Warming, Vegetation, & Remote Sensing:

The Use of NDVI to Track the Influence of Climate Change on Arctic and Alpine Plant Communities

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Abstract

The influence of climate change on earth systems as well as social and cultural systems is a pressing topic in many disciplines in the world today. The response of vegetation to climate change can alter biodiversity, land conservation, and human health. I frame this research by asking *what effect will climate change have on plant communities around the world?* The Arctic is warming at a faster rate compared to the rest of the world and vegetation there can be used as a signal for a changing climate. Arctic vegetation also appears in the alpine zone of the White Mountains, New Hampshire and are bio-remnants of the last glacial period. In this research I ask, how will climate change alter arctic communities in Ísafjörður, Iceland and alpine communities in the White Mountains, New Hampshire? I used Normalized Difference Vegetation Index (NDVI) data, collected by satellites, to track climate responses at a global scale. I supported these findings with species observations in survey plots around two mountain tops in the White Mountains with alpine vegetation and one hillside in Iceland, with arctic vegetation. From this data I found that although there a similarities in species composition in these two locations, climate change will affect them in different way. This is due to a number of factors including anticipated changes in climate at the local scale, land management style, and microclimatic conditions. Collectively this research suggests that effects of climate warming on plants are not homogeneous across latitudes or altitude and local management should be applied to support species conservation a the regional scale.

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1.0 Background

1.1 Climate Change

The influence of climate change on earth systems as well as social and cultural systems is a pressing topic in many disciplines in the world today. The IPCC (2014) has suggested that the major source of climate change is from anthropogenic greenhouse gases produced by burning fossil fuels. The amount of carbon dioxide in the atmosphere has almost twice that of pre-industrial levels and changes in local climates and behavior of plants and animals has been noticed by scientists and everyday citizens. Without harnessing CO2 emissions as well as CH4, the average temperature will continue to rise. Every continent, not including Antarctica, has observed an increase in mean surface temperature, and anthropogenic forcings have contributed to this rise (IPCC 2014). The IPCC predicts an increase in warm air temperatures and more frequent precipitation on top of increased CO2 in the atmosphere (IPCC 2014). There is a medium confidence that the global mean surface temperature for the period 2016-2035 will change and rise in the range of 0.3 °C to 0.7 °C (assuming there would be no major volcanic eruptions or changes in natural sources of CH4 and N2O).

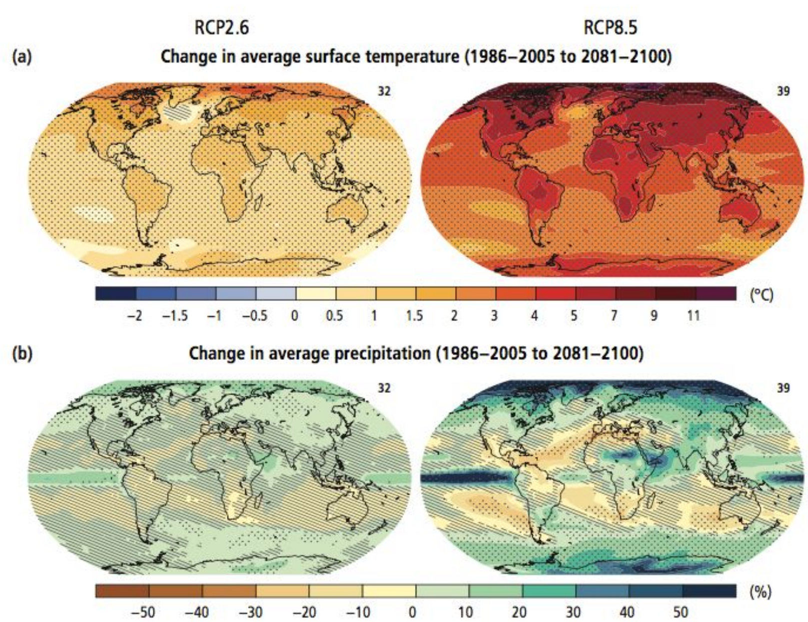


Figure 1: (a) Change in average surface temperature and (b) change in average precipitation (IPCC 2014)

The global surface temperature is expected to rise towards the end of the 21st century and exceed 1.5 °C (IPCC 2014). It is virtually certain that there will be more frequent hot and fewer cold temperature extremes over most land areas on daily and seasonal timescales, as global mean surface temperature increases (IPCC 2014). This can have a drastic effect on vegetation, land conservation, and human lives. Many scholars have been interested in the effect of climate change on vegetation and Bordeaux (2004) asks, can we expect life to evolve or adapt rapidly to changing climate conditions? Bertin (2008) has noticed a change in plant distribution due to warming in several areas, especially Scandinavia and Mediterranean Europe, though reactions vary depending on the location. Shifts in vegetation are not dictated by surface temperature along, changes in precipitation and slow cover have shown to have a big effect on species (Kelly 2008).

1.2 Framing Question & Thesis Statement

Here, I ask, what effect will climate change have on plant communities around the world? I will address this question in the context of the White Mountain National Forest, New Hampshire as a representative of alpine vegetation and Ísafjürður, Iceland to represent arctic vegetation. These two vegetation communities, while sharing similarities in species composition, have different responses to climate change. This is due to land management styles, predicted changes to climate, as well as microclimatic conditions at the local scale.

1.3 Phenology

Plants and their annual growth cycles and patterns are a valuable resource indicating climate change. Phenology is the study of cyclic natural phenomena and generally relates climate to plant and animal life (Forrest & Miller-Rushing 2010). Phenological observations are sensitive data establishing how plants are responding to regional climate conditions and climate change (Chmielewski & Rötzer

2001). Phenology is a way to study the relationship between climate and life. Phenology of plants is a direct result of the cues associated with changing climate conditions. There are two mechanisms responsible for phenological changes in a species. First, phenotypic plasticity, which is the change in individual acclimation to short-term changes in weather (Chmielewski & Rötzer 2001). Phenotypic plasticity is reversible in the species (Chmielewski & Rötzer 2001). The second is evolution, in which whole species change gene frequencies between generations to cope with long-term changes in climate (Chmielewski & Rötzer 2001). A large fraction of plant species may face extinction from extreme changes in climate, especially as climate change acts with other stressors. There is high confidence that most species cannot naturally shift their geographical location or evolve at the current rate and the projected rates of climate change in order to (IPCC 2014). The general shift toward rising temperatures globally is leading to an increased urgency to understand the vegetation-climate interactions across several biomes.

There are several types of phenological observations that can be made by a researcher: species-level, ecosystem- and global-scale phenology through satellite data, and carbon dioxide measurement via satellites. Phenological shifts have been widely documented using satellite data since the 1980's and 1990's, as well as longer-term species-level observations. Using remote sensing as a method to track climate change has the potential to be a great source of data collection, but being a relatively new form of climate tracking, it cannot support any paleoclimate records. One indicator of the green vegetation that is collected via satellites and is related to vegetation growth status is Normalized Difference Vegetation Index (NDVI).

1.4 Normalized Difference Vegetation Index

Normalized Difference Vegetation Index serves as a strong proxy for gross photosynthesis (Goetz et al. 2005) and is a useful tool for the assessment of vegetation health and productivity (van Leeuwen et al. 2006). NDVI is influenced by two major factors of global change: (i) regional weather or climate dynamics and (ii) direct land-cover changes (Detsch et al. 2016).

$$NDVI = (NIR - RED)/(NIR + RED)$$

NDVI values, from -1 to 1, show the differences in the reflection between the red and near-infrared portions of the spectrum. The variety in the difference of reflection is characteristic of many kinds of land cover categories, such as dense vegetation, sparsely vegetated and bare surface. NDVI has become one of the most common indices used to study vegetation phenology via remote sensing (Zeng et al. 2013).

2.0 Situated Context

Tundra vegetation is relatively slow-growing and reproduction is highly variable and dependent on climatic conditions. The tundra and arctic plant species have been known as the “bellwether” of changes in the weather and climate. Like a sheep wearing a bell, from which the term came from, led to signal danger, these species are the first to signal changes in the climate (Kimball 2014). Tundra vegetation affects ecosystem processes, services and climatic regulation of scales ranging from the local to the global. Therefore, climate-induced changes in tundra vegetation could have wide-ranging consequences. For example, plant composition directly influences nitrogen cycling, productivity and decomposition, active layer depth in the soil, forage quantity and quality, snow distribution and surface albedo (Elmendorf et al. 2011). On a local scale, shifts in vegetation are expected to substantially alter key resources, such as medicinal plants and faunal biodiversity, with strong ramifications for subsistence harvest, ecotourism and local livelihoods.

The photosynthetic capacity of arctic vegetation, as measured from satellites using the NDVI, has increased over the last 20 years. This trend has been attributed to an increase in shrubs and a longer growing season (Bhatt et al. 2010). Changes of Max-NDVI in northern Alaska and the Beaufort sea region are the largest in the Arctic and are likely linked to the strong retreat of sea ice in this region and changes in erect shrub production (Bhatt et al. 2010). In these sparsely vegetated ecosystems, the NDVI changes are most likely a result of greater plant density. Places that are close to sea ice or land ice throughout the year will see a larger change in NDVI if these sources of ice melt due to warming (Bhatt et al. 2010).

2.1 Justification of Comparison

Here I will be using Iceland and the White Mountains, NH to provide a unique comparison of alpine and arctic plant species. In the White Mountains, the regional atmospheric mixing layer, also known as the atmospheric boundary layer, is typically 3,500 feet to 5,000 feet. The region is made up of mountains that are under 5,000 feet with a few exceptions. Six summits are in between 5,000 and 6,000 feet and one summit is above 6,000 feet. This means that these peaks are in the "free atmosphere" which, according to Siedel et al. (2009), is a likely explanation for similarities in species makeup between New Hampshire alpine species and Arctic tundra species. These biogeographical islands are results from the last glacial period. Ísafjörður, Iceland, because it is at sea level, is within the atmospheric mixing layer, so it could be expected to see heterogeneous changes between the species in this location due to climate warming. The Presidential Range in New Hampshire has approximately 70 alpine species, nearly all of which also occur in the arctic (Bliss 1962). Although the flora are small, it is decidedly more arctic floristically than the alpine flora of the western mountains. The alpine environment in New Hampshire is more like that found in Labrador and Alaska than that in the western alpine areas (Bliss 1962). The Presidential Range in New Hampshire holds about 34 square kilometers of continuous alpine. This is the largest amount of alpine in the Northeast. There are other smaller areas of alpine zone, like Franconia Ridge, Mt. Guyot, and Mt. Moosilauke. The Presidential Range have a higher affinity to the arctic than to other alpine zones in the Continental US. (Hadley and Bliss 1964). Iceland has been included in some classification of the arctic and sometimes it has not. It's an interesting case because it is a northern island but it is surrounded by the North Atlantic Deep Water Formation (NADWF), where the ocean released heat brought by the Gulf Stream from the equator. This makes Iceland have both boreal forest and tundra vegetation communities. Climate warming is not synchronous across all altitudes, landscape, or latitudes. To establish a better understanding of the effects of climate change on the vegetation cover in the White Mountain National Forest, NH and in Iceland, baseline research about plant species distribution would be needed. In this research I ask, how will climate change alter arctic communities in Ísafjörður, Iceland and alpine communities in the White Mountains, New Hampshire?

