



Department of Environmental Studies

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**The description and distribution of natural communities on
Mount Monadnock, NH: implication in the face of climate change.**

presented by David R. Mallard

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**The description and distribution of natural communities on
Mount Monadnock, NH: implication in the face of climate change.**

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ABSTRACT

Mount Monadnock, located in southwestern New Hampshire, has a unique set of environmental and ecological conditions that may prove to be extremely valuable in determining the impacts of climate change on the region's natural communities. In order to track the response of Mount Monadnock's natural communities to future climatic changes, permanent sampling plots were established to describe their current characteristics and distribution. During the spring and summer of 2007, 88 plots were established between 2000 and 3000 feet in elevation. At each plot, the size and species of each tree (greater than two inches in diameter), tree canopy height, a tally of saplings of each species, the percent cover of shrubs, the presence of ground cover plant species, and soil depths were recorded. A qualitative health assessment of live trees was conducted and a qualitative assessment of dead tree decay was recorded, as well as the general community structure and composition outside of each plot. Seven distinct community types were identified within the study area; subalpine rocky bald, sheep laurel-Labrador tea heath-krummholz, red spruce-heath-cinquefoil rocky ridge, high elevation spruce-fir forest, northern hardwood-spruce-fir forest, sugar maple-beech-yellow birch forest, and hemlock-beech-oak pine forest. Subalpine rocky bald and sheep laurel-Labrador tea heath-krummholz communities are both rare statewide (S2) and along with the dominant high elevation spruce-fir forest are regionally extremely rare and considered to be highly sensitive to climate change. The presence of rare communities on Mount Monadnock sensitive to climate change makes this mountain an important early indicator of the impacts to northeastern mountain ecosystems if rapid climate change occurs.

INTRODUCTION

The purpose of this study was to describe the vegetative characteristics and current distribution of the natural communities with an emphasis on the forest communities on Mount Monadnock, New Hampshire in relation to elevation and aspect. The proximity of Mount Monadnock to ecotone boundaries and the elevational rise of the mountain allow it to support natural communities from the different ecotones as well as different biomes. Given its relatively southern location among northeastern forests, Mount Monadnock may serve as an early indicator for forest community as a result of climate change. The baseline community descriptions and tree level data collected in this study can be followed with subsequent, incremental studies to determine how Monadnock's forest communities are changing over time and if these changes are correlated with changes in the regional climate.

The following pages summarize the effect of climate change on northeast forests, the description of New Hampshire's natural communities, and ecological information on Mount Monadnock based on current literature. A detailed description of the study methods and results are followed by a discussion of the distribution of natural communities on Mount Monadnock, their significance in terms of current rarity and sensitivity to changing climate, and the value for further research on the mountain.

Climate Change Effects on Northeast Forests

It is predicted that our rapidly changing climate will have profound effects on forest systems at local, regional, and continental scales (Halpin 1997, Saxe et al 2001, Frumhoff et al 2007, Beckage et al 2008). As global temperatures increase, substantial changes will occur in the distribution of species and natural communities, with shifts in geographical and latitudinal

ranges expressed in a poleward migration (Halpin 1997, Saxe et al 2001, Beckage et al 2008). The limits of many species and community ranges are most directly controlled by climate and are defined where species associations converge. These so called ecotones are particularly sensitive to climate change and may be the first areas to be altered by changing environmental conditions (Halpin 1997).

In addition to geographical and latitudinal transitions, altitudinal changes are expected to occur, with upslope movement of climatic habitats in response increasing temperatures. Beckage et al (2008) have documented that an upward shift of forest ecotone has already occurred in the Green Mountains of Vermont, a shift that is consistent with regional climate change. With a narrowing availability of habitat area with increased elevation on mountain summits, such an altitudinal migration has been suggested to be a representation of potential habitat loss (Halpin 1997). Climate change may also affect forests indirectly through disturbances, by exceeding their natural range of variation, altering both forest structure and function significantly (Dale et al 2000). Such disturbances include fire, drought, introduced species, insect and pathogen outbreaks, hurricanes and wind storms, and ice storms. Storm damage in particular is projected to have major effects because it is predicted that their frequency and intensity will increase (Frumhoff et al 2007).

The potential effects of climate change for the northeastern United States has been extensively studied in recent years. The Northeast Climate Impacts Assessment (NECIA), collaboration between the Union of Concerned Scientists (UCS) and a team of independent experts, was conducted to develop a new assessment of climate change and associated impacts on key climate-sensitive sectors in the northeastern United States (Frumhoff et al 2006). The NECIA reports that the average temperature is projected to increase at least (in the lower-

emissions scenario) 3°F in winter and 4°F in summer by late-century (Frumhoff et al 2007), resulting in a migration of State climates. It is projected that between 2070 and 2090, the climate of New Hampshire will have shifted to that of (present day) central Virginia under the lower-emissions scenario, and to that of northern North Carolina under the higher-emissions scenario (Frumhoff et al 2007).

Such a dramatic shift in climate will affect the ecosystems and native biodiversity of New Hampshire profoundly (NH Fish and Game 2005), as the center of suitable habitat for most of the region's tree species will shift northward as much as 500 miles (Frumhoff et al 2007). Many tree species may be able to persist as their optimal climate zones shift northward, but many may succumb to climate stress, increased competition, and other pressures (Frumhoff et al 2007). Impacts will likely be most severe for habitats with narrow temperature regimes, such as alpine habitats and high-elevation spruce-fir forests (NH Fish and Game 2005).

Natural Community Description

Species adapted to specific physical and environmental conditions develop associations which are identified as natural communities (Thompson and Sorenson 2000, Sperduto and Nichols 2004). Natural community types are distinguished using three primary characteristics; a definite plant species composition, a consistent physical structure (such as forest, shrubland, grassland), and a specific set of environmental conditions such as nutrient level, moisture regime, soil type, and climate conditions (Thompson and Sorenson 2000, Nichols 2002, Sperduto and Nichols 2004). Plant species composition is the primary component in the classification of natural communities because plants are sensitive indicators of both environmental and biological factors that influence a wide range of species (Thompson and Sorenson 2000, Sperduto and

Nichols 2004). This close correspondence of plant assemblages to other groups of organisms allows natural communities to serve as coarse filters; a powerful strategy for conservation planning that protects the various species and processes that occur within a community (Thompson and Sorenson 2000, Sperduto and Nichols 2004).

The study of natural communities is important for many additional reasons. Most importantly, it broadens our understanding of the distribution of species and the complex interactions between species and their environments. This knowledge enables us to classify the landscape into a limited number of units that share certain key features (Thompson and Sorenson 2000, Sperduto and Nichols 2004). Sperduto and Nichols (2004) state that classifying the landscape into discrete natural communities allows us to: (1) compare similarities and differences between areas, (2) determine whether an area is unique or common, (3) determine if it is a large or small example of its type, (4) identify the combination of circumstances that likely affect the organisms present, (5) infer how management and stewardship may influence the species composition, and (6) ensure the conservation of ecological processes and species that occur in a community, whether they are presently known or not. Additionally, the classification of natural communities provides a framework for evaluating the ecological significance of pieces of the landscape in both state and regional contexts. Knowledge of these functions and relationships provides a common language for the purposes of land use planning, land management, and conservation (Thompson and Sorenson 2000). This allows ecologists and land managers to effectively communicate when making management decisions regarding ecological systems so that they can develop management and conservation strategies to ensure the survival of all species (Nichols 2002, Sperduto and Nichols 2004).

Natural communities occur in the landscape at spatial scales ranging from continental to regional to site levels, creating a mosaic of patterns. Natural community size and distribution is determined by the various environmental and ecological influences on a particular community and the relative scale at which these influences operate (Thompson and Sorenson 2000). In order to better recognize the patterns of vegetation distribution that occur in the landscape, a hierarchical system of progressively smaller sets of vegetational patterns has been developed based on the scale of their influences (Sperduto and Nichols 2004).

Climate is the dominant influence on the distribution of vegetational patterns in the landscape, operating over large geographic areas; therefore, broad zones of vegetation correspond to different major climate regions (Thompson and Sorenson 2000, Sperduto and Nichols 2004). At the continental scale, these zones are called biomes. In the northeast United States, climate gradients occur both latitudinally and elevationally. New Hampshire, having significant gradients in both latitude and elevation, represents three biomes; alpine tundra, boreal forest, and eastern deciduous forest (Sperduto and Nichols 2004).

Latitude, elevation, physical factors such as landforms and soils, and microclimates are significant influences on the distribution of vegetational patterns at a smaller, regional scale, and provide for the division of regions into natural subsets called ecoregions. New Hampshire lies within three ecoregions: the Lower New England section, the Vermont-New Hampshire Upland section, and the White Mountain section (Figure 1). Each ecoregion is composed of subsections, the next smaller natural division of vegetational patterns based on physical and biological attributes. There are ten ecoregional subsections in New Hampshire (Figure 1) (Sperduto and Nichols 2004).

Within each ecoregional subsection occurs the finest scale of vegetational patterns; natural communities. Based on a natural community type's relative abundance in the landscape, its average size of contiguous occurrence, and the degree to which it is influenced by environmental conditions, Thompson and Sorenson (2000) group natural communities into three categories; matrix, large patch, and small patch. Matrix communities occur within the spatial scales of biomes and ecoregions as their distribution and range is determined mainly by climatic conditions and to a lesser degree by local physical conditions. Matrix communities dominate the landscape, with contiguous occurrences of 1,000-10,000 acres, forming the backdrop within which smaller scale communities occur (Thompson and Sorenson 2000). Unlike matrix communities, patch communities are highly influenced by physical conditions including soil and bedrock types, slopes and slope aspects, and hydrology as well as ecological processes such as disturbances and succession. Both large patch communities (50-1,000 acres) and small patch communities (1-50 acres) are discretely nested within matrix communities.

