Predicted Effects of Climate Change on The Distribution of The Invasive Grass Dichanthium Annulatum

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PREDICTED EFFECTS OF CLIMATE CHANGE ON THE DISTRIBUTION OF THE

INVASIVE GRASS *Dichanthium annulatum*

A Thesis

by

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ABSTRACT

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Kleberg bluestem (*Dichanthium annulatum*) is an invasive grass species native to Africa but now found in southern United States, Mexico, and other tropical and subtropical countries throughout the world. Using the modeling software MaxEnt, climatic variables from WorldClim, the Intergovernmental Panel on Climate Change (IPCC) scenario A1B, and two General Circulatory Models: the Canadian model (Canadian Centre for Climate Modelling and Analysis or CCCMA), and the Australian model (Commonwealth Scientific and Industrial Research Organisation or CSIRO), several models were developed to determine the possible implications of climatic change on the suitable habitat for *D. annulatum,* in the year 2050. Models indicated suitability could expand northward into the United States in all southern-most states. Further analysis is recommended to better understand effects of climate change on the distribution of the species. For example, the inclusion of variables such as soil types or land use could be considered.

DEDICATION

This thesis project could have not been accomplished without the love, support and guidance from God, my family, and friends. God provided me with the strength, wisdom, talent and dedication to find and continue on a path that leads me to better myself every day. My family has always supported and encouraged my desire to continue my studies. They provided much essential and valuable advice that led me to this accomplishment. Finally, my friends provided me with plenty of encouragement and reassurance.

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CHAPTER I.

INTRODUCTION

Biological invasions coupled with climate change are challenging native ecosystems worldwide (Gritti *et al.*, 2006). The increase of CO2 and temperature as well as changes in patterns of precipitation could favor the spread and establishment of invasive species (Dukes & Mooney, 1999). Invasive plants introduced into an area where they have not evolved and have no natural enemies, can cause a major threat to native organisms and natural environments (Kuvlesky *et al*., 2002). Several biological (e.g., species interactions) and non-biological factors (e.g., climate) determine the distribution of species, but the primary cause for invasions are emigrating and immigrating human populations that introduce species from one location to another (Goodwin *et al.,* 1999; Sharma *et al*., 2005). Transport of souvenir plants from another country for gardens and landscaping, or from controlled research facilities receiving permission from government to import an insect or other animals that will serve as a biocontrol agent against an invasive plant could be reasons for the spread of invasive species worldwide (Goolsby *et al.*, 2009). Invasive species are also transported through ships, as they fill their ballast in one port before they leave and empty it in another after they arrive from their voyage (Bright, 1999; Chan *et al.,* 2013). Introduction of foreign agricultural seeds to either revegetate a landscape or as a new food source for animals (D'Antonio & Meyerson*,* 2002) are contributing to the invasion problem. In any case, the invasive species is almost always detected once it is causing some type of harm, such as the loss of biodiversity (Didham *et al.,* 2005; Wilcove *et al.,* 1998), economical loss (Sharma *et al.,* 2005) due to an effort of controlling the spread of invasive species (Perring *et al.*, 2002), or even harm to human health such as the African *Aedes aegypti* mosquito which transmits the dengue fever (Masters & Sheley, 2001; Moore *et al.,* 2013; Richardson *et al*., 2000). By the time an invasive species is detected, most species are usually well established and widely distributed, making it extremely difficult to eradicate them. The introduction of invasive grasses coupled with climate changes such as the increase of carbon dioxide and temperatures, has already increased the spread of numerous invasive grasses in the United States (Dukes & Mooney, 1999).

The United States spends about $138 billion each year trying to control invasive species (United States Department of Agriculture, 2001). Nonetheless, most of these invasive species were brought to the United States directly or indirectly for economic reasons (Perring *et al*., 2002).

Invasive plants have been considered a leading cause of species extinction (Fritts & Rodda, 1998; Wilcove *et al*., 1998). One of several ecological impacts that an invasive plant poses is related to their interruption of natural succession in native plant communities (Flory & Clay, 2010; Rutherford *et al.,* 2011). Plant succession is the natural process by which one plant community modifies its physical environment enough in a manner that allows another plant community to become established by means of competitive exclusion, ultimately reaching a stable end-point (climax; Pianka, 2011; Powell, 2000). This process of continuous re-colonization by new species allows the natural progression of different life forms to establish themselves, conventionally resulting in an increase in biodiversity (Bazzat, 1979; Burga *et al.,* 2010). Other factors such as wild fires and anthropogenic constituents can alter this process by initiating the cycle at any point (Ricciardi, 2004).

Native grasses, shrubs, trees and interactions with other species create niches (e.g., optimal conditions based on the availability of distinctive resources and organismic interactions (Kearney, 2006)) for different types of native fauna. Yet once invasive grasses occupy an area, the cycle is often arrested in its 'pioneer' stages, thereby preventing the establishment of natural competitors and adversely affecting the biodiversity of that area (Clavero & Garcia-Berthou, 2005; Ricciardi, 2004). This can cause several problems. If native grasses are outcompeted, for example, a variety of native animals that depend on the grass could potentially be affected if they are not able to adapt to the invasive grass. Also, such changes can prevent other animals that live in trees or shrubs from populating the area in the future. If these animals are not present, the predators of these animals could either be deprived of food or they could also be absent, resulting in a negative cascading effect on natural ecosystems.

Furthermore, invasive grasses can increase the frequency of fires (D'Antonio & Vitousek, 1992; Platt & Gottschalk, 2001; Rossiter *et al.*, 2003), occasioning yet another chain reaction since fires expand the area invasive grasses can populate by eliminating the native plant population (Alexander Eilts & Huxman, 2013). Therefore, increasing the abundance of invasive grasses (D'Antonio *et al*., 2000; Milberg & Lamont, 1995) leads to even more intense fires (D'Antonio & Vitousek, 1992).

Competitive exclusion is a driving force behind plant succession and natural shifts in a locale's biodiversity. This biological phenomenon is based on a theoretical premise that, if two species are competing for the same resources, only one will succeed due to their inability to coexist, assuming the ecological factors are constant (Funk *et al*. 2008; Gause, 2003). The consequences of competitive exclusion usually result in either local extirpation, the complete extinction of native species, or resource partitioning by the competitors (Mooney & Cleland, 2001). For example, invasive populations of Dichanthium *annulatum,* or Kleberg bluestem, can inhibit seed germination of the bundleflower, *Desmanthus illinoensis,* (Kuvlesky *et al.*, 2002), resulting in this native species' disappearance. When niche overlap is only partial, an invasive organism can reduce the distribution and relative abundance of a weaker competitor. This natural process determines thereby a smaller, realized niche (see Chapter II) of a weaker competitor (Beaumont *et al*., 2009). Even if the area of suitable habitat is not altered by climate change, competitive exclusion and niche overlap can cause a species to become restricted to a limited area.

Another possible outcome of competitive exclusion is niche partitioning, whereby two competing species experience a shift in niches and adapt to one another by exploiting different resources while coexisting. This phenomenon is a basic process of natural succession and generally results in an increase in biodiversity (Mooney & Cleland, 2001). Yet if a generalist invasive species succeeds in eliciting niche partition between an entire community of native species, biodiversity can be reduced (Huebner, 2010). The adaptability of generalist invasive grasses and their inherent ability has caused some invasive plants to have a higher efficiency, compared to natives, in acquiring resources such as light, possibly making them a bigger threat (Deng *et al.,* 2004).

