## 1. Introduction

One of the most urgent if not the largest global environmental concern is the question of accelerated climate change due to anthropogenic activity. The earth's biosphere is currently experiencing rapid climate change according to the recent assessment report of the International Protocol on Climate Change (IPCC) (Watson, R.T., Zinyowera, M.C., & Moss, R., 1998). This accelerated climate change will continue to occur if emissions of greenhouse gases, thought to be the driver, are not curbed. The ecological and societal implications of major geographic shifts in vegetation as a response to climate change are profound. Arctic and alpine ecosystems are thought to be sensitive to climate change. No long-term observations currently exist for detecting the impacts of climate change on high mountain ecosystems. However, recent investigations of historic summit sites revealed that vascular plants have been migrating upward toward the higher altitudes (Gottfried et al 1994; Grabherr et al 1994, 1999; Pauli et al 1996). The most likely cause of this upward migration process is global warming since the $19^{th}$ century (Grabherr and Pauli, 2000).

Alpine regions are ideal to monitor climatic change because of several factors: 1) Alpine areas are exposed to low temperature conditions and short growing seasons and therefore are considered sensitive to climate warming; 2) Their ecological complexity is relatively low; and 3) abiotic factors (particularly climatic factors) are more important than the biotic factors within the ecosystem, thus the impacts of climate change are expected to be more pronounced than of lower altitudes (Grabherr and Pauli, 2000). Altitudinal sequence of thermal zones on high mountains are compressed; small ecotones constitute the only separations between these zones. Alpine environments are, therefore, a kind of microcosm where environmental gradients occur along short distances. Invaders lower down in elevation might appear earlier than along latitudinal gradients because of the short distance (Grabherr and Pauli, 2000). Additionally, the impacts of human land use are negligible or of little significance in mountainous regions which are often within protected parcels of land. However, mountain tops downwind of anthropogenic atmospheric pollutants are more influenced than adjacent valleys due to direct transport. Finally, alpine environments can be found virtually within all major life zones from the tropics to the far north. No other biome type on earth is distributed as evenly over the whole world as alpine biomes, thus allowing for comparative ecological observation. These reasons and factors have been identified by the global climate research initiative: GLORIA, a Global Observation Research Initiative in Alpine Environments. The primary objective of the initiative is to establish a network of permanent plots of observation sites in alpine environments from tropical to polar latitudes to provide a standardized reference data for long-term climate monitoring. Research is currently occurring worldwide. However, there is limited research occurring in the northeastern United States contributing to this program (Pauli et al., 2001) or others like it.

Temperature changes in the northeast between 1895 and 1999 indicate that regional climate in general is warming. New England and northern New York have warmed by 0.7 degrees Fahrenheit yet other states such as Rhode Island and New Hampshire have warmed by two to three times the regional average, although Maine appeared to have cooled slightly (See Figure 1) (NERA, 2001).

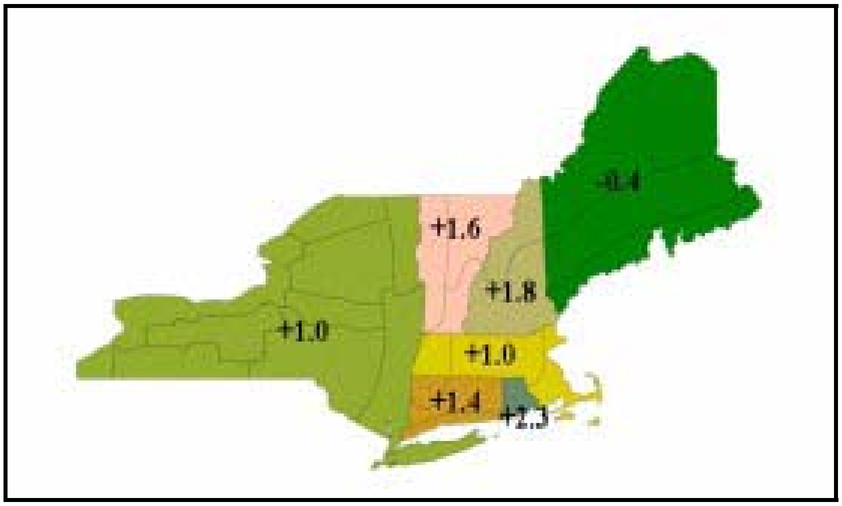



**Figure 1. Average Temperature Changes in the Region Between 1895 and 1999.** (NERA, 2001)

In the eastern United States, alpine environments are a relatively rare habitat occurring within isolated islands of the higher mountain peaks. In total it is estimated about 8,401 acres of alpine habitat occurs in the eastern United States primarily in the mountainous northeast region including northern Maine, New Hampshire, Vermont, and New York (Kimball & Weihrauch, 2000). The largest alpine areas exists primarily on New Hampshire's Presidential Range, and Mount Katahdin, Maine with smaller isolated alpine peaks in Vermont and New York (Kimball & Weihrauch, 2000). Moderate climate warming would put the smaller alpine areas including the Adirondack High Peaks and the Green Mountains, excluding Mt. Washington and Mt. Katahdin, as well as others in New Hampshire and Maine vulnerable (Kimball, 1997).

This project produced a comprehensive assessment of alpine areas in relation to potential alpine bio-monitoring. These bio-monitoring methods will be discussed and their usefulness of their use in the northeastern alpine zone will be determined. Recommendations of adjustment and feasibility will be discussed when examining their application. This paper serves as a comprehensive guide to future long-term alpine bio-monitoring research for climate change in the northeast.

## 2. Methods

This qualitative study used several resources to collect informative data for comprehensive research investigating the northeastern alpine zone and its potential as a bio-monitor of climate change. Three methods of investigation were used; 1) literature, 2) data research, and 3) field surveys.

First, three primary methods of using alpine vegetation as biomonitors were identified. The three methods are the alpine-treeline ecotone (Kimball & Weihrauch, 2000), alpine plant phenology adapted from the International Tundra Experiment (Molau and Mølgaard, 1996), and the *Multi-Summit Approach* (Pauli et al., 2001). Methods and specifications for each of these procedures were identified and then theoretically applied to the northeastern alpine zone. Applying these methodologies involved past and present alpine vegetation research and field surveys.

### a. Alpine Bio-Monitoring Literature Review

Literature and data research was conducted and studies that employed methods using alpine vegetation as a bio-monitor/indicator of climatic change are described in the results section below. Literature and data research investigating species richness, composition, and natural history within the northeastern alpine zone was also reviewed. The extent of research and data collection that has taken place in each of the four primary mountain regions which harbor alpine areas or vegetation was identified. Historical and biological inventories of northeastern alpine vegetation that were found are discussed as to their potential for baseline data for long-term climate change research.

A comprehensive inventory of alpine summits, areas, and sub-alpine peaks with alpine affinities were compiled from field surveys and previous alpine inventory studies. The Adirondack alpine areas have been identified by DiNunzio (1972) and the New York State Natural Heritage Program (2002). The Green Mountain alpine areas have been identified by the Vermont Nongame and Natural Heritage Program (2002). The White Mountain alpine areas were identified by Sperduto & Cogbill (1999) using *Alpine and Subalpine Vegetation of the White Mountains, NH* through the New Hampshire Natural Heritage Inventory. Sperduto and Cogbill (1999) identified 7 types of alpine/sub-alpine communities in New Hampshire. In this paper, New Hampshire alpine areas that harbored community types 1-3 as defined by Sperduto and Cogbill (1999) were included in the alpine inventory. Community types 5 through 7 were excluded because they do not have true alpine or sub-alpine affinities. (See Table 2) These communities are transitional to sub-alpine heath/krummholtz communities (Sperduto & Cogbill 1999).

The eight alpine areas of Maine have been identified by the Maine Critical Areas Program based on the findings of May and Davis (1976) "Arctic Alpine Vegetation in Maine" Planning Report (Pierson and Vickery).

**b. Field Survey**

Field visits were mostly conducted during the snow-free duration from June-October 2003, trailside, within the alpine peaks of the White Mountains of New Hampshire, Green Mountains of Vermont, and the Adirondack High Peaks of New York. Field surveys of Camel's Hump, Mt. Mansfield, VT and Franconia Ridge, NH were administered during the 2002 season. These visits provided better assessment of feasibility and logistical challenges that would be faced when implementing a monitoring program. Five critical variables were compiled from the three methodologies identified and were qualitatively noted during the field survey:

1. The relative size of the alpine area.
    - Noted above treeline area; vegetated and unvegetated accessible near the trail using trail maps, guides, and an altimeter.
2. Abundance and diversity of alpine vegetation trailside.
    - Noted community types and a casual assessment of species diversity.
3. Profile and topography of the alpine peak within the above-treeline area.
    - Noted biogeomorphology of peak. Used the Multi-Summit Approach (Pauli et al. 2001) biogeomorphology specifications.
4. Human impact upon the alpine area.
    - Noted alpine community connectivity between either sides of the trail in which pass through the alpine zone. Very little connectivity will inhibit species migration especially along ridges and summits.
5. Preliminary assessment of untrammeled alpine vegetation which may be available for long-term study. Primarily untrammeled sites away from human impacts.

Alpine areas visited were selected based on the amount of above-treeline area and altitudinal gradient using maps and guidebooks. The largest alpine areas were selected from each mountain range to assess their potential for future research in monitoring climate change. Table 1 is a comprehensive list of the alpine areas visited within each mountain range/state.

**Table 1. Field Survey of Northeastern Alpine Peaks**

| **Mountain/Area** | **Elevation (ft.)** | **Date Observed** |
|---|---|---|
| **Presidential Range, NH** | | |
| Mt. Madison | 5,367 | 7/23/03 |
| Mt. Adams | 5,799 | 7/23/03 |
| -Edmunds Col* | 4,938-5,100 | 7/23/03 |
| Mt. Jefferson | 5,712 | 7/23/03 |
| -Monticello Lawn | 5,390 | 7/23/03 |
| -Mt. Clay* | 5,533 | 7/23/03 |
| -Bigelow's Lawn* | 5,500 | 7/23/03 |
| Mt. Washington | 6,288 | 7/23/03 |
| -Alpine Garden* | 5,175-5,575 | 7/23/03 |
| -Tuckerman's Ravine* | 4,525-5,125 | 7/24/03 |
| -Lakes of the Clouds* | 5,012 | 7/24/03 |
| Mt. Monroe | 5,384 | 7/24/03 |
| -Monroe Flats* | 5,075 | 7/24/03 |
| -Mt. Franklin* | 5,001 | 7/24/03 |
| Mt. Eisenhower | 4,760 | 7/24/03 |
| **Franconia Ridge, NH** | | |
| Mt. Lafayette | 5,260 | 5/2001; 2002 |
| Mt. Lincoln | 5,089 | 5/2002 |
| Mt. Liberty | 4,459 | 5/2002 |
| **Green Mountains, VT** | | |
| Camel's Hump | 4,083 | 7/2002 |
| Mt. Mansfield | 4,393 | 7/2002 |
| Mt. Abraham | 4,003 | 8/6-8/7/03 |
| **Adirondacks, NY** | | |
| Mt. Marcy | 5,344 | 9/6, 9/13/03 |
| Algonquin Peak | 5,114 | 9/20/03 |
| Mt. Haystack | 4.960 | 9/05/03 |
| -Little Haystack* | 4,700 | 9/05/03 |
| Skylight Peak | 4,926 | 9/27/03 |
| Basin Mt. | 4,827 | 9/06/03 |
| Dix Mt. | 4,857 | 9/26/03 |
| Iroquois Peak | 4,840 | 9/22/02 |
| -Boundary I* | 4,840 | 9/22/02 |
| -Boundary II* | 4,780 | 9/22/02 |
| Gothics Mt. | 4,736 | 10/2002 |
| Wright Peak | 4,580 | 10/03/03 |
| Mt. Colden | 4,714 | 9/12/03 |
| -Northeast Colden* | 4,560 | 9/12/03 |

*Subsidiary summits and areas.

