). Both packages contained built-in programs that could accomplish the objectives of this study, but PCI was chosen for the majority of operations because it was the easiest of the 2 to program and use. A sample DEM of the Hightown study area is shown in Fig. 1. Each 30 m x 30 m pixel within the image contains an elevation value along 1 m increments. Due to the large area encompassed in Fig. 1, the edges of each pixel are not visible. Each topographic quadrangle covers approximately 15,660 hectares (ha) depending on latitude. Northerly quadrangle sheets display less area because of the trapezoidal shape of each area.

Digital data used in a GIS come in 2 forms, raster and vector. Vector data include points, lines, and polygons with attributes assigned to each point, line, or polygon (Fig. 2a). An attribute is any item of interest at a location. Raster data are those for a map grid. Each cell (pixel) in the grid has an attribute assigned to it (Fig. 2b). The DEMs used for this study were raster based. Each pixel had dimensions of 30 meters per side. The attributes associated with each pixel were a Universal Transverse Mercator Easting and Northing coordinate and elevation in meters.

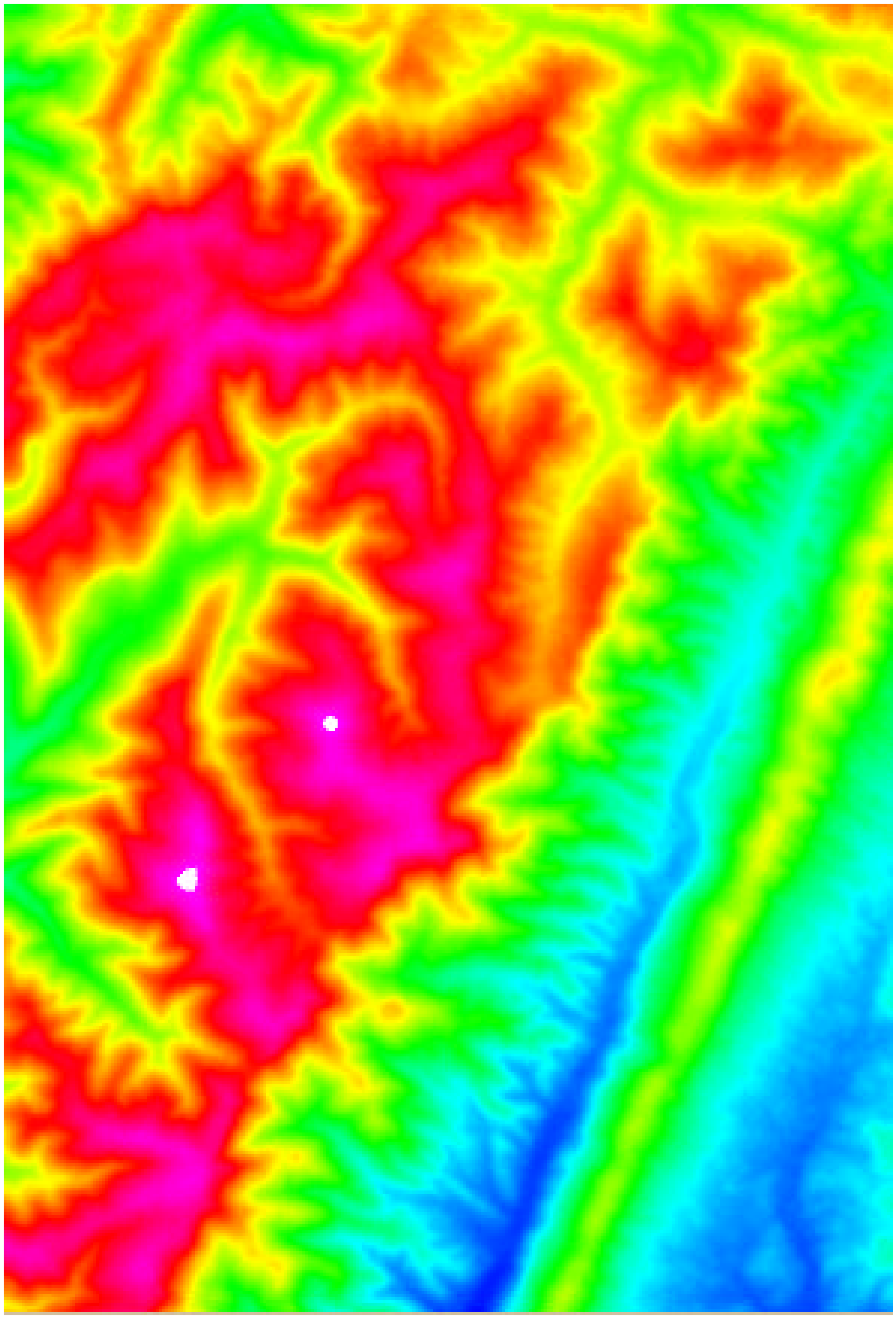

Figure 1. Raw elevation is displayed for Hightown topographic quadrangle in 1 meter increments. The color transition from dark blue, to blue, to green, to yellow, to orange, to red, to white represents increasing elevation. The minimum elevation is 792 m. The highest elevation is 1404 m.

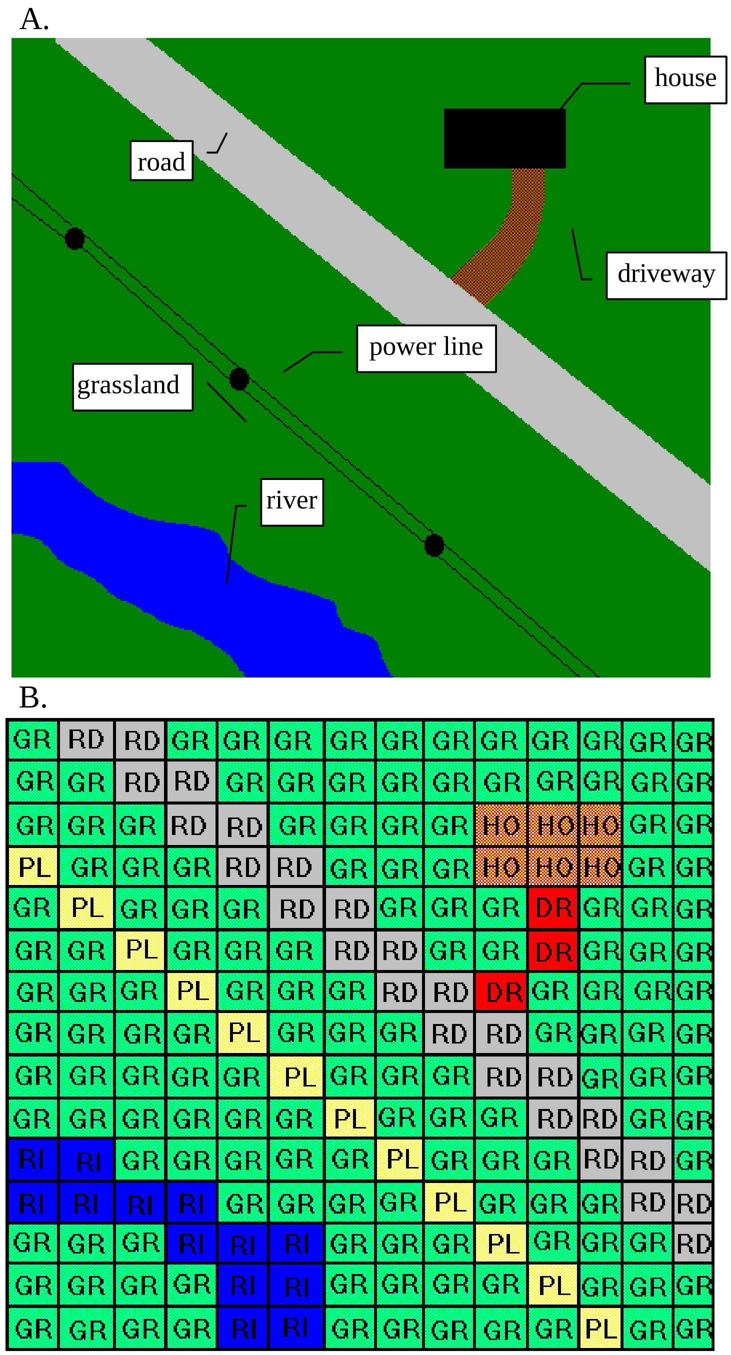

Figure 2. Demonstration of vector and raster data. Figure 2a represents a vector diagram of an area with points, lines, and polygons. Figure 2b represents the same area in raster form with each pixel assigned a value corresponding to the item at each location (GR=grassland, RI=river, PL=powerline, DR=driveway, HO=house).

Most species of plants or animals are limited in some way by elevation, but not along the 1 m increments as shown in Fig. 1. A simple program (Appendix, Number was written in PCI language that would separate elevations along a user-specified increment, such as 50 m increments.

Slope

Overview

Slope is one of the most fundamental measures of landscape characteristics. Slope refers to the steepness of the land as measured in percent or degrees (Fig. 3). The value of slope may be related to its ease of measurement or calculation and its power in explaining ecological phenomena. In the field, slope is commonly measured for a site with a clinometer in a matter of seconds. Slope may be calculated from paper topographic maps by measuring rise over run for a particular area. Both of these measures may yield accurate expressions of slope, but they can be time consuming to compute. Through using a computer, slope can be calculated for each pixel from digital elevation data for a large area in the time it takes to measure slope at a few sites in the field.

Slope has been reported as a driving variable in many ecological studies. It has been found to be related to: soil surface depth, subsoil texture, and internal soil drainage (Turner 1936, 1937, 1938), soil group (Zahner 1958), and depth to least permeable soil horizon (Linnartz 1961). Slope steepness is included as a major factor in determining the soil erosion rate from a site through the Universal Soil Loss Equation. Slope stability is

Percent slope = (rise/run) * 100 = (100/200) * 100 = 50% slope

Degrees slope = $\tan^{-1}$ (rise/run) = $\tan^{-1}$ (100/200) = 26.6° slope

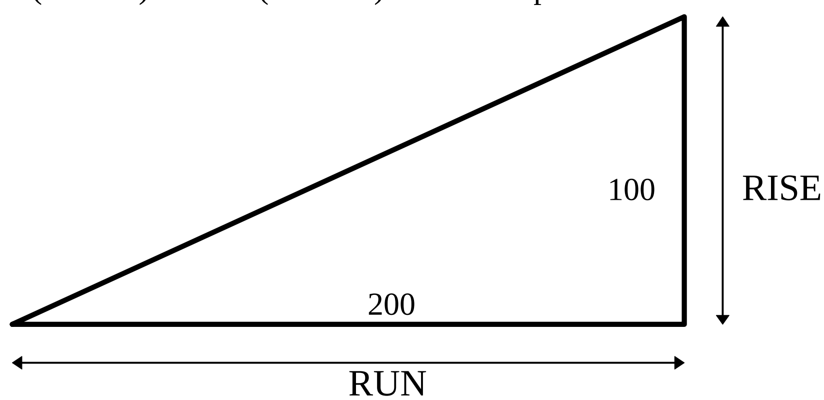

Figure 3. Methods of calculating slope. The standard measure of rise over run can be used to determine percent slope steepness. The inverse tangent of rise over run can be used to determine slope steepness in degrees.

directly related to slope steepness (Sidle 1985). It has been estimated that road maintenance costs increase 50 to 100 percent in areas with slope stability problems (Burroughs 1985). Slope has been used in equations to estimate the climatic variable solar radiation (Lawrence 1976). Timber harvest operations consider slope steepness in determining which equipment and harvest methods to use (Giles 1982). Sites with slopes less than 20 percent are often harvested by different methods and vehicles than sites with slope between 20 percent and 40 percent. As slope exceeds 40 percent, little, if any, harvesting is done by ground-based vehicles. Slope length and angle affect soil depth, texture, profile, and erosion of soil (Wishmeier and Smith 1965, Pearson 1968, Swanston and Dyrness 1973, Way 1973, Verstappen 1983).

Similar to the effects of elevation, floral and faunal species are often segregated along slope breaks. Species segregation along 1 degree increments, the result of the slope-creation program included within PCI, has not been reported. The same program (Appendix, Number 1) used to delineate elevation classes was used to separate slope along various increments including: 5 degree classes, and Wathen's (1977) classes. Any user-specified step-size (in degrees) could be programmed for mapping. Wathen's scored slope ranges were based on the perceived ability of each slope class to retain moisture and influence tree growth. Wathen's slope classes and associated scores are shown in Table 1.

Table 1. Percent slope ranges and associated forest site quality index (FSQI) scores from Wathen (1977).

Slope Range (percent)	FSQI Score
0-14	5
15-29	4
30-44	3
45-59	2
60+	1

Aspect

Overview

Land aspect, the direction a slope “faces” or the compass direction downhill from a point, is a profound land form. This component of topography is a driving force in the development of a forested landscape. Many differences in landscapes, for example different floral or faunal assemblages, can be attributed to differences in aspect. It is possible to have 2 sites located at the same elevation, slope steepness, and geology, yet the floral assemblages may be very different if the aspect is different. Floristic, as well as faunal, differences may be due to different aspects. On the windward side of mountains there is often much more rainfall than on the leeward side. This orographic rainfall has been studied and reported by many authors (Swanson 1979, Howard and Mitchell 1985, and Osmond et al. 1990). In the Northern Hemisphere, south-facing slopes generally receive more sunlight than north-facing slopes. Increased solar radiation can be directly linked to increased floral productivity through greater photosynthetic activity and soil moisture effects, provided there are no other limiting factors.

In a study of bighorn sheep (*Ovis canadensis*) food habits and range use, Schallenberger (1966) observed sheep preference for southward-facing slopes 79% of the time. Aspect was one characteristic found to play an important role in tree survival, growth potential, growing season, and seedling survival (Shoulders and Tiarks 1980, Gemborys 1979, Rehfeldt 1993, Griffin 1971, Muick and Bartolome 1987). Scribner et al.

(1991) found differing amounts of toxins in *Populus tremuloides* and *Liriodendron tulipifera* on a north-to-south gradient.

Aspect has been used as an indicator of site quality in numerous forest studies. Table 2 contains a partial listing of the available literature citing aspect as a factor modifying site index for a variety of tree species.

Aspect was a unique variable in that it was not possible to take a mathematical average of aspects of an area, and to have that value be meaningful. Aspect is a circular function. For example, if an area had aspects that were predominantly north-facing (from 315° to 45° azimuth), the average aspect would be near 180°, which is due south. In order for aspect to be treated as a continuous variable, the data had to be transformed. A common transformation used for ecological studies was first proposed by Gaiser (1951). It was determined that the effect of aspect can be coded as a cosine function, with a 45° shift clockwise, taken in radians. The effect of this transformation was to give the raw aspect value of 45° a maximum value of 1, and a raw aspect value of 225° the lowest value of -1. The remaining aspects were scaled between -1 and 1. A program was written in PCI (Appendix, Number 2) to transform raw aspect data with this shift. An example of the resulting image is shown in Fig. 4. After the data were transformed, it was then possible to treat aspect as a continuous northeast-to-southwest variable.

Other methods exist for using aspect data without mathematical transformations. Aspect was listed as a dominant factor in determining forest site quality in studies by Smith and Burkhart (1976) and Wathen (1977). In their studies, aspect was separated

Table 2. A partial listing of studies citing aspect as a factor in determining site index for various species of trees (adapted from Carmean 1975).

Species	Geographic Location	References
shortleaf pine (*Pinus echinata*)	Ozarks of Missouri and Arkansas	Nash (1963), Graney and Ferguson (1971, 1972), Ferguson and Graney(1972)
red pine (*P.resinosa*), Eastern white pine (*P.* strobus), and Scotts pines (*P. sylvestris*)	Vermont	Hannah (1971)
white oak (*Qurecus alba*)	S.E. Ohio	Gaiser (1951), Merz (1953)
black (*Q.* velutina) and white oak (*Q. alba*)	S.E. Ohio, S. Indiana	Carmean (1965, 1967)
mixed oaks (*Quercus spp.*)	Appalachian Mtns.	Weitzman and Trimble (1955), Trimble (1964), Yawney (1964), Yawney and Trimble (1968)
yellow poplar (*Liriodendron tulipifera*)	Central States	Auten (1945)
black locust (*Robinia pseudoacacia*)	West Virginia	Brown (1973)
black walnut (*Juglans nigra*) and green ash (*Fraxinus pennsylvanica*)	S.E. Iowa	Thompson (1957), Hansen and McComb (1958)
sugar maple (*Acer saccharum*)	Vermont	Post and Curtis (1970)

Figure 4. Aspect map for the Hightown topographic quadrangle after Gaisers' (1951) transformation. White represents southwest aspects. Black represents northeast aspects. Blue and green shades represent northerly and easterly aspects, respectively. Red and purple represent southerly and westerly aspect, respectively.

into discrete classes based on available moisture. Each class was scored based on its perceived influence on tree height growth. Classes used by Wathen, and their score, are shown in Table 3. Aspect can also be used in other ways. Discrete ranges of aspect can be created to fit the needs of most studies. Smalley (1984) used aspect in 2 classes, north-facing (315 to 135), and south-facing (135-315). Common discrete classes of aspect include those shown in Fig. 5. A program written in PCI (Appendix, Number 1) had a portion dedicated to creating aspect classes based on Fig. 5a, and Fig. 5c, and Wathen's classes.

Landform

Overview

Landform is 1 of the elements studied to learn of the topographic variation of areas within Virginia and elsewhere. In many mountainous regions, large ecological differences may be found between 2 sites. "Site" is used herein as a point on the landscape, a map-coordinate location. It is also used to connote differences in forest quality, as in "site index" for a stand of trees. Differences in vegetation at a site may be due, for example, to the point on the land being exposed to or sheltered from drying winds and sun. Examples of major landforms are convex ridges, flat side slopes, and concave coves. Within this thesis, they are described mathematically with an index showing their position along a continuum from narrowly convex to narrowly concave. Sites located in coves are generally much more sheltered from sun and wind than are sites on ridges. Such sites are

Table 3. Aspect classes and their ranges and forest site qualtiy index (FSQI) scores assigned by Wathen (1977).

Aspect ranges	FSQI Score
196-260	1
166-195, 261-280	2
146-165, 281-340	3
0-20, 341-360	4
81-145	5
21-80	6

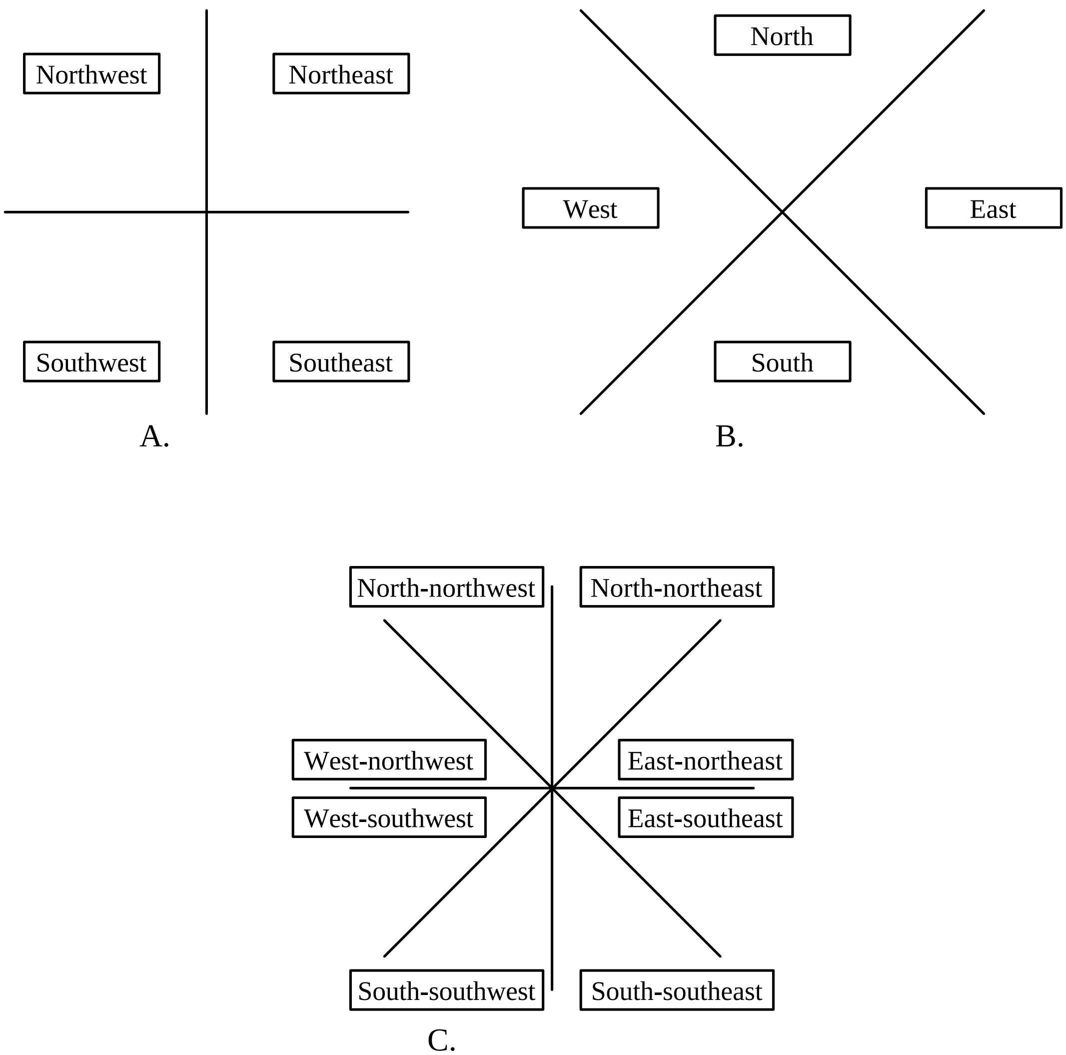

Figure 5. Three respresentations of aspect classes commonly used in ecological studies.

protected by the surrounding slopes. Coves often are locations having deeper soil than those on ridges because of erosion and the mass wasting of soil from upslope to local low spots (Brown 1980, Hewlett 1982). Differences in exposure and soil depth may then give rise to different species assemblages, shading from solar radiation, and productivity.