2.2 Ísafjörður, Iceland

At roughly 65°N, Iceland is part of the Palearctic Boreal ecoregion, a major ecosystem defined by distinctive geography and receiving uniform solar radiation and moisture. It is only partially covered with vegetation, the rest being bare rock, snow, or ice. Iceland has a relatively mild coastal climate due to the effect of the NADWF and precipitation ranges anywhere from 400 to 1,000 mm/year. High winds and precipitation lead to rapid erosion of soil and coastline, which hosts a large diversity of migratory birds, who need the vegetation to support themselves. Iceland's dynamic landscape is due to variations in altitude, proximity to volcanoes or glaciers, and effects of agricultural or industrial land use changes (Raynolds et al. 2015). The Westfjords, the Northwest peninsula of Iceland makes up one-third of Iceland's coastline due to the abundance of fjords, while only making up only a fifth of Iceland's surface area. The Westfjords also hosts 2% of Iceland's population. Coastal communities in Iceland, like Ísafjörður, are milder than other coastal arctic communities. The moist and warmer air allows places like Ísafjörður to host a variety of plant species, many rare and only appearing in this part of Iceland.

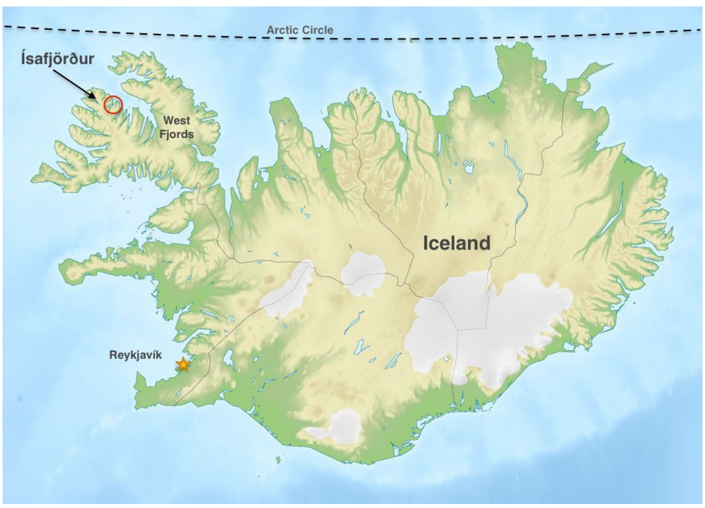


Figure 2: Map of Iceland

2.3 New Hampshire

In contrast, the White Mountains National Forest in New Hampshire, at 44°N, is part of the Northern Mixedwood forest of North America which is generally temperate with clear seasons. The majority of the White Mountain National Forest is covered in vegetation ranging from northern hardwood-conifer, high elevation spruce-fir, and alpine ecoregions. The White Mountains feature hundreds of trails leading to mountain peaks over 4,000 ft and hold a rich history of land use dating back to the colonialism. The White Mountain alpine region covers 50 square kilometers in New Hampshire and Maine. Mid-latitude alpine ecosystems are typically characterized by short growing season, and alpine areas in New England are geographically distant from their glacial origin and tundra range (Kimball 2014). There is a particularly special connection between the Arctic tundra plant species and the alpine species found in New Hampshire. According to Seidel et al. (2009), the northeast U.S. alpine communities are remnant biogeographic islands from the last glacial period (roughly 100,000 to 11,000 years ago). These communities are similar to those in northern latitudes across the world. This specific characteristic of the White Mountains is the motivation of researching how climate change could affect the vegetation cover in the White Mountain National Forest and in Iceland.

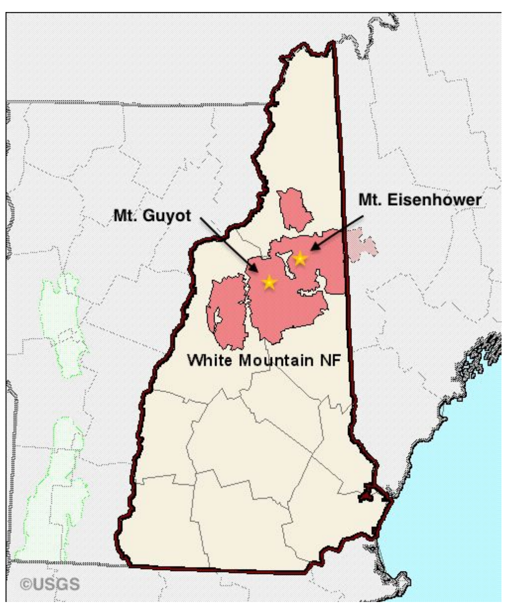


Figure 3: Map of The White Mountain National Forest, New Hampshire, USA

3.0 Methodology

My methodology to analyze the effect of climate change on vegetation in the alpine areas of New hampshire and the arctic vegetation in Iceland consists of two parts. The first parts is a larger scale view of arctic plant communities. I will use Normalized Difference Vegetation Index (NDVI) to compare my situated context to broader bioregions, like the Arctic as a whole, and continuous alpine regions in the continental United States. The second part is a species-level overview of how different possibilities and scenarios of climate change act as a drive for change in a species phenotype. I expect that NDVI as well as species-level observations will tell the same story at different scales.

3.1 NDVI

Normalized Difference Vegetation Index (NDVI) is getting more and more popular to look at changes in plant communities as an effect of climate change. Considering climate is measured as a 30-year average, collecting data from Moderate Resolution Imaging Spectroradiometer (MODIS) or other remote sensing satellites is a relatively new method to collect climate impact data.

Advanced Very High-Resolution Radiometer (AVHRR) tends to gather coarse, large-scale data, which dilutes small-scale NDVI changes. In ecosystems that are more diverse, identifying problem areas would be a challenge because a heterogeneous landscape would appear more homogenous in the data collected. On the other hand, AVHRR has more temporal coverage because it has been used since the 1980's. More modern sensors have a higher resolution but do not have vast temporal coverage as AVHRR does. Zeng et al. (2013) compared the SOS (start of the growing season), EOS (end of the growing season), and LOS (length of season) between several satellites spectrometers. Zeng et al. (2013) analyzed and compared Normalized Difference Vegetation Index (NDVI) time series derived from the AVHRR, MODIS, and SPOT-Vegetation (VGT) during the decade 2000–2010. The results of the study concluded that MODIS and VGT data were considered to be preferred data for monitoring vegetation phenology in northern high latitudes. Tundra vegetation is considered sensitive to climate change while simultaneously serving as important rangelands for people and their reindeer or sheep herds.

Previous studies on Arctic vegetation phenology have been mostly based on single satellite time series, i.e. AVHRR at 8 km spatial resolution which leaves major uncertainties due to the resolution (Zeng et al. 2013, Guay et al. 2014). There have been a few comparative studies of arctic and alpine populations of the similar species (Hadley & Bliss 1964) and the findings were quite similar across several studies. Many findings including arctic plants having a lower photosynthetic light saturation points, higher rates of respiration at all temperatures, and attainment of maximum photosynthetic rates at lower temperatures. This could lead to differences in the NDVI of alpine or arctic regions. It can be generalized that arctic species would have a lower NDVI than alpine species because alpine species are at a higher latitude and do not receive the same amount of direct sunlight that lower latitude plants, any elevation, would receive.

3.2 Species-Level data collection

Virtanen, Eskelinen, & Gaare (2003) repeated the methodology of a study that was 70 years old to see if plants on mountainsides in Norway and Finland have changed their location as a result of warming. Their research sites were chosen randomly and used to calculate the percent coverage of a plant in a small quadrat. The research sites were picked because of the lack of human impact. It is not stated why randomly choosing their data sites is preferable, but the lack of human impact in these sites may have contributed to this decision.

Along with long-scale data collection, researchers have also used experimental warming to speed up the process. Within 5-10 years, researchers have noticed reactions in several species reaction to warming, including earlier flowering times, longer root systems, or inability to withstand warming and dying (Thórhallsdóttir 1998; Virtanen, Eskelinen, & Gaare, 2003; Ylanne, Stark, & Tolvanen 2015). Others have found resistance to warming and no changes in plants to experimental warming (Einar 2002; Llorens & Penuelas 2005; Wasowicz, Pasierbinski, Przedpełska-Wasowicz, Kristinsson 2014).

Results of short term (under 6 years) studies come with the concern because the ultimate goal of climate change experimentation is to forecast the long-term effects of climate warming over a wide region (Elmendorf et al. 2011).

3.3 Ground Truthing

The species-level overview acts as a form of scientific ground truthing for satellite data. NDVI time series show, in a coarse resolution, the seasonal activity of vegetation communities, while phenological studies generally confirm findings through remote sensing by noting similar shifts in phenological phases (Manzel 2002). Using conventional observations as well as satellite-derived measurements is needed to understand spring onsets of photosynthesis, also known as “green wave” or “green up.” The challenge with comparing phenological trends with satellite-derived data is that the satellite “Spring Green Wave” represents species-averages information over large and diverse spatial and temporal scales (Schwartz 1998). Knowing how species are going to react to climate warming through experiments and researcher observation will give us a more robust prediction of how plants will respond to future environmental change. Using NDVI, it’s possible to differentiate forest vs grassland, but NDVI cannot highlight the difference between species assemblages of species produce the same NDVI. The species-level observation acts as a supporting system to get a large-scale view of plant communities that NDVI would produce.

4.0 Procedure

4.1 NDVI

For analyzing the White Mountains in New Hampshire, I downloaded data from USGS data collection, EarthExplorer. From there I downloaded eMODIS NDVI data for the middle of July. The data came in composite values for 7 to 10-days and ranged from July 14 to July 25th. The data only extends back to 2000 and is therefore not representative to attribute any major changes as an effect of climate change, which is normally a 30-year average. Each data set delivers acquisition, quality and Normalized Difference Vegetation Index (NDVI) information at 250-meter (m) spatial resolution.

I also downloaded an NDVI trend map from 1982-2012 which are derived from the Advanced Very High-Resolution Radiometer AVHRR on the NOAA satellite. The NDVI data, which show vegetation activity, were averaged annually for the Arctic growing season (GS; June, July, and August) and has a resolution of 8 kilometers (Guay et al. 2014). I also used NOAA CDR NDVI data found on Earth Explorer. While the full data set from NOAA spans from 1981 in 10-day averages, data on Iceland was only available from 2011-2013. Lastly, I reviewed NDVI maps created in past studies in order to get an accurate representation of Iceland.

4.2 Species-Level

Field observations and surveys in Iceland were taken in October 2016 and field surveys in the White Mountains, NH were taken in July 2017. While the phenological phase of species may differ between the months of July and October, the abundance of species would not have changed. Every 10 meters along a hiking trail at the respective locations of Naustahvilft Valley in Iceland, Mt. Guyot and Mt. Eisenhower in New Hampshire, I recorded the coordinates. These mountain tops were chosen due mainly to accessibility to me. Naustahvilft Valley is a hanging valley in the fjord where Ísafjörður is located.

Figure 4: Ísafjörður, Iceland (left) looking at the troll seat/study area, (Right) looking at Ísafjörður from the summit of the troll seat.