The primary area investigated within the White Mountains were the seven alpine peaks that make up the Presidential Range, the largest expanse of alpine tundra east of the Rocky Mountains and south of Quebec. The field survey covered the whole range traversing the range north to south from Mt. Madison to Crawford Notch. The map of the Presidential Range published by the AMC (Garland, 2003) provided relative above treeline acreage. The second largest alpine area in the White Mountains studied was the Franconia Ridge traversing north to south from Mt. Lafayette to Mt. Liberty. Field investigation of the alpine peaks within the Green Mountains extended from past visitation in 2002 - 2003 including the only three alpine peaks in Vermont; Mt. Mansfield, Camel's Hump, and Mt. Abraham.

Through the fall 2003 Adirondack Summit Steward Program, a cooperative partnership with the Adirondack Mountain Club, Adirondack Chapter of the Nature Conservancy, and the New York State Department of Environmental Management and personal field survey, 11 of the Adirondack alpine peaks as well as 4 subsidiary summits and alpine areas were visited.

The alpine peaks of the mountains of Maine were not field surveyed but were researched though literature.

**Table 2. White Mountain Alpine Community Types**
(Sperduto & Cogbill, 1999)

*Included Community Types:*

Type 1: Alpine herbaceous snowbank and herbaceous-heath meadows
 a =alpine herbaceous snowbank meadow [4700'-5500']
 b = moist alpine herb-heath meadow [5000'-5500']

Type 2: Diapensia shrublands
 a =Diapensia-azalea-rosemary dwarf shrubland [4400'-5500']
 b =Diapensia-bilberry heath [4000'-4600']

Type 3: Dwarf shrub/sedge-rush meadows
 a =alpine heath snowbank [4600'-5500']
 b =Bigelow's sedge meadow [4300'-6000']
 c =sedge-rush-heath meadow [4800'5500']
 d =dwarf shrub-bilberry-rush barren [3400'-4800']

*Excluded Community Types:*

Type 4: Heath/Krummholtz
 a =Labrador tea heath/krummholtz [3500'-4900']
 b =sheep laurel-Labrador tea heath/krummholtz [3000'-3700']

Type 5: Subalpine bogs and subalpine heath snowbanks
 a =wet alpine/sub-alpine level & sloping bog
 b =sub-alpine wooded heath snowbank, slope bog, & bog margin
 c =Sliding fen

Type 6: Red spruce/heath/cinquefoil rocky ridge and moist montane heath woodlands

Type 7: Undifferentiated subalpine cliffs, ledges, cold-air talus slopes, landslides, red
 Pine woodlands

## 3. Results

### a. Past & Present Vegetation Research in the Alpine Zone

The northeastern alpine zone has received much attention in the context of alpine research (Zwinger, 1972). Historically documentation and inventory of vegetation has been extensive in the Presidential Range and Mt. Washington since the first scientific expedition by Dr. Manassh Cutler in 1784 (Rees, 2003). Bliss (1963) was the first to systematically study and describes the alpine communities of the Presidential Range into nine community types. Sperduto and Cogbill (1999) have recently composed a more comprehensive study of 94 alpine and sub-alpine sites in the White Mountains including peaks beyond the Presidential Range. The Appalachian Mountain Club has also recorded alpine communities throughout the Presidential Range. Although, historical alpine species loss has received little attention (Dibble et al., 1990; Zika, 1992).

In the Green Mountain alpine peaks considerable research has taken place. Historical species loss in the alpine zone atop Camel’s Hump has been documented. Herbarium and literature evidence suggest four alpine plant species atop this peak have disappeared since the first biological inventory in 1829 (Zika, 1993). *Alnus viridis* and *Vaccinium vitis-idaea* were last documented to be present between 1840 and 1874. *Hierochloe alpine* and *Polygonum viviparum* were last recorded in 1876 (Zika, 1993). No further loss of species has been documented.  This data does not fit the warming trend in the last 100 years and therefore is likely unrelated to climate.  These extirpations could be due to human disturbance but not enough evidence exists. Zika (1993) suggested that the alpine endemics and threatened species could be monitored in the Green Mountains to assess the impacts of pollution and predictions of climatic warming.

The biological inventory of alpine species atop Mt. Marcy, NY dates back to 1898 as a *Report of the State Botanist*. *Plants of the Summit of Mt. Marcy* includes a comprehensive listing of alpine and sub-alpine vegetation. Included is a comprehensive listing of alpine plant species as well as lichens and mosses. Bryological studies atop New York's highest summit have also been historically documented by bryologists in the late 1800s and early 1900s. E.H. Ketchledge in the 1940s and '50s has also added to the knowledge of contemporary Adirondack bryoflora (Miller, 2001).

In 1957, H.E. Woodin established a permanent 300 foot triangular transect above treeline on the isolated west slope of Mt. Marcy's summit cone. The purpose of this study was to monitor recreational impact to vegetational and look for evidence of damage due to acidic deposition. The transect was established to allow "future investigators to determine whether timberlines in the eastern United States are ascending or descending." (Ketchledge & Leonard 1984). The transect was re-measured in 1981, 24 years after the transect was established. Comparison of data from 1957 to 1981 revealed only minor changes in vegetation present in both years. However, they divided the plant species into what the authors considered arctic and non-arctic species and found the addition of four non-arctic species in 1981 being; *Cornus Canadensis, Abies balsamea, Betula cordifolia, Carex bigelowii*. Ketchledge and Leonard (1984) included other non-arctic species including: *Picea mariana*, Alnus viridis ssp. crispa, *Chamaedadaphne calyculata, Kalmia polifolia*, *Ledum groenlandicum*, *Vaccinium oxycoccus* and *Trientalis borealis*. Both suggested that future investigators should note any change in arctic vs. non-arctic species percentages and should evaluate the invasion or loss of species in the transect (Ketchledge & Leonard 1984). The non-arctic species consisted of 19.88% in 1957 and

22.08% in 1981, an increase of 3.20% during a quarter of a century (Ketchledge & Leonard 1984).

**b. Northeastern Alpine Areas**

In total 46 alpine peaks in the northeast have been identified constituting approximately 8,401 acres of alpine communities (Kimball and Weihrauch, 2000). (See Appendices 1-4). Elevation of these alpine communities range from 3, 475 ft. (Chocorua Peak) to the summit of Mt. Washington at 6,288 ft. Climatic treeline within the northeastern United States generally is 4,900 ft (Cogbill and White, 1991; Cogbill et al., 1997). Twelve peaks and numerous subsidiary summits in the northeast actually surpass this elevation (See Table 3). The White Mountains contain the largest expanse of alpine area east of the Rocky Mountains and south of Quebec, mostly concentrated in the Presidential Range including Mt. Washington the highest peak in the northeast at 6,288 ft. This expanse of above treeline alpine tundra constitutes 2,792 acres (Kimball & Weihrauch, 2000).

Alpine areas within the Adirondack High Peaks of New York are found atop Mt. Marcy, the McIntyre Range, the Great Range, and other isolated peaks constituting approximately 85 acres in total (DiNunzio, 1972) (See Appendix 1). Alpine areas in the Green Mountains are restricted to three isolated peaks in northern Vermont including Mt. Mansfield with the largest alpine acreage (See Appendix 2) The Maine Critical Areas Program has documented eight alpine areas (Pierson and Vickery). The largest alpine area in Maine is the Mt. Katahdin massif constituting 1,803 acres making it the second largest expanse of alpine tundra in the northeast (Kimball & Weihrauch, 2000). Other alpine areas in Maine are located within the Mahoosuc and Longfellow Mountains of western and central Maine. Alpine acreage includes Bigelow Mountain with 60 acres, Saddleback Mt. with 638 acres, and five others with less than an acre (Pierson and Vickery). Sugarloaf Mountain also has a small alpine area above treeline but the alpine vegetation has been disturbed by ski lift structures and a radio tower. (See Appendix 3)

**Table 3. Northeastern Peaks that Exceed Climatic Treeline, 4,900'**

| **Peak** | **Elevation (ft.)** | **Mountain Range** |
|---|---|---|
| Mt. Washington | 6,288 | White Mountains |
| Mt. Adams | 5,799 | White Mountains |
| Mt. Jefferson | 5,712 | White Mountains |
| Mt. Monroe | 5,384 | White Mountains |
| Mt. Marcy | 5,344 | Adirondacks |
| Baxter Peak | 5,268 | Katahdin Range |
| Mt. Lafayette | 5,260 | White Mountains |
| Algonquin Peak | 5,114 | Adirondacks |
| Mt. Lincoln | 5,089 | White Mountains |
| Mt. Haystack | 4,960 | Adirondacks |
| Skylight Peak | 4,926 | Adirondacks |
| South Twin | 4,902 | White Mountains |

**c. Methods of Alpine Vegetation Monitoring**

**Alpine-Treeline Ecotone**

Treeline is a tension zone where growing conditions become too severe for even the hardiest of cold-adapted trees (Ketchledge, 1989). This altitudinal gradient is the alpine-treeline ecotone (ATE). The upper limits of the ATE boundary can vary from a sharp boundary to a band of diminishing islands of krummholtz; characteristic trees shaped by climatic exposure. Climatic changes that alter cloud frequency, wind, precipitation and ice loading at the upper elevations could influence shifts in the ATE boundary. Exposure to wind and rime formations in the winter may predict the extent of tree growth (Kimball & Weihrauch, 2000). Determinants of alpine communities and the ATE boundary includes climate, topographic features of exposure including elevation, aspect, slope and slope shape (concavity and convexity) (Kimball & Weihrauch, 2000). Spatial changes in the ATE boundary have potential to be sensitive indicators of vegetative response to climate change (Kimball & Weihrauch, 2000). In 1941, Griggs (1942) addressing the "Symposium on Alpine Ecology" to the Ecological Society of America questioned the dynamic history of treeline on Mt. Washington, New Hampshire since glacial retreat. His concern was that the change in climate towards a repeat of colder conditions again could cause further retreat of treeline on the mountain. More than half a century later, changes in the earth's atmosphere and climate may constitute a different scenario of advancing treeline, due to greenhouse gas emissions.