Pyatt et al. (1969) as well as others, have noted site differences due to landform (Smith and Burkhart 1976, Wathen 1977, Auten 1945, Doolittle 1958) and created the Topex measurement to quantify the condition of exposure of a site. Wilson (1984) detailed a method to calculate a Topex score from topographic maps without visiting the field. McNab (1989, 1993) and Rutledge (1995) used computers and digital elevation data to calculate similar indices. The studies by McNab (1989, 1993) and Rutledge (1995) indicated that coves generally had higher tree productivity and species diversity than ridge tops. Remezov and Pogrebnyak (1969) discussed the effects of landform on forest composition and production. Their description stated that as landform changed from a convex hilltop, downward to a concave lowland, the forest composition changed from dry-site pines to moist-site birches. The change in composition was attributed to increasing soil moisture and soil-rooting-depth down slope from the ridge. Land classification systems by Steinbrenner (1975) and Hills (1952, 1961) used landforms as indicators of forest site quality.

Previous work has classified landform into discrete classes (Barnes et al. 1982, Deitschman 1973) but other studies used continuous variables. Both approaches are appropriate for the studies for which they were developed. No classification scheme seems universally applicable. For this reason, I used both approaches (a continuous variable and discrete classes) to describe landform. The continuous landform index (termed K) is the average percent slope from a site to 8 locations (4 corners and 4 sides) on the edge of a 9 x 9 pixel group, hereinafter called a window. For example, on a mountain peak, the land generally slopes down in all directions. The slopes from the central peak pixel to each adjacent down-hill pixel are all negative and thus the landform index is negative. The opposite would occur if an observer was in a cove or sinkhole; all slope values would be positive. Based, in part, on McNab's (1989) study, it was decided to measure the slope in 8 directions from each pixel, starting with 0° North, and measuring slope along 45° azimuth increments.

The landform index, K, was computed in 2 steps since the distance between the corner cells to the center cell (or site) was different from the distance from the edge cells to the site in question. The slope of the eight compass direction transects was estimated. This was a conventional linear "rise-over-run" slope estimate where the run was 120 meters for the orthogonal cells, and 169.71 meters (rounded to 170 meters) for the corner cells.

To compute K, a data layer was created for the case in which each output pixel value was the average elevation to the 4 corners of the window. A second layer was created which contained the average elevation to the 4 orthogonal pixels of the window. The next step was to create 2 temporary variables using a program written in PCI language (Appendix, Number 3). Each temporary variable was calculated by subtracting the original elevation at each pixel from the averaged elevation (i.e., the 8 averaged elevations of adjacent corners or sides). This was an average deviation in rise. By dividing the average change in elevation by the distance from the center pixel to the corner (or edge) of the window, an average slope estimate was gained for one half of the window. The landform value was then found by averaging these 2 values. Fig. 6 demonstrates a sample calculation, and a sample map is shown in Fig. 7.

The values for K commonly ranged from less than -20 on very convex sites (less than -40 in a few locations), to greater than 20 on very concave sites (some extreme sites exceeded 40). Raw landform values from -10 to 10 throughout a region indicate an area without any dominant landform features (rolling landscape).

Being a unique measurement, it was not possible to link directly raw landform index values to commonly used terms. It was decided to separate landform values into the 6 classes shown in Table 4. The criteria for delineating the classes are given in Table 4. To classify the areas with rolling landform, the slope steepness of each site was examined. If the slope was less than or equal to 10 percent, the site was termed <u>planar horizontal</u>; if the slope was greater than 10 percent, the site was called <u>planar sloped</u>.

Phenologic Change

Overview

Phenology is the study of the occurrence and timing of biological events, whether they are bud break on red maples (*Acer rubrum*), the arrival of the first robins (*Turdus migratorius*), or the first singing of spring peepers (*Hyla crucifer*). Different geographical

149				143				145
145				120				140
149				140				148

Average elevation to the four corners = (149+145+149+148) / 4 = 147.75 m
Average elevation to the four sides = (143+145+140+140) / 4 = 144.50 m
Average slope to corners = rise over run = 100*(147.75-120) / 170 = 16.3%
Average slope to sides = rise over run = 100*(144.50-120) / 120 = 20.4%
Final raw value (K) = (16.3 + 20.4) / 2 = 18.4%
Final landform class = Concave

Figure 6. Sample calculation of landform value, K, from a digital elevation model. Numbers in the grid cells indicate elevation in meters.

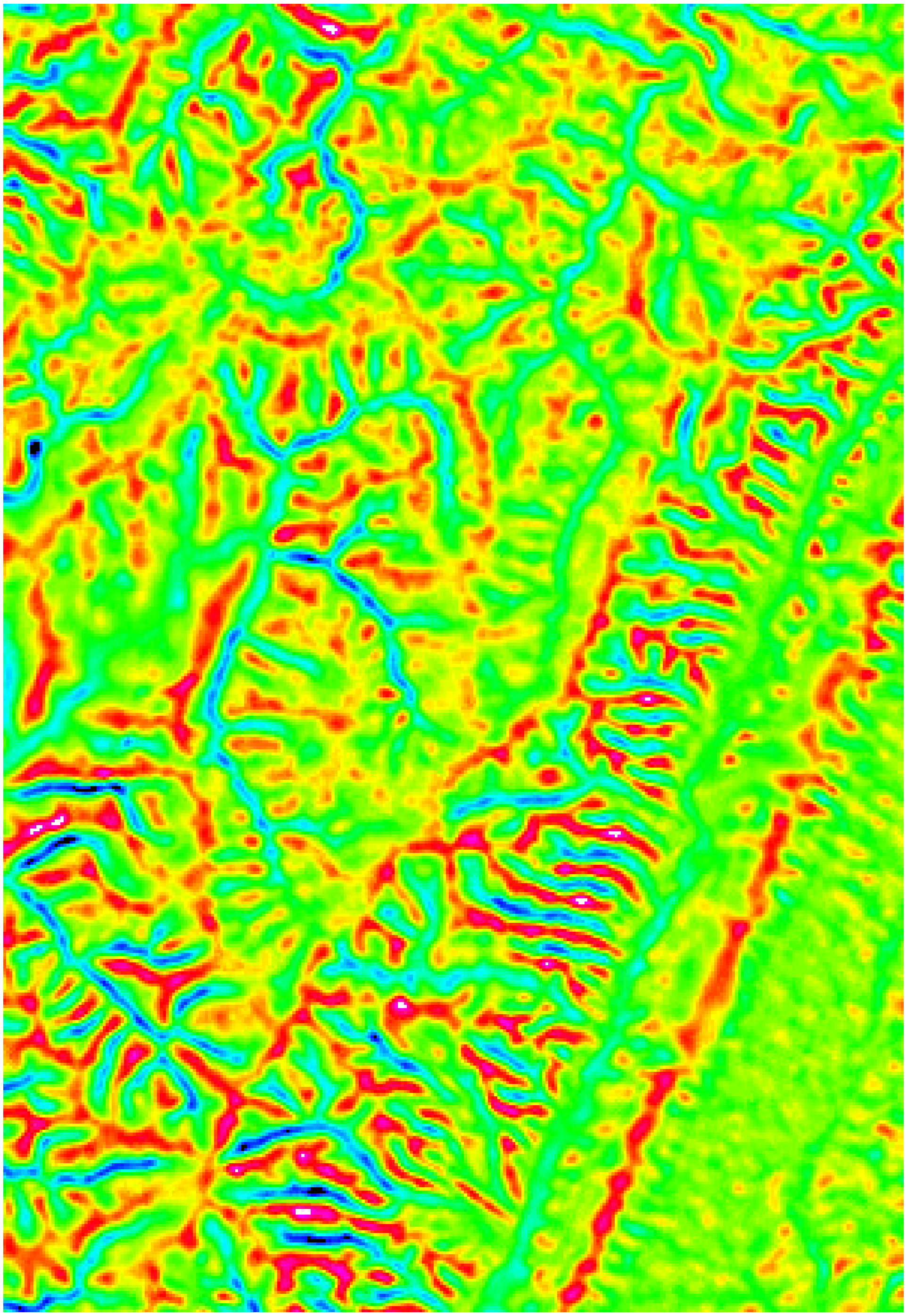

Figure 7. Raw landform indices are shown for the Hightown topographic quadrangle. Very concave areas, such as coves, are colored blue. Sharp narrow ridges that would have a very convex landform are colored red to white. The color transition from yellow to green indicates the transition from slightly convex upper slopes to slightly concave lower slopes.

Table 4. Landform classes with their K index criteria.

Landform class	Criteria
Very convex	K ≤ -20
Convex	K > -20 and ≤ -10
Planar sloped	K > -10 and < 10, slope > 10%
Planar horizontal	K > -10 and < 10, slope ≤ 10%
Concave	K ≥ 10 and < 20
Very concave	K ≥ 20

locations may experience these events at different times throughout the year. Knowledge of the timing of phenological events across a region can be used by land managers for a variety of purposes. Hunting seasons are often based on the timing of biological changes in animals (broods reared, deer rutting, migration of waterfowl). Herbicide application is closely tied to phenological events depending on the mode of action and uptake route of the herbicide. Fall leaf color tours can be timed to coincide with peak foliage color based on phenological changes. Hopkins (1938) studied and quantified the change in the timing of phenological events as geographical location changes. His results stated that for every increase of 122 meters (400 feet) in elevation, 1 degree of latitude northward, or 5 degrees longitude eastward, phenological events happen 4 days later. These numbers are called Hopkins Law of Bioclimatics. While the exact numbers have been debated (Beattie 1985, Bailey 1984) there is little or no argument as to whether such biological differences exist, or that they are correlated with, if not functionally related to, latitude, longitude, and elevation. Of course many biological phenomena are triggered by photoperiod; phenology relates to these events and, herein, I seek to understand these 3 related factors.

Application of Hopkins Law to an area such as Virginia may show subareas that are likely to have equivalent timing of biological events. The timing of biological events in subareas may be compared to those of other subareas. A base point can be selected as a standard subarea for generalized comparisons. A low elevation, easterly, southern starting point, may be selected to which all Hopkins values can be compared. For this study the weather station located at the Great Dismal Swamp National Wildlife Refuge (GDSNWR) was chosen as the base point. This location was chosen because it represents the location with the earliest onset of most phenological events within the state (due to the high elevations in the western portion of the state most phenological events occur later than at GDSNWR). The value calculated for each pixel was the delay in the timing of a phenological event from the base point. For example, a pixel with a value of 15 is one that would have the same phenological event happen 15 days later than that event in a pixel at the base point. It is also possible to compare events at any 2 points with each other. If a sample point on a map of relative biological time has a value of 10 and a second point has a value of 15, it can be stated that the same phenological event will happen approximately 5 days *earlier* at the *first* point than at the *second* point, which is 10 days *later* than at the *base* point.

In order to calculate a Hopkins value for a site, 3 factors were used. These were elevation, latitude, and longitude at the base site and at each pixel. The values for the base site were attained from Owenby and Ezell (1992). In order to determine a Hopkins value for each pixel, a program was written in PCI (Appendix, Number 4). The process involved determining the Hopkins value associated with each of the 3 factors, and then summing them, to yield a final value.

The first step was to calculate a value associated with each individual factor of the final Hopkins value, namely elevation, latitude, and longitude. The change in timing of phenological events due to elevation was a simple procedure. The Hopkins Law stated that for every increase in elevation of 122 meters (400 feet) phenological events are delayed by 4 days, i.e., 0.0327869 days delay per 1 meter increase (4 days / 122 meters). Therefore, all other factors being equal, phenological events happen later at higher elevations, than at lower elevations. To calculate the Hopkins component value associated with elevation, the difference in elevation was found from the pixel of interest to the base point. This difference in elevation was converted to a Hopkins component value by multiplying the difference by 0.0327869 (days delay per 1 meter elevation increase). For example, given a base point elevation of 7.62 m and a sample point elevation of 320 m, the difference in elevation would be 292.38 m (320 m - 7.62 m). The Hopkins component value associated with this change in elevation would be found by multiplying 292.38 meters by 0.0327869 days per meter, which equals 9.58 days. That is to say that the same phenological event would occur between 9 and 10 days later at the pixel of interest than at the base point. Output values were truncated to integer values.

The second step in calculating a final Hopkins value was to calculate the Hopkins component values associated with changes in geographical location (latitude and longitude). The latitude and longitude of the base point was known, but these units were needed in Universal Transverse Mercator (UTM) units. UTM coordinates of the base point were needed to determine the distance to each pixel (from the base point), which were also geo-referenced in UTM coordinates. It was necessary to have all data referenced to UTM coordinates because PCI modeling language could only analyze and perform mathematical functions on geocoordinate data in UTM form.

Since the Hopkins Law relates the change in the timing of events to changes in latitude and longitude, and the model was written to use UTM data, it was necessary to determine the number of meters per degree of latitude and longitude. Data for this were obtained from the Forestry Handbook (Forbes 1955) which contained a table that listed the number of feet per degree of longitude along different degrees of latitude. Due to the shape of the world, the number of meters per degree of latitude and longitude are variable, depending on the point of interest. For example, along the equator, 1 degree of longitude is roughly 111318 m, while at 85 degrees latitude, 1 degree of longitude is roughly 9731 m. The state of Virginia extends from nearly 36.5 to 39.5 degrees latitude, and 75 to 84 degrees longitude. Along the southern border of Virginia (36.5 latitude), 1 degree of longitude is roughly 89591 meters; at 39.5 degrees latitude 1 degree longitude is 86012 meters. Due to the small range of difference in distance (in meters) per degree longitude in the state, it was decided to use the average value (87802 meters per degree longitude). The same formula was used to determine the average number of meters associated with 1 degree of latitude for the state at varying degrees of longitude. The final number used was 119950 meters per degree of latitude.

To calculate that aspect of the Hopkins value associated with the change in latitude, the difference in UTM coordinates was taken from the pixel of interest to the base point. The difference was divided by 119950 (meters per degree latitude), to determine how many degrees latitude the point of interest was away from the base point. This value was then multiplied by 4 (days change per 1 degree latitude). The Hopkins component value for a sample point with a Northing of 4130022 meters, as compared to a base point with a Northing of 4060033 meters would equal 2.33 days later (integer value of 2 days) as shown below.

$$\left(\frac{4130022m - 4060033m}{119950m / \deg}\right) * \text{ 4 days / degree latitude = 2.33 days later}$$

More northerly points (than the base point) have a positive number; the same phenological event would happen later than at the base point.

The Hopkins component value associated with changes in longitude was found in the same manner as latitude, with 1 change to adjust for the less pronounced effect of longitude on bio-events. The effect of longitude on phenological events was found by Hopkins to be equal to 4 days delay for each 5 degrees longitude eastward, or 0.8 days per degree longitude. The difference in UTM coordinates (Easting) was calculated from the point of interest to the base point. This difference was divided by 87082 (meters per degree longitude) then multiplied by 0.8 (days per degree longitude) to yield the Hopkins value associated with longitude. The Hopkins component value associated with a sample point with an Easting of 426070 meters, as compared to a base point with an Easting of 908877 meters would equal -4.40 days, as shown below. The negative value indicates that biological events would happen earlier at the sample point.

$$\left(\frac{426070m - 908877m}{87802m / \deg}\right) * \text{ 0.8 days / degree longitude = -4.40 days}$$

The final Hopkins value was then found by summing the 3 separate components; change due to elevation, latitude, and longitude. The above examples would yield a final

Hopkins value of 7 [9 + 2 + (-4)] for the sample point, as compared to the base point. This value indicates that the same biological event would happen approximately 1 week later at the sample point than at the base point. The result was a GIS map layer for Virginia in which each pixel value was equal to the likely delay in the occurrence of a biological event from the occurrence of the event at the base point.

Slope Position

Overview

Delineating slopes is a well known activity, but specifying *slope position* is subjective. Depending on the discipline and geographic location of a writer, slope positions, features of the landscape, have numerous names, such as: ridge, summit, side slope, toe slope, shoulder, bench, table, mesa, plateau, saddle, knob, cove, floodplain, and terrace. These terms are used to describe very similar features, yet each may have different meanings. Landform and drainage class are other terms that have been used to describe the generic location or shape of a site. Slope position was used in this study to describe the 3-dimensional space a site occupies in relation to its surroundings, not just the shape of the land surface, the "landform" previously described. In the field, it is very difficult, if not impossible, to get a large group of land managers to describe a site as having the same slope position. However, following a set of rules to classify slope positions may improve communication about the land. The following sections describe a set of such rules, the forms of various slope positions, and the approach used in this study to delineate them.

Slope position has long been studied as a factor in forest site quality measurements. Forest site quality is an expression of "...the ability of forest land to grow trees..." (Carmean 1975). Listed among these forest studies, as well as many other related studies, are the relationships between slope position and: soil nitrogen (Lunt 1939), surface soil depth (Turner 1936, 1937, 1938), surface soil pH (Weitzman and Trimble 1955), subsoil moisture, exchangeable potassium, surface drainage (Hebb 1962), and erosion and past land use. All of the relationships listed above have been shown to bear directly on forest site quality. Site quality, in turn, often affects the type or productivity of fauna present on a site.

In additional to being of environmental importance, knowledge of slope position is also of economic importance. Costs incurred by timber companies during routine operations on difficult slope positions (i.e., ridges, steep side slopes) often subtract from profit margins. Average per hectare costs for forestry practices in the southern United States have increased dramatically over the past few decades (Dubois et al. 1995). These increases are pronounced on difficult slope positions. In order to maintain profit levels, often by reducing operating costs, seeking to maximize use of advantageous slope positions has become a dominant factor in timber management plans.

As discussed, slope positions have various names and definitions that are often related to local environmental conditions. For the purpose of this study, many different classification approaches were analyzed for use. It was decided to use a modified version of the slope position classification used by Smith and Burkhart (1976) and Wathen (1977). Their method was chosen because it was developed and used in the Southern Appalachian Mountains, the same as the study area. The following paragraphs give a brief description of each slope position and its characteristics.

Ridge tops

Ridge top was not a category of slope position used by Wathen (1977). In many areas of the Southern Appalachians, the mountain tops drop off rapidly, and cause narrow ridges. The same situation occurs on the narrow spur ridges that run perpendicular to the tops of these mountains. Wathen's (1977) classification scheme would have termed these areas "summits." The ridge top category was created for those areas that represent the very convex and often narrow ridges of an area. They are, in essence, narrow elongate summits.

Summits

In the slope-position delineation scheme used as a base for this study, *summits* were areas located on tops of mountains, were fairly flat, and often extended over broad areas. Summits were considered areas that had relatively high amounts of available moisture (Smith and Burkhart 1976, Wathen 1977) and had high potential site indices. Broad flat summits may meet both of these conditions. The term itself implies a local high spot. In this study, summits are considered to be local high spots (with criteria to be discussed later) or relatively flat areas adjacent to ridge tops. Landscapes with rolling topography may also have summits that are not clearly defined. In such areas, summits may often be of high elevation, but fairly broad flat areas. The extent of these summits varies, and where they stop and start is often very subjective. As in other areas, they have been difficult to delineate. The criteria used to delineate these areas of limited scope are described in greater detail later.

Shoulder

Smith and Burkhart (1976) and Wathen (1977) described the *shoulder* as an area of land, a map pixel, near a summit, over which elevation drops rapidly, slope rate increases rapidly (described as "steep"), and the shape of the land around the pixel is convex. As with summits, the edges of shoulders are subjective and can differ depending on the observer. Shoulders are areas that are transition zones between summits or ridge tops and side slopes, thus generally they are quite narrow. Sample tests at shoulder delineation resulted in a very limited distribution of shoulders. Often less than 1% of an area would be delineated as shoulder. Due to the coarseness of the DEMs used (30m-per-side pixels), the limited extents (1 to 2 pixels wide maximum) of shoulders, and the difficulty in defining criteria and programming an efficient algorithm to delineate shoulders, it was decided not to map them.

Floodplains

Floodplains are locations along perennial or intermittent streams that may be prone to flooding and or water saturation. In general, the land shape is flat-to-slightly-concave with little to no slope. It is characteristically a collection area of overland water flow. The distance the floodplain extends from a stream or drainage channel is limited by the slope of the area. Steep slopes create narrow floodplains. Flat areas may have wide floodplains.

Toe slopes

Sites that surround floodplains, but are too steep to be considered floodplains, are generally termed *toe slopes*. These are locations where the generally flat topography of the floodplain meets the steeper landform of side slopes. Unlike narrow, limited shoulders, toe slopes can be wide, but can be subjectively separated from surrounding slope positions. Toe slopes can also be found distant from floodplains. Between consecutive spur ridges, similar to those found in the study area, there is an area of transition between 2 side slopes. This area is best described as a toe slope. It is an area of transition between the down side-slope of 1 ridge to the up side-slope of the next ridge. This transition area can be narrow (1 pixel) to several pixels wide.

Plateaus

Many areas exist throughout the Southern Appalachians that are described with terms including: saddles, benches, tables, or *plateaus*. Generally these terms refer to topographic forms that are local flat spots that are surrounded by gentle slopes. These area categories can occur wherever there are broad summits, mid-slopes, or floodplains. The steepness of these areas (called plateaus for this study) is usually flat or it has little slope (< 20% for this study) and a landform index (K, as discussed previously) indicating flat land as well (not concave or convex). The discrimination between a floodplain and a plateau will be provided later.

Side slopes

By far the most common slope position found throughout the study area, and most areas, are *side slopes*. When a site does not fall into any of the above categories, it is usually called a side slope. For the purposes of this study, side slopes were defined as being steeper (slope > 6°) than the other positions, and not having other characteristics already held by the above named positions.

Delineating Slope Position

While slope positions may be defined with terms such as "flat summits", "convex summits", "narrow ridge tops", "steep side slopes", or "rolling plateaus", there are no limiting statements about how steep is "steep" or how narrow is "narrow." As stated before, delineating slope positions is a subjective procedure and 2 people may call the same site 2 different slope positions. In order to delineate slope positions for this study, several steps involving numerous small programs were employed to achieve consistency. Once a pixel was classified as having a particular slope position, that pixel was taken out of further analysis. The following sections discuss the procedures and rationales used. The first operation used was a package in PCI called DWCON. This program created drainage networks from elevation data. Output from DWCON produced 4 data layers:

1) Filled depressions: The logic is transparent. In order to imagine a drainage network hypothetically, a fluid must flow in some direction. In a depression, all fluid would flow in and none would flow out. The algorithm in DWCON scaled all elevation values in a depression, of any size, to the lowest elevation value at the edge of the depression. This procedure configures all land pixels so that they are all related logically (in relation to gravity flow of liquids) to some drainage network.