Mt. Guyot is just above 4,000 feet tall and located in the Pemigewassett region of the Whites and borders the Pemigewasset Wilderness. Mt. Guyot is about seven miles from any road and is completely in the alpine zone even though the closest mountains over 4,000 feet are not above treeline. This aspect of Mt. Guyot makes it unique and was one of the reasons was I was interested in studying it.

Figure 5: White Mountains, NH, (left) Mt. Guyot from the summit looking South, (right) Mt. Guyot looking toward the summit

Mt. Eisenhower is part of the Presidential Range in the White Mountains and is relatively close to Mt. Washington the tallest mountain in the Northeast at 6,288 ft. Mt. Eisenhower is at the edge of the largest continuous section of alpine zone in new England, which is about 34 square kilometers, and is roughly 4 miles up the Edman's Path, the oldest maintained trail in the White Mountains.

Figure 6: White Mountains, NH, Mt. Eisenhower summit looking West.

At each location, I walked 10 meters to the right and left, perpendicular to the trail, recorded the coordinates and identified plant species in a 1mx1m plot. I chose to hike off the trail to prevent human impacts on the species. Some species, like the alpine krummholz and diapensia in New Hampshire, take several years to grow a small amount and trampling can have a large effect, so collecting plant samples farther away from the trail will minimize human impact.

In Iceland, plants were identified using the guide Flowering Plants and Ferns of Iceland by, Hördur Kristinsson (2013). In New Hampshire, At timberline: a nature guide to the mountains of the northeast by, Frederic L. Steele (1984) was the best guide to use based on the descriptions and drawings for identification. Using ArcGIS I mapped out my plots based on coordinates.

5.0 Results

Here, I will share the results of NDVI data analysis from a large scale context of the Arctic to smaller contexts of the White Mountains and Iceland. By using NDVI data from multiple scales, a link is created connecting the effects of climate change on small plant communities as well as changes in ecosystems that are observed across the globe. Then from the results of the survey plots, a closer look at the effect of climate change on individual species can help inform predictions of large scale patterns.

5.1 NDVI

5.1.1 The Arctic

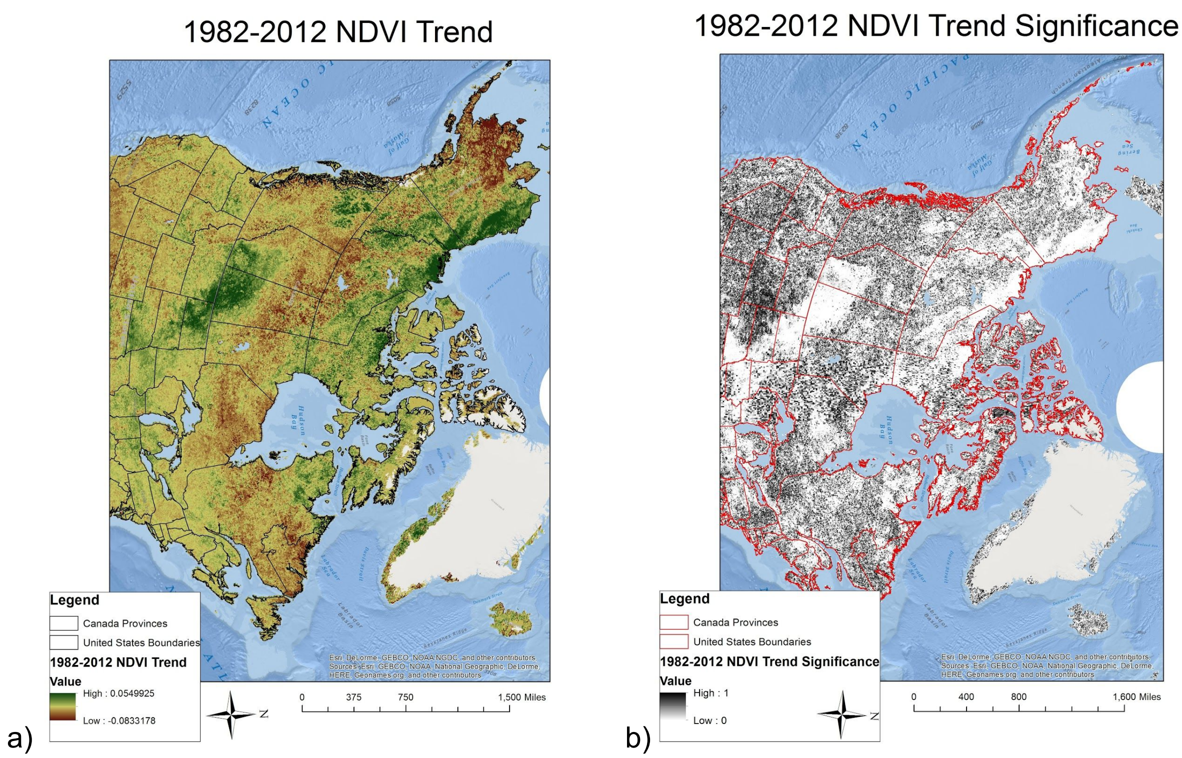


Figure 7: a) NDVI trend from 1982-2012- North America. b) NDVI trend (1982-2012) significance- North America (Guey et al. 2013)

Figure 7 looked at Northern North America. Some patterns here are a high NDVI trend in Northern Canada and Alaska along with a high NDVI trend in the plain regions of the Northern US and Southern Canada. I also see a band of lower NDVI in central Canada and at the western shore and mountains in Alaska. The high NDVI trend in northern Canada includes the mouth of the Mackenzie River, and this region is generally pretty flat. If you look at Greenland, there is high NDVI trend on the west coast, but a patch of low NDVI on the east coast. Because there is a large resolution in this data, it is challenging to pick out individual Fjords in Greenland. There are so many fjords that are smaller it couldn't be captured in the NDVI trend data, so the 8 km resolution includes both ocean and land.The biggest similarities I see between this significance map (Figure 7b) and the NDVI data of the same region (Figure 7a) is that a lot of the places with a high NDVI also have a low significance, and vice versa. This can be seen in Northern Canada, and the plain regions of the US and in Canada. It's a little hard to make out the significance in the Greenland because the ice sheet is colored white as well as the places that are labeled with a low significance.

5.1.2 New Hampshire

The following NDVI maps are from a dataset and paper called Long-Term Arctic Growing Season NDVI Trends from GIMMS 3g, 1982-2012 (Guey et al. 2013). Figure 8a shows the NDVI trend from 1982-2012 with an 8 square km resolution. It is in a circumpolar projection, which supports the size and shape of land in the arctic. Note that the state of New Hampshire and most of New England have no distinct patches of changes. Everything is roughly the same color which indicates no change, so, statewide, there is not a large enough trend in the change in NDVI. There are some areas in New York which is showing a decreasing trend in NDVI. The coasts are also showing large variations in NDVI trend, but this may be because of the tides or the impact of humans and waste disposal. Though, as you can see in Figure 8b, the significance of these changes varies from high statistical significance to low significance.

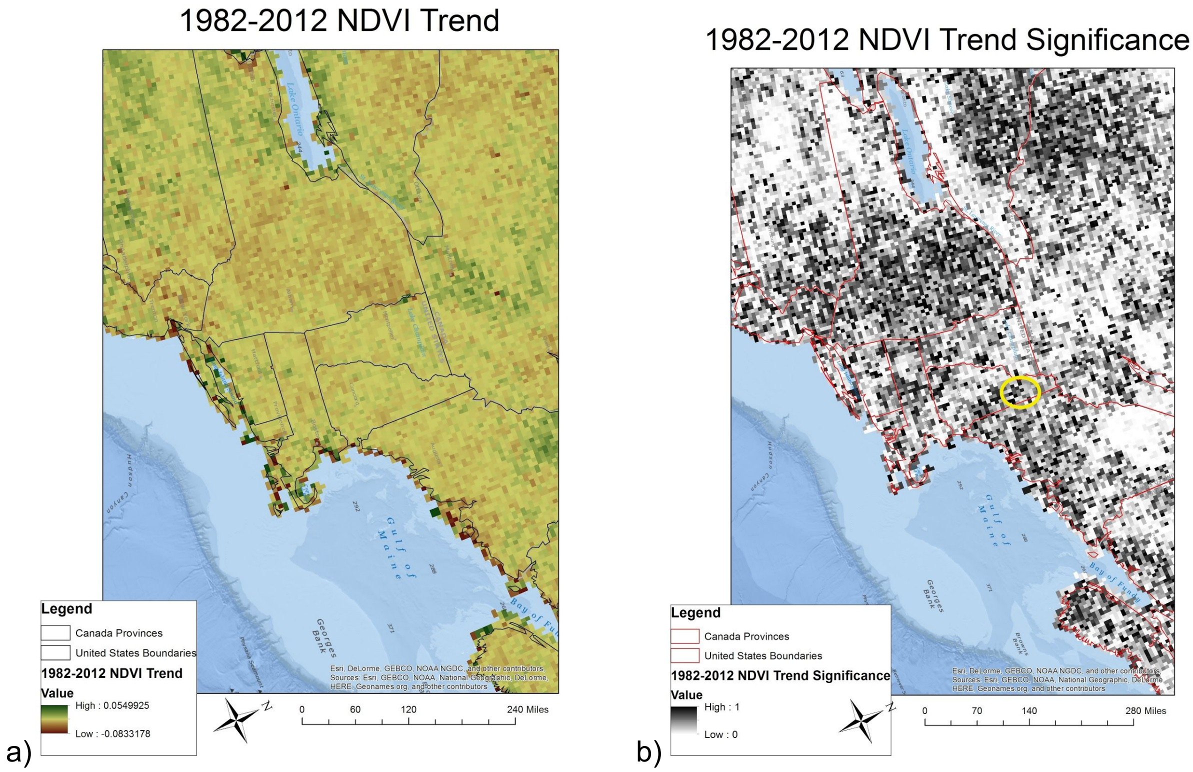
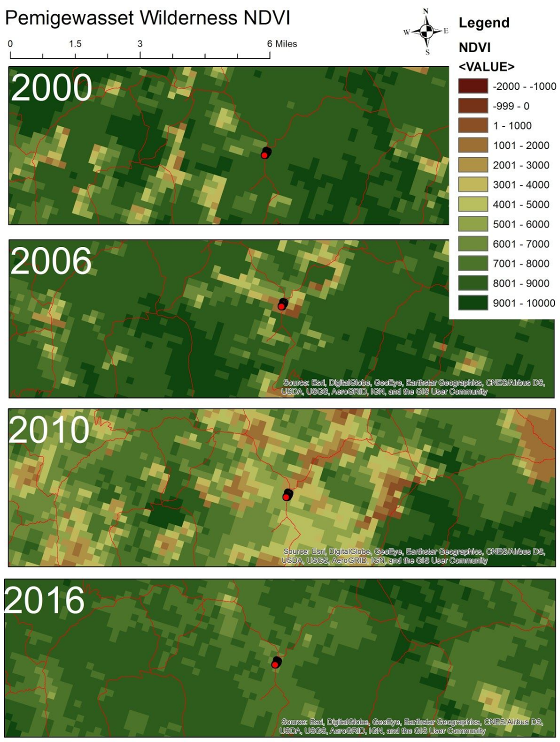
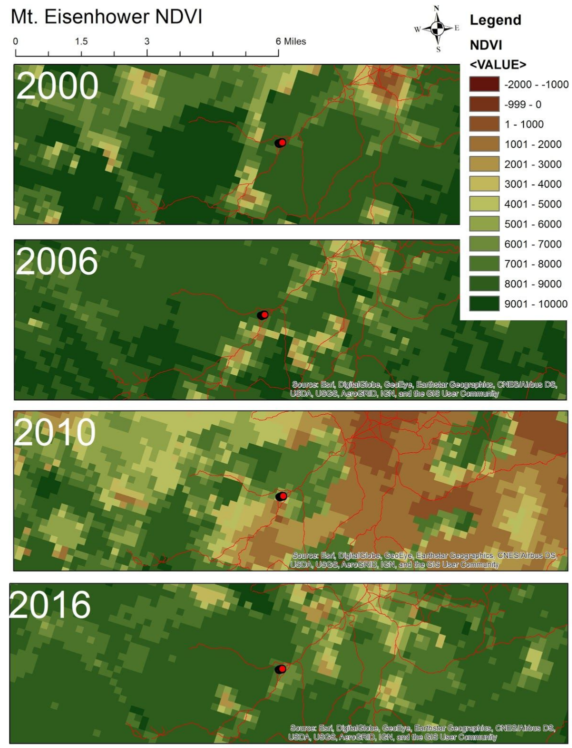