***Characteristics of Presidential Range ATE Boundaries***

The ATE boundary and alpine vegetation communities of the Presidential Range were field mapped during 1991-1993. Field mapping of the Katahdin Massif was also conducted throughout 1998 (Kimball & Weihrauch, 2000). (See Appendix 5 & 6) The ATE boundary was delineated where lower limits of krummholtz were defined as vegetative growth generally 2.5 m in height for the two mountain areas. On the Presidential Range the ATE boundary ranged in elevation from 3,654 (1,114m) to 5,534 ft (1,687 m) and varied from 2811 (857m) to 4, 980 (1518m) on the Katahdin Massif (Kimball & Weihrauch 2000). Kimball and Weihrauch (2000) hypothesize that tree growth on the northeastern mountains is strongly influenced by the climatic growing season and exposure factors. For example the extent of treeline on the Presidential Range and Katahdin Massif reaches higher elevations in the valleys compared to the exposed ridge. The research resulted in maps where the ATE boundary and alpine community delineations can be readily identified for future bio-monitoring purposes. The ATE boundary will be updated approximately every ten years by the Appalachian Mountain Club (G. Murray per. com., 2003).

### ***Characteristics of Adirondack and Green Mountain ATE Boundaries***

Definitive ATE boundaries also occur on the alpine peaks of the Adirondacks and the alpine areas of the Green Mountains. The Adirondack High Peaks have approximately 11 peaks in which possess a definitive treeline. Mt. Marcy and Algonquin Peak part of the MacIntyre Range possess the most definitive ATE boundary (Ketchledge, 1989). Few Adirondack peaks have a definitive treeline on the southern aspect of their summits facing the warm sun and exclusive sunlight. The three alpine peaks of the Green Mountains including Mt. Mansfield, Camel's Hump, and Mt. Abraham all have definitive treelines ranging in above treeline acreage. Mt. Mansfield and Camel's Hump truly exceed treeline while Mt. Abraham just barely harbors an alpine meadow at the very summit.

## Alpine Plant Phenology

Phenology is the study of periodic biological events and their relationship to seasonal climatic changes. For plants, phenological events include growth, bud initiation, bud burst,  leaf development, flowering, seed development, and leaf senescence (Gates, 1993). By observing the timing of phenological processes year after year, one can trace continuous and changing patterns of climate. Gates (1993) identifies that careful study of timing of phenological events for a particular plant may be of a considerable value when interpreting climate change over a period of many years. Leafing out among some species may start earlier in the spring and in the Northern Hemisphere it will progress northward and upward in elevation more rapidly with a long-term warming of the climate (Gates 1993). Hopkins (1918) states that:

> "… the time of occurance of a given periodical events in life activity in temperate North America is at the general average of 4 days to each 1 degree of latitude, 5 degrees of longitude, 400 feet of altitude, later northward, eastward and upward in the spring and early summer, and the reverse in late summer and autumn."

Long-term phenological monitoring of alpine plant species could be established using a standardized rating system for each phenological event, specified by species. Individual species and small alpine communities could be used along an altitudinal gradient. The International Tundra Experiment (ITEX) (Molau & Mølgaard, 1996) uses arctic/alpine plant species as bio-monitors for climate change. The program currently includes 11 countries including all those with arctic ecosystems. ITEX seeks to examine the response of circumpolar cold adapted plant species to environmental change; specifically to an increase in summer temperature. The Appalachian Mountain Club's Mountain Watch Program is currently using an adaptation of the ITEX methodology to develop a rating system for select alpine species in the White Mountains of New Hampshire. Figure 2 on pages 18 and 19 shows an example of the photographic field guide and associated rating values for *Diapensia lapponica*.

| | |
|---|---|
|  | **Dl0** ***Majority of Leaves Red with No Emerging Flowers*** |
| ***NO PHOTO AVAILABLE*** | **Dl1** ***Majority of Leaves Green, no swollen flower buds*** |
|  | **Dl2** ***Majority of leaves green with flower buds beginning to swell*** |
|  | **Dl3** ***Flower Begins to Emerge. Stalks and white petals can be seen.*** |

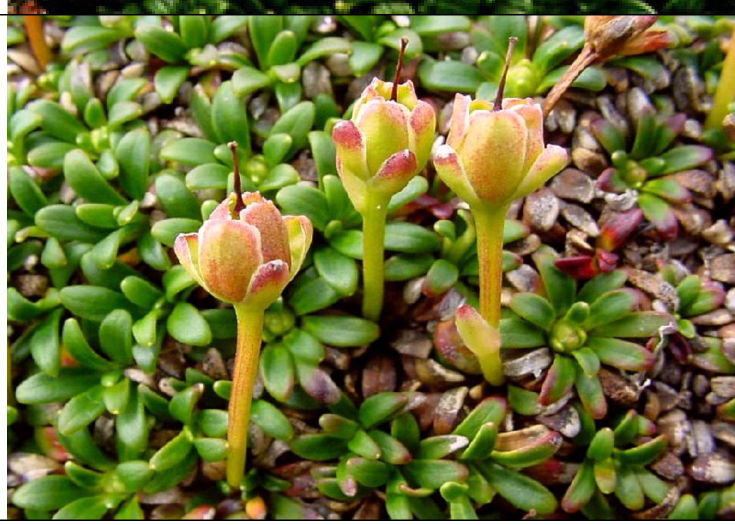
| | |
|---|---|
|  | **Dl4** ***Flower Fully Opens*** |
|  | **Dl5** ***White flower petals fallen, only sepal remaining*** |
|  | **Dl6** ***Hardened Fruit Develops*** |

**Figure 2. Diapensia, *Diapensia lapponica* Phenology Ratings.**
Alpine Phenology field guide ratings developed by Georgia Murray and Ryan Harvey (2003) for the Appalachian Mountain Club's Mountain Watch Program.

The Appalachian Mountain Club's alpine phenology monitoring piloted in the summer of 2003 under the Mountain Watch Program was facilitated by hut staff naturalists at Lakes of the Clouds Hut, Madison Hut in the Presidential Range and Greenleaf Hut on Franconia Ridge of the White Mountains. In addition to alpine phenology ratings for various species (See Appendix 7) hut naturalists, and visiting guests, will record the time and date in which these phenological events occur. Co-located weather stations will record local meteorological conditions. The Mt. Washington Observatory has been recording daily meteorological observations since 1933 as part of the National Weather Service Network. The Appalachian Mountain Club has also been maintaining a weather station on the eastern slope near Lakes of the Clouds and some temperature data at other backcountry huts during the summertime since the early 1980's. These reference meteorological sites in addition to the new weather data collected at backcountry huts will be useful in assessing overall weather patterns in complex mountainous terrain. Long-term phonological data will be examined to determine plat responses to changing weather and climate patterns (G. Murray per. com., 2003).

**Fig. 3. Balsam Fir in the Alpine Zone at 5120' ft.** on Mt. Jefferson, Presidential Range of the White Mountains, NH. (Harvey, 2003)

In the northeastern alpine zone a few tree species are present in the alpine as well as the lower elevations. One of the most common tree species found in the alpine krummholtz is balsam fir, *Abies balsamea.* Monitoring phenological stages in this species across an altitudinal gradient could provide interesting information and is included in AMC's Mountain Watch Program. This species could provide data on how vulnerable the alpine zone is or is not to climatic changes. Balsam fir seed and pollen cone phenological rating system has been developed by AMC using photos from Dr. G.R. Powell of the University of New Brunswick; Forestry and Engineering Department as a field guide. Balsam fir develops and drops cones within one growing season. However in the alpine zone cone production may be limited due to mechanical damage from icing and winds. AMC's program will first assess if cones are present in enough abundance in krummholtz to be used in phenological monitoring.

**Multi-Summit Approach**

The *Multi-Summit Approach* (Pauli et al., 2001) developed by GLORIA: Global Observation Research Initiative in Alpine Environments is a standardized formatted research initiative throughout the world.

Objectives of GLORIA (Pauli et al., 2001):

1. To quantify changes in vascular plant bio-diversity patterns along the altitudinal gradient and their relation to environmental gradients in mountain systems of all major life zones.
2. To asses the potential risks for bio-diversity losses due to climate change by comparing the current distribution patterns of species, vegetation, and environmental factors along vertical and horizontal biogeographical gradients.
3. To quantify changes of biodiversity patterns in the temporal dimension by using monitoring data from the *Multi-Summit* sites reinvestigating at interval of 5 to 10 year intervals.
4. To provide risk assessment by comparing the monitoring data.

Criteria for Summit Selection from GLORIA

Below includes the criteria for summit site selection from the *Multi-Summit Approach* (Pauli et al., 2001):

Site Selection along Altitudinal Gradient

1. First priority is that the summit sites along a vertical gradient in ecotones between the vertical vegetational belts. Climate induced changes are most likely to occur here first.
2. If the ecotones between vertical belts are difficult to define, each summit site should be located within a different vegetation belt.
3. When no clear vertical zonation can be distinguished summit sites should be distributed in equal elevation intervals along the vertical gradient.

Human Disturbance Pressure

1. Summit sites should not be affected by heavy pressure from human land use and or/grazing.
2. Selection should focus on the least affected sites, preferably in national parks or preserves where human disturbance can be expected to remain low in the future as well.

Geomorphologic Shape of the Summit Area

1. Summits should be of “moderate” geomorphologic shape. Both very steep as well as flat, plateau shaped summits are not appropriate for applying the multi-summit approach method.
2. Summit sites need not to be located at the uppermost peak of mountain even small humps, ridges, and other geomorphodic projections.

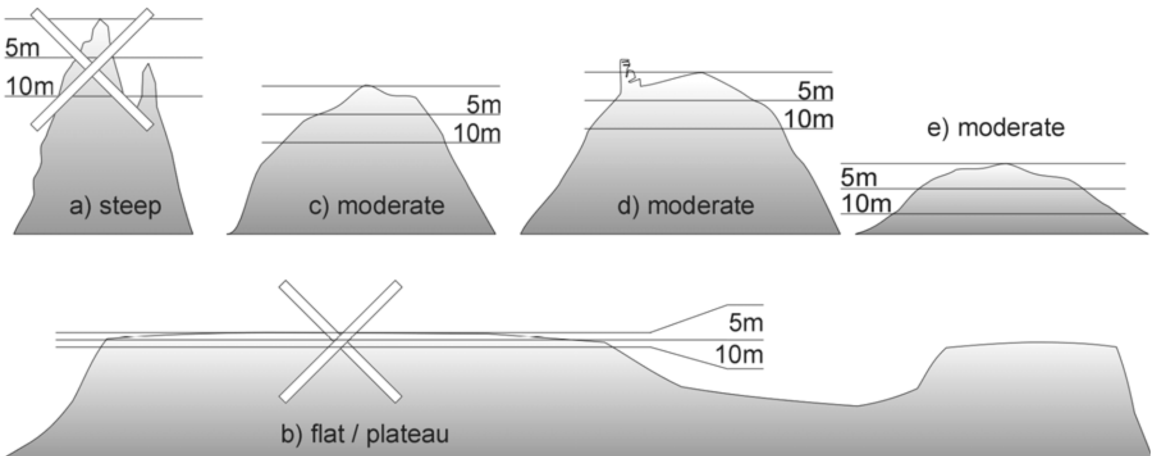



**Figure 4. Appropriate Geomorphological Shape of the Summit Area.**
From (Pauli et al., 2001)

Bedrock of the Summit Area

1. All summits within the target area should be composed of similar bedrock.
2. Mountain areas with active volcanoes should be avoided.