2) Flow direction: After depressions were "filled" as above, a data layer was created that contained values that specified the direction that fluid would flow out of each cell.

3) Flow accumulation: The value computed in this step was equal to the number of pixels that would hypothetically empty their fluid to that cell. Along first order drainages, flow accumulation values were low because few cells flow to that part of the network. High-order streams and rivers had many cells to which there would be a logical "flow." Thus, each pixel value in such areas was large.

4) Delta values: Each pixel in this layer was set equal to the increase in the number of cells that flow to it along the flow direction.

The second procedure in slope position delineation was to decide on the maximum extent of the floodplains. As stated earlier, floodplains are areas with high potential overland waterflow and accumulation, and areas that are located along drainage networks. The flow accumulation values (layer 3 from DWCON) were examined to decide upon a cut-off value beyond which all pixels of greater value were possible drainage networks, and all pixels less than the cut-off were not. The desired effect was to keep only pixels of high overland fluid collection to designate areas within high-order drainages. The cut-off value decided upon was 300. The value of 300 was determined through examination of the flow accumulation data layer. The flow accumulation values associated with a random sample of 20 second-order drainages were taken and averaged. Average second-order flow accumulation values ranged from 250 to 350, so it was decided to take the center value of 300. A value of 300 meant that a pixel had to have at least 300 pixels (27 ha) with a potential flow to it in order to be considered a drainage network. Only pixels that met or exceeded this value were kept, all other pixels were not considered drainages. Earlier attempts at slope position delineation set the drainage cut-off value higher and lower than 300. Values lower than 300 often resulted in the over classification of floodplains and toe slopes. In many areas floodplains were classified on tops of apparent ridges and mountains. Values larger than 300 often had the opposite effect. Floodplains and toe slopes were rarely classified in an area. The largest problem with using a value greater than 300 was that toe slopes between consecutive spur ridges were mis-classified (typically as side slopes). These areas represent unique habitats in that they often have very different floral assemblages (and thus faunal assemblages) than their surroundings.

Ridge tops were delineated next. As stated above, ridge tops are usually narrow, very convex areas. In addition to being convex, ridge tops are also rarely adjacent to drainages. To identify convex cells, the raw landform index value, as discussed in previous sections, was used. Proximity analysis (PRX program in PCI) was performed on the drainage network layer to calculate the distance of every pixel to the nearest drainage network. The result was that each pixel was assigned a value, T, which was equal to the number of pixels from a drainage network. A model (Appendix, Number 5), using the layers mentioned above, was written in PCI to delineate ridge tops. The criteria that each pixel had to meet to be delineated as a ridge top pixel were: K (landform index) value of ≤ -20, *and* K multiplied by T (number of cells to a drainage network) had to be ≤ -60. The first criterion only allows very convex sites to be considered. The second criterion was developed to ensure that ridge tops were not delineated adjacent to drainages, unless the site was extremely convex. The value of ≤ -60 for K multiplied by T, was decided upon subjectively. In first experiments with this value I set a high value (e.g., -40), but its use resulted in many pixels being classified as ridge tops directly adjacent to drainages. In terrain with great changes in elevation in short distances, it is possible to have ridge tops relatively close to drainages. In pixels close to drainages (situations having a low T value), the K value had to be highly negative in order for those pixels to be designated as ridge tops. The PCI program PRX, for proximity analysis, was then run on the ridge top layer to calculate the proximity of all other pixels to the nearest ridge top.

In order to run the final slope position delineation program (Appendix, Number 6), 4 layers were needed: slope (degrees), raw landform index (K), proximity to drainages (in pixels), and proximity to ridge tops (in pixels). Each step in program Number 6 eliminated potentials for overlap or equivocation, that is to say, once a pixel was classed as having a particular slope position, it was taken out of further analysis.

The first 2 slope positions delineated were ridge tops and floodplains. These 2 were chosen because they represent the extremes of the slope positions used. All other slope positions were between them. Ridge tops were delineated as described earlier. Floodplains were delineated as being ≤ 5 pixels away from a drainage network, and having slope ≤ 3§ (roughly 5 percent).

Distinct summits were delineated next (less obvious summits were delineated in a later step). The first set of criteria used was very similar to those used to designate ridge tops. The only difference was that the site did not have to be as convex as a ridge top (K ≤ -20 for ridge top vs. K ≤ -15 for summit). A landform value of ≤ -15 was decided upon after several trials of summit delineation with different values. More negative values (of K) resulted in very few sites being classified as summits, and less negative values (of K) resulted with the opposite situation. A large negative value was wanted in this step to classify distinct, fairly convex summits. The other criteria were based on proximity of each pixel to a ridge top, proximity to a drainage, and slope steepness. A pixel had to be

≤ 5 pixels from a ridge top, *and* > 5 pixels from a drainage, *and* had to have slope ≤ 6° to be a summit.

Toe slopes were delineated next using proximity to drainages, proximity to ridges, and slope steepness. A pixel had to be ≤ 5 pixels from a drainage network, *and* > 5 pixels from a ridge top, *and* have slope > 3° and ≤ 12° (approximately 5 to 20 percent). To delineate the thin toe slopes between consecutive spur ridges, 1 more set of criteria was added. If the proximity to a drainage network was zero, *and* the slope was > 3° (not a floodplain), *and* the K value was > 0, then the pixel was delineated as a toe slope.

The remaining pixels were delineated in the final step. If the slope was > 6°, the pixel was a side slope. The next criterion delineated summits that were not distinct in form. If the slope was ≤ 6° *and* the K value was ≤ -5 (slightly convex) the pixel was designated as a summit. The remaining pixels were all termed plateaus.

Application of Data Layers

Abundance of data does not imply either high or low value of data or anything about the quality of maps derived from the data. Through mathematical transformations of 1 layer of data (i.e., elevation), numerous layers have been derived, as described in previous sections. Some transformations were simple mathematical functions (slope and aspect at a site were derived from the elevations of adjoining pixels), while others involved multiple steps of math, logic, and multilayer modeling (e.g., phenologic change and slope position). A value of these created layers can be found in their application to ecological problems. To demonstrate the potential uses and suggest the value of several of these layers, 3 different modeling approaches (exclusionary approach, logistic regression, and a combination of these 2 approaches) were used to delineate ecologically similar areas.

Delineating ecologically similar areas is a form of landscape classification. The term classification refers to “ordering or arranging of objects into groups or sets on the basis of their similarities or relationships” (Bailey et al. 1978). In this study the criteria for deciding about ecological similarities are based on GIS layers, either singly or in combinations. Many other classification systems have been based on the idea of similarities including: Kuchler’s (1964) potential natural vegetation, Bailey’s (1980) ecoregions, and Merriam’s (1899) life zones. Braun (1950) classified the Eastern United States on the basis of similar soils and tree species present. The state of Maine was separated into 9 zones of similarity based on climatological factors by Briggs and Lemin (1992). The usefulness of these classification schemes is limited for some purposes by their scale. Few farm, forest, or wildlife area management plans are written to encompass areas large enough to use the results of these approaches.

Exclusionary Approach

Any piece of land can be described using an apparently endless number of variables. The variables used will depend on the goals desired. For timber industries wishing to maximize timber production, variables typically used for analyzing tree growth include soil depth, soil moisture, soil texture and structure, slope steepness, elevation, aspect, soil fertility, and parent material. Through years of studies, foresters have learned that a certain few variables may have a large influence on wood or biomass production. For an architect selecting a location to build a house, the variables of interest and influence may include visible areas, nearness to roads, nearness to floodplains, and tax and zoning areas. All of these variables influence the cost of building and the subsequent value of the home. Wildlife biologists studying home ranges of different faunal species select habitat variables that are deemed to have the largest influence on those species. A person studying the black bear, for example, may use a set of variables, one entirely different from one used to study a salamander (Klopfer 1997)

A common problem incurred by wildlife biologists during many studies lies in determining which habitat variables to use. The most common solution to this problem today is to search the literature. For species that have been extensively studied, this literature may contain valuable information. Often literature may contain vast amouts of information, and a problem may arise as to how to decide which information is relevant. Another problem is that the exact locations of study sites are often not reported. With many species, the opposite problem exists, i.e., there is too little literature. The literature about many endangered or non-game species is scarce. Studies on rare or endangered species are often limited, and decision makers or managers are hampered by not knowing the factors that influence them, certainly not knowing the relative importance of variables. Without such knowledge, managers may not even know where to start cost-effective studies about influential factors.

An approach outlined here may aid in situations where a clear starting point for ecological studies is difficult to find. It is called the *exclusionary approach*. Locating possible habitat for threatened and endangered species is of great importance. These areas may serve as refuges or possible areas for reintroducing endangered species. Unfortunately, there is little information known about specific habitat requirements for many endangered species. The exclusionary approach can be used with little information to delineate possible equivalent sites.

With only few known observation points or physical sites where an endangered species has been observed, and with a GIS, it may be possible to use the exclusionary approach to delineate sites that are not unlike[2] the known points. The GIS can be used to create and analyze numerous variables that are stored in layers of data. These data are associated with the general area within which occur the known observation points. From these known points, and associated data layers, it is possible to locate sites with features equivalent to those of the points. For example, the elevation at each of the collection points could be plotted as a histogram. From this histogram it may be found that the species in question has no observation points below elevation 850 meters. It would then be possible to create a map of all areas with elevation greater than 850 m. Areas with elevation less than 850 m would then be excluded from future analysis (hence the name "exclusionary approach"). A single step may be sufficient to eliminate large tracts of land

[2] Similarity cannot be proven, only dissimilarity or the condition of "not unlike". The logic of this is outlined in Hoar (1980) and is identical to that surrounding the null hypothesis of statistics. "Similarity" or "similar" is used because of its prior use and connotation, not its denotation.

from further analysis or subsequent inappropriate acquisition or treatment. The same analysis can be performed with as many variables that can be created and used within the GIS. More complex analyses of combinations of multiple variables can be analyzed in the same manner as elevation. For instance, it may be found that the species in question prefers south-facing slopes with less than 20 percent steepness. It would then be possible to filter the image to keep only those areas that met these criteria, and to drop the remaining areas. A series of similar analyses could be performed based on histogram reports from single GIS data layers and from combinations of many GIS data layers. Each step in this process could then be applied to an area in the form of a model in which similar areas are kept and dissimilar areas are excluded. This process of creating a model made up of several steps was used in this study. The final images are maps of residual areas, all meeting the same criteria as a sample of points where an animal was observed and known to live.

For use in the exclusionary approach it was decided to classify several of the data layers along discrete classes for reasons discussed earlier (e.g., minimal likely faunal response to changes of only 1 meter in elevation, or 1° slope change), as well as decreasing the number of values to be analyzed. Elevation was classified along 50 m intervals. All elevation between 0 to 49 m would be in class 1, 50 to 99 m would be class 2, and so on. The elevation class size of 50 m was chosen to create a number of classes that could be easily handled, yet still allow for likely ecological differences to be detected. Slope was classified in the same manner as elevation, but along 5° increments. Aspect was divided into 9 classes (8 compass directions and 1 class for flat or no aspect). Landform index was classified into the 6 discrete classes discussed earlier. The Hopkins' values were used as raw values. Finally, slope position was used in the classes discussed earlier.

It is possible, and very likely, that some known points were excluded during the exclusionary process. In the above example where there is an hypothetical case of preference for south-facing slopes having less than 20 percent steepness, some known observation points may occur on north-facing slopes greater than 20 percent steepness. In this situation, these known north-facing points would be dropped. The decision to drop known points must be based on the overall distribution of known points. For example, it may be found that 97 percent of observations of a species of interest occur at sites with slope less than 15 percent, with the remaining 3 percent observed at sites with slope greater than 30 percent. The decision to drop all sites with slope greater than 15 percent (thus losing 3 percent of known pixels) may be given 2 rationales. The first rationale is based on potential error in the field and in the GIS. There is possible error associated with locating observation points in the field, digitizing known points for use in a GIS, and possible error associated with the GIS slope data layer. The second rationale is based on one goal of the exclusionary approach, it being to keep as many known points as possible, while excluding background (non-equivalent) points. The decision was similar to that used in statistical decision making, using a range of 1 or 2 standard deviations, discounting numbers in the tails of normally distributed populations or samples. Only 3 percent of known pixels were associated with slopes greater than 30 percent, but it may be found that 20 percent of the study area had slopes greater than 30 percent. Excluding the steep slope points may result in the loss of a limited percent (3) of known points, but may exclude a large percent (20) of background points.

For use in this study each exclusionary step had to meet 3 criteria. In order to be used as an exclusionary step, more than 2% of the full image pixels had to be excluded. The second criterion dealt with the exclusion of known squirrel pixels. If known squirrel pixels were to be excluded, the percent excluded had to be no greater than 1% more than the percent of all image pixels excluded. For example, if a step excluded 2.5% known observation points, but also excluded 3.2% of the full study area, it would be used in the exclusionary approach. The last criterion was that no single exclusionary step could exclude more than 5% of the known observation pixels.

Logistic Regression

Based on the same set of collection points, i.e., the known GIS map pixels in which the species was observed, a different analysis can be performed that may yield a similar map. Regression analysis has been used in wildlife studies for many years, ranging from analyzing population trends to analyzing species distribution along some environmental gradient. While useful for many analyses, standard regression analyses require that many assumptions be met, (e.g., normality of data, continuous or discrete variables, minimum number of observations). More recently, logistic regression analysis has begun to be used in place of standard regression techniques (Thomas et al. 1996, Decarie et al. 1995, Pauley et al. 1993, Adler and Seamon 1996). Logistic regression analysis applicibility stems from it not requiring assumptions about the normality of the data, and that it may deal properly with both continuous and categorical variables in the same equation.

Logistic regression analyses have been incorporated into GIS-based wildlife studies recently. Adler and Seamon (1996) used logistic regression to predict that the presence or absence of opossum (*Didelphis virginia*) was related to island size and isolation. Decarie et al. (1995) and Nadeau et al. (1995) described several of the abiotic and biotic characteristics associated with lakes and ponds that served as habitat for green-winged teal (*Anas crecca*). Other wildlife studies incorporating logistic regression include, but are not limited to Thomas et al. (1996), Pauley et al. (1993), Klopfer (1997), Virgina Gap Analysis Project.

A data set can be constructed which contains the dependent variables (extracted from GIS data layers) associated with each known observation point. Each observation point would receive a value of 1; all other non-observation points would be set to 0 within a bitmap. A second data set may be constructed with the same variables taken from a set of randomly located points. The pool of points, from which the random points are drawn, excludes known points in the map study area. It is possible that "good" sites for the species being studied may be included with the random points selected, but it must be assumed that the likelihood is low. Proving a species *exists or may exist* in an area is difficult; proving that it does *not or may not* is impossible.

Once the data sets have been constructed, logistic regression is able to compute a regression equation of the type shown in Equation 1.

$$\rho\,(equivalency) = \frac{e^{(\beta_0+\beta_1 x_1+\beta_2 x_2+\ldots\beta_n x_n)}}{e^{(\beta_0+\beta_1 x_1+\beta_2 x_2+\ldots\beta_n x_n)}+1} \qquad \text{Eq. 1}$$

β_0 = intercept
$\beta_1, \beta_{2,}, \ldots \beta_n$ = coefficients
x_1, x_1,... x_n = variables

It is then possible to apply the equation to each pixel throughout the area, inserting at each pixel the physical variable x_1, x_2, ...x_n. The result of completing the logistic equation is to be able to estimate a probability of equivalency. Due to the nature of the dependent variables (1 for known observation points, 0 for random non-observation points) output probabilities that meet or exceed 0.50 are considered equivalent. Probabilities less than 0.50 are considered unlikely to be equivalent. With binary dependent variables, it is not possible to say that a probability of 0.99 is better than a probability of 0.50 (SAS Manual 1990). To attach a probability of a pixel being equivalent would require that the dependent variables have a probability attached to them. The dependent variables in this study were binary, indicating that the pixel was a known squirrel pixel (a value of 1), or assumed to not be a squirrel pixel (a value of 0). If it was possible to assign a probability of each dependent pixel being a squirrel pixel it would then be possible to use the output of the logistic regression as a probability of equivalency. The results are interpreted as equivalent or not equivalent with no intermediate values of equivalency.

Combination of Exclusionary Approach and Logistic Regression

Both of the approaches outlined above result in a bitmap of equivalent sites. Pixels in those bitmaps are deemed equivalent, or not unlike. Known training data are given a value of 1. Pixels that are considered not equivalent, or unlike those training data, are given a value of 0. Pixels that receive a 1 will be termed “turned on” (as if lighted), pixels that receive a 0 will be “turned off”. Ideally, both approaches would turn on and turn off the same pixels, but more likely, there will be pixels that are turned on through 1 approach that may be turned off by the other approach, and vice-versa. This may happen in situations where 1 approach is more (or less) sensitive to changes in 1 or more input variables. It may not be possible to determine which approach is correct and which is not. To decide whether these pixels should be turned on or off would be purely subjective. The most conservative approach may be to turn on only those pixels which are turned on by both approaches, and turn off those pixels that are either turned on by only 1 approach, or are turned off by both approaches.

To delineate only those pixels that were turned on by both approaches, a simple mathematical GIS procedure was used. As stated above, both approaches assigned a value of 1 to turned on pixels, and 0 to turned off pixels. The layers resulting from the exclusionary approach and logistic regression together were multiplied together. Output pixels were turned on only if both approaches were equal to 1 (turned on). If either, or both, approaches equal 0 (turned off), then the output pixels were equal to 0.

Species Collection Points

To demonstrate the application of the created GIS data layers and the 3 approaches outlined above, a faunal species was chosen and a map created of known observation points of that species. I then attempted to create a map showing areas having approximately the same characteristics as the sites where the animal had been observed. The equivalent areas would be delineated based on the topographic characteristics of a series of known collection/observation points of the species chosen. The Northern dusky flying squirrel (*Glaucomys sabrinus*) was selected because it is a federally endangered species and has limited distribution within the state. These 2 criteria make it of high importance in land management plans within the state for several agencies and companies. The database, Biota of Virginia (BOVA), created by the Virginia Department of Game and Inland Fisheries (VDGIF) was used to extract observation points for the species. The known distribution of the squirrel was limited to areas included within 3 Virginia topographic quadrangles, Thornwood, Hightown, and White Top Mountain. A 3x3 pixel bitmap centered over each observation point was used to represent the ecological characteristics where the squirrel was observed. There were totals of 324, 189, and 108 squirrel pixels in Thornwood, Hightown, and White Top Mountain respectively. The purpose of using a window around each observation point was 3-fold. The first reason was to sample not only the actual observation point, but also to sample the surrounding environment that may be influencing the squirrel distribution. The second reason was to avoid singular cells (a stable squirrel population cannot exist in the 30m x 30m space of a singular pixel) and to include the variable conditions common in forests of the region. The third reason for using a window was to compensate for possible errors in digitizing the observation point.

The collection points in Thornwood and Hightown were combined to serve as the model building area for all 3 approaches. These 2 maps were joined because they were located adjacent to each other in Highland County, Virginia. These 2 topographic quadrangles will be referred to as the Highland study area. The last topographic quadrangle, White Top Mountain, was chosen as the area to which the models created in the Highland study area would be applied and tested.

All 3 approaches created a model that when applied to an area resulted in a map of equivalent areas. Once a model was built using 1 of the 3 approaches outlined above, the model was applied to the White Top Mountain topographic quadrangle. The known squirrel points within the White Top Mountain area were then overlaid upon the areas resulting from the application of the models to the area. Histogram analysis was performed to determine how many known squirrel pixels were kept by each respective model, and how much of the full study area was kept.

Results

Elevation

Elevation was separated along 50 m increments using program Number 1 (Appendix) in PCI. The resulting map for Hightown is shown in Fig. 8. All pixels of the same color represent areas in the same 50 m elevation class. The histogram of elevation distribution for the full study area showed a bell curve was approximately normally distributed (Fig. 9). Over 58% of the study area (Table 5) was within elevation classes 20 to 23 (950 m to 1149 m). The majority of the “known squirrel pixels” (recall that this phrase means that a Northern dusky flying squirrel has been observed in the pixel) occurred in elevation classes 22 (34.70%), 23 (28.07%), and 25 (24.76%). The proportion of pixels in class 24 was small (1.95%), but observations appear disproportionate (Table 5) and may reflect the rarity of the species, effects of geology, or observer effort, or other factors. The observations above above class 27 were absent, implying limits to the squirrels range, limits to observer effort, or other phenomena. No known squirrel pixels were found below elevation class 22 (1050 - 1099 m) or above class 27 (1300 - 1349 m).

