I. Introduction

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EFFECTS ON PLANT COMMUNITIES IN THE COLORADO BASIN ALPINE TUNDRA

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Abstract

The Colorado Basin alpine tundra region has been introduced to new climate changes and it has affected the plant communities greatly. The plants in this area are very sensitive to changes because of their adjustments to such a harsh environment. Limited research of the plant communities in this region makes knowing what is happening up there difficult to predict. This project reviewed the literature related to how climate change in the alpine tundra of the Colorado Basin and described what may be happening to the plant communities and understand why or how the ecology of this region may be in jeopardy.

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The Alpine tundra plant community has often been referred to by scientists as the canary in the coal mine warnings for all ecosystems. (1) These communities are good representation on how human and global changes may affect all ecosystems. This is because their delicate ecosystems are not able to handle even the slightest of changes. These changes over the years have included global warming and nitrogen deposition, and the plant communities' distribution of species is changing because of this.

The alpine tundra that will be focused upon in this paper is the Colorado Basin area. This area encompasses parts of New Mexico, Utah, Arizona, and Colorado and all the tundra generally begins at elevations 11,500 feet and higher, pictured in Figure 1.1.

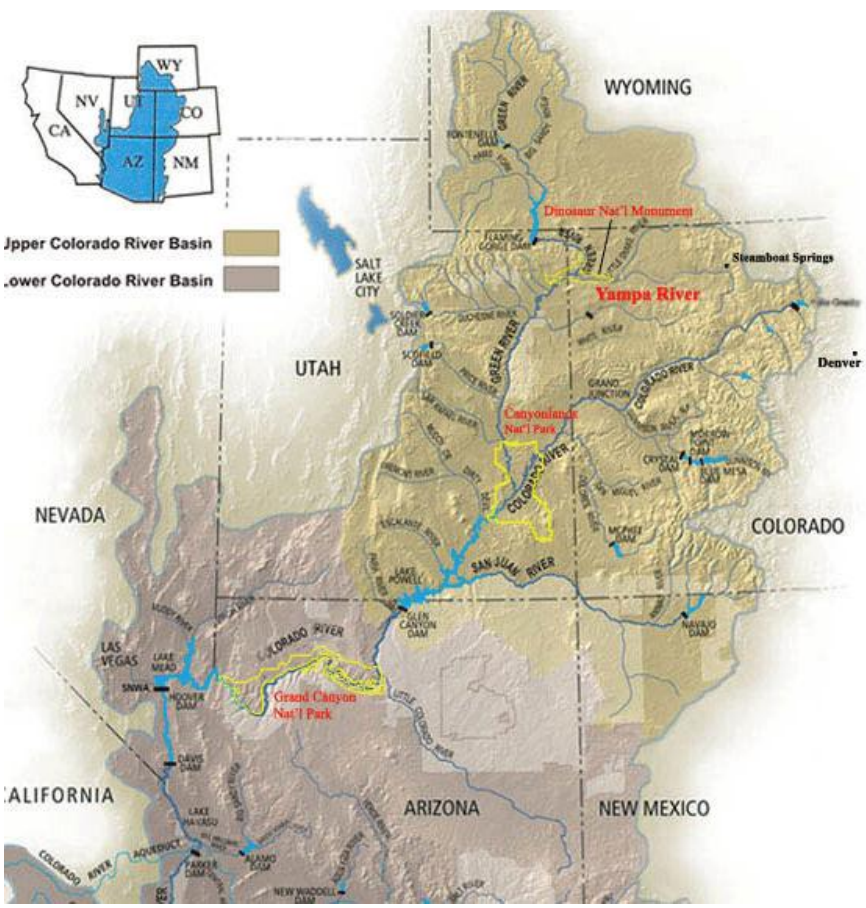

Figure 1.1 The Colorado River Basin consisting of New Mexico, Utah, Arizona, and Colorado
http://www.gcdamp.gov/aboutamp/crb.html

These communities experience harsh weather, extreme cold, and a shortened growing season and have adapted to these environments to be able to survive.

Changes in the composition of the alpine tundra biota have been predicted to happen due to the consequences of global warming. (2) Global temperatures are on a rise from a variety of factors, but mostly are contributed to human impact and the release of excess CO_2. This is also known as the greenhouse effect and the trapping of infrared radiation in our atmosphere causing global temperature changes. The tundra region is ecologically very sensitive to these changes and life there is experiencing challenges in competition with other species, longer growing seasons, and earlier snowmelt dates.