At least four summits with different altitudes should represent an elevation gradient from the ecotone to the uppermost reaches of the vegetation belt (subnival). The mountainous area in which all these summits are located is called the target region. The *Multi-Summit* sampling design for each summit consists of two different plot types: 1m x 1m permanent quadrats and summit area sections with four sections in the upper summit area (5-m summit area) and 4 sections in the lower summit area (10-m summit area).

If the ecotones between vertical belts are difficult to define, each summit site should be located within a different vertical vegetation belt. When there is no clear vertical zonation (mountain regions which slightly exceed treeline) summit sites should be distributed in equal elevation intervals along the vertical gradient.

For example in the northeast:

Summit 1: in the alpine treeline ecotone

Summit 2: in the transition from krummholtz to open sedge/dwaft shrub communities

Summit 3: in the transition from sedge/alpine lawns to exposed alpine communities

summit 4: in the upper limits of vascular plant life, sub-nival zone (e.g. summit of Mt. Washington)

The northeastern alpine summits do possess vertical vegetational gradients from sub-alpine forests, alpine-treeline ecotone (ATE), and above treeline alpine areas in which is required of the GLORIA *Multi-Summit Approach* method.

**Table 4. Northeastern Peaks and Alpine Areas Observed for Multi-Summit Approach Method.**

| **Peak** | **Elevation (ft.)** | **Meets Criteria + Yes - No** | **Notes:** |
|---|---|---|---|
| **Presidential Range, NH** | | + | (+) great potential |
| Mt. Madison | 5,367 | + | (+) great potential |
| Mt. Adams | 5,799 | + | (+) great potential |
| -Edmunds Col* | 4,938-5,100 | - | (-) flat area |
| Mt. Jefferson | 5,712 | + | (+) Great potential |
| -Monticello Lawn | 5,390 | - | (-) plateau area |
| -Mt. Clay* | 5,533 | - | (-) small alpine acreage |
| -Bigelow's Lawn* | 5,500 | - | (-) plateau area |
| Mt. Washington | 6,288 | + or - | Careful site selection advised due to disturbance |
| -Alpine Garden* | 5,175-5,575 | - | (-) plateau area |
| -Lakes of the Clouds* | 5,012 | + | (+) good alpine acreage |
| Mt. Monroe | 5,384 | + | (+) great potential |
| -Monroe Flats* | | - | (-) plateau area |
| -Mt. Franklin* | 5,001 | - | (-) plateau area |
| Mt. Eisenhower | 4,780 | + | (+) good biogeography |
| **Franconia Ridge, NH** | | + or - | Careful site selection due to human disturbance along ridge crest |

| | | | |
|---|---|---|---|
| Mt. Lafayette | 5,260 | + | (+) great potential |
| -Little Lincoln* | | + | (+) great potential |
| Mt. Lincoln | 5,089 | + | (+) great potential |
| Mt. Liberty | 4,459 | - | (-) Human disturbance; severely impacted |
| **Green Mountains, VT** | | | (-) No potential; need at least three summits |
| Camel's Hump | 4, 083 | + | (+) enough alpine acreage<br>(-) cliff areas |
| Mt. Mansfield | 4,393 | + | (+) good alpine acreage<br>(-) cliff areas |
| Mt. Abraham | 4,003 | - | (-) Human disturbance; highly disturbed (Thomson & Sorenson, 2000) & author |
| **Adirondacks, NY** | | | Isolated peaks contain very small patches of alpine acreage |
| Mt. Marcy | 5,344 | + | (+) good alpine acreage<br>(-) avoid human disturbance areas near summit and along trails |
| Algonquin Peak | 5,114 | + | (+) good alpine acreage<br>(-) avoid human disturbance near summit and trails |
| Mt. Haystack | 4,960 | + | (+) great potential |
| -Little Haystack* | 4,700 | - | (-) small alpine acreage |
| Skylight Peak | 4,926 | + or - | (+) good alpine acreage<br>(-) plateau-shaped summit |
| Basin Mt. | 4,827 | - | (-) small alpine acreage |
| Dix Mt. | 4,857 | - | (-) small alpine acreage |
| Iroquois Peak | 4,840 | - | (-)small alpine acreage; human impact |
| -Boundary I* | 4,840 | - | (-)small alpine acreage; human impact |

| | | | |
|---|---|---|---|
| -Boundary II* | 4,780 | - | (-)small alpine acreage; human impact |
| Gothics Mt. | 4,736 | - | (-) small alpine acreage |
| Wright Peak | 4,580 | + or - | (-) human impact (+) good alpine acreage |
| Mt. Colden | 4,714 | - | (-) small alpine acreage |
| -Northeast Colden* | 4,560 | - | (-) small alpine acreage |

*Subsidiary summits and areas

**d. Land Ownership and Existing Protection of Alpine Areas**

Almost the entire northeastern alpine ecosystem offers some degree of land ownership and protection. See Appendix 8 for a summary of land ownership of alpine areas.

Most of the alpine habitat in New Hampshire lies within the boundaries of the White Mountain National Forest. The Presidential Range, constituting the largest expanse of alpine habitat with the strictest of regulations being located in the Great Gulf and Presidential/Dry River Wilderness Areas. Percy Peaks, Monadnock, and Success are the only peaks listed by Sperduto and Cogbill (1999) have potential alpine habitat and are unprotected. Mt. Cardigan is within the bounds of Mt. Cardigan State Forest (Rees, 2003).

The Adirondack alpine peaks primarily all reside in the High Peaks region of the northeast corner of the Adirondack Park. All alpine peaks are protected constitutionally by state congress and are all included within state forest preserve almost all within the High Peaks Wilderness Area.

The summit ridge of Mt. Mansfield is owned by the University of Vermont for scientific monitoring purposes. Camels Hump is part of the Camels Hump State Forest while Mt. Abraham lies within the northern half of Green Mountain National Forest.

The alpine areas of Maine consist of a wide variety of land ownerships. The largest alpine area, Mt. Katahdin is protected under a forever wild clause within Baxter State Park as well as Traveler Mt. Old Speck Mountain lies within Grafton Notch State Park under the administration of Maine Department of Conservation. Mahoosuc Mt., Baldpate, Mt. Bigelow, and Mt. Mount Carlo are within Maine Public Reserve Land under the administration of Maine Department of Conservation; Bureau of Parks and Lands. The alpine area on Saddleback Mt. has recently (November 2000) been acquired to the Appalachian Trail corridor lands owned by the National Park Service.

## 4. Discussion

### a. Alpine Treeline Ecotone

All four major mountain ranges with alpine ecosystems contain above treeline acreage. The ATE boundary varies from one peak to another considering various degrees of exposure. As already mentioned the ATE boundary delineation has already commenced within the Presidential Range of the White Mountains and the Katahdin Massif. These two alpine areas have already been identified to be exceptional sites due to the ATE gradient and above treeline acreage available for study.

Using the alpine-treeline ecotone within the Adirondack alpine peaks is recommended to the four summits that exceed climatic treeline (4,900') which are Mt. Marcy, Algonquin Peak, Mt. Haystack, and Skylight Peak. Several other peaks do also posses above-treeline affinities but consist of very small alpine acreage with very short ATE gradients sometimes reaching just short of the summit. Limited ATE gradients may inhibit spatial shifts. Definitive treelines in the Green Mountain alpine peaks include Mt. Mansfield, Camel's Hump, and Mt. Abraham. From field survey on Mt. Abraham, the ATE boundary comes too close to the actual summit and human disturbance is high. Thomson and Sorenson (2000) also report that the alpine meadow atop Abraham is highly disturbed making this site unsuitable to be used as an alpine bio-monitoring site. These factors may inhibit a long-term ATE boundary study on this specific peak, however Camel's Hump and Mt. Mansfield are appropriate peaks for ATE boundary delineation.

Other than the ATE boundary delineation on the Mt. Katahdin Massif other alpine areas in Maine have not been field surveyed for potential ATE boundary delineation study sites. The handful of northeastern peaks with enough of an alpine zone with definitive ATE boundaries could be useful in monitoring spatial shifts in vegetation.

**b. Alpine Plant Phenology**

Alpine plant phenology offers the greatest opportunity in long-term bio-monitoring research in the northeast. The existence of large above treeline acreage is not required, rather just the presence of alpine plant communities or species. Sub-alpine peaks harbor alpine species which are also commonly found in the alpine zone. Alpine as well as sub-alpine peaks of the northeast share potential where long-term monitoring could occur. Generally sub-alpine ecosystems are found between 3,500 ft, and 4,500 ft. depending on the exposure. The higher and more exposed the peak the more likely to potentially harbor alpine vegetation. The addition of sub-alpine peaks in the northeast would nearly double the sites available for alpine plant bio-monitoring. The advantage of using this method is that it covers the greatest potential altitudinal gradient between study sites considering the greatest altitudinal range from approximately 3,500 to 6,288 feet.

**c. Multi-Summit Approach**

The multi-summit approach is the most intensive and restrictive alpine bio-monitoring methodology when applied to the northeastern alpine zone. The approach should be used within the four separate mountain ranges considering similar bedrock geology. Altitudinal species migration comparison across the west-east (Adirondacks-Maine) gradient would be interesting to plot. The geomorphologic structures of most peaks are of a moderate profile abiding by GLORIA's guidelines for site selection. Although not all ranges possess ideal altitudinal gradients from the alpine treeline ecotone to the subnival belt. The Adirondack and Green Mountain alpine areas would provide poor summit selection sites with little range of an altitudinal gradient. The Green mountain alpine areas are immediately not qualified because only 3 alpine areas exist within the mountain region. GLORIA specifications require 4 summits within the target region. Alpine plateau areas are not suitable for vegetation plots. Areas that would constitute alpine plateau/flat areas would include the alpine lawns of the Presidential Range, the tableland of the Katahdin Massif, as well as other plateau shaped summits; Skylight Peak being an example. The northeastern alpine zone does possess steep slopes that would not constitute good site selection. As well as being the most restrictive in the context of site selection this method is the obtrusive in the fragile alpine zone requiring the establishment of permanent vegetational plots. This method is advised with caution because of the northeast’s marginal alpine acreage and the potential impact.

