I. Introduction

Project Number: TCC – 08B

GLOBAL WARMINGS EFFECT ON ANIMAL SPECIES IN COLORADO RIVER BASIN ALPINE TUNDRA

An Interactive Qualifying Project

Submitted to the faculty

Of the

WORCESTER POLYTECHNIC INSTITUTE

In partial fulfillment of the requirements for the

Degree of Bachelor of Science

By:

Calvin Robertie

Date: May 4, 2009

Approved:

Professor Theodore C. Crusberg, Advisor

Abstract

The Colorado River Basin alpine tundra has experienced recent climate changes which are affecting the animal wildlife in the tundra. It was very hard to find the exact numerical changes in species population in alpine tundra's. However animals are very dependent on there environment, so when that changes it is safe to assume it affects the wildlife. This project investigated the changes occurring in the Colorado River Basin alpine tundra and draws conclusions on how it may be affecting animal wildlife.

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Alpine tundra are an ecosystem that are at extremely high elevations, the highest that allow for plant and animal life. The harsh environment of cold temperatures, long winters, and short growing seasons make it possible for very few species to survive. Because of these extreme conditions even the slightest change in climate has an effect. Alpine tundra is a very good indicators for global warming for this reason.

The Colorado River basin is a watershed area in the south western United States as shown in figure 1.1

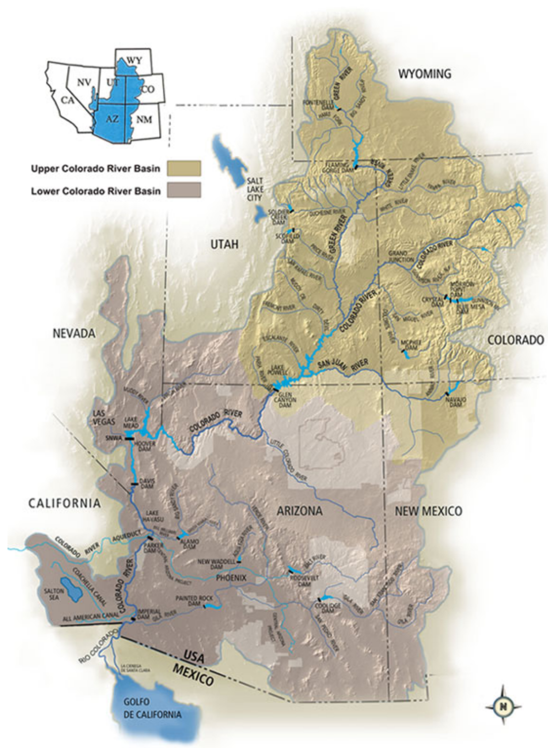

Figure 1.1 the Colorado River Basin watershed.
http://www.gcdamp.gov/images/ColBasinfinal.jpg

The Colorado River stretches 1,440 miles long through seven states. The water from the river supports over 24 million people in the southwest from Denver to Los Angeles, and is an irrigation source for two million acres of farm land (1).

The area of concentration for this paper was the Niwot Range, in the Front Range of the Colorado Rockies. Niwot Range is a particularly good site to investigate because of the LTER station there. The Long Term Ecological Research site at Niwot range has been there since 1980. This LTER station records extensive climate records, which helps in our understanding of the changing climate in the area. It is also a base point for many short and long term scientific studies on the alpine tundra (28).

Animals are a good indicator of a change in an environment because they rely on it to survive. Plants are also a good indicator of a change in climate. However exotic species can invade a new ecosystem because of a short term trend in climate, by human interactions, or a number of other factors. Animals are less likely to be affected by small changes in their environment. A significant change must occur for it to effect the entire population of a particular animal species.

Global warming is a real current threat to the world. However it is not known what is an acceptable variance in global temperatures. Figure 1.2 shows the change in global warming since 1900.

