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Climate Change And Ragweed Allergy Risk Assessment: A Study Of The Grand Forks Metropolitan Statistical Area

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CLIMATE CHANGE AND RAGWEED ALLERGY RISK ASSESSMENT: A STUDY OF THE GRAND FORKS METROPOLITAN STATISTICAL AREA

by

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This thesis, submitted by Shumila R Ahmad in partial fulfillment of the requirements for the Degree of Master of Science from the University of North Dakota, has been read by the Faculty Advisory Committee under whom the work has been done and is hereby approved.

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This thesis meets the standards for appearance, conforms to the style and format requirements of the Graduate School of the University of North Dakota, and is hereby approved

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Date

PERMISSION

Title	Climate Change and Ragweed Allergy Risk Assessment: A Study of the Grand Forks Metropolitan Statistical Area
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Signature ________Shumila Rani Ahmad_____

Date __________April 26, 2013__________

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DEDICATION

"I used to wake up at 4 A.M. and start sneezing, sometimes for five hours. I tried to find out what sort of allergy I had but finally came to the conclusion that it must be an allergy to consciousness."
– James Thurber

This thesis is dedicated to my parents.

ABSTRACT

Nowadays the association between anthropogenic climate change and public health is in the early stages of universal recognition. Yet one fundamental aspect that remains largely unappreciated is the impact of climate change on ragweed (*Ambrosia* species) biology and the ensuing pathophysiology of human systems. Ragweed pollen is one of the primary causes of seasonal pollen allergy in the world. Allergic reactions to ragweed pollen can range from mild hay fever to life-threatening asthma attacks. The aim of this thesis was to conduct a ragweed allergy risk assessment for the Grand Forks ND-MN Metropolitan Statistical Area (MSA).

The study area is part of the Northern Great Plains, a region of short- and mixed-grass temperate grasslands, and is the native habitat for the most allergenic of the ragweed species. Through a ragweed habitat suitability modeling, it was discovered that 0.94% of the Grand Forks MSA was of high suitability for ragweed growth, 54% of medium suitability, and 35% was of low suitability. Overall, only 10% of the region was classified as not suitable for ragweed growth. The total ragweed potential increase for the whole MSA between 2000 and 2010 was 10%.

To examine the prevalence of ragweed allergies in the study region, a survey was conducted on students attending the University of North Dakota. According to the survey, 24% of the population sampled was allergic to ragweed. The ragweed-allergic respondents experienced all of the common symptoms related to ragweed allergies such as hay fever and asthma in addition to other symptoms such as vocal cord dysfunction

and nose bleeds. Over 89% of the ragweed-allergic respondents admitted to allergies having an impact on their quality of life. Thirteen percent of the ragweed allergy sufferers (and all 6 of those originally from rural areas) did not develop allergies until they moved to the study region and had been living there for about 2 years.

Due to climate change, we can expect an increase in incidence of allergies in the coming years. Whereas climate change for the study region is not predicted to induce dangers such as hurricanes and heat waves by 2050, an upsurge in allergenic diseases can be forecasted. By 2050 we can expect a 9.6% increase in existing ragweed biomass and pollen producing stems due to increased temperature alone. Moreover, as the CO_2 emissions of the study region are projected to rise by at least 50%, we can expect a subsequent 50% escalation in the amount of pollen being produced and released by ragweed plants.

CHAPTER I

INTRODUCTION

As our awareness of climate change progresses, we are coming to realize that climate change can no longer be framed as a mere economical or environmental issue. Climate change "puts at risk the protection and improvement of human health and well-being" (WHO, 2010). It has the potential to endanger human health in all sectors of society, both domestically and globally, in a variety of ways (ASTHO, 2009, Ebi et al., 2008). Among the many health risks posed by the changing climate, its impacts on aeroallergens such as ragweed pollen and related allergic diseases and symptoms (i.e. hay-fever, asthma, chronic sinusitis, headaches, impaired sleep, and depression) have been neglected (Beggs, 2008). It has been established by scientific research that climate change alters global carbon dioxide concentrations and precipitation patterns (IPCC, 2007) and this in turn alters plant physiology (Ziska, 2004). However, whereas there are numerous inquiries focusing on the impact climate change will have on agronomical plant species, studies on weed species such as ragweed (*Ambrosia* species) are a niche discipline. This is unfortunate because allergies to ragweed pollen reduce the quality of life of millions of people worldwide and can even lead to prolonged morbidity and, in severe cases, mortality (Ziska & Caulfield, 2000a). Furthermore, studies project that more individuals will become susceptible to allergenic diseases as climate change progresses (Ziska & Caulfield, 2000a).

Statement of Need

Drawing on pertinent literature, satellite imagery, and survey data, this study evaluates the extant and probable link between climate change and ragweed plant functions as it pertains to human health. In order to evaluate this paradigm, it was the aim of this thesis to examine this question at a contained and practicable local level, namely the Grand Forks, ND-MN Metropolitan Statistical Area. To date, a risk assessment of this nature has not been conducted for the region. Information obtained during the course of this study can be invaluable in drawing up public health plans for the region and in any future climate change discourse.

Research Objectives

The objective of this study was to conduct a quantitative risk assessment for the Grand Forks, ND-MN Metropolitan Statistical Area in order to evaluate the current and future (taking into account climate change) threat levels of ragweed allergies in the region. For the duration of this thesis, ragweed pollen has been classified as a pollutant. This study follows the risk assessment process as laid out by the Environmental Protection Agency, and involves answering the following questions: (1) what problems are caused by the pollutant, (2) how much of the pollutant the study population is exposed to, and (3) how many people are exposed and vulnerable to the pollutant?

Overview of Study

The primary tool used in this project is a survey of 233 undergraduate students attending University of North Dakota in the spring of 2011. The survey was designed with intent to gather information about students' allergies. In an effort to maximize survey response rate the survey was generated and handed out to students in a paper form. The results have been compiled and analyzed using SPSS and Microsoft Excel.

The secondary tool utilized in the ragweed allergy risk characterization for the region was a landscape level ragweed habitat suitability model. The data for this analysis was acquired from the United States Department of Agriculture (USDA), National Agricultural Statistical Services (NASS), and the National Atlas. The ragweed habitat suitability maps for Grand Forks County, ND, and Polk County, MN, were then developed using ArcGIS 10.1 software.

CHAPTER II

REVIEW OF LITERATURE

Climate Change

The pervasive consensus is that Earth's climate is changing due to decades-long accumulation of greenhouse gasses (such as carbon dioxide, methane, and nitrous oxide) in the atmosphere. According to climate scientists, the global increases in carbon dioxide concentrations are due primarily to fossil fuel use and land-use change, while those of methane and nitrous oxide are due to agriculture (Alley et. al, 2007). These greenhouse gas concentrations have increased markedly as a result of human activities since 1750 and now exceed pre-industrial values as determined from Lake Vostoc ice core data spanning thousands of years (Alley et. al, 2007). Over the past 100 years, average global surface temperature has risen by about 1.5°F (Karl et al., 2009). Over the next 100 years, depending on which emission scenario is being deliberated, it is projected to rise another 2°F to 11.5°F (Karl et al., 2009; Shindell et. al, 2008). As can be seen from Figure 1, the mean annual temperatures of the states of North Dakota and Minnesota have been rising steadily at a rate of 0.037 °F per year and 0.036 °F per year respectively since 1950. Figure 2 and 3 show the mean annual 2010 temperature and the projected change in temperature by 2050 for both states according to the IPCC 4th Assessment A1B scenario.

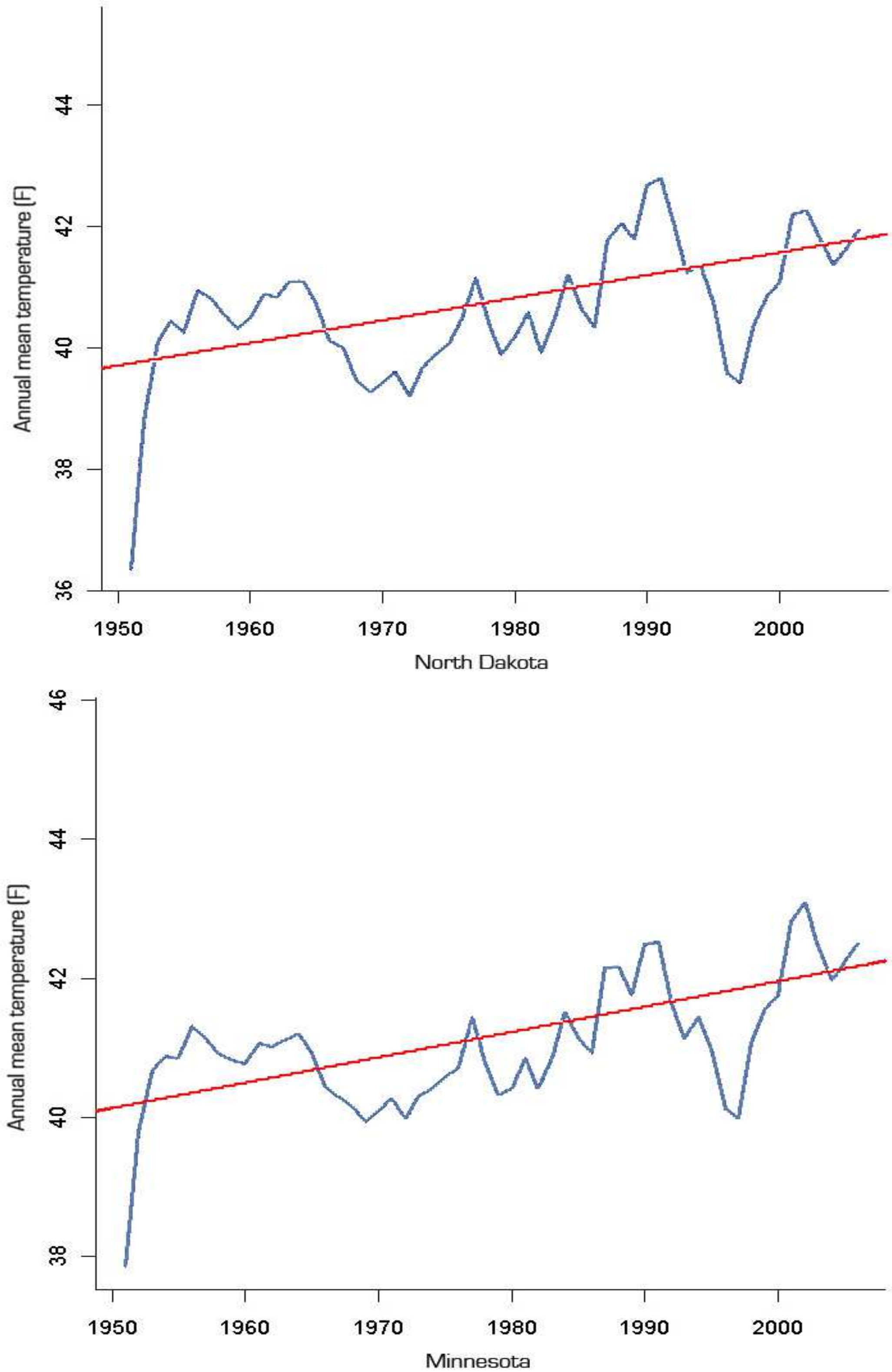


Figure 1. Annual temperature of ND and MN from 1961 to 2008 (Source: USGS).

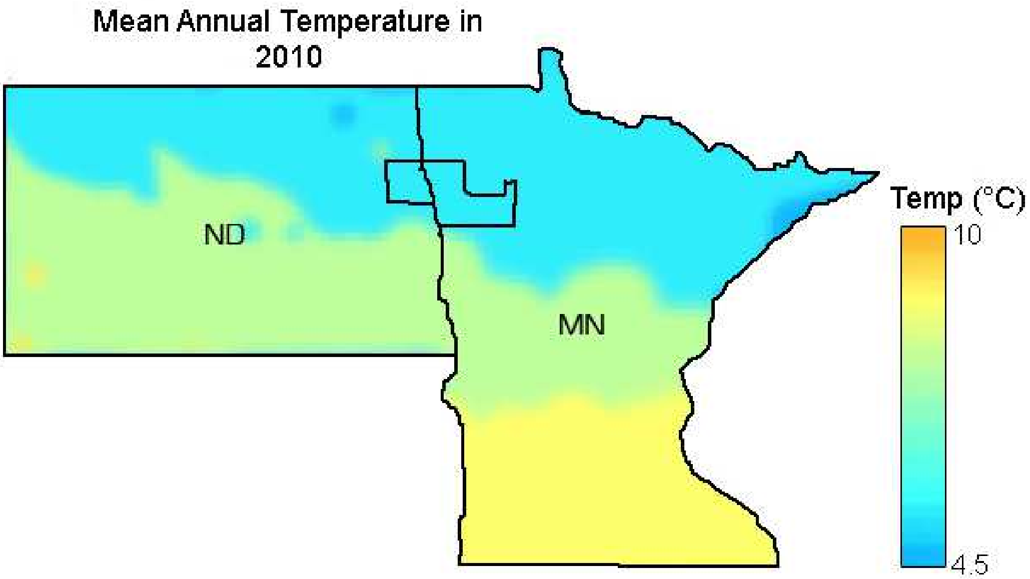


Figure 2. Average annual temperature for 2010 (Data sources: Esri, Intermap, USGS and GeoBase). The two counties that make up the study area (Grand Forks County, ND, and Polk County, MN) are outlined on the map.

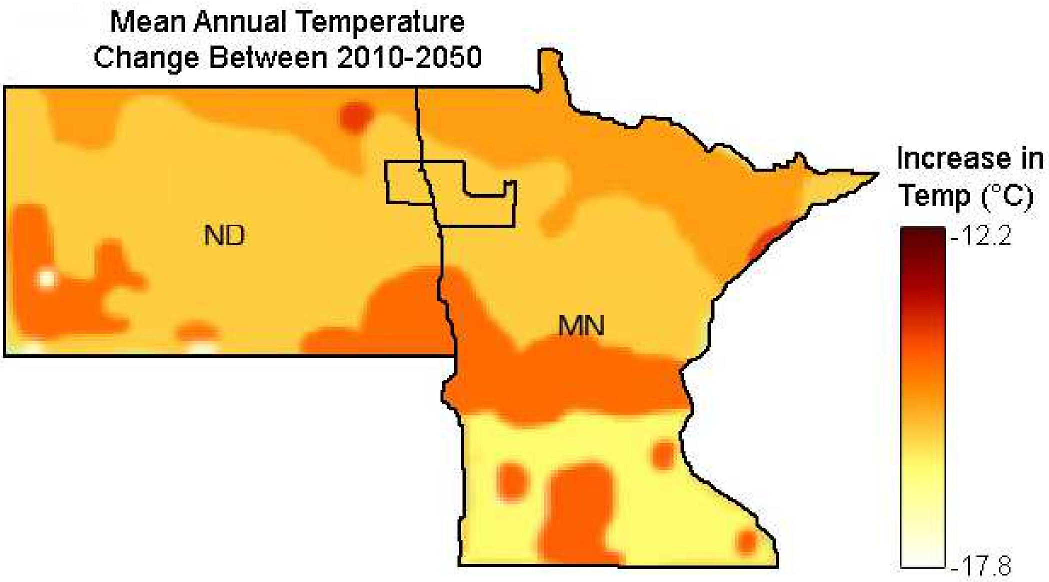


Figure 3. Change in mean annual temperature between 2010 and 2050, as determined using the IPCC 4th Assessment A1B scenario (Source: Climate Wizard).

The A1B climate scenario assumes a balanced progress across all resources and technologies (from energy supply to end use) as well as balanced land-use changes (IPCC, 2007). This scenario assumes a future of improved efficiency of technologies and a global population that peaks to 9 billion in 2050 but declines thereafter (IPCC, 2007). The A1B scenario also predicts a balanced use of fossil and non-fossil energy sources. According to the 4 km resolution downscaled climate model for this scenario in Figure 3, for the study area the mean annual temperature is projected to rise from 5.6^{o}C (42^{o}F) in 2010 to 8.9^{o}C (48^{o}F) in 2050.

Increased temperature is not the only cause for concern. The changes in global surface temperature will contribute to the warming of the oceans and a rise in sea levels (Karl et al., 2009). Melting of glaciers and polar ice caps will also contribute to sea level increases (Karl et al., 2009). Climate and sea level changes will cause changes in global precipitation patterns and result in extreme weather events (heat waves, flooding, droughts, and hurricanes) (IWGCCH, 2009). For the Grand Forks MSA region, however, the A1B scenario does not anticipate changes in precipitation patterns.

Climate Change and Public Health Concerns

Climate change has the potential to stress public health in several ways. While some of these negative effects are unpredictable, many are supported by scientific evidence. The IPCC and the World Health Organization (WHO) have categorized a wide-range of vulnerabilities and threats to human health that fall under four broad classes: “temperature effects, climate sensitive diseases, more extreme weather events, and air quality changes” (WHO, 2010).

Temperature Effects

With change in global climate, severity and frequency of heat waves are projected to intensify, which will increase heat-related morbidity and mortality (Bernard & McGeehin, 2004; Confalonieri et al., 2007; USEPA, 2008). According to the EPA's Excessive Heat Events Guidebook, there are up to 1,800 heat-attributable deaths during summer in the United States (USEPA, 2008). The Guidebook notes that heat waves have the greatest impact in the Northeast and Midwest United States where populations "are not as acclimatized to elevated temperatures" and that "structures in less susceptible areas are better designed to accommodate elevated temperatures" (USEPA, 2008)

Climate-Sensitive Diseases

As a result of changes in temperature and precipitation, certain vector-borne, food-borne, and water-borne diseases are expected to occur more often and affect new populations (CDC, 2009a; IWGCCH, 2009; TFAH, 2009). For example, as a result of warming temperatures, vectors such as mosquitoes will be able to live and reproduce at higher elevations (CDC, 2009a). Populations living in colder states will become susceptible to vector-borne diseases that they never had before (CDC, 2009a).