The highest northeastern alpine peaks provide the best conditions for the multi-summit approach to be administered primarily where the greatest altitudinal gradient exists. The Presidential Range consists of seven major alpine peaks within the immediate target region with an altitudinal gradient from the ATE boundary to the subnival vegetation belt throughout the whole range. However, the impacts of recreation atop the ridgeline would have to be avoided especially when selecting the immediate 1m x 1m summit plots.

The northeastern alpine areas also possess many steep slopes that do not constitute good site selection. In addition to being the most restrictive in the context of site selection the GLORIA method is the most intrusive in the fragile alpine zone requiring the establishment of large numbers of permanent vegetational plots that would frequently be visited. This method is advised with caution because of the northeast's marginal alpine acreage and the potential impact.

Along with co-located weather stations, alpine bio-monitoring can be researched into the long-term correlating weather/climatic trends with species composition, migration, and phenological events. The Mt. Washington Observatory atop Mt. Washington has been recording daily meteorological observations since 1933 along with several other weather stations in the mountains as well as the valleys (Kimball and Weihrauch, 2000). The AMC has also recently installed small weather stations at Lakes of the Clouds, Greenleaf, Lonesome Lake, Carter Notch and Zealand Falls Huts. Meteorological observations are also recorded atop Whiteface Mt. in the Adirondacks and atop Mt. Mansfield in Vermont.

**d. Human Impact and Stewardship in the Alpine Zone**

Immediately there appears to be a problem when applying any of these methodologies to the alpine peaks of the northeast. All three methodologies require a degree of undisturbed alpine habitat for research. Human impacts within the alpine areas nearly exist on every alpine summit. Human impact especially is concentrated on alpine ridges and summits. Although the Presidential Range and Mt. Washington have seen considerable impact over two centuries, alpine communities are relatively undisturbed (Randall, 1983).

Due to the modest elevations and proximity to a large population centers (e.g. Boston metro area-New York) nearly every alpine area has experienced a degree of human impact. Though resilient to harsh climate, alpine vegetation cannot withstand trampling from hikers. The summits of many of the alpine peaks have been trampled and denuded decades ago, whereas the Franconia Ridge in New Hampshire experienced impacts as long as the late last century (Cogbill, 1994). Few peaks are without trails and remain intact, but do range from very little impact to heavily trampled down to bedrock with little hope of recovery.

Human impact could possibly inhibit species migration by creating obstacles of disturbed soils and exposed bedrock. In extreme situations impact may cause premature extinction of species due to the area available for future seeding especially on the summit itself where the greatest species diversity could be threatened. Any researchers monitoring alpine plants should be cognicent of the influence of human impact on their study and should if unable to mitigate it directly should report its extent. For example the Mountain Watch Program is using trailside plots in order to mitigate further degradation.

Region-wide summit steward programs have been employed in order to mitigate adverse recreational impacts. Trained staff and personnel work within the alpine zone of the Green Mountains, Adirondacks, and the White Mountains. Education, ongoing trail maintenance, and onsite education continues to be the best combination for future alpine stewardship. Table 5 is a list of cooperative stewardship or research programs in the northeastern alpine zone.

**Table 5. Stewardship and Cooperative Programs in the Northeastern Alpine Zone**

| Mountain Range | Program | Agency/Institution |
|---|---|---|
| Adirondack High Peaks | Summit Steward Program | Nature Conservancy<br>Adirondack Mountain Club<br>NY Dept. of Conservation |
| Green Mountains | Summit Caretakers | Green Mountain Club |
| | Vermont Cooperative | University of Vermont |
| White Mountains | Volunteer Summit Stewards | Appalachian Mountain Club<br>U.S. Forest Service |
| | Mountain Watch | Appalachian Mountain Club |

**e. Opportunities**

The applications of these alpine bio-monitoring methodologies have potential for implementation using the existing alpine stewardship and cooperative programs working in the northeastern alpine zone. With the presence of summit stewards throughout the hiking season atop these alpine summits there is potential for these programs to incorporate cooperative alpine bio-monitoring programs. Summit stewards are stationed atop Mt. Marcy and Algonquin Peaks in the Adirondack High Peaks every day through the late spring/summer and fall season as well as Mt. Colden and other various alpine summits through the Adirondack Summit Steward Program. Summit caretakers are positioned atop Mt. Mansfield and Camel's Hump throughout the season through the Green Mountain Club. Volunteer summit stewards for the AMC and the USDA Forest Service are positioned atop Franconia Ridge in the White Mountains every weekend throughout the hiking season. Expanding the range of the program may position future summit stewards on Bondcliff and throughout the Presidential Range. Mountain Watch, an alpine climate bio-monitoring program is currently being developed by the Research Department of the Appalachian Mountain Club and will be fully implemented in the 2004 season in the White Mountains of New Hampshire.

The climate monitoring opportunities within the alpine zone may be of interest for resources managers considering the application of possible long-term bio-monitoring. Two Class I Wilderness Areas in the White Mountain National Forest; the Presidential Range-Dry River Wilderness and the Great Gulf Wilderness contain significant alpine acreage. Class I designation safeguards Wilderness areas of negative effects of new sources of anthropogenic air pollution under the Clean Air Act amendments of 1977. Long-term alpine bio-monitoring may be an important factor in monitoring of this fragile resource that is strictly protected by law sustaining wilderness characteristics and value.

The northeastern alpine zone has definite potential for alpine bio-monitoring research. Alpine plant phenological methods offer the greatest opportunity for climate bio-monitoring making available the greatest altitudinal gradient (sub-alpine & alpine) and acreage. The alpine treeline ecotone recommend as the second most applicable bio-monitoring methodology to monitor climate on northeast peaks. The *Multi-Summit Approach* offers limited opportunity in this region as it is restricted to the highest alpine areas and requires larger spatial requirements. This methodology is only recommended to be considered in the Presidential Range of the White Mountains. Data from one of these new approaches should be compared with past and present comprehensive alpine inventories to increase validity. With proper site selection and careful planning at least one of these methodologies can be employed across the northeastern alpine zone. A compilation of these three methodologies or others may exhibit the greatest potential for alpine bio-monitoring in the northeast. By continuing cooperative relationships and stewardship within the alpine zone research opportunities for alpine bio-monitoring in the northeastern alpine zone are feasible and recommended.

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**Appendix 1. Alpine Peaks and Areas of the Adirondacks, NY.**

| Peak | Altitude (ft) | Total Acres | Vegetated Acres |
|---|---|---|---|
| **Mt. Marcy** | 5,344 | 15.2 | 6.6 |
| **Algonquin Peak** | 5,114 | 21.6 | 13.5 |
| Northwest Algonquin | 4,100 | 1.3 | 0.7 |
| Northwest Algonquin, Bluff I | 3,900 | 0.2 | 0.1 |
| Northwest Algonquin, Bluff II | 3,740 | 0.1 | 0.1 |
| **Mt. Haystack** | 4,960 | 18.5 | 6.5 |
| Little Haystack | 4,700 | 2.7 | 0.9 |
| **Skylight** | 4,926 | 3.6 | 1.9 |
| **Iroquois Peak** | 4,840 | 4.6 | 2.4 |
| Southwest Iroquois | 4,500 | 0.3 | 0.2 |
| Boundary I | 4,840 | 3.4 | 1.6 |
| Boundary II | 4,780 | 0.8 | 0.4 |
| **Basin** | 4,827 | 1.0 | 0.6 |
| **Gothics Mt.** | 4,736 | 1.0 | 0.8 |
| **Mt. Colden** | 4,714 | 0.8 | 0.6 |
| Northeast Colden | 4,560 | 0.5 | 0.3 |
| **Wright Peak** | 4,580 | 5.5 | 2.8 |
| Northwest Wright | 3,840 | 0.2 | 0.1 |
| **Dix Mountain** | 4,857 | 1.0 | 0.8 |
| **Whiteface Mt.** | 4,867 | 2.7 | - |
| **Totals** | | **85** | **-** |

(DiNunzio, 1972)

**Appendix 2. Alpine Peaks of the Green Mountains, VT.**

| Peak | Altitude (ft.) | Alpine Area (acres) |
|---|---|---|
| Mt. Mansfield | 4,393 | - |
| Camel's Hump | 4,083 | 2.5 |
| Mt. Abraham | 4,006 | - |
| **Total** | | - |

**Appendix 3. Alpine Areas of Maine.**

| Peak | Altitude (ft.) | Alpine Area (acres) |
|---|---|---|
| Mt. Katahdin | 5,268 | 1200+ |
| Traveler Mt. | 3,541 | - |
| Old Speck Mt. | 4,170 | - |
| Mahoosuc Mt. | 3,470 | - |
| Baldpate Mt. | 3,662 | - |
| Bigelow Mt.<br>-Avery Peak<br>-West peak | <br>4,090<br>4,145 | 60 |
| Mount Carlo | 3,565 | - |
| Saddleback Mt. | 4,120 | 638 |
| **Total** | - | **-** |

(May and Davis, 1973); (Pierson and Vickery); (Kimball and Weihrauch, 2000)