Nitrogen deposition is also occurring in this region resulting in an elevated amount of nitrogen in the soil and snow. (3) The excess nitrogen is being released into the atmosphere ranging due to an increase in nitrogen based fertilizers used on farms and households to nitrogen being released from industrial factories, car exhaust, power plants, and anything emitting NO_x while in use. Since the tundra is known to not be a nitrogen-limited environment and is now experiencing large amounts of it, this could be causing many adverse effects to the communities alongside global warming. (4)

These changes have caused a concern from many scientists and it is believed to be early warnings of what could occur in ecosystems lower in elevation, such as the Great Plains. Although, there is such great concern, not much research has been done on this region. The alpine tundra region in the Colorado Basin has almost no research sites available or funding. There is a Long-Term Ecological Research Site (LTER) located on the East side of the Continental Divide on Niwot Ridge, CO. This Continental Divide is also referred to as the Great Divide and can be seen in Figure 1.2. Precipitation from the Divide runs off either towards the west or towards the east. The western side of the Divide will receive more precipitation because of the process orgographic precipitation. This means as the clouds are pushed westward by westerly wind, the Rocky Mountains will then block travel of these clouds. The blocking will then cause the clouds to move to higher elevations resulting in the condensation and precipitation before traveling over the mountains. (5) Niwot Ridge will receive different precipitation and run off levels than the area of focus, the Colorado River Basin located on the west side of the divide.

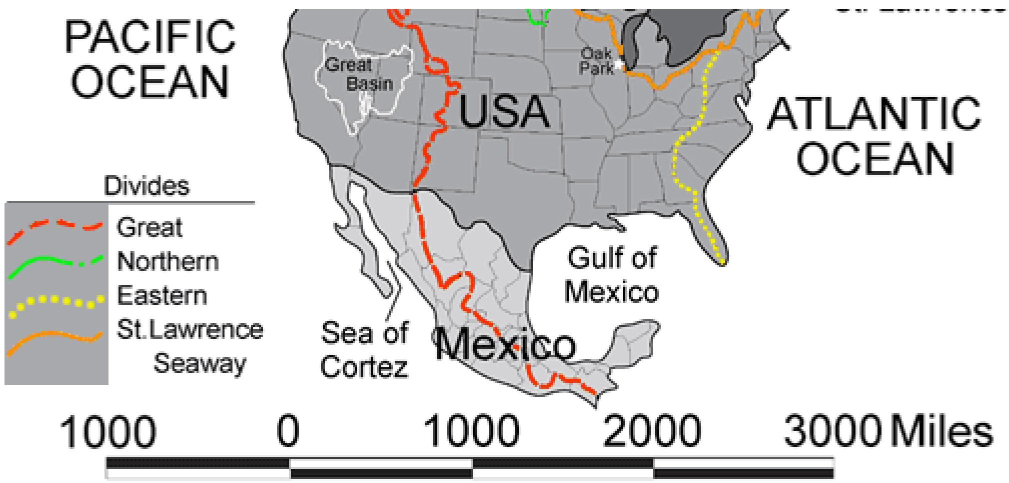

Figure 1.2: Continental Divide location across the United States.

http://www.nationalatlas.gov/articles/geology/a_continentalDiv.html

Research in other tundra biomes has also been carried out and is being studied for the effects described above.

II Background

A. Snowbed Communities

Snowbed communities are very sensitive to many factors and are manly protected by the cover of snow for most of the year. Snowbed communities have this snow cover for much of the spring thaw and even into the summer months. This same snow cover acts like an insulator for these plant species and keeps the soil temperature stable during the winter months. Since this is such a specialized area, not many plant species can survive and this results in low species diversity. (6) In a plot with an area of m^2, the variety of plants ranges generally from five to ten different vascular plant species (7). An example of a snowbed community can be seen below in Figure 2.1.

Figure 2.1: Snowbed forb communities during late summer months.
http://www.nps.gov/wrst/naturescience/plants-communities.htm

These snowbed communities have become specialized to be able to survive in this harsh environment and have lost their ability to easily adapt and survive in new environments. With almost constant snow cover the growing season is very short. Plants have adapted to this by having very quick vegetative life cycles and some plants in these communities have adapted by extending their vegetative life cycle to multiple growing seasons. Many plants will even emerge through the snow pack with depths of 5 cm and then begin to flower just a few days after they emerged. These Alpine plants have the ability to grow at temperatures as low as 0°C and have the ability to go through subnivean photosynthesis. Carbohydrates stored in the rhizomes and roots are most likely the explanation for the ability of rapid growth and subnivean photosynthesis. (6)

Snow melt can vary to the extent of five weeks from year to year from a variety of explanations. This date of snow melt though is very important to the communities and determines the species distribution across the snow bed. The plant distribution within the community is also affected by the air and soil temperatures before snow cover in the fall, which will determine the snowbed temperature for the entire winter. The plant distribution within the community can change depending on nitrogen as well, although they are considered not limited by nitrogen like many other communities. (6)

Snowbed plants are affected though by shading during the early part of the growing season, but are more tolerant to shade during the later part of the growing season. They have been able to gain a resistance to low-temperature photo-inhibition. This allows them to maintain carbon gain even on days that follow frost and increased sunlight exposure.