Figure 8: a) NDVI trend from 1982-2012- New England. b) NDVI trend (1982-2012) significance- New England (Guey et al. 2013)

Figure 8 shows the significance of each 8 km square in the 1982-2012 NDVI Trend data. New England looks very patchy, there doesn't seem to be a trend between parts of New England that are more significant than others. Since I am interested in the White Mountains, looking closely at that area (which is marked by the yellow circle), I see a higher significance. The White Mountains are north-middle New Hampshire, the part that is showing a higher significance. Looking closely at low resolution NDVI data has posed a challenge of finding trends at the smaller scale. More accurate trends can be derived by looking at North America as a whole. Figure 7 shows almost no change in NDVI trend for the New England area.



a)



b)

Figure 9: NDVI New Hampshire, 10-day average of July 15-25 for years 2000, 2006, 2010, & 2016. a) Shows the Pemigewasset Wilderness, where the red dot represents Mt. Guyot. b) shows part of the Presidential Range, with the red dot representing Mt. Eisenhower

Projected in Figure 9a and 9b is the NDVI for a the Pemigewasset Wilderness and for the Mt. Eisenhower region in the White Mountains, NH. The red dot in either map show where the plant surveys were taken during the summer of 2017. While some of the negative NDVI pixels are due to the sparse vegetation cover, precipitation has proven to be an important factor in plant growth and productivity. From this map, the vegetation growth and productivity has a negative trend in 2010. Though, this may not be an indicator of climate change but rather other annual weather effects, like drought or low precipitation. Vegetation growth heavily relies on the amount of precipitation in an area. This can be seen in both case studies in the White Mountain National Forest.

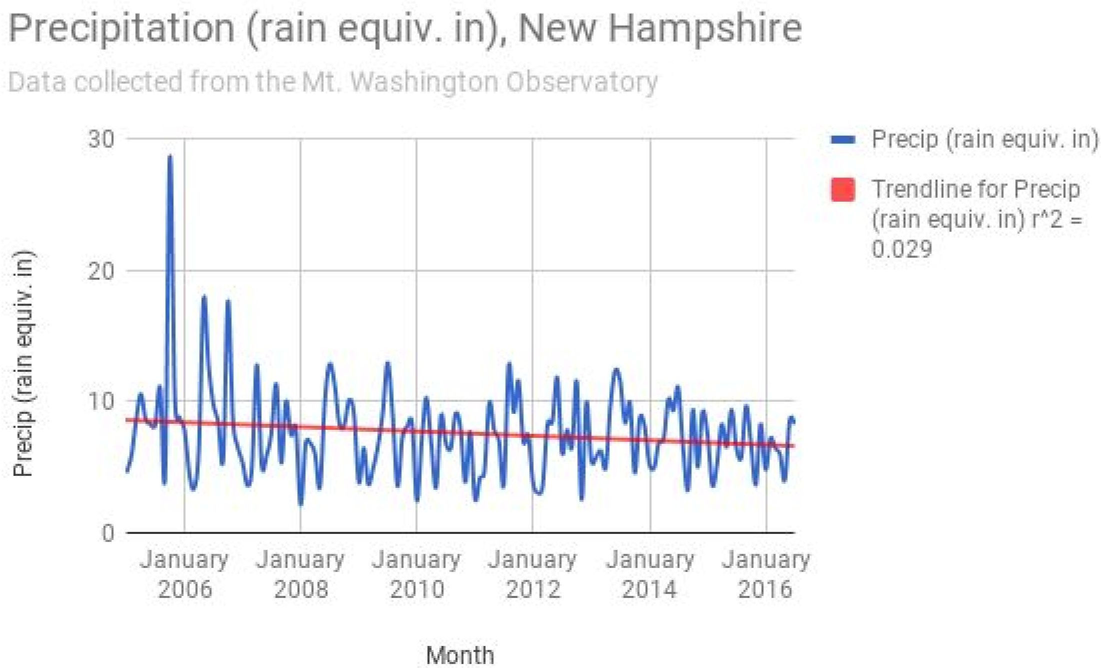


Figure 10: Annual precipitation 2005-2017, White Mountains, New Hampshire, data from the Mt. Washington observatory.

Figure 10 is a annual precipitation map from the year 2005-2016. As you can see from the trend line, in this decade, there has been a decrease in annual precipitation. In October 2005, there was an anomalous storm that caused record-breaking flooding in New Hampshire, which received about 28 inches. Looking closely at the years 2009-2011 and 2015-2017, there seems to be more fluctuation in precipitation between 2009-2011 than in 2015-2017. When looking at the NDVI projection in Figure 9a and 9b the year 2016 has a noticeably higher NDVI than 2010. This may be a result of more continuous precipitation rather than larger fluctuations.

5.1.3 Iceland

Figure 11 shows the trend in Iceland of NDVI data from 1982-2012. In this map, there is a mixture of high and low trends. Some of the highlands (central Iceland) are showing an increase of NDVI, while the coasts are also showing a mix of high and low trends.

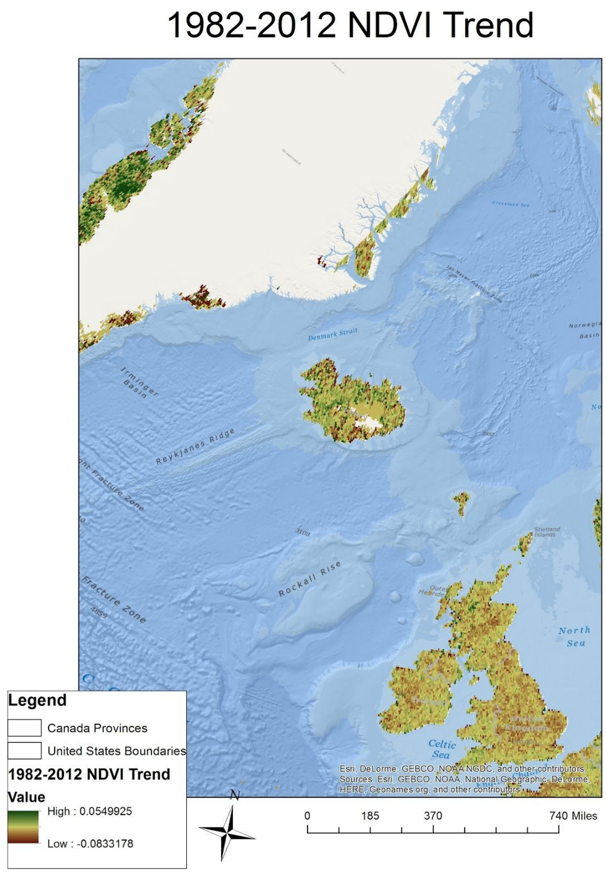


Figure 11: The NDVI trend 1982-2012- Iceland (Guey et al. 2013)

In Figure 12, the mean NDVI data for July in Iceland. Something to take note of is the data that is projected over known glaciers, like Vantajökll, in these parts of Iceland there is no vegetation, so there should be no vegetation change in the maps above. The central highlands, which is central iceland has very sparse vegetation cover, while on the hills of fjords, there is expected to be more vegetation. This is seen here. The coastline appears to have low NDVI, while this is true on sandy or rocky beaches, this very low NDVI can also be an effect of the ocean, which has low NDVI in all data.

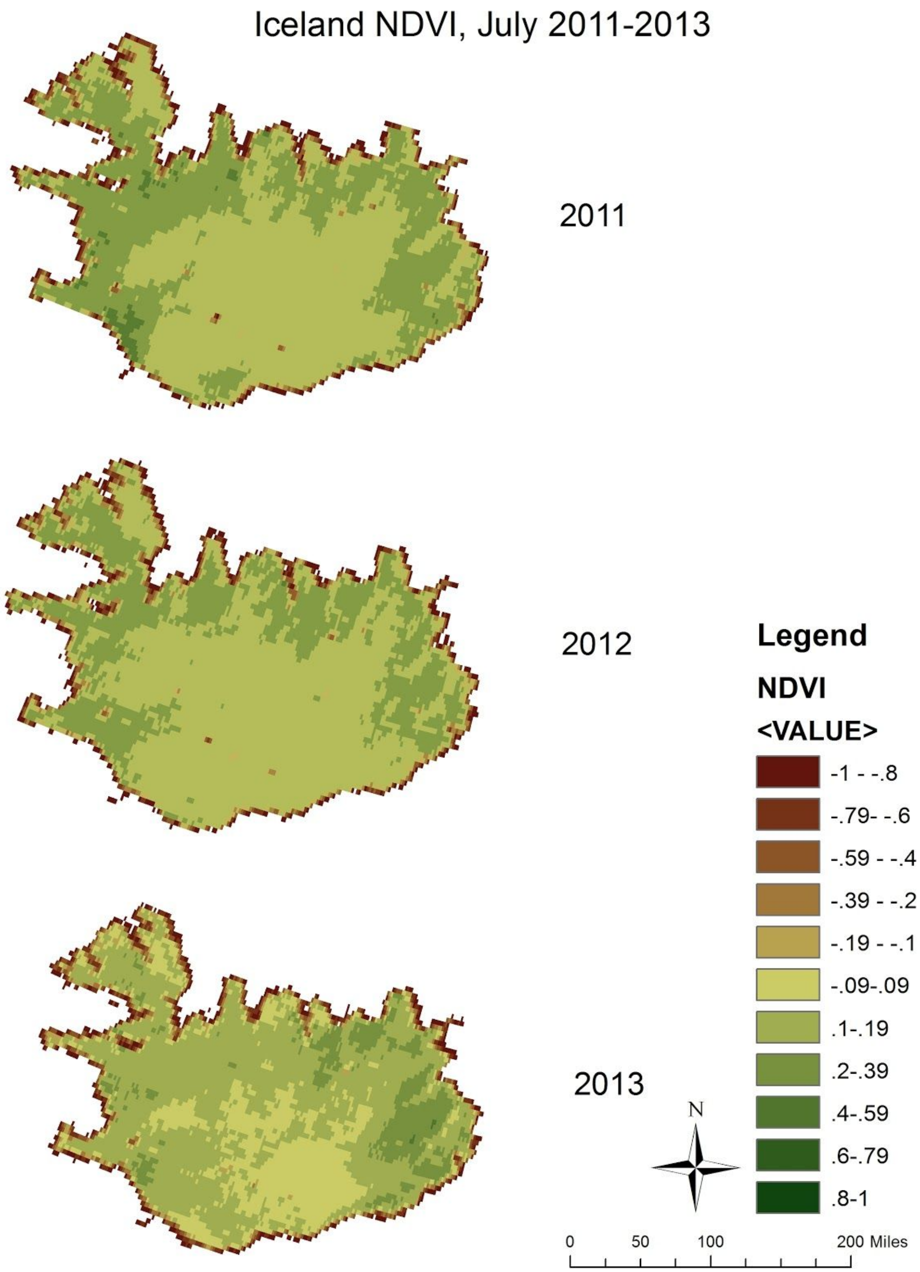


Figure 12: Mean NDVI July in 2011, 2012, and 2013- Iceland

Over the course of three years, there is a slight negative trend of NDVI around the coasts of Iceland. In 2011, the east side of Iceland is noticeably greener than the west side, and this can be seen in Figure 12 as well as 13.