**Appendix 4. Alpine Peaks and Areas of the White Mountains, NH.**

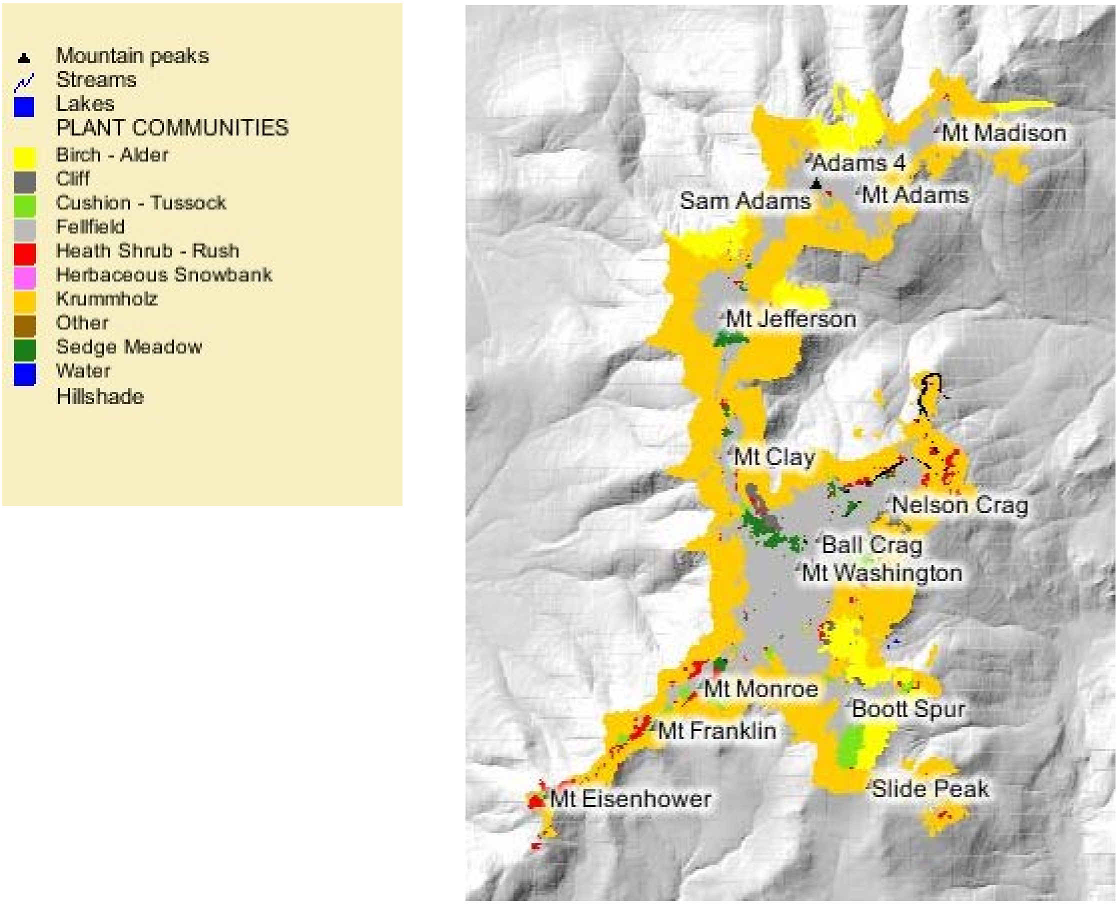
| **Mountain** | **Elevation (ft.)** |
|---|---|
| **Mahoosuc Ridge** | |
| Mt. Success | 3,565 |
| **Baldface Ridge** | |
| S. Baldface | 3,570 |
| N. Baldface | 3,610 |
| **Carter-Moriah Range** | |
| Carter Dome | 4,832 |
| Imp Summit | 3,730 |
| **Presidential Range** | |
| Mt. Washington | 6,288 |
| -Alpine Garden | 5,175-5,575* |
| -Bigelows Lawn | 5,500* |
| -Great Gulf | 4,228-5,828* |
| -Huntington Ravine | 4,075-5,475* |
| -Tuckerman's Ravine | 4,525-5,125* |
| -Lakes of the Clouds | 5,012* |
| -Monroe Flats | 5,075* |
| -Oakes Gulf | 4,400-5,000* |
| -Washington Summit | 6,288 |
| **Northern Presidentials** | |
| Mt. Adams | 5,799 |
| -Bumpus Brook | Data Not Available |
| Mt. Clay | 5,533 |
| Mt. Jefferson | 5,714 |
| -King Ravine | 3,825-5,000* |
| Mt. Madison | 5,367 |
| -Spaulding Spring/Edmunds Col | 4,938-5,100* |
| **Southern Presidentials** | |
| Mt. Eisenhower | 4,761 |
| Mt. Franklin | 5,001 |
| Mt. Monroe | 5,382 |
| **Montalban Ridge** | |
| Mt. Davis | 3,819 |
| **East Branch of the Pemigewasset Region** | |
| Mt. Bond | 4,690 |
| Bondcliff | 4,265 |
| Mt.Guyot | 4,580 |
| South Twin | 4,902 |
| **Franconia Ridge** | |
| Mt. Flume | 4,328 |
| Mt. Lafayette | 5,260 |

| | |
|---|---|
| Mt. Liberty | 4,459 |
| Mt. Lincoln/Little Haystack | 5,089 |
| **Cannon-Kinsman-Moosilauke Region** | |
| Mt. Moosilauke/ Blue Mt. | 4,802 |
| **Sandwich Range-Scar Ridge Region** | |
| Chocorua Peak | 3,475 |

(Sperduto and Cogbill, 1999) Alpine and sub-alpine peaks that are certain to possess Types 1, 2, and 3 communities included. Uncertain presences of alpine or sub-alpine affinities were excluded.

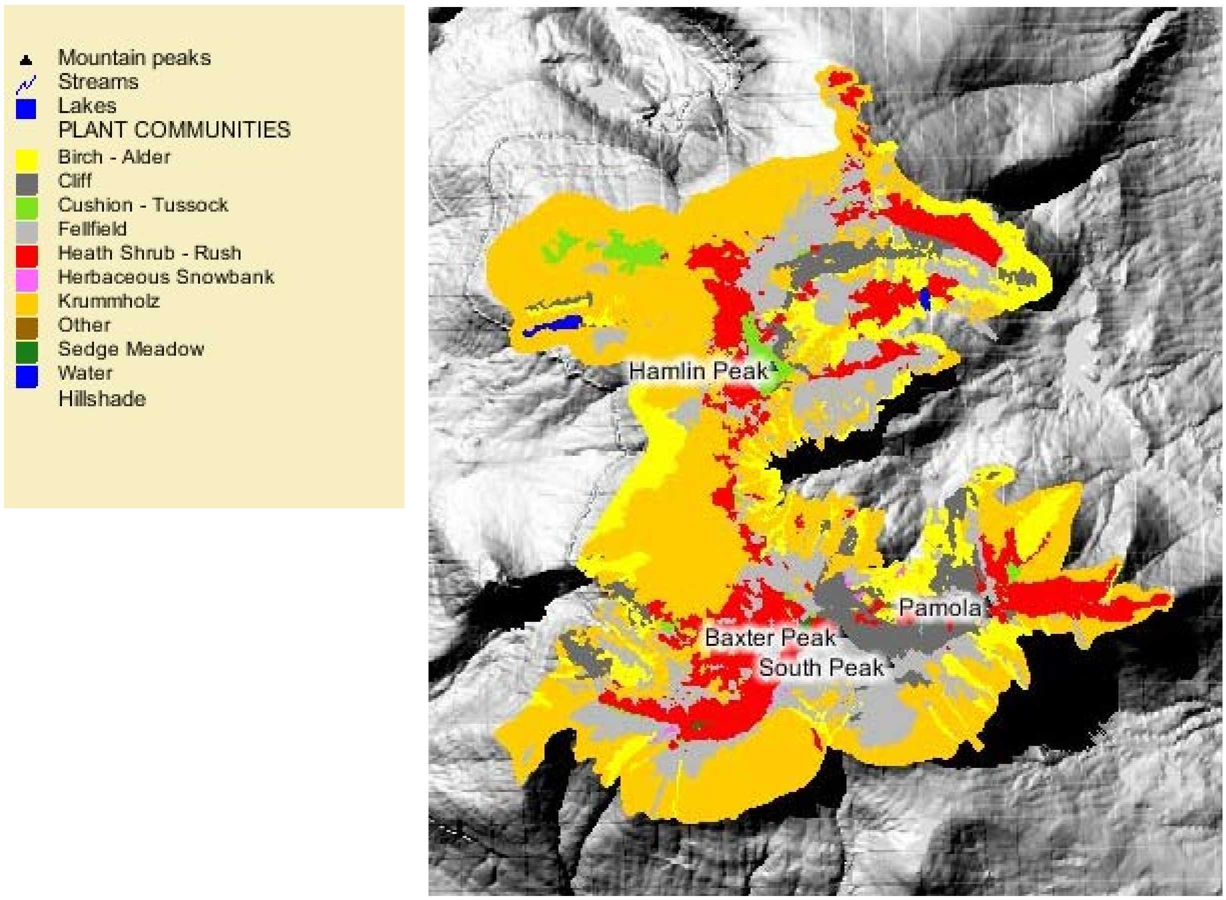
*Approximate elevations determined by the White Mountain Guide (Daniell and Smith, 2003) and the Map of the Presidential Range (Garland, 2003).

**Appendix 5. ATE Boundary & Alpine Communities of the Presidential Range, NH**




(Research Department of the Appalachian Mountain Club, 2003)

## Appendix 6. ATE Boundary and Alpine Communities of Mt. Katahdin, ME




(Research Department of the Appalachian Mountain Club, 2003)

## Appendix 7. AMC Mountain Watch Alpine Phenology Target Species

| **Species** | **Scientific Name** |
|---|---|
| Balsam Fir | *Abies balsamea* |
| Bigelow’s Sedge | *Carex bigelowii* |
| Bog Bilberry | *Vaccinium uliginosum* |
| Cotton Sedge | *Eriophorum vaginatum* |
| Diapensia | *Diapensia lapponica* |
| Dwarf Birch | *Betula grandulosa* |
| Moss Plant | *Cassiope hypnoides* |
| Mountain Ash | *Sorbus decora* |
| Mountain Avens | *Geum peckii* |

**Appendix 8. Summary of Land Ownership of Alpine Areas within the Northeast**

**New York**

| **Mountain** | **Name** | **Administration** |
|---|---|---|
| Mt. Marcy<br>Algonquin Peak<br>Haystack Mt.<br>Skylight Mt.<br>Iroquis Peak<br>Basin Mt.<br>Gothics Mt .<br>Mt. Colden<br>Wright Peak | High Peaks Wilderness Area | New York Department of Environmental Conservation |
| Whiteface Mt. | McKenzie Mountain Wilderness Area/Intensive Use | New York Department of Environmental Conservation |
| Dix Mt. | Dix Mountain Wilderness Area | New York Department of Environmental Conservation |

**Vermont**

| **Mountain** | **Name** | **Administration** |
|---|---|---|
| Mt. Mansfield | Mt. Mansfield State Forest<br>Underhill State Park | Vermont Department of Forests, Parks, and Recreation<br>University of Vermont |
| Camel’s Hump | Camel’s Hump State Park | Vermont Department of Forests, Parks, and Recreation |
| Mt. Abraham | Green Mountain National Forest | USDA Forest Service |

