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HOW CAN THE RELATIONSHIP BETWEEN CLIMATE CHANGE AND THE COAST REDWOOD FOREST BE INCORPORATED INTO FIFTH AND SIXTH GRADE ENVIRONMENTAL EDUCATION PROGRAMS?

by

Dorea Eve Martin

A capstone submitted in partial fulfillment of
the requirements for the degree of
Master of Arts in Education: Natural Science and Environmental Education.

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To all of my family and friends that have encouraged me to pursue my dreams and become who I want to be, especially those that introduced me to nature and conservation in those early years. I am grateful for the mind-opening lectures of Teryl Schessler and Mike Merrifield that opened my eyes to the wonders of science—you are both truly missed. A special thank you to Bec Detrich and Diann Rastetter for dedicating valuable personal time to counsel me both academically and mentally, and to the naturalists at Westminster Woods who were excited to participate in this project. My deepest gratitude is to all of those that kept reminding me that I am strong, smart, and capable. This capstone would not exist without your words of wisdom.

TABLE OF CONTENTS

CHAPTER ONE: INTRODUCTION

Why Climate Change?

I began my career in the outdoor industry in 2007 when I came across a job posting for a naturalist position. When I interviewed for the job, we took a walk in the nature preserve and stopped at an unusually tall cactus growing next to an oak tree. The interviewer asked me why I thought the cactus was so tall, and I could not fathom a reason, so he explained that it was competing for sunlight with the tree and by growing taller it could escape the tree's shadow. Needless to say, I did not get the job.

What did happen, though, was a shift in my understanding of possible career options. I had no idea that there were jobs out there where I could learn about nature and play games with children to teach them about nature. I ended up getting my foot in the door as an office assistant at a different land reserve where, after a short while, I started to teach one field trip each week. I was in love with this newly discovered career field. Since then, I have worked as a naturalist, traveling scientist, park ranger, residential outdoor science school instructor, challenge course facilitator, and trail crew leader.

Throughout that time I was eager to learn all that I could about biology, ecology, geology, astronomy, chemistry, anthropology, and archaeology; if it had to do with connecting with nature, I wanted to know more. Every now and then, though, I would hear something about climate change and instead of peaking my interest, it made me want to turn and run. I was intimidated by the subject because I had no understanding of weather or climate and it all seemed so overwhelming. I remember someone close to me telling me that climate change could not be real because one volcanic eruption puts more carbon dioxide in the sky than thousands of cars. I believed that for a long time, but now I know that science shows that volcanic eruptions actually have a cooling effect on global climate (Mathez, 2009).

The volcano argument kept me in denial for a long time until a few years into my outdoor career, when I realized that as a naturalist/park ranger/environmentalist, I should probably know more about climate change to answer any questions that came my way. I was intimidated to the point of being scared—I was worried that my worldview would change and I wasn’t sure if I was ready for such a shift. I was ready to know the science, though, so I started reading. I did end up experiencing that shift in thinking that I feared, and it changing everything.

I included my initial climate change research into my first campfire ranger program on human impact, and while I worked hard on it and the visitors received the information well, I felt like a fake. I had only scratched the surface of climate science—I felt like I knew so little that there was no way I could participate in a discussion about it with a visitor. This led me to do much more research, write more ranger and environmental education programs, take Earth sciences and climate change graduate classes, and eventually undertake this climate-focused graduate research project. Because of these experiences, I now feel I have a solid background on the topic to participate in an educated discussion, but the biggest thing I have learned is that there is so much more to learn.

Environmental Education Philosophy

Much of my environmental philosophy stems from my experience as a naturalist and what works in my practice to connect my students with their surroundings. My personal experience in environmental education in California has seen two schools of thought: one focuses on state science standards and connecting concepts taught in the classroom to the real world, and the other focuses on developing observational skills and a personal relationship with nature. Most of my time has been spent in the former school of thought and for most of it my focus was on developing my group refocusing skills and my own content knowledge. I had a chance to work under the second school of thought for a year with Westminster Woods Camp and Conference Center in Occidental, California. During this time, I had to move away from a mental checklist of standards to cover and focus on having the students question and wonder about what they see, hear, smell, touch, and taste.

As I moved through that school year with this program my philosophy shifted and I found that my environmental education philosophy moved closer to the inquiry-based side and away from the standards-based side. I see the value of standards-based environmental education because it enables students to interact with real life versions of concepts discussed in the classroom and read in textbooks. It also prevents teachers (our customers) from feeling like they are losing classroom time that can be used to raise standardized test scores. This immediate, short-term need for environmental education must be balanced with long-term goals of cultural environmentalism and sustainability. By also placing an importance on observation and cultivating a sense of wonder for nature, students can better develop a sense of value for nature for its own sake and not as a commodity.

In “Common Cause: The Case for Working With our Cultural Values,” Tom Crompton (2010) suggests a process to shift our culture away from the extrinsic values of money, power, and individual success and toward intrinsic values of community, affiliation with friends and family, and self-development. Intrinsic values deal with bigger-than-self problems and one who has them will focus on helping others and on problems that do not directly affect that individual (Crompton, 2010). If, as a culture, we shift more toward intrinsic values, then we will better be able to tackle environmental problems and make meaningful changes in the structure of our civilization toward a more sustainable way of life (Crompton, 2010).

One of Crompton’s (2010) steps in his process toward a cultural values shift is using frames to more frequently activate our intrinsic values, which will in turn strengthen them. Frames are the cognitive structures that we use to perceive reality, according to Crompton (2010); they are the thoughts, images, feelings, and related ideas tied to any one particular word, idea, or experience. If environmental educators can help students build frames that strengthen their value of natural objects and systems, we can help them become more intrinsic in their value systems, which will in turn move our culture toward a more sustainable future (Crompton, 2010).

Westminster Woods Camp and Conference Center

Outdoor environmental education programs, especially those that have a residential component where students spend one or more nights at the program site, have been very influential in my life and have helped me grow as a person, an educator, and an environmentalist. One of these programs, Westminster Woods Camp and Conference Center, is located just north of the town of Occidental in Northern California. Westminster Woods focuses on inquiry-based education, encouraging its naturalists to put together lesson plans that focused on the interests and strengths of the naturalist and the students, and to modify the activity structure based upon what each group of teachers wished to focus. I struggled with this for a period before I realized that this was the perfect place to develop and teach a climate change lesson plan in a school setting. I wanted to teach children about climate, and I was teaching in a redwood forest ecosystem, so naturally I formulated the research question of this capstone: How can the relationship between climate change and the coast redwood forest be incorporated into fifth and sixth grade environmental education programs?

The Greater Environmental Education Community

I came to this research question not only because I worked at an environmental education program in a redwood forest, but because there are a number of other similar programs also located in redwood forests that could benefit from the information. I chose to focus on fifth and sixth grade because there are many residential environmental education programs in California, as well as across the country, that focus particularly on these two grade levels. I did not find any previous research on teaching climate in the redwood setting and felt that this project would be beneficial to the greater environmental education community.

Project Overview

Now that I have discussed the personal journey that has led me to this capstone, this paper will transition from personal to academic. The research question, again, is, how can the relationship between climate change and the coast redwood forest be incorporated into fifth and sixth grade environmental education programs? To answer this research question, scientific reports on the effects and potential effects of climate change on the redwood forest were studied, a lesson plan that integrates these concepts was developed for naturalists within and outside of Westminster Woods, and a pre- and post-questionnaire was used to measure and analyze the success of the lesson plan. The goal was to develop a successful lesson plan in which students would increase their knowledge of climate processes and their effects on the redwood forest so that they could develop frames that motivated them to help. Climate change education is an increasingly important as we move forward into a time that requires us to make changes in infrastructure, policy, and each of our daily lives. Reduction of consumption of energy, water, goods, and transportation is essential to ensure that humans can keep living at a desirable quality of life. This capstone was conducted to help lead the next generation toward a more sustainable way of life.

This paper is written for environmental educators to use as a tool for teaching climate science to their students, and can be used partially or completely as educators see fit. Chapter Two will focus on basic climate science and scientific literature on climate change effects on redwoods being conducted by the Redwoods and Climate Change Initiative of the Save the Redwoods League. Chapter Three will detail the methodology of the research portion of this project, including an in depth discussion on the lesson plan and logistical considerations. The hypothesis for this project is that students will increase their understanding of climate change and its relationship to the redwood forest. Chapter Four will discuss the results and analysis of the research conducted, which showed that the lesson plan was successful in increasing student knowledge of climate change and the redwood forest. The paper will conclude in Chapter Five, where the reader will find a reflection of the literature review and research project, the project limitations and need for further research, and plan for sharing the findings with the greater environmental education community. All lesson plan information, including an outline, graphics, and questionnaires, as well as data collected and statistical analysis, can be found in the Appendices of this paper.

CHAPTER TWO: LITERATURE REVIEW

There is a wealth of research on the processes of global climate and how anthropogenic greenhouse gas emissions are affecting Earth’s greater systems, but there is still much to be learned about what the future will look like, especially for the coast redwood tree (*Sequoia sempervirens*). For readers to gain familiarity on the subject of climate change, this chapter will start with an overview of the carbon cycle, greenhouse effect, climate history, and consequences of climate change. The chapter will continue with general coast redwood ecology and a look at ancient climate changes in North America. The last section will cover current research on climate change effects on the coast redwood tree. The research reviewed includes historic climate variability of the redwood region, dendrochronology, chemical signals of climate in redwoods, impact of fog frequency changes, and seedling response to drought.

The Fundamental Science of Climate Change

Climate change and *global warming* are terms used by the scientific community when discussing the present and future effects of greenhouse gases emitted into the atmosphere due to human activity. The idea that more atmospheric carbon dioxide causes increases in global surface temperatures has been widely accepted since the 1970s (Zhong & Haigh, 2013). There is now solid evidence that greenhouse gases have an effect on long term climate, which will be discussed in the following sections; what is unknown is the extent of the effects anthropogenic greenhouse gas emissions and how soon they will be seen (Mathez, 2009).

The climate system is a dynamic system of physical and chemical interactions between Earth’s major parts: the atmosphere; the hydrosphere of Earth’s oceans; the biosphere of all living organisms; the cryosphere of frozen water in glaciers, terrestrial ice sheets, and sea ice; and the lithosphere of all the land, rocks, and magma (Mathez, 2009). Each of these parts of the Earth move matter through a variety of cycles and patterns such as the rock cycle, the water cycle, and weather, which are covered regularly by environmental education programs. The parts also interact with each other; for example, the spherical shape of the Earth causes sunlight to heat the planet unevenly because the rays hit the equator more directly than the poles. This uneven heating creates wind that distributes the heat across the atmosphere and also contributes to the circulation of the ocean (Mathez, 2009).

The Carbon Cycle

Carbon moves through every one of Earth’s major components in short-term and long-term cycles; the atmosphere, oceans, biomass, soils, permafrost, and rocks are all carbon reservoirs because they store carbon and exchange it between each other in a multitude of ways (Riebeek, 2011). According to Mathez (2009) and Riebeek (2011), the process of photosynthesis is one short-term carbon exchange in which plants take in carbon dioxide from the atmosphere for use in the production of carbohydrate molecules. The carbon in the carbohydrates moves through the biosphere up food chains; some is stored in the bodies of organisms, some is released back into the atmosphere through cellular respiration, and when organisms die they decompose and the carbon cycles into the soil (Mathez, 2009; Riebeek, 2011).

The long-term carbon cycle is thought to take place over hundreds of thousands to millions of years and occurs between the solid Earth, the ocean, and the atmosphere (Mathez, 2009; Riebeek, 2011). According to Mathez (2009), as rock in mountainous regions weathers, the silicate and carbonate minerals in the rocks reacts with carbon dioxide (CO_2) in the air, removing it from the atmosphere. The reaction results in calcium, magnesium, bicarbonate, and silica in a solution of water, which washes down from the mountains and eventually ends up in the ocean (Mathez, 2009). Ocean organisms use the calcium and bicarbonate ions to make their shells, and as they die, their shells layer on the ocean floor and are buried under successive layers of shells and sediment. Over millions of years of accumulation and pressure, the layers turn to limestone rock, trapping the carbon into the solid Earth—over 99.9 percent of all carbon on the planet is locked up in the lithosphere (Mathez, 2009). The rocks can eventually release their carbon back into the atmosphere through tectonic activity that lifts them to the surface where they can start the weathering process again (Riebeek, 2011; Mathez, 2009). The carbon atoms easily bond with oxygen molecules (O_2) to form carbon dioxide (CO_2). If instead the rocks are buried deep within the Earth, the carbonate minerals break apart under the intense pressure and release carbon dioxide, which percolates out of the crust and into the atmosphere (Mathez, 2009).

The Greenhouse Effect

While the atmosphere is mostly made up of nitrogen and oxygen, these gases do not contribute to the warming of the planet because they are transparent to incoming solar radiation and outgoing infrared radiation. Atmospheric carbon dioxide, along with water vapor, methane, nitrous oxide, ozone, and chlorofluorocarbons (CFCs), are known as greenhouse gases because they do contribute to the warming of the planet and act in a similar manner to the glass of a greenhouse (Mathez, 2009). In the article, "The Greenhouse Effect and Carbon Dioxide," Zhong and Haigh (2013) describe how greenhouse gases allow solar radiation to pass through the atmosphere, with about thirty percent reflecting back into space by the clouds, reflective atmospheric particulates, and various parts of the Earth's surface, such as snow and ice. The rest is absorbed by the surface, which warms and gives off heat in the form of infrared radiation. The greenhouse gases allow a small amount of infrared radiation to escape back to space and the rest is absorbed and radiated back to the surface (Mathez, 2009; Zhong & Haigh, 2013). The function of greenhouse gases is vital to life on this planet because it allows temperatures to stabilize to habitable levels. This greenhouse effect is commonly explained using a blanket analogy: when one uses a blanket (greenhouse gases), the blanket traps much of the body heat (infrared radiation), and allows some of it to escape. The trapped air around the body (the atmosphere) warms and keep the person's body temperature warm and stable. If the blanket is too thick, too much heat can be retained and the person might feel too warm (increasing global temperature) and feel the need to remove the blanket.

Presently, the balance between incoming and outgoing energy results in a mean global temperature of about 15°C, or 59°F (Mathez, 2009). While water vapor is the most important greenhouse gas because it has the greatest capacity to absorb infrared radiation (Zhong & Haigh, 2013), its abundance in the atmosphere depends on global temperatures that influence evaporation, condensation, and precipitation; this cycle is known as a feedback loop, which will be described in the following section. Carbon dioxide is the second most abundant, and therefore important, greenhouse gas (Mathez, 2009; Zhong & Haigh, 2013). Changes in CO_2 or any greenhouse gas will cause more or less infrared energy to be trapped (Zhong & Haigh, 2013). When more energy is trapped, mean global temperature will increase until a new equilibrium between incoming and outgoing energy is achieved (Mathez, 2009; Zhong & Haigh, 2013).

Climates Past and Present

Since detailed weather and climate data collection has only occurred in the past century or so, scientists turn to other resources to decipher Earth’s past climates. Information from core samples of Greenland and Antarctic ice sheets, deep-sea sediment cores, tree rings, and stalactites and stalagmites reveals a climate record of five million years (Mathez, 2009). These records show that temperature and atmospheric carbon dioxide are linked; Figure 1 shows 800,000 years of atmospheric carbon dioxide and temperature data from the trapped air and composition of an Antarctic ice core (“Changes in the Carbon Cycle,” n.d.). There are regular fluctuations in climate, with each temperature low corresponding to an ice age and each temperature high responding to the peak of a warming period (“Changes in the Carbon Cycle,” n.d.; Mathez, 2009).

Although the climate record shows that atmospheric carbon dioxide and temperatures have fluctuated over time, there is great concern regarding the current levels of CO_2. Antarctic ice core samples show that for 800,000 years CO_2 levels remained between 170 and 300 parts per million (ppm) until now (“Changes in the Carbon Cycle,” n.d.; Mathez, 2009). According to the National Aeronautics and Space Administration (NASA), ninety-seven percent of climate scientists agree that the warming we have seen in climate over the past century is likely due to human activities ("Global Climate Change," n.d.). In the past 150 years, human industrial activities, especially burning fossil fuels for energy, have increased atmospheric carbon dioxide from 280 ppm to over 400 ppm (Mathez, 2009; "Global Climate Change," n.d.). This rate of CO_2 increase is causing a rise in temperatures that is already being measured—the most recent Intergovernmental Panel on Climate Change (IPCC) has stated that there is over ninety percent probability that the warming seen over the past fifty years is due to anthropogenic greenhouse gas emissions and that the rate of increase in global warming is very likely unprecedented for the last 10,000 years ("Global Climate Change," n.d.). According to NASA ("Global Climate Change," n.d.), Earth's average surface temperature has increased 1.5°F (0.8°C) since 1880.

An increase of 1.5°F may not seem significant, but the consequences of temperature increases of just a few degrees can be widespread due to feedbacks, also known as forcings, that make climate more sensitive to external factors (Mathez, 2009).

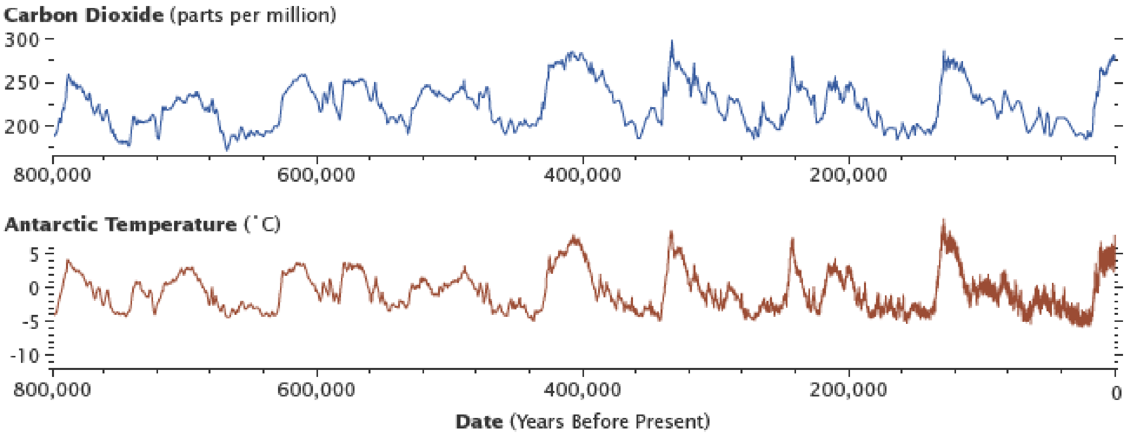


Figure 1: Antarctic ice core data showing the correlation between atmospheric carbon dioxide and Antarctic temperature levels from the past 800,000 years ("Changes in the Carbon Cycle," n.d.).