More Extreme Weather Events

Storm impacts, hurricanes and tropical storms in particular, are likely to be more severe. Severe precipitation events associated will increase the risk of flooding (IWGCCH, 2009; TFAH, 2009; WHO, 2010). Other than the direct effects of flooding, the runoff of sewage and soil erosion can have adverse water quality effects, leading to an increase in the number of people at risk for water-borne disease (Field et al., 2007; IWGCCH, 2009; TFAH, 2009; WHO, 2010). Other areas will be afflicted by declines in annual precipitation, which will lead to an increase in the number of people affected by disease and injury related to droughts and wildfires (IWGCCH, 2009; TFAH, 2009).

Air Quality Changes

Increases in ground-level ozone, airborne allergens, and other pollutants have been associated with risks of respiratory disease exacerbations such as asthma, allergic rhinitis, sinusitis, and other respiratory infections (Bell et al., 2007; CDC, 2009b). Hay fever and sinus infections are also predicted to increase (Bell et al., 2007; CDC, 2009b).

Allergy: a Modern Malady

Until the commencement of the 20th century, allergic sensitivities were unheard of; over the past few decades allergies have skyrocketed. According to a 2008 study by the National Health and Nutrition Examination Survey at least 58% of Americans are allergic to at least one airborne allergen such as plant pollen and fungal spores (Arbes et al., 2005). Nationwide surveys further assert that there has been a rise in the prevalence of allergies (Beggs & Bambrick, 2006). As Dr. Jonathan Correns notes in *100 Questions & Answers about Allergies*: “3% of all Americans had allergic asthma in 1990 while now the number is 7%. Nasal allergies have jumped from 10% to 20%, skin-based allergies have gone from 5% to 8%, and anaphylaxis has increased in incidence from 1% to 3%” (Beggs & Bambrick, 2006; Correns, 2010).

Epidemiologists have been trying to explain the upsurge of allergies around the world for decades. The first of the two most popular explanations for allergy is the "hygiene hypothesis." According to this theory a lack of early childhood exposure to infections (bacterial and viral), symbiotic microbes (such as gut flora), and parasites suppresses the natural development of the immune system and increases the susceptibility of allergies (Strachan, 2000). This theory explains the surge in allergies since industrialization and the higher incidence of allergies in developed nations (Strachan, 2000). However, though the hygiene hypothesis has been useful in explaining food allergies, studies examining the hygiene hypothesis have failed to be consistent when examining pollen allergies such as asthma and allergic rhinitis (Shaaban et al., 2008; von Hertzen & Haahtela, 2004).

The theory that aligns more with pollen allergies is the so called "bucket theory." According to this concept an overflow of allergens in the immune system's "bucket" causes allergic symptoms to appear (Enelow, 2008). This would explain farmer's lung, a "hypersensitivity pneumonitis prompted by the inhalation of biologic particles" coming from hay dust, mold spores, and other agricultural product (Enelow, 2008). The second theory also explains why individuals who have moved to a new geographical location develop allergies to novel air-borne allergens, and how certain allergenic diseases have been linked to climate change (Beggs & Bambrick, 2006; Enelow, 2008). As allergies to pollen are most commonly developed during early childhood, exposure to allergens in childhood can sensitize individuals to develop allergic asthma and allergic rhinitis (Beggs & Bambrick, 2006, Pearce et al, 2000). A comprehensive 1981 longitudinal study found that exposure to intense pollen seasons in early infancy increased the likelihood of future allergy development (Björkstén et. al, 1981). Therefore, extended pollen seasons and increased pollen quantity due to climate change can lead to both an increase in the development of allergies in addition to greater morbidity among those who are already allergic (Beggs & Bambrick, 2006).

Physiology of an Allergy

An allergy is defined as a “hypersensitivity of the immune system” (Dorland's Medical Dictionary). In susceptible individuals, allergic reactions occur to normally harmless environmental substances such as ragweed pollen. Of the four forms of hypersensitivities, allergies fall under the type I (immediate) hypersensitivity. Type I sensitivities are characterized by excessive activation of certain white blood cells (mast cells and basophils) by an antibody known as IgE. The activation of these specialized immune cells results in production of histamine and other chemicals which cause a localized inflammatory response (Figure 4). Depending on the individual and the degree of hypersensitivity, the inflammatory response can range from mild irritations and swellings to life threatening anaphylactic reactions.

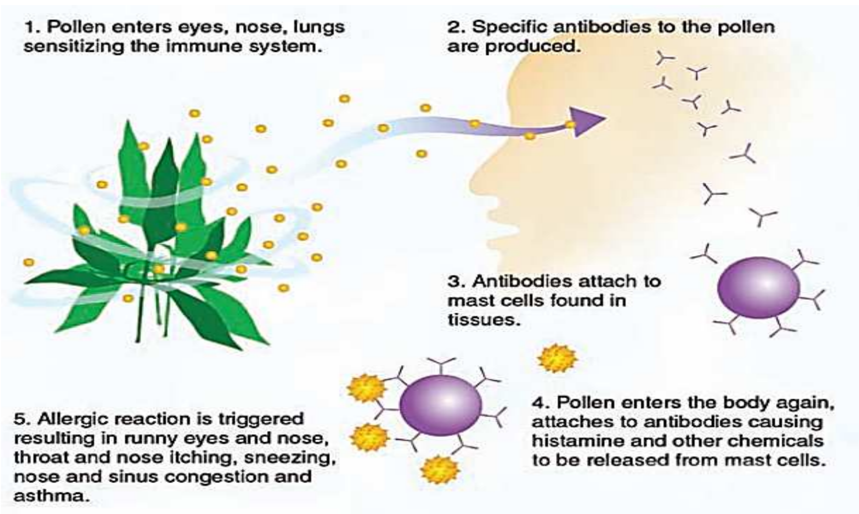


Figure 4. An allergic reaction (Source: American Academy of A A I, 2009).

Various methods of lessening the effect of pollen allergies have been suggested, including indoor air purification and the wearing of breathing masks while outdoors during pollen season. Pharmaceuticals, such as histamine blockers, are already being utilized by millions of allergy sufferers. However, these medications can have unsavory side effects, the most common of which are “dry mouth, drowsiness, dizziness, nausea and vomiting, restlessness or moodiness (especially in children), hesitancy urinating, blurred vision, mental fog, and confusion” (Motala, 2009; WebMD, 2012a). Moreover, people who have enlarged prostates, heart disease, high blood pressure, thyroid problems, kidney or liver disease, bladder obstructions, or glaucoma are advised against taking anti-histamines (Motala, 2009; WebMD, 2012a). The long-term consequences of ingesting anti-histamines are still unknown, and for some people, due to as of yet unidentified reasons, anti-histamines lose their effect over time. (Rakel, 2007).

Allergy as a medical condition is generally treated not cured. The only touted cure for allergies is allergen immunotherapy. However, though reports have shown that allergen immunization reduces the symptoms of allergy, often considerably, it does not remove them (Bousquet, 2000; Sur, 2010). Allergen immunotherapy is an expensive procedure that requires ongoing immunization injections delivered to allergic individuals with increasing concentrations of the allergen. The injections are given weekly for the first few months, followed by monthly maintenance injections for a period of 3–5 years. The whole process is repeated once the effect wears off as early as a decade later (Straley, 2013). Though immunization has been effective on some forms of allergy, a clinical report on recorded hay fever hours showed that the ragweed-allergic group responded as well to placebo as to active emulsions (Loveless, 1957).

Ragweed Allergenicity

Ragweed (*Ambrosia* species) pollen is one of the primary causes of seasonal pollen allergy worldwide, and the major cause of allergy in North America (Wopfner, 2005; Ziska & Caulfield, 2000a). Of Americans who are allergic to pollen-producing plants, 75% are allergic to ragweed (Ziska & Caulfield, 2000a). Overall, some 36 million Americans (10.6% of U.S. population) suffer from ragweed allergy (Ziska & Caulfield, 2000a). Scientists are still conducting research on what makes ragweed pollen so allergenic. One study has found that the major allergenic component of ragweed pollen is a protein identified as Amb a 1 (Wopfner, 2005). In addition to Amb a 1, ragweed pollen contains calcium-binding proteins and profilin, elements generally present in most common allergens (Wopfner, 2005). Due to genetic and abiotic factors governing allergen expression, ragweed pollen may be more allergenic in some areas than others, regardless of pollen count (Singer et al., 2005).

Ragweed Induced Allergic Diseases

The allergenic diseases most commonly allied to ragweed are hay fever, acute and chronic sinusitis, and asthma (The Diagnosis and Management of Rhinitis, 2008). Headaches, impaired sleep, fatigue, and depression are secondary symptoms (The Diagnosis and Management of Rhinitis, 2008). All the allergenic diseases involve inflammatory responses to ragweed pollen. The only difference between these ailments is where the inflamed tissue is located (The Diagnosis and Management of Rhinitis, 2008).

A 2009 study showed that over 8% of the US population (18 million adults and over 7 million children) suffered from hay fever pollen allergies (CDC, 2009b; Janson, 2001). Hay fever, or allergic rhinitis, is a group of symptoms affecting the nose (Sur et al, 2010). The symptoms of allergic rhinitis are: "rhinorrhea (excess nasal secretion), itching, and nasal congestion and obstruction" (Sur et al, 2010). Secondary symptoms include "conjunctival swelling and erythema, eyelid swelling, lower eyelid venous stasis, swollen nasal turbinates, and middle ear effusion" (Valet, 2009). Hay fever develops when a susceptible individual is exposed to and breathes in an allergen such as pollen (Nathan, 2007; Wallace & Dykewicz, 2008). Allergic rhinitis is chronic and expensive to treat. In 2008 there were more than 13 million physician office visits because of allergic rhinitis (CDC, 2009b). Between 2000 to 2005, the cost of treating hay fever almost doubled from $6.1 billion (inflation being accounted for) to $11.2 billion (Soni, 2008). Over half of that was spent on prescription medications (Soni, 2008).

Rhinosinusitis, or commonly known as sinusitis, and hay fever often go hand in hand, with over 60% of sinusitis diagnoses made to hay fever sufferers (AAFA, 2005). In sinusitis the mucous membranes lining the nose and the paranasal sinuses become inflamed (i.e. swell) and obstruct fluid draining from the sinuses (Shaikh et al., 2012). Over time the fluid thickens and becomes viscous and pus-filled, causing pain, swelling, infection, and fever (Shaikh et al., 2012). Sinusitis is one of the principal forms of chronic disease, with over 18 million cases reported and at least 30 million courses of antibiotics dispensed per year (AAFA, 2010). Twelve percent of Americans under 45 have symptoms of protracted sinusitis, and about 40,000 people require sinus surgery every year in the U.S. alone. (AAFA, 2010).

In 2009, 7.6% of the US population (16.4 million adults and 7 million children) suffered from asthma (CDC, 2009b). Over 50% of these adults and 90% of the children suffered from “allergic asthma” as opposed to cough-variant or exercise-induced asthma. Asthma is characterized by inflammation of the bronchioles and increased production of sticky secretions within the bronchioles (Shenfield et al., 2002). People with asthma experience symptoms when the airways tighten, inflame, or fill with mucus (Shenfield et al., 2002) (Figure 5).

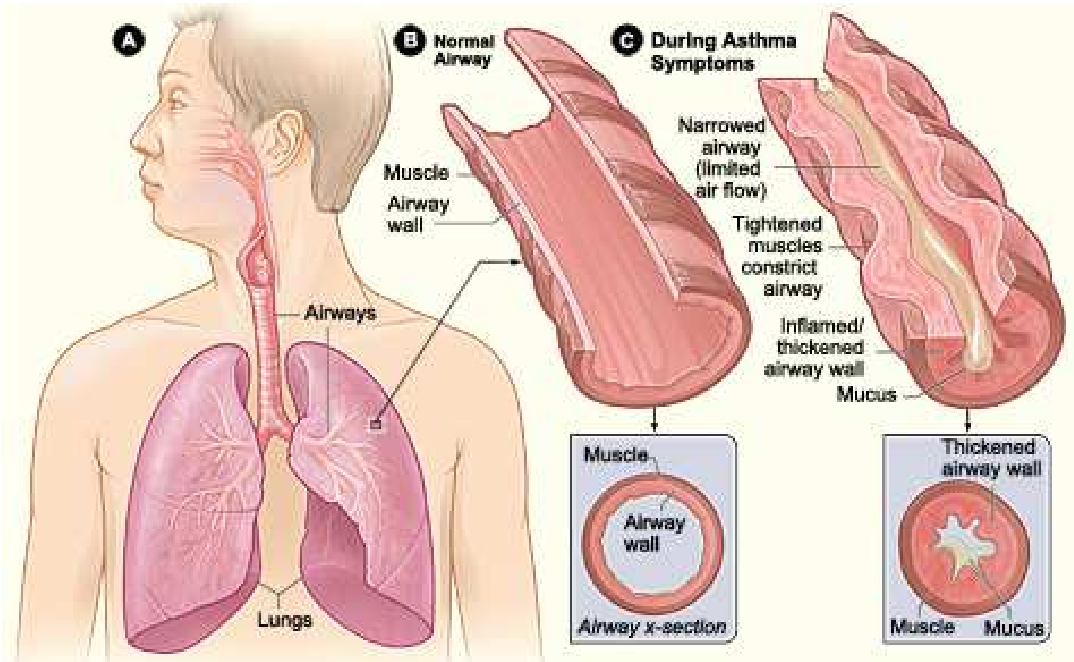


Figure 5. Bronchiole constriction during an asthma attack (Source: U.S. Department of Health and Human Services)

Common asthma symptoms include coughing (particularly at night when the body is in a supine position), wheezing, shortness of breath, chest tightness, and pain (Knowlton et al., 2007). Asthma is a dangerous disease, resulting in around 4,000 deaths per year in the U.S. (American Lung Association, 2010). Worryingly, asthma morbidity and mortality have increased noticeably over the past recent decades (Bach, 2002; Isolauri et. al, 2004; Pearce et al., 2000). Because this rising trend has been considered too rapid to implicate a genetic basis, environmental factors are suspect (Bach, 2002; Grammatikos, 2008; Isolauri et. al, 2004; Pearce et al., 2000). Asthma is also considered an expensive chronic disease. In 2010 alone asthma resulted in 14.2 million days of work missed, $15.6 billion in medical cost, and $5.1 billion in lost earnings (American Lung Association, 2010). Not only does asthma reduce the quality of life of children in a variety of ways, it also affects their education. In 2010 14.4 million days of school missed were reported due to asthma (American Lung Association, 2010). Figure 6 describes how climate change can increase the burden of asthma.

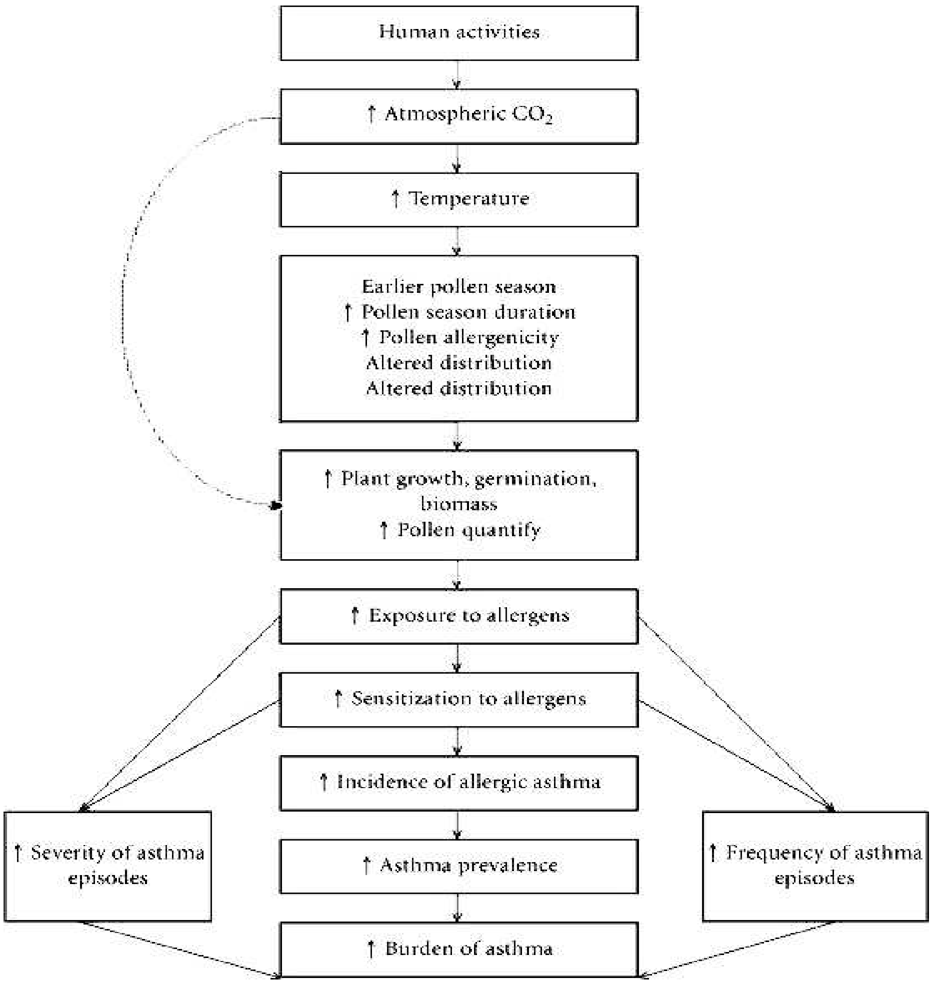


Figure 6. Diagram of the relationship between climate change and the rise in asthma prevalence (Source: Beggs & Bambrick, 2006).