Mount Monadnock

An example of a region where biomes, ecoregions, subsections, and natural communities come together is Mount Monadnock. Mount Monadnock, in southwestern New Hampshire, is considered by many to be the most distinctive mountain in the northeast. Its solitary presence and position in the landscape, as well as its natural and cultural history, have established Mount Monadnock as unique both ecologically and culturally (Baldwin 1977, Nichols 2002, Sperduto and Nichols 2004). In fact, Mount Monadnock was named a National Natural Landmark in 1987. Mount Monadnock is also claimed as the second most frequently climbed peak in the

world, next to Mount Fuji in Japan, with approximately 95,000-100,000 hikers annually (Nichols 2002, Kokx et al 2003).

The ecological uniqueness of Mount Monadnock is primarily the result of its location in the landscape. The Monadnock region is positioned within the northern extent of the Vermont-New Hampshire Upland ecoregion (Figure 1). Mount Monadnock and the Monadnock reserve are located in the extreme southern end of the Sunapee Uplands subsection of this ecoregion, which is closely surrounded by the Hillsboro Inland Hills and Plains subsection (Figure 1). This close proximity of subsections allows the lower slopes of Mount Monadnock to support natural communities from both subsections (Nichols 2002). Mount Monadnock also shares some ecological characteristics of the White Mountain ecoregion that borders to the north. Being at the threshold of two ecoregions as well as two subsections, Mount Monadnock represents an ecological crossroads, encompassing an ecotone/biome boundary (Whitney and Moellor 1982, Nichols 2002). Additionally, the summit of Mount Monadnock has a disturbance induced timberline that replicates many of the conditions of climatic treeline that occurs higher than 4,700 feet in the White Mountains. The combination of Mount Monadnock's latitude and elevation, as well as its natural and cultural disturbance history, has created a unique assemblage of species representative of all three biomes (alpine tundra, boreal forest, and eastern deciduous forest) present in New Hampshire (Baldwin 1977, Whitney and Moellor 1982, Nichols 2002, Spurduto and Nichols 2004).

Mount Monadnock Vegetation History

A history of disturbance from grazing, fire, windstorms, and cutting has shaped the current vegetational patterns of Mount Monadnock. The treeless summit of Monadnock was once completely forested with the upper portions of the mountain covered with mature red spruce and the lower portions a mixed hardwood and spruce forest (Baldwin 1974, 1977). In the early 1800s, the lower slopes were cleared for cattle pasture. The now denuded summit is thought to be primarily the result of repetitive fires, possibly as a result of pasture clearing fires. A major fire in 1800 that burned for two weeks killed the trees and burned off the humus. The great September gale of 1815 uprooted the remaining trees on the upper mountain which provided fuel wood for another fire in 1820 that was so intense it burned all of the organic material remaining on the summit less some large stumps (Baldwin 1977, Nichols 2002). Additional smaller fires in 1842 and in the 1880s may have reached the summit as well (Nichols 2002).

With the abandonment of the pastures, the lower and middle slopes of Monadnock reverted back to forest while primary succession proceeded relatively rapidly on the denuded summit, with shrubs and alpine plants establishing in crevices (Baldwin 1977, Nichols 2002). The second growth forest on the lower slopes of Monadnock was logged in several locations early in the 1900's (Baldwin 1977, Nichols 2002). Much of these areas (below 2000 feet elevation) are currently being managed for timber production (SPNHF 2004).

The vegetational patterns on Mount Monadnock have historically been described within four broad altitudinal zones (Baldwin 1974, Reiners and Lang 1979, Kincad and Lyons 1981, Whitney and Moellor 1982). These zones are: 1) Lower Slopes; the gentle slopes up to about 600 m (1,968 ft), 2) Middle Slopes; a belt of forest from about 600 – 750 m (1,968 – 2,460 ft), 3)

Scrub Zone; extending from the upper reaches of the middle slopes to the treeline at approximately 800 m (2,625 ft), and 4) the Treeless Zone above 800 m (2,625 ft) (Baldwin 1974).

Nichols (2002) identified several community types from data collected on targeted areas focusing on rare plant and exemplary communities of Mount Monadnock. On the lower slopes, hemlock-beech-oak-pine forest was dominant and semi-rich mesic hardwood forests occurred along some drainages. The lower middle slopes identified were red oak forest. The steep middle slopes were comprised of red oak-black birch/marginal woodfern talus forest/woodlands and the yellow birch variant of the northern-hardwood-spruce-fir forest, with patches of dry rich red oak-ironwood talus forest/woodland. The slopes above 2200 feet were primarily composed of montane spruce-fir forest. Above the (induced) treeline, subalpine rocky balds, red spruce/heath/cinquefoil rocky ridges and montane poor fen/bogs were noted to occur.

Why is it important to document the natural communities of Mount Monadnock?

The combination of subalpine rocky balds, red spruce/heath/cinquefoil rocky ridges, and montane poor fen/bogs with montane spruce-fir forest, red oak-black birch/marginal woodfern talus forest/woodlands and the yellow birch variant of the northern-hardwood-spruce-fir forest make Mount Monadnock possess a richness and diversity of natural resources that is significantly unique. Monadnock's status as a National Natural Landmark is one indication of the importance of the mountain and its natural and biological resources (Nichols 2002). Developing an understanding of Mount Monadnock's ecosystems and a determination of the current distribution of the forest and natural communities is important for many reasons.

First, there is a deficit of current ecological information on Mount Monadnock. Only two studies focusing on forest and natural communities have occurred on Mount Monadnock in recent years, both of which cite the need for additional natural community information. The first study by Nichols (2002) focused on identifying rare plant species and intact, high quality natural communities to guide future conservation and help inform management decisions. Though extremely important, the study was limited in several aspects. First, the study was designed to focus survey attention on areas with the greatest potential to contain significant features. This prioritized inventory was not intended to be, nor could it replace, a more resource-intensive and detailed botanical survey of all lands (Nichols 2002). Secondly, it was beyond the scope of the study to document or map all natural communities and their boundaries. Additionally, the study was only conducted on the portions of Monadnock owned by the State of New Hampshire and the Town of Jaffery, which excludes a majority of the Monadnock preserve. The second study by the Society for the Protection of New Hampshire's Forests (SPNHF 2004) was a biological timber inventory conducted to develop a management plan for the Monadnock Reservation; their ownership of the mountain in the towns of Jaffery, Marlborough, and Dublin, NH. As this study focused on timber management, it excluded areas above 2000 feet in elevation where cutting is not conducted. This management plan states that a further inventory of the areas above 2000 feet would be valuable to track the presence of rare plants or communities and, because of the elevation and rugged terrain of the area, it should be surveyed for possible old growth (SPNHF 2004).

It has been documented that a unique assemblage of species representative of all three biomes present in New Hampshire has developed on Mount Monadnock (Baldwin 1977, Whitney and Moellor 1982, Nichols 2002, Sperduto and Nichols 2004). This phenomenon, in

conjunction with the potential patch occurrence of natural communities, may create unique and uncommon vegetational patterns in the natural and forest communities that are distributed within the Mount Monadnock preserve (Nichols 2002, Sperduto and Nichols 2004). An effective method for determining the distribution of community types in mountain environments is to analyze their distribution in relation to elevation and aspect (Baldwin 1977, Reiners and Lang 1979, Kincad and Lyons 1981, Whitney and Moellor 1982, Foster and Reiners 1983). Currently, however, no studies of this type have been conducted for the Mount Monadnock preserve. A determination of the current distribution of the forest and natural communities would provide a baseline set of data that can be used as a foundation for further studies. Subsequent and additional data sets can be collected over time to determine trends in the change of the forest and community composition, structure and health. Establishing such a baseline at this time may prove to be particularly important with the rapid onset of climate change and subsequent ecological impacts. Given the mountain's ecoregion/subsection juxtaposition, latitude, and elevational rise, Mount Monadnock may serve as an early indicator of how forests of the northeast may change, and how rapidly, if climate change progresses as predicted.

The National Research Council (2000) states that indicators are needed to inform us about ecological status and trends at all spatial and temporal scales, ranging from the status of local populations to the functioning of large ecosystems and that forests are important local and regional indicators. The most valuable indicators for forests are indicators that can provide early warning of adverse trends in productivity, species diversity, and structural diversity; all of which can be aggregated usefully at regional, national, and continental scales (National Research Council 2000). The National Park Service (NPS) (2008) identifies that forest vegetation structure and composition are highly relevant and important to understanding forest ecosystem

condition and therefore uses this information to monitor status and trends in the structure, function, and condition of forested ecosystems in the Northeast Temperate Network of parks to inform management decisions affecting those systems. Relative abundance, species composition and condition of plant communities provides an integrated measure of vegetative response to stress, while canopy vegetation condition is an indicator of stress which can lead to changes in forest ecosystem function, habitat quality, and stand composition (NPS 2008). Additionally, tree sapling regeneration provides an anticipatory indicator of future forest cover type.

In this manner, a determination of the current forest community distribution on Mount Monadnock may prove to be critical information for the management of the preserve (Nichols 2002, Kokx et al 2003). An understanding of natural community changes and the rates of change would help in the long term conservation planning of this unique natural resource. Although the Mount Monadnock preserve is owned by three separate entities, the State of New Hampshire has been contracted to manage these holdings, along with the State's holdings of the preserve, for the public's use. A Monadnock Master Plan Steering Committee was established in the fall of 2000 to assist the New Hampshire Division of Parks and Recreation in the master planning process. Along with other responsibilities, the Steering Committee worked with the Division to formulate strategies for park programs and facilities that would accommodate and better manage the intensity of use at Monadnock State Park. The stated goal was to "develop a management plan that will balance the needs for recreation, conservation, education and financial stability" (Kokx et al 2003). In this, conservation includes protecting the natural and cultural resources of Mount Monadnock while promoting the use of these resources in an appropriate, ecologically sound manner. Resources include vegetation, wildlife, soils, water, trails and recreation facilities, sites of historical, geological or archaeological interest, scenic views, vistas and areas of high

aesthetic value. Education involves methods of deepening visitors' awareness of Mount Monadnock's geological past, its biological and zoological diversity, and the cultural, social and political aspects of its past (Kokx et al 2003). By conducting a study designed to determine the distribution of the forest and natural communities of Mount Monadnock, the resulting information would provide information necessary in attaining these goals that the Monadnock Master Plan Steering Committee has established.