In *Climate Change: The Science of Global Warming and Our Energy Future*, Edmond A. Mathez (2009) describes a feedback as what happens when a process influences itself; a positive feedback amplifies the effect of that process, and a negative feedback dampens the effect of the process. For example, albedo is the portion of solar radiation that is reflected back into space by objects on the surface of the planet. Arctic ice contributes to albedo; as global temperatures warm some of the ice will melt. In turn, there is less ice to reflect sunlight, causing more to be absorbed by the planet, causing further warming and more ice to melt. This albedo feedback accelerates the effects of warming (Mathez, 2009).

Atmospheric water vapor and permafrost are among other positive feedbacks that cause an acceleration of warming (Mathez, 2009). As the planet warms, more evaporation will occur and cause the amount of atmospheric water vapor to increase. Since it is a greenhouse gas, more atmospheric water vapor means more heat will be trapped on the planet which leads to further warming, more evaporation, and more atmospheric water vapor (Zhong & Haigh, 2013; Mathez, 2009). Permafrost is rock or soil that has been frozen below 0°C (32°F) for at least two years (Schuur et al., 2008) and can be tens to hundreds of meters thick or more—about twenty-five percent of the entire land area of the Northern Hemisphere is permafrost (Mathez, 2009). Frozen, windblown dust known as yedoma holds roughly half of all permafrost carbon stores; it is estimated that yedoma contains 500 billion metric tons (gigatons) of carbon in organic debris and that the rest of the non-yedoma permafrost contains another 400 gigatons of carbon (Mathez, 2009). As the planet warms and permafrost starts to melt it will release these stores of carbon, contributing to another feedback loop that accelerates warming (Schuur et. al, 2008; Mathez, 2009).

Consequences of Climate Change

The consequences of climate change are numerous and affect both humans and other species across the entire planet. Most of the warming since the 1880s has been since the 1970s, according to global surface temperature reconstructions, with the twenty warmest years since the 1980s and the ten warmest years in the last twelve years ("Global Climate Change," n.d.). While it is difficult to attribute any specific weather event to climate change, climate science shows that weather severity will increase as global temperature warms (Mathez, 2009). Storms are fueled by evaporation, and as temperatures rise, more water is evaporated into the atmosphere. Generally, drier places will become drier and heat waves, fires, and droughts will take their toll; as the increased atmospheric water moves, condenses, and precipitates, it can create more extreme weather events, including more severe rainstorms, snowstorms, and hurricanes ("Global Climate Change," n.d.; Mathez, 2009). These events can be catastrophic and costly as the winds and floods destroy lives and towns.

Looking at the ocean, since water is slow to heat up and slow to cool down, the ocean has absorbed and held the majority of the heat increase; in the last 40 years, the ocean has absorbed 84% of the heat from global warming ("Global Climate Change," n.d.). Due to the expansion of water as it warms, as well as the melting of the Greenland and Antarctic land ice sheets draining into the ocean, sea level has risen 17 centimeters (6.7 inches) in the last century ("Global Climate Change," n.d.). Further rise can be disastrous for those living on islands and along coastlines as sea water inundates their communities and freshwater tables, requiring millions of people to seek refuge further inland.

More atmospheric carbon dioxide means more carbon dioxide is absorbed by the ocean, increasing its acidity—since the Industrial Revolution, ocean acidity has increased by about 30% (“Global Climate Change,” n.d.). Coral reefs are in jeopardy with this increase in ocean acidification. Coral absorbs calcium carbonate to make their skeletons, as snails and clams do for their shells, and with increased ocean acidity, it will be more difficult for these organisms to absorb the calcium carbonate (“Global Climate Change,” n.d.; Mathez, 2009). In addition, continued increasing acidity will cause coral skeletons to dissolve, which would destroy these vital habitats for many other marine organisms (“Global Climate Change,” n.d.).

Further warming of the atmosphere will increase the rate of snow melt, resulting in faster loss of mountain snowpack. Over the past fifty years, spring snow cover in the Northern Hemisphere has decreased and is melting faster, according to satellite observations (“Global Climate Change,” n.d.). Many communities rely on the snow pack lasting through the summer, and as it melts faster, there is less water available to these people in the dry season. Combined with more evaporation, increased snow melt will likely result in less water available for households, agriculture, fisheries, and ecosystems, which will create increased strain on human health, economies, and wildlife habitats.

A Time for Change

Climate scientists have known how carbon dioxide affects climate for the past century (Mathez, 2009). Global climate is very likely changing due to human activity because burning fossil fuels releases carbon dioxide into the atmosphere from long-term carbon stores. Although scientists can use climate models to show what the future might look like, it is currently impossible to know, with any level of certainty, how severe the aforementioned consequences will be or how quickly they will come. This is, in part, because it is unknown what future anthropogenic greenhouse emissions levels will be. There are many more known consequences than described here, and likely more that are yet to be discovered (Mathez, 2009). More research is needed to understand the complexity of the planet's reactions to these changes.

Coast Redwood Ecology

Coast redwood trees are currently being researched to understand the complex ways they react to climate fluctuations and how they will respond to today's changing climate. Before looking at the research, it is necessary to start with an overview of the coast redwood, both past and present. According to the Save the Redwoods League ("Redwood Trees," n.d.), there are three species of redwoods in the world—the coast redwood (*Sequoia sempervirens*) is the world's tallest tree species and is found only on a narrow 450-mile strip of coastline from southernmost Oregon to central California. The giant sequoia (*Sequoiadendron giganteum*) is the world's most massive tree and is found only in 77 scattered groves along the western slope of California's Sierra Nevada mountain range, and the dawn redwood (*Metasequoia glyptostroboides*) is a deciduous tree found in south-central China and was once thought to be long-extinct ("Redwood Trees," n.d.). Since the coast redwood is the focus of this paper, hereafter it will be referred to as "redwood."

The redwood can be easily identified by its great height and its deep red, furrowed, thick bark that peels off in thin, hair-like fibers. It can live for over 2,000 years, grow more than 320 feet high, and have a trunk with over 24 feet in diameter at breast height, which gives it a very tall but thin appearance in comparison to other trees (“Redwood Trees,” n.d.). The cones measure only about an inch long and contain only 14 to 24 seeds, though most redwood trees grow from basal sprouting off the roots of the parent tree (“Redwood Trees,” n.d.).

According to the field guide, *California and Pacific Northwest Forests* (Kricher, 1998), winters are wet, averaging a range of 35 to 100 inches of rainfall per year. Summers, however, are usually very dry with little to no rainfall, which contributes to the fire frequency of the region. Fire occurs once every 250-500 years along the coast to every 100-150 years more inland, and because of this, the redwood has adapted well to fire. It has very thick bark that lacks flammable resin, the tree is rich in tannins, which resist decay, and the seedlings also grow rapidly after a fire (Kricher, 1998).

Dry summers can be a challenge to the redwoods—being such massive trees, they need a high amount of moisture year-round. The redwoods are able to survive the dry season because their narrow strip of coastal land is prone to a cool, wet fog that forms almost daily as cold ocean water upwells along the coast, which cools the warm air and condenses the water vapor (Kricher, 1998; “Redwood Trees,” n.d.). Redwood canopies help the trees, as well as the soil, retain the fog moisture because they block over ninety percent of sunlight from reaching the ground (Kricher, 1998).

Ancient Climate Changes of North America

The redwood was once found across much of the North American continent. Kricher’s (1998) field guide describes the changes over the past forty million years. Vegetation of North America before 40 million years ago in the Tertiary Period consisted of only three major plant communities; the redwood was part of the Arcto-Tertiary Geoflora, a community that ranged from San Francisco east to the Atlantic and up to the northernmost reaches of the continent and had a warm, moist, and tropical climate (Kricher, 1998). About forty million years ago, at the beginning of the Oligocene Epoch, things became more arid, cool, and temperate and led to fewer forests and more grasslands (Kricher, 1998). During the Pliocene Epoch twenty million years ago, the Cascades, Coast Ranges, and Sierra Nevada began to uplift, blocking eastern moving moisture and creating today's dry climate of the Great Plains, and then beginning two million years ago, glaciers carved the remaining landscapes (Kricher, 1998). All of these dramatic changes fractured the original Arcto-Teriary Geoflora into separate distinct communities, most notably the conifer domination of the west and the broad-leafed trees of eastern North America (Kricher, 1998).

Climate Change and the Coast Redwood

Current research on both past and future redwood forest climate history and responses is being conducted through the Redwoods and Climate Change Initiative (RCCI), which is a scientific collaboration between University of California, Berkeley, Humboldt State University, and Save the Redwoods League that began in 2009 and is expected to last through at least 2025 (Brown, 2013). It includes studies on both the coast redwood and its close relative, the giant sequoia (*Sequoiadendron giganteum*), and initial findings were reported during a three-day symposium in August, 2013 (Brown, 2013). The study sampled fourteen sites throughout the range of the two species; eight of those sites represent the full north-to-south range of the redwood species: Jedediah Smith Redwoods State Park, Prairie Creek Redwoods State Park, Redwood National Park, Humboldt Redwoods State Park, Montgomery Woods State Natural Reserve, Samuel P. Taylor State Park, Big Basin Redwoods State Park, and Landels-Hill Big Creek Reserve (Carroll, Sillett, & Kramer, 2014). RCCI studies looked at many factors, including an analysis of local historic climate records, the creation of a dendrochronological record, isotopic chemical response signals to climate variation, fog frequency and dependency, and drought response.

Historic Climate Variability and Redwood Responses

To understand how redwoods respond to climate variability, Healy Hamilton (2013) of the Marine Conservation Institute analyzed data from PRISM, the official climatology data sets of the United States Department of Agriculture. The United States is divided into grid cells of 800 meters; PRISM gathers topographically sensitive data from each cell and uses a complicated mathematical algorithm to fill in the data between data points to create continuous spatial information about weather patterns (Hamilton, 2013). The analysis of this data was important to RCCI because global climate models are not fine-tuned enough to account for the regional variability of the redwood range, which is affected by topography, fog, and ocean upwelling (Hamilton, 2013).

Using climate records from the past century from all known weather data in the state of California, temperature and precipitation data from the years 1901 to 1980 were used as a baseline and means and standard deviations were calculated; 68% of all the data values fall within 1 standard deviation, and 95% of all the data values fall within 2 standard deviations (Hamilton, 2013). A low standard deviation would indicate that redwoods are accustomed to low variability of weather, while a high standard deviation would indicate that the redwoods are accustomed to high variability of weather. Being accustomed to high levels of variability would mean that a lot of climate change would be needed to push the trees outside of the variability range (Hamilton, 2013). The analysis, however, showed that the baseline standard deviation was low, so the trees are adapted to low levels of variability (Hamilton, 2013).

Hamilton's (2013) analysis included values for summer minimum and maximum temperatures, winter minimum and maximum temperatures, and annual total precipitation, and different graphic representations were used to create a "climate space" in which all of the data fell within. Looking at summer minimum temperatures, seventy percent of the data points from 1981 to 2010 were above the baseline value, which can be seen in figure 2 (Hamilton, 2013). The increase of minimum summer temperatures was greater than baseline over 1981-1990, even greater over 1991-2000, and even greater than

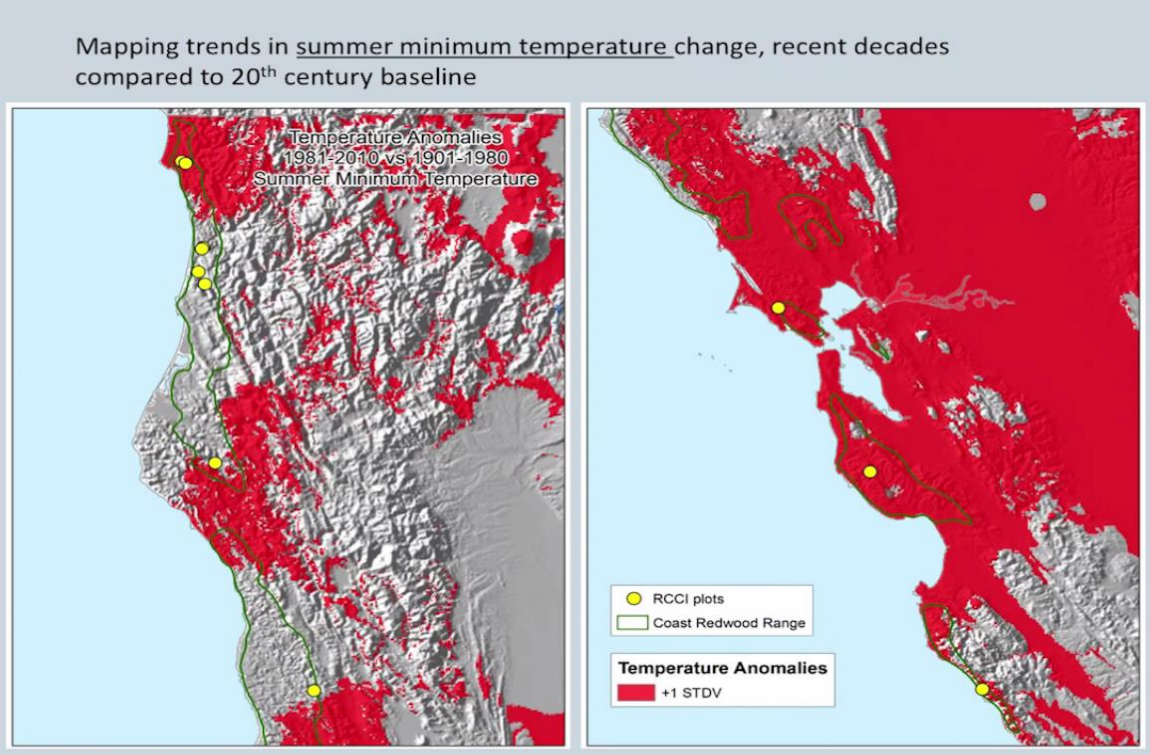


Figure 2: Summer minimum temperature anomalies in the coast redwood range from 1981 to 2010 as compared the 1901 to 1980 baseline (Hamilton, 2013).

that over 2001-2010; in other words, temperatures are continuing to increase throughout the range (Hamilton, 2013). In addition, Figure 2 shows more dramatic increases in the southern part of the redwood range (right) than the north (Hamilton, 2013).

Hamilton (2013) then used all of the data, graphs, and maps to extrapolate what the climate distribution of the areas would look like under different scenarios. In the distribution of mean annual temperature versus annual total precipitation (Fig. 3), everything in the middle square is “normal” and within one standard deviation of the baseline mean. From this, Hamilton (2013) created a species distribution model to show what climate conditions coast redwoods *need* to survive based on where they occur today,

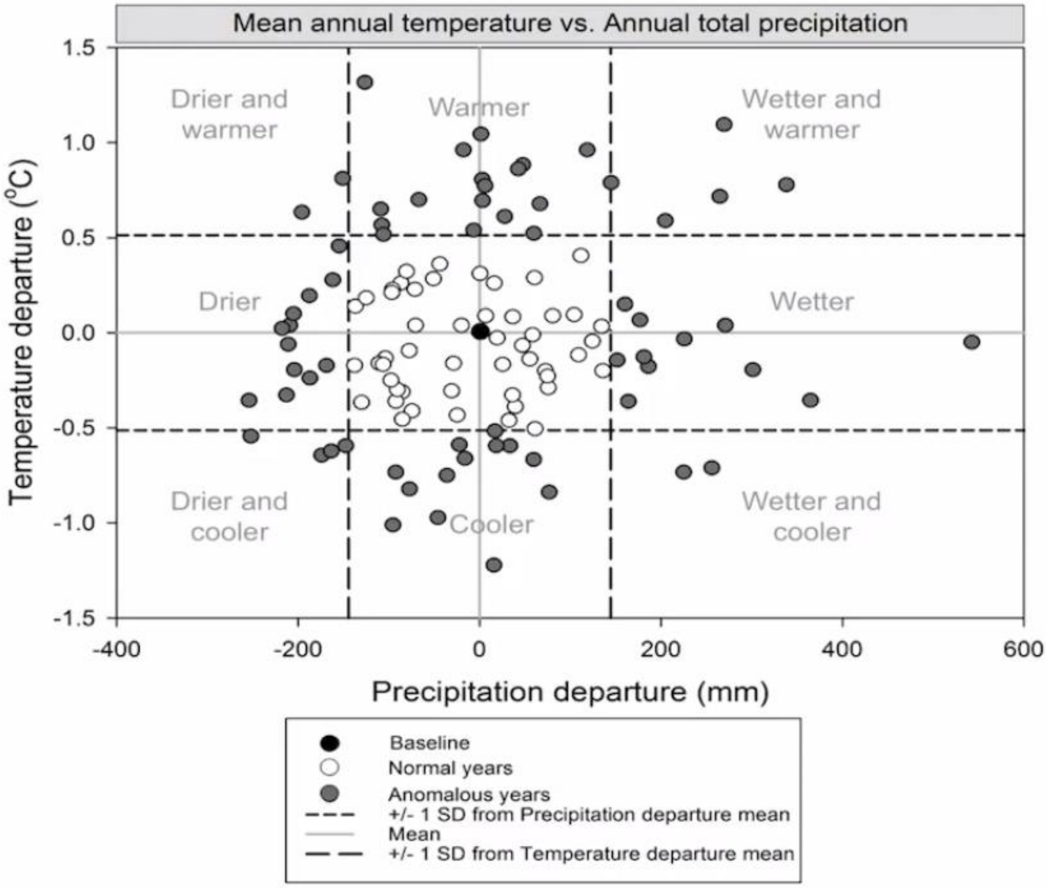


Figure 3: Mean annual temperature versus annual total precipitation in the coast redwood range from 1901 to 2010 (Hamilton, 2013).

then projected the data onto a map to see where the total potential range of these conditions occurs, and then projected the species distribution against maps that show conditions of past climate extremes (Fig. 4).