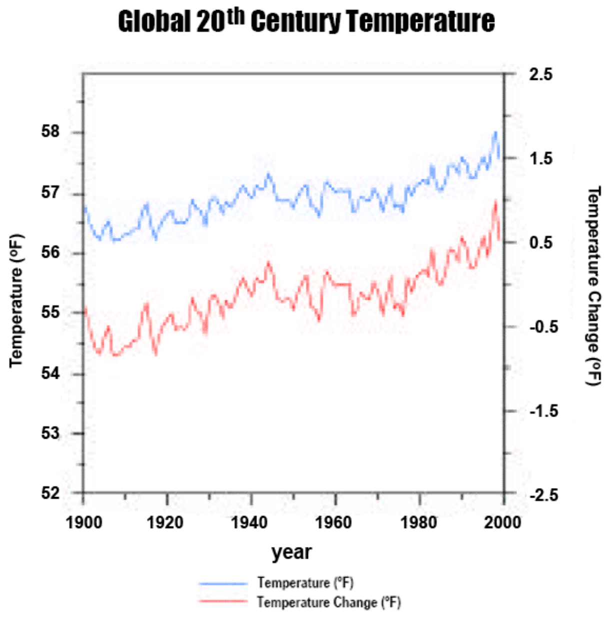

Figure 1.2 Global warming in the 20th century
http://www.cabq.gov/albuquerquegreen/stop-global-warming-1/albuquerquegreen/images/20th-Century-Temperature.gif

Since alpine tundra is so sensitive to changes in climate it is a good warning signal for a significant change in global temperatures. The growing seasons in the alpine tundra is so short that a small change will have a proportionally larger effect to the ecosystem than the same change in other ecosystems.

Tree line is another indicator of climate change. Changes in temperature will affect the elevation limit of trees. However what amount of advancement of tree line is significant, 5 feet, 50 ft, 500 ft? Small variations on tree line can be accounted to the variations such as seed dispersal. Seed dispersal can vary from year to year depending on wind direction. Tree lines must be studied over a long period of time to find significant changes in elevation.

Nitrogen deposition is another relatively new occurrence in alpine tundras. While N deposition is a natural occurrence, levels in the past decades have been higher than normal. Nitrogen in being pumped into the atmosphere from the burning of fossil fuels and farming fertilization and is causing an excess amount to become deposited in the alpine tundra. It is not known if this excess amount of N will have a positive or negative effect on the alpine tundra community.

Although the alpine tundra is seen as a great indicator for global warming, not much research is being conducted there. The extreme location is partly to blame. Studies conducted in the tundra are also limited because it is such a sensitive ecosystem. Damages to alpine tundra can take hundreds of years to recover, so experiments have to be conducted very carefully and on very small scales. The studies that are being conducted in alpine tundra across the world are producing alarming conclusions.

II Background

A. Alpine Tundra

Alpine tundra is roughly described as an alpine area above tree line. In the Niwot Range of Colorado tree line is roughly 12,000 feet. Alpine tundra is similar to arctic tundra, however there are differences. Arctic tundra has more permafrost which limits the types of plants that can grow. Alpine tundra then has a smaller number of native animal species and a larger number of plant species. In alpine tundra the climate is so harsh that many plants can’t grow in it. The physical terrain of the tundra is mostly a mix between grasslands, rock patches, and glaciers.

The climate in an alpine tundra is one of the harshest found on the planet. The weather is so extreme that it is on the edge of not being able to sustain any form of life. For eight months of the year the mean temperature is below freezing. This creates a short growing season, affecting the types of plants that are able to grow in the tundra. The tundra receives a large amount of precipitation yearly. A large amount of this comes in the winter months, meaning the tundra receives large amounts of snow. Wind is another harsh characteristic of the tundra. The treeless tundra is very susceptible to high winds. Also the location of the tundra increases its winds. being so much higher than all other ground, the wind has very few obstructions.

Due to altitude and climatic affects, the terrain in the alpine tundra is somewhat barren. Lower elevations in the tundra support grassy plains with flowers and small shrubs. At these lower altitudes the growing season is longer due to slightly warmer temperatures and the snow pact melting earlier. The middle regions of the tundra do support some plant growth but are often rocky outcrops. These regions are covered in snow for a large portion of the year and have a short growing season. The highest elevations in the tundra are the tops of the mountains. These mountains are often jagged rocky peaks, which support a very small amount of life forms.

Figure 2.1 Alpine Tundra during the summer months.
www.wy.blm.gov/botany/pics/tundra-320.jpg

Glaciers also cover large areas of the tundra. A glacier is roughly described as an area of land, roughly larger than 2 kilometers square that is covered in snow for two years. Glaciers are a snow and ice mass that move down through a valley, and often have a pond, lake, or stream form at the bottom where the runoff accumulates. Some glaciers have been present in the tundra for thousands of years, and it is not always certain what lies in the ground below them. Glaciers are the main source of water for the plants in the tundra. Since the summers offer very little precipitation, runoff from the melting glaciers becomes the main source of water for the live on the tundra. In recent years shrinkage of glaciers in the Rookies has occurred and it has created more open land for plants and animals to inhabit.