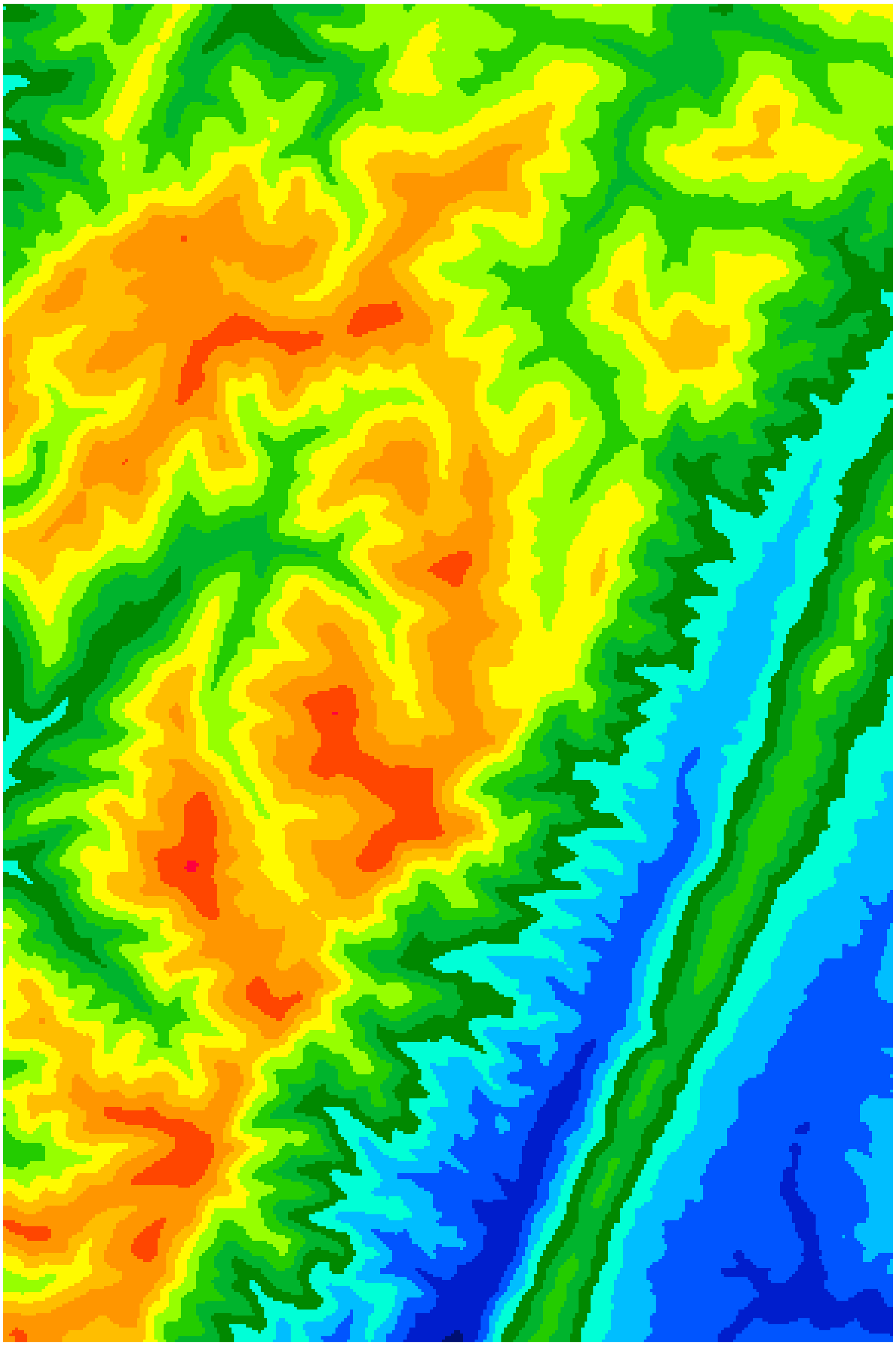

Figure 8. Elevations for Hightown topographic quadrangle shown in 50 meter increments. The elevations increase as color changes from blue, to green, to yellow, to orange, to red. The minimum elevation is 792 m. The maximum elevation is 1404 m.

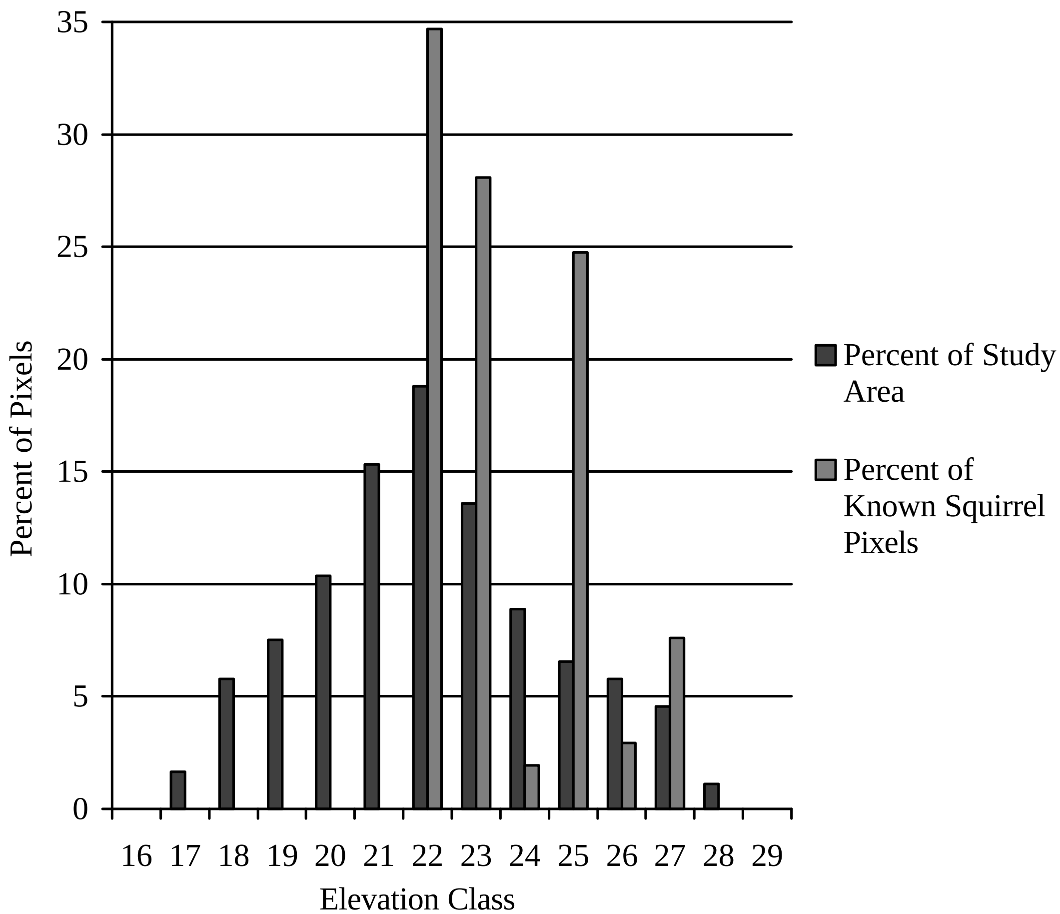

Figure 9. Histogram of the elevational distribution of the full Highland study area and known squirrel pixels.

Table 5. Elevational distribution of the full Highland study area and known squirrel pixels only. Elevation classes are 50 meter increments (e.g., 0 - 49 m was Class 1, 50 - 99 m was Class 2).

Elevation Class	Percent of Full Study Area	Percent of Known Squirrel Pixels
16	<0.00	0
17	1.66	0
18	5.78	0
19	7.53	0
20	10.38	0
21	15.32	0
22	18.80	34.70
23	13.59	28.07
24	8.88	1.95
25	6.56	24.76
26	5.77	2.92
27	4.56	7.60
28	1.11	0
29	<0.00	0

Slope

Slope was classified along 5° increments with the same program used to separate elevation. The resulting map for Hightown is shown in Fig. 10. Dark blue colors indicate the flattest areas (flat to 4°), red areas represent the steepest sites (40° - 44°). Slope class distribution for the full study area and for the known squirrel pixels are shown in Table 6. Over 69% of the study area was in slope classes 3, 4, and 5. Less than 2% of the study area had slopes steeper than class 7 (30° - 34°). There were no known squirrel pixels above slope class 5 (20° - 24°). The distribution of the known squirrel pixels among the slope classes was predominantly in classes 2, 3, and 4 with 23.78%, 38.60%, and 22.42%, respectively.

Aspect

Fig. 11 was produced using program Number 1 (Appendix) that was used to separate aspect into the 8 compass directions shown in Fig. 5c (see "Methods"), plus a class for flat sites not having aspect. Histogram analysis of the aspect map shown in Fig. 11 indicated that aspect was fairly uniformly distributed over the 8 compass directions. The percentages of the study area and the known squirrel pixels within each aspect class are shown in Table 7. Less than 1% of the study area was in class 9 (flat). The percent of the study area in each of the remaining 8 compass directions ranged from 10.91% (class 8) to 14.83% (class 7). The distribution of the known squirrel pixels was not as even among the aspect classes as the full image. No known squirrel pixels were found on flat sites

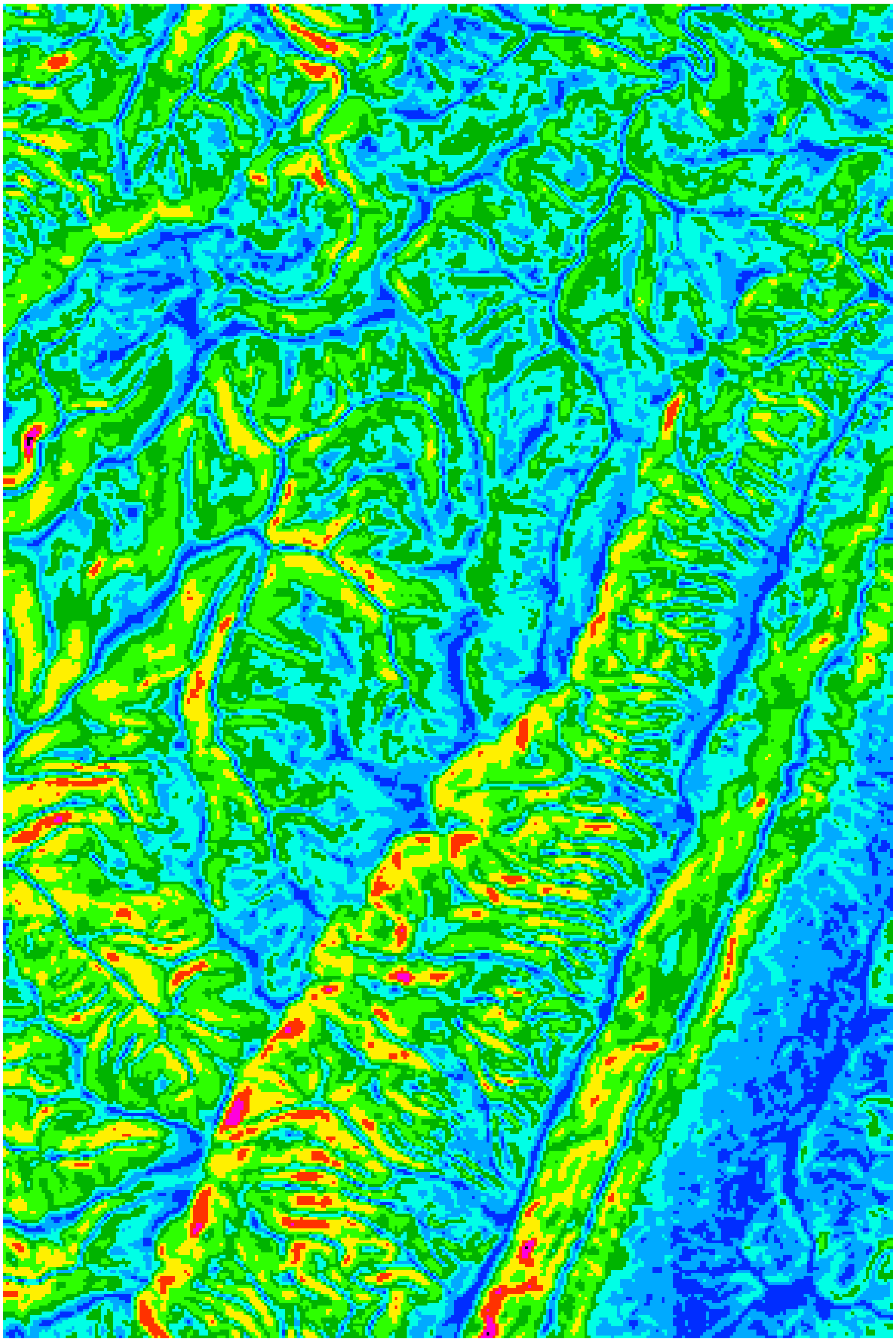

Figure 10. A map of slope for the Hightown topographic quadrangle. Slope increments of 5 degrees are shown. Steepest slopes are red (>20°), and are progressivley less to dark blue areas having slopes of 0° to 4°.

Table 6. Slope distribution of the full study area pixels and known squirrel pixels for the Highland study area. Slope classes were in 5° intervals (e.g., 0° - 4° was Class 1, 5° - 9° was Class 2).

Slope Class	Percent of Full Study Area	Percent of Known Squirrel Pixels
1	5.60	9.75
2	14.98	23.78
3	23.45	38.60
4	26.44	22.42
5	19.47	5.57
6	8.35	0
7	0.59	0
8	0.11	0
9	<0.00	0

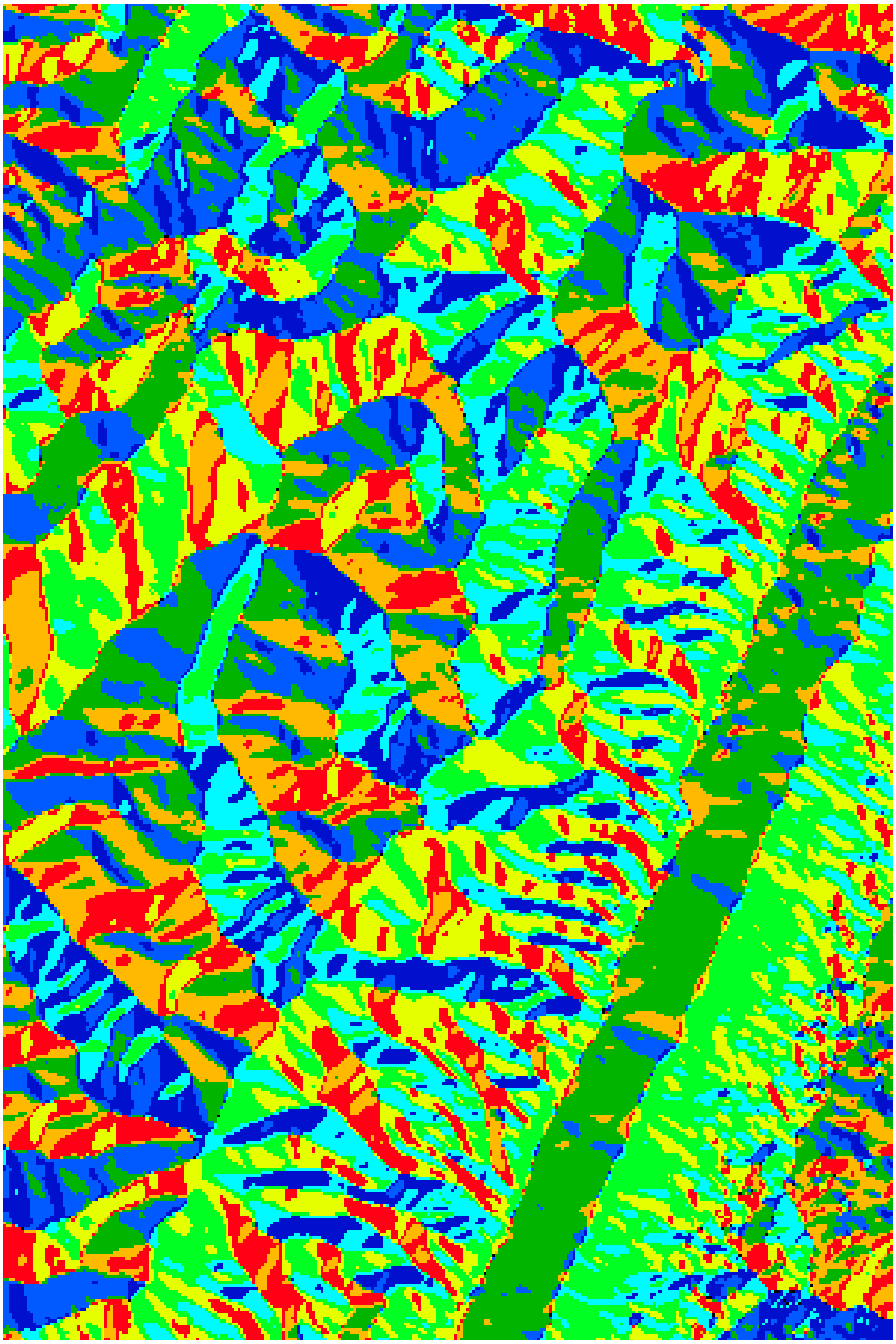

Figure 11. Aspect image for the Hightown topographic quadrangle showing 8 primary compass directions. The darkest blue shades represent north-northeast and east-northeast aspects, red and orange represent south-southwest and west-southwest aspects. Light blue is north-northwest, dark green is west-northwest. Light green and yellow are east-southeast and south-southeast, respectively.

Table 7. Distribution of aspect among the full study area pixels and known squirrel pixels for the Highland study area.

Class Number	Aspect Class Range	Percent of Full Study Area	Percent of Known Squirrel Pixels
1	0-44	12.35	6.82
2	45-89	12.43	12.28
3	90-134	12.73	12.09
4	135-179	12.48	7.21
5	180-224	12.76	16.57
6	225-269	11.26	21.44
7	270-314	14.83	15.40
8	314-359	10.91	8.19
9	No aspect	0.26	0

(class 9). The aspect class with the most known squirrel pixels (21.44%) was class 6, i.e., 225° to 269°. Aspect classes 5 and 7 had the second and third most squirrel pixels respectively. The distribution of known squirrel pixels among the 8 compass directions ranged from 6.82% in class 1 to 21.44 % in class 6. The non-uniform distribution of known squirrel pixels among the 8 aspect classes may be explained through simple combinations of slope classes and aspect classes. This possiblity was further examined through the exclusionary approach, and was reported in that section of the Results.

Landform Index

The landform of the study area was very diverse. Raw K values ranged from -29 to 37, but over 96% of all pixels were within the much narrower range of -17 to 17. The landform index was classified into the 6 classes listed in Table 4 in the ”Methods” section to create the image shown in Fig. 12 for the Hightown topographic quadrangle. The dominant classed landform of the Highland study area was planar sloped surfaces (66.96% of the full area) (Table 8). Convex and concave landform classes each comprised approximately equal amounts of the study area (12.24% and 11.46%, respectively). Very little of the study area was classified as very convex (1.02%) or very concave (1.19%). The distribution of the known squirrel pixels over the landform index values was more narrow than the distribution of the landform index of all study area pixels. The landform value range of -15 to 19 contained all of the known squirrel pixels. This narrow range of K values indicated that no known squirrel pixels occurred on very convex or very concave

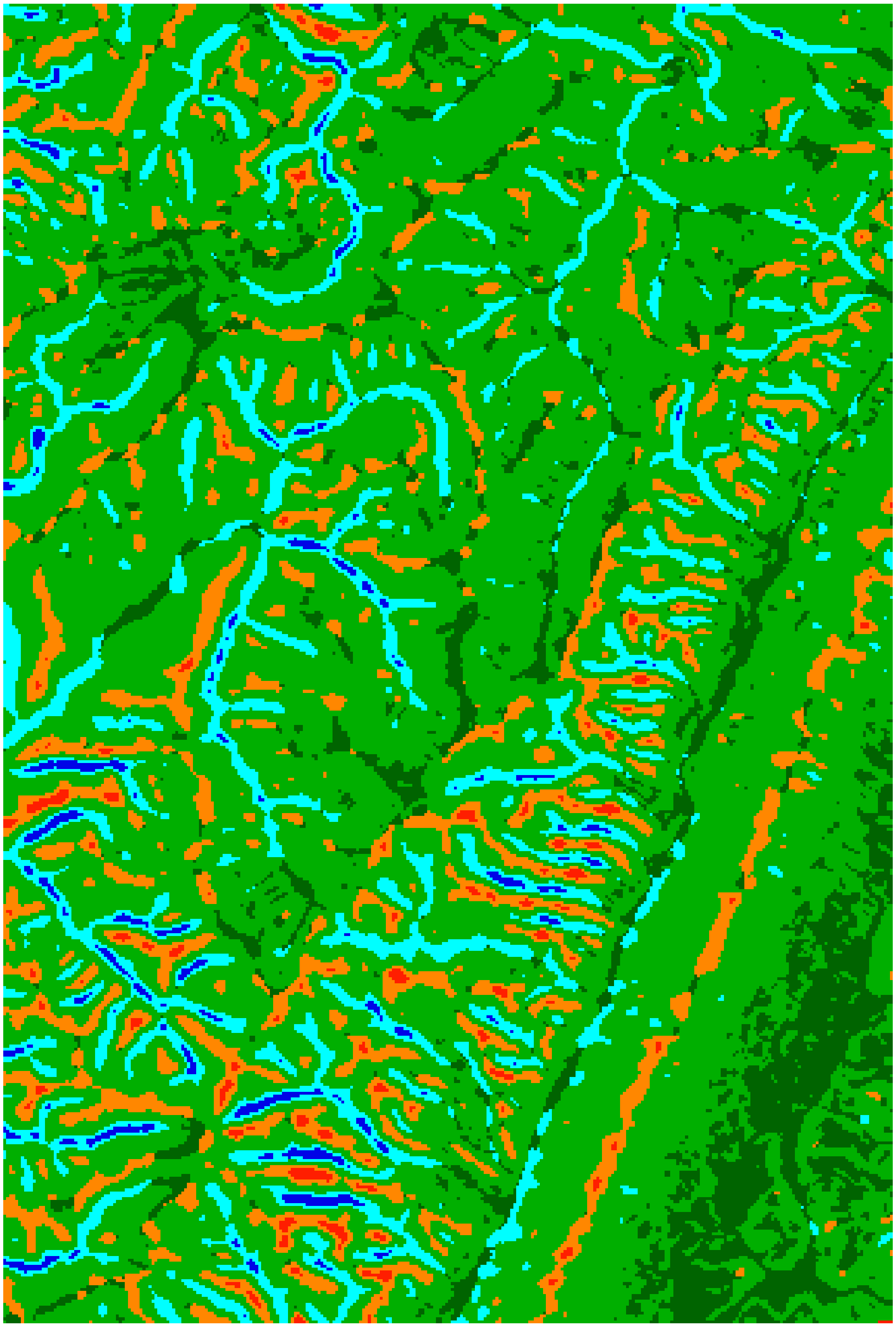

Figure 12. Hightown topographic quadrangle shown in 6 landform classes. Colors are scaled from dark blue (very concave) indicating a sheltered landform, to red (very convex) indicating an exposed landform. Intermediate colors of light blue, dark green, light green, and orange represent concave, planar horizontal, planar sloped, and convex, respectively.