Another allergic disease related to ragweed is known as the Oral Allergy Symptom (OAS) or pollen-food syndrome (WebMD, 2012b). OAS is different from other food allergies in that it is not a distinct allergy, but is cross-related and closely associated with inhaled pollen allergies (WebMD, 2012b). One archetypal facet of this cross-relation is that OAS is generally worse during pollen season (WebMD, 2012b; Zarkadas et al., 1999). Different foods are associated with different inhaled pollen allergies, and those associated with ragweed are “banana, chamomile, cucumber, dandelion, echinacea, cantaloupe, honeydew, watermelon, sunflower seeds, and zucchini” (WebMD, 2012b; Zarkadas et al., 1999). OAS symptoms generally progress within minutes of eating or coming in contact with the associated food (Zarkadas et al., 1999). Milder symptoms include a rash, itching or swelling where the food has touched the skin, burning sensation of the lips, mouth and throat, watery/itchy eyes, runny nose, and sneezing (Zarkadas et al., 1999). More serious reactions that may occur include generalized hives, swelling of the mouth, pharynx and windpipe, vomiting, diarrhea, asthma, and anaphylactic shock (WebMD, 2012b; Zarkadas et al., 1999). Some plant parts, such as the skin, are more allergenic than others and raw food is more allergenic than cooked (Zarkadas et al., 1999).

Ragweed Biology

Ragweed belongs to the genus *Ambrosia* in the sunflower family *Asteraceae* (Oswalt, 2008). It is a flowering plant native to temperate grasslands of the North and South America (Oswalt, 2008). It has been estimated that a single ragweed plant releases up to a billion grains of pollen over the course of its growing season and that 1 million tons of ragweed pollen are produced each year in North America alone (Rees, 1997).

Ragweed pollen is anemophilous (i.e. wind pollinated) and so small and light that even gentle breezes are capable of dispersing it (Rees, 1997). Scientists have detected ragweed pollen 3.5 kilometers up in the atmosphere and as far as 700 kilometers out at sea (Rees, 1997). In years past mountain regions, desert settings, and rural areas were safe haven for allergy sufferers (Corden & Millington, 2001; Rees, 1997). Nowadays increased anthropogenic soil disturbances such as building, farming and irrigation have caused ragweed to spread there as well (Rees, 1997). Ragweed, native to the Americas, has become an established nuisance invasive in several European and Asian countries where it was introduced in the 19th century, particular around the time of World War I when grain was being imported from the U.S. (Rees, 1997). In 2005 the Swiss official inspection found ragweed seeds contaminating up to 75% of the bird feed products on shelves imported from Germany, Slovenia and Denmark (Frick et. al, 2011). Among weed species, ragweed has the fourth highest spread potential. Only South African ragwort (*Senecio inaequidens*), Canadian horseweed (*Conyza canadensis*) and Japanese knotweed (*Reynoutria japonica*) show higher spread potentials (Weber & Gut, 2005).

Ragweed grows particularly well in grassy plains and river banks (Werner et al., 1980). *Ambrosia* is a ruderal (i.e. growing in rubbish, poor land, or waste) genus and therefore very effective at colonizing disturbed lands such as fallow land, railway-side gravel, and road-side ditches (Ziska, 2003). While ragweed grows well in waste sites, it does even better in cultivated sites when herbicide use is absent or ill managed (Oswalt, 2008). Ragweed grows particularly well in corn, soybean, and wheat fields (Oswalt, 2008). Ragweed plants are generally annuals (few are perennials), grow in colonies, and can become thick and bushy as the growing season progresses (Werner et al., 1980). It is a monoecious plant, producing male and female flowers on the same plant (Figure 7a). The pollen-producing male flowers are yellowish green in color, disk-shaped, and form at the tips of stems (Oswalt, 2008). The female flowers are whitish green and more unobtrusively located. They tend to form under male flowers at leaf bases and in the forks of upper stems (Werner et al., 1980). Figure 7b shows what ragweed flowers look like when they have gone to seed. A plant usually has many branches and fern-like hairy leaves up to 6 inches long that are alternately positioned on each stem (Werner et al., 1980). *Ambrosia* plants normally grow one to five feet tall (Oswalt, 2008).

a b

Figure 7. a) A Common Ragweed plant b) Common Ragweed flowers gone to seed (Source: Minnesota Wildflowers <http://www.minnesotawildflowers.info>)

When ragweed plants flower they are often mistaken for goldenrod plants (*Solidago* species) which bloom around the same time (Cavendish, 2010). Though both plants look similar in that they produce yellow flowers in long tufts atop the plant, goldenrod flowers are showy and brighter when compared to the pale yellowish-green hue of ragweed flowers (Figure 8). Moreover, goldenrod is entomophilous; its pollen is much larger in size and insect pollinated rather than wind pollinated as ragweed pollen is (Cavendish, 2010). For this reason goldenrod is not associated with allergy symptoms.

Figure 8. Figure comparing goldenrod plant to a common ragweed plant (Source: Minnesota Wildflowers <http://www.minnesotawildflowers.info>)

There are 17 species of ragweed native to the U.S. but three are most common in Northern Great Plains: Common Ragweed (*Ambrosia artemisiifolia)*, Western Ragweed (*Ambrosia psilostachya*), and Giant Ragweed (*Ambrosia trifida*) (Davis et. al, 2005). Two of these species, the Common and Western, are considered the most noxious ragweed species for allergy sufferers (Oswalt, 2008). Common Ragweed (Figure 7), as the name suggests, is the most widespread plant of the genus (Werner et al., 1980). It is very competitive and a particular scourge of soybean fields (Davis et. al, 2005). It has been known to produce over 50% yield losses in soybean crop (Davis et. al, 2005). Common Ragweed is an annual that reproduces from seeds. It is a shallow rooted plant that grows one to four feet tall, has hairy purple stems, and smooth leaves (Werner et al., 1980). Western Ragweed, also called perennial ragweed, reproduces by means of creeping rhizome-like root stalks and by seeds (Werner et al., 1980). Seeds of all *Ambrosia* species are not airborne; seeds fall to the ground and spread of ragweed is greatly favored by human activities. Western Ragweed's tall hairy stems form dense, bushy patches and its leaves are hairy (Werner et al., 1980). Western Ragweed can reduce wheat crop yield by up to 40% (Davis et. al, 2005). Giant Ragweed is most commonly found in Minnesota but grows in all states (Werner et al., 1980). Though the general height for Giant Ragweed is 6 feet, in ideal habitats this annual produces coarse rough stems that have been known to reach a record 21 feet in height (Davis et. al, 2005). Giant Ragweed leaves are not as hairy as those of Western Ragweed and can grow almost a foot long (Werner et al., 1980). Giant Ragweed grows well in corn and soybean crops and can reduce their yields by up to 50% (Davis et. al, 2005).

Ragweed Control

Ragweed is aptly referred to as a symptom of sick soil. Whereas it is not an aggressive competitor in virgin grasslands, when the competitive edge is taken away from native grasses by disturbing the soil, ragweed thrives. Control methods that have been attempted on ragweed include mowing, burning, herbicides, grazing, and pulling (Vermeire et al., 2001). Through experimentation it has been discovered that mowing is ineffective, and, unless it is done every two to three weeks, often proves to be beneficial to the plant. Damaging the main stem during the first half of the growing season merely results in a shorter bush with numerous flowering branches rising low from the base of the plant later in the season (Vermeire et al., 2001). If mowing is being utilized as the method of control, continuous mowing is crucial in attempting to prevent flowering and seed production. Yet continuous mowing harms native grasses and reduces their ability to compete with ragweed and other weedy species, including invasives (Vermeire, 2000). Burning is advised against as studies have shown ragweed to intensify in mixed prairies following spring burns (Vermeire et al., 2001). Chemical spraying is used for control in large areas when damaging native flora and fauna is not a concern. However, ragweed is a hardy weed that responds to the more aggressive herbicides and only when applied at the right time of year when the plants are still small and growing close to the ground around early May (Vermeire et al., 2001). Because of this ragweed outbreaks need be identified early in the year, long before the plant is easily identifiable. In badly infested areas 0.2 to 0.7 gallons per acre of herbicides need be applied. Herbicide application is a costly endeavor and ragweed generally endures and recurs the next year (Vermeire et al., 2001). Combining herbicide use with grazing on rangelands has been shown as the most cost effective means to control ragweed on larger scales. Grazing as a means of ragweed control can be a double-edged sword, and it needs to be properly managed. Overgrazing leads to shallow growth of native grasses and bare soil, allowing ragweed to establish and thrive (Vermeire et al., 2001). Overall, in prairie systems, maintenance of a healthy prairie with strong grass root systems is the best means of preventing and/or curing ragweed outbreaks.

In urban areas ragweed becomes even trickier to control (Lewis, 1973). Roadside ditches are mowed by the Department of Transportation and mowing generally aggravates the weed situation (Vermeire et al., 2001). The Ontario Lung Association has reportedly reduced pollen levels in some Quebec municipalities by promoting and organizing community action to control ragweed along roadside edges and private properties like backyards and lawns. The program endorses pulling the ragweed plants out individually by the root and/or spraying ragweed plants with a salt water solution to desiccate the flowers and prevent them from releasing pollen (Ontario Ragweed, 2009). These programs will have to be ongoing because, though ragweed is an annual, only a scant amount of ragweed seeds sprout the first year. The rest remain dormant for up to 39 years for later germination (Vermeire et al., 2001). Moreover, studies on manually uprooting ragweed have shown that this method is no more effective in the long run than leaving the weed alone, and that skin contact with ragweed while pulling can induce latent allergies in individuals to emerge (Lewis, 1973).

Climate Change and Plant Biology

A substantial impact of climate change is already discernible in plant populations (Root et al., 2003). USDA hardiness zones have shifted considerably across the map (Figures 9, 10, and 11). A hardiness zone is a geographic area in which certain groups of plants are capable of flourishing. Climatic conditions, such as the plant’s ability to withstand minimum temperatures of the zone, are included in the deliberation. As can be seen from the maps, between 1999 and 2006, large portions of North Dakota and Minnesota (46.5% of both states) underwent a zone shift from 3 to 4. Whereas Grand Forks County retained its zone 4 status, part of Polk County shifted from zone 3 to zone 4. This means that many species of plants that were unable to survive Polk County winters can now do so.

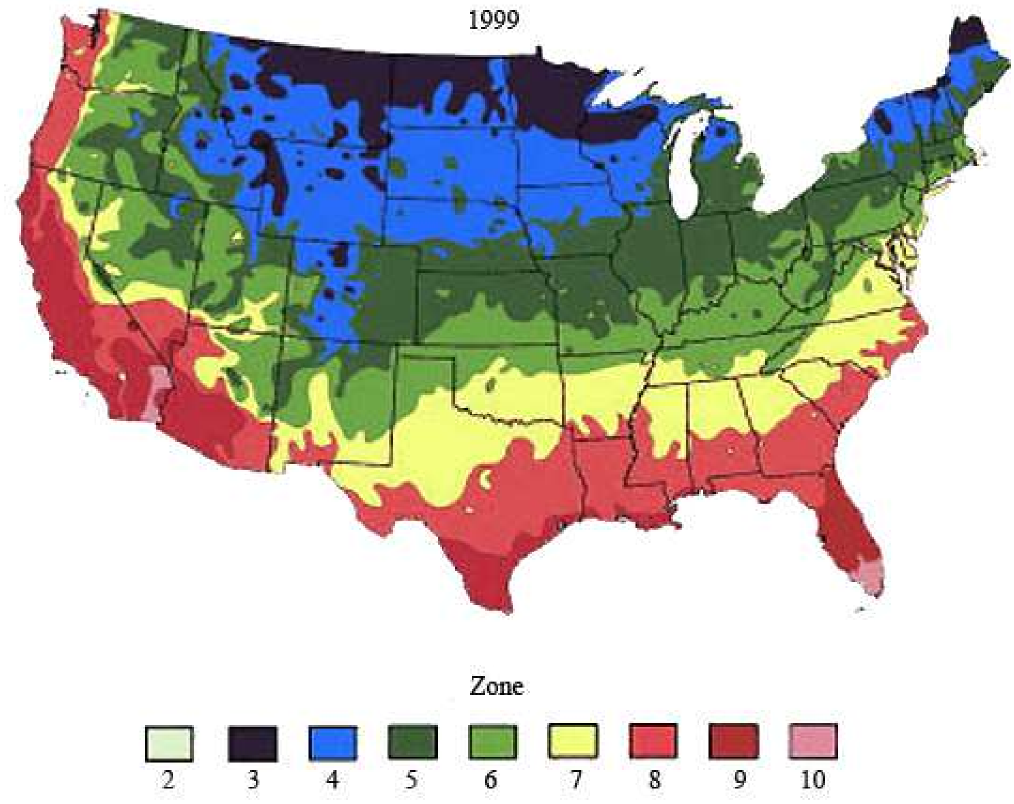


Figure 9. 1990 U.S. plant hardiness zones (Source: USDA Publication no. 1475 and National Arbor Day Foundation).

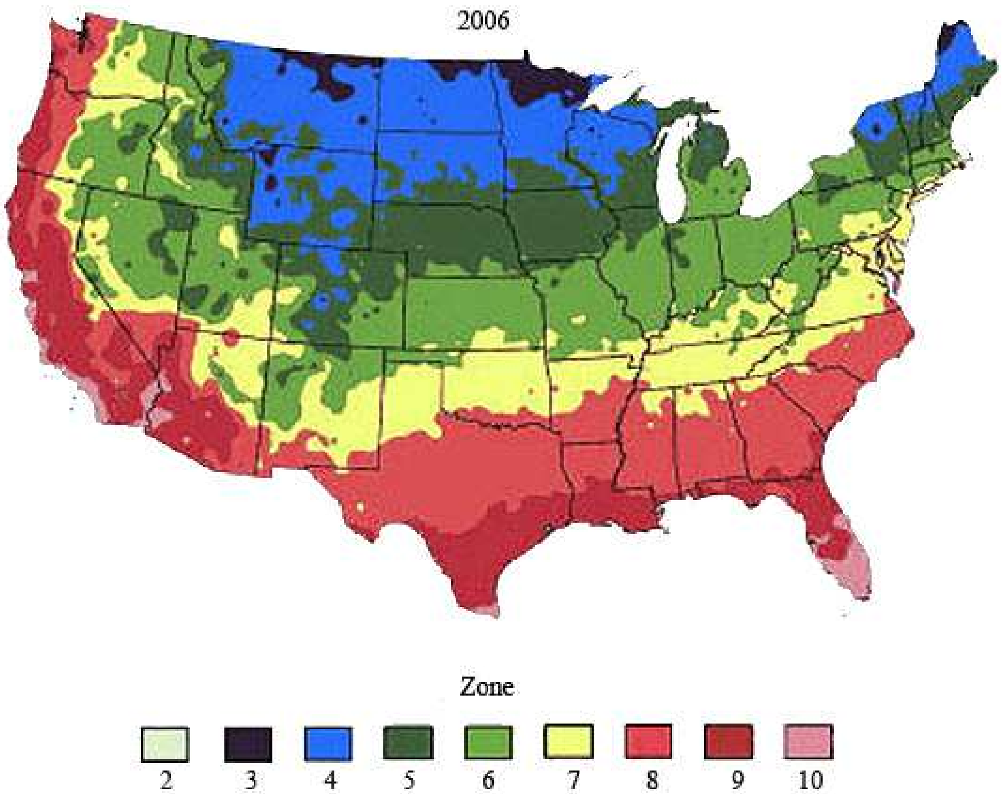


Figure 10. 2006 U.S. plant hardiness zones (Source: USDA Publication no. 1475 and National Arbor Day Foundation).

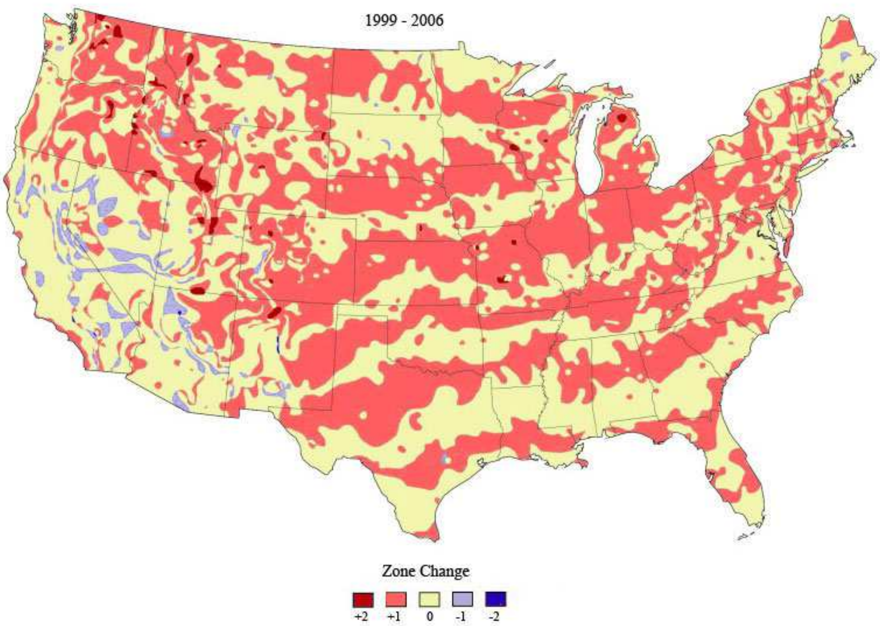


Figure 11. Change in U.S. plant hardiness zones from 1999 to 2006 (Source: USDA Publication no. 1475 and National Arbor Day Foundation).