As detrimental as these effects can be exclusively, synergic interactions with climate change can cause an even greater threat to native flora. Factors of climate change such as changes in precipitation, increased levels of CO_2 and change in temperature can further the magnitude of invasion (Bradley *et al*., 2010).

Due to the palatability of many invasive grasses to cattle and their robust growth habits, cattle ranchers are responsible for having deliberately introduced most invasive grasses into the United States. These continuing habits pose a serious challenge for efforts to eradicate invasive grasses. Such is the case for *D. annulatum*, which was introduced for cattle grazing purposes in the United States in 1944 (Cook *et al*., 2005).

Dichanthium annulatum is a C4 grass that grows in clusters which can reach up to 60 cm in height (Grassland species profiles, 1990). The species proliferates asexually by means of runners or apomixis, a distinctive means of seed production by which an embryo can develop from diploid maternal tissues without contribution of a male gamete or genome (Spielman *et al.,* 2003). Axillary buds grow from stems of the main tuft to form branches, the lateral stems spreading outward from the primary shoot. Independent plants eventually arise from expanding clones, usually sprouting and eventually rooting from stems that emanate from the distal portions of aerial branches (Husain *et al.,* 2009). Nodes of *D. annulatum* stems produce white hairs from 3-5 mm long, linear blades about 30 cm long and 2-7 mm wide and a pale green or purplish raceme. Roots generally grow close to the earth's surface, rarely penetrating deeper than 1 m deep (Cook *et al.,* 2005).

Dichanthium annulatum is a native to Africa and temperate and tropical parts of Asia. This grass was introduced to the southwestern region of the United States by livestock producers, federal and state agricultural agencies for cattle grazing and to control erosion (Celarier *et al*., 1958; Kuvlesky *et al.,* 2002). The species is outcompeting native grasslands and preventing natural vegetation from growing, resulting in the loss of the natural flora and fauna in many subtropical areas throughout the world, including Australia, parts of Mexico and the United States. In south Texas, specifically, Kleberg bluestem is taking over most open grasslands, and moves rapidly along road cuts in the region. With the resulting dense populations, *D. annulatum* prevents natural vegetation from growing, resulting in the loss of the natural flora and fauna. When invasive grasses like *D. annulatum* establish a population, the entire native flora is often outcompeted (Kuvlesky *et al.,* 2002). Also, due to the species' high tolerance to drought, short floods and seasonal fires, when native species become unsuccessful under these extreme conditions, *D. annulatum* is able to extend into under-disturbed native plant communities with ease (Besaw *et al*., 2011; Cook *et al.*, 2005; Ortega *et al.,* 2007; Rossiter *et al.,* 2004; Van Devender *et al.,* 1997).

Dichanthium annulatum grows in moderately dry to moist areas and in warm climate (Cook *et al*., 2005; Husain *et al.,* 2009). In the Rio Grande Plains ecoregion of Texas (Texas parks and wildlife, 2013), Hernàndez *et al.* (2007) identified *D. annulatum* as one of the dominant grasses. This region is classified as semi-arid, subhumid and has a mean annual rainfall of 57.7cm and a 30-year mean temperature of 22°C (coldest month mean, 12.2°C; hottest month mean, 29.4°C) (Hernàndez *et al.,* 2002). In South Texas, Wiemers (2012) determined that *D. annulatum* was able to tolerate drought conditions of 13cm of precipitation from October 2008-July 2009 and an average maximum temperature of 33°C in 2008 and 36.5°C in 2009.

The main goal of this study was to predict future (year 2050) habitat suitability for *D. annulatum* in North America (Mexico and the United States) in order to help prevent the potential spread of this invasive grass. There are above 110 species of invasive grasses in North America, however *D. annulatum* was selected for the study based on several reasons concerning its taxonomy, distribution and danger. The taxonomy of this species is clear, contrary to other taxa labeled as a “species” that are actually a potential mix of two or more species, (e.g., *Panicum maximum* and *Panicum infestus*; Andersson *et al*., 2003; Reinheimer *et al.,* 2005; Salariato *et al.,* 2008), which presents difficulties in predicting distributions accurately. The current know distribution of this species has been well documented in native and invaded areas. Invaded areas range to southern parts of the United States, giving this grass opportunity of spreading northward if climatic conditions are suitable for it. Other invasive grasses, such as buffel grass, *Cenchrus ciliaris,* have ample existing studies in terms of their future distribution (Arriaga *et al.,* 2004; Balch *et al.,*2013; Stevens & Falk, 2009; Uliat *et al.,* 2002) or are already widely distributed in North America, such as cheatgrass, *Bromus tectorum L.* (USDA, 2013).

Objectives

To forecast the potential distribution of *D. annulatum* based on its climatic requirements through the use of a maximum entropy approach.

Dichanthium annulatum is invasive to the southern parts of the U.S., including southern parts of Texas, Louisiana, New Mexico and Arizona. The main concern is whether this species will expand to northern areas of the United States, threatening native species elsewhere and posing extensive economical impacts for its eradication. Knowing if the suitable habitat of this grass will be affected by future climatic changes can help policy makers in Texas and other southern states to prevent its likely expansion to northern areas. By looking at the potential suitable habitat of this grass, a plan can be devised for eliminating it from its current distribution and preventing its spread to locations predicted by the models developed as part of this research. This in turn will help use time and resources in a wiser manner helping to adapt (Parry, 2007) for the potential impacts of climatic change on the distribution of this species.

It was hypothesized that the distribution of *D. annulatum* would decrease in some areas but expand in others due to climate changes. This prediction is based on the pattern seen with other species affected by climate change, such as plants, birds and marine species (Cheung, W. W. *et al.,* 2009; Hitch & Leberg, 2007; Salazar *et al.,* 2007). It was predicted that areas currently inhabited by this grass would become unsuitable, and areas currently unsuitable would become suitable, thus, creating a shift in distribution.

Based on current observations, the presence of *D. annulatum* in southern United States poses limitations for this species to spread, possibly due to climatic constraints (Hernàndez *et al.,* 2002). Therefore, as climate changes in states such as California, Oklahoma, Arkansas, and Mississippi, *D. annulatum* could move north to colonize new suitable areas. Also, changes in climate could cause some of the southern states such as Arizona, Texas, and Louisiana which already harbor this invasive grass to become unsuitable based on *D. annulatum*'s climatic restrictions.

CHAPTER II.

LITERATURE REVIEW

Species Distribution

Several factors determine the limits of species distributions. Factors that affect a species' distribution are abiotic conditions, biotic factors, availability of areas for dispersal and the capacity for a species to evolve and adapt to new conditions all of which can be associated with each other (Soberon & Peterson, 2005; Pulliam, 2002; Hong-Wa & Feria, 2012). An interaction of all of these factors at different intensities is what ultimately determines a species distribution, yet anthropogenic factors such as the ones mentioned in Chapter I have also become very influential when referring to an invasive species.

Historical factors such as mountains or rivers and other abiotic factors such as the amount of wind in an area can limit seed dispersal. Availability of resources such as sunlight in an area can also determine how much a species is able to expand.