Hamilton (2013) focused on three future possible climate scenarios: drier and warmer, warmer, and wetter and warmer. In Figure 4, the blue color indicates the current redwood populations that would remain stable under the future climate extremes, the green shows new areas that would have the right climate conditions for redwoods to expand into, and the orange shows the areas that have redwoods now but, in the future scenario, would no longer have the right climate conditions to support them (Hamilton, 2013). As one can see, the biggest loss of habitat would occur when there is both a warmer and drier climate, and when compared to a warmer climate, indicates that it is the

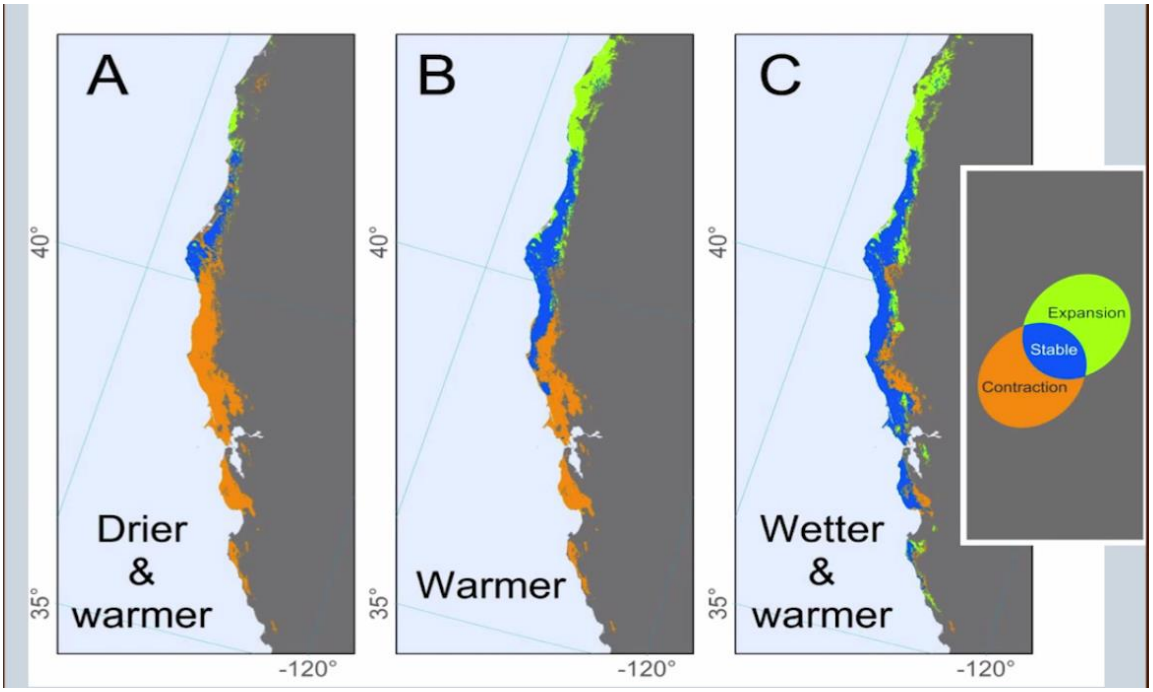


Figure 4: Projections of redwood bioclimatic envelope model over three types of past climate extremes (Hamilton, 2013).

dryness that will likely have the biggest impact on redwood trees. Also, like the summer minimum temperatures shown in Figure 2, the southern distribution of redwoods will be impacted the most (Hamilton, 2013).

This analysis shows that there is stability in the northern redwood regions and projects big changes in climate conditions of the southern redwood regions (Hamilton, 2013). This is all very new information and calculated from only one hundred years of climate data, so it really only gives a look at what the very near future might look like. Over time, more climate observations, as well as further studies of other redwood factors, will increase the amount of data and provide researchers with a more comprehensive picture of the future.

Dendrochronology

Dendrochronology, the dating and studying of annual rings in trees, is important to the study of climate because trees put on new growth rings annually, and the size and composition of those rings depends on surrounding environmental and climatic conditions at the time of wood production. Ring history is sampled from a tree without having to cut it down and kill it by using an increment borer, which is a hollow hand drill that can remove a pencil-thin section of wood from the trunk, called a tree core. These tree cores can be used to cross-date the ring history of a forest by recording and matching common patterns of rings across the population of trees (Carroll, 2013). The practice of cross dating was widely accepted after A.E. Douglass developed a 3,200 year tree-ring chronology of the giant sequoia, a species with generally easy-to-read rings. When Douglass attempted to develop a chronology of the coast redwood, however, his attempts proved to be much more complicated and unsuccessful (Carroll, Sillett, & Kramer, 2014).

The decay resistant wood of both the redwood and the giant sequoia have the potential of providing researchers invaluable historical climate data because downed trees can tell their tales long after their death. Douglass' attempts to cross-date redwoods failed, though, because redwoods have frequently missing or discontinuous rings, basal buttressing, tight rings, and spiral compression wood (Carroll, 2013). Since Douglass' attempts, others have had better luck with by taking samples from higher up on the trunk, and a chronological fire record using the redwood was dated back to the year 1750 (Carroll, 2013).

The first successful long-term cross dating study of redwoods was conducted by Allyson L. Carroll, Stephen C. Sillett, and Russell D. Kramer, of the Department of Forestry and Wildland Resources at Humboldt State University (2014). Between 2005 and 2012, the researchers collected one to seven cores each from 76 redwoods from across their natural range, at varying heights and positions, with the lowest samples collected above basal buttressing no lower than 5 meters above ground level to avoid irregular growth patterns (Carroll et al., 2014). By cross dating multiple samples at varying heights from the same tree, the researchers were able to have a much more accurate account for the tree than the one-sampled studies in the past. Once each tree's chronology was determined individually, it was then added to a database using significant marker years, which are good growing years that are thick and easy to find across individuals (Carroll et al., 2014).

The preliminary results of the study established a chronological redwood history as far back as the year 328, and a new oldest individual redwood has been discovered to be 2,520 years old (Carroll et al., 2014). Radial growth decreased significantly with maximum temperatures, as well as decreased with increasing summer drought severity; however, radial growth increased with decreasing summer cloudiness (Carroll et al., 2014). So, the redwoods grow less during the hottest years and the driest years, but grow more when there is less summer fog and clearer skies. Fire occurrences were also revealed, not only with apparent fire scars, but also with known histories combined with small rings. For example, at the Landers Hill site, there was a known fire in 1985, resulting in thin 1986 rings due to most of the trees' growing energy being directed into rebuilding their leaf/crown areas instead of producing more wood (Carroll et al., 2014; Carroll, 2013). The study also revealed that while ring width declined with age, the rate of wood production continues to increase with age (Carroll, 2013). The geometry of laying wood on the outer surface makes the rings appear thinner, but in actuality the total volume of the wood in each ring is greater. It was previously thought that the wood production declined in the oldest trees, but the analysis shows that the oldest trees are actually growing the most and making the most wood (Carroll, 2013; Sillett, 2013).

Another known event, El Niño, occurred in 1983. El Niño is a dramatic and rapid warming of ocean waters of the coast of Peru and Ecuador that occurs every several years and influences climate across much of the globe, bringing stormier, wetter weather events to North America (Mathez, 2009). The 1983 rings in all individuals across all sites were consistently larger, indicating that the wetter conditions brought on by that El Niño year caused more growth in redwoods (Carroll, 2013). Analyzing rings from years with known events can reveal how the trees respond to these types of events, which can then be used to infer earlier events in time using similar rings.

Making the redwood chronologies was the first step in understanding redwood forest environmental and climate history from the trees themselves, but the work is not finished yet. There is still a period of discrepancy where the chronologies need to be improved, which is roughly between the 1850s and the 1950s (Carroll, 2013). There is also a need to start analyzing downed wood to get older chronology farther back than the oldest living sample. Despite this, analyzing the information through other methods, such as isotopic analysis, can begin and start proving to be useful in understanding redwood response to climate changes.

Chemical Signals of Climate in Redwoods

It is common knowledge that trees take in sunlight, carbon dioxide (CO_2), and water (H_2O) during photosynthesis to store energy for later use and growth (Mathez, 2009). What is less commonly known is the role of isotopes, which are atoms that have different numbers of neutrons than protons. Hazen and Trefil explain this well in their book, *Science Matters: Achieving Science Literacy* (2009). Normally, a carbon atom has six protons and six neutrons, so it can also be called carbon-12, but a carbon atom can have more than six neutrons and still be a carbon atom, because atoms are defined by the number of protons they contain (Hazen & Trefil, 2009). So a carbon atom with six protons and seven neutrons would be called carbon-13; since there are more neutrons in carbon-13, it weighs more than carbon-12, and would be considered “heavy” (Hazen & Trefil, 2009).

Isotopes such as carbon-13 are everywhere on the planet and atmospheric carbon dioxide can have carbon-12 or carbon-13 in it (Hazen & Trefil, 2009). Carbon dioxide with carbon-12 can be written as $^{12}CO_2$, and carbon dioxide with carbon-13 can be written as $^{13}CO_2$. Plants prefer to use $^{12}CO_2$, but will use $^{13}CO_2$ when the $^{12}CO_2$ supply is low or they are photosynthesizing at a high rate and aren’t being too selective (Dawson, 2013). Todd Dawson of the University of California, Berkeley (2013), presented his research team’s isotopic analysis of carbon and oxygen in redwoods at the 2013 Redwood Ecology and Climate Symposium. They chemically analyzed the wood within each tree ring for the presence of carbon-13, as well as the presence of oxygen-18 from $H_2{}^{18}O$, or heavy water (Dawson, 2013). Oxygen-18 is more prevalent in warmer summertime fog than in colder winter rains and snow, so its presence can indicate which source of water used to make that wood (Dawson, 2013). The amount of each of these isotopes tells the conditions of supply and demand at the time the wood was created (Dawson, 2013).

It is necessary to first explain what supply and demand means. Each redwood can have billions of leaves, each leaf of which can have hundreds of stomata, which are pores that open to allow the intake of carbon dioxide. In his presentation, Dawson (2013) explained that the degree that the stomata are open determines the level of *supply* of carbon dioxide, and the photosynthesizing leaf cells create the level of *demand*. When the stomata are open, they are increasing the available supply of carbon dioxide to the leaf, but this comes as a trade-off: when the stomata are open, the leaves are prone to losing more water vapor via transpiration, which means a greater loss of oxygen-18 (Dawson, 2013). The number of carbon and oxygen isotopes transferred to the mass of a tree not only depends on how open the stomata are (supply), but how much and how fast the tree is processing these inputs (demand), and how much water loss is occurring (a direct correlation to supply) (Dawson, 2013).

Dawson's team (2013) found that the higher you go in the tree, the isotopic composition of the leaves changes, but the change is *only with the amount of carbon-13*. Carbon-13 presence increases as height sampled increases, but oxygen-18 does not have any significant change based upon height within the tree (Dawson, 2013). These results suggest a change in demand when carbon-13 and oxygen-18 are found together. If it were a change in supply, when carbon-13 went up, oxygen-18 should have gone down, because the stomata would have been more open and more oxygen-18 would have been lost by means of water vapor transpiration (Dawson, 2013). Since carbon-13 went up and oxygen-18 stayed the same, it meant that there was no change in how much the stomata were open (Dawson, 2013). The trees photosynthesized faster as height within the tree increased (Dawson, 2013).

The differentiation between supply and demand conditions is important because two tree rings can appear very similar, but isotopic analysis of tree rings can reveal very different conditions, since there can be many variations between temperature and water source/availability. Dawson (2013) explained this in an example of two similar sets of thick rings in one tree: one would expect that there was more water available during both years to cause the increased growth, but isotopic analysis revealed that for one year the tree grew more because of warmer than average conditions, and for the other year the tree grew more because of wetter than average conditions. The isotopic analysis was compared to known PRISM climate records from 1973 to 1995 and the data sets matched up, which means that this method of studying isotopes can be used for the next step in their research: to determine what climate was like in these forests before recorded climate history (Dawson, 2013).

Impact of Changes in Summer Fog Frequency

The climate along the narrow coast of central California up to southern Oregon tends to have many cool, foggy summer days that provide moisture to what would otherwise be a very dry season (Kricher, 1998). In the journal article, “Climate Context and Ecological Implications of Summer Fog Decline in the Coast Redwood Region,” James A. Johnstone and Todd E. Dawson of the University of California, Berkeley (2010), discuss their analysis of direct hourly measurements of cloud ceiling heights, from 1951 to 2008, from ten Pacific coast stations from central Oregon to southern California measured by the National Climatic Data Center. Their work showed that fog frequency is greatest in northern and central California, at 40-44%, and declines below 30% toward Oregon and southern California. The coast redwood distribution stops at both the northern and southern 35% fog frequency thresholds, which seems to indicate a correlation between fog and redwood habitat (Johnstone & Dawson, 2010). This correlation is supported by research by Emily Burns Limm (2009), in which she found that plant species across the redwood forest benefit from leaf wetting due to fog through additional water absorption and reduced transpiration.

Johnstone and Dawson (2010) also concluded that summer fog frequency is coupled with wind-driven ocean upwelling in the area known as the California Current upwelling zone, where cold, nutrient rich water flows up from the deeper ocean. The cold water temperature cools the overlying atmosphere, which combines with other atmospheric conditions, allowing the condensation of atmospheric water vapor and resulting in the development of low-level stratocumulus clouds (Bakun, 1990; Johnstone & Dawson, 2010). Areas in the world where this occurs have reduced temperatures, increased humidity, and a higher level of moisture retained in the land than that of the immediately surrounding areas (Bakun, 1990; Johnstone & Dawson, 2010). The frequency of summer fog days can be patchy and might seem to be irregular to a casual observer, but according to Johnstone and Dawson (2010), the long-term records show that the fog occurs regularly on inter-annual to multi-decadal time scales.

By comparing the relationship between fog frequency, temperature maximums, and sea surface temperatures from known data sets from 1951-2008, Johnstone and Dawson (2010) were able to then use temperature maximum and sea surface temperatures dating back to 1901 to determine the missing fog frequency information for those fifty years. Mean fog frequency from 1901 to 1925 is estimated at 56%, which is 33% above the level observed from 1951 to 2008 (Johnstone & Dawson, 2010). Graphically, one can see a downward trend in the number of fog days across the century, and statistically, the authors concluded that there have been moderate fog reductions since 1951 (2010).

How will this decrease in fog frequency affect the coast redwood? Previous research on redwood sap flow, leaf wetness, and ambient atmospheric vapor pressure deficit (VPD; a measure of the atmospheric demand for water from leaves), has shown that when low clouds are present, there is reduced forest VPD and reduced redwood transpiration, both day and night (Johnstone & Dawson, 2010; Limm, Simonin, & Dawson, n.d.). Johnstone and Dawson’s (2010) analysis showed that sap flow rates during low cloud periods were 26% of the rates observed under clear skies. Since redwoods are poor regulators of their own water use, they tend to leave their stomata open both day and night and, as a result, transpire significant quantities of water (Johnstone & Dawson, 2010). The low clouds reduce the atmospheric demand for water from the leaves, and keep them cooler, which enables the trees to hold more water than they would on sunny days (Johnstone & Dawson, 2010).

Johnstone and Dawson (2010) also note that studies on tree rings of coastal California pines have shown significant correlations between summer fog frequency and annual growth (Johnstone & Dawson, 2010). Another study on foliar uptake, which is the absorption of water into plants by leaves and stems, was conducted on redwoods and other redwood forest trees and plants to see if and how much fog they absorb. The study showed that most of the plants in the forest are taking in moisture through their stems and leaves, with redwoods averaging an over 2% increase in leaf water content (Limm, Simonin, & Dawson, n.d.; Limm, 2009). While more research needs to be conducted, current science suggests that if fog continues to decline, the redwood will likely face heightened water-related stress.

Redwood Seedlings and Drought

Analysis of PRISM data, redwood distribution, and fog frequency have shown that redwoods are likely to be facing increasingly drier conditions in the near future (Hamilton, 2013; Carroll, 2013; Johnstone & Dawson, 2010). So what is the response of a redwood tree to increasingly drier conditions?

As discussed in the previous section, atmospheric pressure demands water from leaves and is measured using vapor pressure deficit (VPD) (Ambrose et al., 2015; Johnstone & Dawson, 2010). The pressure is like a straw; the atmosphere is pulling moisture from the leaves and water draws up from the roots and through the tree to replace it (Ambrose et al., 2015; Johnstone & Dawson, 2010; Ambrose, 2013). So when the stomata are open to take in carbon dioxide, they allow the loss of water due to VPD, but if the organism closes the stomata to combat the water loss, there is less opportunity to photosynthesize because there is a decreased supply of carbon dioxide (Ambrose et al., 2015; Limm, Simonin, & Dawson, n.d.). Redwoods are poor regulators of water loss and tend to keep their stomata open—this can be harmful if there is not enough soil moisture to replace the water being drawn up the tree and can lead to embolisms, or air bubbles (Ambrose et al., 2015; Ambrose, 2013). These are created because the tension from the vacuum pressure becomes too great and tiny air bubbles form to release some of that pressure (Ambrose et al., 2015; Ambrose, 2013). Enough emboli in enough vessels can block entire sections of water conduction, and portions of the tree that are distal, or after, those embolisms will not get water and die (Ambrose et al., 2015; Ambrose, 2013). The more emboli a tree has, the more tension for the remaining working cells, causing the effect of the emboli to be exponential (Ambrose et al., 2015; Ambrose, 2013)

A research team at the University of California, Berkeley, subjected redwood seedling to drought conditions to determine a more detailed understanding of redwood drought response (Ambrose et al., 2015; Ambrose, 2013). The researchers planted and grew seeds from each of the north, central, and south RCCI research regions; each region had a control group and a drought-stress treatment group, for a total of six groups, each with twenty seedlings. The drought treatment groups were put under six weeks of drought treatment followed by two weeks of post-drought recovery periods (Ambrose et al., 2015; Ambrose, 2013). Measurements and observations were recorded before the drought, during mid-drought, during severe drought, and during recovery, and temperature, humidity, and soil moisture were monitored throughout (Ambrose et al., 2015; Ambrose, 2013).

To determine stem hydraulic function and reveal any emboli, the researchers (Ambrose et al., 2015; Ambrose, 2013) cut the plants at the base, put them in a fluorescent dye and water solution for 15-20 minutes, then cut the stem again and observed the cross-section using various computer imaging models to calculate out what percent of total conducting area that was embolized. Figure 5 shows typical binary computer images of both the redwood (*S. sempervirens*) and giant sequoia (*S. giganteum*), and as the graph shows, redwood has significantly higher amount of embolism than the giant sequoia: 43.9% embolized versus 16.5% embolized periods (Ambrose et al., 2015; Ambrose, 2013). The giant sequoia has a much more strict control of closing off stomata to prevent embolism than the redwood (Ambrose et al., 2015; Ambrose, 2013).