The vegetation in alpine tundra is controlled by the topography and weather. Harsh winds do not permit the growth of trees, and cold temperature creates a short growing season. The rocky outcrops in the mid to high elevations of the tundra are only able to sustain small lichens. These areas are snowless throughout the year due to high winds. In the mid and lower altitudes of the tundra many different types of grass and flowers are able to grow in the grassy plains. This area has soil that is nutrient rich and supports turf. These areas have the least amount of snow cover throughout the year, creating the longest growing seasons, sometimes lasting 200 days. These areas can differ depending on snow pack and snow melt. The only areas that allow any plant growth larger than grass and flowers are on the edges of the ponds and streams. These shrubs grow to roughly eighteen inches tall. The vegetation in the alpine tundra is very fragile. Variations in yearly weather patterns including temperature and precipitation can have large effects on species populations (2).

The native animal species in the tundra consist mostly of herbivores. The food and weather conditions greatly limit the number and type of species that can survive in the tundra. The majority of species that live in the tundra are voles, marmots, and shrews. The small herbivores feed off the grass and flowers that grown the grassy plains. They are also very good at insulating themselves and can survive extreme temperatures. Mountain sheep, elk and deer also graze the grassy plains and are good at protecting themselves from the harsh environment. The only carnivores that are found occasionally in the tundra are coyotes, wolves, bears, and weasels. These larger animals prey on the small herbivores that are also in the tundra (3).

These animals found in the tundra also live in the Krummholz, the area just lower in altitude than the alpine tundra, which is mostly small elfin trees. The alpine tundra in more constricting of the plants found there than the animals found there. The animals often wander into the lower Krummholz zone or even lower. These animals are all known to hunt and live in the tundra from year to year. Many other species are rarely found in the tundra, however if they are not a working part of the ecosystem from year to year they are not consider natives to the tundra. None of the native species are truly native and live in the tundra year round, they spends there winters in sub-alpine zones (4).

Birds are also found in the alpine tundra. There are very few species of breeding birds, however a large number of visiting birds who still play a large role in the ecosystem. Predator birds include hawks and falcons which hunt the open grassy plains. Other birds regularly found in the tundra include doves, crows, sparrows and finches. These birds forage the open grassy plains to feed their young.

The alpine tundra is an intricate ecosystem and is greatly affected by the climate and terrain. Because of the high elevations, people have very little direct impact on the tundra. Alpine tundra is a place of extreme weather, and the flora and fauna that live there are able to adapt to the harsh environment and survive. However none of them can survive all year, as many move further down the mountain in the winter months. Slight variations in yearly weather can affect the plant growth and diversity during the summer, which in turn affects the animals that can survive in the tundra. The alpine tundra is a harsh and unforgiving ecosystem that is also fragile and affected greatly by small changes in climate.

B. Colorado River Basin Features

Running over 1,400 miles through the Western United States, the Colorado River is a key feature of the US, providing water, irrigation, and power to millions of people, while creating and influencing the habitats and environments of untold other forms of life in the area surrounding it. At its beginning, the Colorado River runs through the Rocky Mountains, at an elevation of nearly 10,000 feet. However, it eventually does reach the ocean, after passing through Colorado, Utah, Arizona, Nevada, California and Mexico. Coincidentally, these areas are some of the most arid parts of the United States (with the exception of Mexico), making the fresh water of the Colorado River necessary for many people. Despite the fact that the majority of the land through which the Colorado River passes receives substantially less than 15 inches of rain annually, the river is still able to amass about 15 million acre-feet per year of water flow by the time some of it is discharged, very occasionally into the ocean, making it the sixth largest river in terms of flow in the U.S.(1). This water is put to use not only providing freshwater to approximately 31 million people living in the Western United States- including the residents of Pheonix, Las Vegas, and Las Angeles- but also providing irrigation to two million acres of land in the West (5).

Despite flowing through an incredibly dry area, the Colorado River is still able to amass a considerable volume of water because of the size of the basin from which all flowing water flows into Colorado River. This watershed covers approximately 244,000 square miles of land area, or one thirteenth of the total area of the United States. Water comes to the river from seven different states- in addition to those already stated, it also flows from Wyoming and New Mexico- flowing into ten different major river systems (the Green, Yampa, White, Virgin, Little Colorado, Verde, Salt, Gila, San Pedro, and San Juan Rivers) which themselves eventually join the Colorado River. Within these rivers and the Colorado River, there are 10 major dams and 80 major diversions set up, creating reservoirs for drinking water and with 4000 megawatts of hydro-electric generating capacity (1). Within the Colorado Basin are a large portion of the Rocky Mountains, and all the environments contained therein, in addition to various desert regions, a considerable amount of agricultural land, and several natural wonders such as the Grand Canyon and other national parks and monuments. The basin itself is split into two sections: the Upper Basin including parts of Wyoming, Colorado, Eastern Utah, and Northwestern New Mexico; and the Lower Basin, including parts of Nevada, Southwestern Utah, Arizona, and California. Each section has its own rules and regulations for the use of the Colorado River and as a result there is a well-defined line between the two.