Table 8. The distribution of the landform index for all study area pixels and known squirrel pixels for the Highland study area.

Landform Class	Percent of Full Study Area	Percent of Known Squirrel Pixels
Very Convex	1.02	0.00
Convex	12.24	2.53
Planar Sloped	66.96	75.05
Planar Horizontal	7.13	13.26
Concave	11.46	9.16
Very Concave	1.19	0.00

sites. “Planar sloped surfaces” was the landform class within which fell over 75% of the known squirrel pixels (Table 8). Planar horizontal surfaces and concave sites had 13.26% and 9.16% of the known squirrel pixels, respectively. Only 13 out of the 513 (2.53%) of the known squirrel pixels occurred on convex sites.

Phenologic Change

A relative phenologic change layer was chosen as a variable for this study because it represents a union of 3 ecological factors (elevation, latitude, and longitude). It is possible to examine species distribution maps and observe trends that appear to be related to 1 of the factors involved in the Hopkins value. Examples can be seen along the Appalachian Mountain chain. In the northern reaches of the Appalachians, a species may have a wide distribution. As the distribution extends south, the range becomes narrow, and often follows, or is limited to, the mountain range. This change may be due to elevation, latitude, or longitude. Analysis of the distribution of a species along only 1 of these variables may miss the changes in habitat that result from the combination of all 3 variables.

Histogram analysis was performed on the raw Hopkins value map (Fig. 13 represents the Hightown topographic quadrangle). Relative Hopkins values for the Highland area ranged from 29 to 49 (Table 9). The Hopkins values of 39, 40, and 41 had the most pixels associated with them (35.02% of the full study area), and the values of the remaining pixels were spread throughout the tails of the distribution. The Hopkins value

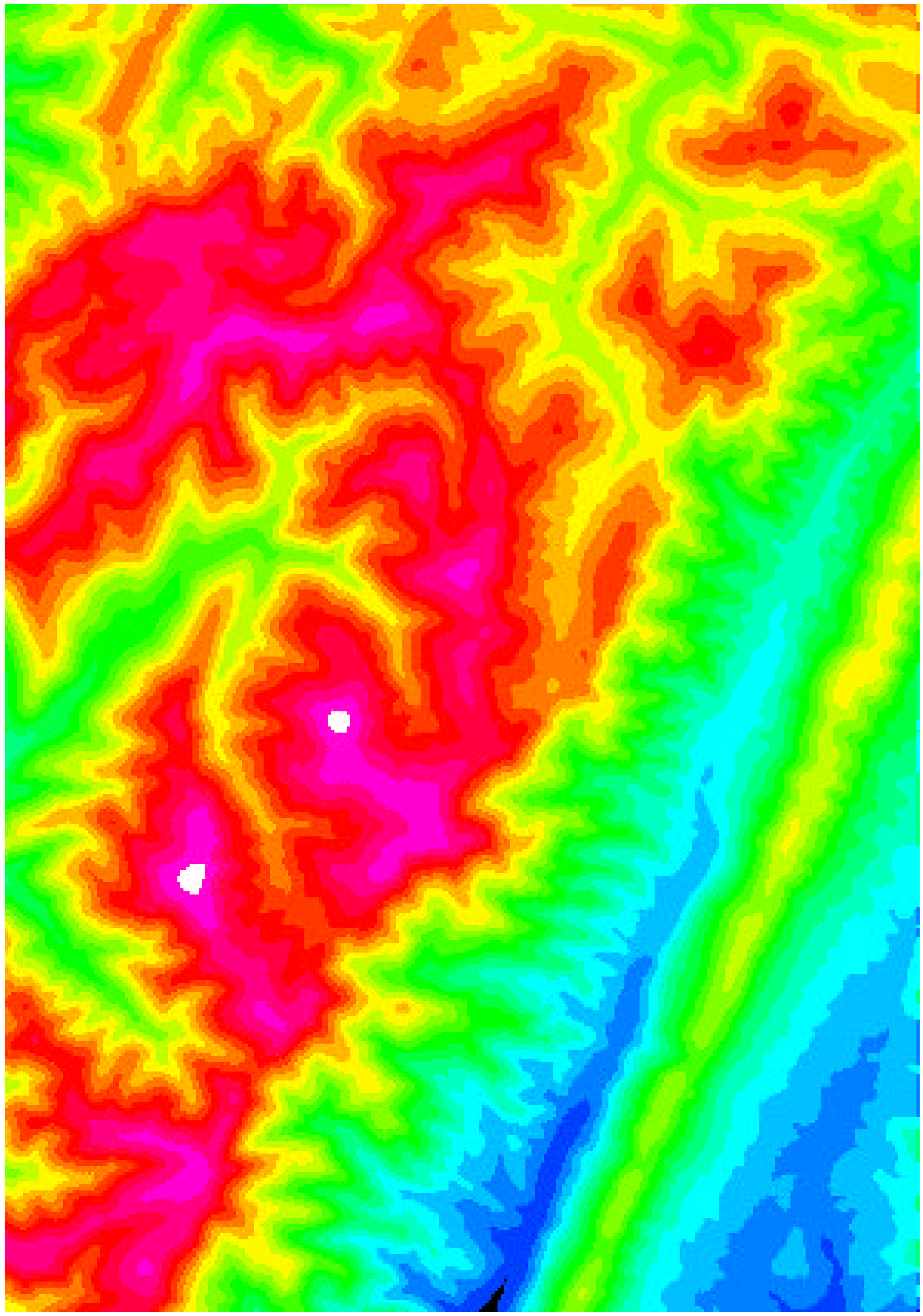

Figure 13. Hopkins' values for relative phenological time for the Hightown topographic quadrangle. The values range from black, the earliest date (29), through yellow and red to white, the latest equivalent date (49). Areas of similar color are expected to have uniform event occurrence dates.

Table 9. Relative phenological distribution of the full Highland study area and known squirrel pixels only. Hopkins value was computed as discussed in the Methods section.

Hopkins Value	Percent of Full Study Area	Percent of Known Squirrel Pixels
29	0.07	0
30	0.51	0
31	1.62	0
32	2.61	0
33	3.01	0
34	3.49	0
35	4.19	0
36	4.98	0
37	6.44	0
38	7.93	4.09
39	10.61	25.15
40	12.51	23.59
41	11.91	10.33
42	8.90	2.14
43	6.41	22.61
44	4.71	1.56
45	3.74	0.97
46	3.37	9.16
47	2.20	0.39
48	0.76	0
49	0.04	0

associated with the known squirrel pixels ranged from a minimum of 38 to a maximum of 47. The distribution of the known squirrel pixels was clumped at various Hopkins values (Table 9). The most known squirrel pixels were associated with Hopkins values of 39, 40, and 43 with 25.15%, 23.59%, and 22.61% of the known squirrel pixels respectively. The clumping of squirrel pixels in a few Hopkins values was similar to the distribution of squirrel points along elevational gradients. The study area was relatively small which made elevation have the strongest effect on the Hopkins value (latitude and longitude had little relative effect on the Hopkins value within the study area). Latitude and longitude may have larger effects when comparing geographically isolated locations over a larger area.

Slope Position

Fig. 14 was the result of the slope position delineation process applied to the Hightown topographic quadrangle. The percent of the study area in each of the 6 slope positions is listed in Table 10. Side slope was the predominant slope position present in the study area (71.53%). The slope positions of summit (9.94%) and toe slope (10.09%) made up nearly identical percentages of the study area. Ridge tops made up over 4% of the study area. Plateaus and floodplains made up the remaining area, 2.13% and 2.04% respectively. The known squirrel pixels occurred predominantly on side slopes (64.91%) and toe slopes (21.25%). Plateaus were classified as having 6.82% of the known squirrel

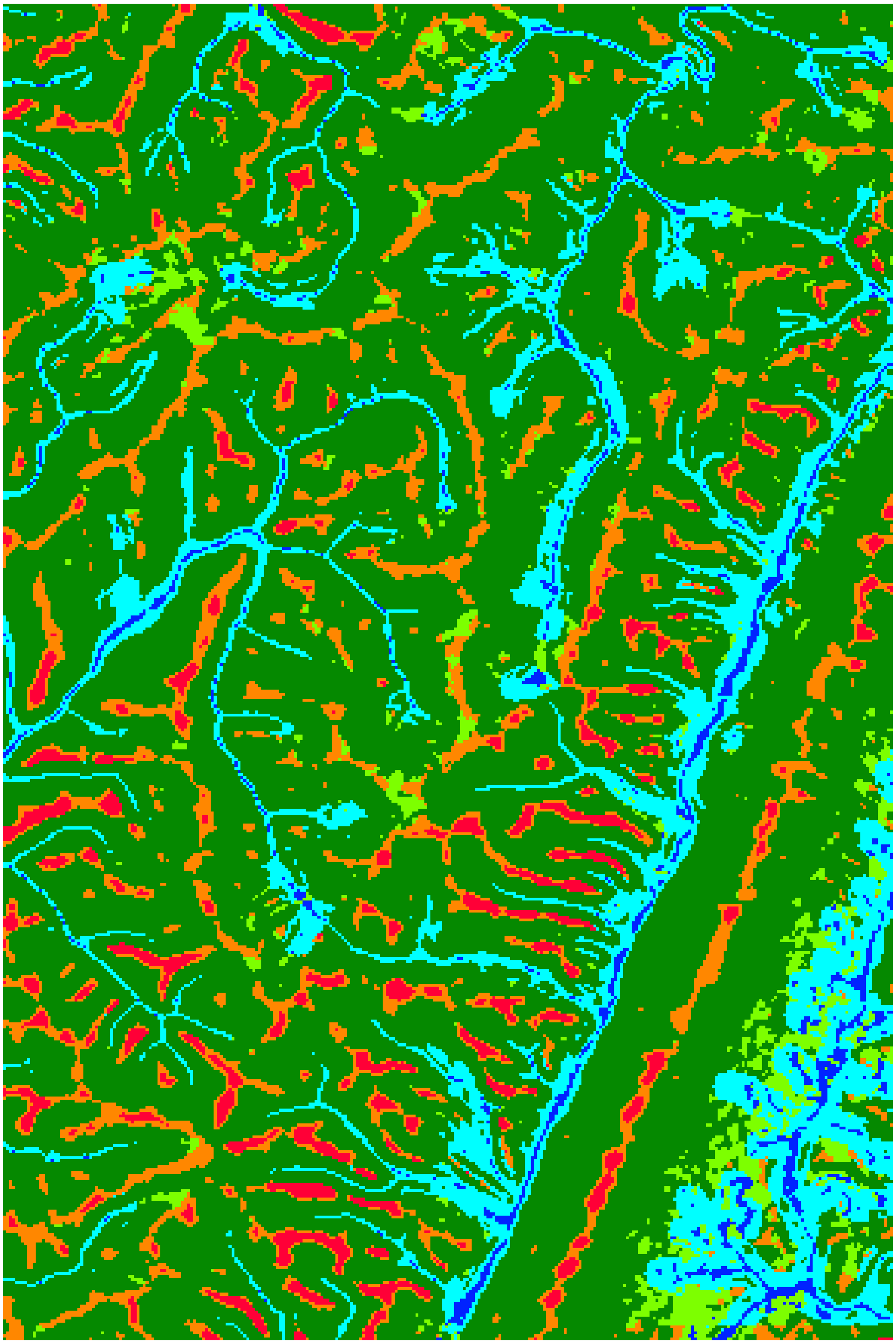

Figure 14. Slope position map for Hightown topographic quadrangle. Slope position classes are: ridge top (red), summit (orange), side slope (dark green), toe slope (light blue), plateau (light green), floodplain (dark blue).

Table 10. The distribution of slope position for the full Highland study area and known squirrel pixels.

Slope Position	Percent of Full Study Area	Percent of Known Squirrel Pixels
Ridge Top	4.28	0.19
Summit	9.94	3.12
Side Slope	71.53	64.91
Toe Slope	10.09	21.25
Plateau	2.13	6.82
Floodplain	2.04	3.70

pixels. Summits and floodplains each made up over 3% of the known squirrel pixels. Only 1 known squirrel pixel was classified as ridge top (Table 10).

Exclusionary Approach

After creating all of the previously discussed GIS data layers and histograms, it was necessary to create histograms of combinations of data layers to be considered in the exclusionary approach. The histograms were used to create the criteria to exclude pixels as discussed in the "Methods" section. The PCI program HIS was used to create histograms for combinations of all GIS data layers. The program HIS was run twice for each combination of data layers to create 2 histograms. The first histogram report was for the full topographic quadrangle, the second was only for those pixels with a known squirrel presence or observation. The result of the HIS procedure was a report of the number of image pixels associated with each raster value within the image. For a full topographic quadrangle (i.e., Thornwood, Hightown, or White Top Mountain) the total number of pixels was 135,000. The second histogram report was performed only for known squirrel pixels. The count of pixels was 324, 189, and 108 for Thornwood, Hightown, and White Top Mountain, respectively.

As discussed in the "Methods" section, the desired outcome of the exclusionary approach was to produce maps for a species of interest. Areas were classified that had characteristics similar to sites where animals had been observed. The distribution of known squirrel pixels along topographic gradients was compared through histogram analyses to the distribution of all pixels along the same topographic gradients. The topographic variables used were the layers described in the “Methods” section; elevation along 50 meter intervals, slope along 5° increments, 9 classes of aspect, raw Hopkins values, 6 landform index classes, and 6 slope positions.

Analysis of the histograms was undertaken at several levels, with each level becoming more complex. The most basic level was in comparing a single topographic variable gradient between known squirrel pixels and all pixels (listed in Tables 5, 6, 7, 8, 9, and 10). For example, the distribution of known squirrel pixels along an elevational gradient was compared to the distribution of all study area pixels along the same elevational gradient. At each higher level of analysis combinations of variables were analyzed, starting with 2-way combinations (e.g., slope and aspect), then 3-way combinations (e.g., slope,aspect, and landform index) etc.

After the histograms of the single data layers were analyzed, the first criteria by which to exclude pixels were decided upon. Any topographic variable class that did not have any known squirrel pixels was excluded from further analysis. The topographic conditions that were excluded were:

1) Very convex and very concave landforms.
2) Aspect class 9.
3) Hopkins’ values less than 38.
4) Slope class greater than 5.
5) Elevation class less than 22.

One additional criterion was included in the first level of the exclusionary process. This was “slope position ridge top”. Exclusion of ridge tops excluded 4.28% of all image pixels, and only excluded 0.19% of known squirrel pixels. Using this extra criterion begins to establish the basis of the exclusionay strategy, that is, minimum chance of decision error with maximum influence on the map. It “costs” data to generalize.

After the above single-layer criteria were established and applied to the study area, the PCI program HIS was used to determine the number of pixels in the study area, and known squirrel pixels that were excluded by this first step. For the study area, 89,825 (33.27%) pixels out of 270,000 were excluded (Table 11). This proportion can be viewed as a major increase in knowledge, at least a reduction in probable error about the species of interest. Of course this can be translated in various ways, e.g., sampling stategy economies. Only 1 pixel (0.19%) of the known squirrel pixels was excluded. The squirrel pixel was located in the Thornwood topographic quadrangle.

The next level in the exclusionary process was to examine the distribution of known squirrel pixels along 2-way combinations of topographic variables. The first level, just described, excluded pixels from consideration of equivalency based on single topographic variables. If no known squirrel pixels occurred in a single topographic variable class, then all pixels in that class were excluded. Pixels that occurred in a topographic variable class were also excluded if only a few known squirrel pixels were in that class, but there were many study area pixels within that class (a high ratio of pixels in

Table 11. Results of the exclusionary process applied to the Highland study area. Each level number indicates the number of data layers used to exclude pixels (e.g., Level 1 examined only 1 variable at a time, Level 2 examined all 2-way combinations of variables).

Level Number	Number of Study Area Pixels Excluded (%)	Number of Known Squirrel Pixels Excluded (%)
1	89825 (33.27)	1 (0.19)
2	160113 (59.30)	37 (7.21)
3	166166 (61.54)	53 (10.33)
4	175595 (65.04)	65 (12.67)

a class to known squirrel pixels in that class). The same process was used for 2-way combinations of variables.

There were 15 possible 2-way combinations of the 6 topographic variables used. Each possible combination was analyzed for differences between the distribution of known squirrel pixels and the distribution of all pixels in the study area over the 2-way combinations. Of the 15 possible pairwise combinations of data layers, only 4 combinations were used to exclude pixels from consideration of equivalency. The combinations and number of pixels excluded are shown in Table 12. The first combination was of slope classes and aspect classes. All pixels with slope class equal to 5 were excluded *unless* the aspect class was 5 or 6. This combination kept all pixels with slope class less than 5 for this stage of the analyses (all pixels with slope greater than class 5 were excluded by the combination). This step raised the total percent of the study area excluded to 49.67% (Table 12), and resulted in 1.56% of known squirrel pixels being excluded (an increase of 1.37% from the first level). The procedure is a combination of efforts, similar to discounting observations in the tails of a normal distribution when only 1 or 2 standard deviations of information are used with a mean. It is also one of discovering relevant and meaningful ecological factor combinations for a population of animals. Of the squirrel pixels that were excluded, 2 were in the Hightown area, and 5 were in Thornwood.

The next 2-way combination that was used to exclude pixels was the combination of landform index class 2 (convex) *and* all slope classes greater than or equal to 3. As

Table 12. Number and percent of pixels excluded as the result of 2-way combinations of topographic variables.

Combination of Data Layers	Number of Study Area Pixels Excluded (%)*	Number of Known Squirrel Pixels Excluded (%)*
slope class = 5 *and* aspect class ≠ 5 or 6	134115 (49.67)	8 (1.56)
landform index class = 2 *and* slope class ≥ 3	145677 (53.95)	12 (2.34)
slope position = summit *and* slope class ≥ 2	151822 (56.23)	18 (3.51)
landform index class = 5 *and* slope position = side slope	160113 (59.30)	37 (7.21)

*percent of pixels excluded are cumulative starting from single data layer exclusions.

shown in Table 12, 53.95% of the study area was excluded after this step, an increase in excluded study area pixels of only 3.83%. The percent of known squirrel pixels that were excluded increased to 2.34% from 1.56%. Only 2 known squirrel pixels were excluded from each of the Hightown and Thornwood areas.

A third 2-way combination involving slope class was used next to exclude pixels. Any pixels that had the combination of slope position summit *and* slope class greater than or equal to 2 were excluded. As shown in Table 12, the percent of the study area excluded increased by 2.28% to 56.23%, while the percent of known squirrel pixels excluded increased by 1.21% to 3.51%. All known squirrel pixels that were excluded during this step were within the Hightown topographic quadrangle.

The last pairwise combination of data layers used to exclude pixels was landform index class 5 (concave) *with* slope position side slope. A greater percent of known squirrel pixels were excluded (3.70%) by this step than study area pixels (3.07%), but met all 3 criteria mentioned in the "Methods." All other pairwise combinations violated 1 or more of the criteria. The known squirrel pixels that were excluded were all located in the Thornwood topographic quadrangle.

Of the 20 possible 3-way combinations of the data layers, only 1 combination met the 3 criteria discussed in the "Methods" section and was used as a step to exclude pixels. The combination of landform index class 3 (planar sloped) *and* slope position side slope *and* slope class greater than or equal to 5 resulted in 2.24% of the full image being excluded, raising the total to 61.54% (Table 11). Similar to the last 2-way combination of factors, there were more known squirrel pixels excluded (3.12%) by this step than full-image pixels. All of the known squirrel pixels excluded (16) by this step were within the Thornwood topographic quadrangle. After the exclusion of pixels based on 1, 2, and 3-way combinations of data layers, 61.54% of the study area was excluded, and only 10.33% of the known squirrel pixels had been excluded (Table 11).

All of the remaining combinations of data layers (4-way, 5-way, and 6-way) resulted in only 1 combination of factors that was used to exclude pixels. The 4-way combination of landform index class 3 (planar sloped) *and* slope position side slope *and* slope class equal to 4 *with* aspect class 3 or 4 was used to exclude pixels. This combination of factors excluded an additional 3.50% of the study area pixels, and only 2.34% of the known squirrel pixels (Table 11). The exclusionary approach excluded 65.04% of the study area pixels, and only 12.67% of the known squirrel pixels.

The result of the exclusionary approach was an image in which all non-equivalent pixels had been excluded, and only similar, or not-different pixels were kept, and a model to delineate these areas was created. The final model is listed in Table 13. Fig. 15 resulted from the application of the final model to the Hightown topographic quadrangle.

Application of the Exclusionary Model

As described in the "Methods", I applied the above procedure to test the results. This was an independent data set not used in developing the squirrel mapping procedure. After the final exclusionary model was applied to the White Top Mountain topographic

Table 13. Steps in the exclusionary approach to delineating the areas of probable occurrence of the Northern dusky flying squirrel in areas of western Virginia.

1-way analysis of variables (Step 1)

Exclude pixels with classed landform index = very convex or very concave.

Exclude pixels with slope position = ridge top.

Exclude pixels with aspect class = 9 (flat).

Exclude pixels with Hopkins value < 38.

Exclude pixels with slope class > 5.

Exclude pixels with elevation class < 22.

2-way analysis of variables (After Step 1, Steps 2, 3, 4, and 5)

Exclude pixels with slope class = 5 *and* aspect class $\neq$ 5 or 6.

Exclude pixels with classed landform index = convex *and* slope class > 2.

Exclude pixels with slope position = summit *and* slope class > 1.

Exclude pixels with classed landform index = concave *and* slope position = side slope.

3-way analysis of variables (Following 2-way analysis, Step 6)

Exclude pixels with landform index = planar sloped, *and* slope position = side slope, *and* slope class > 4.

4-way analysis of variables (Following 3-way analysis, Step 7)

Exclude pixels with landform index = planar sloped, *and* slope position = summit, *and* slope class = 4, *and* aspect class = 3 *or* 4.