Biotic factors include competition between grass species for nutrients from the soil, or symbiotic relationships that are needed for the survival of the species. These factors have an important contribution to the dispersal limitations of grass species and in determining their niche (Garcia-Palacios *et al.,* 2011; Warren *et al.,* 2013).

As defined by Hutchinson (1957), a niche is a combination of suitable factors where a species is suitable to occur. Fundamental niche is the multidimensional environmental hyperspace, excluding biotic factors, where the fitness of an individual is greater or equal to one (Kearney, 2006). The realized niche of a species is typically a portion of the fundamental niche due to competition, consisting of both abiotic and biotic factors necessary for the survival of a species (Hutchinson, 1957). Taking this into consideration, Pulliam (2000) suggested a more detailed definition of a niche and several ways it can be achieved in relation to species distribution. He incorporates factors such as competition, source-sink dynamics (see below), dispersal limitations and metapopulations in the characterization of a niche. These three factors define determinant limitations that species encounter in nature.

Pulliam (2002) notes that species tend to inhabit an area with optimum climatic conditions for a given species' survival. This he defines as a suitable habitat. This habitat can be limited, however, through competition by other species trying to occupy the same area and competing for the same resources. He also explains how dispersal can be limited by 'source-sink dynamics'. A 'source habitat' is explained as a population with a high reproduction rate and a low mortality rate, and 'sink habitat' is the opposite. In this dynamic the sink habitat is able to survive due to the overpopulation of the source, the denizens of which migrate to and repopulate the sink habitat in order to survive. With this dynamic dispersal, it is possible to have a species surviving in an area that is not completely suitable for that species, with this constant influx of the species. Finally, Pulliam explains how dispersal limitations and metapopulation dynamics can decrease the dispersal of a species. Dispersal limitations (as mentioned above) and metapopulations can cause a species to be absent from suitable areas. Within metapopulations, some suitable areas may be unreachable by the species and other populations of the species can go locally extinct.

Although all of these determining factors are important for the distribution of a species, for this study, only climatic variables will be used to formulate the predictive models due to several limitations. Most of the biotic factors, and positive or negative interactions, are difficult to quantify and measure. Quantification of how much a species is dependent on a symbiotic relationship or how it is threatened by a competitor cannot be fully measured in uncontrolled environments outside of a laboratory. Other factors such as soil type or land use are also very important yet there is no compilation of data available to study effectively. In this paper, we will refer to the outcome of the modeling methods as the predicted suitable habitat for the species.

Climate Change

Climate is the long-term average pattern of temperate, humidity, precipitation, wind, cloudiness, and other atmospheric conditions (Smith *et al.*, 2009), all of which are affected by anthropogenic global climate change (the accelerated long-term change in climate due to human activity. At present, carbon dioxide levels are increasing, and our environment is experiencing changes in the duration and intensity of seasons. Climate change may potentially exacerbate the spread of invasive species. Many invasive plants respond positively to high temperatures and some species show enhanced competitiveness due to rising carbon dioxide levels (Sasek *et al.,* 1991). Because of these climate changes, researchers are attempting to predict our future environment and how it is going to affect invasive species. Two predictions were made by Bradley *et al.* (2009;

Figure 1), including a worst-case scenario, and a best-case scenario. In the worst-case scenario climatic condition shift in a manner that increases the suitable habitat (climatically) for the invasive species. If this occurs, more land will be suitable for the invasive species to populate, since the shift favors the species' optimum climatic conditions. In contrast, the best-case scenario conditions will shift so that areas that are currently suitable for the species will become unsuitable. This climatic shift moves away from the species' necessary conditions, thereby making the area possibly climatically unsuitable for the species. For example, the climatic suitability of cheatgrass, (*Bromus tectorum*), another non-native grass in the United States, was predicted to be lost in southern Nevada and southern Utah due to higher temperatures and an increase in precipitation. Yet, for this grass, climatic suitability was also predicted to expand in areas of southern Wyoming, Idaho and Montana due to reduced summer precipitations (Bradley, 2009). Other invasive grass studies have also shown a similar pattern of climatically suitable areas (Bradley, 2010; Thuiller *et al.,* 2007).

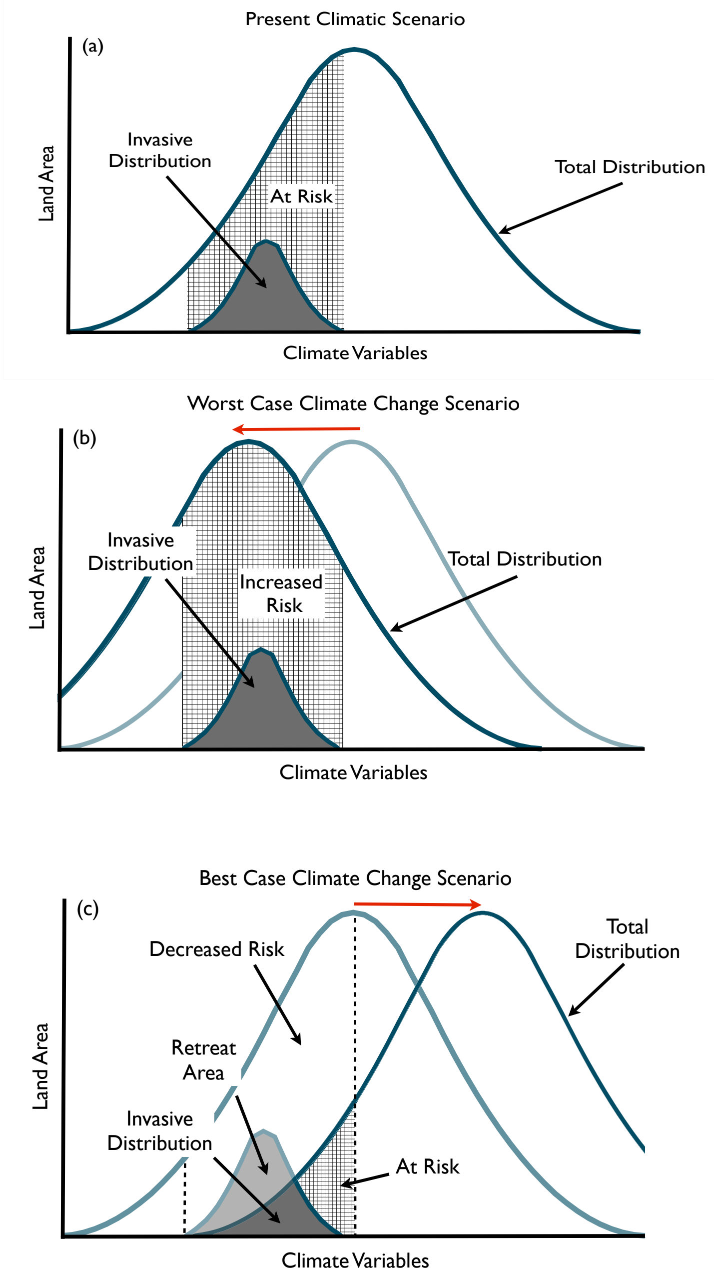

Figure 1. Theoretical Climate Change Scenarios Based on Bradley *et al.* (2009).