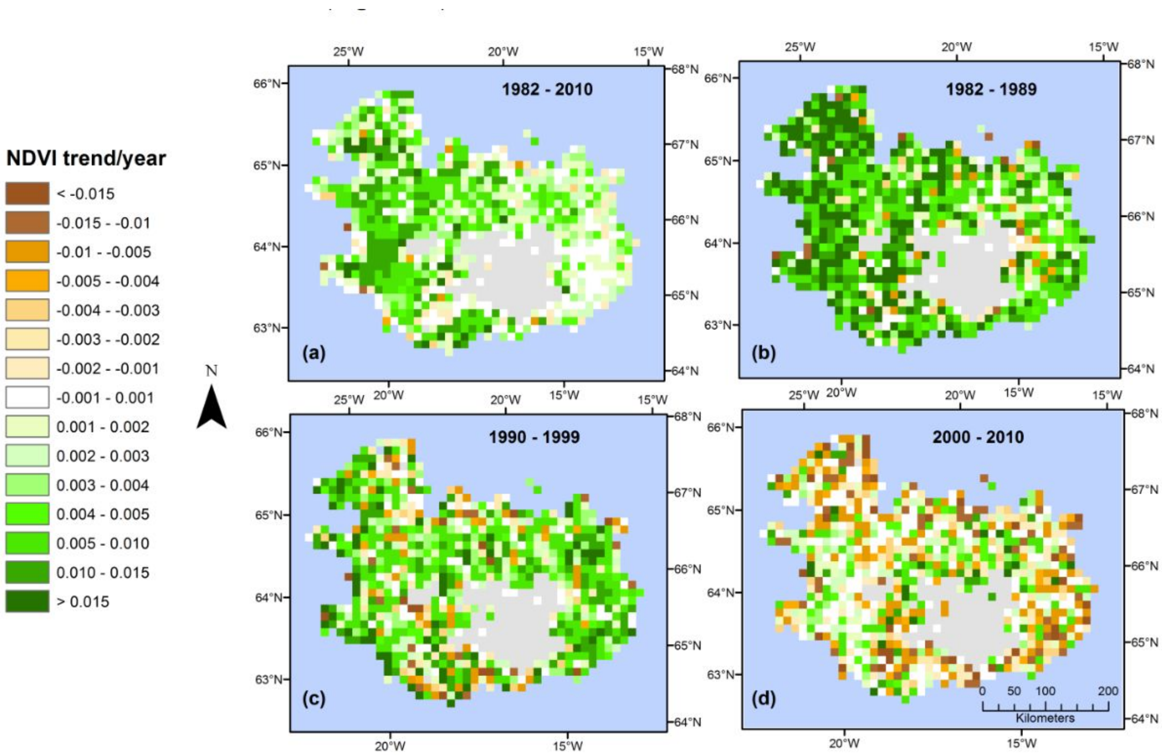


Figure 13: From Raynolds (2015) Iceland trend in maximum annual NDVI (GIMMS NDVI3g, Theil-Sen robust regression) for (a) the full record 1982–2010; (b) the first (partial) decade 1982–1989; (c) the second decade 1990–1999; (d) and the third decade 2000–2010.

Raynolds (2015) in her paper, *Warming, Sheep and Volcanoes: Land Cover Changes in Iceland Evident in Satellite NDVI Trends*, found that the annual NDVI increased for most areas of Iceland during the last three decades. NDVI trends were mostly positive in the 1980’s, a few areas shows some negative trends in the 1990’s, and trends were mostly negative in the 2000’s.

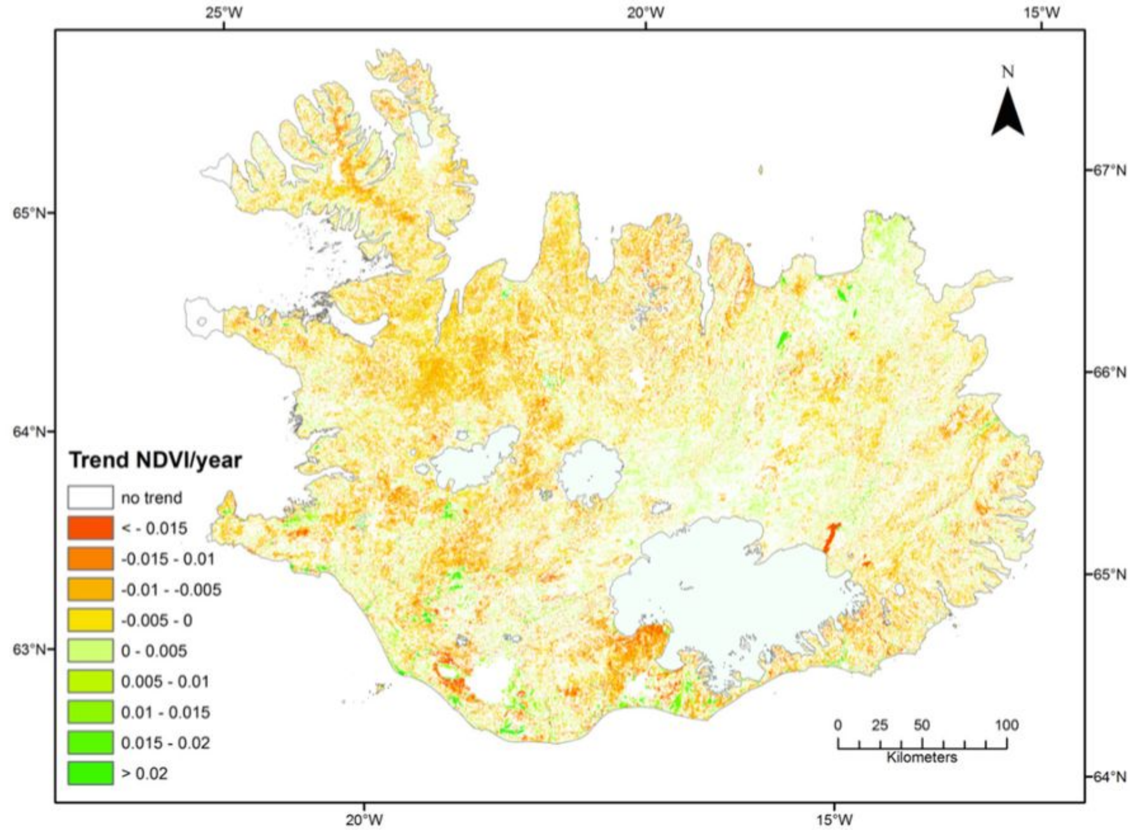


Figure 14: Iceland trend in maximum annual NDVI from MODIS aqua, 2002-2013 (Raynolds 2015).

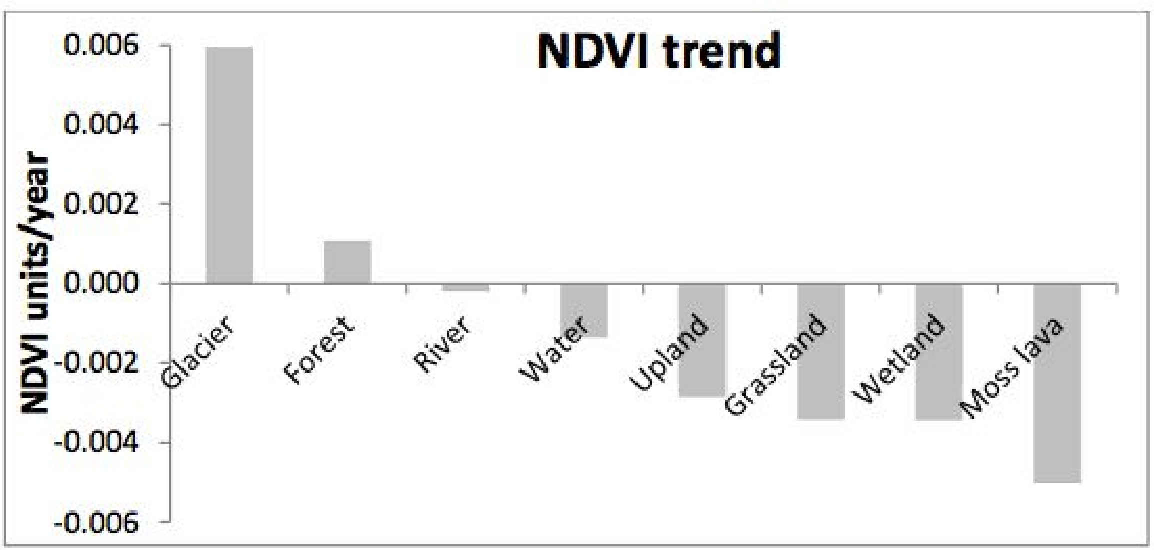


Figure 15: Iceland annual maximum MODIS NDVI trend 2002–2013 by vegetation type (Raynolds 2015)

In a more recent data set taken by MODIS Aqua from 2002- 2013, the resolution is much smaller and there are some clear trends. Anomalies here are results of human-induced forestry restoration and greening from industrial runoff of aluminum processing plants. Volcanic eruptions and greening due to glacial melting are other factors to take into account (Raynolds 2015). From the same study, the NDVI trend data was separated by vegetation type. As seen in Figure 15, glaciers are shown to have a positive NDVI, this was due to glacial melting and the new area that became available for plant growth. Forests increased in NDVI mainly due to restoration projects. The grassland most represents the study area in Ísafjördur, and shows a decrease in NDVI.

5.2 Species-Level

I examined at three separate mountainsides to gather my information, two in the White Mountains in New Hampshire, and one on Iceland. In the White Mountains, on Mt. Guyot, I found 9 species in 16 different plots. On Mt. Eisenhower, I found 15 species in 18 different plots, some of which were the same as those I found on Mt. Guyot. Lastly, I found 29 species in 24 different plots on the hiking trail up Naustahvilft valley near Ísafjörður, Iceland. The variety in the number of plots was due to accessibility of alpine zone vegetation on the respective peaks in New Hampshire.