Reproduction in snowbed communities has been adapted as well to this short growing season. Many shrubs in these communities lose the ability to form seeds and have adapted by reproducing vegetatively with layering and adventitious roots. Forbs and graminoids are relatively unaffected by this harsh habitat and are still able to have sexual reproduction. Germination of seeds have even adapted to the constant snow cover by being able germinate at temperatures as low at -5°C. (6)

B. Waters Effects on Plant Communities

In the alpine region ground water determines many factors in plant communities, including species distribution, spatial pattern, community composition, and productivity of plant species. These plant species are so sensitive to ground water that they cannot have too much water or too little to be able to survive. Water availability is considered a limiting factor to plant productivity in the Alpine tundra. (8) Droughts, winter snow patches, and precipitation increase determine this water availability for these plants. In turn plant cover in regions will also determine the amount of available ground water. Increased plant cover increases the evapotranspiration, which will decrease plant productivity due to lack of water.

C. Global Warming

Global warming is the increase in the overall global climate change and is causing adverse effects to the environment. The most common effect of global warming is the rise of average temperature worldwide. Since 1880, global temperatures have risen 0.8°C; all studies were done by NASA's Goddard Institute for Space Studies. The Intergovernmental Panel on Climate Change stats that eleven of the past twelve years have been the warmest since 1850. (9)

This has caused the average temperatures in the Arctic to rise and is causing Arctic ice to rapidly melt and cause problems for the indigenous species in that area. With the habitats getting damaged by these extreme weather patterns from natural changing of climate, many animal and plant species may face extinction. This is because some may not be able to handle the new warmer climate and need a cooler climate to live. A great example is in the Arctic Circle where the ice is melting in the seas, which helps support polar bear, pictured in Figure 2.2, survival by allowing them to travel on the sheets of ice. With warmer weather, less ice will be the norm and the habitat for the polar bear will shrink. (10)

Figure 2.2: Polar bear yearling. Credit: Susanne Miller / USFWS
http://www.fws.gov/home/feature/2008/polarbear012308/polarbearphotos.html

Those are not the only ice forms that have been melting around the world; many mountain glaciers have disappeared and about 113 glaciers have disappeared from Montana's Glacier National Park. Climate change is not only limited in affecting colder climates, the coral reefs are experiencing bleaching, which causes many of these habitats to die off. (12)

The cause of global warming is a very widely debated topic amongst experts and the one common cause is human impact. The rise of greenhouse-gas emissions has in turn made many experts feel it caused global warming. The probability that humans have caused this problem is around 66%. This study was researched by a panel set up by National Geographic in 1990, 1995, and 2001. This study is not completely credible because this panel may not have been made up of experts, but many people speculate that with placing more blame on the human causes, more of an effort will be placed in lowering harmful emissions. (13)

Greenhouse gases are emitted from many different sources with the most common being combustion of fossil fuels, ranging from cars, power plants, factories, and any other process that rely on fossil fuels as its primary energy source. Think of it this way thousands upon millions of more emissions occur daily in the United States that did not previously occur 100 years ago. The amount of people driving cars has risen and new energy plants created has risen to fit society's energy needs.

Many measures have been taken to reduce the amount of energy emissions recently and these include hybrid cars, electric cars, wind mills, solar panels, and other renewable energy sources. These efforts have been proven to reduce the amount of CO_2 -emissions from using a renewable energy that doesn't give off harmful emissions, to driving a more fuel efficient vehicle. Countries like China are putting up a coal burning power plant about once a month to accommodate their growing middle and upper class and haven't yet created similar environmental considerations or philosophies that the United States has implemented. This is the case for many countries that are going through economic and social growth and cannot afford to put in place environmental regulations.

The problem that has occurred due to all of these industrial emissions, deforestation, and other carbon releasing acts humans do to nature is that plants and the ocean cannot absorb all of this excess carbon fast enough for there to not have an increase in its abundance. With this occurring, concentrations of water vapor, carbon dioxide, methane, and nitrous oxide are getting collected in the atmosphere resulting in the trapping of the suns heat.

Some experts oppose the idea that global warming being caused from human disturbance and suggest the warming cycle is naturally occurring whenever the Earth shifts orbit. Even though this process of climate change usually happens over hundreds of thousands of years and is now appearing to happen in the span of a single century. The excuse of a naturally occurring cycle makes it hard to ignore that humans have been cutting down trees that help assimilate the carbon dioxide, and have been releasing harmful emissions more than ever into the atmosphere as a possible explanation. (25)

What will happen to the Earth if global warming continues on the trend it seems to be heading? One answer is that the experience of extreme weather will continue to get more dangerous. Coastal cities alone would experience high levels of coastal erosion, stronger hurricanes, storms, and various other extreme weather occurrences. With a rise of 1m in sea level, along United States Coast lines it is estimated to cost four hundred billion dollars in damages, all estimations done by the Environmental Protection Agency. (14) With sea levels estimated to rise between 0.18m to 0.59m from 1990 to 2100, according to a report released from the Intergovernmental Panel on Climate Change, this estimated cost may become a reality. (15)