(a) Present climatic scenario: current climatic variable ranges in different parts of the land. Shaded area: Area at risk of being invaded. Dotted area: Currently invaded area.

(b) Worst-case scenario: Area in risk of being invaded increases due to a climatic variables shift to the left.

(c) Best-case scenario: Area in risk of invasion is reduced due to a climatic variables shift to the right, also decreasing the areas already invaded.

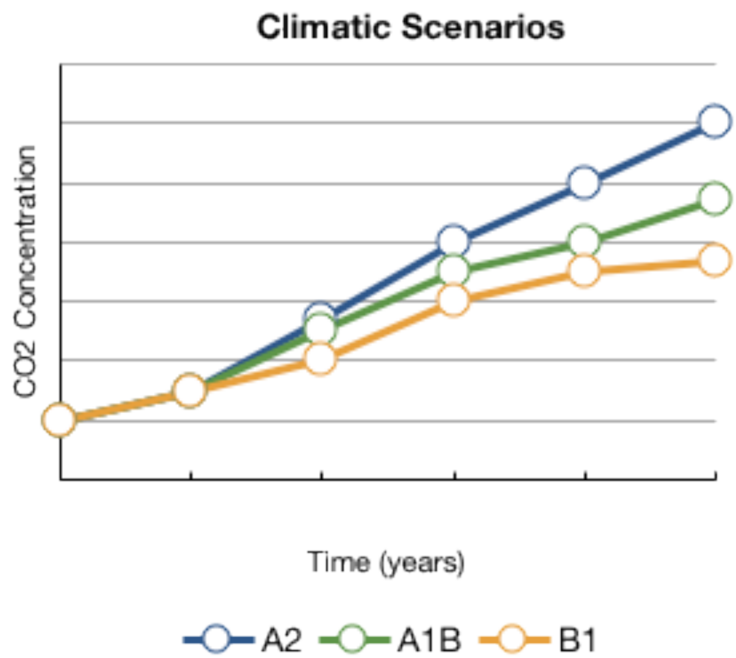

Figure 2. Example relationship of Climatic Scenarios A2, A1B and B1. A2 is a high prediction, A1B is a moderate prediction and B1 is a low prediction, all in respect to future emissions (Angel & Kunkel, 2010).

CHAPTER III.

MATERIALS AND METHODS

Present and future models of distribution for *Dichanthium annulatum* were constructed using geographic known information for the species and climatic variables from various sources. Analysis and visualization of this information was carried out using a maximum entropy approach.

Distributional Data

Distributional data points used in this study were obtained from different databases and herbaria, including: Global Biodiversity Information Facility website (gbif.org), Flora of Texas Database (orchid.biosci.utexas.edu), University of Arizona Biodiversity Informatics: Taxon Tracker (loco.biosci.arizona.edu), Southwest Environmental Information Network (swbiodiversity.org), University of Central Oklahoma Natural History Museum and Herbarium (biology.uco.edu), University of Mississippi Thomas M. Pullen Herbarium (herbarium.olemiss.edu), and the American Society of Plant Taxonomists (http://www.aspt.net). This data provided longitude and latitude coordinates and date of collection of observed presence of *Dichanthium annulatum* in North and Central America. These southern state herbaria and databases were selected due to their current, abundant holdings of *D. annulatum* specimens (plants.usda.gov). As previously described, *D. annulatum*'s native range occurs in Africa and parts of Asia, but in this study we only include the invasive range know in North America. According to Bradley *et al.* (2010), predictive models are more accurate to the study area if the occurrence data points are only from the geographical regions were a species is invasive. A weakness of only using this data could be an under-representation of occurrences or a biased data. However, since introduction of this species occurred in 1839, a species could be considered as well adapted to the conditions in an area, thus the use of native ranges could not necessarily provide new information (Bradley *et al.,* 2010).

In total, from all these sources 711 unique geographic locations were obtained for *D. annulatum* containing longitude and latitude coordinates in North and Central America. It is important to note that some information collected from these databases were omitted due to lack of relevant information (longitude and latitude and/or date of collection). Also, for some of the data points, the precise longitude and latitude coordinates were not given yet directions and roads or landmarks with close approximation were given. For these points, Google Maps (itouchmap.com) was used to determine the latitude and longitude coordinates. Figure 3 shows the recorded distribution of Kleberg bluestem from the year 1839 to 1923 in the United States and Mexico. The data was arranged in a chronological order to show the progressive movement of the invasive species. This map was created with the use of ArcMap, the main component of ArcGIS 10 in order to better visualize the data.