METHODS

Study Area

Mount Monadnock is located in southwestern New Hampshire at 42° 52' N Latitude 72° 6' W Longitude and solitarily rises from the landscape to a height of 3,165 feet in elevation (Figure 2). The Monadnock Reserve is comprised of approximately 6,817 acres that encompass the mountain in the towns of Jaffrey, Marlborough, and Dublin and includes three primary watersheds. The land within the study area is owned by the Society for the Protection of New Hampshire Forests, the State of New Hampshire, and the Town of Jaffery (Figure 2). This study occurred on the slopes above 2,000 feet in elevation that encompass the summit of Mount Monadnock.

Experimental design

This study was conducted to describe the vegetative characteristics and extent of the natural communities on Mount Monadnock between 2,000 and 3,000 feet in elevation, with an emphasis on the woody vegetation. Four distinct study areas were selected on the slopes of Mount Monadnock based on aspect; northeast, northwest, southeast, and southwest. The boundaries of these study areas were determined by topographical features, primarily ridges, and trails that naturally defined the slope of the mountain. In doing so, transect locations were minimally exposed to trails. The northeast slope was defined by Pumpelly ridge and the ridge that the Dublin Trail ascends, the northwest slope was defined by the ridge that the Dublin Trail ascends and the ridge that the Marlborough Trail ascends, the southwest slope was defined by the ridge that the Marlborough Trail ascends and the Halfway House/White Arrow Trail, and the

south slope was defined by the Halfway House/White Arrow Trail and the White Cross Trail (Figure 2).

Each study area contained two randomly selected transects. Transects were selected by determining the map distance along the 3,000 foot contour for each study area on a USGS Topographical map. Within that distance, two distances were randomly selected using random number selection to determine the placement of the top plot for each transect. The end points of each transect were determined by measuring along the 2000 foot contour the same proportional distance used to located the plot at the 3000 foot contour. The azimuth of each transect was then determined by taking a map azimuth from the upper elevation plot down slope to the lower point.

Plot Location and Establishment

Eight, permanently marked transects were randomly selected on four different slopes of Mount Monadnock as described above between May and September of 2007. Each transect was mapped using GPS waypoints from each study plot and GIS software Arcmap 9. Each transect began at 3000 feet in elevation in the scrub zone and ended at 2000 feet in elevation in the hardwood zone. The top point for each transect was determined by pacing out the distance and direction that had been determined on the topographical map. Once the top plot was determined, the azimuth for each transect was followed down slope using a Suunto MC-2 sighting compass.

Along each transect, five meter radius sampling points were established every 100 feet in elevation, yielding 11 plots per transect for a total of 88 plots. Elevation points were determined by use of Garmin GPS 12 units and a Thommen barometric altimeter. Along the azimuth between plots flagging was used to mark the transect.

The center of each five meter radius plot was established by pounding a 30 inch PVC pipe in the ground. Each pipe was labeled and flagged with the plot number. All distances were measured from the exposed end of the pipe. A five meter rope was fixed to a peg which was inserted in the end of the pipe. The rope was then used to establish the perimeter of the plot by placing flags at 90 degree increments parallel and perpendicular to the azimuth. No slope correction was made on either the parallel or the perpendicular.

Data Collection

All data was collected on individuals rooted within the five meter radius plots. The distance from the center stake to borderline trees was measured to determine if a tree was in or out of the plot. Within the plot area the DBH and species of each live and dead tree greater than two inches in diameter was measured. Each tree was tagged with numbered aluminum tags and nails at one meter below DBH. For each tree, a qualitative assessment of tree health was conducted based on percent of needle/leaf loss. Four classes of health were identified; one indicated $0 \leq 10\%$ loss, two indicated $10 \leq 50\%$ loss, three indicated greater than 50-99 loss, and four indicated 100% loss (i.e., dead). For each dead tree, a qualitative assessment of tree decay was recorded. Five classes of decay were identified; one indicated the tree had twigs, two indicated the presence of branches, three indicated the absence of branches/bark, four indicated the tree was punky on the outside, and five indicated the tree was punky to the core. Tree canopy height was measured by estimating the height of two co-dominant trees in each plot.

Live and dead saplings (trees less than two inches in diameter but greater than one meter in height) of each species were tallied, the percent cover of shrubs was estimated, and the presence of species of herbaceous plants was noted in each plot. The slope aspect of the plot was

determined by taking an azimuth of the down slope direction. The degree of slope was determined by averaging an up slope and down slope clinometer reading from the plot center. Soil depth to bedrock were recorded at the plot perimeter at four locations at 90 degree increments parallel and perpendicular to the transect azimuth. To ensure that the center points could be re-established in the future (in the event they are inadvertently removed) two witness trees were established by measuring their distance and azimuth from the center point. The general community structure and composition of each transect, outside of the plots, was also recorded.

Data Analysis

Several steps were taken to describe the distribution of forest community types on Mount Monadnock. Data were managed and analyzed using Microsoft Excel and JMP software. Density and basal area for each tree species at each plot were calculated. Density of each sapling species at each plot was also calculated. The dominant species at each plot was based on the total basal area of each tree species. The dominance of trees at each plot was then analyzed in conjunction with forest structure information, the percent of total density of saplings at each plot, the percent coverage of shrub species, and the presence of herbaceous plants, and compared to the natural community descriptions for New Hampshire from Sperduto and Nichols (2004) and the natural community system descriptions from Sperduto (2005). Each plot was then labeled as a specific natural community type and coded as such on a GIS generated map of the plot placements overlain on digital orthophotos (aerial photos) (Figure 2). The natural community types were then delineated on the GIS map by interpreting the signature of the plot communities on the orthophotos in conjunction with field notes and personal experience on the mountain

(Figure 3). The distribution of the natural communities was then analyzed by their placement in relation to elevation and aspect.

RESULTS

Natural Community Types

Seven natural community types were identified and delineated within the study area; subalpine rocky bald, sheep laurel-Labrador tea heath-krummholz, red spruce-heath-cinquefoil rocky ridge, high elevation spruce-fir forest, northern hardwood-spruce-fir forest, sugar maple-beech-yellow birch forest, and hemlock-beech-oak pine forest. These community types occur within five classifications of natural community systems for New Hampshire (Sperduto 2005) (Table 1). Within these communities, a total of 18 species of trees were recorded (Table 2). Throughout the 88 plots, 1195 trees were tagged, 985 of which were alive. The subalpine communities are naturally void of trees, so almost all of the trees recorded occurred within the other community types. Throughout the sample plots 32 species of shrubs and herbaceous species were recorded (Table 3).

Community Distribution and Descriptions

Subalpine rocky bald – Subalpine rocky bald communities cover a narrow band of the mountain at the highest elevations (n=2). Since the highest elevation of this study was 3000 feet the 165 feet above the highest sample plots was not actually sampled. However, any vegetative communities above 3000 feet are limited to small patches of ground level plants that would be considered characteristic of the subalpine rocky bald community. The communities sampled occurred as crevice communities and small pocket communities in areas of primarily exposed bedrock with shallow pockets of soil averaging 4.3 ± 0.1 cm deep (Table 4). This community contained no trees, however, mountain ash was present as saplings with an average density of 63.7 ± 90.0 stems/ha (Table 5).

Sheep laurel-Labrador tea heath-krummholz – Sheep laurel-Labrador tea heath-krummholz communities cover a narrow band of the mountain (n=5) primarily at 3000 feet, ranging down to 2900 feet (Figure 3). As with the subalpine rocky bald communities, areas upslope of 3000 feet were not sampled, however, limited protected areas above 3000 feet contain pockets of shrubs that would be considered characteristic of the sheep laurel-Labrador tea heath-krummholz community. The communities sampled occurred as pocket communities with soil depths averaging 6.2 ± 3.3 cm (Table 4). Red spruce was the only tree present with an average basal area of 0.4 ± 0.8 m²/ha and an average density of 101.9 ± 227.8 stems/ha (Table 5). The average density of saplings of this community are red spruce 432.9 ± 521.9 stems/ha, heart-leaved paper birch 127.3 ± 220.5 stems/ha, and mountain ash 50.9 ± 69.7 stems/ha (Table 5).

Red spruce-heath-cinquefoil rocky ridge – The red spruce-heath-cinquefoil rocky ridge communities (n=13) occur between 2500 and 3000 feet in elevation. Continuous areas of this community occur within a narrow band around the mountain at 2900 feet (Table 4); however, the presence of this community in lower elevations widely occurs in sporadic patches and on rock outcrops (Figure 4). The communities sampled ranged in structure from sparsely treed rock outcrops to semi-open woodlands with an average canopy height of 2.6 m (0-8) and an average soil depth of 8.4 ± 5.8 cm (Table 4). The dominant trees are red spruce with an average BA of 5.6 ± 7.4 m²/ha and an average density of 489.7 ± 431.3 stems/ha and heart-leaved paper birch with an average basal area of 0.1 ± 0.4 m²/ha and an average density of 29.4 ± 76.3 stems/ha (Table 5). The average density of dominant saplings of this community are mountain ash 470.1 ± 593.5 stems/ha, red spruce 274.2 ± 193.4 stems/ha, and heart-leaved paper birch 137.1 ± 132.1 stems/ha (Table 5).

High elevation spruce-fir forest – The most dominant community within the study area is high elevation spruce-fir forest (n=41). The high elevation spruce-fir forest has the largest elevational range of all the communities within the study area ranging from 2300 to 2900 feet in elevation (Table 4). It occurs in a broad band that blankets the mountain between 2400 and 2800 feet that broadens in many areas to encompass over 600 feet of elevation (Figure 4). Red spruce dominates this community with an average basal area of 29.2 ± 16.3 m²/ha and an average density of $1,478 \pm 752.7$ stems/ha. Spruce is accompanied by heart-leaved paper birch with an average basal area of 1.5 ± 3.6 m²/ha and an average density of 251.5 ± 536.8 stems/ha and paper birch with an average basal area of 0.9 ± 2.6 m²/ha and an average density of 105.6 ± 444.6 stems/ha (Table 5). Balsam fir is completely absent with the exception of a few saplings. Dominant saplings are red spruce with an average density of 1018.6 ± 1099.0 stems/ha, mountain ash with an average density of 124.2 ± 428.5 stems/ha, and heart-leaved paper birch with an average density of 80.7 ± 263.6 stems/ha (Table 5). Structurally, the communities sampled vary from areas of large trees (up to 54.8 cm dbh) to areas with a high density of smaller trees over a wide range of ground conditions; yielding an average canopy height of 10.3 m (4-20) and an average soil depth of 13.6 ± 5.7 cm (Table 4).