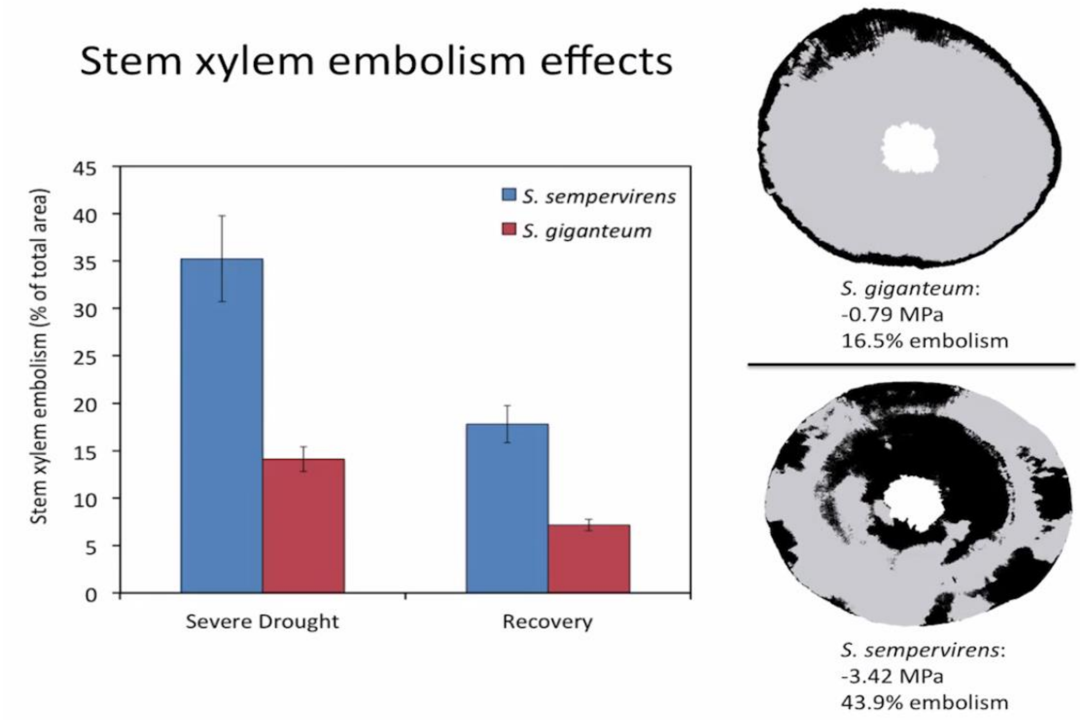


Figure 5: Stem embolism effects on the coast redwood and giant sequoia after being subjected to a six-week drought treatment (Ambrose, 2013).

In addition to the experiment revealing a high rate of emboli among drought-treated redwood saplings, the researchers found that the redwood was more susceptible to drought-induced die-back and mortality compared to the giant sequoia, but showed greater capacity to recover from stem hydraulic dysfunction, had higher growth rates when well-watered, and had a greater proportion of biomass allocated to the woody stems (Ambrose et al, 2015; Ambrose, 2013). Among the three regions of both species there was not any significant drought reaction variability (Ambrose et al, 2015; Ambrose, 2013).

According to this experiment, redwood saplings undergo severe damage under drought conditions, but can recover from those conditions better than their giant sequoia relatives (Ambrose et al, 2015; Ambrose, 2013). Like the aforementioned studies, there needs to be more research conducted because more questions start to arise: what will be the effect of longer-term drought patterns, such as over an entire summer or for multiple years? Is the effect on mature redwoods similar to that of saplings? What about the effect of drought on basal sprouts versus seedlings, since redwoods sprout much more often from parent roots than from seeds?

Conclusion: The Future of the Redwood

Climate scientists agree that it is highly likely that humans are contributing to global climate change (“Global Climate Change,” n.d.; Mathez, 2009). Levels of atmospheric carbon dioxide are increasing at the fastest rates seen in hundreds of thousands of years (“Global Climate Change,” n.d.). Despite all of the negative implications of climate change, there is some good news: redwoods are carbon storage champions. One average mature redwood tree removes 1,600 tons of carbon dioxide from the atmosphere, and the mass of these trees is so significant that ancient redwood forests store at least three times more carbon than any other forest (Herbert, 2014). They even help after they die. Usually, when organisms die, the decomposition process releases their stored carbon back into the atmosphere. The redwoods slow this process down because they have decay-resistant wood laden with tannins (Kricher, 1998), so even after death they are holding carbon back from the atmosphere (Herbert, 2014). In the face of climate change, these species are even more important than ever.

Another promising piece of news is that some of the redwoods have been growing at a faster rate since the 1970s than *ever before*; speculations for this include the possibility that the trees are growing faster because less foggy days allow for more sunlight and more photosynthesis (Boxall, 2013; Brown, 2013; "Past, Present, and Future," 2013). Another possibility is that the decreasing level of air pollution from North Coast wood processing plants is increasing the available sunlight for photosynthesis (Boxall, 2013). Maybe a century of wildfire suppression has a big influence, since fires burn branches and leaves, which forces trees to regrow their canopies instead of producing more wood. Without fires, there was no energy diverted, and those full canopies could keep making more and more wood (Boxall, 2013). Regardless, how much longer can these accelerated growth rates be sustained before there are consequences?

All of the research thus far has yet to give us a clear picture as to the fate of the redwood. Observed weather records indicate that the climate of the redwood region is highly variable and that the redwood will face the most strain under future drier conditions, especially in the southernmost areas of distribution (Hamilton, 2013). Dendrochronology of the redwood gives us climate data prior to observed historical records (Carroll, 2013), and isotopic analysis shows how the redwoods respond to these changes (Dawson, 2013). It is likely that fog frequency will continue to decrease, but it is unclear whether this will have a positive or negative impact on these trees (Johnstone & Dawson, 2010). Redwood seedlings respond negatively to drought conditions but can recover quickly from those effects (Ambrose et al., 2015; Ambrose, 2013); how well will they, or mature trees, recover from long-term and multiple years of droughts? The trees are growing faster than they ever have before (Boxall, 2013; Brown, 2013; Save the Redwoods, 2013)—will this pattern continue as time moves on, and how long is it sustainable? None of these studies can tell us what exactly the future regional climate will look like, but as the research continues, the redwoods' response to these changes will only become clearer.

CHAPTER THREE: METHODOLOGY

This capstone is intended to provide a climate change and redwoods resource for environmental educators by providing a literature review on climate and redwood research and a lesson plan for teaching climate change in the redwood setting. The lesson plan focuses on teaching climate and redwoods to fifth and sixth grade students attending outdoor education programs and was evaluated using pre- and post-questionnaires.

The science behind climate change is complex, and when teaching the subject to elementary school age children, one be mindful of the psychological impacts of learning about environmental crises (Thomashow, 1995). While the research portion of this paper goes into great scientific detail, most of it will not be included in the lesson plan because it is too advanced for the students. Instead, the lesson plan will focus on an introduction to climate science, how humans effect climate, how climate change might affect the redwoods, and how students can help. The lesson plan emphasizes the most basic concepts of changing global climate, including greenhouse effect, photosynthesis and carbon, the carbon cycle, the relationship between drought, redwoods, and climate, dendrochronology research, and anthropogenic sources of carbon dioxide. Most importantly, the lesson plan concludes with a discussion on how the students can reduce their own impact on carbon emissions, called their carbon footprints, particularly by reducing the amount of goods and food they buy.

Climate and Redwoods Lesson Plan

Lesson Plan Logistics

This lesson plan will introduce basic climate concepts, the potential effects of a changing climate on the redwood forest, and actions students can take to help the forest. It is written to take place during Westminster Woods' all-day redwood hike, which lasts approximately six hours. The property consists of 200 acres of coast redwood forest situated approximately ten miles from the Pacific Ocean. Much of the land lies on a slope, with numerous hiking trails that switchback up the slope and connect together by way of a dirt road near the top of the hill.

The plant community is dominated by redwood trees, but Douglas fir also grows up into the canopy, and the understory consists primarily of tan oak, madrone, and California bay laurel. The redwoods provide a heavily shaded forest floor in which few shrubs and forbs grow; this moist environment is ideal for the ferns, fungus, banana slugs, and lichens which are common in the forest. The bottom of the property flattens out, providing room for a grass play field, buildings, and parking areas. Dutch Bill Creek flows adjacent to the flat area and, if teachers should choose to add the lesson to the schedule, provides an ideal setting for teaching stream ecology.

Groups of students are led by teacher naturalists, or simply "naturalists." Each naturalist has a group of ten to fifteen students, though the lesson plan can be modified for use by other organizations for groups of up to twenty-five students. Naturalists at Westminster Woods can choose any route on the property to take their group, and will carry supplies to facilitate all the activities outlined in the lesson plan. The groups will also carry adequate food to sustain students and adults during the day, and water bottles can be refilled at three water stations along the trail. Students should be reminded after breakfast to each bring a backpack, a full water bottle, and their Westminster Woods journal with them on the hike.

Prior to the start of the lesson plan, all trail groups will gather in a meeting room and participate in a food chain lesson and skit to prepare them to think scientifically during the day. Groups will then split up, divide food supplies to be carried by everyone in backpacks, and have one last restroom break. At this point, the lesson plan will start, and naturalists will have five and a half to six hours to complete the activities. The lesson plan includes discussions and activities that are meant to take place at different stops along the hike. As in any environmental education day, more frequent movement to more places might be necessary to keep students active and engaged, students should be consistently given positive feedback for active participation, and food should be provided frequently during the day to maintain high energy levels.

To provide a quantitative measure of learning, students will complete a questionnaire prior to participating in discussions and activities, and then complete the same questionnaire at the end of the all-day hike. The questionnaire is designed to cover the major concepts of the lesson plan; each individual’s pre-test and post-test scores will be compared and all scores statistically analyzed to determine the effectiveness of the lessons and student understanding of the major concepts. While this chapter will discuss the lesson plan in detail, an outline version can be found in Appendix A, which includes a list of supplies necessary for the day. The original questionnaire is located in Appendix B and a revised version is in Appendix C. Printable graphics needed to conduct the lesson plan can be found in Appendix D.

Objectives

Objectives of the lesson plan are as follows:

- Students will understand the carbon cycle and greenhouse effect.
- Students will understand how a warming atmosphere will affect the water cycle, causing many dry places to become drier and many wet places to get wetter.
- Students will know that scientists are currently researching how redwood trees have responded to past climate changes.
- Students will connect global climate to anthropogenic carbon emissions.
- Students will commit to at least two new ways to reduce their carbon footprints and start them upon arriving back at home.

Lesson Plan Introduction

Naturalists can introduce the topic of the day as global warming and climate change, but should make sure to have the students fill out the pre-questionnaire prior to any teaching of climate concepts so that their answers only reflect knowledge of the topic prior to their visit. Students should be reassured that they will not be graded on their answers, and that the purpose of the questionnaire is to see how much they already know about what they will be learning about during the hike. Students should work on the questionnaire quietly and alone and be given as much time as they need to complete it, which will likely be ten minutes or less. Once finished, naturalists will collect the sheets, ensuring that the students have all filled out the identification information and circled "pre-test," and then will ask the students to discuss in partners the following question as they walk to their next stop: what do you think the difference is between weather and climate?

Prior to reaching the next teaching spot there should be a group discussion on weather and climate, including the formal definitions for the terms. Weather, according to Mathez, is “the conditions at any one time at any one place—temperature, precipitation, humidity, wind, atmospheric pressure, and cloudiness” (2009, p. 255). Climate is “the average weather for a particular region for a significant period of time, typically several years” (Mathez, 2009, p. 248). To transition to the next section on the greenhouse effect, naturalists should tell the students that weather and climate patterns are influenced by how much of the sun’s energy reaches the surface of the Earth and how much of it can escape back out to space.

The Greenhouse Effect

The purpose of this next section is to have students understand what the greenhouse effect is and how it is important to life on Earth. Naturalists should ask students if they have any idea what “greenhouse effect” means and support them in their thought processes. Then, two volunteers should be chosen to be actors in a play about the greenhouse effect, preferably students that are more inclined to be silly and entertaining for the rest of the group. The actors will play the roles of “Jenny” and her dog, “Fido,” and will act out each line of the story that the naturalist reads.

“Jenny and her dog, Fido, are playing fetch at the dog park on a sunny day. Fido is a young and really hyper puppy. They play fetch for a while, but then they both start to get tired. They get into the car to go home. Jenny realizes she forgot to buy apples for the fruit salad she is making for her friend’s birthday party. Jenny drives the car to the supermarket, parks the car in a sunny spot, and rolls the windows up so crazy Fido can't run away. Jenny goes into the store and picks her apples. She runs into a neighbor and gets distracted" (naturalist enlists a third volunteer). "Meanwhile, it doesn't look like Fido is doing too well in the hot car. Jenny suddenly remembers Fido! She leaves the apples and runs to the car. Fido is lying down on the seat and panting really hard. Jenny opens the door and walks Fido to the shade. She gives him water and apologizes."

After the skit, the naturalist should ask the audience what happened to Fido and why, using a dry erase board and marker to draw a car and illustrate how sunlight energy can pass through glass, but once it hits the interior surfaces of the car it converts to heat energy, which cannot pass back through the glass to escape the car. More and more sunlight comes in and changes to heat, making the inside of the car become hotter and hotter. A greenhouse can then be drawn to explain why the phenomenon is called "greenhouse effect."

Most importantly, naturalists should be sure to draw the Earth with a thin atmosphere around it, explaining that greenhouse gases, such as carbon dioxide, do the same thing as the car/greenhouse glass: they allow the sunlight to reach the Earth's surface and prevent some of the heat from escaping back into space. These greenhouse gases are vital to life on this planet, and without them, it would be too cold for anything to live (Mathez, 2009). To transition to the next place, students should find a new partner and discuss how they think carbon dioxide gets into the atmosphere.

Photosynthesis and Carbon

This section focuses on reviewing photosynthesis and a simple version of cellular respiration, which are concepts that students will likely already be familiar with from science lessons at their home school. At the next stop on the hike, the naturalist will ask some students to share with the group what they discussed during the transition with their partners.

The naturalist will then ask the group about photosynthesis and what components are needed for plants to produce their own food, what the food is that they produce, and what gas plants give off into the air. As students give the answers for water, carbon dioxide, energy from the sun, sugar/glucose, and oxygen, the naturalist will write their answers on the dry erase board as a chemical equation: $6H^2O + 6CO^2$ + energy (from sun) = $C^6H^{12}O^6 + 6O^2$. Then, the naturalist will remind them that animals use cellular respiration to process the energy they eat, and it is the reverse of the photosynthesis equation. Under the equation on the board, the naturalist will ask the students what animals/humans eat (sugar like glucose), what they breathe (oxygen), and what they breathe out (carbon dioxide and water vapor). If students do not come up with exhaling water vapor, the naturalist can remind them of seeing their breath on a cold day, or breathe into a plastic baggie to show the exhalation of water. As students answer, the naturalist can write the chemical equation for cellular respiration: $C^6H^{12}O^6 +6O^2 = 6H^2O + 6CO^2$ + energy (that is used to live and given off as heat).

The naturalist can also draw lines from the components of the photosynthesis equation to the components of the cellular respiration equation to show that the equations contain the same components and that they are the reverse of each other. Once the concept is reviewed, the naturalist can circle all the “C”s and explain that carbon is almost everywhere on Earth, including in rocks, and that fossil fuels like coal, oil, and natural gas are made from microscopic organisms that were buried under sediment millions of years ago (Mathez, 2009). To transition to the next stop, the naturalist should have the students choose a new partner and discuss, while walking, what other places on the planet carbon might be stored.

The Carbon Cycle

Please Pass the Carbon (n.d.) is a game from the Massachusetts Department of Elementary & Secondary Education website that is intended to illustrate the major types of carbon sinks on the planet where carbon is stored, and to show how carbon moves among the sinks, at different rates, in the carbon cycle. Once arriving at the new stop, the naturalist will have each student find three items each, roughly the size of their fists, such as pinecones, rocks, sticks, etc. The next step is to set up the game, which should be done quickly so as to not lose students' attention. Sitting in a circle, students will be assigned the following roles, and the naturalist will give them "nametags" of tape or stickers that indicate their role. It might be beneficial to make nametags prior to the start of the day. The following roles are to be assigned in clockwise order: atmosphere, plants, animals, humans, soil, ocean, a second ocean, fossil fuels, underground rocks, and a second underground rocks ("Please Pass the Carbon," n.d.). If there are more than ten students, assign more ocean and underground rock roles, or even one other atmosphere, making sure to keep them in the order listed above. Making more ocean and underground rock students shows that these are the biggest carbon sinks ("Please Pass the Carbon," n.d.).

For the first round that illustrates the short-term carbon cycle, the students representing rocks and fossil fuels should stand outside of the circle—the naturalist will have each remaining student pass one "carbon" to their left in this order: atmosphere to plants to animals to humans to soil to ocean to atmosphere ("Please Pass the Carbon," n.d.). If the group has demonstrated a high level of understanding, the naturalist can ask them how the carbon would actually move from each sink to the next, otherwise, the naturalist can explain each transition. Atmosphere gives plants carbon dioxide to make glucose; animals eat plants and the carbon inside of them; humans eat the animals; humans die, or make scat, or fingernail clippings, or hair falls off and decomposes in the soil; soil erodes into the ocean; ocean currents circulate carbon to other parts of the ocean; ocean algae takes in carbon dioxide, dies, and layers on the ocean floor to make fossil fuels; fossil fuels are trapped in between underground rocks; and rocks get uplifted, break apart, and release carbon into the atmosphere as carbon dioxide. Once this is explained, have everyone pass one "carbon" again to their left, and then once more. The naturalist will then ask how many "carbons" each person has, which should still be three, and point out that this is a balanced system.

For round two, the naturalist will explain that sometimes there are trades between sinks—where the ocean and atmosphere meet, they exchange carbon—this is illustrated by having an ocean student and atmosphere student trade one "carbon" for one "carbon" ("Please Pass the Carbon," n.d.). Plants and soil can trade because plants die and decompose carbon into the soil, and soil gives off carbon dioxide that plants can use for photosynthesis. A three way exchange can take place between atmosphere, animals, and plants because animals eat plants, breathe out carbon dioxide into the atmosphere, and plants take in carbon dioxide from the atmosphere. The round should conclude by pointing out that everything is still in balance and that passing the "carbon" in the full circle or by trading shows how carbon cycles daily on the planet, but that some carbon movement can take thousands to millions of years ("Please Pass the Carbon," n.d.).