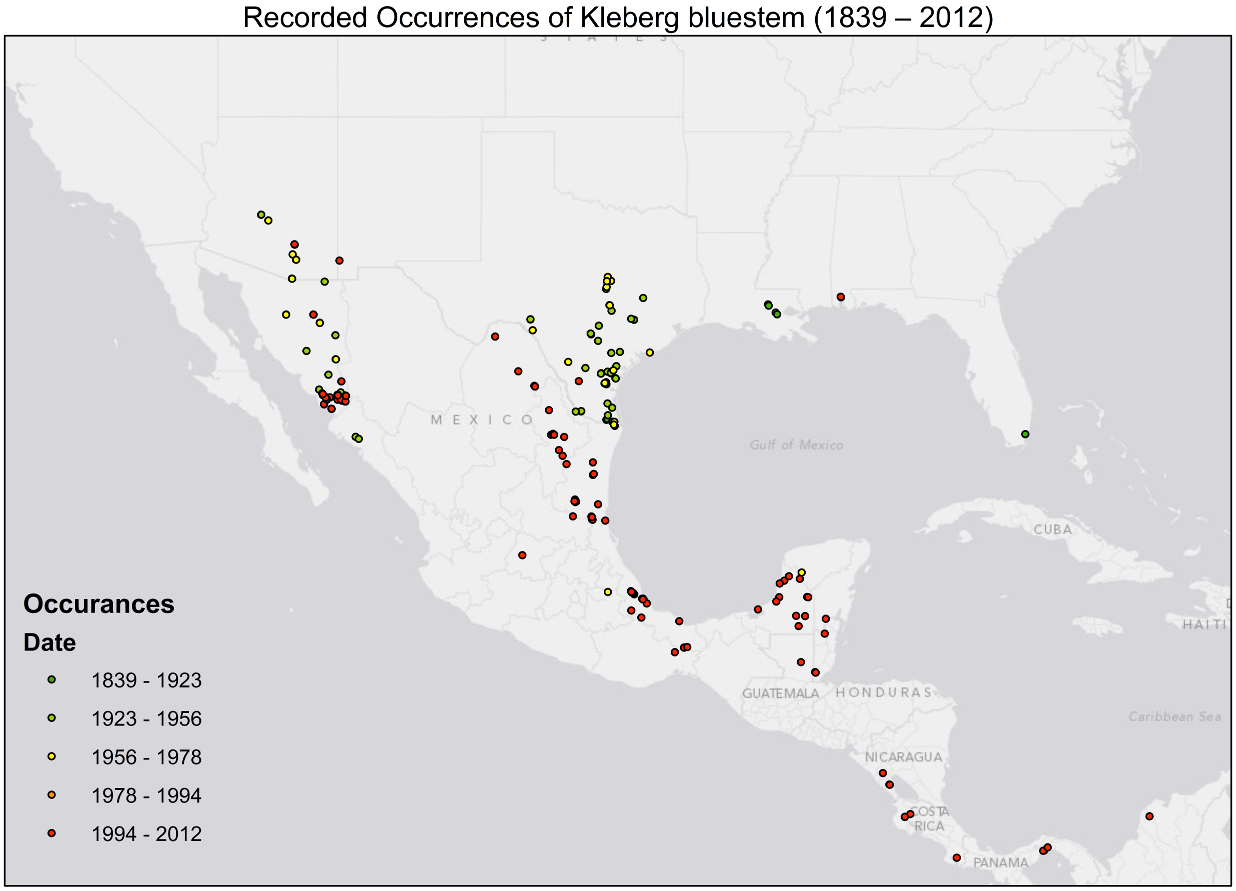

Figure 3. A distribution of *Dichanthium annulatum* (Kleberg bluestem) in the United States and Mexico. Observed occurrences in the United States and Mexico of the invasive grass kleberg bluestem are shown in this map. The data points are arranged by range of year when they occurred from the earliest recorded occurrence in 1839 to the latest in 2012.

Climate Data

Current climatic data was obtained from WorldClim.org (Hijmans *et al.*, 2005), which contains a set of global climatic layers with a spatial resolution of one square kilometer. These layers consist of 19 climatic variables dealing with different measurements of temperature and precipitation. The 19 variables used are listed in Table

1. To gather this data, WorldClim calculated the monthly average climate from weather stations in one kilometer squared grids, and interpolated these values. Interpolation refers to the mathematical process of calculating in-between points based on scattered data points given. Each point has an association of temperature and precipitation parameters. With this information MaxEnt then generates a model for the present suitable conditions of the species and then projects that model to future variables (Bradley, 2009; Elith *et al*., 2006; Elith *et al.,* 2010; Hernandez *et al.*, 2006; Phillips *et al.*, 2006). Results of these models depend on the different general circulatory models (GCM) and climatic scenarios used. A comparison between three climatic scenarios is shown in Figure 1. Scenario A2 describes a self-reliant world, with an increase in population and economic development mainly oriented regionally. Scenario A1B is a world of rapid economic growth and with a balanced use of fossil and non-fossil energy sources. Scenario B1 is a prediction where there is resource efficient technologies that emphasize on global solutions for environmental sustainability (IPCC, 2007). The 'middle of the road' (Bradley, 2009) future climatic scenario prediction, A1B, of the year 2050 was used.

Variable Number	Variable Description
BIO1	Annual Mean Temperature
BIO2	Mean Diurnal Range (Mean of monthly (max temp - min temp))
BIO3	Isothermality (BIO2/BIO7) (* 100)
BIO4	Temperature Seasonality (standard deviation *100)
BIO5	Max Temperature of Warmest Month
BIO6	Min Temperature of Coldest Month
BIO7	Temperature Annual Range (BIO5-BIO6)
BIO8	Mean Temperature of Wettest Quarter
BIO9	Mean Temperature of Driest Quarter
BIO10	Mean Temperature of Warmest Quarter
BIO11	Mean Temperature of Coldest Quarter
BIO12	Annual Precipitation
BIO13	Precipitation of Wettest Month
BIO14	Precipitation of Driest Month
BIO15	Precipitation Seasonality (Coefficient of Variation)
BIO16	Precipitation of Wettest Quarter
BIO17	Precipitation of Driest Quarter
BIO18	Precipitation of Warmest Quarter
BIO19	Precipitation of Coldest Quarter

Table 1. List of all the climatic variables used to predict the suitable potential habitat of *D. annulatum*. Taken from WorldClim (www.worlkclim.org: Hijmans *et al*., 2005).

Species Distribution Modeling

Species distribution modeling (SDM) is used widely for determining suitable climatic areas based on a relationship made between current occurrences of a species and the associated climate of those areas (Bradley, 2009). Although there are several SDMs, MaxEnt was selected since it has proven to have high predictive accuracy (Bradley, 2009; Bradley, 2008; Elith *et al.,* 2006; Elith *et al.,* 2010; Phillips *et al.,* 2006; Phillips & Dudik, 2008) comparing to other modeling methods (Bioclim, Domain and GARP; Hernandez *et. al.,* 2006).

MaxEnt (version 3.3.3k) was used to take as input the layers of environmental variables as well as the geo-referenced occurrence locations, to produce a model of the given species, based on the maximum-entropy approach for species habitat modeling. Environmental layers of temperature and precipitation of the United States and data points (latitude, longitude), where *D. annulatum* was observed, were input into MaxEnt. With this information MaxEnt created a complex association between specific occurrence of *D. annulatum* and the different climatic variables associated with that location. For instance, an occurrence point is observed and the climatic conditions of that point are noted. Then, another occurrence is observed along with its climatic variables, but this time the two occurrences are compared. In this comparison, if a similarity in climate is detected, MaxEnt interprets this climatic variable as a slightly higher contributor than the rest. This is done with all of the climatic variables until MaxEnt creates a ranking of all of them based on the occurrences (Table 2). These rankings are then used to in conjunction with the predictive climatic scenario. When this is done, MaxEnt predicts future habitat suitability based on these previous climatic associations.

The accuracy of the predicted models created by MaxEnt is evaluated through a series of calculations done by MaxEnt using the presence and testing data (Berger, 1996). In this study, the data was divided in 70% to train and 30% to evaluate the model. Because of this, twenty replicates were run for each model and an average model was developed for each prediction. The final map and evaluation assessment are the average of the 20 replicates.

A confusion matrix, as employed by Fielding and Bell (1997), comprises four possible outcomes, for the evaluation of MaxEnt (Figure 3). To evaluate the model

MaxEnt used the Area Under the Curve in a ROC plot (Fielding & Bell, 1997). Predicted suitability area is evaluated using a confusion matrix (Figure 4), that illustrates four possibilities for model outcomes. From these four prediction outcomes two formulas can be equated (Sensitivity = a/(b + c) and Specificity = d/(b + d) and plotted on a Receiver Operating Characteristic (ROC) Curve to determine the overall accuracy of the present modeling done by MaxEnt (Figure 4)(Fielding & Bell, 1997). From this ROC Curve the Area Under the Curve (AUC) is calculated which ranges from 0 (less suitable) to 1 (most suitable).

General Circulatory Models were obtained from the Canadian Centre for Climate Modeling and Analysis (CCCMA) and the Australian Analysis Commonwealth Scientific and Industrial Research Organization (CSIRO). For this study a moderate or "middle of the road" (Bradley, 2009) climatic scenario prediction (A1B) was used for the year 2050. This information was obtained from the Intergovernmental Panel on Climatic Change (IPCC).

All of the different variables were input into MaxEnt and an association was made between the current distribution of *Dichanthium annulatum* and its location's climate. To do this, only specific information from gbif.org and the different herbaria sources was selected to be input into MaxEnt. On an excel data-sheet, three types of information were organized (each with its respective header): Species, Longitude and Latitude. This information was then saved as a comma-separated value (.csv) document. A .csv file is the required format to input samples into MaxEnt. The climatic variables were also changed into the correct format for MaxEnt. All of the variables were in raster format and were converted into ASCII format with the use of ArcMap.