Another example of this change in plant functions comes courtesy of the International Phenological Gardens in Europe. Their documentations show that, compared with the early 1960's, spring events (such as flowering) have advanced by 6 days, and autumn events have been delayed by 4.8 days (Emberlin et al., 2002; Fitter & Fitter, 2002; Menzel & Fabien, 1999; Menzel, 2000). Figure 12 shows the peak vegetation growth maps for Grand Forks County and Polk County from 1990 to 2010. The peak vegetation growth maps (or greenness composites) were produced by evaluating the maximum NDVI (Normalized Difference Vegetation Index) values from bi-weekly AVHRR (Advanced Very High Resolution Radiometer) data for each year. As can be seen from the maps and from Figure 13, peak vegetation growth has been increasing steadily for both counties over the course of 20 years. In fact, the percent increase in the "most vigorous growth" greenness pixel count between 1990 and 2010 was a remarkable 1155%.

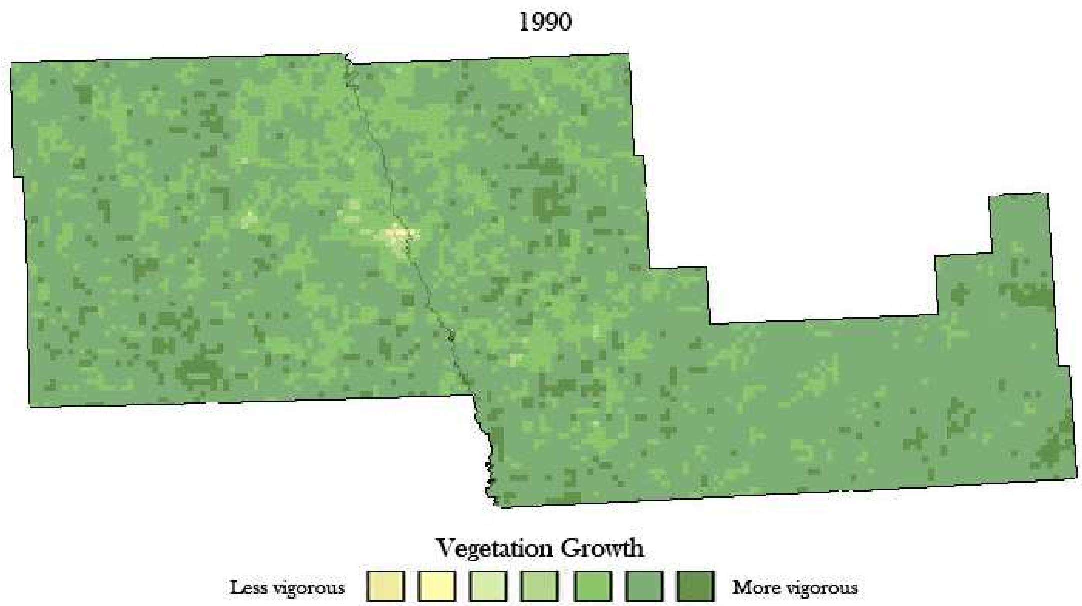
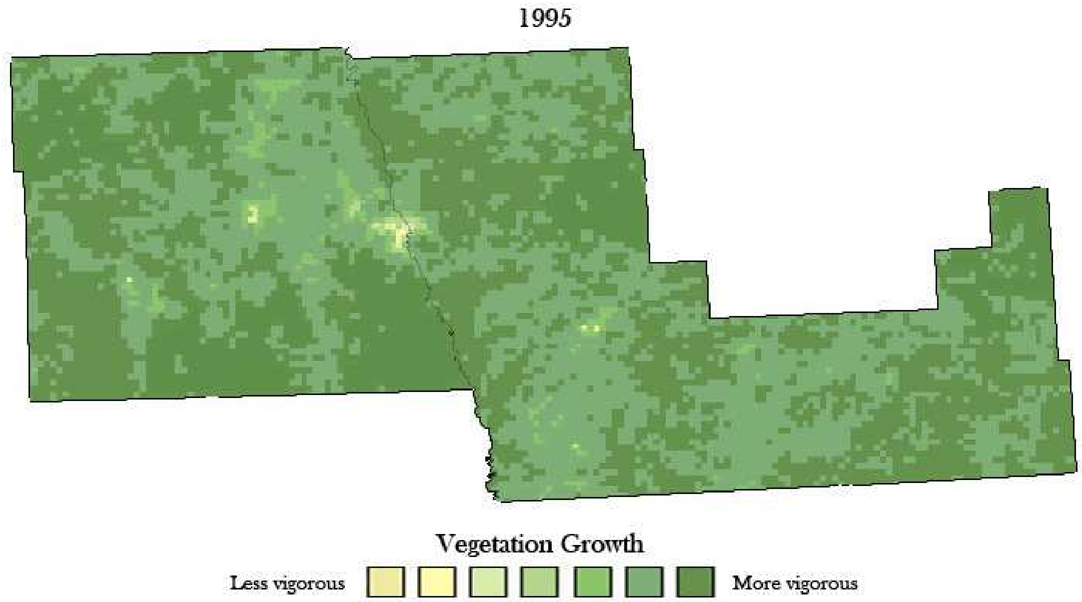


Figure 12. Peak vegetation growth maps for Grand Forks County and Polk County from 1990 to 2010 (Data source: USGS, EROS, and the National Atlas, created by ArcMap).



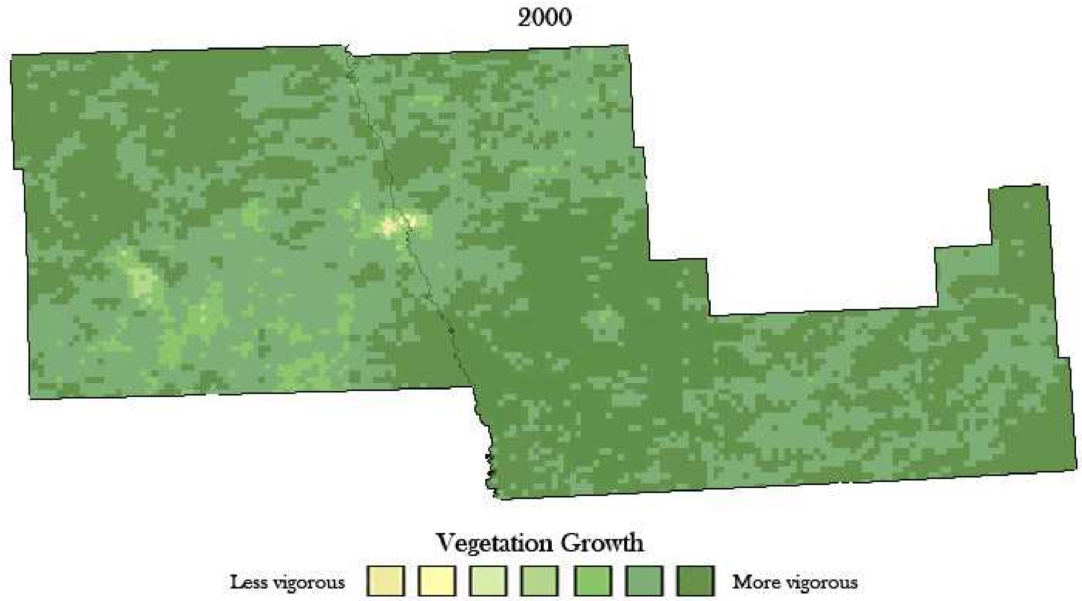
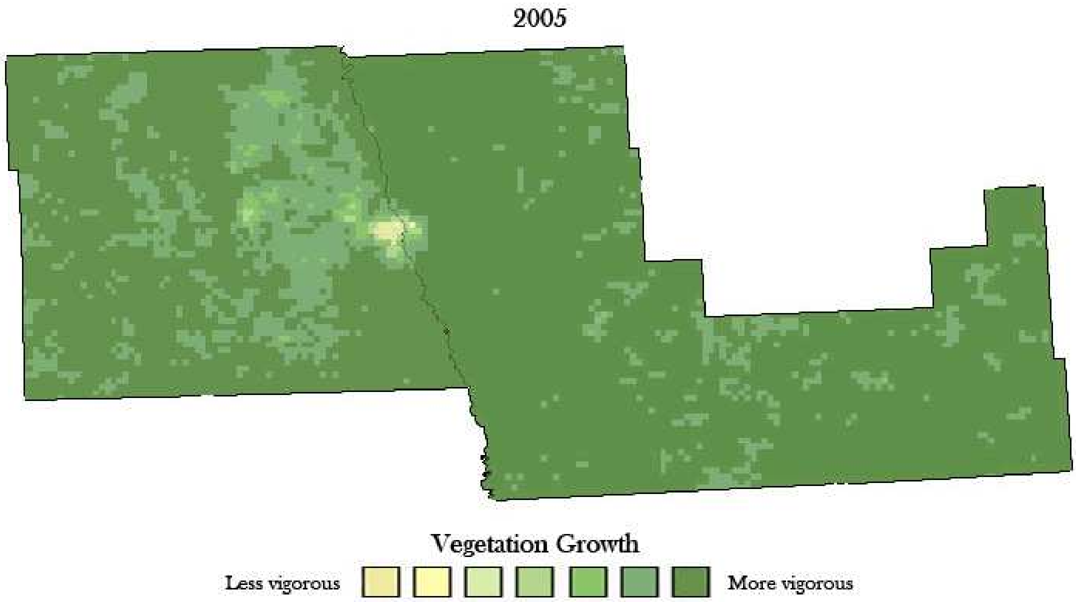


Figure 12 continued. Peak vegetation growth maps for Grand Forks County and Polk County from 1990 to 2010 (Data source: USGS, EROS, and the National Atlas, created by ArcMap).



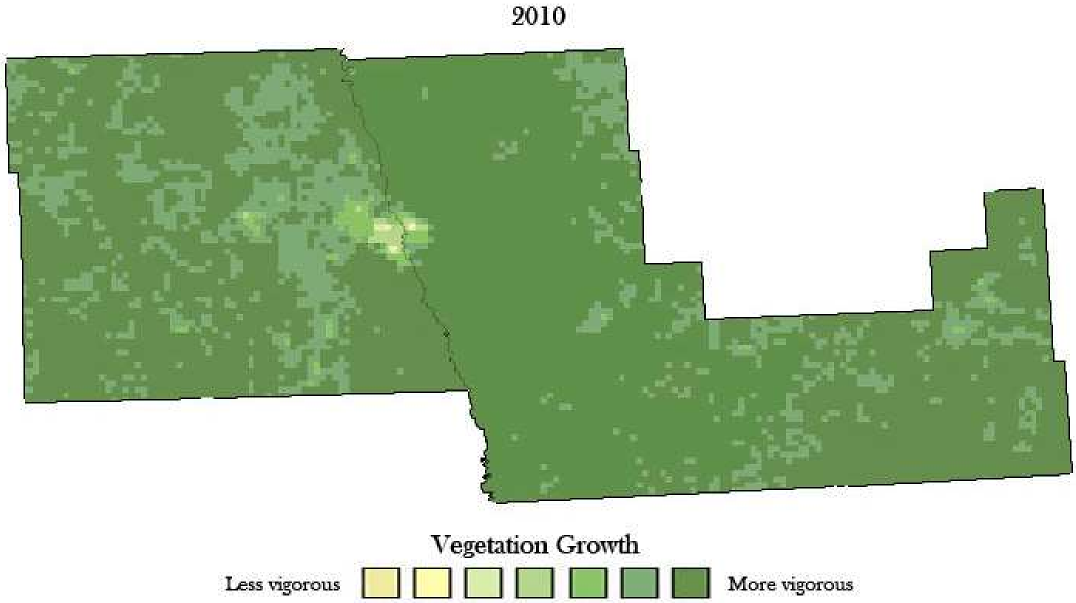


Figure 12 continued. Peak vegetation growth maps for Grand Forks County and Polk County from 1990 to 2010 (Data source: USGS, EROS, and the National Atlas, created by ArcMap).

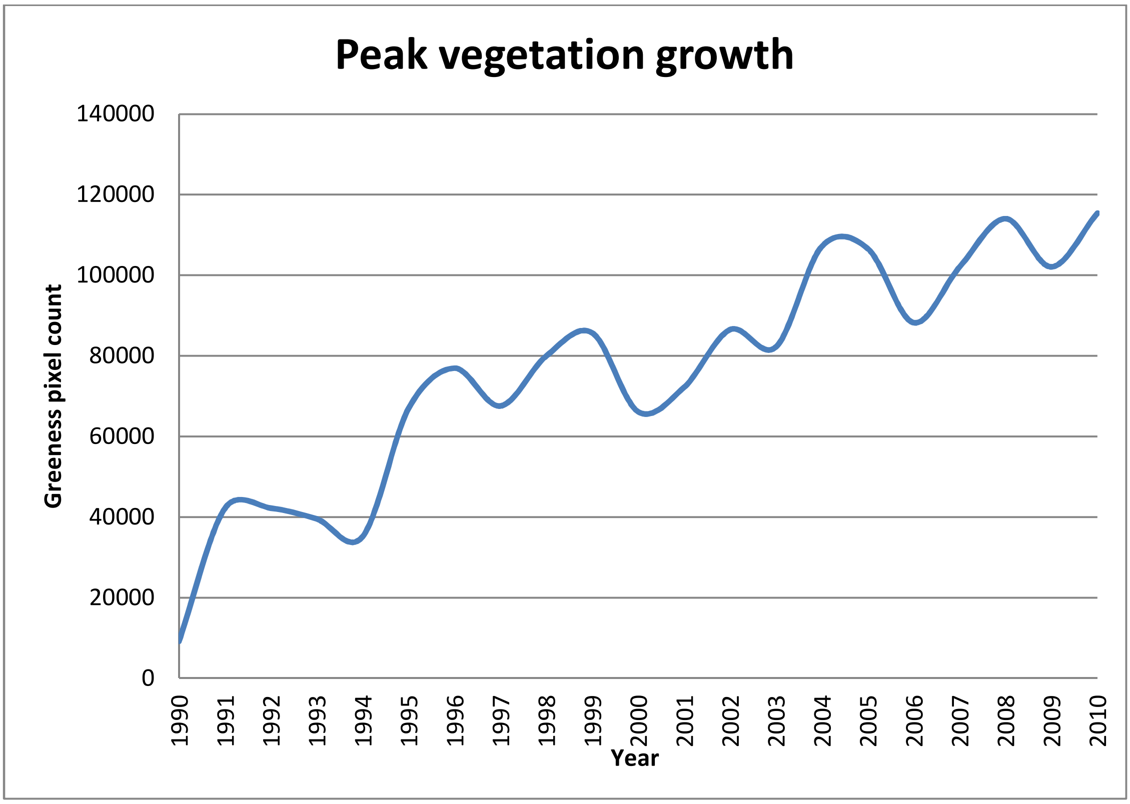


Figure 13. “Most vigorous growth” greenness pixel count

Specific to ragweed, studies in the US have shown that, whereas ragweed allergy season began in mid-August and ran through September in the 1960’s, it now on average begins from the first of August through mid-October. That is about a month added to the pollen season (Ziska & Caulfield, 2000b; Huynen, 2003). Not only will ragweed have a longer pollen season due to the increased temperature, it has been shown that ragweed produces a greater quantity of pollen under increased carbon dioxide concentrations (Beggs, 2008; Walther et al., 2002; Wayne et al., 2002; Ziska & Caulfield, 2000b). Ragweed plants grown at different levels of carbon dioxide (including from levels equivalent to preindustrial carbon dioxide to current concentrations) showed this alarming trend (Figure 14) (Beggs, 2008; Wayne et al., 2002; Ziska & Caulfield, 2000b).

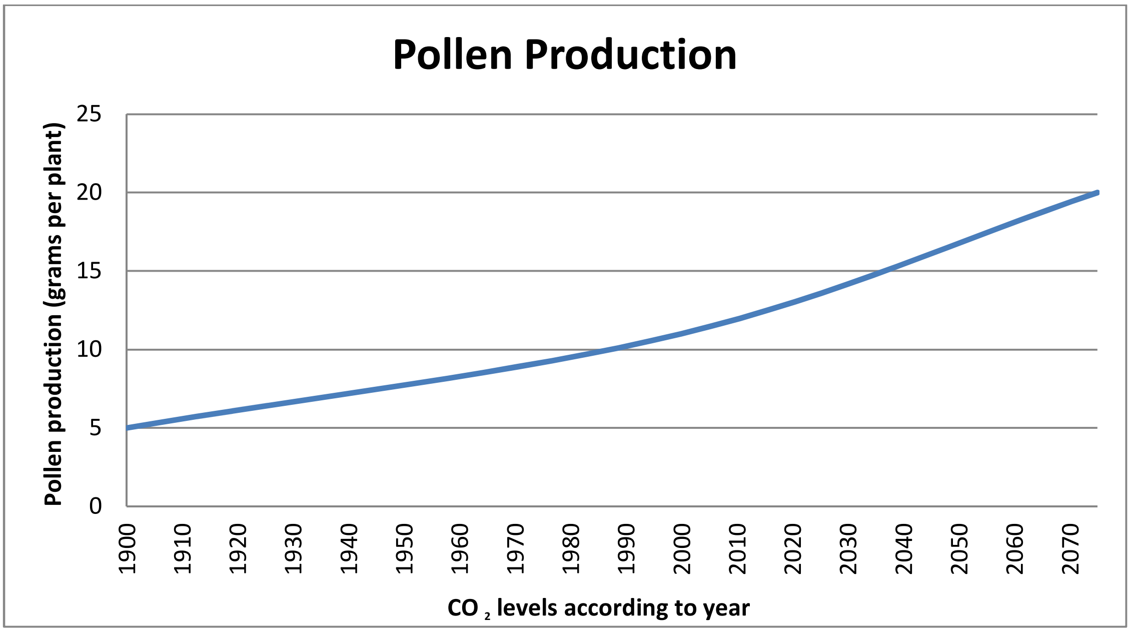


Figure 14. Pollen production from ragweed grown in chambers at the CO_2 concentration of 1900 (~280 ppm) was 5 grams per plant; at 1990's level (~370 ppm) it was 10 grams; and at a level projected to occur at 2075 (~720 ppm) it was 20 grams. (Data source: Ziska & Caulfield, 2000b).