**New Hampshire**

| **Mountain** | **Name** | **Administration** |
|---|---|---|
| Mt. Success | Appalachian Trail Corridor Lands | National Park Service |
| S. Baldface<br>N. Baldface<br>Carter Dome<br>Imp Summit | White Mountain National Forest | USDA Forest Service |
| Mt. Washington<br>-Alpine Garden<br>-Huntington Ravine<br>-Tuckerman's Ravine | Culter River Drainage Area; White Mountain National Forest | USDA Forest Service |
| -Oakes Gulf<br>-Monroe Flats<br>-Bigelows Lawn | Presidential-Dry River Wilderness Area; White Mountain National Forest | USDA Forest Service |
| -Washington Summit | Mt. Washington State Park | NH Division of Parks and Recreation |
| -Great Gulf | Great Gulf Wilderness Area; White Mountain National Forest | USDA Forest Service |
| Mt. Adams<br>-Bumpus Brook<br>Mt. Clay<br>Mt. Jefferson<br>-King Ravine<br>Mt. Madison<br>-Edmunds Col/Spaulding Spr. | Great Gulf Wilderness Area; White Mountain National Forest | USDA Forest Service |
| Mt. Eisenhower<br>Mt. Franklin<br>Mt. Monroe | White Mountain National Forest | USDA Forest Service |
| Mt. Davis | Presidential-Dry River Wilderness Area;<br>White Mountain National Forest | USDA Forest Service |
| Mt. Bond<br>Bondcliff<br>Mt.Guyot<br>South Twin | Pemigewasset Wilderness Area; White Mountain National Forest | USDA Forest Service |
| Mt. Flume<br>Mt. Lafayette<br>Mt. Liberty<br>Mt. Lincoln/Little Haystack | Pemigewasset Wilderness Area; White Mountain National Forest | USDA Forest Service |
| Mt. Moosilauke/ Blue Mt. | Dartmouth Outing Club<br>White Mountain National Forest | Dartmouth College<br>USDA Forest Service |

| | | |
|---|---|---|
| Chocorua Peak | Mt. Chocorua Scenic Area; White Mountain National Forest | USDA Forest Service |

**Maine**

| **Mountain** | **Name** | **Administration** |
|---|---|---|
| Mt. Katahdin<br>Traveler Mt. | Baxter State Park | Baxter State Park Authority |
| Old Speck Mountain | Grafton Notch State Park | Maine Department of Conservation |
| Mahoosuc Mt.<br>Baldpate Mt.<br>Bigelow Mt.<br>Mount Carlo | Maine Public Reserve Land | Maine Department of Conservation<br>Bureau of Parks and Lands |
| Saddleback Mt. | Appalachian Trail Corridor Lands | National Park Service |

**Appendix 9. Capstone Project Prososal**

**Using the Northeastern U.S. Alpine Zone as a Bio-Monitor for Climate Change**
[PROJECT PROPOSAL]

Ryan J. Harvey
4/14/2003
Natural Resources; Management & Policy
5/2003 – 12/2003

**Abstract**

Temperature-limited environments such as boreal, arctic, and alpine regions are thought to be very sensitive to greenhouse warming. It has been hypothesized that alpine plant species will migrate upwards in elevation in response to a warmer climate. This vulnerability has spurred investigation towards alpine vegetation monitoring as predictors of climate change. Until recently, worldwide alpine vegetation monitoring has commenced but has not officially been established within the mountainous northeastern United States. This study will identify methods to use alpine plants as bio-monitors/indicators of climate change and asses if these methods could be applied to the small alpine zone of the northeastern U.S. In addition to reviewing these methods of monitoring, recommendations of adjustment, concerns, and identification of applicable components of long-term alpine bio-monitoring programs will be incorporated. Researching historical as well as current documentation of the alpine zone in context of climate change will be complemented with on-site evaluation within the four mountain ranges with alpine areas. This document will identify feasible methods in which to use the biota of the northeastern U.S. alpine zone as a bio-monitor for climate change as well as providing groundwork for future research.

**Introduction**

One of the most urgent if not at the least largest global environmental concern is the question of accelerated climate change due to anthropogenic activity. The ecological and societal implications of major geographic shifts in vegetation as a response to climate change are profound. No such long-term observations exist for detecting the impacts of climate change on high mountain ecosystems. A recent investigation of historic summit sites revealed that vascular plants have been migrating upward toward the higher altitudes (Gottfried et al 1994; Grabherr et al 1994, 1999; Pauli et al 1996). The most likely cause of this upward migration process is global warming since the 19$^{th}$ century.

Alpine regions are ideal to monitor climatic change because of several factors: Alpine areas are exposed to low temperature conditions and short growing seasons and therefore are considered sensitive to climate warming. Their ecological complexity is relatively low, and abiotic factors, particularly climatic factors are more important than the biotic factors within the ecosystem thus the impacts of climate change are expected to be more pronounced than of lower altitudes (Grabherr et al, 2000). Compared with latitudinal sequences of thermal life zones from the equator to the poles, altitudinal sequence of thermal zones on high mountains is compressed; small ecotones constitute the only separations between these zones. Alpine environments, are, therefore a kind of microcosm where environmental gradients occur along short distances. Invaders lower down in elevation might appear earlier than along latitudinal gradients because of the short distance (Grabherr et al, 2000). Additionally, the impacts of human land use are negligible or of little significance and are often within protected parcels of land. Mountain tops can not escape all human influence though; as atmospheric pollution can often be more of a problem at higher elevations than in adjacent valleys. Finally, alpine environments can be found virtually within all major life zones from the tropics to the far north. No other biome type on earth is distributed as evenly over the whole world as alpine biomes, thus allowing for comparative ecological observation.

These reasons and factors have been identified by the global climate research initiative GLORIA, a Global Observation Research Initiative in Alpine Environments. The primary objective of the initiative is to establish a network of permanent plots of observation sites in alpine environments from tropical to polar latitudes to provide a standardized reference data for long-term climate monitoring. Research is currently occurring worldwide. However, there is limited research occurring in the northeastern United States contributing to this program (GLORIA, 2000).

In the eastern United States, alpine environments are a relatively rare habitat occurring within isolated islands of the higher peaks. In total it is estimated about 34 $km^2$ of alpine habitat occurs in the eastern United States primarily in the mountainous northeast region including northern Maine, New Hampshire, Vermont, and New York (Kimball & Weihrauch, 2000). The majority of the alpine zone exists primarily on New Hampshire's Presidential Range (11.3 $km^2$), and Mount Katahdin, Maine (7.3 $km^2$) (Kimball & Weihrauch, 2000).

This study will examine the potential of using the alpine zone of the northeast in long-term monitoring of climatic change highlighting advantages and disadvantages of this ecosystem as a bio-indicator. Biotic and abiotic factors will be identified and analyzed in the context of assessment towards feasibility. Information will be gathered from past and current research within the alpine zone of the northeast and included.  This study will ultimately produce feasibility, recommendations, and concerns in using the northeastern alpine environments as a climate change indicator.

**Major Questions**

Ultimately the major question being addressed is if the northeastern alpine zone has a promising potential to be used as a bio-monitor/indicator of climate change. Listed are other related issues that will be addressed:

- What existing alpine bio-monitoring methods for indicating climate change using alpine vegetation as an indicator can be used in the northeastern alpine zone?
- Can these methods be applicable to the small alpine zone of the northeast?
  - Identify and address special concerns/problems of applying these techniques to the northeastern U.S. alpine zone.
  - Identify the positive applicable components of applying these techniques.
- Have there been past, present, or future planned alpine bio-monitoring in the context of climate change in the northeast?

**Project Objectives and Significance**

This qualitative study will investigate the northeastern alpine zones' potential as a bio-indicator for long-term climate change research. Data and research from other long-term alpine climate monitoring worldwide will be considered and placed in the context of the northeastern alpine zone. Primarily, the data collected will include an inventory of past research pertaining to this subject within the alpine zone, as well as current research that may be underway. Secondly, the four alpine regions including the mountains of

Maine, the White Mountains of New Hampshire, Green Mountains of Vermont, and the Adirondack High Peaks of New York will be documented highlighting pertinent data and information in the context of climate monitoring. As a third component, actual alpine zone observations and investigation will be documented from experience within the alpine zone.

This study will primarily be a reference laying out potential ground work for future long-term climate change alpine monitoring. Potentially, it will address advantages, disadvantages, and recommendations of using the northeastern alpine zone as a bio-indicator for climate change. This qualitative study may be of interest for resource managers of the northeast as well as other managed alpine areas considering the application of possible long-term alpine bio-monitoring.

There are two Class I Wilderness Areas in the White Mountain National Forest; the Presidential Dry River Wilderness and the Great Gulf Wilderness managed by the USDA Forest Service that constitute strict government protection and have significant alpine diversity. Class I designation safeguards wilderness areas of negative effects of new sources of anthropogenic air pollution under the Clean Air Act amendments of 1977. This paper may be of some interest for the monitoring of this fragile resource that is strictly protected by law sustaining wilderness characteristics (i.e., scenic beauty, vegetation, wildlife, water) and value.

**Assumptions, Scope, and Limitations**

It is assumed by many that due to accelerated climate warming alpine vegetation will migrate upwards in elevation (Gottfried et al 1994; Grabherr et al 1994, 1999; Pauli et al 1996). This is the major assumption that will be used in evaluating the northeastern alpine zones' potential as a climate change bio-indicator.

All the northeastern alpine summits will be used as the eco region of study. This includes Mt. Katahdin and the alpine summits of Maine, the White Mountains of New Hampshire, the alpine summits of the Green Mountains, and the Adirondack High Peaks. The largest alpine areas within each mountain system will primarily be used due to the relatively small alpine zone in the northeastern United States. Mt. Katahdin will be the primary alpine representative in the mountains of Maine with the second largest alpine zone in the northeast. Mt. Washington, the summits of the Northern Presidential Range and Franconia Ridge will be the primary representative of the White Mountains with the largest alpine zone in the northeast. Mt. Mansfield and Camels Hump will be the primary alpine representatives for the Green Mountains. Mt. Marcy and Algonquin Peak will be the primary representatives for the Adirondack High Peaks. Smaller islands of alpine habitat may also be evaluated in the context of climate change monitoring but their small areas may limit their potential.

Obviously, these alpine areas are located on isolated peaks throughout these mountain ranges which encompass four northeastern states. It is not likely that I will be able to visit each and every alpine area within this region. The areas that I have personally visited will be assumed that they are not incredibly dissimilar to the rest of the northeastern alpine areas. Data and research that may have taken place within these unvisited areas will be mentioned. The northeastern alpine zones throughout the northeast are very similar in the context of vegetational species composition and may very little between ranges (Slack & Bell, 1993; 1995). However, climatic regimes may extremely vary between mountain regions.

**The Project Plan**

Primarily the data that will be collected will be of a qualitative nature. Quantitative data in the context of this subject would be too time intensive for such a short-term project such as this.

First, an in depth literature review and evaluation will be conducted on the subject of alpine bio-monitoring and climate change. The current authority on alpine bio-monitoring for climate change is GLORIA: Global Observation Research Initiative in Alpine Environments. This worldwide initiative is advocating a formalized monitoring campaign using uniform methodology. This initiative has developed criteria which have been published which list variables and essential components of a successful monitoring program. Other alpine research initiatives will be used such as the International Tundra Experiment when discovered. Various methodologies are but not limited to; vegetation plot monitoring, phenology monitoring, alpine-treeline ecotone (ATE) monitoring, as well as other integrated methods. Variables such as size of study area, slope, aspect, species composition and richness, human disturbance, as well as many other variables that arise, will be investigated and applied to possible bio-monitoring study in the northeast. Information will also be gathered on research or documentation in the northeastern alpine zone on using this ecosystem as a bio-indicator.