D. ITEX

The International Tundra Experiment (ITEX) organization was started in 1990 to help research for observing the effects of climate change on global tundra regions. The founder of this was Professor Patrick J. Webber at the Kellogg Biological Station of

Michigan State University. The focus of the experiments initially started just in the tundra found in the Arctic and had encompassed over twenty five sites worldwide. All experiments have to be carried out in the same fashion to insure that the data can be compared among the different sites. ITEX established that 10 plant species are the main focus because they are observed to have a dominant importance in these regions and are all over the entire tundra biome. These species are studied for phenology, and growth. Other simple experiments are carried out measuring temperature of soils and air, along with the measurement of soil moisture as well. Since 1992 some alpine tundra study sites have been identified, but the number is limited due to funding.

Once a year an ITEX workshop is held to compare data from the different sites to make sure everyone is carrying out experiments the same way and if new experiments should be added. Subgroups are created to allow a concentrated focus on carrying out new experiments on individual biotic species. Some of these new experiments include monitoring the photosynthesis of plants, testing and measuring leaf size of graminoids, and how changes in snowmelt is altering plant nutrient contents.

ITEX employs two major protocols in their experiments. The first one is to passively warm small areas of tundra, and the second is changing the length of the growing season by timing the snowmelt. There are also three different degrees of sophistication that these experiments occur and the higher the level the more complex the experiment gets. Degree 1 is the most basic and is just monitoring of the change in phenology, growth and the climate in the area. Degree 2 is a little more complex in the fact that simple warming and snow manipulations are carried out artificially and then employ the same aspects that are observed in Degree 1. Finally Degree 3 is the most complex and is completely controlled in a laboratory.

Many sites use a contraption called an open-top chamber (OTC), which is a site that has walls made of fiber-glass or Plexiglas to create a warm layer of air around the site. The top of the OTC is left open to allow precipitation and sunlight in, refer to Figure 2.3 for an example of an OTC. These OTCs are sometimes left year round and measured for snow depth and temperature. A variation of this experiment is to change the amount of snow in the OTC. This is achieved by the either addition or removal of snow or the building of a snow fence.

Figure 2.3: Open-top Chamber similar to the ones used for an ITEX experiment.
http://www.ars.usda.gov/IS/AR/archive/jul97/gcf0797.htm

Short term results from ITEX and the OTC sites have been compiled from many of these annual workshops. (16) The first major observation is the fact that temperatures at OTC sites were 1-3 °C warmer during the growing seasons. From this increase in temperature it was observed that plant growth and phenology had changed. In some sites researchers even added nutrients to the OTC's and the growth is even more significant. In fact in many of those sites the dominance of one species was taken over by another.

However, long term effects may cause the results to become eschewed. Pollination is a major concern because with the OTC in place, wind and insect pollination maybe impeded. This would cause another variable in the calculations and unwanted data would then be collected. Scientist wants to ensure that the OTC's are not disturbing the tundra any more than what is already occurring.

III Methodology

To be able to make decisions on what is going on in the alpine tundra of the Colorado Basin area, the research for this paper must make many assumptions. There is very little information on this exact tundra region, but research has been done in other tundra regions. The information from all the sites will have to be compared to one another and then the most common factors will be assumed to be also applicable to the tundra biome of the Colorado Basin.

Alaskan Arctic and alpine tundra have been studied extensively for the shifting of plant community zones caused by global warming, soil warming, and N deposition. The data and results from these regions will be compared to the little experimental data and results collected from the alpine tundra of Colorado. Temperature difference in the two regions can be ignored because the primary focus is on the change on global temperature. If the plant species are similar in both the tundra regions in which the study is carried out and the Colorado River Basin tundra then inferences can be made on what may be occurring.

To make sure the experiments are carried out in a similar fashion, so later that they are able to be comparable to one another, organizations have been started to ensure that experiments are done in this similar manner. These organizations also carry out many laboratory experiments to ensure that the complete control of variables have proven helpful. The data collected from these organizations will be a helpful insight, but cannot be considered 100% comparable. If the data that has been collected from natural sites and laboratory sites have a significant difference, it can be assumed that more is going on in this ecosystem beyond our comprehension.

These different sources of information and collected data will be used to make logical inferences on what is going on in the alpine tundra of Colorado Basin region for this paper.

IV Plant Community Research

A. Global Climate Change

1. Alaskan Tundra ITEX Experiment

Alaskan tundra has had a lot of research done on its ecosystem and contains many similar plant species as the alpine tundra of the Colorado Basin. This particular experiment was carried out using the ITEX guidelines and an example of one of the many experiments this organization carries out. Since this was a controlled experiment, it should provide a strong basis of comparison and help assist certain hypothesis about the alpine tundra of the Colorado Basin.