In round three, the rock and fossil fuel students will take their places back in the circle. Everyone will pass one “carbon” again to their left, and the naturalist will explain how it takes millions of years for algae to build up on the bottom of the ocean to create fossil fuels like coal, oil, and natural gas (Mathez, 2009). It also takes millions of years for plate tectonics to uplift underground rocks above the surface, where they will take many more years to erode and break apart (Mathez, 2009). This is the carbon cycle over the long-term, and the naturalist can ask the students: is everything still in balance?

Round four will illustrate how humans are causing an imbalance in the carbon cycle. The naturalist will explain that humans burn fossil fuels to generate energy to power cars, planes, trains, and ships to transport people and goods—this releases carbon dioxide from fossil fuels to the atmosphere (Mathez, 2009; Zhong & Haigh, 2013). The naturalist will have the “human” student take one “carbon” from “fossil fuels” and give it directly to the “atmosphere.” Then, the naturalist will explain that electricity for homes and factories is generated by burning fossil fuels, too, which also releases carbon into the atmosphere, and will have the “human” take one “carbon” from “fossil fuels” and give it to the “atmosphere” (“Please Pass the Carbon,” n.d.). Then the group will be asked: is the system still in balance? Are humans having an effect on the carbon cycle? Carbon from fossil fuels is part of the long-term carbon cycle, but humans are moving that carbon into the short-term cycle (Mathez, 2009).

To transition to the next place, the naturalist will have the students recall the greenhouse effect and how carbon dioxide is a greenhouse gas that keeps the planet warm. The naturalist will then tell them to walk and talk with a new partner, discussing what they think will happen to Earth's temperature if carbon dioxide is released faster into the atmosphere.

Drought, Redwoods, and Carbon Dioxide

In the new teaching spot, the group should share their answers to the transition question, which provides set up for defining the term, "global warming." The naturalist will explain that more carbon dioxide in the atmosphere will cause an increase in global temperature, but different places might experience the warming differently. Using the dry erase board, the naturalist will draw an ocean that connects to a beach and some mountains, and then ask students the following questions:

- Remember the water cycle? What is the word for when water heats up and rises into the atmosphere as a gas (evaporation)?
- If Earth's temperature gets warmer, will more or less water evaporate from the ocean (more)?
- Will this mean there will be more or less water in the atmosphere (more)?
- When the extra water in the atmosphere moves to other places and rains or snows down, will these be bigger or smaller storms (bigger) ("Global Climate Change," n.d.; Mathez, 2009)?
- So can global warming mean colder, wetter weather in some places (yes) ("Global Climate Change," n.d.; Mathez, 2009)?

The naturalist will then explain that this is why scientists use the term "climate change" now instead of global warming, since not everywhere will experience an increase in average temperatures.

Using the drought map graphic (see Appendix D), the naturalist will explain that some places in the country are experiencing more dryness, and some are experiencing more wetness, with California currently experiencing the worst drought on record (since the late 1800s) (US Drought Monitor, 2015). The naturalist will then lead a discussion of local drought effects by asking the students, “What will happen to these giant redwood trees if there is less water?” During the discussion, the naturalist will let the students know that scientists are currently researching the effects of climate change on redwoods, and these scientists were surprised to find out that the redwoods are actually growing at faster rates now than ever before (Boxall, 2013; Brown, 2013; Save the Redwoods, 2013). Some reasons could be that the warmer weather means less foggy days, which expose the trees to more sunlight, or maybe the higher amount of atmospheric carbon dioxide means the trees can photosynthesize more quickly (Boxall, 2013; Brown, 2013; Save the Redwoods, 2013). The point here is that research is being conducted *right now* on the climate and redwood relationship, and although climate science shows that humans are contributing to climate change, the extent of the effects of the change is largely unknown (“Global Climate Change,” n.d.).

Wood cookie analysis activity. Students will each be given a redwood branch cross sections, known as wood cookies or tree cookies, and the naturalist will prompt the students to discuss what the rings mean on the wood cookie, what the thicker and thinner widths indicate, and what the black or brown spots on them are (fire scars) (Carroll et al., 2014). The naturalist can even have the students count backwards to a fire scar to calculate the year that the fire occurred.

Students will be told that one way scientists are learning about how redwoods might react to climate change is by studying how they reacted to climate changes in the past. The study of tree rings is called dendrochronology, and scientists can not only learn how old a tree is or when a fire was, but also when the last drought was and how the tree responded to it. They can even figure out how old historic wood buildings are by comparing the rings of living trees to the rings in the logs of the building, as long as the buildings were made from nearby trees. At this point, students will be shown the tree ring sample timeline (Appendix D), in which tree rings can be lined up to determine when the tree was cut down to make the building, followed by the photo of tree cores (Appendix D) and an explanation about how cores are taken using hollow drills to avoid cutting and killing a whole tree (Carroll et al., 2014).

As part of recent redwood dendrochronology research, there is now a timeline of redwood history that dates back to the year 328 (Carroll et al., 2014). Now that this history is recorded, scientists will analyze it to understand how redwoods changed during past climate changes. What is known now, though, is that ancient redwoods do a great job of removing carbon dioxide from the atmosphere—ancient redwood forests process three times more carbon dioxide than any other forest (Herbert, 2014). To transition to the next place, the naturalist should point out that the trees cannot take in all the extra carbon dioxide that humans are emitting into the atmosphere, and that the students can all help by doing less things that use energy from fossil fuels, like using less electricity and less gasoline in vehicles. While hiking to the next place, students should discuss in partners how they can use less electricity and gas.

Closure and Commitment

This section focuses on empowering students to reduce their carbon footprints when they return home. The naturalist will start by explaining that a person's carbon footprint is how much carbon they contribute to the atmosphere with their lifestyle. He can ask the group which person would have a bigger carbon footprint: the person that rides in a car to school every day or the person that rides a bike to school every day? Would a person that leaves the computer, television, and lights on in the house all day have a bigger or smaller carbon footprint than someone that turns things off when not using them?

The naturalist will then lead the group in a brainstorming session on ways to reduce their carbon footprints, and will start by having students open their journals to two blank pages that face each other. At the top of the left page they should write the label, "Things I already do to reduce my carbon footprint," and label the right page, "New things I can do to reduce my carbon footprint." Students will likely give ways that they can avoid riding in vehicles, but the naturalist should try to steer them more toward ways they can reduce their electricity use. The naturalist should explain again that most electricity for buildings comes from power plants, which burn fossil fuels to get the energy, which releases carbon into the atmosphere. A fun fact to share with the students that helps to put electricity use in perspective is about the video game console, Xbox One. The naturalist can ask if anyone has, or know anyone that has, and Xbox One at home. There is a feature where one can walk into a room and say "Xbox on" and it will turn on. This means it is always on and using electricity to listen for someone to tell it to do something—nearly half the electricity used by the game console is during this standby mode (Delforge, 2014).. If everyone who bought an Xbox 360 upgrades to an Xbox One and doesn't change the settings, it will cost the Xbox owners $400 million a year in electricity bills and consume as much electricity as a large, 750-megawatt power plant produces in an entire year (Delforge, 2014).! To prevent the waste of energy, all Xbox One owners need to do is turn of the voice control option in the settings, or simply unplug the unit when not in use (Delforge, 2014).

Once the discussion on transportation and electricity starts to slow somewhat, the naturalist should show students the U.S. Greenhouse Gas Emissions pie chart (Appendix D) and explain that all the things they talked about fell into the Electricity and Transportation sections, but their answers really only addressed part of the Transportation section ("Sources of Greenhouse Gas Emissions," n.d.). He should ask, "What other reasons do vehicles use gas—especially trucks, trains, airplanes, and ships? What do big semi-trucks transport?" This will lead into a discussion of consuming goods, and how buying less goods will enable them to tackle the rest of the Transportation section, as well as the Industry section. The naturalist can use a water bottle as an example of how raw materials are harvested, transported, manufactured into goods, transported again, and sold; all of these steps contribute carbon into the atmosphere. The group should be led to answer that they can reduce their carbon footprints by buying less stuff, fixing broken things, buying used goods at secondhand stores, etc. Once the conversation slows, the naturalist will have the students circle the things on the right-side list that they commit to doing once they get home.

Closing ceremony. To celebrate the students' learning and commitments, the naturalist will tell them that Westminster Woods has a special ceremony to tell the redwoods that they want to help them keep carbon in the atmosphere at lower levels. To become part of the Carbon Warrior Club, students can rub soot from a burned tree onto their face and say one of their commitments out loud to the forest. If possible, the naturalist should plan the route so that this stop along the hike has a burned tree with soot, or she can carry a few pieces of charcoal wood in his pack.

Final Logistics

After the ceremony, the group should walk to another place close to camp, but not all the way back to camp to avoid distractions from groups of other students. Naturalists should then give the students the questionnaire and make sure they fill out the identification section, especially circling the words, "post-test." Students should have as much time as they need to fill out their questionnaire, which will, like the pre-questionnaire, likely be approximately ten minutes. To ensure that students write thoughtful and complete answers, naturalists should not dismiss each student as they finish. Instead, as typical at Westminster Woods, the group can circle up and share a few words in a closing debrief.

Proposed Data Analysis

The hypothesis for this project is that students will increase their understanding of climate change and its relationship to the redwood forest. Quantitative data for this project will be collected through the pre- and post-lesson questionnaires, and scores of each individual will be compared to determine if there is an increase in understanding. This data will be analyzed by determining the mean change in test scores among individual trail groups, as well as the mean of the entire project population. Comparisons will be made between the two different versions of the questionnaire to see if there is a measurable amount of success between the two versions. Comparison of naturalist mean group score changes will also occur to see if there is any difference to note.

Statistical significance of the change in test scores will be analyzed using a t-test, in which the pre- and post-test values are paired. The null hypothesis is that the post-test scores will not be significantly higher than the pre-test scores. The t-test analysis will determine whether the null hypothesis will be accepted or rejected.

Conclusion

The described lesson plan and its accompanying questionnaire will be used to teach climate change to fifth and sixth grade students participating in a multi-day, residential outdoor and environmental education program at Westminster Woods Camp and Conference Center. The lessons focus on teaching the fundamental principles of climate change, current research on climate change impacts on the redwood forest, and how students can apply this knowledge to reduce their consumption of goods. The hypothesis for this project is that students will increase their understanding of climate change and its relationship to the redwood forest. To measure the amount of learning among students, each will fill out a pre- and post-questionnaire to compare their knowledge of the topic before and after participating the lesson plan activities. These scores will be analyzed by comparing mean changes in paired scores among naturalist groups and as a whole population. A paired two-sample t-test will also be calculated to determine if there is a statistically significant increase in individual test scores.

CHAPTER FOUR: RESULTS

More evidence is suggesting that current climate changes are directly linked to anthropogenic sources (Mathez, 2009; “Global Climate Change,” n.d.). Because of this, it is increasingly important to teach students about climate change and how human use of fossil fuels for energy affects global climate. The goal of this project is for students to understand the relationships between climate change, the coast redwood forest, and their own consumption of goods and energy. The objectives of the lesson plan are the following:

- Students will understand the carbon cycle and greenhouse effect.
- Students will understand how a warming atmosphere will affect the water cycle, causing many dry places to become drier and many wet places to get wetter.
- Students will know that scientists are currently researching how redwood trees have responded to past climate changes.
- Students will connect global climate to anthropogenic carbon emissions.
- Students will commit to at least two new ways to reduce their carbon footprints and start them upon arriving back at home.

Having students learn about climate change through dendrochronology is a great way for them to connect through past understanding. The dendrochronology research described in Chapter Two is a concept fifth and sixth grade students can understand because they have already learned about tree rings. Many of the students that participated in this project were easily able to build on their past knowledge of tree rings to understand that scientists are using those rings to learn about redwood climate response (Carroll, 2013).

Ninety-nine students were taught the lesson plan in Chapter Three and learning was measured by having students complete a questionnaire before and after participating in the activities. The hypothesis for this project is that students will increase their understanding of climate change and its relationship to the redwood forest. Analysis of the data showed that there was an overall mean increase of 31 percentage points among the entire population, and all t-tests calculated showed that the increases in questionnaire scores were a direct result of the lesson plan.

Questionnaires: Versions One and Two

The questionnaire was designed to directly measure student knowledge of each key concept in the lesson plan: greenhouse effect, photosynthesis and carbon, the carbon cycle, the relationship between drought, redwoods, and carbon dioxide, and steps an individual can take to reduce one’s carbon footprint. Some questions required a short answer so that students could not guess and achieve a perfect score. There are also some multiple choice questions so that concept learning can be measured in a less time consuming fashion. Version one of the questionnaire can be found in Appendix B, and asks the following questions:

1. What does “greenhouse effect” mean?
2. What greenhouse gas is the biggest concern for climate change?

3. Will more greenhouse gases make the planet's average temperature warmer or cooler?

   Circle one: WARMER COOLER

4. Do scientists think climate change will make the redwood forest wetter or drier?

   Circle one: WETTER DRIER

5. What can scientists learn from studying redwood tree rings?

6. Is the Earth's climate changing because of humans?

   Circle one: YES NO

7. Name two major ways humans are adding greenhouse gases into the atmosphere.

8. Name 2 OR MORE things you will do at home to reduce your carbon footprint.

The questionnaire was revised after peer review suggestions that the multiple choice questions should include an option to circle "I don't know." In this way, student guessing would become less of a factor and the measurement of learning could be more accurate. In addition, after three groups of students participated in the project it was apparent that question seven was confusing. To clarify the question for future students, it was revised from a short answer question to a multiple choice question that asked students to circle ways in which humans add greenhouse gases to the atmosphere. Version two of the questionnaire can be found in Appendix C of this paper, and the questions are as follows:

1. What does "greenhouse effect" mean?

2. What greenhouse gas is the biggest concern for climate change?
3. Will more greenhouse gases make the planet's average temperature warmer or cooler?

   Circle one: WARMER COOLER I DON'T KNOW
4. Do scientists think climate change will make the redwood forest wetter or drier?

   Circle one: WETTER DRIER I DON'T KNOW
5. What can scientists learn from studying redwood tree rings?
6. Is the Earth's climate changing because of humans?

   Circle one: YES NO I DON'T KNOW
7. Below are some things that humans do. Circle those activities that add greenhouse gases to the atmosphere (Note: we breathe doing all these things, so don't count breathing).

   I DON'T KNOW
   WATCHING TV
   READING
   DRIVING CARS
   HIKING
   RIDING BIKES
   PLAYING SOCCER
   BUYING STUFF
   PLAY VIDEO GAMES
8. Name 2 OR MORE things you will do at home to reduce your carbon footprint.

Student questionnaires were scored out of a total of eleven points, with questions one, seven, and eight carrying more weight than the less detailed ones. Points were consistent between each questionnaire version, and the answer key can be found in Appendix E. Questions one, seven, and eight were each worth two points each, and questions two, three, four, five, and six each were worth one point.

Student and Naturalist Participation

This project was implemented in April and May of 2015. A total of ninety-nine students from five different schools participated in this research project; fifty-six were in fifth grade and forty-three were in sixth grade. Five naturalists participated: two naturalists only taught the lesson plan to one group each, two naturalists taught to two groups each, and one naturalist taught to three groups, which equals a total of nine groups. These groups ranged from nine to thirteen students; five groups consisted of fifth grade students and four consisted of sixth grade students.

Other naturalists were interested in participating in the project; some declined due to a lack of personal time necessary to prepare and others used portions of the lesson plan in their teachings. Data collected and analyzed in these results is only from those naturalists that were able to complete the entire project with a group of students.

Data Analysis

Score Changes: Means and Percentage Point Increases

A spreadsheet of the data collected can be found in Appendix F, which includes participant totals, pre- and post-scores, individual score changes, mean score changes for each trail group, and mean score changes for the entire population. Since the goal of the project was for students to increase their knowledge on the topics, it was important to keep each student's pre- and post-scores paired together for all analyses. Percentage points were calculated according to this example: one student scored 2 points on the pre-test and 9 points on the post-test. The 7 point difference divided by 11 equals a gain of 64 percentage points, increasing her grade from 18% to 82%.

For all ninety-nine students, the data showed a mean 3.44 point mean increase, out of 11 points, in pre- and post-test scores, which is an increase of 31 percentage points. Conversely, the average post-score was only 6.68 points/62 percentage points, which would equate to a D grade. Of all the students, there was only one that had a decrease in score (-0.5 point decrease); of the other 98 students, the lowest change was 0%, and the highest change was 91%. Nine students had a 0% change in score, which means that 91% of the students increased their scores. Since the hypothesis for this project is that students will increase their understanding of climate change and its relationship to the redwood forest, the statistics shows that this lesson plan supports the hypothesis.

There were three groups, with a total of thirty students, which were given the first version of the questionnaire before it was revised. The three groups overall had a mean 2.97 point increase, or 27 percentage points. In comparison, there were six groups, with a total of sixty-nine students, which were given version two of the questionnaire. These groups had a mean increase of 3.65 points, or 33 percentage points. It seems likely that this difference between the two versions is directly related to the changes in the questionnaire. Another explanation could be that three of the naturalists had groups during the use of both questionnaire versions—it is possible that the scores in their subsequent groups were higher because the naturalists were more familiar and comfortable with the lesson plan when they used version two.

Looking into individual naturalists further, Naturalists A, B, and C all conducted the lesson plan more than once, and all had used both versions of the questionnaire. Naturalist A had a 3.70 point/34% increase with Group 1, 4.71 point/43% increase with Group 6, and 5.83 point/53% increase with Group 9. Naturalist B had a 3.73 point/34%

increase with Group 2 and a 3.29 point/30% increase with Group 7. Naturalist C had a 1.22 point/11% increase with Group 3 and a 1.70 point/15% increase with Group 5. Naturalist A had an increasing trend in mean group score over time among the three groups she taught, as did Naturalist C, but this does not seem to be the case for Naturalist B. Another possibility for the increasing trend among Naturalist A's groups is that Naturalist A is the author of this paper. Researching the climate and redwoods connections, writing the lesson plan and questionnaires, and a personal desire to see this project succeed are all likely factors for the increasing trend in the scores of Naturalist A's groups.

T-Test Analysis

Data was also analyzed to determine if the increase in test scores was statistically significant using one-tailed, two-sample t-tests, which can be found in Appendix G. Since there were two different questionnaire versions, three t-tests were calculated: one for the entire population of all ninety-nine students, one for the thirty students that were tested with questionnaire version one, and one for the sixty-nine students that were tested with version two. All three t-tests kept student pre- and post-scores paired together, and the null hypotheses of all three tests were that the post-test scores were not statistically different than the pre-test scores.