This information is significant as annual carbon dioxide emissions for the states of Minnesota and North Dakota are projected to rise by at least 50% between 2010 and 2050 (USEPA, 2010). This value was calculated by a conservative estimate of 1.05% increase in carbon dioxide emissions per year, though with change in infrastructure, urbanization, and population growth, the estimate will likely be higher (Table 1).

Table 1. Annual CO_2 emissions in thousands of metric tons (Data Source: USEPA Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2010)

Year	Minnesota	North Dakota
1990	83,418	43,629
2010	93,204	48,748
2020	102,990	53,867
2030	113,804	59,523
2040	125,754	65,772
2050	138,958	72,678

In addition to this, there is evidence that the higher the ambient carbon dioxide the more allergenic ragweed pollen is. Ragweed pollen was harvested from plants grown in current and 2050 carbon dioxide levels and there was a reported 1.8 times increase in the allergenic protein Amb a 1 (Singer et al., 2005). Moreover, another study growing ragweed in heated plots in a prairie found that elevating air temperature by 1.2 °C (34.16 °F) increased ragweed biomass by 46% by the end of the growing season (Wan et al., 2002). As the mean ragweed pollen season temperature of the study area is expected to increase from 65 °F to 72 °F (Figures 15 and 16), we can expect a 9.6% increase in ragweed biomass (and ragweed pollen producing stems) by 2050 due to increased temperature alone.

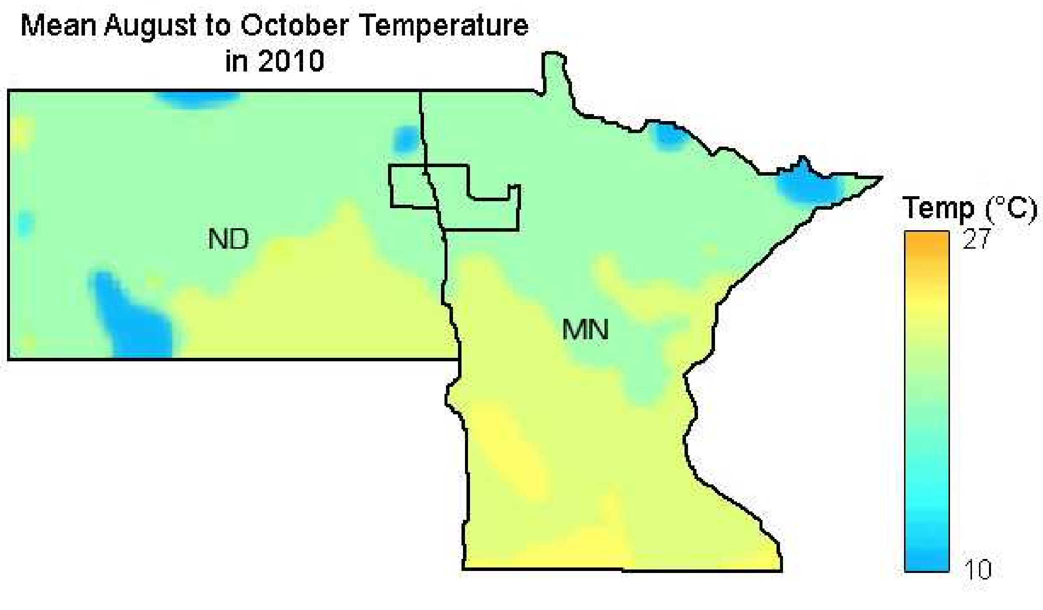


Figure 15. Mean ragweed pollen season (August to October) temperature for 2010 (Data sources: Esri, Intermap, USGS and GeoBase).

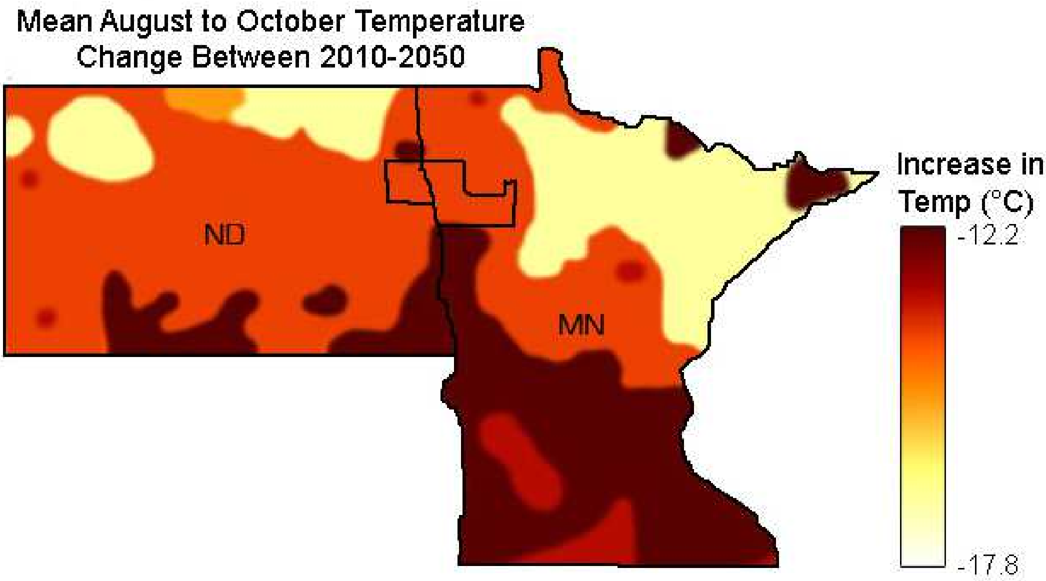


Figure 16. Change in mean ragweed pollen season (August to October) temperature for 2010 and 2050, as determined using the IPCC 4th Assessment A1B scenario (Source: Climate Wizard).

CHAPTER III

METHODOLOGY

Study Area

The study focuses on the Grand Forks, ND-MN Metropolitan Statistical Area (MSA). This MSA is part of the Northern Great Plains, a region of short- and mixed-grass temperate grasslands. In the United States a MSA is classified as "a geographical region with a relatively high population density at its core and close economic ties throughout the area" (U.S. Census Bureau). The counties making up the MSA are Grand Forks County in ND and Polk County in MN. As of the 2010, the MSA had a population of 98,461 (2010 American Community Survey). Figure 17 shows the location of the MSA.

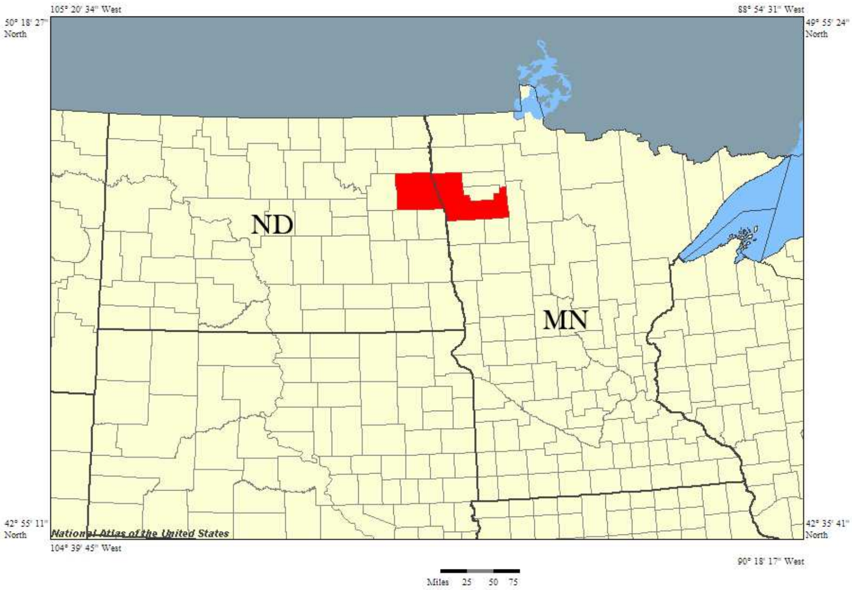


Figure 17. Grand Forks ND-MN Metropolitan Statistical Area (Grand Forks County, ND, and Polk County, MN) are highlighted in red (Source: The National Atlas).

Greater Grand Forks is the label designated to the twin cities of Grand Forks, ND and East Grand Forks, MN, as well as the surrounding area. The twin cities lie directly across from each other divided by the Red River. The Greater Grand Forks Greenway is a park system that borders the Red River and Red Lake River in the cities and occupies 2,200 acres (9 km^2). At the region's pedagogic heart resides the University of North Dakota (UND), a public research university established in 1883. In the 1880s, UND hand a handful of students and consisted of a couple of buildings and a few acres of property surrounded by crop fields. Today it has an enrollment of over 14,000 students and has 240 buildings and 550 acres (2.2 km^2) of land (UND, 2012).

Allergy Prevalence Survey

The concern of the survey portion of this study was determining the current threat levels of ragweed allergies in the region. In order to do this it was important to ascertain what proportion of the sample population suffers from ragweed allergies and if ragweed affects the sufferers' quality of life. Questions about the size of the respondents' original communities and the beginning and ends of their allergies each year were also asked. Many of the survey questions were adapted from a 2009 Trust for America's Health report (TFAH, 2009). Other questions, such as the one inquiring about allergy symptoms, were developed on the basis of literature review. The survey was field tested on 60 students in the fall of 2010 to determine if the questions were well-defined. After making appropriate changes, the survey was conducted in the spring of 2011. The questionnaire can be seen in its entirety in Appendix A. Supplementary questions on students' perceptions and opinions about climate change were included in the questionnaire.

However, it was determined that the opinion based results did not conform to the scope of this thesis.

The sampled population consisted of undergraduate students attending University of North Dakota in the spring of 2011. Permission was acquired from professors teaching large courses in the departments of Geography, Social Science, and Math, and the survey was administered to the classes before lecture began. As this project is a master's thesis, this sample was selected due to cost and operational concerns. This form of non-probability sampling is known as accidental sampling or convenience sampling (Trochim, 2006). At all times during perusal of this study, it should be kept in mind that the survey samples only a select portion of the study area.

Ragweed Habitat Suitability Analysis

In order to understand the health issues derived from ragweed allergies associated with the current and future climate, it was important to develop a ragweed habitat suitability map for the region. Normally habitat suitability is modeled using known presence data points of the species being studied and running an algorithm (taking into account any factors relevant to the species). However, since ragweed is so ubiquitous, any study using known geographic ragweed presence data would be meaningless. Instead for this study a land cover analysis was conducted on where ragweed would likely thrive in the Grand Forks MSA.

Studies on ragweed distribution in urban areas above latitude 40° N have found ragweed density to range from 6% to 11% total of the study area (Carreiro & Tripler, et al, 2005; Simard & Benoit, 2010). In situ studies of monitored plots have shown ragweed to gain up to 25% more biomass than when it is grown in rural areas (Eggleston, 1999; Ziska, 2003). This is in part because of the urban heat island effect and also because of the higher localized concentrations of CO_2 in urbanized areas (Neil & Jianguo, 2006; Taksey & Craig, 2001; Ziska, 2003). Fallow land is a haven for ragweed (Brandes & Jens. 2006; Ziska, 2003). The bare damaged soil and lack of competition from native grasses allows ample room for ragweed seeds to germinate and ragweed roots to spread (Gard, 2012; Oswalt, 2008; Werner et al., 1980). Up to 80% of fallow land surveyed at latitudes 20°- 50°N was infested with ragweed (Reznik, 2006; Richter, 2012). Similarly roadside ditches provide suitable habitat and ragweed has been known to comprise up to 85% of the absolute annual cover of roadside ditches (Austin et al., 2000; Christiansen & Lyon, 1975; Joly et al, 2011). Though ragweed grows well in dry sandy soils, it grows up to 40% better in the heavy soils in riverbanks (Branson et al., 1965; Parker & Leck, 1985; Jung & Reisinger & , 2006; Ruch, 2009). Ragweed in riparian zones and wetlands has been found to comprise up to 5% of the vegetative cover (Brandes & Jens, 2006; Davis, 2007; Sickls & Simpson, 1985). Studies have shown that farm areas suited for growing corn, soybean, and wheat are also suited for ragweed (Davis et al., 2005; Jacob, 2006). Ragweed establishes itself in seed beds and has been known to cause up to a 40% loss in harvest for soybean and corn and up to 50% for wheat (Cowbrough et al., 2009; Davis et. al, 2005; Munn et al., 1998; Weaver, 2001). Up to 15% of hay acreage surveyed was ragweed infested (Vermeire et al., 2001).

The map layer used for the habitat analysis was the USDA National Agricultural Statistics Service (NASS) Cropland Data Layer (CDL). The 2010 CDL was created using Landsat TM/ETM+ and AWiFS (Advanced Wide Field Sensor) imagery for the production of a 30m resolution map. The CDL is different from a National Land Cover Data Layer (NLCD) as it is the product of combining remote sensing imagery with the NASS June Agricultural Survey data as well as Farm Services Agency data. Other shapefiles for roads and county boundaries were acquired from the National Atlas webpage. Roadside ditches average 5m in width (Austin et al., 2000) so for the habitat analysis a 5m buffer layer was applied. For the fields, areas around fields, urban areas, wetlands, and the riparian areas around the Red River, ragweed potential was mapped by applying a raster overlay analysis (using the overlay union tool in Spatial Analyst). Table 2 summarizes the ragweed growth potential for each land cover type and the index value assigned to each for the habitat suitability model overlay analysis.

Table 2. Habitat suitability index

Land cover type	Ragweed potential (max)	Habitat suitability index
Corn	40%	0.4
Fallow land	80%	0.8
Hay	15%	0.15
Riparian corridor	5%	0.05
Roadside ditches	85%	0.85
Soybean	40%	0.4
Urban areas	11%	0.11
Wetlands	5%	0.05
Wheat fields	50%	0.5

Data source: Austin et al., 2000; Brandes & Jens, 2006; Branson et. al, 1965; Carreiro & Tripler, 2005; Christiansen & Lyon, 1975; Cowbrough et al., 2009; Davis et al, 2005; Davis, 2007; Eggleston, 1999; Gard, 2012; Jacob, 2006; Joly et al., 2011; Jung & Reisinger, 2006; Munn et al., 1998; Neil & Jianguo, 2006; Oswalt, 2008 Parker & Leck, 1985; Reznik, 2006; Richter, 2012; Ruch, 2009; Sickles, 1985; Simard & Benoit, 2010; Taksey & Craig, 2001; Vermeire et al., 2001; Weaver, 2001; Werner et al., 1980; Ziska, 2003)

CHAPTER IV

RESULTS

Survey Response Rate

The survey received 233 completed responses out of 272 successful contacts, a response rate of 87%. The response rate was lower than expected given the "captive" nature of the survey participants in lecture rooms. The unanswered surveys were either returned blank or with a sentence explaining the particular student's lack of belief in climate change. For the surveys that were filled all the questions had been answered and no blank data had to be dealt with.

Demographic Data

Overall the breakdown of gender was about 47% male and 52% female (n=233). This ratio is similar to the male to female ratio of the Grand Forks MSA. The respondents were 33 different ages, with the youngest being 18 and the oldest 51. An overwhelming majority of students (93%) were 24 years old or younger. Only around 14% the population of the Grand Forks MSA fits this age range. Male respondents were about 5% older than the female respondents. General demographic characteristics of survey respondents are reported in Tables 4 and 5.