Glaciers and Role in Tundra Ecosystem

At the top of any mountain of considerable size is an area of alpine tundra, upon which one may often find glaciers, although their size and position may vary depending upon when the sighting is done. Throughout the world, glaciers contain 75% of the available freshwater, despite covering only 10% of the Earth's land (approximately 15,000,000 square kilometers), although the majority of glacial area is in the poles rather than alpine glaciers, and these numbers are subject to gradual change- in the last ice age, which ended about ten thousand years ago, glaciers are estimated to have covered 32% of the world's land surface. In addition to major ice ages, minor climate shifts that affect glacial coverage are relatively common, as shown by the “Little Ice Age”, which lasted from the 17th to late 19th century, and allowed substantial glacial advances.

Glaciers themselves are ice masses that are formed by snow buildup that does not melt through the year and so is able to form solid ice, individual crystals of which have been known to be the size of baseballs. However, this ice is of such considerable mass that the pressure of its own weight is enough to transform it into a plastic material and allow it to flow, albeit very slowly, on the order of 10-200 meters per year. This flow results in several characteristics of glaciers. First, the top of the glacier tends to flow faster than the bottom as a result of friction with the ground. Also, when the glacier surges and flows faster than the ice bonds are able to handle, crevasses form where it is flowing fastest. Finally, glaciers will grind up the material they flow over, leaving bands of debris and ground stone behind them. There are a wide variety of types of glaciers, depending upon their shape, orientation, flow direction, and where they are situated. While “ice fields” and “valley glaciers” will likely have little to do with the alpine tundra, types such as “ice caps” and “mountain glaciers” will likely be of more relevance (6).

With regard to climate change, the examination of glaciers can give substantial information about both past climate trends and current ones. Since glaciers can be hundreds of thousands of years old, accumulating a new layer of snow each year that is eventually packed into ice, it is possible to remove a core of ice from the glacier and by examining the thickness and composition of the layers ascertain various information about past climates, much like looking at tree rings. As to current climate change, glaciers are very susceptible to changing climates, advancing more rapidly as the climate cools (allowing more snow to stay frozen) and retreating or advancing more slowly in a warming climate (as additional snow melts each year). Therefore by examining the movement of glaciers over a series of years scientists are able to ascertain a general trend of climate change throughout a region or worldwide.

Glaciers, although not being particularly conducive to life in and of themselves, are in fact integral parts of the ecosystems of the alpine tundra. Most importantly, the water that comes from melting glaciers is a primary source of freshwater for both the species of the tundra and those living below the tree line (including humans). Particularly in years of drought, glaciers can be counted on to supply much needed freshwater for alpine animals and plants. In addition, species of animals in the alpine tundra have often evolved so as to be able to camouflage themselves with the glaciers, making these areas key to their survival. These animals also tend to be dependent upon the cool temperatures of the tundra, and so when the temperature is particularly warm during the summer glaciers are sometimes necessary in order to keep the animals' body temperature down.

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 states that eleven of the past twelve years have been the warmest since 1850 (7).

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 (8).

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 (10).

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 conducted 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 (11).

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 building 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 accumulating in the atmosphere resulting in the trapping of the sun's heat.

Some experts oppose the idea that global warming is being caused by 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 (12).

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 1 m 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 (13). With sea levels estimated to rise between 0.18 m to 0.59 m from 1990 to 2100, according to a report released from the Intergovernmental Panel on Climate Change, this estimated cost may become a reality (14).

III. Methodology

In order to predict the future of animal wildlife in the alpine tundra of the Colorado Front Range I will have to draw conclusions from many other factors and sources. Unfortunately due to the remote location, geography, and habits of animals in the alpine tundra it is very difficult to track exact population numbers. While there are very few studies being conducted on animal species in the tundra, they are being done on locations all over the world. To better predict what will happen in the alpine tundra of the Colorado Front Range, findings from other parts of the world will be considered, similar to what is happening in the Colorado basin.

While there are studies that focus directly on specific species in the alpine tundra, there are not many that examine the whole spectrum of wildlife in the tundra. Many animals that live in the tundra migrate between the tundra and alpine zones in mountain ranges. Because of this it is very hard to track animals. Also it is very hard to define the direct impacts global warming is having on the species living in the tundra. When studying plant species it is very easy to take a sample area and conduct tests on it. This is an easy way to test what effect continued global warming has on that particular species. However it is very hard to do this on living moving animals, most of which do not exclusively live in the tundra.