The parameters and focus of this experiment were to increase the growing season by 30% and in turn increasing the soil temperature. This experiment was performed 1.5 km southwest of the Toolik Field Station, Arctic Alaska at 2,395 ft above sea level. The use of snow blocks, removal of snow cover in early spring was used to help increase the growing season by having the snow melt completed earlier in the spring. Another key factor in an earlier growing season was having warmer soil temperatures. This was accomplished at this field site by using a 1400-watt generator to heat greenhouse heating wires for two hours a day. Photosynthesis was then measured in seven different vascular plant species over a three year period (1997-1999). These species included *Eriophorum vagginatum* L. (graminoid), *Carex bigelowii* Torr (graminoid), *Ledum palustre* L. (dwarf evergreen shrub), *Vaccinium vitis-idaea* L. (dwarf evergreen shrub), *Betula nana* L.(dwarf deciduous shrub) and *Salix pulchra* Cham (dwarf deciduous shrub). Examples of these species can be seen below in Figure 4.1. Negative, positive, and inconclusive effects were found during this three year experiment. (17)

Figure 4.1: Tundra meadow consisting of *Eriophorum vagginatum* and *Betula nana* plant species. http://esp.cr.usgs.gov/research/alaska/alaskaC.html

Lengthening the growing season can lead to many negative effects in the plant community. Water limitation or stress, becomes a factor during the later part of the growing season for many these species during a normal growing season. With an extended growing season, this water limitation was predicted to become worse and limit plant photosynthesis and growth rate. Transpiration will then decrease as the depth at which the soil was thawed increase and if there are warm-dry periods of weather, this can lead to major complications. Complications can include reduction in plant growth due to a decrease of water in the rhizosphere. If the water stress was continued for a long enough periods then photosynthesis will also decrease and the carbon sink capacity could be reduced as well.

When water was not a limiting factor for plant growth, then many positive effects occurred for a lengthened growing season. With the addition of warmer soil temperatures, roots of the *Eriophorum vaginatum* gained the ability to acquire nutrients improved and that increased its plant growth. The deciduous shrub *Salix pulchra* also showed signs of a positive response to warmer soil and no water limitation. This shrub was able to increase the diameter of its xylem vessels. This vessel controls the rate at which water is absorbed and that helped lead to an increase in physiological activity. These two plants experienced individual significant changes due to treatment for at least one year during the study. Most species were not able to provide significant statistical change in the physiological measurements year after year.

Insignificant statistical change during this experiment has led many scientists to think that other limiting factors may occur for these communities. Internal constraints could have caused this low change in compared with the control. It was possible that the plants have constraints on their physiological processes even when climate change occurs. The photosynthetic capacities of these plants remained unchanged and may be a sign that these plants have set growing season lengths no matter what occurs.

2. Isla Myers-Smith Alaskan Experiments

Isla Myers-Smith has carried out a study on the Alaskan tundra shrub expansion and has had some significant results. The field research for the Alaskan tundra shrub line expansion was done through the Arctic Institute of North America's Kluane Lake Research Station and with some remote field studies in the Ruby Mountain Range, Burwash Uplands, and in Kaskawulsh Glacier valley. These field studies were mostly in the southwestern Yukon and these regions experience air masses from the coast and from the Arctic. Climate change would then invariably affect the temperature during the winter months and the amount of precipitation could be greatly affected. (18)

Myers-Smith based much of her study from the increase of the shrub region in the Arctic Alaska that has been observed over the past 50 years from aerial photographs. These photographs have shown a rapid expansion of these areas and demonstrate the newest invasions of tall shrubs because of local climate warming. Figure 4.2 below, shows an example of the types of vegetation maps created to observe the rapid expansion of the shrub line. Paleoecological evidence shows that the last time this has occurred was between 7,000 to 12,000 years ago during the warming after the last glacial period. Even though satellite imagery has shown that as the climate warms, the tundra seems to be getting greener, it was not necessarily caused completely by global warming. Many other factors were considered to be contributing factors, including nutrient mineralization, snow depth, disturbances, and species interactions for this rapid expansion of shrubs in the tundra. The effects of having an increase in shrub coverage in the arctic and alpine tundra will have its positives and negatives for the ecosystem. (18)