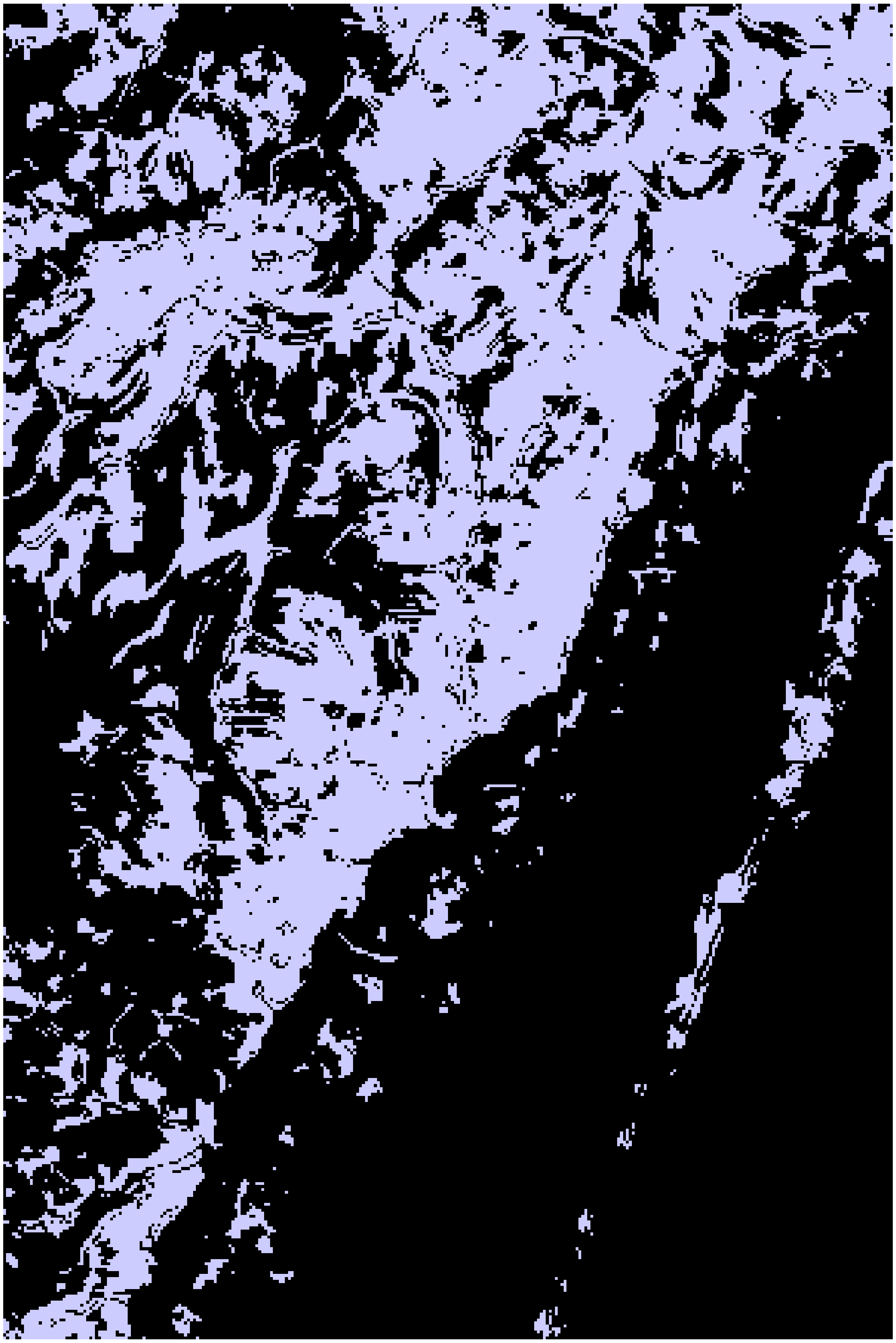

Figure 15. Result of the exclusionary approach applied to the Hightown topographic quadrangle. Highlighted pixels were those considered to be equivalent. Black areas represent those areas considered non-equivalent and were excluded.

quadrangle, histograms were run after each exclusionary step. The number of known squirrel pixels and full White Top Mountain topographic quadrangle pixels excluded at each step are listed in Table 14. After the exclusion of pixels based on single data layers, over 66% of the full area was excluded while only 0.93% (1 pixel) of the known squirrel pixels were excluded. Step 2 excluded an additional 6.68% of the White Top Mountain area, and only 1 more known squirrel pixel. Only 1.14% of the White Top Mountain area was excluded by step 3, while 3.71% more known squirrel pixels were excluded. Step 4 resulted in 0.65% and 4.63% of the full image and known squirrel pixels being excluded, respectively. The last pairwise combination (step 5) excluded an additional 0.26% of the full image pixels and 1.85% of the known squirrel pixels. Step 6 resulted in 1.29% additional image pixels and no known squirrel pixels being excluded. The last step excluded 3.32% additional image pixels and 2.77% known squirrel pixels. The resulting image of the White Top Mountain area is shown in Fig. 16. The exclusionary model excluded over 79% of the full area and kept over 85% of the known squirrel pixels.

Logistic Regression

The second approach used to classify potential squirrel pixels was through logistic regression. After 513 random "non-squirrel" pixels were established in the Highland study area, the topographic variables associated with each known squirrel pixel and each non-squirrel pixel were extracted from the study area data set. The data for topographic variables associated with each pixel were run through the SAS procedure PROC

Table 14. Results of the exclusionary process model built in the Highland study area applied to White Top Mountain.

Step Number	Number of Total Area Pixels Excluded (%)	Number of Known Squirrel Pixels Excluded (%)
1	90378 (66.95)	1 (0.93)
2	99400 (73.63)	2 (1.85)
3	100940 (74.77)	6 (5.56)
4	101820 (75.42)	11 (10.19)
5	102178 (75.69)	13 (12.04)
6	103928 (76.98)	13 (12.04)
7	107061 (79.30)	16 (14.81)

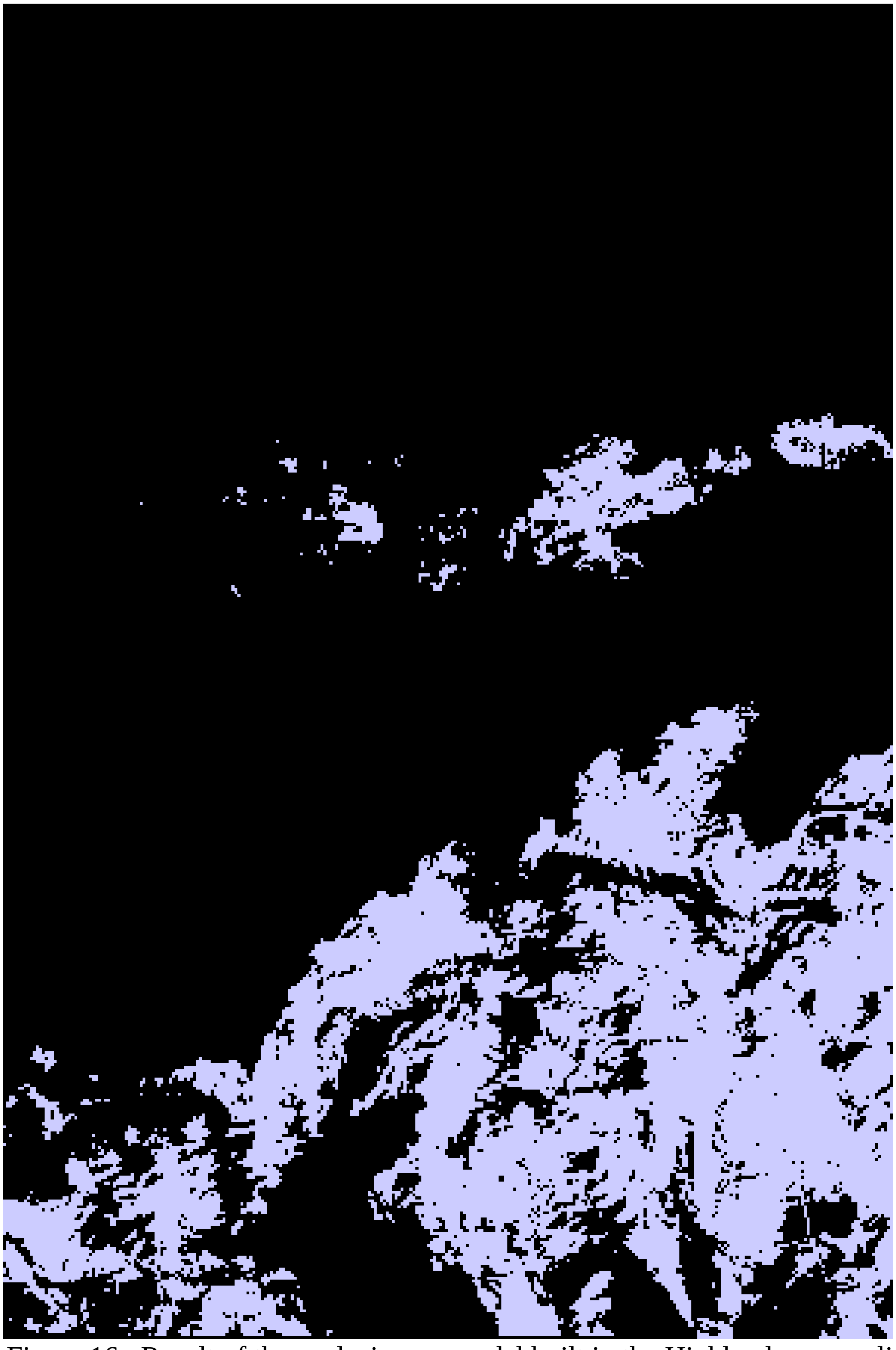

Figure 16. Result of the exclusionary model built in the Highland area applied to the White Top Mountain topographic quadrangle. Highlighted pixels were those considered to be equivalent. Black areas represent those areas considered non-equivalent and were excluded.

LOGISTIC, with the stepwise selection option with SLENTRY = 0.05 and SLSTAY = 0.05. The stepwise selection allowed only 1 variable to enter the regression at a time. Variables were added according to the amount of variability in the squirrels distribution they could explain, and all had to be significant at the 0.05 level. The variables that accounted for the most variability were added first. After each variable was added, if the significance of a variable added previously dropped below the specified level (0.05), that variable was dropped. The process of adding and dropping variables continued until all variables were added, or no other variables met the 0.05 significance level. The following equation (Eq. 2) was found:

$$\mathrm{r}\ (\mathit{equivalency}) = \frac{e^{(-16.7766-0.0321x_1-0.1262x_2-0.6748x_3+1.3282x_4+0.0902x_5+0.2571x_6)}}{e^{(-16.7766-0.0321x_1-0.1262x_2-0.6748x_3+1.3282x_4+0.0902x_5+0.2571x_6)}+1} \qquad \text{Eq. 2}$$

Where the variables were as follows:

x_1 = Raw Elevation x_2 = Raw Slope x_3 = Cosine Transformed Aspect
x_4 = Raw Hopkins Value x_5 = Raw Landform Index x_6 = Slope Position.

Application of the Logistic Regression Equation

Application of Eq. 2 to the Highland study area resulted in Fig. 17. The raw output of Eq. 2 was a probability that ranged from 0 to 1.00, but for this study only pixels with a probability greater than or equal to 0.50 was considered equivalent. Fig. 18 shows only those pixels that met or exceeded probability of 0.50. In the Highland study area 66.55% of the pixels were considered not equivalent and excluded. Of the known squirrel pixels, 22.22% had probabilities below 0.50 and were considered not equivalent.

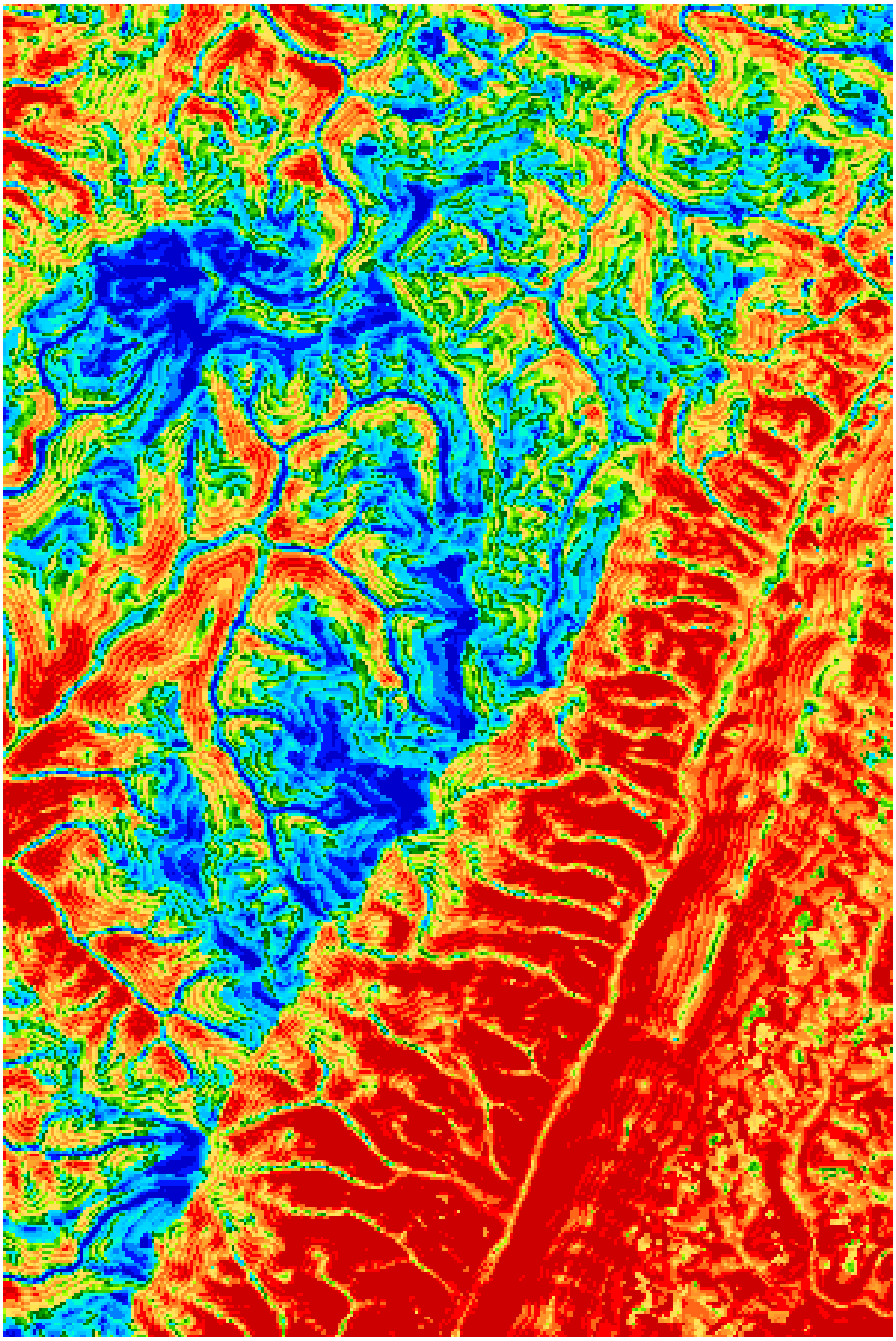

Figure 17. Result of the logistic regression applied to the Hightown topographic quadrangle. Dark red colors represent the lowest probability of equivalency scaled up through yellow to green to blue. Dark blue areas had the highest probability of equivalency.

Figure 18. Result of the logistic regression applied to the Hightown topographic quadrangle. Highlighted pixels were those areas that had a probability greater than or equal to 0.50.

Application of above Eq. 2 to the White Top Mountain topographic quadrangle excluded the complete image. There were no pixels in the full White Top Mountain image that met or exceeded the probability of 0.50, therefore no known squirrel pixels were kept. The highest probability found in the White Top Mountain topographic quadrangle after the application of Eq. 2 was 0.43.

Logistic Regression II

It was decided to drop elevation from the process of creating a logistic regression equation to create a new equation. There were 2 reasons to drop elevation. The first reason arose after examining the elevation of the White Top Mountain area. Elevation in the White Top Mountain topographic quadrangle was generally much higher than the elevation of the Highland study area. The input of the high elevation values from White Top Mountain into Eq. 2 resulted in the final probabilities, all less than 0.50. The elevation values used to create Eq. 2 were lower than the elevation values from White Top Mountain. The second reason was that elevation was included as a factor in the Hopkins value. The use of both elevation and the Hopkins value in the logistic regression made elevation considered twice. The result of PROC LOGISTIC in SAS (with the same options as before) performed on the same data set as before without elevation resulted in Eq. 3:

$$\mathrm{r}\ (equivalency) = \frac{e^{(-12.0097 - 0.1245x_1 - 0.6690x_2 + 0.3191x_3 + 0.0900x_4 + 0.1994x_5)}}{e^{(-12.0097 - 0.1245x_1 - 0.6690x_2 + 0.3191x_3 + 0.0900x_4 + 0.1994x_5)} + 1} \qquad \text{Eq. 3}$$

Where the variables were as follows:

x_1 = Raw Slope x_2 = Cosine Transformed Aspect x_3 = Raw Hopkins Value
x_4 = Raw Landform Index x_5 = Slope Position.

Application of the Second Logistic Regression Equation

Application of Eq. 3 to the Highland study area resulted in 65.19% of all pixels with probability less than 0.50, and thus not considered equivalent and were not considered squirrel pixels. Equation 3 resulted in 23.98% of the known squirrel pixels in the Highland area being considered not equivalent. The percent of all pixels considered equivalent in the White Top Mountain area increased from 0% as a result of Eq. 2 to 18.84% as a result of Eq. 3. All 108 known squirrel pixels in the White Top Mountain area had probabilities greater than 0.50, and thus were considered equivalent. Fig. 19 represents those pixels that met or exceeded the probability level of 0.50 after the application of Eq. 3 to the White Top Mountain topographic quadrangle.

Combination of the Exclusionary and the Logistic Regression Approaches

After the above 3 methods (the exclusionary approach and first and second logistic regression analyses) were used to classify potential squirrel pixels, it was decided to classify pixels based on the combination of the exclusionary approach with either of the 2 logistic regressions. To combine the 2 approaches used to delineate equivalent sites, the single data layers resulting from each approach were added together to create a single new

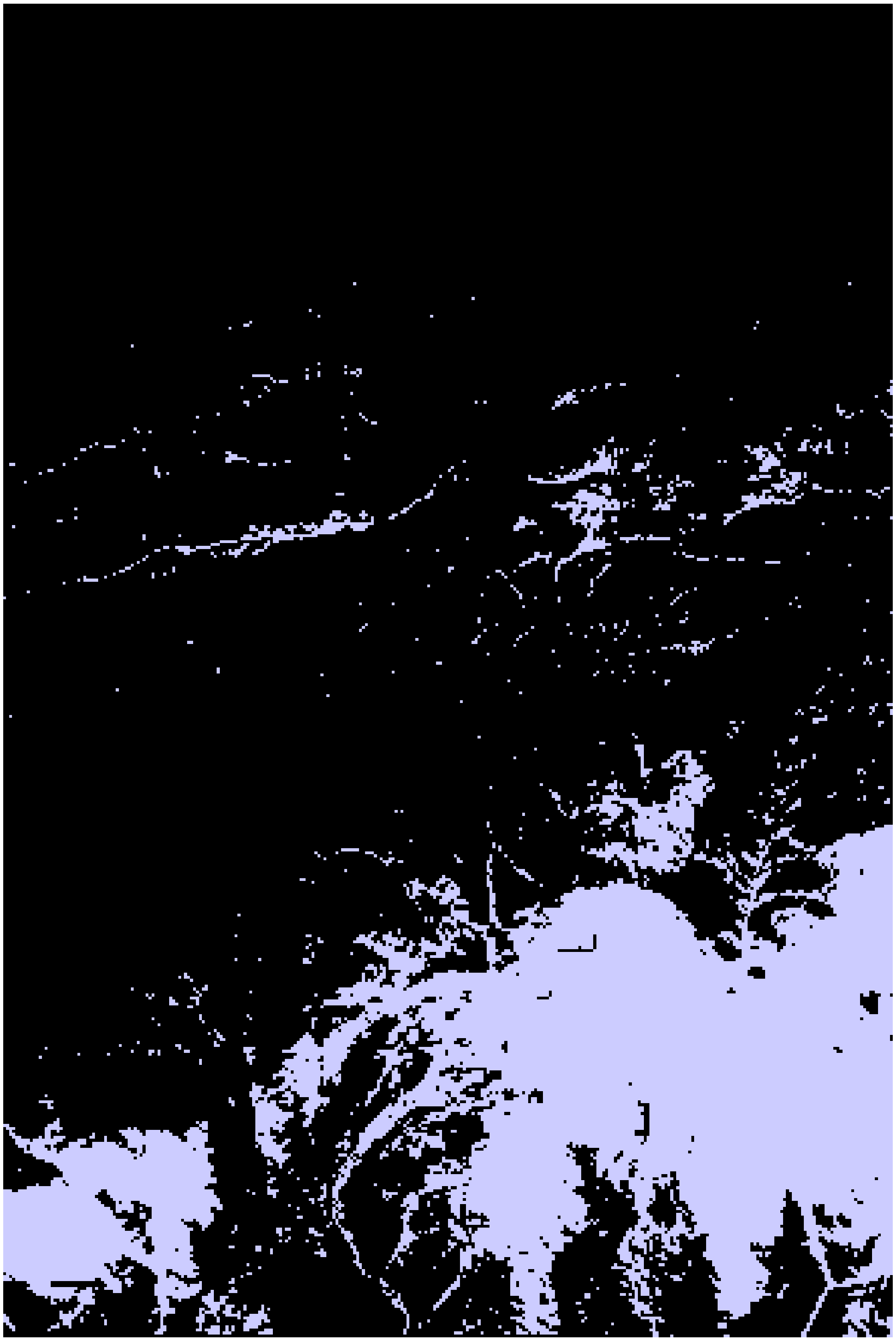

Figure 19. Result of the second logistic regression applied to the White Top Mountain topographic quadrangle. Highlighted pixels were those areas that had a probability greater than or equal to 0.50.

layer. Output pixels had 3 possible values: 0 if neither approach kept that pixel, 1 if only 1 approach kept that pixel, or 2 if both approaches kept that pixel.