		Actual	
		+	-
Predicted	+	a	b
	-	c	d

Figure 4. Confusion Matrix obtained and modified from Fielding and Bell (1997). Diagram explains climatic variable analysis. a) A species is predicted as present due to climatic variable association, and it is verified as present there. b) A species presence is predicted but not observed. c) A species is not predicted as present in an area but it is found there (worst prediction). d) A species is predicted not to be present and is not present. Values “a” and “c” are termed true positive fraction, “b” and “d” termed false positive fraction. Measures derived from this matrix are: Sensitivity = a/(b + c) and Specificity = d/(b + d).

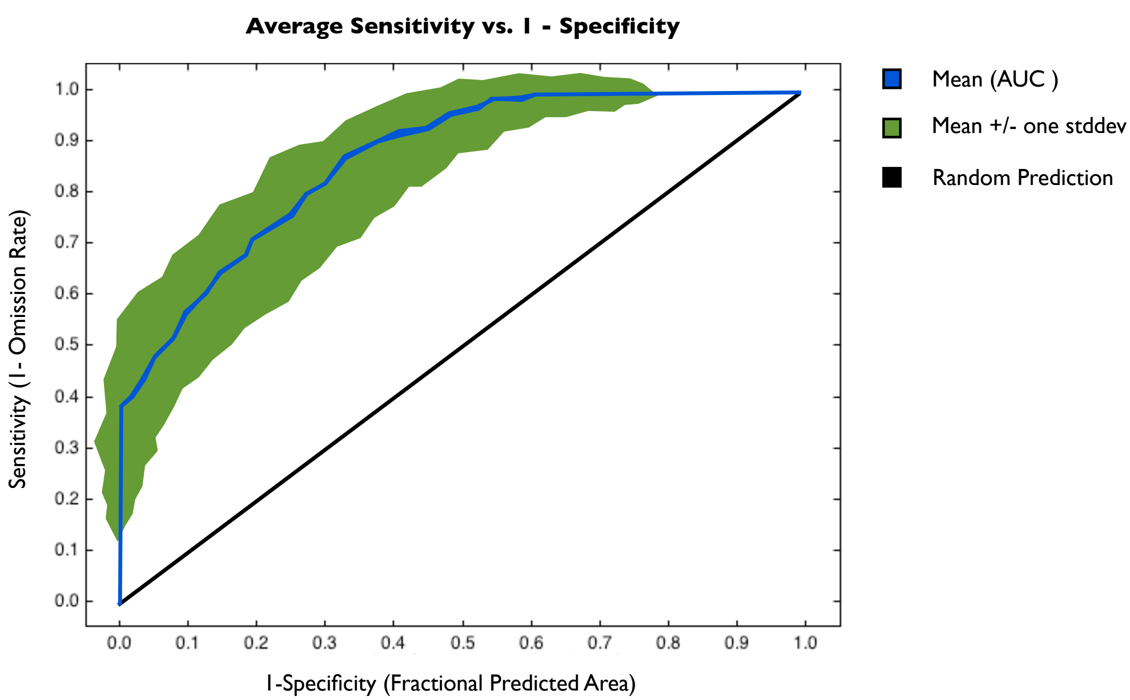

Figure 5. An example of a receiver operating characteristic (ROC) plot. This graph, generated by MaxEnt, plots sensitivity values (true positive fraction) on the y-axis and equivalent 1-specificity values (false positive fraction) on the x-axis. The area under the curve (AUC) measures the precision of the modeling with ranges from 0.5 to1.0; 0.5 being the least accurate and 1.0 being the most accurate (Fielding & Bell, 1997).

CHAPTER IV.

CHAPTER IV.

RESULTS

The model's average AUC value was 0.978, with a standard deviation of ±0.002, demonstrating a high accuracy in prediction of the models (Phillips *et al.*, 2004; Elith *et al.*, 2006; Hong-Wa & Arroyo, 2012). Three climatic variables that contributed the most to the models, shown in Table 2, were annual mean temperature (BIO 1), mean temperature of the warmest quarter (BIO 10), and mean temperature of coldest quarter (BIO 11). It is noteworthy that the top four most influential climatic variables all dealt with temperature.

The CCCMA model, predicted a northern expansion of suitable habitat. Relative to the current model, expansions were predicted further north into all of the southern states excluding California with higher suitability increases in southern and central Texas and southern Arizona (Figure 6).

Predictions using the CSIRO model were almost identical to predictions using the CCCMA model. The CSIRO model also predicted an increase in suitable habitat northward relative to current distribution of the species (Figure 9). It predicted an increase of suitability also in all of the southernmost states except California, but this model had a higher suitability prediction for the Texas and Arizona. All of south and most of central Texas was predicted to be extremely suitable with this model. Arizona as well had a higher predicted suitability compared to the present predicted suitable model.