Northern hardwood-spruce-fir forest – The Northern hardwood-spruce-fir forest (n=16) is the second largest community found within the study area. Continuous areas of this community occur within a narrow band around a majority of the lower portion of the mountain between 2000 and 2200 feet, however, the community also exhibits some patch occurrence at 2400 feet (Figure 4). Structurally, this community occurs as a closed canopy forest with an average height of 13.7 m (8-18) and an average soil depth of 12.5 ± 5.3 cm (Table 4). The dominant species are red maple with an average basal area of 12.3 ± 11.6 m²/ha and an average

density of 421.8 ± 420.3 stems/ha, red spruce with an average basal area of 12.1 ± 13.4 m²/ha and an average density of 660.5 ± 435.4 stems/ha, and yellow birch with an average BA of 9.1 ± 11.5 m²/ha and an average density of 270.6 ± 254.1 stems/ha (Table 5). Dominant saplings are red spruce with an average density of 588.9 ± 587.9 stems/ha, striped maple with an average density of 580.9 ± 1337.0 stems/ha, and yellow birch with an average density of 95.5 ± 177.0 stems/ha (Table 5).

Sugar maple-beech-yellow birch forest – The sugar maple-beech-yellow birch forest (n=9) occurs along the lowest portion of the study area at 2000 feet, ranging as high as 2200 feet (Table 4). As 2000 feet was the lowest elevation of the study area, communities down slope were not sampled. However, the composition and structure of a majority of the forest immediately below the study area are characteristic of what would be considered to be sugar maple-beech-yellow birch forest. The dominant species are yellow birch with an average basal area of 8.2 ± 14.5 m²/ha and an average density of 297.1 ± 318.3 stems/ha, red maple with an average basal area of 5.3 ± 7.4 m²/ha and an average density of 282.9 ± 483.9 stems/ha, and American beech with an average basal area of 4.9 ± 8.7 m²/ha and an average density of 297.1 ± 501.3 stems/ha (Table 5). Dominant saplings are striped maple with an average density of 1103.5 ± 795.1 stems/ha, yellow birch with an average density of 438.6 ± 720.6 stems/ha, and American beech with an average density of 410.3 ± 616.5 stems/ha (Table 5). The communities sampled occurred in an average canopy height of 16.7 m (13-20) with average soil depths of 12.0 ± 4.1 cm (Table 4).

Hemlock-beech-oak pine forest – Hemlock-beech-oak pine forest communities (n=2) occurred below 2100 feet on one transect on the southwest side of the mountain (Figure 4). Since 2000 feet was the lowest elevation of the study area, communities down slope were not

sampled; however, the composition and structure of the forest immediately below the occurrence of the community are characteristic of what would be considered to be hemlock-beech-oak pine forest. Two tree species are present in this community, red oak with an average basal area of $29.6 \pm 12.3 \text{ m}^2/\text{ha}$ and an average density of $382.0 \pm 180.1 \text{ stems/ha}$ and red spruce with an average basal area of $5.6 \pm 2.4 \text{ m}^2/\text{ha}$ and an average density of $509.3 \pm 360.1 \text{ stems/ha}$ (Table 5). Hemlock is completely absent from the communities sampled and beech occurred only as seedlings. Dominant saplings are red spruce with an average density of $445.6 \pm 450.2 \text{ stems/ha}$, yellow birch with an average density of $191.0 \pm 270.1 \text{ stems/ha}$, and striped maple with an average density of $127.3 \pm 180.1 \text{ stems/ha}$ (Table 5). The communities sampled occurred in an average canopy height of 16 m (15-17) with an average soil depth of $16.3 \pm 7.4 \text{ cm}$ (Table 4).

DISCUSSION

Community Distributions and Descriptions

The distribution of natural communities found on Mount Monadnock was based on plot level data. Although the majority of the plots were distinctive as a particular community type, some plots exhibited characteristics of bordering communities as well, signifying a transition between types. Although transitions of natural communities on Mount Monadnock occur quite abruptly in many areas, “soft” transitions are also exhibited through high interspersions of two bordering communities and through inclusions of patch communities within a more dominant community type. Therefore, the delineation of the communities based on the assignment of plot level characteristics and orthophoto signature interpretation should vary at the site level.

Subalpine rocky bald – Although only two plots captured the subalpine rocky bald community, the majority of the summit area is composed of this community type. Limited soil, high exposure, and hiker traffic are likely strong influences on the distribution of this community. The two plots that registered this community were below 3000 feet in elevation according to the contour line on the delineation map. Delineation of this community did not include a large portion of the area in which it occurs, due to the fact that sampling plots were not placed above 3000 feet.

Sheep laurel-Labrador tea heath-krummholz – The sheep laurel-Labrador tea heath-krummholz community is more extensive on west facing exposures. It transitions above into the subalpine rocky bald community and below to the red spruce-heath-cinquefoil rocky ridge community and exhibits a high amount of interspersions with both communities throughout its elevational range. The diagnostic shrub species of this community, sheep laurel (*Vaccinium*

angustifolium) is exhibiting stress with wide-spread browning of the foliage in many areas. This is also apparent in the red spruce-heath-cinquefoil rocky ridge community, but to a lesser extent.

Red spruce-heath-cinquefoil rocky ridge – The red spruce-heath-cinquefoil rocky ridge community is more prominent on the north side of the mountain where it occurs in continuous bands with relatively little interspersed and a more distinct transition to the high elevation spruce-fir forest below. On the south side, however, this community occurs more so in patches and exhibits a high rate of interspersed with the high elevation spruce-fir forest below, ranging lower in elevation. It seems likely that this distribution is highly influenced by the abundance of rocky outcrops and ridges in this area, as well as the southwestern exposure. Northern wild raisin is a widespread addition to this community (Table 3).

High elevation spruce-fir forest – Several aspects of the high elevation spruce-fir forest are unique. The elevational range of this community on Mount Monadnock (2300-2900) (Table 4), for example, is notably lower than the elevational range (2500-3000) stated in the community description (Sperduto and Nichols 2004). Structurally, this community varies with aspect, with a higher density of smaller (spruce) trees on the north side of the mountain and larger trees with less density on the west and south sides. Several areas on the western and southern sides areas have some very large trees in protected areas such as ravines and cliff bases, some of which (out of plots) measured over 60 cm dbh. This community transitions to the red spruce-heath-cinquefoil rocky ridge community above, exhibiting a relatively hard transition on the north side of the mountain, whereas on the south side the transition is much more variable with large patches of rocky ridge interspersed.

Compositionally, the high elevation spruce-fir forest is unique as well. The expression of this community on Mount Monadnock is almost completely devoid of balsam fir, which occurs

very rarely and only as saplings. Northern wild raisin is also a very common addition to this community and contributes significantly to the percent cover of shrubs in most plots. Sperduto and Nichols (2004) state that the composition of this community type is much influenced by the fire history and to a lesser extent by soils and elevations. It seems very possible that the unique disturbance history and environmental conditions of Mount Monadnock has influenced the expression of this community type to the extent that it could be considered a unique variant.

Northern hardwood-spruce-fir forest – This community accurately represents its description as a transitional forest type between the high elevation spruce-fir forest above and the sugar maple-beech-yellow birch forest below. The degree of transition between these bordering communities is variable, however, it is very distinctive at the site level. Notable aspects of the community composition is the lack of sugar maple, which appears to have its niche filled by red maple. Also, American beech is limited in this community, likely due to the elevation. The most unique aspect of this community type, however, is the presence of the yellow birch variant. The yellow birch variant of this community was identified at two plots; 003-07 and 360-10, both of which are in the northeast study area. One of these plots (003-07) is easily recognized on the delineation map as a large patch inclusion within the high elevation spruce-fir forest (Figure 4).

Sugar maple-beech-yellow birch forest – This community becomes apparent as it transitions into the northern hardwood-spruce-fir forest above. Only the very upper elevation of this community type was registered, as a vast amount of forest below the study area is characteristic of this community type. The most notable aspect of this community is the absence of sugar maple.

Hemlock-beech-oak pine forest – The plots that recorded this community type are characteristic of what Nichols (2002) describes as a mature red oak forest that is an expression of

the hemlock-beech-oak pine forest that usually occurs upslope of this forest type. This expression is also associated with transition to sugar maple-beech-yellow birch forest. There is no hemlock present in these areas, likely due to the warm dry southwestern slope on which it occurs and being at the high elevation range of community, however, SPNHF (2004) identifies that inclusions of hemlock forest and hemlock-beech-oak-pine forest are present primarily at low to mid elevations.

Community Significance

State Rankings and Exemplary Communities – Several of the natural communities found on Mount Monadnock are of significant importance based on their State rarity ranking and their uniqueness as an exemplary community (Appendix A). Exemplary natural communities include all examples of rare types and high-quality examples of common types. High-quality natural communities are identified as having relatively little human impact (Sperduto and Crowley 2001).

Both of the subalpine communities found on Mount Monadnock (Table 1) are ranked S2 - imperiled because rarity (generally six to 20 occurrences statewide) or other factors demonstrably make it very vulnerable to extinction. Additionally, Nichols (2002) identifies the subalpine rocky bald communities on Mount Monadnock as exemplary.