Application of the Exclusionary Approach and the First Logistic Regression

Combination of the exclusionary approach and the first logistic regression equation (Eq. 2) resulted in Fig. 20 for the Hightown topographic quadrangle. The percent of study area pixels excluded (i.e, not likely to be suitable for squirrels) was 77.83%, which was higher than either of the previous methods. The percent of known squirrel pixels excluded within the study area was 28.46%. Because the first logistic regression equation excluded all pixels in the White Top Mountain topographic quadrangle, all pixels remained excluded when the 2 approaches were combined. All known squirrel pixels in the White Top Mountain topographic quadrangle were also excluded through combining the exclusionary approach and the first logistic regression.

Application of the Exclusionary Approach and the Second Logistic Regression

Combining the exclusionary approach and the second logistic regression created results in the study area similar to the previous combination (exclusionary approach and the first logistic regression). The number of known squirrel pixels excluded in the study area increased from 146 pixels to 157. Fig. 21 resulted from combining the exclusionary approach and the second logistic regression equation. The percent of pixels excluded in the White Top Mountain topographic quadrangle was 86.12% after the combination of the

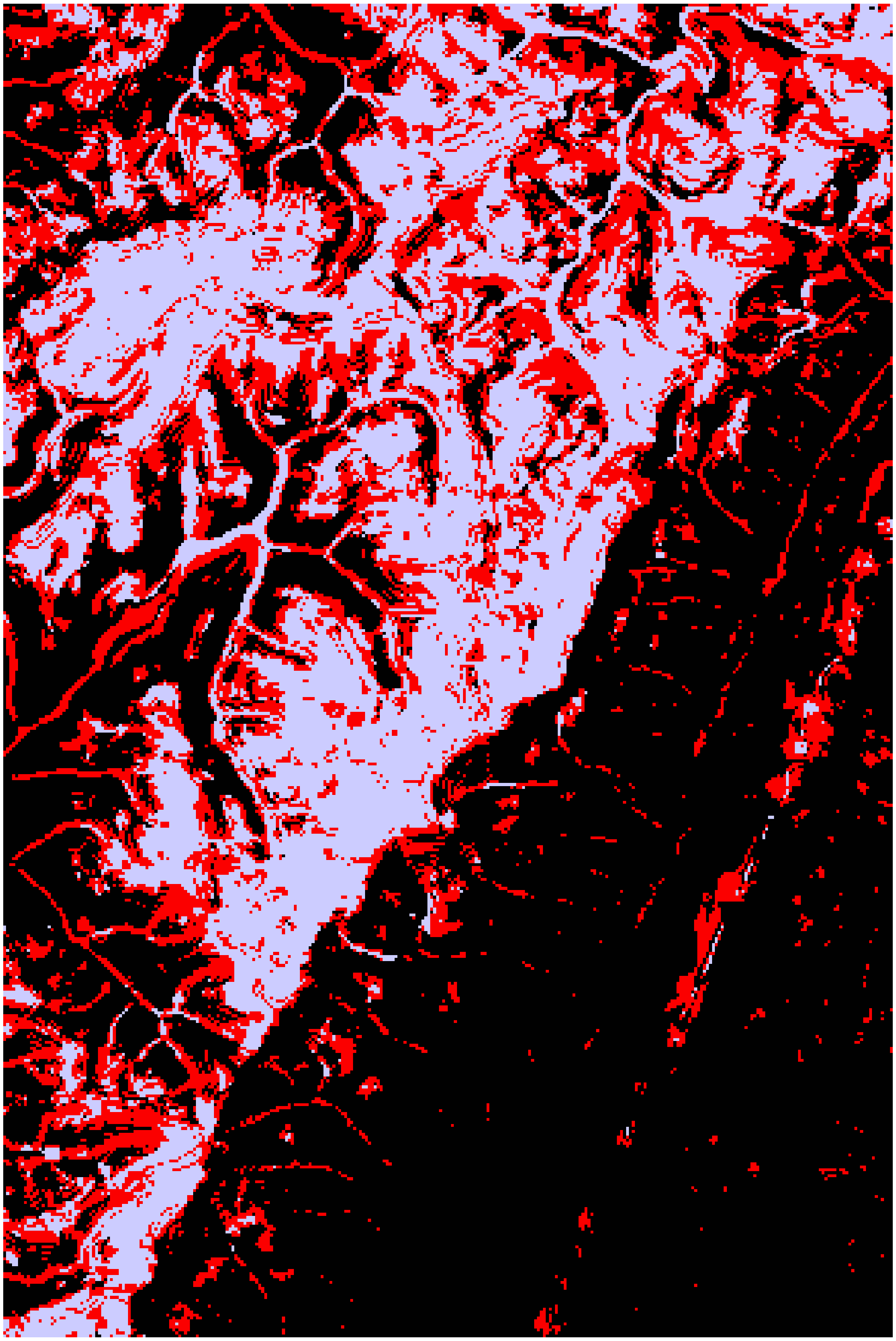

Figure 20. Result of the combination of the exclusionary approach and the first logistic regression applied to the Hightown topographic quadrangle. Lightest, intermediate, and black shades represent areas accepted by both models, only 1 model, and by neither model as equivalent, respectively.

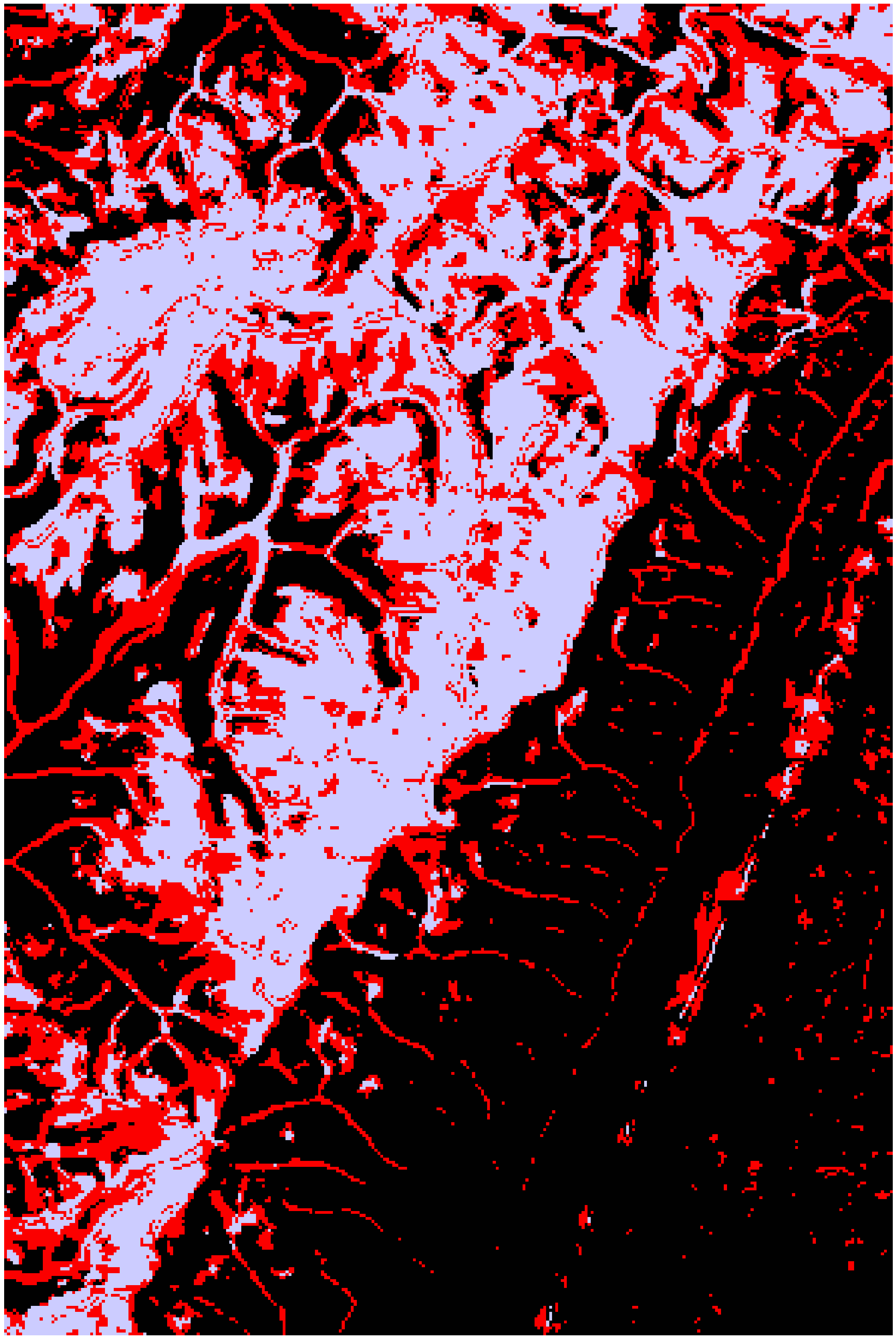

Figure 21. Result of the combination of the exclusionary approach and the second logistic regression applied to the Hightown topographic quadrangle. Lightest, intermediate, and black shades represent areas accepted by both models, only 1 model, and by neither model as equivalent, respectively.

exclusionary approach and second logistic regression equation. With the first combination of approaches, all known squirrel pixels in the White Top Mountain were excluded by the logistic regression portion. The opposite situation occurred with the second logistic regression, all known squirrel pixels were kept. The 16 known squirrel pixels that were excluded were the result of using the exclusionary approach. Fig. 22 represents the combination of the exclusionary approach and the second logistic regression equation applied to the White Top Mountain topographic quadrangle.

Summary of Classification Approaches

To map equivalent squirrel habitat, 5 modeling approaches were used, the exclusionary approach, 2 logistic regressions, and a combination of the exclusionary approach with each logistic regresion. The goal of each approach was to create a model to delineate sites that were equivalent to sites at which squirrels had been observed, i.e., based on a known sample set of data (squirrel observation pixels in the Highland study area). Each model was then applied to a separate location and tested against a second set of known data (squirrel points in the White Top Mountain topographic quadrangle). A summary of the results are shown in Table 15 for the Highland study area and Table 16 for the White Top Mountain area.

The model created by the exclusionary approach excluded the fewest Highland study area pixels (65.04%, Table 15) of all approaches, but kept the most known squirrel pixels (87.33%) within the Highland study area. Application of this model to the White

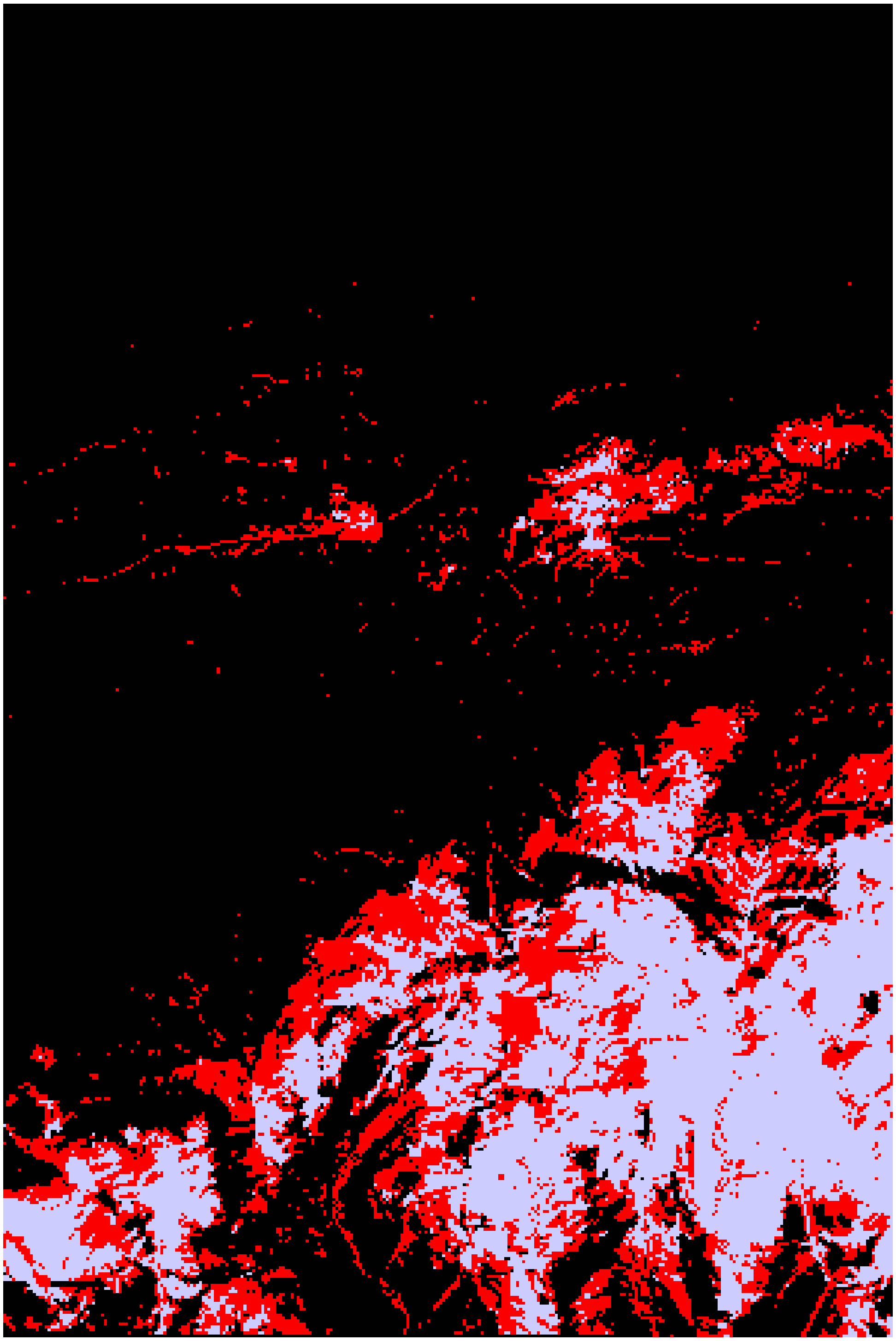

Figure 22. Result of the combination of the exclusionary approach and the second logistic regression applied to the White Top Mountain topographic quadrangle. Lightest, intermediate, and black shades represent areas accepted by both models, only 1 model, and by neither model as equivalent, respectively.

Table 15. Number and percent of pixels considered not equivalent as a result of various classification approaches in the Highland study area.

Classification Approach	Study Area Pixels Excluded (%)	Known Squirrel Pixels Excluded (%)
Exclusionary	175595 (65.04)	65 (12.67)
Logistic Regression I	179691 (66.55)	114 (22.22)
Logistic Regression II	176002 (65.19)	123 (23.98)
Exclusionary + Logistic Regression I	210130 (77.83)	146 (28.46)
Exclusionary +Logistic Regression II	208198 (77.11)	157 (30.60)

Table 16. Number and percent of pixels considered not equivalent as a result of various classification approaches in the White Top Mountain topographic quadrangle.

Classification Approach	Total Area Pixels Excluded (%)	Known Squirrel Pixels Excluded (%)
Exclusionary	107061 (79.30)	16 (14.81)
Logistic Regression I	135000 (100.00)	108 (100.00)
Logistic Regression II	109566 (81.16)	0 (0.00)
Exclusionary + Logistic Regression I	135000 (100.00)	108 (100.00)
Exclusionary + Logistic Regression II	116267 (86.12)	16 (14.81)

Top Mountain area excluded 79.30% of all pixels, and kept 85.19% of the known squirrel pixels (Table 16).

The first and second logistic regression models excluded very similar percentages of full image pixels and known squirrel pixels in the Highland study area (Table 15). The high elevation in the White Top Mountain topographic quadrangle resulted in the first logistic regression equation (Eq. 2) failing to classify any pixels in that area as equivalent to known squirrel pixels from the Highland study area. The second logistic regression equation (generated without elevation as a variable) resulted in all known squirrel pixels in the White Top Mountain area being classified as equivalent (100%) while excluding 81.16% (Table 16) of the full area. The lower latitude of the White Top Mountain area (as compared to the study area) lowered the Hopkins value, but the higher elevation in the White Top Mountain area (as compared to the study area) raised the Hopkins value. The combination of the changes due to latitude and elevation (longitude had minimal effect) on the Hopkins value resulted in very similar Hopkins values within both the study area and the White Top Mountain area.

The model comprised of the exclusionary approach <u>and</u> the first logistic regression excluded the highest percent of the full Highland study area (77.83% Table 15), but also excluded 146 (retained only 61.54%) of the known squirrel pixels. The exclusionary approach combined with the second logistic regression resulted in very similar numbers for the Highland study area. Application of the exclusionary approach and the first logistic regression combined model to the White Top Mountain area resulted in <u>all</u> area pixels and all known squirrel pixels being excluded (Table 16)! The exclusionary model combined with the second logistic regression resulted in a very different image in the White Top Mountain topographic quadrangle. The highest percent of the full White Top Mountain image was excluded (86.12%, Table 16), while 85.19% of the squirrel pixels were retained, (i.e., only 16 (14.81%) known squirrel pixels within White Top Mountain were excluded).

Discussion

Elevation

The base layer of data for this study was elevation. It was used to derive many abiotic GIS data layers. The elevation data layer was made available through a simple import procedure included with the software used. As mentioned in the "Methods" section, most faunal and floral species show changes in population numbers and status with changes in elevation, but not along the 1-meter increments available through a GIS. The process of separating elevation along a user-specified increment (50 m for this study) proved to be more useful than elevation along 1-meter increments. Analysis of the squirrel pixels along 1-meter elevation increments did not show the bell-curve distribution that was found for the analysis along 50-meter increments. The elevational distribution of squirrel pixels along 1-meter increments had gaps, with no clear pattern evident. It was difficult to select a minimum elevation at which to exclude pixels. Specific elevation data may have been lost through this generalization, but trends in the distribution of the flying squirrel seem strongly related to elevation.

It was found that there were no known squirrel pixels below elevation class 22, or above elevation class 27. From the literature it is known that the squirrel is common in cold climates, and is often associated with tree species found at more northerly latitudes than Virginia. It seems reasonable that if the squirrel is to be found in Virginia it would be restricted to high elevation areas that meet criteria more commonly found in areas north of

Virginia. As for other rare species work, area-proportional sampling is needed. High elevations in Virginia are rare and observer-effort within such areas is difficult, costly, and not very rewarding for the average naturalist observer seeking a variety of flora and fauna.

The exclusionary approach dropped all pixels with elevation class less than 22, but did not drop pixels that exceeded a specific elevation class. There were 2 reasons for selecting this elevation range. A lower limit of elevation to delineate squirrel pixels was specified because it was known from field observations that the squirrel does exist at that elevation, but none were observed at lower elevations. That is not to say that the squirrel *does not exist* at lower elevations. It is well documented that as latitude increases (farther North) or that as elevation increases, temperature decreases in the Northern hemisphere (while other factors are perceived to be constant). Because the squirrel typically occurs in a cold climate, the squirrel may be common at lower elevations (below class 22) along higher latitudes than those found in the study area (e.g., Shenandoah National Park). A maximum elevation class was not specified for similar reasons. As latitude decreases (farther South) in Virginia, the squirrel may exist at higher elevations than those common in the Highland study area. Occurrence may be compatible with the low temperatures and oter ecological associations.

Although there were few known squirrel pixels in elevation classes 24 and 26, it was decided to keep those classes to delineate possible squirrel pixels. Logically the squirrel may have been present in much higher numbers in elevation classes 24 and 26, but not at those specific levels. The most likely explanation was that there were not sufficient observations of squirrels made in these high-elevation, difficult-to-access areas to detect the animals full elevational distribution.

Slope

The first vertical derivative of elevation was slope steepness. Slope was treated in the same manner as elevation. Floral and faunal species may respond to changes in slope, but most likely not along 1° increments. Once slope data were computed in digital form, numerous transformations could be performed on the squirrel observations to seek a variety of meaningful values. Forestry professionals may be more familiar with slope in terms of percent steepness than with degrees. Simple mathematical operations can transform slope from degrees into percent. For this study slope was separated into 5° classes.

The terrain of the study area was very diverse with a wide range of slope steepness, flat to 42°. The distribution of the known squirrel pixels was also very wide, but appeared to be limited by slopes greater than class 5. The squirrels are most likely not responding to the steepness of the terrain, but to changes in tree species assemblages associated with changes in soil and other characteristics of steep slopes. Changes in the squirrel population along slope classes could also be caused by the interaction of slope and aspect, which affects temperature, insolation, and other climatic variables.

Aspect

In the study area there was no aspect class most prevalent. The number of pixels in each class was uniformly distributed. This distribution was not surprising because the terrain was very diverse, with slopes facing all directions, and the area considered was limited. At a larger scale, such as along the Blue Ridge Mountains, there may be more pixels facing northwest or southeast than other directions. The Blue Ridge Mountains run northeast to southwest creating large slopes facing northwest and southeast. The known squirrel pixels, however, were grouped in several classes. Most of the known squirrel pixels were in southwest-facing aspects (classes 5, 6, and 7). The preponderance of occurrences in these classes may be due to extended exposure to the sun. The squirrel may be adapted to cold climates, but it could still minimize its energy expenditure by living in those areas exposed to the sun. The squirrel also may be more prevalent on sites in these aspect classes due to changes in the floral composition. At high elevations the growing season is often short. Trees on southward-facing aspects may benefit from the exposure to incoming solar radiation not present on more northeasterly aspects. More solar radiation may result in bigger, stronger, healthier trees that may provide better squirrel habitat.

The aspect classes chosen by Wathen (1977) were used in this study. Each range of aspect was given a score based on its perceived ability to influence tree growth. This transformation of aspect was not a preferred method for use in this study. The range of degrees and score assigned to each aspect class was based on a very specific qualifier (influence on tree growth), therefore, Wathen's aspect classes should probably be limited to use in tree growth studies. Wathen's values probably have narrow applicability. The purpose of this study was to determine topographical variables that have many uses. To fully use the value of aspect measures, aspect should be combined with some indicator of slope. A site with an aspect of 180° would have very different moisture regimes at slope equal to 1° steepness as compared to 45° steepness. The steeper slope receives incoming solar radiation at a more perpendicular angle, and thus receives more energy than the nearly level surface. Whether slope and aspect should be combined in 1 index (Stage 1976), or left as single variables in a regression model (Stage 1976) may be debated and decided for each field situation.