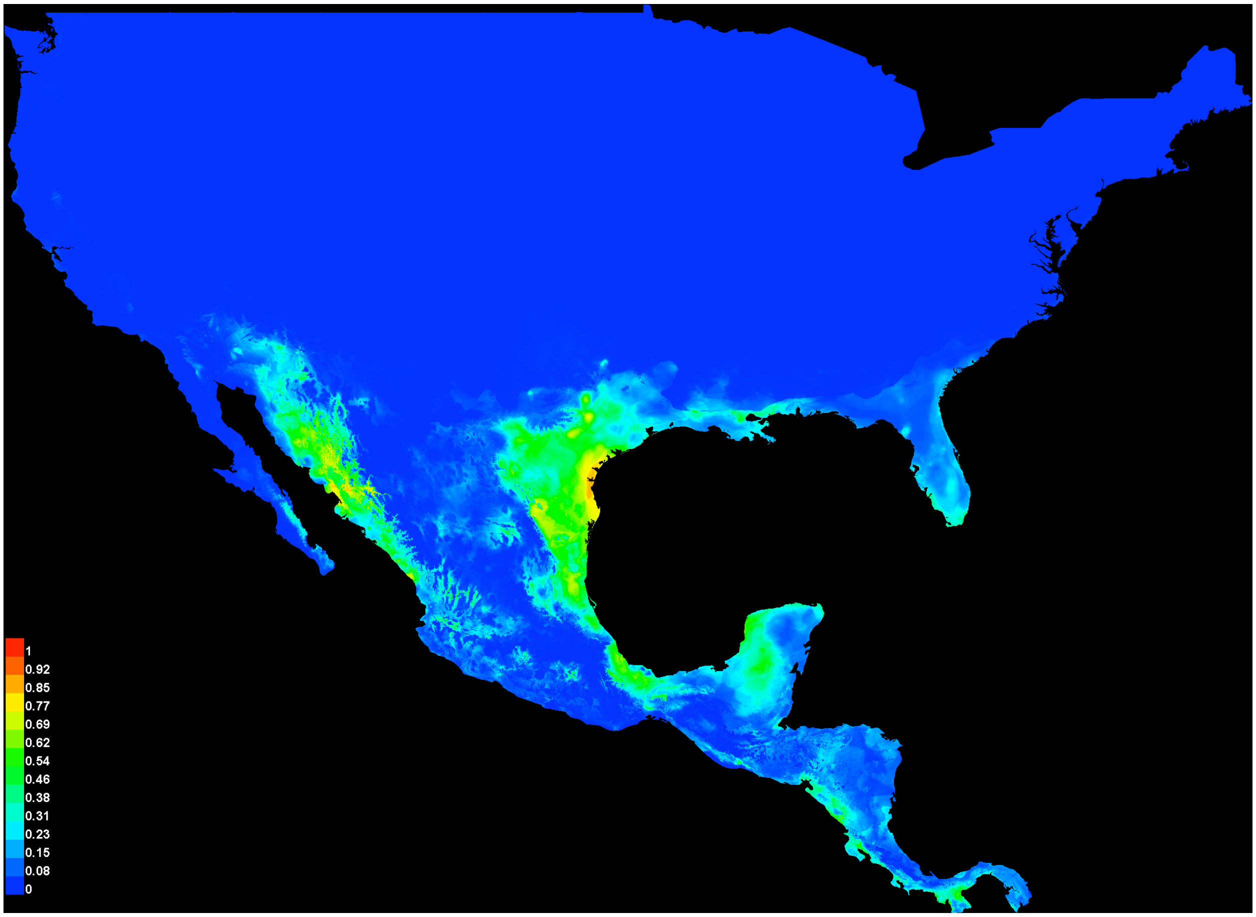

Figure 6. Present predicted suitable habitat of *D. annulatum*. Suitability areas range from least suitable (blue), to most suitable (red).

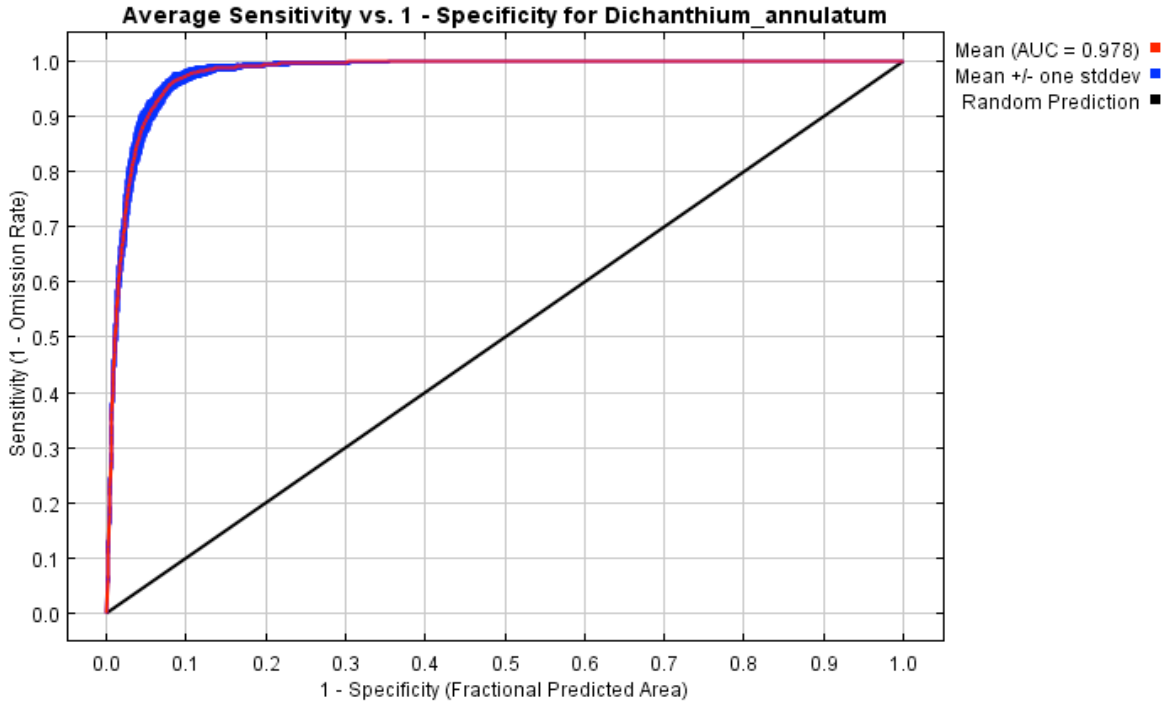

Figure 7. Receiver Operating Characteristic (ROC) Curve. Plot of the average fractional predicted area and omission rate using scenario A1B. Predictions based on a 1 - 0 scale; >0.75 = good prediction; >0.95 = almost excellent prediction from modeling software.

Percent contribution	Variable
33	Annual Mean Temperature
17.2	Mean Temperature of Warmest Quarter
11.6	Mean Temperature of Coldest Quarter
6.4	Mean Temperature of Wettest Quarter
4.3	Temperature Seasonality (standard deviation *100)
3.8	Precipitation of Coldest Quarter
3.6	Min Temperature of Coldest Month
3.6	Annual Precipitation
3.3	Temperature Annual Range (BIO5-BIO6)
2.9	Mean Diurnal Range (Mean of monthly (max temp - min temp))
2.5	Precipitation of Warmest Quarter
1.4	Precipitation of Driest Quarter
1.3	Precipitation Seasonality (Coefficient of Variation)
1.3	Isothermality (BIO2/BIO7) (* 100)
1.1	Max Temperature of Warmest Month
0.9	Precipitation of Wettest Month
0.8	Precipitation of Wettest Quarter
0.5	Mean Temperature of Driest Quarter
0.5	Precipitation of Driest Month

Table 2. Average percent contribution for each environmental variable used, generated by MaxEnt, using scenario A1B.