Table 3. Select demographics (age and gender) of survey respondents and residents of the Grand Forks MSA (Data Source: 2010 American Community Survey)

	Grand Forks MSA	UND Demographics	Survey Respondents
Males	49,505 (50.9%)	7,642 (52%)	110 (47.2%)
Females	47,755 (49.1%)	7,055 (48%)	123 (52.7%)
Age Group			
Under 9	11.8%		0
10-14	6.1%		0
15-19	9.6%		45.9%
20-24	13.3%		47.2%
25-34	12.7%		5.6%
35-44	11.3%		6.4%
45-54	13.6%		0.4%
55-59	5.4%		0
60-64	4.2%		0
65-74	5.6%		0
Over 75	6.5%		0
Median age	30.8	22.5	20
Average age	25-34	21-25	20

Table 4. Age and frequency of survey respondents

Age	Male		Female		Total	
	Frequency	Percentage	Frequency	Percentage	Frequency	Percentage
18	3	1.3%	18	7.7%	21	9.0%
19	40	17.2%	46	19.7%	86	36.9%
20	26	11.2%	28	12.0%	54	23.2%
21	14	6.0%	4	1.7%	18	7.7%
22	9	3.9%	11	4.7%	20	8.6%
23	5	2.1%	5	2.1%	10	4.3%
24	4	1.7%	4	1.7%	8	3.4%
25	4	1.7%	4	1.7%	8	3.4%
26	1	0.4%	0	-	1	0.4%
27	1	0.4%	0	-	1	0.4%
28	2	0.9%	0	-	2	0.9%
33	0	-	1	0.4%	1	0.4%
41	0	-	1	0.4%	1	0.4%
42	0	-	1	0.4%	1	0.4%
51	1	0.4%	0	0.0%	1	0.4%

The students hailed from 11 different countries, but an overwhelming majority (96%) was from the United States. The students were from 19 different US states (Table 5). Most of them were from Minnesota (43.8%) or North Dakota (33%). There were 83 students (32% of the sampled population) originally from the Grand Forks MSA.

Table 5. Geographic origin of students

State	Frequency	Percentage
Arizona	2	0.9%
California	6	2.6%
Colorado	3	1.3%
Connecticut	1	0.4%
Iowa	1	0.4%
Kansas	2	0.9%
Maryland	1	0.4%
Minnesota	102	43.8%
Montana	4	1.7%
New Hampshire	1	0.4%
New Jersey	1	0.4%
North Dakota	77	33.0%
Oklahoma	2	0.9%
Oregon	4	1.7%
South Dakota	3	1.3%
Texas	4	1.7%
Virginia	1	0.4%
Wisconsin	8	3.4%
N/A (other country)	10	4.3%

The sizes of the respondents' original communities are displayed in Figure 18. The population characteristics of these communities were not defined in the questionnaire and students self-determined which categories their original communities fell under. In all, 17% of the students self-identified as being originally from rural areas, 34% from towns, 40% from cities, and 9% from large metro areas.

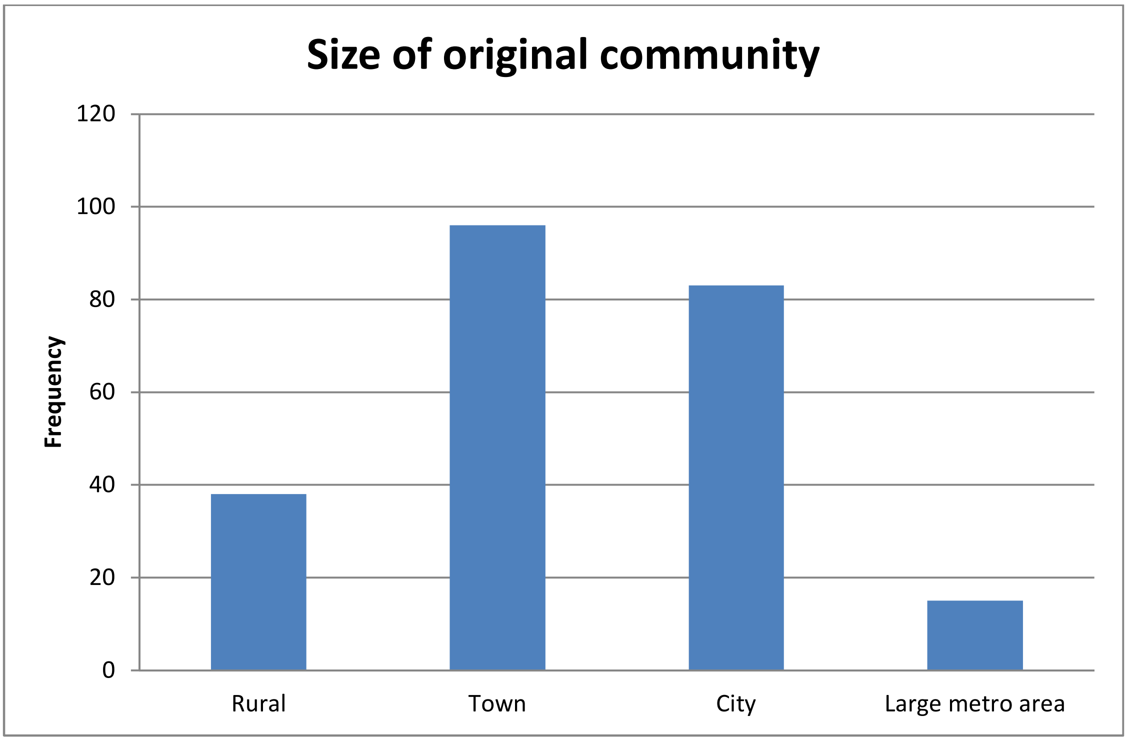


Figure 18. Size of the respondents' original communities

If they were not originally from the Grand Forks MSA, the students were asked to estimate how long they have been living here. The results are summarized in Table 6. The majority of respondents have been here for 1 or 2 years.

Table 6.Years Spent in Grand Forks MSA

Years spent in the Grand Forks MSA	Frequency	Percentage
0.5	7	3.00%
1	61	26.18%
1.5	7	3.00%
2	37	15.88%
2.5	1	0.43%
3	14	6.01%
3.5	1	0.43%
4	8	3.43%
5	5	2.15%
Over 6	9	3.87%

Allergy Information

In all, 22% of the students identified as being allergic to pollen producing plants, 24% were allergic to ragweed specifically, and 67% were not allergic to ragweed or any other pollen producing plants (Figure 19) (n=233). Of the respondents with allergies to any pollen producing plant, 79% were also allergic to ragweed. Of the people originally from the Grand Forks MSA (83 students), 26% had allergies to pollen in general, and 21% were allergic to ragweed.

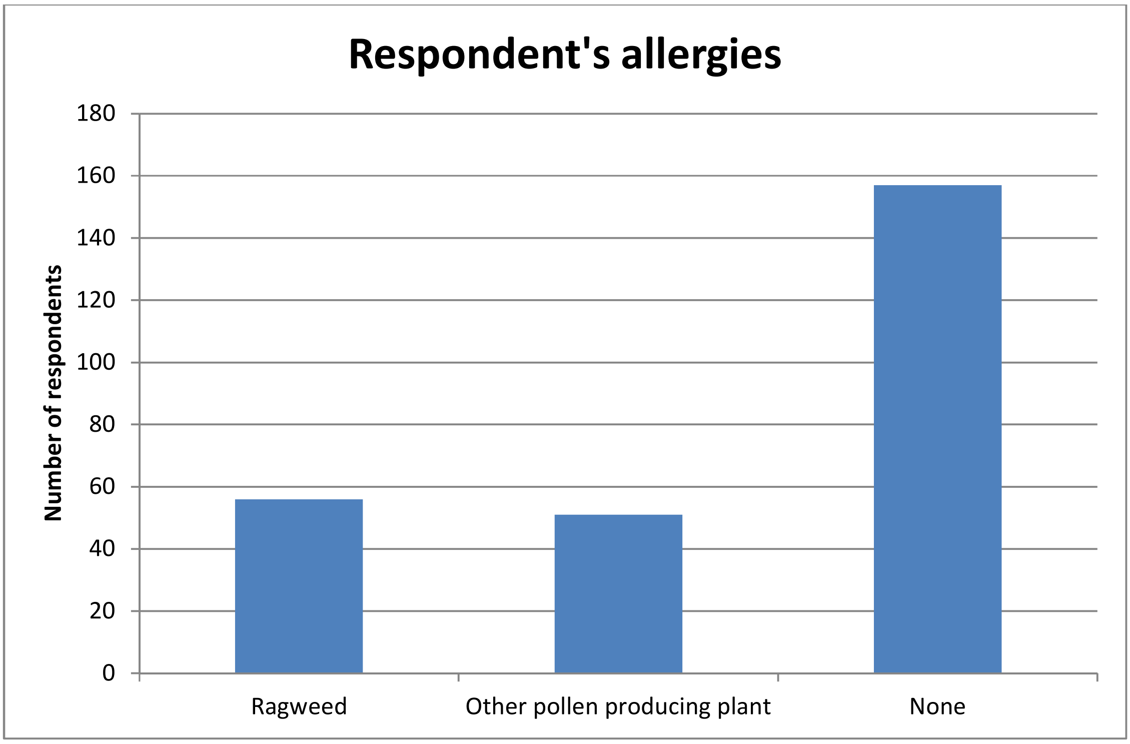


Figure 19. Number of respondents with allergies.

Most of the ragweed allergy sufferers originally came from cities, followed by towns, metropolises, and then rural regions (Figure 20). All of the allergic students in the sample originally from rural areas did not develop allergies until moving to the study area.

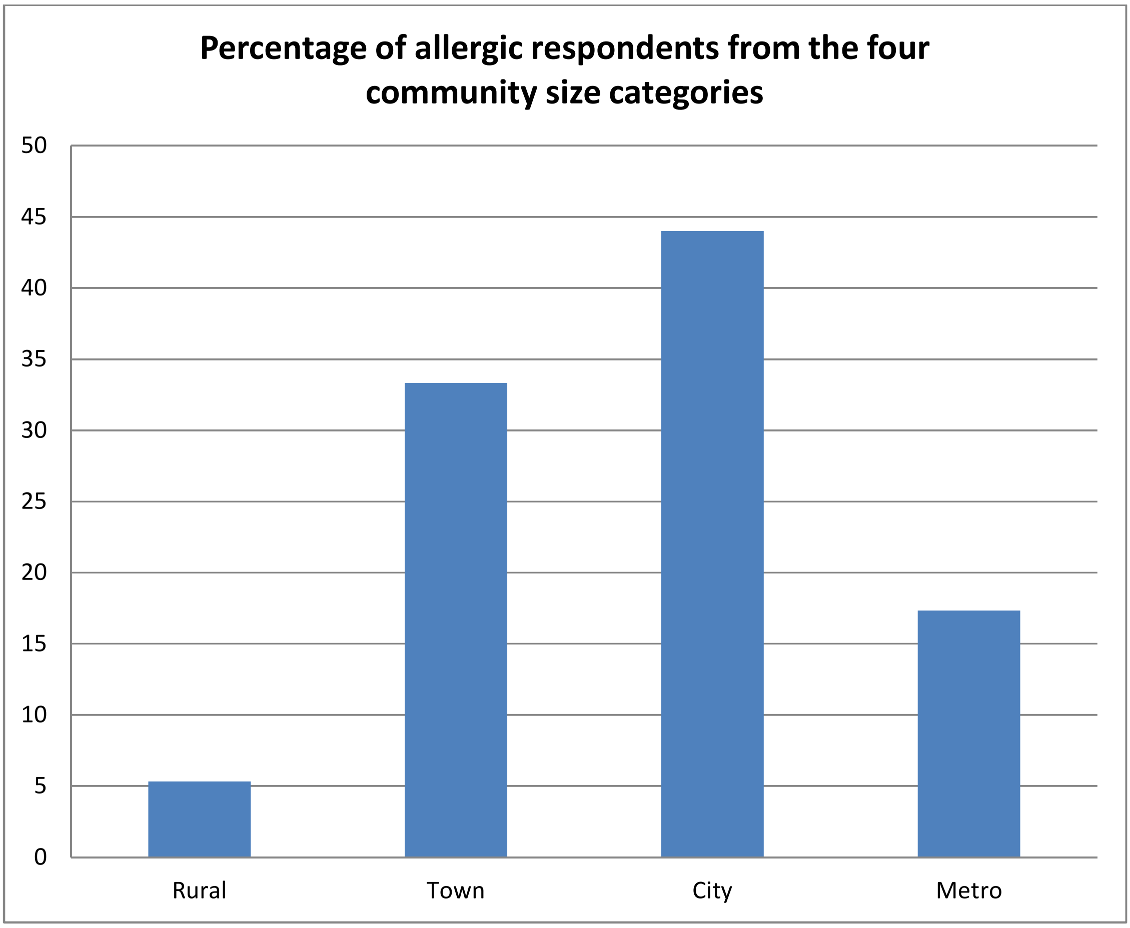


Figure 20. Percentage of allergic respondents from the four community size categories.

Of the 56 respondents who identified as being allergic to ragweed, when asked if allergies have a negative effect on their quality of life, 27% responded with a "yes," 62% with "somewhat," and 11% with "no" (Figure 21). These respondents were then asked to estimate the beginning and ends of their individual allergy seasons. Most (87%) of the allergic respondents' allergy seasons coincided with ragweed pollen season: beginning in August and ending in October. This was true regardless of whether the respondents identified as being allergic to ragweed or not. Additionally, 5% of the students had allergy symptoms throughout the year.

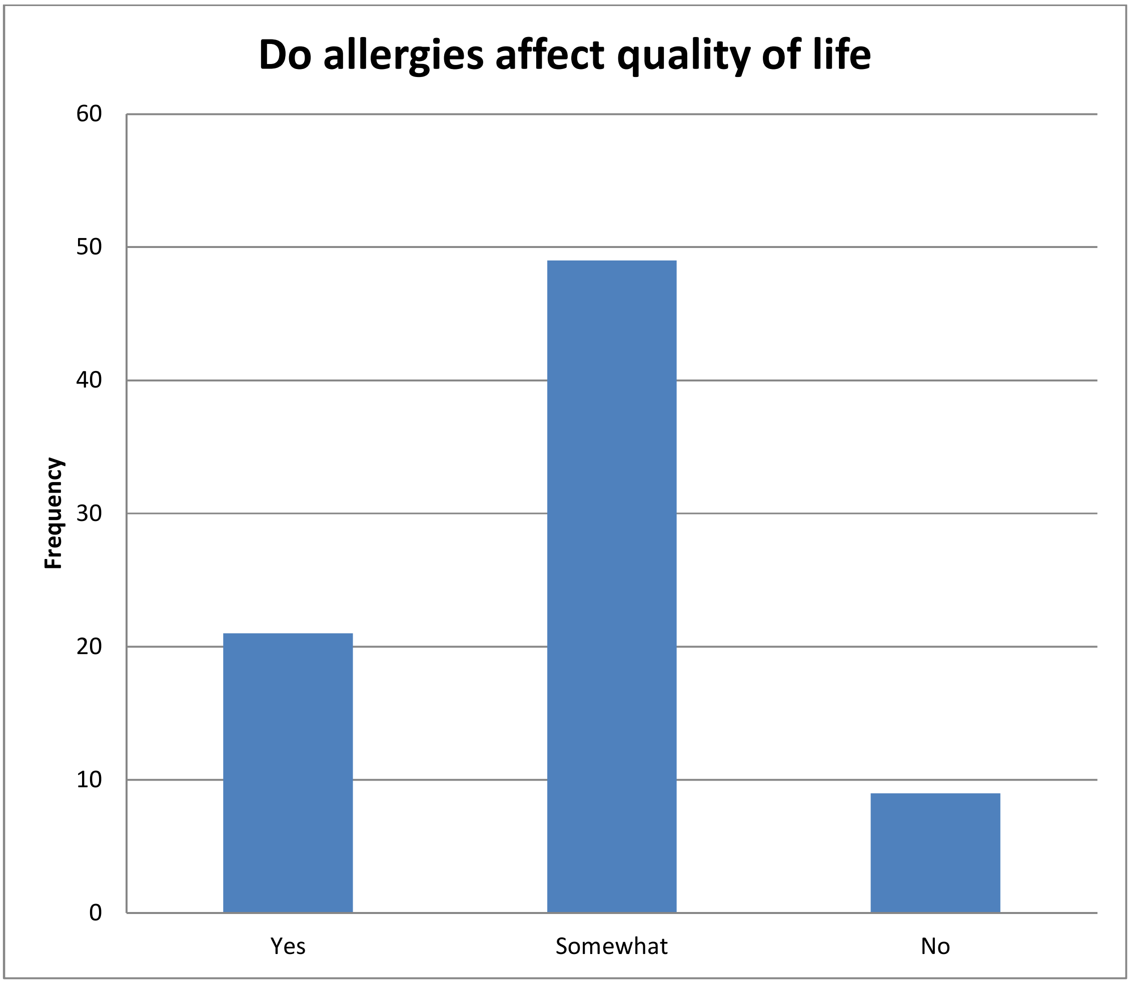


Figure 21. Allergies and quality of life.