The trigonometric transformation of aspect used in this study appeared to be a useful measure. It allowed aspect to be treated as a linear continuous variable and be included in logistic regression. The shift of 45° to set northeast as the highest value and southwest as the lowest value was chosen based on literature reviews of past work. Although this shift created a linear value and allowed means and standard deviations to be computed, it did not allow for differentiation between northwest and southeast aspects. Both aspects of 135° and 315° had a transformed value of 0. The 45° shift was based on the generic idea that northeast aspects (specifically 45°) generally have the best tree growth conditions (not overly exposed to drying sun and heat) for trees, and vice-versa for southwest sites (i.e., tend to be hot and dry). In practice, a 45° shift may not be the best value. Through mathematical formulas it is possible to determine the aspect that receives the most direct sun on a fixed slope for any geographical location, or to find the aspect that represents a combination of radiation, moisture, and temperature conditions most related to some variable of interest such as presence of an animal or plant or the rate of tree growth. The choice of exactly 45° *may* be proper, but the working hypothesis might be that it is not and that conventional statistical analyses may find a more precise answer. McCombs et al. (in prep.) study this idea of aspect transformations. Preliminary results indicate that transformations of aspect are needed that not only account for north to south changes, but east to west changes as well (as implicit within the latitude and longitude differences of the Hopkins Law).

Landform Index

The landform index produced a variable that indicated more than just the shape of the land surface. As discussed in the "Methods" section, landform can be used as a surrogate for ecological variables such as soil depth, soil moisture, exposure to the sun and drying winds, and was observed to be highly correlated to tree species distribution (Virginia Gap Analysis Project). McNab (1987, 1993) created programs to delineate the shape of the land at the micro and macroscale. The programs written by McNab were not used because they were not readily available and were very costly. The landform index, as used in this study, could be created in a matter of minutes for a complete 7.5 topographic quadrangle with PCI. Simple C++ programming could also be used to generate this value with any raster image as well. Statistical measures could also be performed on the K value since it was a continuous variable

Since the raw K values may have little meaning at face value to most people working in wildlife studies, the 6 discrete classes (Table 4, see “Methods” section) were created. The 6 classes delineated were created subjectively and for use in this study. It is possible for workers in any ecological study to use the landform index value to meet the specific needs of a study. Sample field work could be used to collect GPS points that occur on landform classes defined by the researcher. Those GPS points could then be overlayed onto the raw landform layer to compute the statistics associated with the user-defined landforms. The statistics could then be used to classify similar areas, much in the way Landsat images are often classified through supervised classification.

Any measure of the shape of the land surface is highly dependent on the scale used. At the microscale, a site may be convex in form, but as the scale increases it may be found that the site is located in a very concave cove. A 9 x 9 pixel window was used to calculate the K value for this study. This window size was decided upon after the visual and statistical analysis of K values computed from different size windows. The terrain in the Southern Appalachians is very diverse, with sharp narrow ridges, broad valleys, and numerous cove-spur ridge complexes. Results of the K value from smaller windows resulted in a salt-and-pepper image with extreme variability. Pixels that were adjacent to each other on the same landform were often classified differently. With small windows, each pixel could be very different from its neighbors. It was not possible to detect many of the landforms that extended beyond the window. If a site was in a cove (surrounded by higher elevations), the edges of a small window often did not extend far enough to detect the increase in elevation and resulted in the site being classified as planar. When windows larger than 9 x 9 pixels were used, many land features were lost and results were over-generalized. A site in a cove might be classified as planar because the edges of the window extended into the next cove, picked up equal or similar elevations as the site in question, and did not detect the higher surrounding elevations. The size of the window chosen becomes highly dependent on both the scale of the study and on the terrain of the area. To determine the optimal size window to use, the best approach may be to create K values using several different size windows. The researcher could then examine the level of detail achieved with varying window sizes and chose the level that best fits the needs of their study. Studies at the microscale (individual tree or plant growth) or in very diverse rugged terrain may require a smaller window. For landscape scale studies (forest type occurrence), or in broad flat terrain, a large window may be desired.

Phenologic Change Layer

In mountainous terrain, such as that examined in this thesis, the phenologic change layer map closely resembled a map of elevations. This similarity was because the effect of elevation on the timing of biological events is much more pronounced than either longitude or latitude. Sample Hopkins calculations for the Coastal Plain of Virginia, where elevation changes are low, revealed much different images than in the mountains.

In areas with little elevation changes, the effects of latitude and longitude become more obvious (latitude more so than longitude). Similarity to elevation does not make the phenology layer less useful though. As shown in the second logistic regression equation (Eq. 3), the phenology layer may take the place of, or may be of more use in estimating potential faunal habitat, than elevation data.

A relative phenologic change or Hopkins value GIS layer has other advantages over elevation as well. Timber production companies commonly use herbicides to control woody species competition in pine plantations in the Southeast. The application of such herbicides often correspond with the timing of a phenological event (e.g., bud break, leaf out, prior to winter dormancy). Once a desired biological event occurs at a location on the timber company’s land, and herbicides are applied, the relative phenological value may be used to schedule herbicide application for the remaining land. Fall color tours produce a large amount of revenue for places that rely on tourist money. The scheduling of fall color tours can be planned to coincide with peak colors with the knowledge of relative phenological dates.

Slope Position

Deriving a slope position program was a difficult and time consuming process. The programs used to delineate drainage networks (PCI program DWCON) generally took 30 to 40 minutes for a 7.5 minute topographic quadrangle, and required 4, 32-bit GIS data layers. The time involved was still much less than would be required to delineate slope positions for a 7.5 minute topographic quadrangle by hand. The computer-generated drainage networks were used for this study because the existing digital covers of rivers and streams were of varying quality and detail for the state. By using a set series of programs, it was possible to achieve consistency and a set of relative values, a goal of slope-position delineation.

The distribution of study area pixels over the various slope positions closely paralleled the distribution of the pixels over the classed landform index. This similarity was related to the inclusion of landform index in the slope position program. The inclusion of slope in landform class delineation and slope position delineation also could account for the similarity. Similar slopes had similar landform class and slope position.

Slope position was unique in that it considered several data layers (proximity to drainage, proximity to ridge top, landform index, and slope) in 1 program. All of the layers had to be involved to detect the shape of the land at a pixel (slope and landform) and that pixel's position in relation to the surrounding pixels (proximity to drainage and proximity to ridge). The success of slope position delineation as a result of this set of programs may still be argued. As stated before, slope position is a subjective feature of landscape classification. Even with debate about the accuracy of the result of the slope position program, this thesis established and defined a set of acceptable and demonstratably useful slope positions, and a program to delineate slope positions for large areas with speed and consistency. These positions are hypothesized to provide more useful independent variables in forest site quality analyses and related ecological studies than previously used expressions of "landform."

Modeling Approaches

Exclusionary Approach

The exclusionary approach was an effort to analyze the abiotic characteristics associated with observations of a species (a squirrel for this thesis) and to create a model to delineate equivalent sites. Histogram analyses were performed on several levels of combinations of abiotic variables corresponding to a set of known squirrel pixels and to all study area pixels. Pixels that were deemed to have different abiotic conditions than the known squirrel pixels were excluded, and not considered equivalent. The most simple level of analysis, along a single GIS data layer, resulted in the largest percent of Highland study area and White Top Mountain pixels being excluded. The data layers that excluded the most were elevation and the Hopkins value. As mentioned earlier, the squirrel is most commonly associated with cold climates and northern species of trees. Hopkins values alone may be adequate since elevation is a dominant component in its algorithm.

The analyses of histograms became more complicated as combinations of data layers were considered. As a result, the exclusionary process became difficult and time consuming. Each combination of data layers had to be created and analyzed separately. As more data layers became involved, each pixel had the opportunity to become more unusual. Histogram analysis of slope or aspect alone involved 9 classes for each. When slope and aspect classes were combined, the number of possible classes increased to 81 (9 slope classes times 9 aspect classes). The large number of potentially unique categories for any analysis (e.g., 2-way to 3-way combinations) increased the classes but reduced the pixel-excluding criteria. A second reason was that as the number of classes into which a pixel could be classified increased, it became difficult to meet the 3 criteria established in the “Methods” section.

There were several drawbacks to the exclusionary process. The largest drawback was mentioned in the preceding paragraph. The analysis of multiple data layers was very complex. For every combination of data layers, 2 histograms had to be created and analyzed to determine if there were criteria that could be used to exclude pixels. This problem may be alleviated in the future through the use of computer programs to automate the procedure.

A second problem was in establishing criteria on which to exclude pixels. There were no rules of significance or definitive statistical basis used to create the 3 criteria stated in the “Methods.” Different results may have been found if more strict or more lax criteria were established. Users of the exclusionary process should create criteria based on the quality of the known data points, the quality of the GIS data layers, and the objectives of the analysis. If the known point data set used to build the exclusionary model is of low quality, it may be acceptable to exclude more known points (than allowed in this study). The known points excluded may be outliers in the data set. The quality of the GIS data layers should also be verified. Digital data does not imply quality data. GIS layers may have error introduced through incorrect georeferencing, and low quality DEMs create low quality associated data layers. Objectives of the current study also influenced decision criteria. To locate equivalent pixels as accurately as possible it may be necessary to use more strict criteria. Some studies may use the approach described herein to loosely delineate potential geographical ranges, in which case the deciding criteria may be more lax.

The benefits to the exclusionary approach are many. The speed of the process was a large advantage over typical habitat analyses. With limited data set, a model was built and applied to an area to delineate equivalent sites based on a collection of abiotic factors stored in a GIS. Once the analysis procedure was established, a model was built and modified over a period of approximately 3 weeks. The model could then delineate equivalent sites for a 7.5 minute topographic quadrangle in a matter of minutes. Many wildlife habitat analyses require weeks, months, or years of field work to measure and analyze the abiotic factors that may be influencing a species.

The portability of the model created by the exclusionary approach was a second benefit. The model could be used by multiple GIS programs as long as all necessary data layers were created. The model was a simple Boolean program. Each pixel was analyzed using a set of criteria. If a pixel failed to meet any criterion, it was dropped from analysis. The model could also be applied to a location never visited. With DEMs any location could be analyzed in the same manner.

The flexibility and power of the exclusionary approach are its biggest advantages. Computers and GISs are being used to create new data layers at astounding rates. The Gap Analysis Programs of many states have used Landsat imagery to delineate ground cover. Wetland maps are available in digital form (USFWS National Wetlands Inventory, U.S. Dept. of the Interior, Washington, D.C., 1995). TIGER (U.S. Dept. of Commerce, Washington, D.C., 1991) files include digital coverages of urban areas. Climate data layers are being created by Klopfer (1997). Martin (1990) listed over 100 measures of the land surface. All of the above layers may be incorporated into the exclusionary process. More data layers may then lead to new insights about the interactions of fauna with their surrounding environment.

Logistic Regression

Logistic regression has been used to analyze and predict potential wildlife habitat by several authors (Thomas et. al 1996, Adler and Seamon 1996, Decarie et. al 1995, Nadeau et. al 1995, Pauley et. al 1993). Each of these studies used combinations of biotic and abiotic factors associated with known faunal habitat as variables in their analyses. Logistic regression had several advantages over the exclusionary approach for the analysis of faunal habitat. The exclusionary approach excluded pixels based on a set of subjectively decided upon criteria. A set of subjective criteria was not needed to use logistic regression. Statistical analyses were performed on the data set of abiotic variables in SAS to create the regression equations (Eqs. 2 and 3) used in this study. Pixels that failed to meet or exceed the probability of equivalency of 0.50 were dropped. Several statistical analysis packages could be used to perform this process.

The speed at which data were analyzed was the largest advantage of logistic regression over the exclusionary approach in delineating equivalent pixels. With a high powered computer (90 MHz Pentium) the data set was analyzed and a model was created in seconds through logistic regression. New variables could be added to the data set and re-analyzed in seconds as well. This procedure was demonstrated in this thesis through the creation of the second logistic regression equation. The elevation data were dropped from the data set, and SAS was used to generate a new logistic regression equation. In order to analyze new variables in the exclusionary approach, new histograms would have to be created for each new combination of variables (dropping of variables would not slow down the exclusionary approach).

The decision to drop pixels that failed to meet objectively decided upon criteria was mentioned as a power of logistic regression. This was also a weakness. To protect fully, and properly manage a species, it is necessary to protect the biotic and abiotic portions of that species habitat. Both logistic regression equations excluded approximately 10% more known squirrel pixels in the Highland study area than the exclusionary approach. The known squirrel pixels that were excluded by the logistic regression equations may have been outliers in the data set, but it is often better to be conservative in estimating a species potential habitat. As stated earlier, it is often not possible to prove a species does *not exist* in an area. Underestimation in delineating a species' habitat based on improper analyses may result in the loss of species habitat due to improper management decisions. Knowing the locations of areas highly similar to where animals have been seen can aid in decisions about sampling, acquiring and protecting areas, and for allocating scarce managerial resources.

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Appendix. PCI Modeling Programs Used for this Thesis.

Number 1.

```
! This program was written to split various abiotic landform measures
! into unique classes.  Program is set up with elevation, slope, aspect, Hopkins, and
! landform in predetermined channels.

print "This program will take raw data of some sort and split it into classes.";

print"";
print "Elevation=6      Slope=7         Aspect=8";
print "Hopkins=9       Landform=10";
print"";

input "Which channel would like to split into classes? " #in;
print"";
input "If elevation was chosen then input step size in meters, else=0. " #stepe;
input "If slope was chosen then input 1=Wathen classes, 2=other step size, else=0. "
#slpopt;
input "If other slope step size was chosen then input step size in degrees, else=0. " #steps;
input "If aspect was chosen then input 1=Wathen classes, 2=cardinal, 3=NE,SW,etc.,
4=45 deg, else=0. " #aspopt;
input "If Hopkins was chosen then input step size in days, else=0. " #steph;
print"";
input "Which channel for output? " %out;

if (#in=6) then
   %out=int(%6/#stepe)+1;
endif;

if (#in=7) then
    if (#slpopt=1) then
      if (%7<=8) then %out=5;
         extrif (%7>8) and (%7<=16) then %out=2;
         extrif (%7>16) and (%7<=24) then %out=3;
         extrif (%7>24) and (%7<=30) then %out=4;
         extrif (%7>30) then %out=5;
      endif;
    endif;
    if (#slpopt=2) then
       %out=int(%7/#steps)+1;
    endif;
```

```
endif;

if (#in=8) then
        if (#aspopt=1) then
              if (%8<=196) and (%8<=260) then %out=1;
                extrif (%8>=166) and (%8<=195) then %out=2;
                extrif (%8>=261) and (%8<=280) then %out=2;
                extrif (%8>=146) and (%8<=165) then %out=3;
                extrif (%8>=281) and (%8<=340) then %out=3;
                extrif (%8>=0) and (%8<=20) then %out=4;
                extrif (%8>=341) and (%8<=360) then %out=4;
                extrif (%8>=81) and (%8<=145) then %out=5;
                extrif (%8>=21) and (%8<=80) then %out=6;
                extrif (%8=361) then %out=3;
              endif;
       endif;
       if (#aspopt=2) then
              if (%8<45) or (%8>=315) and (%8<=360) then %out=1;
                extrif (%8>=45) and (%8<135) then %out=2;
                extrif (%8>=135) and (%8<225) then %out=3;
                extrif (%8>=225) and (%8<315) then %out=4;
                extrif (%8=361) then %out=5;
              endif;
       endif;
       if (#aspopt=3) then
               if (%8>=0) and (%8<90) then %out=1;
                 extrif (%8>=90) and (%8<180) then %out=2;
                 extrif (%8>=180) and (%8<270) then %out=3;
                 extrif (%8>=270) and (%8<=360) then %out=4;
                 extrif (%8=361) then %out=5;
               endif;
       endif;
       if (#aspopt=4) then
             if (%8>=0) and (%8<45) then %out=1;
               extrif (%8>=45) and (%8<90) then %out=2;
               extrif (%8>=90) and (%8<135) then %out=3;
               extrif (%8>=135) and (%8<180) then %out=4;
               extrif (%8>=180) and (%8<225) then %out=5;
               extrif (%8>=225) and (%8<270) then %out=6;
               extrif (%8>=270) and (%8<315) then %out=7;
               extrif (%8>=315) and (%8<360) then %out=8;
               extrif (%8=361) then %out=9;
             endif;
```

```
    endif;
endif;

if (#in=9) then
     %out=int(%9/#steph)+1;
endif;

if (#in=10) then
  if (%10<=-20) then %out=1;
   extrif (%10>-20) and (%10<=-10) then %out=2;
   extrif (%10>-10) and (%10<10) and (%7>6) then %out=3;
   extrif (%10>-10) and (%10<10) and (%7<=6) then %out=4;
   extrif (%10>=10) and (%10<20) then %out=5;
   extrif (%10>=20) then %out=6;
   endif;
endif;
```

Number 2.

```
! This will turn aspect to radians, then subtract 45 degrees from the
! raw aspect value to make 45 degrees (NE) the highest value once the cosine is taken.
! and 225 (SW) the lowest value.  This program was based on Gaiser (1951).

input "Which channel has aspect? " %asp;
input "Which channel for output? " %out;

#rasp=rad(%asp);
#asp2=#rasp - .7854;   !.7854 = 3.14159/4 = 45 degrees

%out=cos(#asp2);
```

Number 3.

```
! This will take 2 input channels, with each pixel equal to the average
! elevation of the surrounding 4 (1 layer for the side pixels, 1 layer for the corner pixels
! on the edge of a 9x9 filter), then calculate the difference from the original elevation. This
! difference will be divided by the distance between the pixels to get the average percent
! slope. Last, the two layers will be averaged to yield the average slope in 8 directions.
! Pixels on the edge of the image (where elevation is 0) caused LFI values to be not
! acceptable.  To hanlde this, all pixels witha final LFI value greater than 90, or less than
! -90 were set to a value of 90.  This allowed all edge pixels to be detected and managed.
```

```
! Define chanels
! %1=raw elevation
! %4=avgerage elevation to corners
! %5=avgerage elevation to sides
! %6=raw lfi ouput


%4=(%4-%1)/1.7;
%5=(%5-%1)/1.2;
%6=(%4+%5)/2;

if (%6<=-90) or (%6>=90) then %6=90;
  else %6=%6;
endif;
```

Number 4.

```
! This will determine the lag time of phenological events based on
! Hopkins Bioclimatic Law.  The output will be the lag time from
! or time before an event, as compared to Wallaceton Lake Drummond
! (GDSNWR) weather station.

! Base coordinates   (Zone 17)
        ! Northing    4060033
        ! Easting     908877
        ! elevation   7.62 m

! Base coordinates   (Zone 18)
        ! Northing    4051250
        ! Easting     372094
        ! elevation   7.62 m

! LAG TIMES
        ! 1 deg North = 4 days
        ! 5 deg East = 4 days
        ! 122 m up = 4 days     1m =.0327869days

! Channel assignment
! %1=elevation data

input "Which zone is the image in (17 or 18)? " #zone;
input "Which channel for output? " %out;
```

```
if (#zone=17) then
        #latchng=((@geoy-4060033)/119950.1)*4;
        #longchng=((@geox-908877)/88393.43)*0.8;
        #elevchng=(%1-7.62)*0.0327869;
endif;

if (#zone=18) then
        #latchng=((@geoy-4051250)/110950.1)*4;
        #longchng=((@geox-372094)/88377.25)*0.8;
        #elevchng=(%1-7.62)*0.0327869;
endif;

%out=#latchng+#longchng+#elevchng;
```

Number 5

```
! This program is part of the slope position delineation program designated to
! delineate ridge tops based on proximity to drainages and raw LFI values
! Channels are set up previously

! Channel assignment
! %8=proximity to drainage
! %6=raw lfi values
! %10 = ridge output channel

if ((%8*%6)<=-60) and (%6<=-20) then %10=10;
          else %10=0;
endif;
```

Number 6

```
! This will delineate slope positions by using proximities to drainage
! proximities to ridges, landform index and slope.  Ridges are delineated
! using ridge3.txt (Number 5) program.

! Output value assignments
! 1=ridge
! 3=side
! 4=summit
! 8=summit
! 5=toe
! 6=floodplain
! 9=plateau, table, saddle, local flat area
```

```
! Channel assignments
! proximity to drainage=%8;
! proximity to ridge tops=%9;
! lfi value=%6;
! slope=%2;
! output=%10;


if ((%8*%6)<=-60) and (%6<=-15) then %10=1;
  else %10=0;
endif;

if (%10=0) and (%8<=5) and (%2<=3) and (%6>0) then %10=6;
endif;

if (%10=0) and ((%8*%6)<=-60) and (%6<=-10) then %10=4;
endif;
if (%10=0) and (%9<=5) and (%8>5) and (%2<=6) then %10=4;
endif;

if (%10=0) and (%8<=5) and (%9>5) and (%2>3) and (%2<=12) then %10=5;
endif;
if (%10=0) and (%8=0) and (%2>3) and (%6>0) then %10=5;
endif;

if (%10=0) and (%2>6) then %10=3;
  extrif (%10=0) and (%2<=6) and (%6<=-5) then %10=4;
  extrif (%10=0) then %10=9;
endif;
```

Vita

John Wayland McCombs II was born and spent the first 7 years of his life in California. From there he moved to Traverse City, Michigan where most of his family still lives. After graduating from high school in Traverse City he enrolled at Michigan State University to pursue a degree in Wildlife Management. While at Michigan State he supported himself through various jobs. In the summer of 1993 he worked with the Southfield, Michigan Department of Parks and Recreation on a fish habitat restoration project along the River Rouge near Detroit. He graduated in May 1994 with a B.S. degree in Wildlife Management with honors.

After taking a year off and continuing with various odd jobs, he was accepted as a graduate student at Virginia Polytechnic Institute and State University in May 1995. His interest in combining forestry and wildlife management guided most of his course work at VPI and SU. During his time at VPI and SU he was married to Jerilyn Hall, and also became a father to Ian Masselon McCombs. His plans are to look for employment in the southeastern United States.

John Wayland McCombs II