There was some overlap between the species in Iceland and in the United States, and this could be from the last glaciation and the biogeographical remnants it left behind. There are four species that are growing in all three locations. However, many of the species found in New Hampshire are abundant in the Arctic, even though they were not growing in the survey plots in Iceland. This presents a difficulty using Iceland as a representative of the arctic because while, politically, Iceland is a major stakeholder of Arctic countries, the climate is much milder than Siberia, Russia, or Nunavut, Canada.

The species that were found varied from heathland vegetation to tundra vegetation, both of which are being influenced by different factors of climate change. Here, I will review a number of possible climate change effects on species found in the survey plots and what this means for tundra plant communities and alpine communities in general.

a) b)

Figure 16: a) *Carex bigelowii* (Stiff Sedge) b) *Carex Rufina* (Reddish Sedge)

Though the distribution of precipitation is unclear, the IPCC (2014) predicts, with high confidence, that the amount and distribution of global precipitation will change and the Northern Latitudes will be getting more annual precipitation. A larger snow accumulation in the winter but a stronger drought in the summer would change the production patterns of plants compared to an equally distributed precipitation throughout the year. New Hampshire, New England, and the rest of the North Eastern United States have been experiencing stronger droughts in the summer since 2010, and if this trend continues, it is unclear how the alpine plants in the White Mountains will react. Seidel et al. (2009) found that over an almost an 80-year study, the climate change effects, like temperature warming, decline with altitude in the White Mountains as a result of the atmospheric boundary layer. The summit's resistance to climate warming may be related to thermal inversions and intense cloud/fog at or above the regional atmospheric boundary layer.

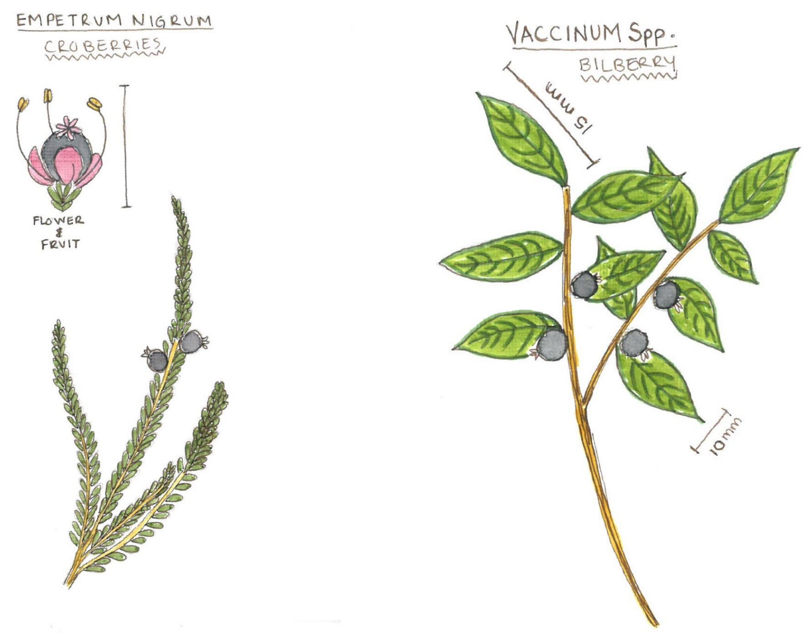


Figure 17: a) *Empetrum nigrum* (Black Crowberries). b) *Vaccinium Spp.* (representing Bog Bilberry and Low blueberry)

Increased warming often leads to a change in flowering times or seeding time and promotes plant growth, though the rates of flowering vary between species. Bunn et al. (2005) project that tundra will continue to grow vigorously in the coming decades while conifer forests will not. Increased tundra productivity will likely be associated with changes in vegetation composition (e.g., woody proliferation). Ylanne, H., Stark, S., & Tolvanen, A. (2015) found in a 2003-2013 study that warming increased the abundance of deciduous dwarf shrubs, mainly *Vaccinium spp*. (Bilberry/Blueberry). They also found that warming decreases the Nitrogen concentration in Bilberry/Blueberry, and increases the carbon concentration in the shoots (Ylanne, Stark, & Tolvanen 2015).

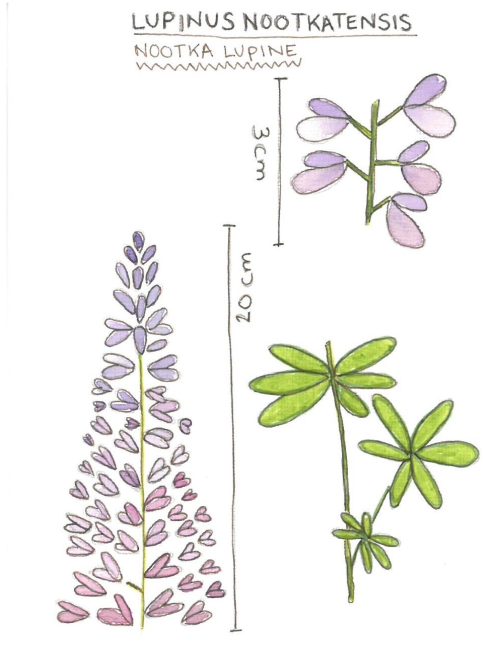


Figure 18: *Lupinus nootkatensis* (Nootka Lupine)

Warmer temperatures are likely to increase the productivity of *Lupinus nootkatensis* (Nootka Lupine) ability to fix Nitrogen and Carbon (Hiltbrunner & Aerts et al. 2014). Lupines are an invasive species in Iceland and were introduced in the 1970's. Since then, they have spread countrywide, and due to warming, Lupine is spreading into the Icelandic Highlands (Wasowicz et al. 2013). Lupine is not found in the alpine region of the White Mountains, but it is often found in bogs and fields at lower altitudes. Lupine and Bilberry have been observed to be invaders and it is likely for these species to out compete snowbed species in Iceland with increased warming and increased winter rain (instead of winter snow) (Wasowicz et al. 2013, Einar 2002). Any excessive seeding of Lupine can increase the NDVI in a particular area (Raynolds et al. 2015).

5.2.1 Explanation of Appendix

Through past studies of the effects of climate change on arctic and alpine plants, like experimental warming and long-term observations, many researchers have found that change within plant communities is likely due to different effects of climate change. The most common effect is an increase of surface temperature and increased precipitation. Other changes include drought, changes in snow cover, and increased CO2 in the atmosphere. Many plants are specific to certain altitudes and some are more likely to be pushed out and others are more likely to be invaders. Here, I will describe observed responses of plant species to climate change factors. Responses include an increase in growth and productivity, which I have noted a positive trends, and decreases in growth and productivity, which I have noted as a negative trend.

The majority of the species within the survey plots have been observed to have a positive response to climate change scenarios, like warming. Often what was observed was an increase in abundance or taller growth due to warming. A trend that is less likely, but still noticeable, is a negative reaction to warming. Some species vulnerable to warming could experience a loss in ground cover. Out of the species where increased precipitation was the variable tested, there was a positive trend in growth including increased ground cover as well as accelerated growth dynamics. *Carex bigelowii* (Stiff Sedge) is an example of a species found in Iceland and on the two mountains in New Hampshire that will have an accelerated growth due to increased precipitation, as well as more productive seeding time due to warming (Thórhallsdóttir 1998; Manel et al. 2012). Molau (1996) concluded that changes in precipitation and growing season length have significant impact on tundra plant growth and performance, differing among communities and species.

On the contrary, more intense droughts could lead to decreased abundance and increased competition for water. While increased droughts due to climate change are not a likely scenario in Iceland, it is more likely in New England. The species in the alpine zone in the White Mountains are likely to experience the drought more intensely because groundwater or runoff as a major source for water is not applicable. *Vaccinium uliginosum* (Bog Bilberry) and *Vaccinium angustifolium* (Low Blueberry) are two examples found in Iceland and in New Hampshire that are likely to decrease in abundance because of competition from fast growing grass species, which need surrounding water (Jentsch et al. 2008).

Increased CO2 is likely to have a positive effect on some plant species, though this change isn't likely to shift entire vegetation communities. *Ledum groenlandicum* (Labrador Tea) and *Agrostis capillaris*

(Common Bent) are the two species from the sample that have been experimented on by increasing the amount of CO2 in the test plot in which the result was greater abundance (Bloor 2010; Dieleman 2014).

Species that rely on winter snow cover may be the most vulnerable to climate change. Early melting could expose several species to harsh winds, cold temperatures and frost damage. *Veronica alpina* (Alpine Speedwell) and *Diapensia lapponica* (Diapensia) are two species, found in New Hampshire and in Iceland, that are dependent on snow cover lasting throughout the winter. With chance of increased precipitation in Iceland due to climate change, snow cover may not last as long as the species needs it to.

5.3 Ground Truthing & Comparison

Species-level observations and surveys as well as the large-scale NDVI data can show changes in vegetation communities at different temporal and spatial scales. When comparing the alpine areas of New Hampshire and Iceland there are come clear similarities and some clear differences of how species will react to climate change. Climate change is likely to change vegetation communities, but what type of changes depend on a number of biological, climatic, and human factors.

In New Hampshire, there was a total of 15 plant species found within surveyed plots. From the table in the Appendix, a few spatial patterns can be noted. For New Hampshire, warming has shown to have an increase in NDVI of species found in the alpine zone. Most reactions to warming are increased abundance and height. Although warming may encourage vertical growth in height, strong winds have the opposite affect and Balsam Fir and Black Spruce are two species that are dwarfed due to strong winds. As noted by the NDVI map by Guey et al. (2013), there are no areas in New Hampshire that show extreme NDVI changes between 1982-2012. The survey plots in the White Mountains are places where vegetation is relatively sparse, which would produce lower NDVI than the surrounding landscapes. Annual NDVI in New Hampshire may vary due to change in annual precipitation. A consistent rainfall may be more beneficial to alpine plants than intermittent storms and heavy rainfall.

In Iceland, there was 24 species found within surveyed plots. The majority of these species have been observed to have increase growth from some mild to moderate warming as well as more precipitation. Both increased in rain in addition to warmer surface temperatures are potential scenarios of climate warming in the arctic.

Increases in NDVI were found to correlate with summer surface temperatures in most parts of the arctic (Raynolds et al. 2015). Temperature directly impacts the growth of a plant species annually. Winter warming has resulted in a lower NDVI due to lack of snow cover, which is necessary to many arctic species (Raynolds et al. 2015).

It is very likely that NDVI in the will increase in the coming decades and this can be from a taller and more successful growth of tundra species, or an increase of invaders from boreal ecotones. Iceland, being an island, is a fragile ecosystem that the government is trying hard not to change with invasive species from bacteria to plants to mammals. So whether or not the Icelandic government can maintain control over the species that come in an out of the country, other Arctic countries do not have the same isolating privilege. The boundary between boreal forest and arctic tundra is likely to become more blurred and with climate warming comes taller and more abundance of arctic plants as well as an increase in boreal species. Boreal species, like Balsam Fir and Black Spruce, have the capacity to migrate northward with warming (Iverson & Prasad 1998). It is unclear if other species will be able to do the same and keep up with warming.