In order to make conclusions on the future of wildlife in the tundra I will draw on information from all aspects of the tundra. I will divide the wildlife in the tundra into two types, predator and prey. The predators follow the prey in search of food; they are solely dependent on prey alone and not as much the environment. The prey however are mostly animals which feed off the plants (or insects if omnivores) that live in the grassy plains. These species are the majority of animals living in the tundra so the paper will focus mostly on them. Studies from alpine tundras all over the globe will be used to help understand what is happening in the alpine tundra in the Colorado Front Range.

IV. Alpine Animal Research

A. Animal Research

Research specifically on how environmental changes affect animal species is the best way to determine how climate change is affecting the animals in the alpine tundra. However, very few articles are published that look at this specifically. Often times these studies can be used to predict how other animals will react to similar changes. Articles generally study only one specific species of animal. Other species that act similarly (eat the same food, and live in the same area, and are of similar size) or are from the same family, can be predicted to have the same response to changes in environment and climate.

One phenomena of climate change is the formation of ground icing, an extreme climatic event. Ground icing occurs during warmer winters. During winters with multiply days above freezing, the snow melts and humidity levels rise. The water sinks to the ground and is frozen again at night. This creates a layer of ice between the snow and ground.

A study in the Svalbard island of Norway investigated how ground ice effected reindeer population. During warm winters where there were many days above freezing it was found that the reindeer populations declined. The ground icing formed in the warm winters blocked the reindeer from foraging for food on the ground after the snow had melted. This unavailability of food is having an increasing negative effect on reindeer population. With past, current and predicted climate changes of increasing temperatures, it is thought that future winters will be warmer and wetter, creating more ground ice (15).

A similar pattern was found in tundra voles. Winter has always played a vital role in the population size of tundra voles but it was not known exactly why. A study conducted over four continuous winters at the Evenstad Research station in southeastern Norway found links to ground icing. The climate at the research center is similar to that of the alpine tundra in Colorado, with snow on the ground from November to late April.

When looking at the survival rates and temperatures during the winter there were two factors, the warmest winters (most days above freezing) had the lowest survival rates and the sex of the vole were also a factor. Females had a higher survival rate than males increasing their ratio to 55% in the autumn, to 70% female in the spring. Females are smaller than males, and it was thought that they could better adapt to the shortage of food better than males.

The winters with the warmest days had a large impact on survival rate. The correlation between warm winters and low survival rates is the formation of ground ice. This ground ice makes food inaccessible in mid-winter. The two warmest winters had large amounts of ice which came from many days where the temperature raised to above freezing. Population density at the beginning of the winter was not a good indicator of population density after the winter, giving more significance to the ground icing effect. There was not an effect due to predators, because the vole's only predators are birds which are not present in the winter. With many other factors taken out, it was shown how changes in climate and specifically the increased number of days above freezing mid-winter had a large effect on survival rates of voles (16).

Figure 4.1 Tundra Vole
http://www.dof.virginia.gov/health/images/wildlife-vole.jpg

The subnivean space is a zone between the snow and ground. It forms from thermal heat given off by the ground melting a small portion of the bottom of snow pack. Small mammals and mostly rodents live and survive in this area during the winter. A study conducted on lemmings show that snow hardness and relative humidity have had negative effects on lemming populations. This is once again the effect of ground icing. While it is believed that predators account for most of the variation in lemming populations increase snow hardness or ground ice also has a negative effect. The ground ice makes it difficult for lemmings to find food and lowers the temperature in the subnivean space (17).

These few studies have shown a negative effect on animal populations due to a trend of warmer winters. However not many studies have looked into how animals deal with rising changing temperatures at other times of the year. Long term studies tracking animal populations throughout the whole year would give a better picture of how changing temperatures are affecting animal species.

B. Rising tree/shrub line

Animals are very dependent on their ecosystems. From finding food to hiding from predators, animals know how to live and survive in their environments. Global warming is allowing the tree and shrub lines to gain elevations and move up mountains. This is shrinking the grassy plains in the alpine tundra. While trees and shrubs can grow and expand into the grassy plains as shown below is figure 4.2,

Figure 4.2: tree line in alpine tundra
http://per.ornl.gov/Kueppers01.jpg

grass cannot expand higher in elevations because soil gets replaced with rock outcrops and eventually ledge.