Figure 22 summarizes the ragweed allergy symptoms students had. Hay fever was the most common symptom with 79% of respondents suffering from it. The other symptoms, in descending order of frequency, were headaches, impaired sleep, asthma, chronic sinusitis, and depression. Additionally, 7 students listed “other” as their allergy symptoms. Their written responses were as follow: “I have vocal chord dysfunction so it's like asthma but my throat closes up”; “Persistent sinus infections”; “Congestion”; “Sinus infections”; “I get nose bleeds”; “Nose and ear aches”; “Congestion and sinus infections”

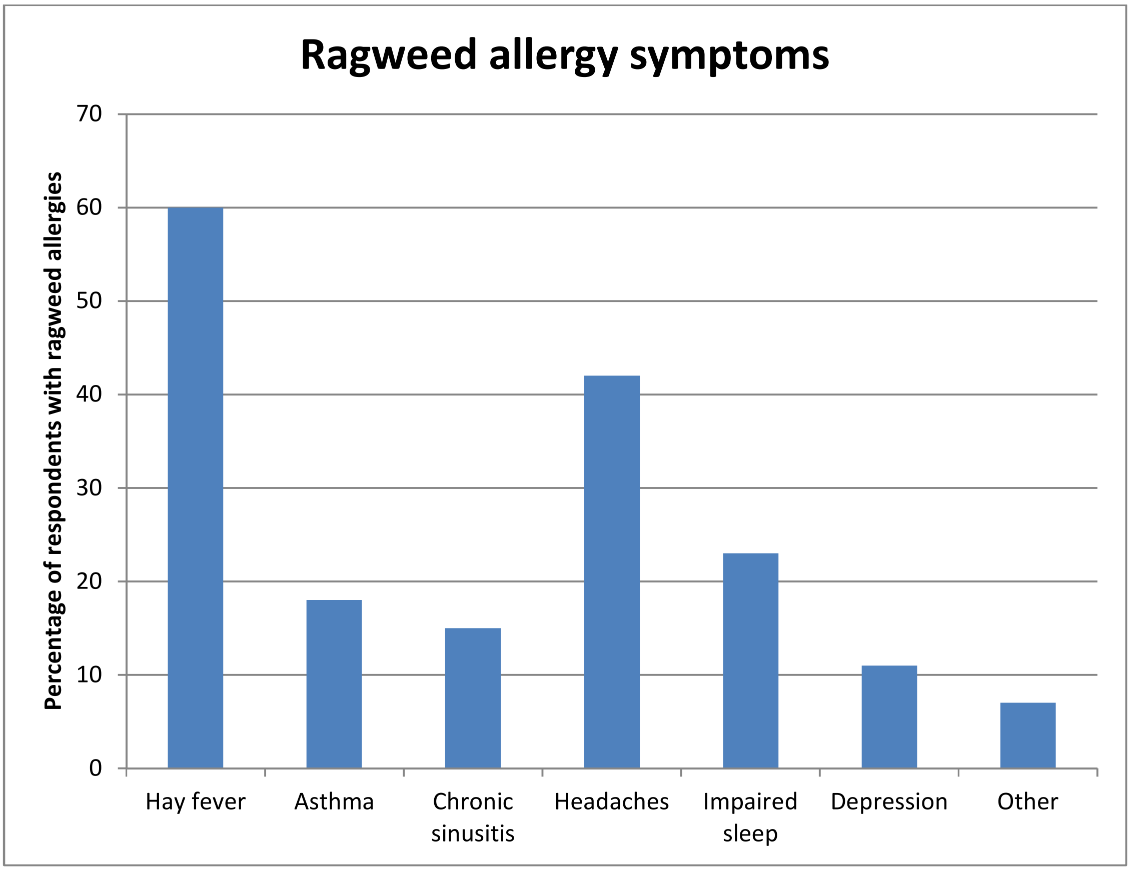


Figure 22. Ragweed allergy symptoms

When asked if they had allergies before moving to the study area, about 87% said "yes" (n=150). Almost all of the respondents (97%), regardless of if they had allergies or not, knew someone who suffered from allergies personally.

Ragweed Habitat Suitability Analysis

The ragweed habitat modeling showed that the study area is quite suitable for ragweed growth. Overall, only 10% of the Grand Forks MSA can be considered unsuited for ragweed. Table 8 shows the relevant land cover classes and the area they occupied in 2010. Crop fields (corn, wheat, soybean, and hay) made up a vast 78% of the area. Urban areas made up 5% of the area, wetlands 6%, and fallow lands, roadside ditches, and riparian zones together made up 1% of the area.

Table 7. Land cover 2010

Land cover	Polk County (km^2)	Grand Forks County (km^2)	Total MSA (km^2)
Corn	180.3	372.2	552.5
Fallow land	17.3	18.7	36.1
Hay/Pasture	1032.9	1113.3	2146.3
Riparian zone	6.7	5.2	11.9
Roadside ditches	24.1	23.5	47.6
Soybean	1163.2	635.7	1798.9
Urban areas	313.5	162.8	476.3
Wetlands	383.3	137.0	520.3
Wheat	1216.6	1231.5	2448.1

Figures 23 and 24 show the Grand Forks County and Polk County ragweed habitat suitability maps created using the index values in Table 3. The highest suitability regions (index values 0.8-0.85) show where ragweed would most likely grow; these make up 0.94% of the area. The medium suitability regions (index values 0.4-0.5) made up the vast amount of the region and account for 54% of the Grand Forks MSA. Low suitability regions (index values 0.1 and lower) accounted for 35% of the area.

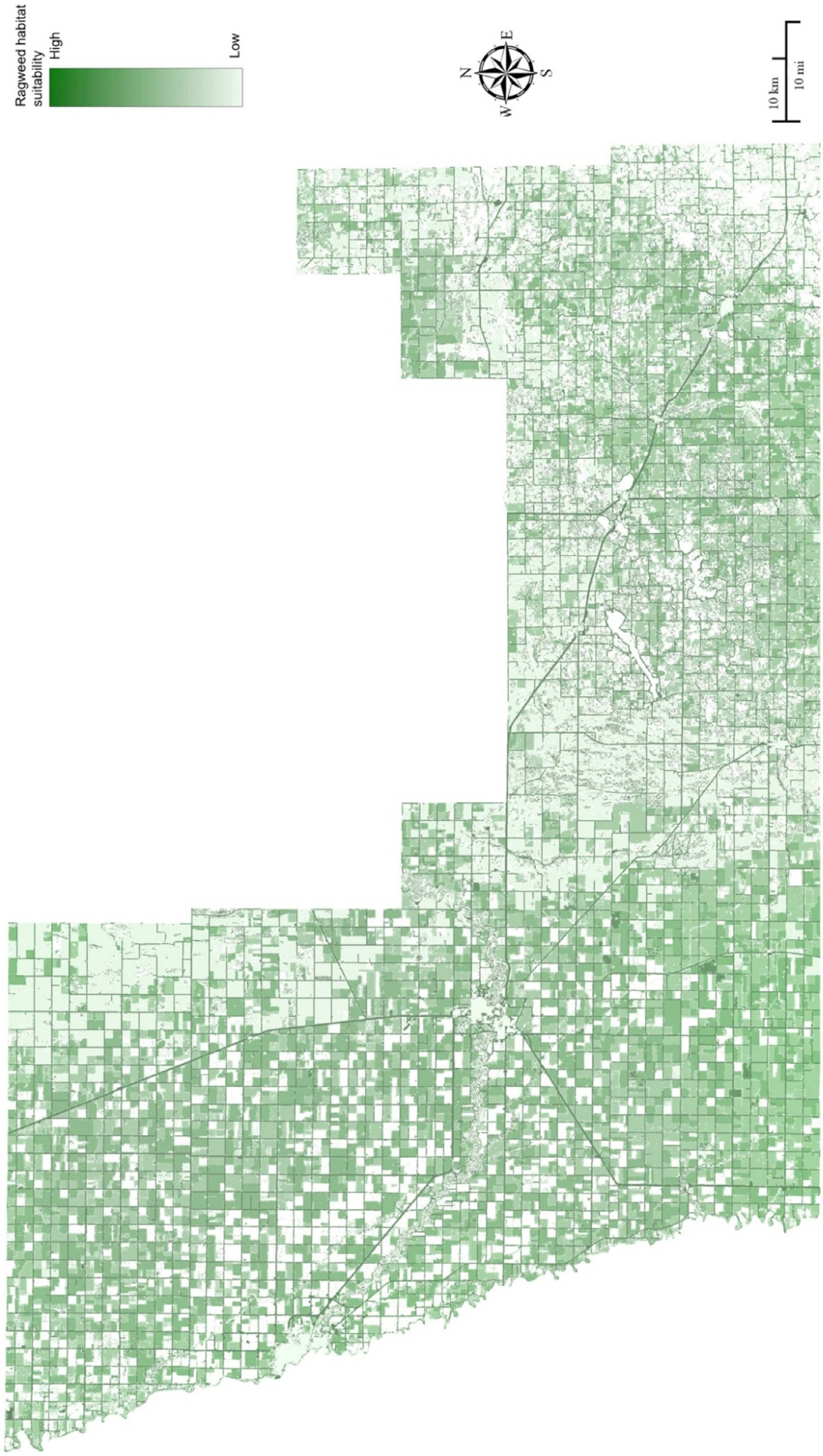


Figure 23. 2010 Polk County ragweed habitat suitability map

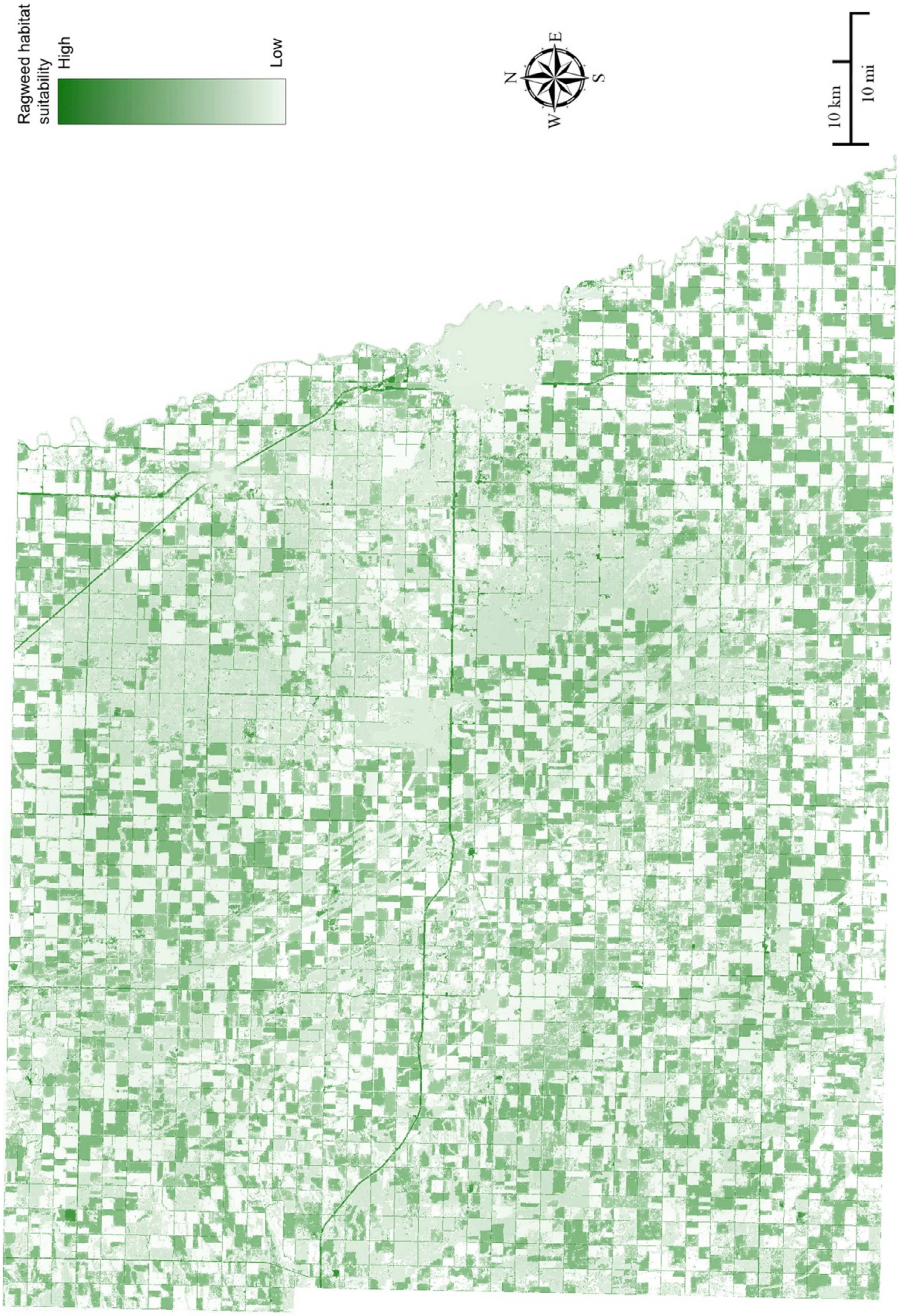


Figure 24. 2010 Grand Forks County ragweed habitat suitability map

Table 9 shows the potential ragweed infestation of each land cover class for 2000 and 2010. Wheat fields showed the highest total ragweed potential for the Grand Forks MSA and riparian zones the lowest. Though roadside ditches had the highest index value in Table 3, because of the considerably low area they occupy on the maps, they ranked 7th in total ragweed potential. Other than riparian zones and soybeans fields, between 2000 and 2010, all ragweed relevant land cover classes gained acreage and therefore ragweed potential. Corn showed the highest percent increase followed by urban areas.

Table 8. Ragweed suitability comparison of the Grand Forks MSA between 2000 and 2010 (Data source: USDA and NASS cropland data layers).

Landcover	2000 ragweed suitability (km^2)	2010 ragweed suitability (km^2)	Percent change
Corn	112.7	221.0	96%
Fallow land	25.8	28.9	12%
Hay/Pasture	287.2	321.9	12%
Riparian zone	2.0	1.8	-8%
Roadside ditches	39.7	40.5	2%
Soybean	852.1	719.6	-16%
Urban areas	38.6	52.4	35.7%
Wetlands	22.7	26.0	14%
Wheat	1029.9	1224.1	19%
Total	2410.7	2636.2	10%

CHAPTER V

DISCUSSION

In the U.S., according to a 2003 survey, over 10% of the population was allergic to ragweed (Ziska, 2004). In contrast, for the population sampled in this study, almost a quarter of the individuals were allergic to ragweed. Due to the lack of pollen counting stations in the region it is impossible to determine if this is due to an excessive amount of ragweed pollen in the area or excessive amounts of the allergenic protein Amb a 1 in Grand Forks MSA ragweed pollen. Most of the ragweed-allergic individuals came from cities, followed by towns, metropolises, and rural areas. The allergenicity rank for metropolises does not match up with studies in which ragweed was monitored in controlled plots. According to the research, higher levels of urbanization cause ragweed to increase in biomass and also to produce more pollen (Ziska et. al, 2003). This is due to the increased localized CO_2 levels in cities versus rural areas, and also due to the urban heat island effect (Ziska et. al, 2003). Thirteen percent of the ragweed-allergic respondents (and 100% of those originally from rural areas) did not develop allergies until they moved to the study region and had been living there for about 2 years. Though allergic sensitivities to pollen are generally established during early childhood (Beggs & Bambrick, 2006), these 13% are experiencing what is known as adult-onset allergies (Künzli et al., 2009). The adult-onset allergy phenomenon has been on the rise for the past two decades yet the reasons for this escalation are as of yet unknown (Guerra, 2002). Experts are considering factors such as higher levels of airborne pollutants, less ventilation in homes and offices, and sedentary lifestyles (Guerra, 2002).

The ragweed-allergic respondents experienced all of the common symptoms related to ragweed allergies in addition to other symptoms such as nose bleeds, and vocal cord dysfunction. Nasal allergies can be both directly and indirectly responsible for nose bleeds. Directly the bleeding can occur due to nasal inflammation caused by the allergies irritating the nasal cavities (Kaiser et al., 1995). Indirectly certain allergy medications, excessive nasal dryness, frequent use of nasal decongestants, and frequent blowing of the nose can cause nasal trauma (Kaiser et al., 1995). In the condition called vocal cord dysfunction (VCD), the vocal cords and surrounding structures constrict causing partial airway obstruction during breathing (Brugman & Newman, 1993). VCD is an asthma mimicker and the symptoms include shortness of breath, chest tightness, and wheezing (Brugman & Newman, 1993). Patients with VCD are often misdiagnosed and treated with strong asthma medications, including steroids (Brugman & Newman, 1993). Even though VCD is often triggered by seasonal allergies, it is not itself considered a medical condition. As such there are no medications to treat or cure VCD. In some cases speech therapy can help the patient control his/her VCD (Brugman & Newman, 1993).

Over 84% of the ragweed-allergic respondents admitted to allergies having an impact on their quality of life, 23% admitting to allergies contributing to impaired sleep, and 10% to depression. The link between allergies and life satisfaction is currently under scrutiny. Studies analyzing medical records found that depression and anxiety symptoms correspond strongly with low and high pollen seasons, and that the rate of allergy is higher among depression patients than in the general population (Bell et al., 1991; Patten et al., 2009). Other studies establish the alarming correlation between pollen season and suicide rates (Postolache et al., 2004; Postolache et al., 2007; Postolache et al., 2008).

Through the ragweed habitat suitability modeling it was discovered that 0.94% of the Grand Forks MSA was of high suitability for ragweed growth, 54% of medium suitability, and 35% was of low suitability. Overall, only 10% of the region was classified as not suitable for ragweed growth. Between 2000 and 2010, due to an increase in roads and fallow land in the MSA, high suitability regions increased by 11%. An increase in wheat and corn farming (soybean farming decreased) in the region led to a 9% increase in medium habitat suitability. Low suitability regions also increased by 13%. This was primarily due to prairie pothole expansion in Polk County, an increase in hay production in Grand Forks County, and increased urbanization in both areas. Overall, as a function of the ragweed habitat index described in Table 2, ragweed habitat suitability increased by 10% between 2000 and 2010 for the study area. For the future, circa 2050, the situation will likely become worse for allergy sufferers living in the Grand Forks MSA. As the annual mean temperature for the study region is projected to increase by up to 5 °F (Figures 1 and 2), and the mean ragweed pollen season temperature of the study area is expected to increase by 7 °F (Figure 14), we can expect a 9.6% increase in ragweed biomass and pollen producing stems by 2050 due to increased temperature alone (Wan et al., 2002). In addition to this, as ragweed plants grown at different levels of CO_2 release different levels of pollen (Beggs, 2008; Wayne et al., 2002; Ziska & Caulfield, 2000b), we have to consider the role increased local CO_2 emissions will have on allergies. For the study region, annual CO_2 emissions are projected to rise by about 50% between 2010 and 2050 (Table 1). By increasing the CO_2 concentrations in the region by 50%, we can expect a 50% increase in the amount of pollen being released by the ragweed plants

(Figure 12). Moreover, regardless of the amount of pollen being released by the plants, we can expect a 1.8 times increase in allergenicity of ragweed pollen by 2050 (Singer et al., 2005).