The red spruce-heath-cinquefoil rocky ridge community is ranked S3S4 - widespread and apparently secure, although the community may be quite rare in parts of its range, especially at the periphery, becoming either very rare and local throughout its range (generally 21 to 100 occurrences), or found locally (even abundantly at some of its locations) in a restricted range, or

vulnerable to extinction because of other factors. Nichols (2002) identifies the red spruce-heath-cinquefoil rocky ridge on Mount Monadnock as a feature of local significance.

All of the other community types found on Mount Monadnock are ranked as either S4 or S5. However, two communities have local significance. Nichols (2002) suggests the yellow birch variant of the northern hardwood-spruce-fir forest (S4) on Mount Monadnock as exemplary. Also, the high elevation spruce-fir forest (S4) is extremely rare in southern New Hampshire as illustrated in the New Hampshire Wildlife Action Plan Habitat Condition maps (Appendix B). Additionally, SPNHF (2004) identifies that areas of old growth forest may be present on areas above 2000 feet on Mount Monadnock, possibly lending to the significance of the presence of the high elevation spruce-fir and northern hardwood-spruce-fir forests on Mount Monadnock. Both of these communities have scattered pockets of very large trees, primarily red spruce with fewer yellow birch and sugar maple, which have old growth characteristics, including structural and bark characteristics, as well as stature. One red spruce found in a protected area between plots measured 64 cm dbh with an estimated height of 20 meters. Based on these characteristics and the disturbance history of the area, this tree may be 250 years old or more.

Climate Impact Implications for Communities – The changing climate in the northeast is expected to broadly affect every species and habitat of concern in New Hampshire with the most severe impacts to occur for habitats with narrow temperature regimes such as alpine and high elevation spruce-fir forests (NH Fish and Game 2005). Red spruce in particular is highly sensitive to temperature fluctuations (Peart et al 1991). The high elevation spruce-fir forests, northern hardwood-conifer forests (both northern hardwood spruce-fir forests and sugar maple-beech-yellow birch forests) and the red spruce-heath-cinquefoil rocky ridge communities on

Mount Monadnock are at their southern-most range in the state (Appendix B), with the high elevation spruce-fir forest on Monadnock being an outlier. As climate impacts are expected to effect species distribution ranges both latitudinally and altitudinally (Halpin 1997, Saxe et al 2001), all of these communities are at risk of being highly impacted, as well as the imperiled subalpine communities above them.

Frumhoff et al (2007) identify specific climate change implications that are expected to occur for forest in the northeast. It is projected red spruce will lose 45 to 65 percent of its suitable habitat across Maine, New Hampshire, and Vermont under the lower-emissions scenario, and up to 55 to 70 percent under the higher-emissions scenario. High elevation spruce-fir forests, which cover just one percent of the region's landscape currently, is expected to remain into the next century only under the lower-emissions scenario (Frumhoff et al 2007), however, will likely recede from Mount Monadnock more rapidly than in northern habitats. Likewise, suitable habitat for many northern hardwood trees including maple, specifically sugar maple, beech, and birch is expected to shift significantly northward.

Conclusion

Study Limitations – This study was established to describe the natural and forest communities found on Mount Monadnock and their current distribution based on woody plants. Some communities are identified by herbaceous species which were not sampled quantitatively, rather qualitative assessments were used. Community delineations are approximations based on community signatures on digital orthophotos which have not been ground-truthed. Eight transects was adequate to capture the major community distributions, however, it is possible that other community types are present at smaller scales within the study area that were not

registered. One particular community that has been reported is the montane poor fen/bog (S2S3) occurring in small, high elevation pockets, (Nichols 2002). Another community that could possibly exist at the site level is the spruce-birch-mountain maple wooded talus (S3).

Future Directions – This study would be greatly enhanced and supported with subsequent studies. First, as it is the intention for this study to serve as a baseline to determine change in the distribution of communities on Mount Monadnock, recollection of data for trend development is necessary. The second phase of the long term study of sampling the herbaceous species will enhance the picture of communities and will further the ability to develop trends of change in species distribution and health.

Nichols (2002) states that additional fieldwork is needed to better determine the extent and significance of these natural communities on the mountain. Other studies that would prove useful would include studies on bryophytes; with the prior rapid onset of pioneer succession, extensive bryophyte communities are abundant. Further study of the crevice and pocket communities, particularly their density and distribution, would be extremely valuable to track changes occurring above treeline. Additionally, further research should be conducted to determine the extent of old growth and legacy trees on the mountain, including tree coring to determine tree ages. NH Fish and Game (2005) also identifies the need to monitor indicators of range shifts of alpine habitat plants.

Monadnock's role as an indicator for climate change impacts – Given the range of natural communities that are present on Mount Monadnock, the location of the mountain in relation to the communities ranges, and the projected ecological changes to occur, it is reasonable to suggest that Mount Monadnock will be extremely valuable in determining rates of change on mountain ecosystems resulting from climate change. Furthermore, the high public

visibility of Mount Monadnock to the greater public, as the second most climbed mountain in the world and the region's namesake, studies conducted on Mount Monadnock can inform the public about the impacts of climate change. Antioch New England University has already initiated the Monadnock Ecological Research and Education project (MERE) utilizing this study as a foundation, for this purpose.

LITERATURE CITED

- Baldwin, H. 1977. The induced timberline of Mt. Monadnock, NH. *Bulletin of the Torrey Botanical Club* 104: 324-333.
- Baldwin, H. I., editor. 1974. *Monadnock Guide*. 2nd edition. Society for the Protection of New Hampshire Forests, Concord, NH.
- Beckage, B., Osborne B., Gavin, D.G., Pucko, C., Siccama, T., and T. Perkins. 2008. A rapid upward shift of a forest ecotone during 40 years of warming in the Green Mountains of Vermont. *Proceedings of the National Academy of Sciences* 105: 4197-4202.
- Dale, V. H., Joyce, L. A., McNulty, S., and Neilson, R. P. 2000. The interplay between climate change, forests, and disturbances. *The Science of the Environment* 262: 201-204.
- Foster, J.R. and W.A. Reiners. 1983. Vegetation patterns in a virgin subalpine forest at Crawford Notch, New Hampshire. *Bulletin of the Torrey Botanical Club* 110: 141-153.
- Frumhoff, P.C., J.J. McCarthy, J.M. Melillo, S.C. Moser, and D.J. Wuebbles. 2006. *Climate Change in the U.S. Northeast: A report of the Northeast Climate Impacts Assessment*. Cambridge, MA: Union of Concerned Scientists (UCS).
- Frumhoff, P.C., J.J. McCarthy, J.M. Melillo, S.C. Moser, and D.J. Wuebbles. 2007. *Confronting Climate Change in the U.S. Northeast: Science, Impacts, and Solutions*. Synthesis report of the Northeast Climate Impacts Assessment (NECIA). Cambridge, MA: Union of Concerned Scientists (UCS).
- Halpin, P.N. 1997. Global climate change and natural-area protection: Management responses and research directions. *Ecological Applications* 7: 828-843.
- Kokx Associates, Thomas and T. Petrozzi. 2003. *Monadnock State Park Master Plan: For Management Strategies and Capital Improvement*. New Hampshire Natural Heritage Bureau. Department of Resource and Economic Development, Concord, NH.
- Kincaid, D.T. and E. E. Lyons. 1981. Winter water relations of red spruce on Mount Monadnock, New Hampshire. *Ecology* 62: 1155-1161.
- Magee, D. and H. E. Ahles. 1999. *Flora of the Northeast: a manual of the vascular flora of New England and adjacent New York*. University of Massachusetts Press.
- NH Fish and Game Department. 2005. *New Hampshire Wildlife Action Plan*. New Hampshire Fish and Game Department, Concord, New Hampshire.

- NH Fish and Game Department. 2006. New Hampshire Wildlife Habitat Land Cover – New Hampshire Wildlife Action Plan. New Hampshire Fish and Game Department, Concord, New Hampshire.
- Nichols, W.F. 2002. Rare Plant and Exemplary Natural Community Inventory of Mt. Monadnock State Park, Gay State Forest, and Adjacent Town of Jaffrey Lands. New Hampshire Natural Heritage Bureau. Department of Resource and Economic Development Concord, NH.
- NPS. 2008. NPS: Nature & Science >> Networks: Northeast Temperate Network >> Forest Vegetation. (Accessed April 6, 2008)
<http://science.nature.nps.gov/im/units/NETN/monitor/forestveg/forestveg.cfm>
- Peart, D.R., Jones, M.B., and P.A. Palmiotto. 1991. Winter injury to red spruce at Mount Moosilauke, New Hampshire. *Canadian Journal of Forest Research* 21: 1380-1389.
- Reiners, W.A. and G.E. Lang. 1979. Vegetation patterns and processes in the balsam fir zone, White Mountains, New Hampshire. *Ecology* 60: 403-417.
- Saxe, H., Cannell, M.G.R., Oystein, J., Ryan, M.G., and G. Vourlitis. 2001. Tansley review No. 123. Tree and forest functioning in response to Global Warming. *New Phytologist* 149: 369-399.
- Sperduto, D.D. 2005. Natural Community Systems of New Hampshire. New Hampshire Natural Heritage Bureau and the Nature Conservancy. Department of Resource and Economic Development, Concord, NH.
- Sperduto, D.D. and K.F. Crowley. 2001. Overview of Natural Communities in New Hampshire. New Hampshire Natural Heritage Inventory. Department of Resource and Economic Development and the Nature Conservancy, Concord, NH.
- Sperduto, D.D. and W.E. Nichols. 2004. Natural Communities of New Hampshire. New Hampshire Natural Heritage Bureau and the Nature Conservancy. Department of Resource and Economic Development, Concord, NH.
- Society for the Protection of New Hampshire Forests (SPNHF). 2004. *Management Plan for the Monadnock Reservation: Jaffery, Marlborough, and Dublin, NH*. Concord, NH.
- Sykes, M.T. and I. C. Prentice. 1996. Climate change, tree species distributions and forest dynamics: A case study in the mixed conifer/northern hardwoods zone of northern Europe. *Climate Change* 34: 161-177.
- Thompson, E.H. and E.R. Sorenson. 2000. *Wetland, Woodland, Wildland: A Guide to the Natural Communities of Vermont*. The Nature Conservancy and the Vermont Department of Fish and Wildlife.