It has been found that in a short growing season, temperature plays a large role on the annual assimilation. Small changes in temperature in the beginning of the growing season can greatly affect the growth of a tree. It previously was thought that tree growth was limited by the supply of the products for photosynthesis. Trees in cold regions build up carbohydrates to be used in the biosynthetic process; the cold limits the rate at which glucose can be used in that process. Trees at the tree line are more sensitive to the change in temperature because they have all the necessary products for photosynthesis. Temperature has a larger effect on the rate of photosynthesis at lower temperatures (close to freezing) than higher temperatures. Trees will grow faster with warmer temperatures because the rate of cell division will increase. A small change in temperature will have a proportionally larger effect on trees at the tree line opposed to trees in the valleys because the growing season is so short. A slight warming will increase the short growing season, and further allow more time for trees to grow (18).

A study conducted in the Swedish Scandes found drastic results. The site chosen had virtually no other characteristics that would affect tree/shrub line besides the weather. It was in an area that had very little human disturbance or animal grazing. This area has had climate warming that is more than the global average. This made it easier to study the effects of climate change on plants without artificial warming, making the results more realistic. The study investigated the change in elevation limits of shrubs and trees saplings. They used the findings of a study done in the early 1950s which recorded the saplings in the study area. Then in 2000 another study was done in the same study area to find the current maximum elevation of the same eleven species.

The study found an apparent rise in elevation in many species of plants. Six of the eleven tree species found in the study area were found 120-340 m higher than in 1950. The five other species were found with a small elevation change (±20) which is expected to be a normal variation. Only one exotic species was found, and it had very few saplings. The accidental spread of these species could be ruled out because of the similar age and high population densities.

Without animal grazing and human disturbance it would be expected that the species in this area had a greater change in elevation than on average. Winds traveling up the mountain side deposited seeds in the snow beds above tree line. This has been the case during the length of the study, but only recently have the seeds been able to germinate and survive for a number of years. This gives good proof that climactic factors are causing the change. Viewing data from other studies in the region the most substantial rise in elevations had occurred during the 1990s. This corresponds with a decade with warmer than average winters and summers (19).

Another study conducted on Mt. Hochschwab in the Austrian Alps tried to model future changes in tree lines. It has a similar climate to the Niwot Range, with snow covering the ground from October to May. The study area consisted of the space above tree line, which was about 53km^2. The study authors created a mathematical model to predict the increase of shrubs (*Pinus mugo*) covering the study area. The model showed that over the next 1000 years the shrubs would increase their cover of the test area from 10% to 24-59%. The largest factor in the mathematical model was temperature change. In some cases the increase in shrub line would extend to the top of mountain peaks, completely eliminating alpine tundra grasslands (20). This model might not have fully taken into consideration the effects of seed dispersion, human disturbance, and other factors. These factors could become the limiting in tree line advance, and it is difficult to accurately predict these in a mathematical model.

Macrofossils and palynological evidence have shown that tree lines are directly effect by climate change. Pine stumps have been found in peat in the Scottish Cairngroms nearly 200 m higher than the tree line. These stumps were dated to the boreal period (3000-8000 BCE) where it is though temperatures averaged 1.4°C warmer than now. If the global temperature raised 1-5°C over the next century as predicted, the tree line could rise 140-700 m (18). However it is likely that the tree line with not rise that drastically because other limiting factors such as seed dispersion and growth rates will govern the change in tree line.

C. Exotic Plant Species

Exotic plant species are a real and current threat for the alpine tundra. The tundra is a harsh environment that many plants cannot survive in. The harsh temperatures and limited nutrients are not suitable for most plant species. However the climate warming and an increase in nutrient deposition is making it easier for exotic species to survive in the tundra. These new exotic species could dominate and overpower the native species, causing them to become extinct. Since many animal species living in the tundra are herbivores, these new plant species could have a negative effect on the alpine tundra ecosystem (21).

A study conducted in the Swiss Alps examined the rise in zones of exotic species. It tried to determine if exotic plant species could survive at higher elevations than possible a century ago. To conduct the study, 232 sites including railway stations and roads in mountain passes were chosen to search for exotic species. These sites were picked because of the high chance of dispersal from lower elevations by means of human trafficking. Sites rangeed from 100 m^2 to 1000 m^2.

It was found that 63% of the exotic species found in the area were recorded at a higher zone than in the 1950s and 1960s. While there is not much alien invasion in the alpine region it is possible for it to increase in the future. The limiting factor of exotic species in the alpine region is the harsh environment. However with global warming and climate changes in the alpine region, it is becoming more susceptible to invasion of exotic plant species. Warmer winters are thought to be the one factor of climate change that will have the greatest effect (22).