The application of this research will be used when visiting these alpine areas personally when potential site-selection of a long-term vegetational monitoring program will be conducted. Written as well as photo-documentation will be used in presenting the conditions of the alpine zone in the context of potential long-term vegetational monitoring. For example, human disturbance patterns which may impede possible species migration will be documented within the alpine zone. Upon these observations, recommendations will be drawn in the context of site selection and success of future bio-monitoring programs.

On-site evaluations in the White Mountains of New Hampshire will be done in conjunction with the Appalachian Mountain Club's (AMC) Mountain Watch program being conducted at Madison Hut in the Northern Presidential Range and Lakes-of-the Clouds Hut on the shoulder of Mt. Washington. This program will show hut guests how to use monitor phenology of alpine plants species and will explain how the measurements will be used to look for as an indicator of climate change and establish an informal long term monitoring program with the hut crew and guests. Through this program I will be working with staff scientist Georgia Murray of the AMC. On-site evaluation will also be documented with a possible alpine steward volunteer position atop the Franconia Ridge for two weekends throughout the year. This steward program is facilitated through the U.S. Forest Service of White Mountain National Forest and the Appalachian Mountain Club. Besides these volunteer positions, personal visits to these alpine areas will be used. The documentation of the Adirondack High Peaks will most likely take place through fall 2003 while attending Paul Smith's College.

**Literature Review**

It has been accepted and concluded that the effects of climate change upon alpine plant species will cause migration upwards in elevation (Gottfried et al 1994; Grabherr et al 1994, 1999; Pauli et al 1996). This possible migration of alpine communities will significantly impact biodiversity, species richness, and distribution. In fact species richness quite possibly may increase toward the highest location on alpine summits (Gottfried et al, 1998). Research in the European Alps has concluded that this phenomenon may be true by comparing historical documentation and present data collection (Pauli et al, 1996). Considering this possible migration upwards in elevation these communities may encounter unsuitable habitat conditions which may result in reduction of habitat surface area and decreased species richness (Guisan and Theurillat, 2000). These factors discussed may ultimately result in forced extinction of many alpine species or communities.

These predictions give light on possible bio-monitoring methodology which could be applied to evaluate climate change. The predictions identify what to sample, where to sample, and what to examine.  First, site selection is crucial of the placement of a bio-monitoring plot (Pauli et al, 2001). Human disturbance has to be minimal which will not impede possible species migration when establishing a monitoring site. Other factors have to be accounted for in the site selection and methodology, such as slope and profile of the peak itself. These geomorphologic variables again influence species migration. Moderate geomorphologic shape mountains are appropriate (Pauli et al, 2001).  It also has been identified that the alpine-treeline ecotone (ATE) can be used as a sensitive indicator of vegetative response to climate change. The alpine-treeline has been identified as early as 1942 by R.F. Griggs observing the treeline on Mt. Washington, New Hampshire concerned, the repeat of colder climatic conditions will cause further retreat of treeline on the mountain (Griggs, 1942). More than a half century later, changes in the earth's atmosphere create the possibility of a very different scenario; global warming due to 'greenhouse' gas emissions.

Worldwide there has been a recent trend in using the alpine environment as an indictor of climate change due to the ecosystem's sensitivity. Already a worldwide initiative GLORIA: Global Observation Research Initiative in Alpine Environments has formalized a uniform bio-monitoring program. The northeastern alpine zone has not yet been incorporated in this program although some research has been conducted and monitoring initiatives are being discussed. The relative small area of the northeast's alpine zone may limit the success of such a program in which could be implemented. Already initiated by the U.S. Forest Service and the Appalachian Mountain Club an alpine-treeline ecotone (ATE) program has been established using this ecotone as bio-monitors for climate change. The ATE boundary within the Presidential Range of New Hampshire and Mt. Katahdin of Maine have been mapped and analyzed for future documentation of community response (Kimball and Weihrauch, 2000). The potential of alpine bio-monitoring using vegeation plots, alpine-treeline boundary, as well as other observational methods will be assessed in the context of the northeastern alpine zone.

## Bibliography


Gates, D.M. (1993) Climate Change and its Biological Consequences. Sunderland, MA: Sinauer Association., Inc. 280p.

-No text available yet. Interlibrary Loan.

Global Observation Research in Alpine Environments. (2003, March 17) Multi-Summit Approach. [Online]. Available. http://www.gloria.ac.at/res/gloria_home/.

This resource is a global research consortium on the establishment of long-term climate change monitoring in alpine environments primarily using alpine vegetation as a monitor/indicator. One of the most important resources available is the Multi-Summit Approach strategy by this initiative by establishing replicate permanent vegetational plots throughout the world's mountains.

Gottfried, Michael., Pauli, Harald., Grabherr, Georg. 1998. Prediction of Vegetational Patterns at the limits of Plant Life: A New View of the Alpine-Nival Ecotone. Arctic and Alpine Research. 30(3). 207-221.

-Research in which incorporated field samples of vascular alpine plants in which were modeled to predict vegetational shifts and migration due to climate change. Conclusion stated that alpine environments will be significantly impacted in the context of biodiversity, species richness, and distribution.

Grabherr, Georg. Gottfried, Michael. Pauli, Harald. May 2000. Gloria: A Global Observation Research Initiative in Alpine Environments. Mountain Research and Development 20(2). pp.190-191.

-This informative article describes the first internationally coordinated initiatives to observe the environment in alpine regions. The initiative takes advantage of the high vulnerability of high alpine ecosystems in terms of climatic detection of climate change.

Grabherr, G., Gottfreid, M, Pauli, H. (1994) Climate Effects on Mountain Plants. Nature. 369:448.

-General short article that initially concluded that climate change will affect alpine plant species significantly. Climate change will affect these species in which they will migrate upward in elevation.

Griggs, R.F. 1942. Indications of Climate Changes from Timberline of Mt. Washington. Science 95: 515-519.

-Historical account on the alpine treeline ecotone (ATE) on Mt. Washington. The article also is an account or regional climatic records using historical evidence and account. The article concludes that the alpine-treeline is retreating on Mt. Washington and the Presidential Range.

Guisan, Anoine & Theurillat, Jean-Paul. 2000. Assessing alpine plant vulnerability to climate change: a modeling perspective. Integrated Assessment. 1: 307-320.

-This paper presents an investigation into the upward shift in alpine vegetation an the conditions in which these communities may encounter through this shift which may be unsuitable conditions. These unsuitable condition may result in reduction in habitat surface area and in turn affect patterns in biodiversity. In this paper results from static plant distribution modeling are used to determine climate change impact scenarios.

Kimball, Kenneth D., Weihrauch, Douglas M. (2000) Alpine Vegetation Communities and the Alpine-Treeline Ecotone Boundary in New England as Biomonitors for Climate Change. USDA Forest Service Proceedings RMRS-P-15-Vol-3.

-This study mapped and analyzed the alpine-treeline ecotone boundary and alpine plant communities on the Presidential Range, NH and Mt. Katahdin, ME. These ecosystems will serve as biomonitoring parameters for plant community responses to climate change.

Pauli, Harald; Gottfried, Michael; Hohenwallner, Danada; Hulber, Karl; Reiter, Karl; Grabherr, Georg. 2001. Gloria: Global Observation Research Initiative in Alpine Environments; Multi-Summit Approach Field Manual, 3rd Ed. Institute of Ecology and Conservation Biology. University of Vienna, Austria.

-A field manual to participate in the global multi-summit alpine research initiative. Contains information about why to study alpine vegetation to detect climate change and how-to produce results from study areas and other information to create a global study that is used using the same format.

Pauli, Harald., Gottfried, Michael., Grabherr, Goerg. 1996. Effects of Climate Change on Mountian Ecosystems – Upward Shifting of Alpine Plants. World Resource Review 8(3): 382-390.

-Another paper in which reinstates that due to climate change alpine plant species will migrate upwards in elevation. This in fact may restrict alpine plant communities into extinction. Data on alpine plant species composition and richness were collected in the European Alps and were compared the results with historical records from the same peaks. Evidence was found in which supports the upwards shift in alpine vegetation.

Slack, N.G., and Bell, A.W. (1993) 85 Acres; A Field Guide to the Adirondack Alpine Summits. Lake George: Adirondack Mountain Club.

Field guide to the alpine zone of the Adirondack Mountains. Primarily within the Adirondack High Peaks region that consists of 85 acres of alpine tundra. Contains detailed photos of vegetation including lichens, mosses and other species.

________________________. (1995) Field Guide to the New England Alpine Summits. Boston: Appalachian Mountain Club.

Field guide to the alpine flora, geology, and climate of New England's alpine zone. Detailed photos are complemented with descriptions and ecological implications of each species as well as a brief natural history of this ecosystem.

Zwinger, A.H., & Willard, B.E. (1972) Land Above The Trees: A Guide to American Alpine Tundra. New York: Harper & Row.

Field guide to the alpine tundra of America. Includes detailed information on each of the major alpine regions including the northeastern mountains. Preceding the regional information is information on morphological and physiological adaptations of alpine species responding to their environment.

**Project Budget**
(as of 4/14/2003)

| | |
|---|---|
| 1. Four rolls of Fuji ISO 400 color film – photo documentation | [$ ~16 ] |
| Film Development | [$ ~24 ] |
| 2. Waterproof field book | [$ ~10 ] |
| 3. Clinometer (college or AMC supplied) | [$------ ] |
| Total | $50 |

**Project Participants**

- Ryan Harvey, Paul Smith's College Natural Resources; Management & Policy program. Looking back I have been fascinated with the alpine zone since my first climb into this unique ecosystem. I have frequented almost every alpine summit throughout the northeastern U.S., except for the Mt. Katahdin massif in Maine. Due to this interest I have personally researched the natural history of these communities as well as become familiar in identifying almost all the alpine species on site. As well as for personal enjoyment I have applied this knowledge into a naturalist / interpreter position atop Mt. Greylock, a sub-alpine peak in northwestern Massachusetts dring the summer of 2002. Greylock being the highest mountain in the state at 3,491 ft., it was representative of the typical forest biomes of the northern mountains of the northeast with few alpine species. I have incorporated acid deposition and sub-alpine ecology programs educating visitors as well as staff. With the knowledge of air pollution and the question of global warming I have often wondered how this would affect the northeastern U.S. alpine zone.

- Mentor: Georgia Murray, staff scientist in the Research Department of the Appalachian Mountain Club (AMC). Working out of Pinkham Notch at the base of Mt. Washington, New Hampshire. Georgia works in the alpine zone of the White Mountains primarily Mt. Washington and the Presidential Range. She is currently implementing a program at the AMC operated backcountry huts that will establish an observational alpine vegetation monitoring program examining changes in phenology while simultaneously monitoring climate. Lakes-of-the-Clouds and Madison Hut are located in the Presidential Range of the White Mountains. These huts are within the alpine zone. I will be volunteering in this program with Georgia throughout the late spring and summer 2003.