- Viner, D., Hulme, M., and S.C.B. Raper. 1995. Climate change scenarios for the assessments of the climate change on regional ecosystems. *Journal of thermal Biology* 20: 175-190.
- Whitney, G.G. and R.E. Moeller. 1982. An analysis of the vegetation of Mt. Cardigan, New Hampshire: a rocky, subalpine New England summit. *Bulletin of the Torrey Botanical Club* 109: 177-188.

Table 1. The Natural Community Systems and associated Natural Communities found on Mount Monadnock, New Hampshire, 2008.

Subalpine heath-krummolz/rocky bald system

Subalpine rocky bald (S2)

Sheep laurel-Labrador tea heath-krummholz (S2)

Montane rocky ridge system

Red spruce-heath-cinquefoil rocky ridge (S3S4)

High elevation spruce-fir system

High elevation spruce-fir forest (S4)

Northern hardwood-conifer forest system

Northern hardwood-spruce-fir forest (S4)

Sugar maple-beech-yellow birch forest (S5)

Hemlock-hardwood-pine forest system

Hemlock-beech-oak pine forest (S5)

Table 2. Tree species found above 2000 feet on Mount Monadnock, New Hampshire, 2008.

	Common Name	Genus species
1	Balsam fir*	<i>Abies balsamea</i> (L.) Mill. *
2	Striped maple	<i>Acer pensylvanicum</i> L.
3	Red maple	<i>Acer rubrum</i> L.
4	Sugar maple	<i>Acer saccharum</i> Marsh.
5	Mountain maple	<i>Acer spicatum</i> Lam.
6	Serviceberry	<i>Amelanchier</i> sp Medik.
7	Yellow birch	<i>Betula alleghaniensis</i> Britton
8	Heart-leaved PB	<i>Betula papyrifera</i> Marsh. var. <i>cordifolia</i> (Regel) Fernald
9	Paper birch	<i>Betula papyrifera</i> Marsh.
10	American beech	<i>Fagus grandifolia</i> Ehrh.
11	White ash**	<i>Fraxinus americana</i> L.**
12	Red spruce	<i>Picea rubens</i> Sarg.
13	White pine	<i>Pinus strobus</i> L.
14	Trembling aspen*	<i>Populus tremuloides</i> Michx.*
15	Pin cherry*	<i>Prunus pensylvanica</i> L. f. *
16	Black cherry**	<i>Prunus serotina</i> Ehrh. var. <i>serotina</i> **
17	Red oak	<i>Quercus rubra</i> L.
18	Mountain ash	<i>Sorbus americana</i> Marsh.

* Indicates only occurred as a sapling.

** Indicate only occurred as a tree.

Table 3. Shrub and herbaceous plant species found above 2000 feet on Mount Monadnock, NH 2008 and their occurrence within the natural communities identified.

<u>Common Name</u>	<u>Species</u> <u>Genus species</u>	<u>SRB</u>	<u>SLLTHK</u>	<u>RSHCRR</u>	<u>Community Type Presence</u>			<u>SMBYB</u>	<u>HBOP</u>
					<u>HESF</u>	<u>NHSE</u>	<u>NHSE</u>		
mountain holly	<i>Ilex montana</i> Torr. & A. Gray ex A. Gray		X	X	X		X		
northern wild raisin	<i>Viburnum nudum</i> L. var. <i>cassinoides</i> L.		X	X	X				
azelea/rhodora	<i>Rhododendron canadense</i> (L.) Torr.	X	X	X					
sheep laurel	<i>Kalmia angustifolia</i> L.		X	X					
mountain cranberry	<i>Vaccinium vitis-idaea</i> L. ssp. <i>minus</i> (Lodd.) Hultén	X	X	X					
black chokeberry	<i>Pyrus melanocarpa</i> (Michx.) Willd.	X		X					
lowbush blueberry	<i>Vaccinium angustifolium</i> Aiton			X			X		
highbush blueberry	<i>Vaccinium corymbosum</i> L.			X					
huckleberry	<i>Gaylussacia baccata</i> (Wangenh.) K. Koch			X					
hobblebush	<i>Viburnum lantanoides</i> Michx.			X			X		
honeysuckle sp	<i>Lonicera</i> L.						X		
raspberry	<i>Rubus ideaus</i> L.					X			
serviceberry sp	<i>Amelanchier</i> sp			X		X			
three-toothed cinquefoil	<i>Potentilla tridentata</i> Aiton	X							
mountain sandwort	<i>Arenaria groenlandica</i> Du Roi	X							
Canada mayflower	<i>Maianthemum canadense</i> Desf.			X			X	X	
yellow clintonia	<i>Clintonia borealis</i> (Aiton) Raf.			X			X		
starflower	<i>Trientalis borealis</i> Raf.			X			X		
wild sarsaparilla	<i>Aralia nudicaulis</i> L.			X			X	X	
bunchberry	<i>Cornus canadensis</i> L.			X			X		
goldthread	<i>Coptis trifolia</i> (L.) Salisb.			X			X		
sharp-leaved aster	<i>Aster acuminatus</i> Michx.			X			X		
white wood aster	<i>Aster divaricatus</i> L.			X			X		
mountain wood sorrel	<i>Oxalis montana</i> Raf.			X			X		
painted trillium	<i>Trillium undulatum</i> Willd.			X					
red trillium	<i>Trillium erectum</i> L.			X					
ostrich fern	<i>Matteuccia struthiopteris</i> (L.) Todaro			X					
rock polypody	<i>Polypodium virginianum</i> L.			X					
hay scented fern	<i>Dennstaedtia</i> Bernh.			X			X		
intermediate wood fern	<i>Dryopteris intermedia</i> (Muhl. ex Willd.) A. Gray			X			X		
ground pine	<i>Lycopodium dendroideum</i> Michx.			X			X		
clubmoss	<i>Lycopodium</i> L.			X			X		
misc. mosses				X			X		
misc. lichens				X			X		
misc. grasses, sedges, rushes				X			X		

SRB = Subalpine rocky bald, SLLTHK = Sheep laurel-Labrador tea heath-krummholz, RSHCRR = Red spruce-heath-cinquefoil rocky ridge, HESF = High elevation spruce-fir forest, NHSE = Northern hardwood-spruce-fir forest, SMBYB = Sugar maple-beech-yellow birch forest, HBOP = Hemlock-beech-oak pine forest

Table 4. Physical characteristics of natural communities found on Mount Monadnock, New Hampshire 2008. Means are shown with ± 1 standard deviation or range.

<u>Community Type</u>	<u>Elevation Range</u>	<u>Dominant Elevation</u>	<u>Mean Soil Depth (cm)</u>	<u>Mean Canopy Height & Range (m)</u>
Subalpine rocky bald (n=2)	3000	~	4.3 \pm 0.1	0
Sheep laurel-Labrador tea heath-krummholz (n=5)	2900-3000	3000 (4)	6.2 \pm 3.3	0
Red spruce-heath-cinquefoil rocky ridge (n=13)	2500-3000	2900 (6)	8.4 \pm 5.8	2.6 (0 - 8)
High elevation spruce-fir forest (n=41)	2300-2900	2700 (8)	13.6 \pm 5.7	10.3 (4 - 20)
Northern hardwood-spruce-fir forest (n=16)	2000-2400	2200 (7)	12.5 \pm 5.3	13.7 (8 - 18)
Sugar maple-beech-yellow birch forest (n=9)	2000-2200	2000 (5)	12.0 \pm 4.1	16.7 (13 - 20)
Hemlock-beech-oak pine forest (n=2)	2000-2100	~	16.3 \pm 7.4	16.0 (15 - 17)

For dominant elevation (the elevation which has the most plots present), (#) equals the number of transects at which community occurs at that elevation.

Table 5. Vegetative characteristics of natural communities found above 2000 feet on Mount Monadnock, NH 2008. Means are shown with ± 1 standard deviation.

Community Type	Dominant Species	Mean BA m²/ha	Mean Density stems/ha	Sapling Mean Density stems/ha
Subalpine rocky bald (n=2)				
	Mountain ash	0	0	63.7 \pm 90.0
Sheep laurel-Labrador tea heath-krummholz (n=5)				
	Red spruce	0.4 \pm 0.8	101.9 \pm 227.8	432.9 \pm 521.9
	Heart-leaved paper birch	0	0	127.3 \pm 220.5
	Mountain ash	0	0	50.9 \pm 69.7
	White pine	0	0	25.5 \pm 56.5
Red spruce-heath-cinquefoil rocky ridge (n=13)				
	Red Spruce	5.6 \pm 7.4	489.7 \pm 431.3	274.2 \pm 193.4
	Heart-leaved paper birch	0.1 \pm 0.4	29.4 \pm 76.3	137.1 \pm 132.1
	Mountain ash	0.0 \pm 0.1	9.8 \pm 35.3	470.1 \pm 593.5
	White pine	0.0 \pm 0.1	9.8 \pm 35.4	19.6 \pm 70.6
	Paper birch	0	0	29.4 \pm 105.9
	Red maple	0	0	19.6 \pm 47.8
	Serviceberry sp	0	0	9.8 \pm 35.5
	Trembling aspen	0	0	9.8 \pm 35.5
High elevation spruce-fir forest (n=41)				
	Red spruce	29.2 \pm 16.3	1478.2 \pm 752.7	1018.6 \pm 1099.0
	Heart-leaved paper birch	1.5 \pm 3.6	251.5 \pm 536.8	80.7 \pm 263.6
	Paper birch	0.9 \pm 2.6	105.6 \pm 444.6	37.3 \pm 201.8
	Red maple	0.5 \pm 1.4	40.4 \pm 92.0	15.5 \pm 50.9
	Yellow birch	0.3 \pm 0.7	34.2 \pm 75.5	18.6 \pm 72.9
	Mountain ash	0.1 \pm 0.7	9.3 \pm 44.0	124.2 \pm 428.5