All three tests showed that the one-tail p-values fell so far on the edges of the distribution that, when rounded to four decimal points, they came out to 0.0000. This shows that the probability that the null hypothesis is true is close to 0%, so the null hypothesis can be rejected. This means that there is a statistically significant difference between pre- and post-scores among all student scores, all version one scores, and all version two scores. According to the t-test, it is nearly impossible for the increase in scores to merely be a coincidence. The t-test supports the hypothesis that lesson plan improved student knowledge of climate change and redwoods.

Conclusion

Climate change is an increasingly important topic for students of all ages to learn, and the concepts, such as dendrochronology, are well within fifth and sixth grade students' ability to grasp. The goal of this project was for students to increase their knowledge about climate change, understand how scientists are currently researching redwood responses to climate, and explore ways to decrease their personal carbon emissions. According to the data analysis, the mean difference between pre- and post-questionnaire scores was a 31 percentage point increase. The t-test showed that the difference was statistically significant and that the increase in scores can be attributed to the activities in the lesson plan. The data shows that this project was successful—as a result of this project, these students will be better prepared to understand more advanced climate change concepts in future school lessons.

CHAPTER FIVE: CONCLUSION

Climate change is a complex concept that involves the interaction between multiple Earth systems, and while there is great understanding of these interactions, there is still much to be learned to predict with any certainty what the future will look like. Current research is being conducted by the Redwoods and Climate Change Initiative and has already revealed a greater understanding of the interactions between climate and redwood trees. Understanding these interactions is important for educators teaching in redwood forests so that they can be confident in teaching climate change to their students. While more research in teaching the climate and redwoods relationship is needed, this research paper will aid educators in this task as it is shared among them and the greater environmental education community.

Climate and Redwoods Literature

By understanding the fundamentals of climate, including the carbon cycle, greenhouse effect, the fluctuation of past climates, and the consequences of climate change, one can form educated decisions in how to live a more environmentally conscious lifestyle. This foundation also helps one to comprehend current research on the relationship between climate change and the redwood forest. This research has shown that the future climate of the redwood distribution can go one of three ways: warmer and drier, warmer, or warmer and wetter (Hamilton, 2013). In all three of these scenarios, a decrease in distribution is predicted, but a warmer and drier future is the most detrimental because it will likely cause the greatest amount of distribution contraction (Hamilton, 2013).

The research also shows a dendrochronology record dating back to 328 A.D., revealing that redwood trees grow faster the older they become, which can provide a slower rate of acceleration of atmospheric carbon dioxide as the trees sequester more of the greenhouse gas, and that the trees also grow faster when there is greater water availability (Carroll et al., 2014). An analysis of carbon and oxygen isotopes within the tree ring chronologies is currently being conducted to determine the precise reasons for faster and slower growth rates, including temperature and water availability changes, which will be used to develop a deeper understanding of redwood responses to past climate changes (Dawson, 2013).

Changes in water variability, especially from fog, will have an impact on redwood trees. Analysis of weather data over the past one hundred years has shown a decrease in the number of summer days that experience fog in the region (Johnstone & Dawson, 2010). Redwood trees and many other plants in the ecosystem rely on this fog to sustain them throughout the otherwise dry summer months because of the increased water availability and the effect fog in reducing transpiration (Limm, Simonin, & Dawson, n.d.; Limm, 2009). Experiments on redwood seedlings has revealed that the species has a low drought tolerance, which causes stem embolisms that cut off transport of water to whole sections of a tree (Ambrose et al, 2015; Ambrose, 2013). Even though drought will have a largely negative effect, if the trees experience short term droughts, then they have a great capacity to recover from these embolisms (Ambrose et al, 2015; Ambrose, 2013).

Another positive result from the studies in the literature review is that redwood trees are growing at faster rates than ever before (Boxall, 2013; Brown, 2013; “Past, Present, and Future,” 2013). A number of explanations could be accountable for this, but regardless of the reason, faster growth rates equal greater carbon sequestration, which is promising as atmospheric carbon dioxide levels continue to rise (“Global Climate Change,” n.d.).

Teaching Climate and Redwoods

The importance of understanding the fundamental concepts of climate change cannot be stressed enough, because it allows one to be able to think critically about human interactions with this planet. This foundation also allows one to make sense of the deeper climate concepts covered in the literature review, which revealed that there are systems within systems that all interact with each other and the greater Earth systems.

In teaching to elementary age students, though, one must be aware of the psychological impacts of learning about environmental crises at a young age (Thomashow, 1995). More detailed information can be taught as they advance in school, but in fifth and sixth grade, climate change concepts should be limited to basic processes and focus on achievable solutions. These students, however, can develop their intrinsic values by being empowered to make changes in their lives to help reduce their carbon footprints.

Because of this, the lesson plan of this project focused on the fundamentals of climate change and used dendrochronology to connect students with the current climate and redwoods research. Overall, the project was successful in achieving the goal of increasing student knowledge of climate change and the redwood forest. A mean increase of 31 percentage points and a statistically significant paired t-test analysis showed that student scores increased as a direct result of participation in the lesson plan activities. Because of peer recommendation and to clarify student confusion, the questionnaire was revised part way through the study and had a positive result: students that tested with version two had a mean percentage point increase 6 points higher than those that tested with version one.

Limitations and Recommendations

Although the data shows success in increasing student knowledge of the topic, the mean post-score was only 62%, which equates to a D grade. It is possible that the lesson plan has too much information to be conveyed in the allotted time frame, so teaching the lessons over two days could result in more success and higher post-scores. Another option would be to remove the carbon cycle section so that more time could be devoted to the other sections. There are other limitations for this study as well: the lesson plan does not factor in is the different academic levels of student groups, and it can also make use of more teaching strategies that engage different learning styles. The latter can be addressed on an individual naturalist basis, however, as each of them becomes more familiar and comfortable with the material.

It is recommended that further analysis be conducted to provide a broader picture of the implications of this research project. Continued and measured use of the lesson plan with more students and naturalists at Westminster Woods could give a better measure of the success of the lesson plan and also reveal if naturalists' groups' scores improve with naturalist comfort with the material over time. Additionally, the true strength of the lesson plan could be revealed by conducting this research at other outdoor environmental education schools. It would also be useful to survey the participating naturalists for feedback on ways to improve the lesson plan—what works and what doesn’t. Re-testing the students at school a month or two later would also reveal they retained any of the information after a period of time. In revisions to the lesson plan, it would be very beneficial to use the lesson plan to address concepts in the Next Generation Science Standards so that the activities align with current teaching pedagogy.

It was not possible to conduct a formal naturalist training of the lesson plan, but it would likely have been very beneficial for them to participate in a run through of all the activities. For this research, staff hours were not available, so training on the activities was rushed and mostly left to individual naturalists to read and learn the lesson plan on their own. It is likely that this limitation would be echoed in other environmental education programs as financial resources are generally limited within this field.

Personal Reflection

It is now time to circle back to my own experience as a researcher. Working on this capstone has taught me the importance of focus—not only focus on the work in general, but also how crucial it is to narrow the focus of a project into something manageable. While I feel I need to be an expert in everything about climate change and redwood trees, the reality is that I am not a climatologist, nor am I working on a doctoral degree. It took me some time, but I was able to narrow the focus to a scope that was not only manageable for me to complete, but also manageable for other environmental educators to digest. I am proud of the work I have done to complete this capstone, and am excited that it can serve to be beneficial for the greater environmental education community, especially for those teaching in redwood forests. I plan to share it with the network of environmental educators through my own personal networks as well as professional networks such as the National Park Service and the Association for Environmental and Outdoor Education, which is the California state affiliate of the North American Association of Environmental Educators.

As I finish this capstone and graduate program, I find myself re-learning what I learned when I finished my Bachelor of Arts in Anthropology—an academic degree does not make me an expert in my field, but shows that I have progressed as a student, researcher, and educator. This capstone directly aligns with Hamline University School of Education’s Conceptual Framework because by writing it, I hope to promote positive change in the environmental education community. It provides a resource for educators that might be intimidated by the topic of climate change, like I was, but value lifelong learning and strive to become better in their teaching practice. The process of development, implementation, and composition of this capstone has allowed me a deeper understanding of a topic of which I am so passionate, the ability to inquire and reflect on my own teaching practice, and an opportunity for greater contribution to my community of educators.

Appendix A: Climate and Redwoods Lesson Plan

Climate Change Curriculum for

Westminster Woods 5th and 6th Grade Environmental Education

Dorea Martin—Hamline University

April and May, 2015

NOTE: More detailed explanation of these activities can be found in Chapter Three.

Objectives

- Students will understand the carbon cycle and greenhouse effect.
- Students will understand how a warming atmosphere will affect the water cycle, causing many dry places to become drier and many wet places to get wetter.
- Students will know that scientists are currently researching how redwood trees have responded to past climate changes.
- Students will connect global climate to anthropogenic carbon emissions.
- Students will commit to at least two new ways to reduce their carbon footprints and start them upon arriving back at home.

Supplies needed:

Whiteboard and marker, tape or blank stickers, wood cookie for each student, magnifying lenses for each student (optional), drought map, tree ring sample timeline, tree core photos, drought map, U.S. greenhouse gas emissions pie chart, 2 questionnaires for each student, pencil for each student, and Westminster Woods journals or one blank piece of paper each.

Trail logistics needed:

- Stop 4—Carbon Cycle needs to have three hand held objects available for each student (rocks/sticks/pinecones/etc.), or bring items for the activity.

- Stop 6—Closure and Commitment needs to have a burned tree or log, or naturalist can bring burned wood pieces.

Stop 1: Introduction

- Today we are going to focus on global warming and climate change and what it means for the redwood forest.
- GIVE STUDENTS 10 MINUTES TO FILL OUT QUESTIONNAIRE
- Some people are confused about what those terms mean, but 97% of climate scientists agree that humans are having an effect on Earth's climate.
- Transition: Partner students and have them discuss what the difference is between weather and climate.

Stop 2: Greenhouse Effect

- Have students share difference between weather and climate with the group.
  - Weather: "The conditions at any one time at any one place—temperature, precipitation, humidity, wind, atmospheric pressure, and cloudiness" (Mathez, 2009, p. 255).
  - Climate: The average weather for a particular region for a significant period of time, typically several years (Mathez, 2009, p. 248).
- Weather and climate are influenced by how much of the sun's energy reaches the surface of the Earth and how much can escape back to space (Mathez, 2009).
- Ask: Who has an idea of what "greenhouse effect means?"

ACTIVITY—SKIT

- Have two student volunteers come up and act out the following story (after each line, pause so they can act it out):
    - Jenny and her dog Fido are playing fetch at the dog park on a sunny day.
    - Fido is a really young, rambunctious puppy.
    - They get in the car to go home.
    - Jenny realizes she forgot to buy apples for the fruit salad she is making for her friend’s birthday party.
    - Jenny drives to the store, parks the car in a sunny spot, and rolls the windows up so crazy Fido can’t run away.
    - Jenny goes into the store and picks her apples.
    - Meanwhile, Fido is in the car in the sun; he’s hot, but ok.
    - Jenny runs into a neighbor and gets distracted.
    - It’s been awhile, and Fido isn’t doing so well.
    - Jenny suddenly remembers Fido!
    - She leaves the apples and runs out to the car.
    - Fido is lying down on the seat and panting really hard.
    - Jenny opens the door and walks Fido to the shade.
    - She gives him water and apologizes.
- Applause! Ask audience to explain what happened to Fido.
- Use a whiteboard to draw a car and show that sunlight can pass through the glass, but as it hits the seats, dashboard, etc., it changes to heat energy and cannot escape through the glass. More and more energy is trapped inside, making it hotter and hotter. Erase board.

- Draw Earth and atmosphere layer around it.
    - Have the group explain to you how greenhouse gases in the atmosphere are like the glass—they hold in the heat. These gases are very important—without them, the planet would be too cold for any life to survive.
        - Carbon dioxide is an important greenhouse gas.
- <u>Transition: Find a new partner and discuss: How does carbon dioxide get into the atmosphere</u>?

Stop 3: Photosynthesis and Carbon

- Have group share how carbon dioxide gets into atmosphere.
- Review **photosynthesis** (use whiteboard).
    - Ask audience for inputs of photosynthesis and write them on board.
        - $H_2O + CO_2$ + energy (from sun) $\rightarrow$ $C_6H_{12}O_6$ (glucose) + O_2
    - Remind them that **cellular respiration** is the same equation in reverse—animals eat the glucose and breathe oxygen, and breathe out water vapor and carbon dioxide.
        - $C_6H_{12}O_6$ (glucose) + $O_2 \rightarrow H_2O + CO_2$ + energy (heat)
    - When we burn a piece of paper, it goes through **combustion,** which the same thing as **cellular respiration**—the heat from the fire breaks apart the glucose molecule's bonds and releases CO_2 and H_2O.
- Circle the C's and explain that the carbon is almost everywhere on Earth, including rocks.

  - Fossil fuels like coal, oil, and natural gas are made from microscopic algae were buried under sediment millions of years ago.
- <u>Transition: Tell students to think about other places on Earth were carbon is stored.</u>

Stop 4: Carbon Cycle

ACTIVITY: PASS THE CARBON

- Have each student find three items to represent carbon. Can be rocks, pinecones, sticks, etc., but something at least as big as an acorn.
- <u>Sit</u> in circle. Tell students they are going to represent **carbon sinks,** or places that carbon is stored. Assign the following parts in order going clockwise, and use tape or blank stickers to give students "nametags" of the roles they represent:
  - Atmosphere, plants, animals, humans, soil, ocean, a second ocean, fossil fuels, underground rocks, and a second underground rocks. (If more than ten students, assign more ocean and underground rock roles, or even one other atmosphere, making sure to keep them in the order listed above. Making more ocean and underground rock students shows that these are the biggest carbon sinks.)
- Round 1—Have rocks and fossil fuels stand outside the circle. Each remaining person passes one carbon to the left in this order: atmosphere to plants to animals to humans to soil to ocean to atmosphere. Have students explain how the carbon gets passed in real life, or explain it to them.

- Round 2—Sometimes "trades" are made between sinks—animals with plants (animals eat carbon from plants and plants use carbon the animals breathe out), atmosphere to ocean (exchange CO2 where they come in contact).
- Explain that rounds 1 and 2 happen on a daily basis and are called the **short term carbon cycle and things are naturally balanced.**
- Round 3—**long term carbon cycle**—Explain that small amounts of carbon are being cycled underground over hundreds of millions of years. Have fossil fuels and rocks sit in the circle (between ocean and atmosphere) and have everyone make one trade to the right. **Things are still in balance.**
- Round 4—
  - Explain that humans burn fossil fuels in cars, planes, trains, and ships and carbon dioxide is released into atmosphere.
    - Have the human take carbon from fossil fuels and give it to atmosphere.
  - Explain that humans burn fossil fuels for electricity. (Fossil fuels main source of electricity in this country).
    - Have human take another carbon from fossil fuels and give it to atmosphere.
- What is happening? **Humans are accelerating release of long-term carbon stores and causing the carbon cycle to become imbalanced.**
- Transition: Remember the greenhouse effect? In partners, have students discuss: What will happen to Earth's temperature as we release more carbon dioxide into the atmosphere?

Stop 5: Drought, Redwoods, and Carbon Dioxide

- Have group share: More carbon dioxide will cause warming around the world.
- Ask: In the water cycle, what happens when water, like the ocean, heats up? **Evaporation.**
- Ask: If there is more water in the atmosphere, will it stay there forever, or fall somewhere else?
  - Global warming means the dry places will get drier, and the wet places will get bigger storms and floods.
  - This is why we now call it **climate change** instead of **global warming.**
  - **Show drought map** and explain that California is experiencing the worst drought on record (records since late 1800s).
- What will happen to the redwood trees if there is less water? Discuss.
- Scientists thought that drought would be really bad for redwoods, but research shows that trees are growing more now than ever before.
  - Possible reasons:
    - Drought means less fog, which gives trees more sunlight.
    - Maybe more CO2 available means more photosynthesis.

ACTIVITY: WOOD COOKIE ANALYSIS

- Scientists are studying redwood tree rings to find out how past climate changes have an effect on redwood trees.
- Pass out wood cookies to each student and have them make observations.
  - Discuss observations as group.

  - Point out that scientists can use tree rings to learn forest fire history, climate history, how trees respond to droughts and other changes, and they can even figure out how old buildings are.
  - **Show tree ring sample timeline.**
- Scientists don’t want to cut all the trees down to examine the rings, so they use a tree corer instead.
  - **Show photo of tree cores** and explain that they use a hollow drill to get the core.
  - In 2005, scientists started collecting redwood cores all across their range to get a complete redwood history.
    - Scientists have a redwood history all the way back to the year 328. The Ancient Roman Empire was still around then!
- Let them know that scientists are still researching how climate change will affect the redwoods.
  - Scientists are currently analyzing the tree cores to find out how the trees responded to changes in the past to see how they will respond in the future.
- **We know that redwoods are doing a great job of removing carbon dioxide from the atmosphere—ancient redwood forests take in three times more carbon dioxide than any other forest!**
  - The trees can’t take in all the extra carbon dioxide humans are putting into the atmosphere. We need to help them by burning less fossil fuels, which means using less electricity and gas for cars.

- <u>Transition: As we walk to the next place, think about how you can use less electricity and gas.</u>

Stop 6: Closure and Commitment—in a spot with a burned tree with soot on it

- Explain that a person's **carbon footprint** is how much carbon dioxide they contribute to the atmosphere with their lifestyle
- What can we do to make less carbon dioxide go into the atmosphere? Obviously, we have to breathe. But there are lots of things we can do that will reduce carbon emissions.
- Have group open up to two blank pages in their journal that face each other (or use a piece of paper and fold it in half).
    - Title one side "Things I <u>already do</u> to reduce my carbon footprint."
    - Title other side "<u>New things I can do</u> to reduce my carbon footprint."
    - As a group, share things they can do to reduce their electricity consumption.
    - Crazy fact—Who has an Xbox One? There is a feature where you can walk into the room and say "Xbox on" and it will turn on. This means it is always on and using electricity, just waiting for someone to tell it to do something. If everyone with an Xbox 360 upgrades to an Xbox One and doesn't change the settings, it will cost the country $400 million a year! (This information can be found at the NRDC website at http://www.nrdc.org/energy/game-consoles/) (Delforge, 2014).
        - To fix it, either unplug it or go to the settings to turn off the voice control option.