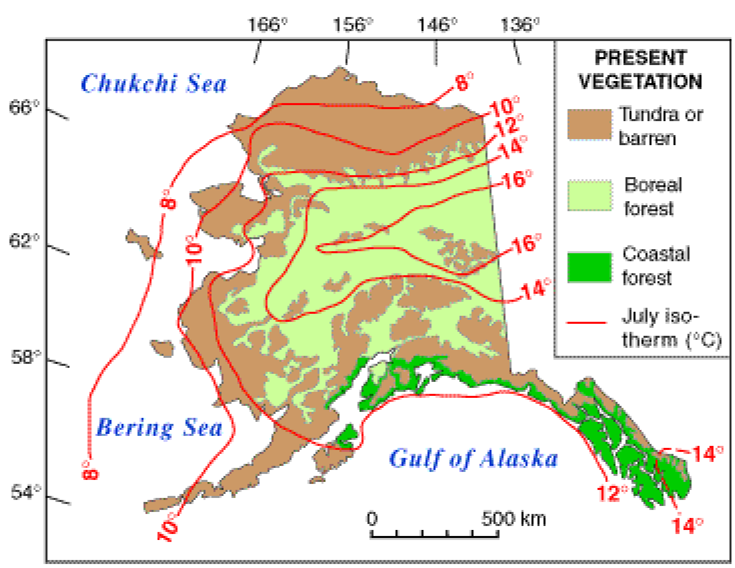

Figure 4.2: 2004 vegetation map of Alaska courtesy of Dan Muhs.
http://esp.cr.usgs.gov/research/alaska/

The largest negative impact was the amount of nitrogen and other vital nutrients for plants and caused them to be distributed differently. These were inferred because some plant species were not able to absorb nitrogen as effectively and were predicted to become extinct. Also the increased size of the canopy of the shrubs was predicted to decrease the amount of light that can be absorbed by the plants underneath these canopies.

The increased canopy size will have less light reflect off the snow and back into the atmosphere. In turn this may be able to reduce the climate warming effect, but no evidence has been discovered to prove this assumption. No matter what the increase in the shrub density and distribution there was a change in the tundra regions that will have been magnified and will result in major ecological structural changes.

Myers-Smith had three major objectives for her study that had to deal with the expansion of the shrub line. Her first objective was to create a pattern in which the shrub line advanced in relation to climate warming and other disturbances. The next objective was to see how the carbon cycle was affected and how the species composition has been changed. The final objective was to evaluate the importance of ground temperature and the amount of nutrients in the soil as a facilitator in shrub expansion.

The increase in temperature of winter soils will result in faster nutrient cycling, and changes in plant communities. The first impact of warmer soils was due to the fact shrubs trap snow underneath them and thus insulate the soil, keeping the temperature warmer. This will in turn increases the shrub canopy cover, which will cause a decrease in species plant diversity and the dominance of herb tundra plant species.

3. Qinghai-Tibetan plateau

Studies have been carried out on the Qinghai-Tibetan plateau, China that showed the affects of global climate change on the distribution of plant species. From 1959-1996 an observation of an annual 0.4°C-0.6°C temperature change was observed in the Haibei Alpine Tundra Ecosystem Research Station area. This temperature led scientist into creating a vegetation map that will explain the affects if the global temperature continues to rise. Figure 4.3 is the Qinghai-Tibetan plateau, which the area of focus for this experiment. (19)

Figure 4.3: Qinghai-Tibetan Plateau meadow.
http://spacescience.arc.nasa.gov/highlights/news.cfm

The map incorporated many different factors that affect the soil temperature on this plateau. The distance from the stream contributes to significant temperature difference. Plants within 10 m of a stream or body of water would experience soil temperatures close to the temperature of the body of water. However, plants at 600 m from the body of water will not be affected by the soil temperature. Another factor that was utilized was the soil temperature decrease because of the increase in elevation. The final factor was the suitable soil temperatures to promote plant growth. The optimum temperature range was found to be from 5° -13° C and the temperatures above and below were found less suitable or reduced plant growth. (19)

The first vegetation map created, observed that the *Dry Potentilla* Shrub could possibly increase its area of growth by 23% if the global mean temperature increased by 1°C. The *Dry korbresia* meadow could also expand its vegetation by 23% especially if the global mean temperature was increased 3°C. Basically areas that are characterized by more wet vegetation will experience a change in dominant plant species if the global mean temperature was increased to 3°C because there was just not enough water available in the warmer climate. (19)

The vegetation model created during this study did leave out other important factors that contribute to the distribution of plant species. The competition from other plant species and grazing animals was not taken into account. Those two forms of competition were harder to model and added some uncertainty to the final vegetation map.

The vegetation model did a good job in representing the affects of global climate change on plant species of the alpine tundra. It was able to map the areas at which the soil would lose water due to higher evaporation rates and the redistribution of the plants in that area. The map was also able to show which species are more water and soil temperature dependent then the others.

B. Exotic and Hybrid Invasive Species

Exotic species can start to inhabit new areas directly or indirectly, but some form of disturbance needs to occur. If a certain resource was increased in availability an exotic species may have the ability to utilize that resource better then the native species. A disturbance in the ecosystem that reduces the native species could also result in the invasion of an exotic species. The last way an exotic species can disturb the native ones was through hybridization. In this case, the hybrid species could obtain the positive qualities of both species and out compete for resources.

Native to North America is the *T. ceratophorum* Alpine dandelion species and then the exotic species to North America is the *T. officinale* dandelion. Figure 4.4 represents the native dandelion species *T. ceratophorum*. These two species were used in an experiment to test what happens during drought conditions. The test was conducted in both lab and natural settings. (20) The experiment used both high and low levels of water availability to observe any differences in physiological performances.