Mountain maple	0.1 ± 0.3	6.2 ± 27.8	21.7 ± 139.2
White pine	0.1 ± 0.1	3.1 ± 19.9	0
Black cherry	0.0 ± 0.3	3.1 ± 19.9	0
Balsam fir	0	0	6.2 ± 39.8
Serviceberry sp	0	0	6.2 ± 39.8
Striped maple	0	0	3.1 ± 19.9
Pin cherry	0	0	3.1 ± 19.9

Northern hardwood-spruce-fir forest (n=16)

Red maple	12.3 ± 11.6	421.8 ± 420.3	39.8 ± 76.7
Red spruce	12.1 ± 13.4	660.5 ± 435.4	588.9 ± 587.9
Yellow birch	9.1 ± 11.5	270.6 ± 254.1	95.5 ± 177.0
White pine	0.8 ± 3.1	8.0 ± 31.8	0
Paper birch	0.4 ± 0.9	31.8 ± 56.9	0
Striped maple	0.2 ± 0.5	39.8 ± 101.0	580.9 ± 1337.0
Mountain ash	0.1 ± 0.5	8.0 ± 31.8	23.9 ± 51.3
Serviceberry sp	0.0 ± 0.1	8.0 ± 31.8	0
Mountain maple	0	0	55.7 ± 167.4
American beech	0	0	8.0 ± 31.8

Sugar maple-beech-yellow birch forest (n=9)

Yellow birch	8.2 ± 14.5	297.1 ± 318.3	438.6 ± 720.6
Red maple	5.3 ± 7.4	282.9 ± 483.9	367.8 ± 443.1
American beech	4.9 ± 8.7	297.1 ± 501.3	410.3 ± 616.5
Red spruce	4.0 ± 8.3	127.3 ± 229.5	127.3 ± 155.9
Paper birch	2.8 ± 5.9	240.5 ± 526.7	70.7 ± 212.2
White ash	0.9 ± 2.8	28.3 ± 84.9	0
Red oak	0.7 ± 2.0	14.1 ± 42.4	28.3 ± 56.1
Sugar maple	0.1 ± 0.2	14.1 ± 42.4	14.1 ± 42.4
Striped maple	0.0 ± 0.1	14.1 ± 42.4	1103.5 ± 795.1
Mountain maple	0	0	183.9 ± 459.6

Hemlock-beech-oak pine forest (n=2)

Red oak	29.6 ± 12.3	382.0 ± 180.1	0
Red spruce	5.6 ± 2.4	509.3 ± 360.1	445.6 ± 450.2
Yellow birch	0	0	191.0 ± 270.1
Striped maple	0	0	127.3 ± 180.1

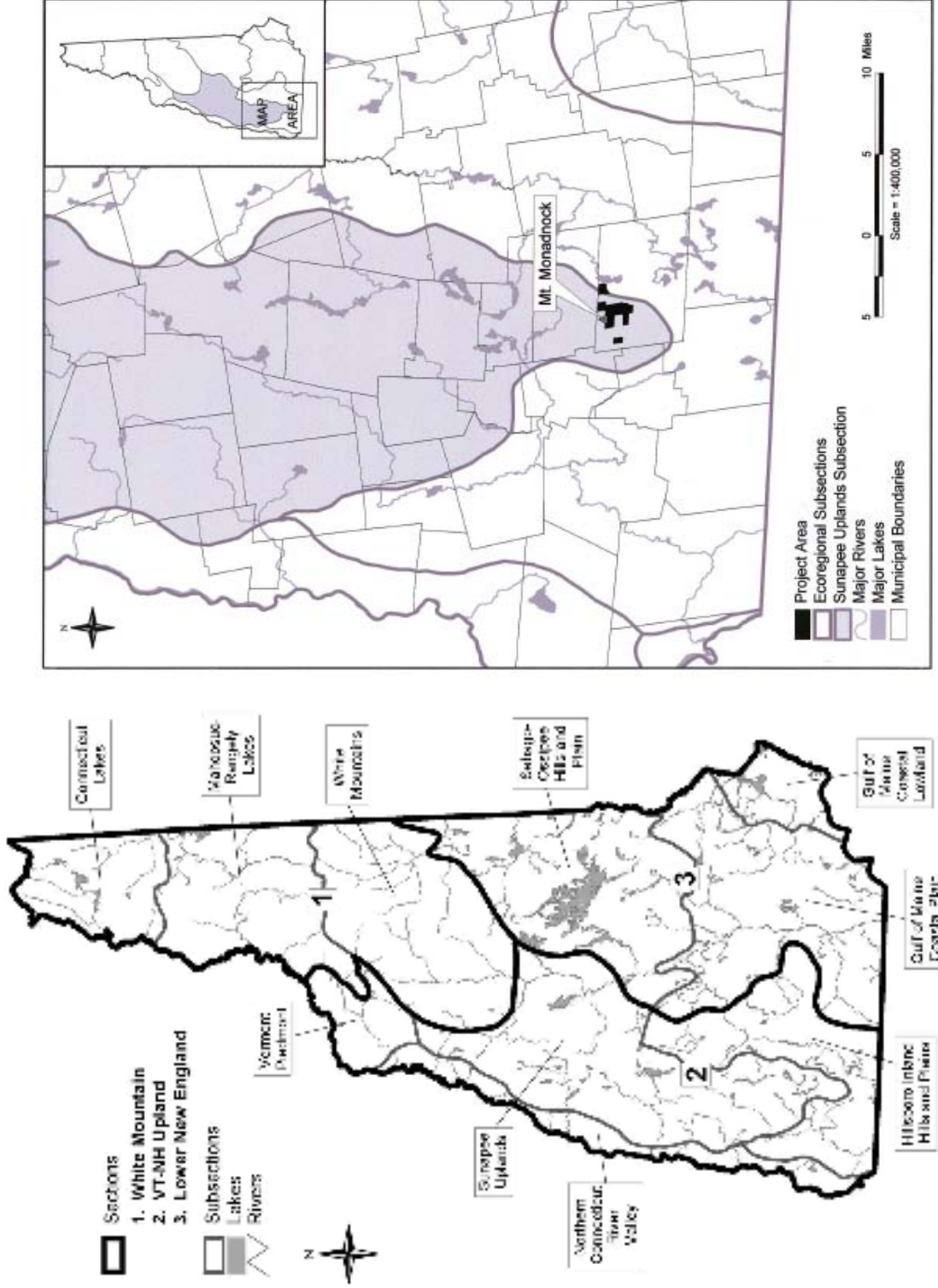


Figure 1. Ecoregions and subsections of New Hampshire (Nichols 2002, Sperduto and Nichols 2004).

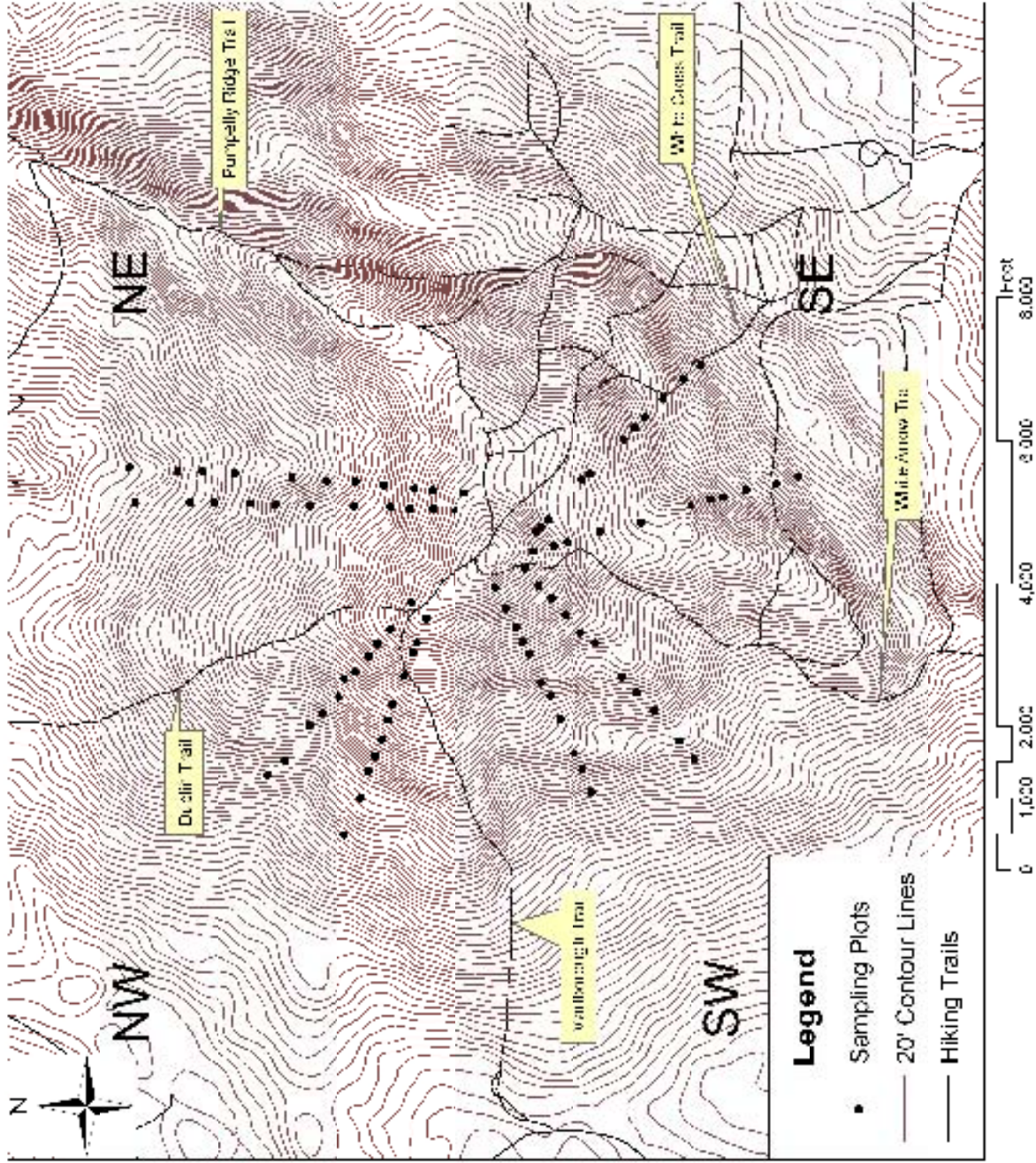


Figure 2. Map of the study areas and sampling plots on Mount Monadnock, New Hampshire, 2008.