A test conducted in the north-central United States, with one site in the alpine zone of Rocky Mountain National Park, examined the vulnerability of the area to invasive species. It was found the most specie-rich areas were the most likely to be invaded by exotic species. Areas that have the greatest chance of invasion are areas that have similar abundant resources that exotic species consume. Habitats with species poor native distributions were less invaded, which was due to the available nutrients. The alpine tundra is a species poor area, however climate often limits plants. The increase of N deposition, especially in high elevations, is allowing exotic species to invade into new habitats (23).

Another study conducted in the Colorado Front Range found that Limber pine is spreading throughout mountain ecosystems. While normally found in the mid-region of mountains, recently it has been expanding higher and lower in elevation. However it is slowly moving into the tundra region. An increase in temperature could allow the limber pine to move into the alpine tundra zone. It is not known if limber pine with have a positive or negative effect of the alpine tundra ecology.

Fig 4.3 Limber Pine
http://www.nrmsc.usgs.gov/files/norock/research/lp_yell.jpg

The invasion of exotic plants is greatly slowed with rising elevations, even with ample sunlight. Ecotones were found to be the most important factor in the spread of exotic species. An ecotone is the area between two distinguishable ecosystems. Once an exotic species can survive and gain enough elevation to go through an ecotone and into the higher ecosystem, it will then spread fast through the next ecosystem. It is though that the only factor stopping exotic species from continuing to rise in elevations is the low temperatures (24).

D. Nitrogen Deposition

Nutrient deposition has greatly increased in the past decades. Human activities such as the burning of fossil fuels and crop fertilization are the main sources for the increase. The Niwot Range has seen largest increase in nitrogen deposition. nitrogen is a naturally occurring fertilizer that is cycled through ecosystems. An overloading of nitrogen can have many effects on an ecosystem, as it is often the limiting nutrient. Increased Nitrogen deposition can cause changes in the environment by altering plant communities, and lowing water quality. These effects can be magnified in the alpine tundra because it is such a sensitive ecosystem (25).

Humans are causing an addition to the natural N cycle. Nitrate and ammonium are by-products of the combustion of fossil fuels and use of fertilizers. These by-products are then put back into the environment by wet and dry deposition. This additional deposition due to human actions is overloading ecosystems with N. The Front Range of Colorado receives 2-4 kg $ha^{-1}yr^{-1}$ of Nitrogen in wet deposition. Compared to N deposition rates across the United States, the amount in the Front Range of Colorado is low. This is shown in Fig. 4.4. While the total amount of N deposition is low, it has increased recently in the area, and has a great effect on the sensitive alpine tundra ecosystem.

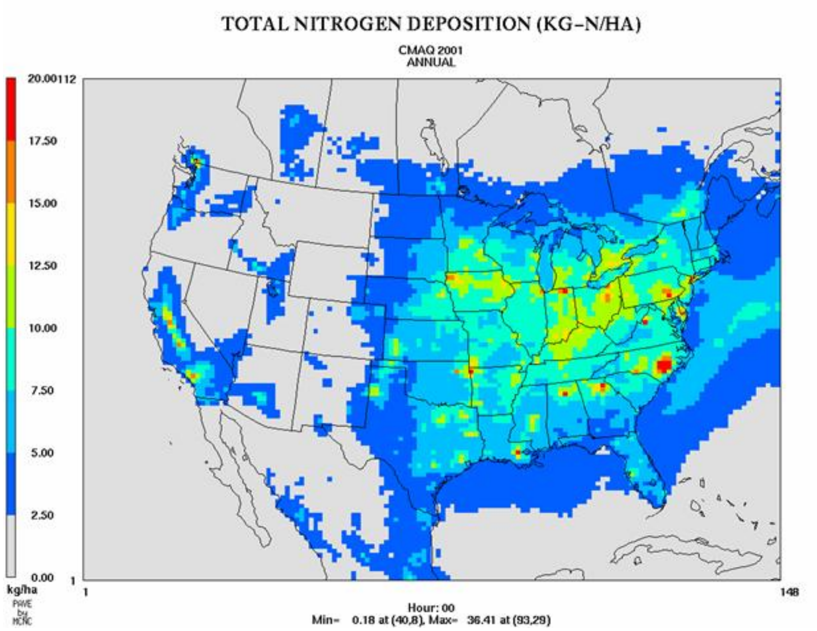

Figure 4.4: Nitrogen Deposition in the United States in 2001
http://www.epa.gov/AMD/Library/AnnualReports/2006/2006_clip_image002_0001.jpg

N deposition rates from past studies and from 18 sites which were part of the National Atmospheric Deposition Program (NADP) and the Clean Air Status and Trends Network (CASTNET) were examined to find the recent flux in N deposition. East of the continental divide receives more wet N deposition than at the divide and west of the divide, with the Niwot Range registering the highest rates. The Niwot Range has also seen the largest increase in N deposition since the mid 1980s. While NH_4^+ concentrations are increasing similar to other sites, NO_3^- is not increasing at fast.