There were some species that are well known in the Arctic that were not a part of the surveys in Iceland. Diapensia, for example, is a species that is known for ability to endure cold weather and harsh winds. With less winter snow, which is predicted for Iceland as a result of climate change, Diapensia could potentially suffer. Diapensia already grows in fairly sparse and rocky terrains and excels in places with direct sunlight and no shade. From the NDVI data, a decrease in abundance in Diapenia would likely result in a negative NDVI. In the surveys, it was found in New Hampshire, but not in Ísafjorður. Labrador Tea, is another example of a well known arctic shrub that was not found in in Ísafjorður.

Iceland and the alpine zone in the White Mountains have a few things in common. First, many of the species that were found in New Hampshire were also found in Iceland. There are clear geographical islands in the White Mountains. Second, many of the species may actually benefit from some mild to moderate warming in the coming decades. With warmer temperatures comes less snow cover, which many species in Iceland and The White Mountains need for survival.

There are clearly some geographic and topographic differences between these two situated contexts that may cause different results from climate warming. The first being that the atmospheric boundary layer in the White Mountains may lessen the effects of warming in places at higher altitudes, which hold the alpine zones. Second, due to Iceland being an island, there may be less of a change in vegetation communities because of the ability for invasive species to take root. Third, while New Hampshire does touch the Atlantic Ocean, the Atlantic's encompassing of Iceland plays a major role in Iceland's weather, climate patterns, and vegetation makeup.

There is an important factor that goes into vegetation, and that's people's direct impact. The White Mountains of New Hampshire is federal land, owned by the forest service. With the help of some non-profits like the Appalachian Mountain Club or the Randolph Mountain Club, volunteers and trail workers maintain the hiking trails to keep people from hiking in the alpine zone. This is something that is not seen in Iceland.

Bunn et al. (2005) project that tundra will continue to grow vigorously in the coming decades while conifer forests will not. The Alpine region of New Hampshire might have more resistance to climate warming due to the atmospheric mixing layer. There have been a few comparative studies of arctic and alpine populations of the similar species (Hadley & Bliss 1964,) and the findings were quite similar. Many found arctic plants to have a lower photosynthetic light saturation points, higher rates of respiration at all temperatures, and attainment of maximum photosynthetic rates at lower temperatures. This could lead to differences in the NDVI of alpine or arctic regions. From this information, it can be generalized that arctic species would have a lower NDVI than alpine species because alpine species are at a higher latitude and would have a shorter maximum growing season.

6.0 Implications

6.1 Comparison & Generalization of Results

Greening and browning dynamics due to climate change in alpine study areas have received considerably less attention than Arctic and sub-Arctic regions. Alpine vegetation can vary between different mountain ranges, latitudes, and regions of the world, this is why it is necessary to look beyond one alpine vegetation community and get a sense of larger patterns of the impact of climate change on vegetation across alpine areas. Here, I will compare the results of my study of Arctic and New Hampshire alpine plants with other NDVI trends in three mountainous regions around the world: Mt. Kilimanjaro, the Himalayas, and the French and Italian Alps.

6.1.1 Kilimanjaro

Meaningful monitoring of NDVI trends around Mt. Kilimanjaro have led to discoveries of direct human impact like clear cutting of forests and intense land transformation (Detsch 2016). In contrast, greening has occurred in the alpine regions of Mt. Kilimanjaro due to reduced human intervention because since 1973, higher altitude sections have been protected within Kilimanjaro National Park. Another factor that plays a role in greening of the alpine zone in Kilimanjaro was a devastating fire at the beginning of the monitoring period. Since then, there has been regeneration of the vegetation areas. Detsch (2016) has also found an increase in greening in alpine areas above 3000m due to an increase in temperature. Glacier retreat has also contributed to greening on Kilimanjaro by increasing exposure of bare ground which can allow new places for vegetation to grow.

6.1.2 Himalayas

Like the Arctic, the rate of warming in the Himalayas is greater than the global average (Shrestha et al. 2012). This biodiversity hotspot is among the regions of the world that has uniquely vulnerabilities to climate change. NDVI trends in this area have been consistent with ground-based phenological observations, showing an advancement in growing period correlated with increases in winter and spring temperatures (Shrestha et al. 2012). This is thought to be linked to climate change. A clear spatial pattern was observed in this study, showing that a high proportion of significant trends of the start of the growing season was apparent in ecoregions of higher elevations. This includes Northwestern and Eastern Himalayan alpine shrub and meadows and Western subalpine forests. Using NDVI data, Shrestha et al. (2012) reported significant changes in temperature, rainfall, and vegetation phenology, all of which can have a profound impact on the well-being of about 20% of humanity who live at the foothills of the Himalayas. Changes in plant phenology will be one of the earliest responses to global warming (Xu et al. 2009). The timing of flowering is strongly linked to the pace of snow melt, and an offset in flowering times and pollinators can have devastating effects to ecosystems as well as agriculture (Xu et al. 2009). Changes in temperature could result in melting of glaciers in the Himalayan Mountains which has a cascading consequences affecting water availability, coastal flooding, and agricultural production for the people living in the foothills.

6.1.3 French Alps

Multiple remote sensing-based studies indicate widespread spatial patterns of recent Arctic and tundra greening caused by expansion of shrubs into areas of tundra as a result of climate warming (Carlson et al. 2017). There are a number of reasons for temporal trends in NDVI in the context of the French Alps, including increased temperature, glacial retreat, shifts in snow cover duration, and changes in alpine land use practices (Carlson et al. 2017). In the context of Ecrins National Park, France, Carlson et al. (2017) found an intensification of greening in alpine vegetation regions. They conclude that this is due to two different mechanisms: (i) a gradual densification and increase in height in plant species and (ii) encroachment of shrubs into alpine grassland communities. Similar to the Arctic and the alpine regions of the White Mountains, NH, expanding shrub cover has been reported in the Italian alps at elevations of over 2500 meters. It was found that areas of more sparse vegetation in the French Alps had a greater increase of NDVI from 2000-2015. Carlson et al. (2017) hypothesize that increasing air temperatures, decreased snow cover duration, and changes in land-use practices are the main drivers of observed greening in the French Alps.

6.1.4 Larger patterns & microclimatic considerations

These three cases are all experiencing changes in NDVI as a result of climatic and anthropogenic changes. Human impacts, like recent fires and land conservation have been found to directly influence of NDVI and vegetation responses around and on Mt. Kilimanjaro. In the Himalayas, ground based observations have supported NDVI data and both methods show that vegetation is responding to climate warming. These changes will have a dramatic effect on people living at the foothills. Just like in the Arctic, shrubs are expected to encroach on alpine plant species in the French and Italian alps due to warming.

There are bigger patterns to take note of when discussing the impact of climate change on alpine vegetation areas. These factors are also relevant in arctic vegetation areas due to similar climatic conditions. Snow cover, temperature, when applicable, glacial retreat are variables controlled by the climate that can dramatically change vegetation growth patterns in alpine and arctic climates. These variables are likely to change due to the effects of climate change and will vary depending on where the research area is. These factors should also be considered in research focusing on the health and productivity of alpine plants. The expansion of shrub cover into alpine and arctic areas is the biggest change of vegetation communities that has been observed. This change is relevant to many of the factors referred to above. With less snow cover duration and increase of temperature, most shrub species can excel and grow in abundance and in height. This therefore creates competitive conditions for species survival.

When comparing alpine and arctic vegetation, microclimatic considerations should be taken into account. Changes in vegetation may differ due to altitude as well as regional atmospheric conditions. As mentioned in the Situated Context, microclimatic conditions should be taken into account in alpine regions. The atmospheric boundary layer is considerably lower in the White Mountains than in Iceland. In

New Hampshire, it is typically 3,500 feet to 5,000 feet, which excludes many mountain tops. This means that these peaks are in the “free atmosphere” which creates conditions more likely to support alpine vegetation (Seidel et al. 2009). Ísafjörður, Iceland, on the other hand, is at sea level and is surrounded by a well-mixed atmosphere.

Microclimates do not only relate to the atmospheric boundary layer, but can have an influence at the edge of forests and ecotones. The degree and distance over which microclimates show any effects differ depending on the location (Gehlhausen 2000). Relative humidity, light, and soil moisture have the greatest effect on microclimate edges and can provide a habitat for a different collection of species than in ecotones that have fewer variables. Species richness has been correlated with microclimate variation (Gehlhausen 2000). This is especially true on microclimate edges where, for example, herbaceous vegetation does not have to compete against larger tree species (Gehlhausen 2000).

Due to several factors, alpine species in New Hampshire will not react the same way that tundra species will in Iceland. First, the predicted changes from climate change will be different in either area. Generally speaking, Iceland is predicted to have more precipitation, while in New Hampshire, there is a current trend of increasing drought. Second, land management styles are very different in Iceland than they are in New Hampshire. New Hampshire has a long history of structured trail systems and a culture of outdoor ethics and species conservation. Iceland, on the other hand, does not have the same culture and there are no definitive trails. Lastly, the atmospheric boundary layer creates stable conditions that are supportive to the survival of alpine plants in New Hampshire. Unlike New Hampshire, Iceland is within a well-mixed atmosphere. Like most areas below the boundary layer, a well mixed atmosphere feels the effects of climate change at a greater rate than the free atmosphere.

Anticipated changes in the climate, land management style, and the location of the atmospheric boundary layer are three factors that can vary over any area. All of which can influence the health and productivity of a vegetation community.

6.2 Application to Framing Question

The driving question that motivated this research is, what effect will climate change have on plant communities world wide? As was noted in the beginning, climate change is accelerating at a speed where plant communities might not be able to acclimate quick enough to survive (Berteaux et al. 2004). Collectively this research suggests that effects of climate warming on plants are not homogeneous across latitudes or altitude. Even with similarities in species, changes can differ depending on regional conditions. Plants globally are predicted to shift current location due to global warming in order to continue to grow in comfortable conditions, though to what extent depends on the predicted change in climate for a region. In more populated parts of the world, land cover change is more directly associated with human impacts like agriculture or deforestation, which could alter the photosynthesis and respiration cycle of plants and change the magnitude of the carbon sink within forests. Other microclimatic conditions should be taken into account as well as other factors that were not considered here. Remote sensing is growing in popularity among researchers and is one of the best ways to research vegetation cover from the global to regional scales.

Although there are similarities between research sites, there are differences in several factors that dictate how some species will be more resilient to climate change than others. It would be far more simple if there was a one solution to support species conservation in the face of climate change, but this research shows that large scale or global solutions will not address the specific dynamics of a an small vegetation community.

6.3 Next Steps

There is thus, no one form of policy that could halt the effects of climate change as well as generate a system of conservation organizations that will reduce the degradation of plant communities. This research shows that though there may be similarities in plant species composition, there are differences in how we should manage them. In fact, a suite of policies at many scales is needed that can address climate change as well as species conservation that can work together to benefit both alpine and arctic plant species as well as other vegetation communities world wide.

Monitoring of vegetation dynamics should continue using remote sensing applications, like NDVI, as well as ground truthing observations. Current projects like the Land Use Cover Change project and the Global Change and Terrestrial Ecosystems project have contributed research on “ecosystem changes under local, regional and global environmental changes” (Canadell et al., 2007). These projects along with the Global Land Programme include multiple scales of vegetation observation in order to get an assorted range of information. These multiple scales of research are beneficial for larger biomes as well as local conservation land.