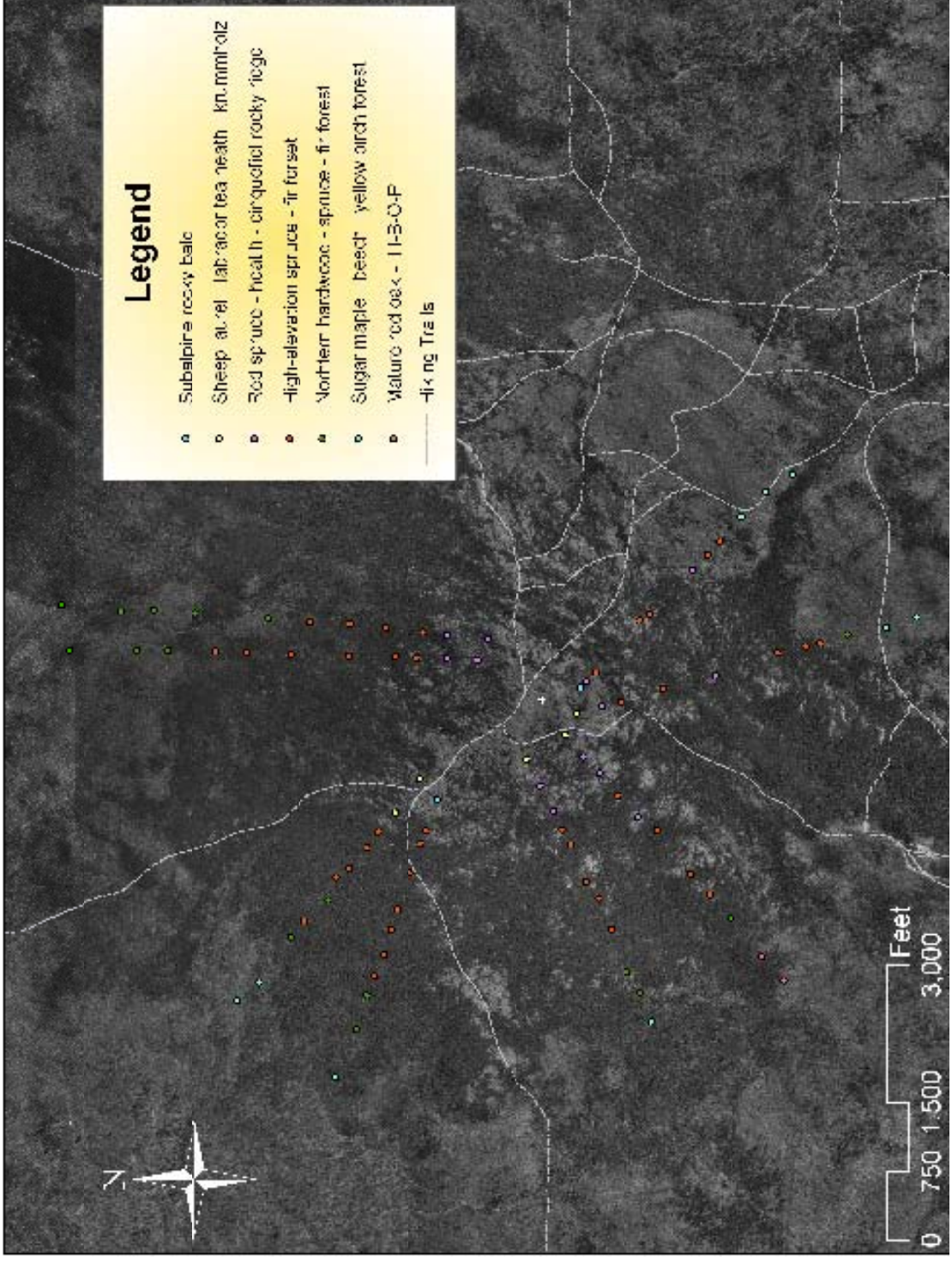


Figure 3. Inventory plot natural community types on Mount Monadnock, New Hampshire, 2008 shown with hiking trails.

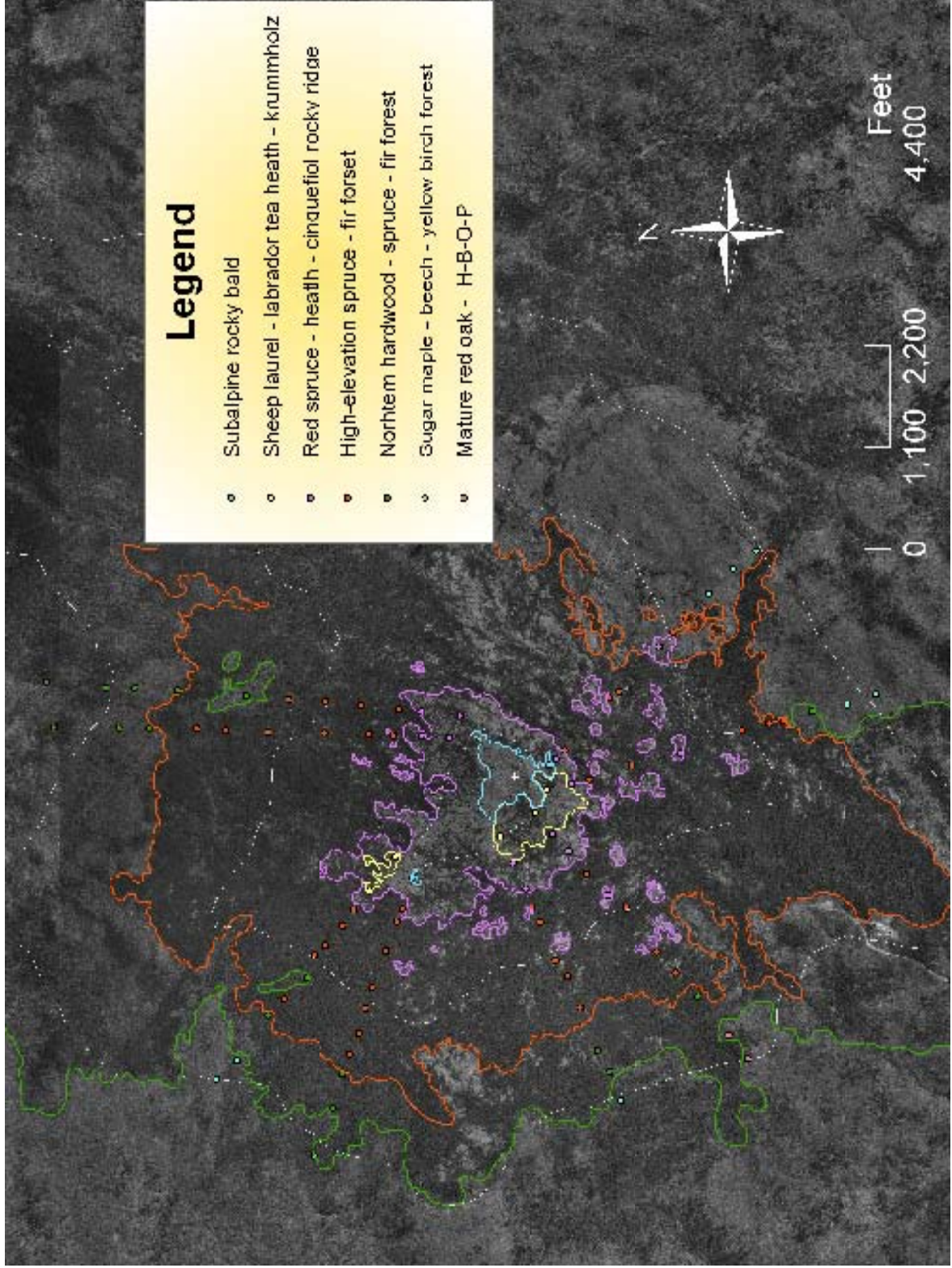


Figure 4. Delineation of the natural communities present above 2,000 feet on Mount Monadnock, New Hampshire.

APPENDICES

Appendix A - Explanation of Global and State Rank Codes.

Appendix B - New Hampshire Wildlife Action Plan Wildlife Habitat Condition maps.

Appendix A - Explanation of Global and State Rank Codes (Sperduto 2005).

Ranks describe rarity both throughout a species' range (globally, or "G" rank) and within New Hampshire (statewide, or "S" rank).

The rarity of sub-species and varieties is indicated with a taxon ("T") rank. For example, a G5T1 rank shows that the species is globally secure (G5) but the sub-species is critically imperiled (T1).

Code Examples Description

1 G1 S1 Critically imperiled because extreme rarity (generally one to five occurrences) or some factor of its biology makes it particularly vulnerable to extinction.

2 G2 S2 Imperiled because rarity (generally six to 20 occurrences) or other factors demonstrably make it very vulnerable to extinction.

3 G3 S3 Either very rare and local throughout its range (generally 21 to 100 occurrences), or found locally (even abundantly at some of its locations) in a restricted range, or vulnerable to extinction because of other factors.

4 G4 S4 Widespread and apparently secure, although the species may be quite rare in parts of its range, especially at the periphery.

5 G5 S5 Demonstrably widespread and secure, although the species may be quite rare in parts of its range, particularly at the periphery.

Appendix B – New Hampshire Wildlife Action Plan Wildlife Habitat Condition maps showing the predicted current extent of high elevation spruce-fir and northern hardwood-conifer forests, as well as rocky ridge communities which includes red spruce-heath-cinquefoil rocky ridge communities (NH Fish and Game 2006). The predicted current extent is based on compiled Geographic Information Systems data layers and not actual distribution data.