It is difficult to predict the land cover makeup of the region by 2050. Though this study examined the land cover of years 2000 and 2010 in detail, brief examination of the years in between indicated a variation in land cover, particularly related to the amount of and types of crops being farmed. The one value that consistently increased and can be projected is urban expansion. At the current rate, due to the population of the study region growing at the rate of 0.94% per year since 2000 (U.S. Census), urban development of the Grand Forks MSA has been rising on average 3.5% per year since 2000. If urbanization continues at this rate, between 2010 and 2050, it will have increased by 143.5%. Taking urbanization alone into account total ragweed potential of the Grand Forks MSA would then increase by 3.5%.

Even though ragweed allergy is a problem with 24% of the surveyed population, ragweed monitoring in the Grand Forks MSA is practically non-existent. In North Dakota and Minnesota ragweed is classified as an “objectionable” weed and does not receive the higher monitored status of “noxious” weed as plants like leafy spurge (*Euphorbia esula*) or barilla (*Halogeton glomeratus*) do (USDA, 2013). The only time ragweed is monitored is during seed variety identification tests during grain quality checks. For instance a “certified” level seed crop of wheat would have a maximum of 1 ragweed seed per 1 lb, “registered” level would have a maximum of 1 seed per 2 lb, and “foundation” level wheat would have a maximum of 1 ragweed seed per 4 lbs (MDA, 2006; NDDA, 2009; NDDA, 2013). Weed management on private land of both sides is left up to the owners so it is impossible to ascertain the ragweed condition there. However, a landscaping company website mentions ragweed, Queen Anne's lace, and crabgrass taking their turns dominating private lawns and backyards on the North Dakota side as the year progresses (Organic Pest Control, 2010). Both Grand Forks and East Grand Forks contract out tracts of city land for vegetation maintenance, which generally involves spraying herbicides once per year and mowing as needed (Grandforksgov.com , 2009a; MDA, 2006). Four agencies are responsible for maintenance of the Greenway bordering the Red River. The city of Grand Forks owns all and manages most of the Greenway on the ND side. The four park areas (Lincoln Golf Course, Riverside Park, Kannowski Park, and Lincoln Drive Park) are managed by the Grand Forks Parks System. On the East Grand Forks side, the city of owns a 200 acre (0.81 km2) section of the Greenway downtown while all other Greenway land is owned and managed by the Minnesota Department of Natural Resources. Though both sides have reported ragweed present on the Greenway, weed control plans remain general in nature and also involve contractors spraying agreed upon tracts with herbicide and mowing as needed (Grandforksgov.com, 2009b). As has been established in the literature review of this study, herbicide application and mowing as the means of ragweed control are often failing ventures. Moreover, there is ongoing danger of the herbicides and/or mowing affecting natural flora/fauna systems in the Greenway. For instance there have been concerning reports of contractors spraying and mowing the park system during migratory bird season (USFWS, 2012). Other than this there is evidence that such broad scale surface application of herbicides can lead to herbicide resistance in ragweed (Tranel & Wright, 2009). Funded by the Red River Regional Council-Red River Basin Riparian Project, a native grass restoration project was initiated on several plots along the Greenway (Grandforksgov.com, 2004). In upcoming years such projects ought to become the primary means of Greenway ragweed management.

Future ragweed allergy survey research in the region could utilize a random sampling method and a larger sample size. When working with non-random samples such as the one employed in this thesis, it becomes difficult to apply statistical generalizations to the population at large. An overwhelming majority of respondents (93%) in this thesis were 24 years old or younger. A random sample of a larger size would be able to provide information about whether ragweed allergies affect this age group more than others. There are limitations to how much information can be garnered from the suitability analysis conducted in this thesis. The basis of the analysis was the maximum ragweed growth potential on particular land cover classes as determined from in situ studies of ragweed growth. Minimum data was unavailable and therefore a range of potential ragweed cover for the region could not be estimated. Moreover, without field verification, outputs from all habitat suitability models remain suspect. For instance, ragweed presence on the farm areas will vary greatly depending on each farmer's herbicide application strategies. Any well-funded ragweed habitat suitability analysis conducted for the region in the future should involve collecting field data as well as using satellite imagery.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

The aim of this thesis was to determine the hazard of ragweed allergy in the Grand Forks MSA. Classifying ragweed pollen as a pollutant, this thesis took upon the task of conducting a risk assessment for the region. According to the U.S. Environmental Protection Agency (USEPA), a risk assessment involves determining the following: (1) what problems are caused by the pollutant, (2) how much of the pollutant the study population is exposed to, and (3) how many people are exposed and vulnerable to the pollutant. It addition to establishing the current risk levels of ragweed allergy in the Grand Forks MSA, it was the intent of this thesis to take climate change into account and quantify a projected risk in the future.

Ragweed, a flowering weed native to temperate grasslands of the Americas, has achieved notoriety due to its being one of the primary sources of allergy worldwide (Ziska & Caulfield, 2000a). In susceptible individuals, allergic reactions occur to normally harmless environmental substances such as ragweed pollen. Depending on the individual and the degree of hypersensitivity, the allergic response can range from mild irritations and swellings to life threatening anaphylactic reactions. Overall an estimated 10.6% of the U.S. population suffers from ragweed allergy (Ziska & Caulfield, 2000a). There are several distinct allergic diseases attributable to ragweed, the most common of which are hay fever, acute and chronic sinusitis, and asthma. Headaches, impaired sleep, fatigue, and depression are secondary symptoms (The Diagnosis and Management of

Rhinitis, 2008). Treatment of ragweed allergies with anti-histamines costs allergy sufferers billions of dollars per year, yet the treatments are not always effective. Moreover, side effects like drowsiness, dizziness, nausea, moodiness (especially in children), blurred vision, mental fog, and confusion are common with anti-histamine use (Motala, 2009; WebMD, 2012a). In addition to anti-histamines, allergy sufferers find themselves relying on various medications and/or surgery to treat their particular form of allergic disease. Allergen immunotherapy is often beneficial for pollen allergy sufferers, but on ragweed-allergic individuals the effect of immunization is comparable to placebo (Loveless, 1957).

It is estimated that a single ragweed plant releases up to a billion grains of pollen over the course of its growing season, and that 1 million tons of ragweed pollen are produced each year in North America alone (Rees, 1997). Ragweed pollen is so small and light that even gentle breezes are capable of dispersing it (Rees, 1997). Among weed species, ragweed has the fourth highest spread potential (Weber & Gut, 2005). It extends its range by creeping rhizome like roots and by seeds that can remain dormant for up to 39 years (Vermeire et al., 2001). Ragweed is often referred to as a symptom of sick soil. Whereas it is not an aggressive competitor in virgin grasslands, when the competitive edge is taken away from native grasses by disturbing the soil through processes such as urbanization and farming, ragweed thrives. Through the ragweed habitat suitability modeling, it became clear that the Grand Forks ND-MN MSA is quite suited for ragweed growth and spread. The study region is part of the Northern Great Plains and a native habitat for the most allergenic of the ragweed species. Moreover, the region has plenty of land cover of the type that ragweed colonizes. Crop fields (corn, wheat, soybean, and hay) made up a vast 78% of the area. Urban areas made up 5% of the area, wetlands 6%, and fallow lands, roadside ditches, and riparian zones together made up 1% of the area. Only 10% of the Grand Forks MSA was considered unsuited for ragweed. Between 2000 and 2010, due to an increase in roads and fallow land in the MSA, high suitability regions increased by 11%. An increase in wheat and corn farming (soybean farming decreased) in the region led to a 9% increase in medium habitat suitability. Primarily due to prairie pothole expansion in Polk County, an increase in hay production in Grand Forks County, and increased urbanization in both areas, low suitability regions also increased by 13%. Overall, ragweed habitat potential increased by 10% between 2000 and 2010 for the study area. As the population of the region continues to grow, further urban development spells an ensuing spread and proliferation of the city-loving weed. Taking urbanization alone into account, total ragweed potential of the Grand Forks MSA would further increase by 3.5% by 2050.

The survey was a means to identify the threat level of ragweed allergy in region. The sampled population consisted of 233 undergraduate students attending University of North Dakota in the spring of 2011. The breakdown of gender was about 47% male and 52% female, a ratio similar to that of Grand Forks MSA. A majority of respondents (93%) were 24 years old or younger. For the population sampled in this study, almost a quarter of the individuals were allergic to ragweed. The most common ragweed allergy attributable disease was hay fever, with 79% of ragweed-allergic respondents suffering from it. Ragweed also caused students to suffer from headaches, impaired sleep, asthma, chronic sinusitis, nose bleeds, earaches, vocal cord dysfunction, and depression. Most of the ragweed-allergic respondents came from cities. All of the ragweed-allergic students in the sample originally from rural areas did not develop allergies until moving to the Grand Forks MSA, further supporting the link between urbanization and ragweed allergy.

To this we add the impending peril of a changing climate. As evidenced by the increase in “greenness” of the region (Figure 12) and the recent altered USDA hardiness zone of Polk County (Figure 11), a significant impact of climate change is already discernible in plant biological systems. Compared with the early 1960’s, spring events such as flowering have advanced by 6 days, and autumn events have been delayed by 4.8 days (Emberlin et al., 2002; Fitter & Fitter, 2002; Menzel & Fabien, 1999; Menzel, 2000). Specific to ragweed, studies in the U.S. show that about a month has been added to the pollen season since the 1960’s (Ziska & Caulfield, 2000b; Huynen & Menne, 2003). Whereas ragweed allergy season began in mid-August and ran through September, it now on average begins from the first of August through mid-October. Not only will ragweed have a longer pollen season due to the increased temperature, it has been shown that ragweed produces a greater quantity of pollen under increased carbon dioxide concentrations (Beggs, 2008; Wayne et al., 2002; Ziska & Caulfield, 2000b) and that the higher the ambient carbon dioxide the more allergenic ragweed pollen is (Singer et al., 2005). Yet another study found that elevating air temperature by 1.2 °C (34.16 °F) increased ragweed biomass by 46% by the end of the growing season (Wan et al., 2002). Taking all this into account an upsurge in allergenic diseases can be forecasted for the future. By 2050 we can expect a 9.6% increase in ragweed biomass and pollen producing stems due to increased temperature alone (Wan et al., 2002). Moreover, as the CO_2 emissions of the study region are projected to rise by at least 50%, we can expect a subsequent 50% escalation in the amount of pollen being produced and released by ragweed plants, and a 1.8 times increase in pollen allergenicity (Singer et al., 2005).

Because allergies are so commonplace, varying in intensity, and often seasonal, there is a tendency to think of allergy as a minor ailment. However, as the millions of allergy sufferers worldwide (including 89% of the ragweed-allergic respondents from the study sample) would attest, allergies play a significant role in diminishing an individual's quality of life. Allergy is a lifelong ailment, children suffer from it just as adults do, and though its symptoms can be treated at cost with pharmaceuticals that often cause unsavory side effects, it is not cured. Not only is treatment of allergies expensive in itself, and often unattainable for poorer populations, prolonged illness due to allergy can lead to loss of earnings for adults, and loss of education for children. On some occasions, particularly due to allergic asthma, morbidity due to allergy can even lead to death. Already studies have showed that extended pollen seasons and increased pollen quantity lead to both an escalation in the development of allergies in young children and a greater morbidity among those adults who are already allergic (Beggs & Bambrick, 2006). For the people raising their children in allergy promoting regions such as Grand Forks MSA, or those allergic adults moving to such regions, all the factors deliberated in this thesis will have to be taken into account. Attempts are being made by the cities to reduce ragweed, but methods of ragweed control are not foolproof, and in essence require the re-establishment of healthy native grasslands in the region. Grassland conservationists would rejoice at this conclusion, but it is not economically viable for the region. For the sake of public health, disease surveillance will have to be increased, and research on developing new pharmaceuticals to counteract allergies will need to be augmented. As the planet continues to undergo its climactic deviations as a result of anthropogenic activities, it will fall on us to learn to cope with the ensuing pathophysiological alterations of plant systems as best we can.

Future Research Recommendations

A ragweed habitat suitability analysis was deemed necessary for the risk assessment conducted in this thesis primarily because ragweed pollen data was unavailable. Funding should be allocated to developing pollen counting stations that would monitor the Grand Forks MSA. Due to genetic and abiotic factors governing allergen Amb a 1 expression, ragweed pollen is more allergenic in some areas than others, regardless of pollen count (Singer et al., 2005). This allergenicity cannot be analyzed for Grand Forks without adequate contiguous years of pollen data. A large percentage of the allergic respondents (87%), regardless of whether the respondents identified as being allergic to ragweed or not, had their allergy seasons coincide with ragweed pollen season: beginning in August and ending in October. This could signify that more individuals were sensitive to ragweed than responded as such. However, the only way to deduce this would be to conduct a study in which clinical data on skin prick allergy tests of respondents is gathered. Another avenue of research would be to gather data from the Departments of Agriculture of both Grand Forks and East Grand Forks on ragweed seeds counted during grain quality checks to determine if ragweed presence in the MSA has been increasing. A weed presence survey conducted on farmers would augment this investigation.

APPENDICES

APPENDIX A
Survey

1) What is your gender?
   □ Male
   □ Female

2) How old are you?
   ___________ years

3) What is your major?
   ____

4) Select all that apply
   □ I am an undergraduate student (□ 1st year; □ 2nd year; 3rd year; 4th year; □ 5th year)
   □ I am a graduate student (□ Masters; □ PhD)

5) Where are you originally from?
   State/Province: ___________
   Country: ___________
   City: ___________

6) How large would you say is your original community?
   □ Rural
   □ Town
   □ City
   □ Large metro area

7) If you are NOT from the Greater Grand Forks region, approximately how long have you lived here?
   _________ years

8) Here are some of the environmental issues that people are talking about. How important are these issues to you personally? Rate from 1 to 5, with 5 being most important.

Extinction of species	1	2	3	4	5
Water pollution	1	2	3	4	5
Toxic waste	1	2	3	4	5
Damage to the ozone layer	1	2	3	4	5
Air pollution	1	2	3	4	5

Loss of tropical rain forests	1	2	3	4	5
Climate change	1	2	3	4	5
Acid rain	1	2	3	4	5

9) For the environmental issues important to you, please select why they are important

	Bad for the environment	Bad for the economy	Bad for human health
Extinction of species	□	□	□
Water pollution	□	□	□
Toxic waste	□	□	□
Damage to the ozone layer	□	□	□
Air pollution	□	□	□
Loss of tropical rain forests	□	□	□
Climate change	□	□	□
Acid rain	□	□	□

10) In the future, do you think climate change will cause more:

	Yes	No	Don't know
Intense hurricanes	□	□	□
Famines and food shortages	□	□	□
Droughts and water shortages	□	□	□
Refugees	□	□	□
Severe heat waves	□	□	□
Forest fires	□	□	□
Insect-borne disease	□	□	□
Food-borne disease	□	□	□
Allergies	□	□	□
Respiratory disease	□	□	□
Floods	□	□	□
Cancer	□	□	□

11) Are you allergic to the following? Please select all that apply.
- □ Ragweed pollen
- □ Other pollen producing plant
- □ Not allergic to any of the above (If not allergic to any of the above please skip to question 16)

12) Do your seasonal allergies affect the quality of your life?
- □ Yes
- □ Somewhat
- □ No

13) Around what months are your allergy symptoms the worst?
From __________ to __________

14) Have your seasonal allergies caused you to experience the following symptoms? Please select all that apply.
□ Hay fever (eye irritation, runny/stuffy nose, puffy eyes, sneezing, and inflamed throat)
□ Asthma attacks
□ Chronic sinusitis
□ Headaches
□ Impaired sleep
□ Depression
□ Other ______________

15) If you are NOT from the Greater Grand Forks region, did you have allergies prior to moving here?
□ Yes
□ No

16) Do you know anyone who suffers from seasonal allergies?
□ Yes
□ No

17) Do you believe climate change is happening?
□ Yes
□ No

If you answered “**No**” to question 17 then your participation in this survey is complete. Thank you for your cooperation. If you answered “**Yes**” please continue to the next page.

18) How likely are you to punish companies that are opposing steps to reduce climate change by not buying their products?
□ Yes
□ Neutral
□ No

19) How likely are you to pay up to 50% more for a product with a low carbon footprint versus its cheaper competitor with a much high carbon footprint?
□ Yes
□ Neutral
□ No

20) How likely are you to write letters, email, or phone government officials to urge them to take action to reduce climate change?
□ Yes
□ Neutral
□ No

21) How likely are you to be part of public rallies protesting climate change?
- □ Yes
- □ Neutral
- □ No

22) If given the opportunity to vote, would you support the following policies?

Require automakers to increase fuel efficiency of cars to 45 mpg (new vehicles will cost up to $1,000 more).	□Yes	□Neutral	□No
Provide a government subsidy to replace old water heaters, air conditioners, lightbulbs, and insulation. This would cost the average household $5 a month in higher taxes.	□Yes	□Neutral	□No
Establish a special fund to help make buildings more energy efficient. This would add a $2.50 surcharge to the average household’s monthly electric bill.	□Yes	□Neutral	□No
Require electric utilities to produce at least 20% of their electricity from wind, solar, or other renewable energy sources. This will cost the average household an extra $100 a year.	□Yes	□Neutral	□No

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