While there is no international alpine management program, policy and management of alpine regions are highly site specific because forces like microclimates as well as land use vary from place to place. The consideration of microclimate boundaries is especially important for management of alpine or arctic conservation because the edge of ecotones is hard to find and can be more biodiverse. For example, management of the White Mountain National Forest in New Hampshire and the Green Mountain Club in Vermont has created a culture of education on alpine species which then limits people hiking off trail (Green Mountain Club 2017).

Kilimanjaro National Park is protected under national legislation as a National Park and a management plan is in place. The property requires effective and organized management at all elevations of the mountain, this includes having an equipped ranger present to carry out surveillance and implementation of management plan (UNESCO). There are education programs associated with Kilimanjaro National Park to integrate park management with stakeholders as well as local communities. These programs would benefit more than just Kilimanjaro National Park, but other park systems at any scale as well. The opportunity for individual stakeholders to discuss the challenges and successful initiatives would be beneficial for all parties. A culture of stewardship and surveillance should be implemented in places where recreation is growing or is popular.

Climate change is not the sole cause of shifts in vegetation. Land use changes like deforestation, rewilding, land conservation, and agriculture have an impact on vegetation dynamics and can be the explanation for any anomalies or drastic changes seen in NDVI data. Identifying the local differences between land management styles, microclimates, and species composition is crucial to create local strategies supporting species conservation. By continuing to learn these site-specific differences and complexities, policy makers and land managers can work to create program in support of species conservation.

6.4 Future Research

Climate warming will continue to change where and when plants are growing and more research and monitoring efforts are needed to learn how plant species are being affected. The comparison of NDVI data and ground-based observations should continue to be studied because the degree of change across many scales can give researchers insight on lager patterns (Manzel 2002). Climate change will continue to affect plant species in different ways, though it is unclear to what degree this changes will affect climate feedback cycles. Could more plant production in tundra species or an increase in invasive plant species or larger trees result in a larger carbon sink? While species-level, ecosystem- and global-scale observations through satellite data have been discussed in this research, carbon dioxide measurement via satellites is another way for researchers to learn about plant health and productivity. With carbon dioxide being an abundant greenhouse gas, an increase in plant growth and productivity can give researchers a insight into climate feedback systems (Zhang 2003).

Future research should expand on these two situated contexts and analyze the change in species across the arctic. The Arctic is more at risk to dramatic change but the rate of change depends on local criteria. In my research thus far, I have not considered the changes in arctic plant dynamics in Europe and Russia (Guay et al. 2014). This area of land is the largest continuous section of boreal, taiga, and tundra ecoregion in the world and is experiencing rapid warming as well. NDVI data from that region can give researchers a clearer understanding of the influence of climate change on arctic and alpine plants (Zeng et al. 2013). Although phenological research is time-consuming, urgency and patience is needed to get results that

7.0 References

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8.0 Appendix

	Alpine Cat's-tail (*Phleum alpinum*)	**Alpine Cranberry/Lingonberry (*Vaccinium vitis-idaea*)**	**alpine sedge (*Carex bigelowii*)**	**Alpine Speedwell (*Veronica alpina*)**	**Annual meadow-grass (*Poa annua*)**
Increase Drought			decrease ground cover due to drought (22)		
Increased Precipitation			Increased ground cover (14)		
Higher surface temperatures	May benefit from low to moderate warming (15), little to no change in growth, flowering, or reproduction due to warming (15)		More productive seeding times (2)	No effect on flowering time (2), habitat may regularly decrease with warming because of competition (15)	Sooner flowering times (3), Increase abundance (5)
Increased CO2					
More winter Snow					
Less Winter Snow				noticeable decline with less snow (9)	
Altitude specific			Found at low altitudes in Iceland (9)		
Other		challenging to predict responses (26)	Will have less space to grow because competitors will likely push it out (7)		
Invader					
Invaded			yes (7)		

	Autumn Gentian (*Gentianella amarella*)	**Balsam Fir (*Abies balsamea*)**	**Black Spruce (*Picea mariana*)**	**Bog Bilberry (*Vaccinium uliginosum*)**	**Brown Bent (*Agrostis vinealis*)**
Increase Drought				decreased abundance because fast growing grass species use the surrounding water (4)	no change (1)
Increased Precipitation					increased their ground cover (21)
Higher surface temperatures		respond relatively more to warming, though it really depends on the soil nutrients and their change to the warming (26).	respond relatively more to warming, though it really depends on the soil nutrients and their change to the warming (26).	No effect on flowering time (4), Increase growth and abundance (6), decrease nitrogen concentration in shoots (6), increase carbon concentration in shoots (6)	
Increased CO2					
More winter Snow					
Less Winter Snow		frost damage to early budding	frost damage to early budding		
Altitude specific	Likely to shift altitude up (27)	Likely to migrate northward... but if so, then it would be nearly eliminated from the United States (28)		Low altitude (13), unknown if it has the ability to move in response to climate change (13)	
Other					
Invader				yes (8)	
Invaded					

	Bunchberry (*Cornus canadensis*)	**Common bent (*Agrostis capillaris*)**	**Common Sorrel (*Rumex acetosa*)**	**Diapensia (*Diapensia lapponica*)**	**Hairy Lady's-mantle (*Alchemilla filicaulis*)**
Increase Drought		no change (1)			
Increased Precipitation		increased their ground cover (21)			
Higher surface temperatures		Sooner flowering times (1), reduced ground cover (1)	No effect on flowering time (2)		Sooner flowering times (2)
Increased CO2		increased in grasslands productivity, increase in population, no advancement of flowering (1)			
More winter Snow			Snow melt dependent (8)		
Less Winter Snow				The less winter snow makes this plant more susceptible to frost damage.	
Altitude specific			moderate to mild climate (10)	occupies the harshest and most exposed of habitats: gravelly ridge-tops, areas where the moisture in the soil is windswept, first to thaw (24)	

Other			expected to shift altitude with warming (18)	Highly plastic in phenological monitoring, Well adapted to the harshest arctic-alpine conditions and has the potential to survive long periods of much more adverse conditions that experienced at the current climatic regime (24)	
Invader					
Invaded					

	Heart-leafed White Birch (*Betula cordifolia*)	**Highland Rush (*Juncus trifidus*)**	**Hornemann's Willowherb (*Epilobium hornemannii*)**	**Irish Saxifrage (*Saxifraga rosacea*)**	**Labrador Tea (*Ledum groenlandicum*)**
Increase Drought					
Increased Precipitation				No effect (14)	
Higher surface temperatures		vulnerable (25)	Sooner flowering times (3)	No effect on flowering time (2)	increased abundance (29)
Increased CO2					increased abundance (29)
More winter Snow					
Less Winter Snow					
Altitude specific		Likely to shift altitude up (27)		low altitude (14, 10)	
Other					
Invader			yes (16)		
Invaded					

	Low Blueberry (*Vaccinium angustifolium*)	**Meadow Buttercup (*Ranunculus acris*)**	**Mountain sorrel (*Oxyria digyna*)**	**Nootka Lupine (*Lupinus nootkatensis*)**	**Purple Crowberry (*Empetrum atropurpureum*)**
Increase Drought	decreased abundance because fast growing grass species use the surrounding water (4)				
Increased Precipitation			accelerated vegetation dynamics (20)		
Higher surface temperatures	No effect on flowering time (4), Increase growth and abundance (6), decrease nitrogen concentration in shoots (6), increase carbon concentration in shoots (6)	Sooner flowering times (3), increase growth and abundance (3),	accelerated vegetation dynamics (20)	Increase the ability to fix carbon and nitrogen (7), Expand into Iceland Highlands (10), increase abundance (10)	brighter color and taller growth (9), flowering time not expected to change (2)
Increased CO2					
More winter Snow					
Less Winter Snow		snow-melt did not have an effect (19)			
Altitude specific	Low altitude (13), unknown if it has the ability to move in response to climate change (13)	Likely to shift altitude downward (27)			
Other					Keystone species for northern ecosystems, although there is no research to see which phenological changes are due to climate

					change (23).
Invader	yes (8)			yes (10)	
Invaded					

	Reddish Sedge (*Carex rufina*)	**Slender Bedstraw (*Galium normanii*)**	**Smooth Meadow-grass (*Poa pratensis*)**	**Starflower (*Trientalis borealis*)**	**Sweet Vernal-grass (*Anthoxanthum odoratum*)**
Increase Drought			no change (1)		
Increased Precipitation	Increased ground cover (14)				
Higher surface temperatures		Sooner flowering times (3)	Sooner flowering times (3), higher abundance (5)		No change to temperature and no area loss (11)
Increased CO2			no change (1)		
More winter Snow	snowbed species (18), growth, flowering, and reproduction rates excel in colder and wind-exposed environments (13), considered one of the most cold-tolerant species (10)				
Less Winter Snow					
Altitude specific					moderate to mild climate (10)
Other					expected to shift altitude with warming (10)
Invader					invader within snowbed species (17)
Invaded					

	Three-toothed Cinquefoil (*Potentilla tridentata*)	**Viviparous Sheep's-Fescue (*Festuca vivipara*)**	**Wild thyme (*Thymus praecox (subsp.) arcticus*)**
Increase Drought		drought tolerant but are less productive in droughts (22)	drought tolerant but are less productive in droughts (22)
Increased Precipitation			
Higher surface temperatures		Unknown change (but change likely) (8)	
Increased CO2			
More winter Snow			
Less Winter Snow			
Altitude specific			
Other			
Invader		invader within snowbed species (17)	
Invaded			

Subscripts	
1	Bloor, J.M.G., et al. (2010)
2	Thórhallsdóttir, T.E. (1998)
3	Totland, Ø. (1999)
4	Jentsch, A., et al. (2008)
5	Chwedorzewska, K.J. (2007)
6	Ylanne, H., Stark, S., & Tolvanen, A. (2015)
7	Hiltbrunner, E., & Aerts, R., et al. (2014)
8	Einar, H. (2002)
9	Virtanen, R., Eskelinen, A., & Gaare, E. (2003)
10	Wasowicz, P., Pasierbinski, A., Prezedpelska-Wasowicz, E.M., Kristinsson, H. (2014)
11	Berry, P.M., et al. (2002)
12	Pearson, R.G., & Dawson, T.P. (2003)
13	Jedrzejek, B., Drees, B., Daniëls, F.J.A., & Hölzel, N. (2012)
14	Manel, S., et al. (2012)
15	Guisan, A., Theurillat, J.P. (2001)
16	Walker, K.J. (2007)
17	Heegaard, E., & Vandvik, V. (2004)
18	Kristinsson, H. (2013)
19	Totland, Ø., & Alatalo, J.M. (2002)
20	Cannone, N., et al. (2008)
21	Sternberg, M., et al. (1999)
22	Grime, J.P., et al. (2008)
23	Väisänen et al. (2013)
24	Molau (1996)
25	Saetersdal and Birks (1997)
26	Shevtsova et al. (1997)
27	Frei, Bodin, & Walther (2010)
28	Iverson & Prasad (1998)
29	Dieleman (2014)