    - Show **<u>U.S. Greenhouse Gas Emissions pie chart</u>**
        - Explain that they just figured out how to reduce the electricity part of the chart.
        - We can also reduce carbon emissions from the Industry and Transportation sections by buying less stuff, like food, clothes, video games, and toys. Use a water bottle as an example: It takes energy to make the bottle and then more energy to transport it in trucks and trains to where you go to buy it.
        - Have students brainstorm ways to use less stuff and record their ideas in their journals (thrift stores, fixing broken items, using things longer, borrowing things, and hand-me-downs).
    - Have students circle two things they will start doing when they get home.
- Do a closing ceremony—celebrate their commitments by having students use charcoal (carbon not completely burned off) as face paint.
    - "We have a special ceremony here at Westminster Woods to tell the redwoods that you want to help them reduce the amount of carbon dioxide that goes into the atmosphere."
    - "As you put on your mark of the carbon, say one commitment out loud to the forest."

Stop 7: GIVE STUDENTS TEN MINUTES TO FILL OUT QUESTIONNAIRE

Appendix B: Questionnaire Version One

Climate Change and Redwoods
Student Questionnaire

My name: ______________________

My school: _____________________

Naturalist's name: ________________

Today's date: ___________________

1. What does "greenhouse effect" mean? ___________________

2. What greenhouse gas is the biggest concern for climate change?

3. Will more greenhouse gases make the planet's average temperature warmer or cooler?

   Circle one: WARMER COOLER

4. Do scientists think climate change will make the redwood forest wetter or drier?

   Circle one: WETTER DRIER

Climate Change and Redwoods
Student Questionnaire

My name: ______________________

My school: _____________________

Naturalist's name: ________________

Today's date: ___________________

1. What does "greenhouse effect" mean? ___________________

2. What greenhouse gas is the biggest concern for climate change?

3. Will more greenhouse gases make the planet's average temperature warmer or cooler?

Circle one: WARMER COOLER

4. Do scientists think climate change will make the redwood forest wetter or drier?

Circle one: WETTER DRIER

5. What can scientists learn from studying redwood tree rings?

6. Is the Earth's climate changing because of humans?

Circle one: YES NO

7. Name two major ways humans are adding greenhouse gases into the atmosphere:

1) ____________________

2) ____________________

8. Name 2 OR MORE things YOU will do at home to reduce your carbon footprint:

---

5. What can scientists learn from studying redwood tree rings?

6. Is the Earth's climate changing because of humans?

Circle one: YES NO

7. Name two major ways humans are adding greenhouse gases into the atmosphere:

3) ____________________

4) ____________________

8. Name 2 OR MORE things YOU will do at home to reduce your carbon footprint:

Appendix C: Questionnaire Version Two

Climate Change and Redwoods
Student Questionnaire

My name: ______________________

Circle grade: 5th 6th

My school: ______________________

Naturalist's name: ________________

Today's date: ____________________

Circle one: Pre-test Post-test

1. What does "greenhouse effect" mean? ____________________

____

____

____

2. What greenhouse gas is the biggest concern for climate change?

   ____

3. Will more greenhouse gases make the planet's average temperature warmer or cooler?

   Circle one: WARMER COOLER I DON'T KNOW

4. Do scientists think climate change will make the redwood forest wetter or drier?

   Circle one: WETTER DRIER I DON'T KNOW

Climate Change and Redwoods
Student Questionnaire

My name: ______________________

Circle grade: 5th 6th

My school: ______________________

Naturalist's name: ________________

Today's date: ____________________

Circle one: Pre-test Post-test

1. What does "greenhouse effect" mean? ____________________

____

____

____

2. What greenhouse gas is the biggest concern for climate change?

   ____

3. Will more greenhouse gases make the planet's average temperature warmer or cooler?

   Circle one: WARMER COOLER I DON'T KNOW

4. Do scientists think climate change will make the redwood forest wetter or drier?

   Circle one: WETTER DRIER I DON'T KNOW

5. What can scientists learn from studying redwood tree rings?

6. Is the Earth's climate changing because of humans?

Circle one: YES NO I DON'T KNOW

7. Below are some things that humans do. Circle those activities that add greenhouse gases to the atmosphere (note: we breathe doing all these things, so don't count breathing).

I DON'T KNOW DRIVING CARS PLAYING SOCCER
WATCHING TV HIKING BUYING STUFF
READING RIDING BIKES PLAY VIDEO GAMES

8. Name 2 OR MORE things YOU will do at home to reduce your carbon footprint:

5. What can scientists learn from studying redwood tree rings?

6. Is the Earth's climate changing because of humans?

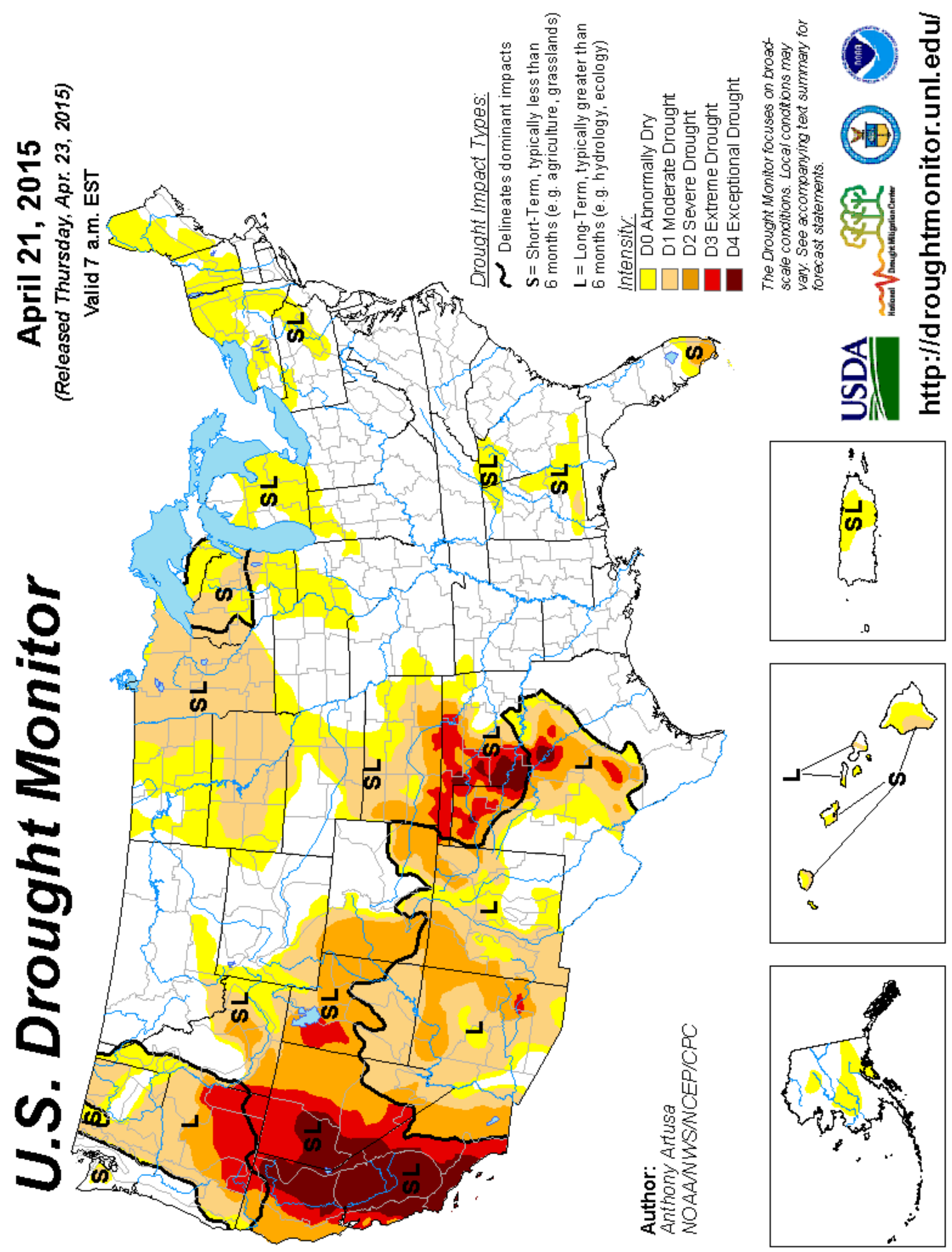
Circle one: YES NO I DON'T KNOW

7. Below are some things that humans do. Circle those activities that add greenhouse gases to the atmosphere (note: we breathe doing all these things, so don't count breathing).

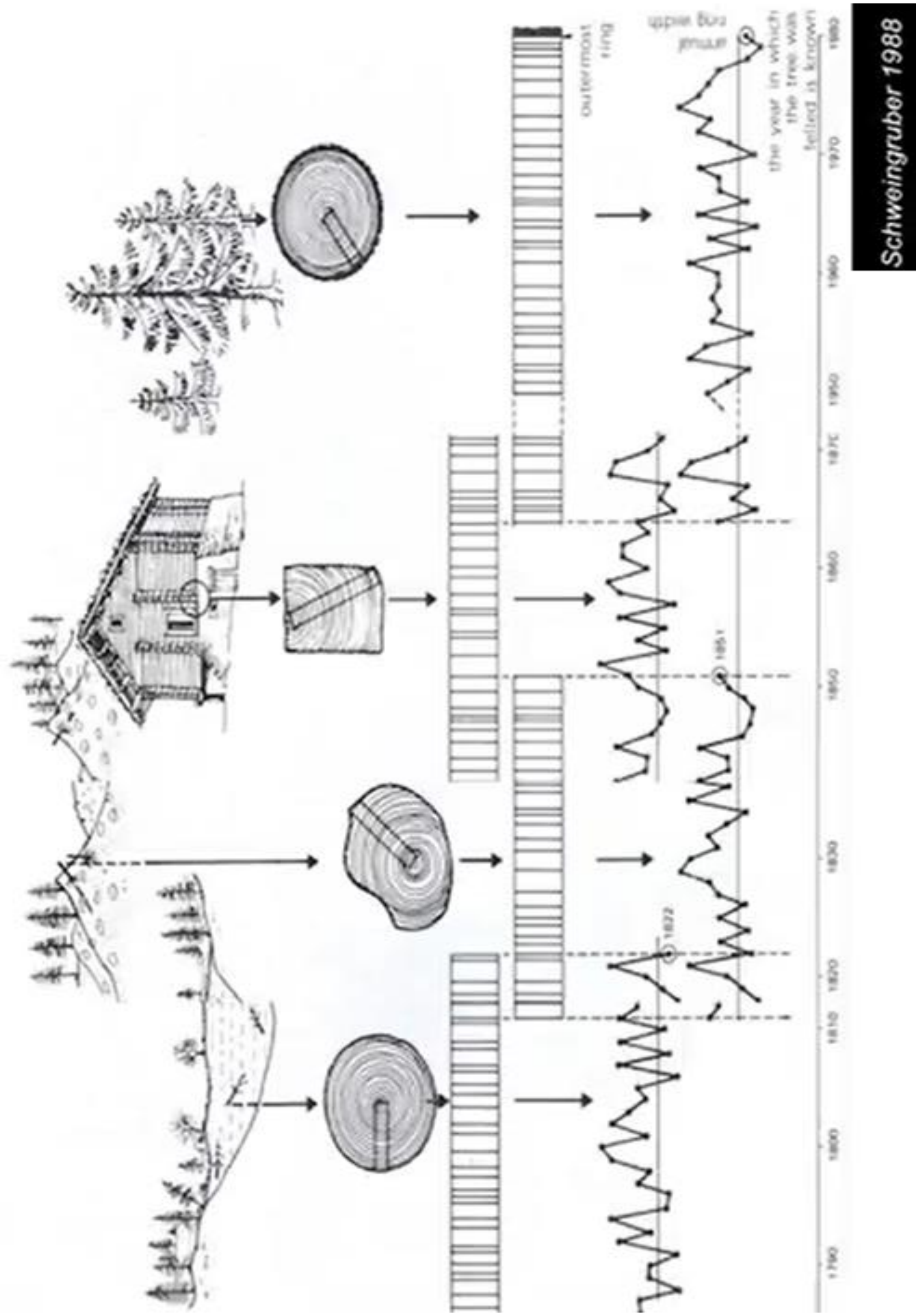
I DON'T KNOW DRIVING CARS PLAYING SOCCER
WATCHING TV HIKING BUYING STUFF
READING RIDING BIKES PLAY VIDEO GAMES

8. Name 2 OR MORE things YOU will do at home to reduce your carbon footprint:

Appendix D: Lesson Plan Graphics

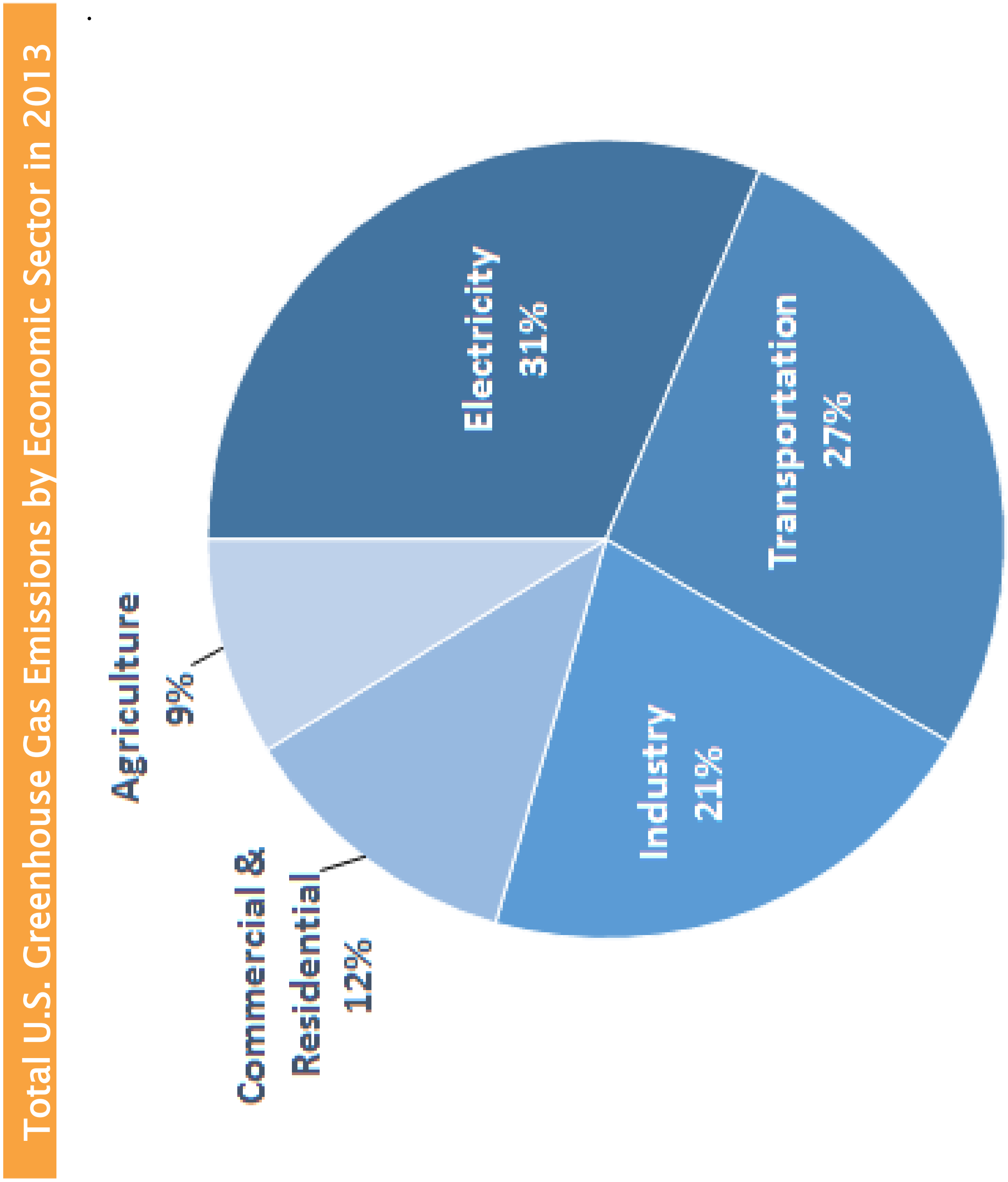


(US Drought Monitor, 2015).



Allyson Carroll, Humboldt State University (Carroll, 2013).

Allyson Carroll, Humboldt State University (Carroll, 2013).



Electricity = generation of electricity from power plants. Approximately 67% of our electricity comes from burning fossil fuels, mostly coal and natural gas.
Commercial and Residential = includes using gas to heat and emissions from trash sent to landfill
Transportation = emissions primarily come from burning fossil fuel for our cars, trucks, ships, trains, and planes.
Agriculture = emissions are primarily from livestock such as cows, agricultural soils, and rice production. (Sources of Greenhouse Gas Emissions, n.d.).

Appendix E: Questionnaire Answer Key

Climate Change and Redwoods
Student Questionnaire ANSWER KEY

My name: ______11 points possible__________

Circle grade: 5th 6th

My school: ______________________

Naturalist's name: ________________

Today's date: ____________________

Circle one: Pre-test Post-test

1. What does "greenhouse effect" mean? ___________________

   2 points—sunlight energy can pass through glass/the atmosphere.

   but when it converts to heat energy it cannot escape.__________

   ____

2. What greenhouse gas is the biggest concern for climate change?

   1 point—carbon dioxide______________________________

3. Will more greenhouse gases make the planet's average temperature warmer or cooler?

   Circle one: [✓ WARMER] 1 point COOLER I DON'T KNOW

4. Do scientists think climate change will make the redwood forest wetter or drier?

   Circle one: WETTER [✓ DRIER] 1 point I DON'T KNOW

5. What can scientists learn from studying redwood tree rings?

   ___1 point—How old the tree is OR if there was a fire OR when the tree was cut down OR when there were wetter years or drier years OR what past climate was like in the area the tree grew.