While the Colorado Rockies have a mostly eastward wind, it is though that most of the N deposition in the Front Range comes from East of the Rockies. It is deposited from high level air flow that travels from the east to the west. The largest amounts on N deposition come from the Denver-Boulder-Fort Collins area in the summer because of the trend of hot air from valleys to travel westward up the mountains. N deposition is believed to be greater at higher elevations than lower elevations. Increasing N deposition in the Niwot Range is coming from increased precipitation. This precipitation comes from summer thunderstorms formed from the warm air masses from the Denver-boulder-Fort Collins area moving westward up the mountains. Increasing populations in Colorado will only cause future increased amounts of N deposition in the Front Range (26).

While N is a nutrient that plants need to survive, excessive N levels in an ecosystem can be detrimental. Long term elevated N levels will make plants more susceptible to insect, disease, drought, and frost damage. Levels in the Rocky Mountain National Park are not this high yet. High levels of N have been shown to decrease the growth rate of some plants and start to kill off vegetation. In alpine ecosystems like those in the Colorado Front Range N deposition will increase the growth rate of grasses, which will overpower other flowering plants. This has happened on Niwot ridge over the past 3 decades. However this increased growth of grass cannot be linked directly to N deposition, there may be additional factors. This change to predominantly grassy plants will create a loss of habitat for some animal species that live and eat other flowering plants.

N deposition can raise nitric acid levels. This in turn can cause acidification. High levels of acid in streams and ponds will start to kill sensitive aquatic species. This is an extreme effect of N deposition. N deposition levels in the Front Range are not yet that high, and it is thought that many other changes will occur in an alpine tundra ecosystem before this happens (27).

N deposition is a present threat for the Niwot range. Changes in plant species and species richness have already been observed. With the current trend of N deposition, rates will only continue to increase and overload the ecosystem. It is difficult to know what the long term effects of this increase of N deposition will be. However, over the past ten to twenty years changes have already started to occur, and it can be assumed that they will continue in the future.

V Conclusion

While it is difficult to make any concrete conclusions about the effect of global warming on the alpine tundra of the Colorado Front Range, it is clear that has been a recent change. Increased temperatures and N Deposition have caused changes in the alpine tundra ecosystem. Changes in the ecosystem include deterioration of animal habitat, rising tree/shrub line, invasion of exotic species, and a change in the N cycle.

Global warming is causing the deterioration of some animal habitats. Warmer winters are causing new climatic events such as ground icing that is making it more difficult for animals to survive through the winter. This particular event has been seen to decrease populations of several species. More studies need to be done on a wider range of animal's species to truly understand what is happening to animals in the tundra.

Global Warming has also caused the rise in tree/shrub lines. This change is a present danger to the alpine tundra. Many animals live and eat in the grassy plains of the alpine tundra, which are being shrunk due to the encroaching tree/shrub line. Earlier springs are creating a longer growing season, allowing trees to survive at higher elevations. Since grassy plains are the last form of plant life before the rocky tops of mountains they cannot rise in elevation along with tree/shrub lines. If global warming continues the alpine tundras of the Colorado basin could altogether disappear from the mountain summits.

Exotic species are a present danger to the alpine tundra with increasing temperatures and N deposition. Very few species of plants can survive in tundra due to the harsh climate and lack of nutrients. Increasing winter temperatures and earlier springs are creating a longer growing season. With such a short growing season to begin with, an addition of one or two weeks will proportionally have a larger impact on the tundra than other ecosystems. A longer growing season along with increased N deposition is making it much easier for exotic species to invade the tundra. It can take a very long time for exotic species to travel and spread. Increase human activities in alpine tundra's bring an elevated risk of human trafficking of these exotic species.

Simply put more research needs to be conducted on the alpine tundra. It has been seen that recent slight shifts in climate are already affecting the alpine tundra more than other ecosystems. With alpine tundra being such a good warning system for the effects of global warming they should be intensely studied. Scientist should be jumping at the opportunity to study what is happening due to global warming in order to predict what will happen to the rest of the world, and try to find ways to stop deterioration of other ecosystems. The changes in the alpine tundras will help predict what will happen to other ecosystems if global warming continues.

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