Figure 4.4: *T. officinale* dandelion or common dandelion is exotic to the United States.
http://www.maine.gov/dep/blwq/doceducation/jeepers/dan.htm

Field results showed no significant difference in the long term and instantaneous water use efficiency of the two species. The data collected had the native dandelion species being less wasteful during drought conditions and was more successful living in the dry Alpine conditions. Although it performed better, the statistical evidence was not so drastically different to make any positive conclusions.

Greenhouse studies showed a significant difference between the two species during drought conditions. The native species' photosynthesis ability during the drought conditions seemed to be unchanged compared to control conditions. The exotic species showed a decline in photosynthesis when being placed under drought conditions compared to the control condition. Both species during the control condition on the other hand showed no difference in photosynthesis from one another. The greenhouse studies represent the ability of the native species in adapting to dry growing seasons in the alpine tundra in the Rocky Mountain area. The exotic species showed its intolerance to moderate or severe drought conditions and inability to overcome them.

Hybrids of the two parent dandelion species did not show any significant differences from the others. During both the well-watered and drought conditions no sign of increased ability to compete for resources was observed.

Drought could be a limiting factor for exotic dandelion species invasion of the Alpine communities. This allows the native dandelion species not to have to compete for resources in this area from an invading exotic dandelion species. Changes to the environment could occur that may allow the exotic dandelion species the ability to move into this environment in the future. Another change that may occur is the increase of atmospheric CO_2, which could allow the spread of this exotic dandelion because it can relieve the stress of water limitation in photosynthesis.

C. Nitrogen Deposition

Nitrogen is used around the world for many different reasons and many of them are for a source of energy, fertilizer production and crop cultivation. The amount humans fix for these reasons are far greater then the rate at which nitrogen can be fixed biologically. All this nitrogen use has resulted in having wet and dry deposits of nitrate and ammonium. Figure 4.5 represents the nitrogen dioxide use of the United States in a two month period. Basically, areas that have not been used to having an excess amount of nitrogen are now getting much larger amounts of it, such as the Alpine tundra. This has been a very controversial issue among many scientists and it seems to be more of a debate on what exactly the ecological effects might be.

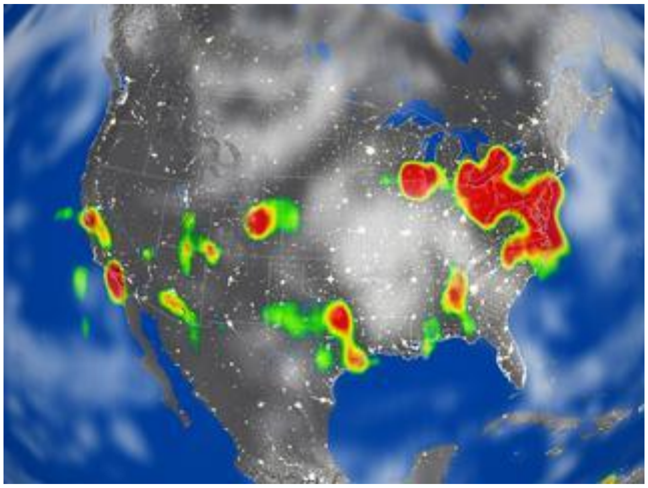

Figure 4.5: Nitrogen dioxide concentration over the United States from September to November in 2004. http://svs.gsfc.nasa.gov/vis/a000000/a003000/a003073/

Studies have shown that there are areas in the Colorado Rocky Mountains that have N saturation, which means that there is more available nitrogen then is naturally used by plants and microbial nutritional demand. However, it has been shown that this is only the case for the Colorado Rocky Mountain Alpine and subalpine watersheds and the Alpine tundra and subalpine forests in the Front Range are nitrogen limited. This is a cause of concern for many ecologists who are trying to figure out what's going to happen in this delicate region. Many predict that with this N saturation it can be expected to have increased rates of N-mineralization and nitrification, more release of nitrous oxide gas from soils and increased foliar N concentrations. With areas with greater N saturation it is expected that a decline in the biomass of fine roots, foliar, and net primary productivity will be observed. The biggest question for many is what will happen to the Front Range if it starts to experience N saturation?

The Alpine tundra has limited primary growth due to the short growing season, high moisture, and low seasonal temperature. The plants in the tundra are very nitrogen sensitive since around 1-2% of the nitrogen in the tundra is stored in plant roots. The rest of the nitrogen varies from being in organic matter and a little is in microbial biomass. Studies done at the Niwot Ridge in the Front Range have done studies that show nitrogen cycling process depends on moisture regime. (10) In the wet meadows of this region an experiment was done in which fixed nitrogen was added directly to the soil. The results were that the dominant plant species shifted from *Acomastylis* to *Dechampsia*. The new plant species will overcome the former because of its greater rate at which N-mineralization and nitrification happens. The hypothesis to date is that the alpine tundra plant communities will shift from N-limited to P-limited, if more nitrogen is added to the region.