6. Is the Earth's climate changing because of humans?

   Circle one: [✓ YES] 1 point NO I DON'T KNOW

7. Below are some things that humans do. Circle those activities that add greenhouse gases to the atmosphere (note: we breathe doing all these things, so don't count breathing). 2 points total possible; ½ point for each correct circle, -1/2 point for each incorrect circle

I DON'T KNOW [✓ DRIVING CARS] PLAYING SOCCER

[✓ WATCHING TV] HIKING [✓ BUYING STUFF]

READING RIDING BIKES [✓ PLAY VIDEO GAMES]

8. Name 2 OR MORE things YOU will do at home to reduce your carbon footprint:

   ___2 points possible—1 point per answer that will reduce the amount of energy or goods the student will consume ___________

   ____

   ____

   ____

   ____

Appendix F: Research Project Data

Redwoods and Climate Questionnaire Scores and Means

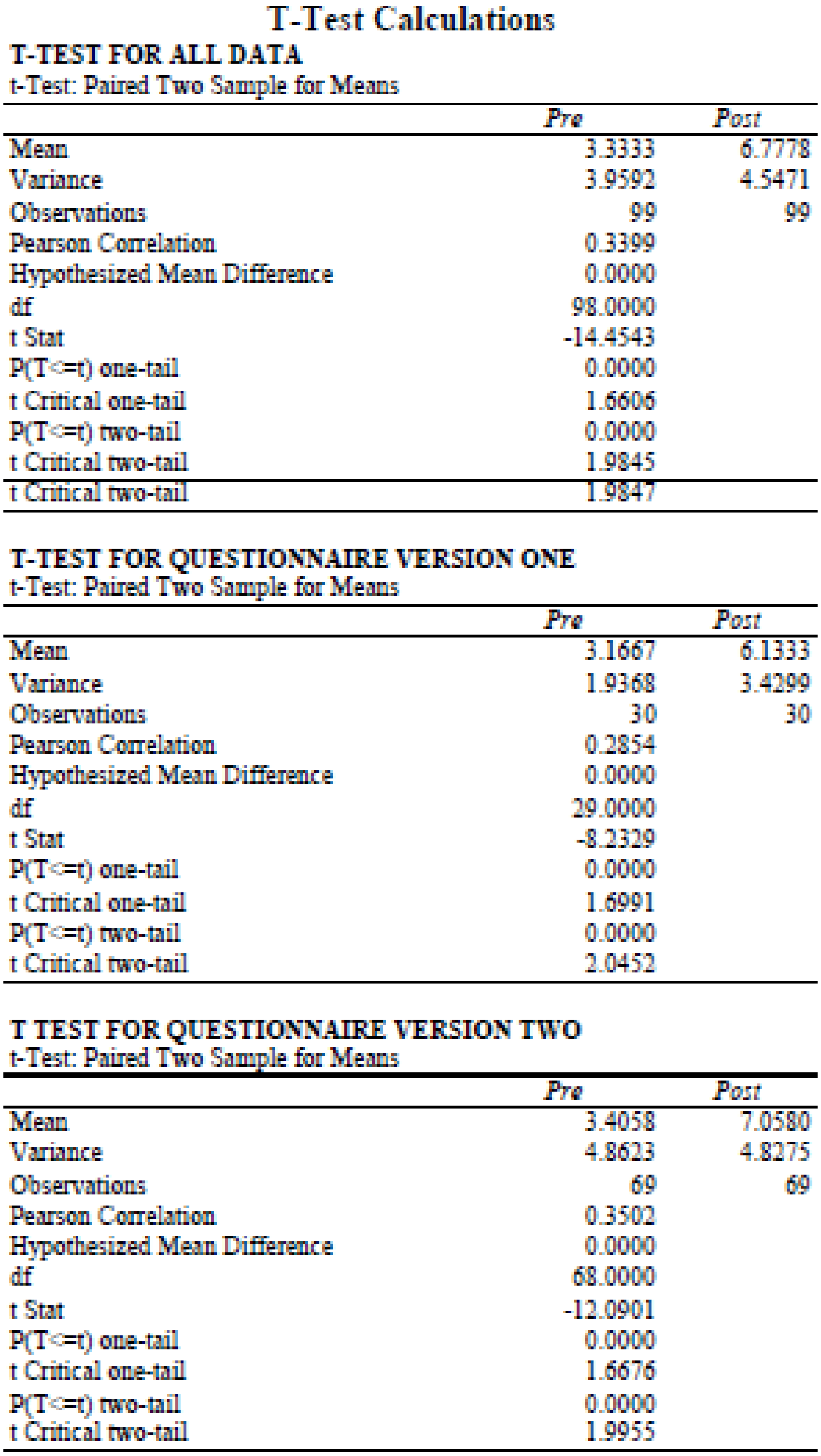
Student #	Pre-score (11 points possible)	Post-score (11 points possible)	Individual Change in Score (Raw)	Individual Change in Score (%)	Mean Change per Trail Group (Raw)	Mean Change per Trail Group (%)
Questionnaire Version 1						
GROUP 1: Naturalist A, 6th Grade, School 1, 4/28/15					3.70	34%
Student 1.1	3	8	5	45%		
Student 1.2	3	8	5	45%		
Student 1.3	1	6	5	45%		
Student 1.4	2	6	4	36%		
Student 1.5	4	5	1	9%		
Student 1.6	4	7	3	27%		
Student 1.7	2	6	4	36%		
Student 1.8	1	7	6	55%		
Student 1.9	2	4	2	18%		
Student 1.10	3	5	2	18%		
GROUP 2: Naturalist B, 6th grade, School 1, 4/28/15					3.73	34%
Student 2.1	2	9	7	64%		
Student 2.2	4	7	3	27%		
Student 2.3	4	6	2	18%		
Student 2.4	1	7	6	55%		
Student 2.5	3	4	1	9%		
Student 2.6	6	9	3	27%		
Student 2.7	4	7	3	27%		
Student 2.8	3	9	6	55%		
Student 2.9	2	7	5	45%		
Student 2.10	5	6	1	9%		
Student 2.11	6	10	4	36%		
GROUP 3: Naturalist C, 5th Grade, School 2, 4/29/15					1.22	11%
Student 3.1	5	6	1	9%		
Student 3.2	2	4	2	18%		
Student 3.3	4	5	1	9%		
Student 3.4	3	4	1	9%		
Student 3.5	2	2	0	0%		
Student 3.6	2	4	2	18%		
Student 3.7	5	6	1	9%		
Student 3.8	4	4	0	0%		
Student 3.9	3	6	3	27%		
Version 1 Totals						
Mean Change Version 1			**2.97**	**27%**		
Number of Students Version 1			**30**			

Questionnaire Version 2

GROUP 4: Naturalist D, 5th Grade, School 3, 5/13/15					3.81	35%
Student 4.1	1	9	8	73%		
Student 4.2	6.5	7	0.5	5%		
Student 4.3	4.5	7	2.5	23%		
Student 4.4	5.5	8.5	3	27%		
Student 4.5	2.5	7.5	5	45%		
Student 4.6	3.5	5	1.5	14%		
Student 4.7	2	9	7	64%		
Student 4.8	3.5	8	4.5	41%		
Student 4.9	2	7.5	5.5	50%		
Student 4.10	1	6.5	5.5	50%		
Student 4.11	3.5	8.5	5	45%		
Student 4.12	7	7	0	0%		
Student 4.13	4.5	6	1.5	14%		
GROUP 5: Naturalist C, 6th grade, School 4, 5/13/15					1.70	15%
Student 5.1	6	7	1	9%		
Student 5.2	2	6	4	36%		
Student 5.3	3	3	0	0%		
Student 5.4	1	1	0	0%		
Student 5.5	3	5	2	18%		
Student 5.6	4	5.5	1.5	14%		
Student 5.7	2.5	4	1.5	14%		
Student 5.8	5.5	5.5	0	0%		
Student 5.9	5	9	4	36%		
Student 5.10	6.5	9.5	3	27%		
GROUP 6: Naturalist A, 6th Grade, 5/13/15					4.71	43%
Student 6.1	8	10.5	2.5	23%		
Student 6.2	3.5	9	5.5	50%		
Student 6.3	8	9	1	9%		
Student 6.4	4.5	10	5.5	50%		
Student 6.5	2	7	5	45%		
Student 6.6	4	9	5	45%		
Student 6.7	0	10	10	91%		
Student 6.8	3	9	6	55%		
Student 6.9	0	8	8	73%		
Student 6.10	4	5	1	9%		
Student 6.11	3	6	3	27%		
Student 6.12	5	9	4	36%		

GROUP 7: Naturalist B, 5th Grade, School 5, 5/21/15					3.29	30%
Student 7.1	2	4	2	18%		
Student 7.2	2	5	3	27%		
Student 7.3	5.5	8	2.5	23%		
Student 7.4	3.5	5.5	2	18%		
Student 7.5	6.5	10	3.5	32%		
Student 7.6	1	7.5	6.5	59%		
Student 7.7	2.5	6	3.5	32%		
Student 7.8	3.5	9	5.5	50%		
Student 7.9	6.5	8	1.5	14%		
Student 7.10	2	5	3	27%		
Student 7.11	1	7.5	6.5	59%		
Student 7.12	9	9	0	0%		
GROUP 8: Naturalist E, 5th Grade, School 5, 5/21/15					1.95	18%
Student 8.1	2	5	3	27%		
Student 8.2	1	3	2	18%		
Student 8.3	2	2	0	0%		
Student 8.4	2.5	4.5	2	18%		
Student 8.5	4.5	7.5	3	27%		
Student 8.6	5.5	5	-0.5	-5%		
Student 8.7	1	5	4	36%		
Student 8.8	2.5	4.5	2	18%		
Student 8.9	3.5	4.5	1	9%		
Student 8.10	2	5	3	27%		
GROUP 9: Naturalist A, 5th Grade, School 5, 5/21/15					5.83	53%
Student 9.1	0	9	9	82%		
Student 9.2	3	8	5	45%		
Student 9.3	5.5	9	3.5	32%		
Student 9.4	1.5	10	8.5	77%		
Student 9.5	1	5	4	36%		
Student 9.6	3	8	5	45%		
Student 9.7	1.5	9	7.5	68%		
Student 9.8	1	7	6	55%		
Student 9.9	5.5	10	4.5	41%		
Student 9.10	1	8.5	7.5	68%		
Student 9.11	1	8.5	7.5	68%		
Student 9.12	9	11	2	18%		
Version 2 Totals						
Mean Change Version 2			**3.65**	**33%**		
Number of Students Version 2			**69**			
ALL STUDENT STATISTICS						
Mean	**Pre:3.33**	**Post:6.78**	**Change:3.44**	**31%**		
Total Number of Students			**99**			
Total 5th Graders			**56**			
Total 6th Graders			**43**			

Appendix G: T-Test



T-Test Calculations

T-TEST FOR ALL DATA

t-Test: Paired Two Sample for Means

	Pre	*Post*
Mean	3.3333	6.7778
Variance	3.9592	4.5471
Observations	99	99
Pearson Correlation	0.3399	
Hypothesized Mean Difference	0.0000	
df	98.0000	
t Stat	-14.4543	
P(T<=t) one-tail	0.0000	
t Critical one-tail	1.6606	
P(T<=t) two-tail	0.0000	
t Critical two-tail	1.9845	
t Critical two-tail	1.9847	

T-TEST FOR QUESTIONNAIRE VERSION ONE

t-Test: Paired Two Sample for Means

	Pre	*Post*
Mean	3.1667	6.1333
Variance	1.9368	3.4299
Observations	30	30
Pearson Correlation	0.2854	
Hypothesized Mean Difference	0.0000	
df	29.0000	
t Stat	-8.2329	
P(T<=t) one-tail	0.0000	
t Critical one-tail	1.6991	
P(T<=t) two-tail	0.0000	
t Critical two-tail	2.0452	

T TEST FOR QUESTIONNAIRE VERSION TWO

t-Test: Paired Two Sample for Means

	Pre	*Post*
Mean	3.4058	7.0580
Variance	4.8623	4.8275
Observations	69	69
Pearson Correlation	0.3502	
Hypothesized Mean Difference	0.0000	
df	68.0000	
t Stat	-12.0901	
P(T<=t) one-tail	0.0000	
t Critical one-tail	1.6676	
P(T<=t) two-tail	0.0000	
t Critical two-tail	1.9955	

REFERENCES

Ambrose, A. (2013). Redwoods & climate change symposium 2013: Anthony Ambrose [Video file]. Save the Redwoods League. Retrieved from https://www.youtube.com/watch?v=S-Y1G77a9C4&index=13&list=PL5572F92380833D6F

Ambrose, A. R., Baxter, W. L., Wong, C. S., Naesborg, R. R., Williams, C. B., and Dawson, T. E. (2015, March 17). Contrasting drought-response strategies in California redwoods. *Tree Physiology, 00*, 1-17. doi:10.1093/treephys/tpv016

Bakun, A. (1990, January 12). Global climate change and intensification of coastal ocean upwelling. *Science, 247*(4939), 198+. Retrieved from http://ezproxy.hamline.edu:2769/ps/i.do?id=GALE%7CA8288559&v=2.1&u=clic_hamline&it=r&p=EAIM&asid=1076636348c4fb83605995fb9ca6829f

Boxall, B. (2013, August 14). Climate change may be speeding coast redwood, giant sequoia growth. *Los Angeles Times*. Retrieved from http://articles.latimes.com/2013/aug/14/local/la-me-redwoods-climate-20130814

Brown, M (2013, August 14). Redwoods thriving as climate changes. *McClatchy-Tribune Business News.* Retrieved from http://search.proquest.com/docview/1420335597?accountid=28109

Carbon Cycle Science. (n.d.). Retrieved from http://www.esrl.noaa.gov/research/themes/carbon/

Carroll, A. (2013). Redwoods & climate change symposium 2013: Allyson Carroll [Video file]. Save the Redwoods League. Retrieved from https://www.youtube.com/watch?v=-XHocsKt6Ig&list=PL5572F92380833D6F&index=12

Carroll, A. L., Sillett, S. C., Kramer, R. D. (2014, July). Millennium-scale crossdating and inter-annual climate sensitivities of standing California redwoods. *PLOS One, 9* (7). Retrieved from http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0102545

Changes in the carbon cycle (n.d.). Retrieved from http://earthobservatory.nasa.gov/Features/CarbonCycle/page4.php

Crompton, T. (2010). Common cause: The case for working with our cultural values. Oxford, England: WWF-UK’s Strategies for Change Project.

Dawson, T. (2013). Redwoods & climate change symposium 2013: Todd Dawson [Video file]. Save the Redwoods League. Retrieved from https://www.youtube.com/watch?v=HSOvlMlCPi0&index=18&list=PL5572F92380833D6F

Delforge, P. (2014, May 16). The latest-generation video game consoles: How much energy do they waste when you're not playing? National Resources Defense Council Staff Blog. Retrieved from http://switchboard.nrdc.org/blogs/pdelforge/the_latest-generation_video_ga.html

Global Climate Change (n.d.). National Aeronautical and Space Administration. Retrieved from http://climate.nasa.gov/

Hamilton, H. (2013). Redwoods & climate change symposium 2013: Healy Hamilton [Video file]. Save the Redwoods League. Retrieved from https://www.youtube.com/watch?v=8_fWGshkrlE&index=15&list=PL5572F92380833D6F

Hazen, R.M. & Trefil, J. (2009). *Science matters: Achieving scientific literacy*. New York: Anchor Books.

Herbert, B. (2014). Redwood champions amid drought and climate change. Retrieved from http://sempervirens.org/discover-redwoods/redwood-champions-amid-drought-and-climate-change/

Johnstone, J. A. & Dawson, T. E. (2010, March 9). Climatic context and ecological implications of summer fog decline in the coast redwood region. *PNAS, 107* (10), 4533-4538. Retrieved from http://www.pnas.org/content/107/10/4533.full

Kricher, J. (1998). *A field guide to California and Pacific Northwest forests.* New York: Houghton Mifflin Company.

Limm, E. B. (2009, Fall). On the acquisition of and physiological response to fog by redwood forest plants. University of California, Berkeley. Retrieved from http://search.proquest.com/docview/507094731?accountid=28109

Limm, E., Simonin, K., & Dawson, T. (n.d.). Foliar uptake of fog in the coast redwood ecosystem: A novel drought-alleviation strategy shared by most redwood forest plants. Retrieved from http://www.fs.fed.us/psw/publications/documents/psw_gtr238/psw_gtr238_273.pdf

Mathez, E. A. (2009). *Climate change: The science of global warming and our energy future.* New York: Columbia University Press.

Past, present, and future of redwoods: A redwood ecology & climate symposium (2013, August 14). Save the Redwoods League. Retrieved from http://www.savetheredwoods.org/our-work/study/understanding-climate-change/rcci-field-notes/

Please pass the carbon (n.d.). Massachusetts Department of Elementary & Secondary Education. Retrieved from http://resources21.org/cl/files/project140_7762/Please%20Pass%20the%20Carbon.pdf

Redwood trees: Three ancient wonders (n.d.). Save the Redwoods League. Retrieved from https://www.savetheredwoods.org/wp-content/uploads/3_Ancient_Wonders.pdf

Riebeek, H. (2011, June 16). The Carbon Cycle. Retrieved from http://earthobservatory.nasa.gov/Features/CarbonCycle/

Sanders, R. (2015, January 20). Warmer, drier climate altering forests statewide. UC Berkeley News. Retrieved from http://newscenter.berkeley.edu/2015/01/20/warmer-drier-climate-altering-forests-statewide/

Schuur, E. A. G., Bockheim, J., Canadell, J. G., Euskirchen, E., Field, C. B., Goryachkin, S. V., ...Zimov, S. A. (2008). Vulnerability of permafrost carbon to climate change: implications for the global carbon cycle. *BioScience, 58* (8), 701+. Retrieved from http://ezproxy.hamline.edu:2769/ps/i.do?id=GALE%7CA185210923&v=2.1&u=clic_hamline&it=r&p=EAIM&asid=6a8b92a2fcea303b4ad32d0774122cff

Sillett, S. (2013). Redwoods & climate change symposium 2013: Stephen Sillett [Video file]. Save the Redwoods League. Retrieved from https://www.youtube.com/watch?v=DK0RMmEPYc0&index=17&list=PL5572F92380833D6F

Sources of greenhouse gas emissions (n.d.). United States Environmental Protection Agency. Retrieved from http://www3.epa.gov/climatechange/ghgemissions/sources.html

Thomashow, M. (1995). *Ecological identity: Becoming a reflective environmentalist.* Cambridge, Massachusetts: Massachusetts Institute of Technology.

Understanding climate change (2015). Save the Redwoods League. Retrieved from http://www.savetheredwoods.org/our-work/study/understanding-climate-change/

US drought monitor (2015, April 21). The National Drought Mitigation Center. Retrieved from http://droughtmonitor.unl.edu/

Zhong, W. and Haigh, J. D. (2013). The greenhouse effect and carbon dioxide. Weather, 68: 100–105. doi: 10.1002/wea.2072