Interesting correlations between N deposition and snow pack have occurred. With just increasing the amount of N by 8g $m^{-2}yr^{-1}$ alone, has resulted in an increase in survival of *Salix* shrub species. The opposite effect is achieved if N is added along with snow to the area causing the survival rate of *Salix* to be decreased. (4)

Nitrogen deposition has been observed to cause many effects to the Alpine tundra in the Niwot Ridge area and other areas around the world. This means the emissions by humans of Nitrogen should be limited to preserve this fragile ecosystem.

D. Herbivores

Herbivores are a major impact on the Alpine tundra plant communities from influencing the biomass, nutrients dynamics in soils, and distribution of plants within the communities. Some herbivores may target certain plants in the region for the nutritional value. Negative results can occur if they are targeting a plant that is already suffering from competition among other plants invading the region. Such as the studies carried out in Alaska, elk-aspen and moose-balsam fur systems proved that the expansion of woody shrubs is could be limited by large herbivores.

Herbivores have helped reduce plants responses to global warming, an example of these herbivores can be seen below in Figure 4.6. As a whole, the tundra plant communities above ground biomass have experienced a 33% increase because of global warming. (21) Muskoxen and caribou in this region helped reduce this response by 19%.

Figure 4.6: Caribou traveling through a meadow.
http://www.nps.gov/archive/lacl/scrapbook/caribou.htm

Dwarf birch and gray willow species in this region were also measured to have a reduction in plant biomass increase because of herbivores. The herbivores are helping control plant species from having rapid growth responses from global warming.

In the absence of herbivores dwarf birch increased in response to warming and graminoids declined. The opposite observation can be made when herbivores are present in the area. This could be caused by herbivores deposit of fecal and urinary nitrogen onto the soil which helps graminoids because of the excess amount of nitrogen available. Thus the effects of global warming may be reduced because of the animals' ability to help the nitrogen cycle.

Snowbed communities are selected by many herbivores for grazing and are thus directly affected. Lemmings during low population density years prefer to graze the snowbed communities and even reindeer during snow free months prefer these communities. The plants have adapted to this grazing by having subterranean rhizomes.

These rhizomes are not damaged during grazing and can regenerate growth as grazing pressures decrease. During these decrease in grazing pressures many snowbed communities experience an increase in biomass and are almost as large as tall herb meadows.

V Conclusion

It is difficult to make any positive conclusions on what is going on in the Alpine Tundra of Colorado basin as the result of climate change, but from the research done many strong inferences can be made. There are many changes that are occurring in these regions because of changes in overall global temperatures and the increased amount of atmospheric nitrogen. These changes in the composition include the increase of invasive local and regional species, exotic species, soil warming, herbivore consumption, and basic disruption.

Global warming has caused similar regions to experience earlier snow melt dates and increased soil temperature. This has had adverse effects on those communities and also had some positive effects on these communities. Many plant species experienced increased growth and earlier photosynthesis's activity, which has caused longer growing seasons. However, due to the earlier snow melt and warmer soil, it has allowed plants from lower elevations to be able to live in this region. The native plants are not capable of being able to always compete and causing their decline. Since native species are in a decline in the area, it also decreases the biodiversity in the tundra and can affect higher trophic levels.

Exotic species are generally able to invade a new region because of a disruption that can include warming of the climate or an excess of available nitrogen. In the case of the native and exotic dandelions of the Colorado Basin area, the native species is only able to survive due to their greater adaptation to the dry Alpine climate. This has been speculated to change if other disruptions, such as excess nitrogen being available, occur and allow the exotic species be able to compete more efficiently with the native one.

Herbivores have also played a major role in tundra regions. In the Alaskan tundra, the herbivores are a consumer of many tundra species. Muskoxen and caribou are able to help reduce the effects of global warming by being able to consume the growth of invasive species, which in turn will give native species the opportunity to survive the competition from invasive plant species. The herbivores also provide a window of new observations on how much theses plant communities have adapted to their environments. Even when populations of herbivores, lemming, are in great density and grazing on the snowbed communities, they are able to carry out new growth due to adaptations they have gone through.

These studies have provided enough data to make strong influences on what is going on in the alpine tundra of the Colorado basin. Climate change and nitrogen deposition has provided a gateway for local and regional species to be able to grow at higher elevation and compete with native species. Exotic species are also able to make an attempt to invade these regions because of these global changes. The native species are able to survive because of varies forms of adaptations that allow them to live in this harsh environment, but may not last long if these changes continue for the foreseeable future. Herbivores have helped in the native plants species survival by eating many of the invasive species and reducing their rapid growth, but it is still under study. If these sensitive regions are any indication on what may happen to other biomes, then a greater focus must be made on these “canary in the coal mine” warnings.

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