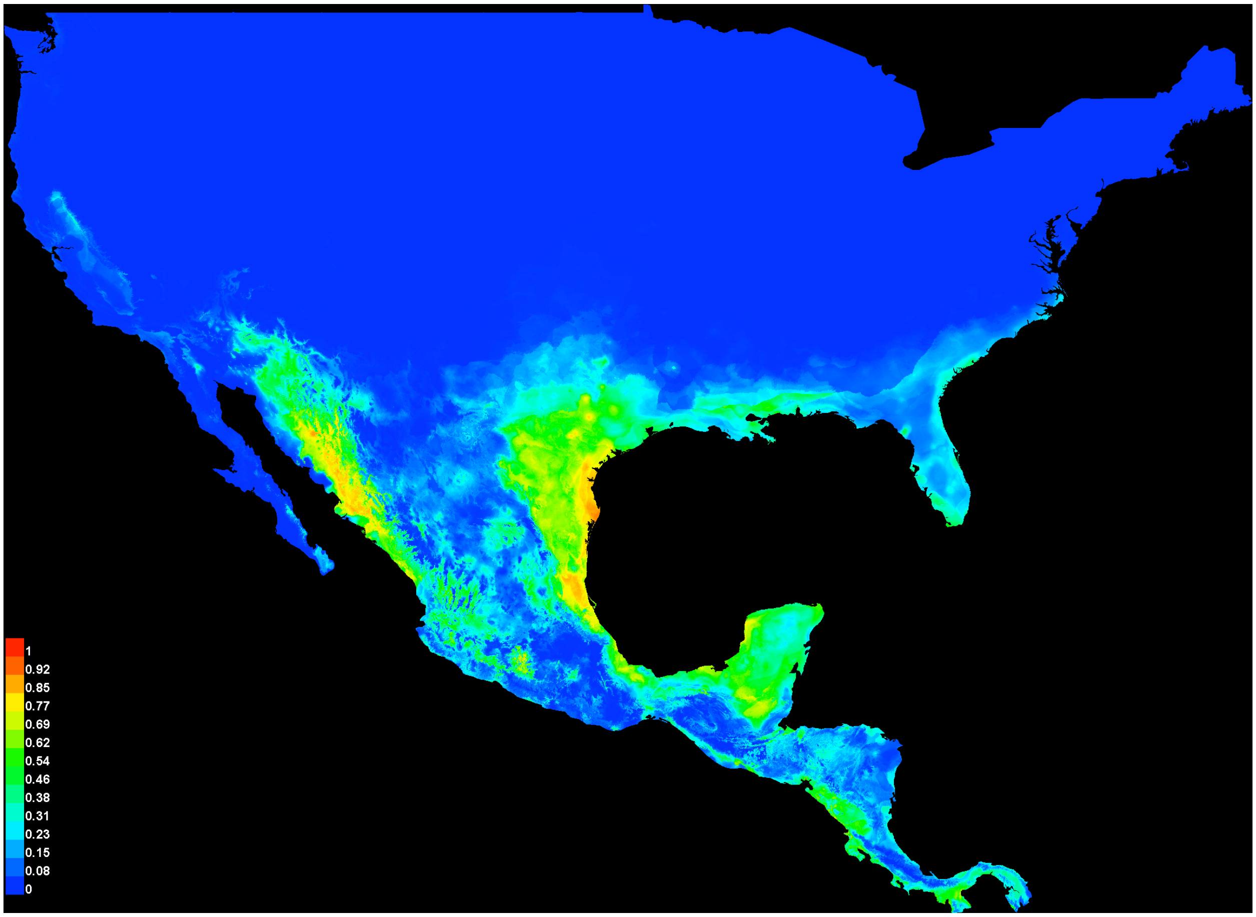

Figure 8. Model of the predicted climatic suitability of *D. annulatum* for the year 2050 using the Canadian model (CCCMA) scenario A1B. Suitability areas range from least suitable (blue), to most suitable (red).

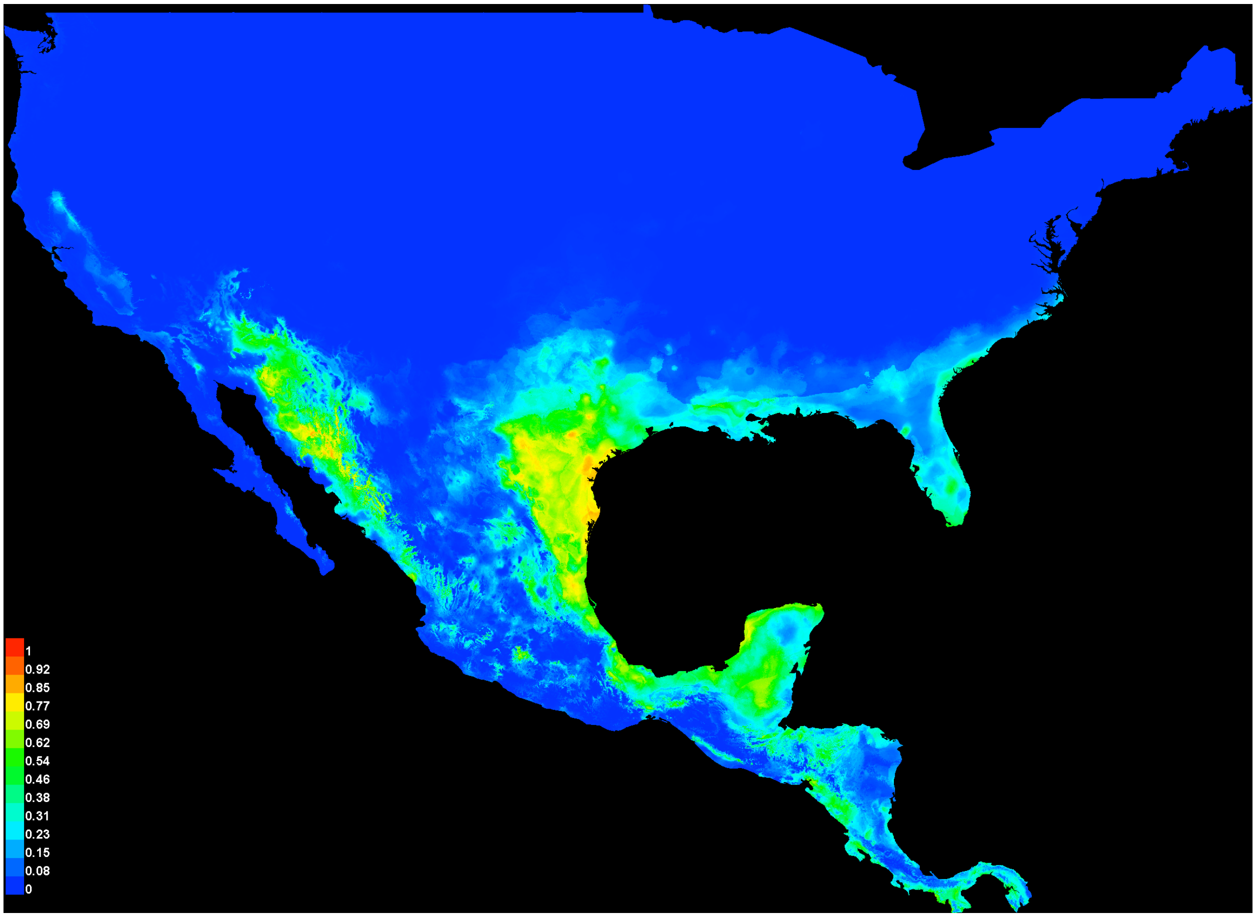

Figure 9. Model of the predicted climatic suitability of *D. annulatum* for the year 2050 using the Australian model (CSIRO) scenario A1B. Suitability areas range from least suitable (blue), to most suitable (red).

CHAPTER V.

DISCUSSION

Modeling

Results show that there could be a shift of habitat suitability for *Dichanthium annulatum* in 2050 based on both CCCMA and SCIRO model predictions. The CCCMA prediction shows an increase in climatic suitability in central and southern Texas, and southern parts of Louisiana, Mississippi, Alabama, Georgia and all of Florida with a greater climatic suitability in the areas of southern Arizona and southern New Mexico. The CSIRO model predicted a climatic suitability increase in the areas of southern Arizona, New Mexico, Texas, Louisiana, Mississippi, Alabama, Georgia and all of Florida, with an extreme increase in central and southern Texas. These results show a very similar pattern in habitat suitability ranges, indicating the strong possibility of these predictive models.

From Table 2 we observe the top climatic contributors for the prediction of the models: Annual Mean Temperature 33%, Mean Temperature of Warmest Quarter 17.2%, and Mean Temperature of Coldest Quarter 11.6%. These contributions show how temperature is the most limiting factor of the species, which is not accurate taking into account previous studies on kleberg bluestem (Hernàndez *et al.,* 2002).

To verify the accuracy of MaxEnt a ROC curve was generated. This curve gave a value of 0.978, out of a possible 1.0, for the AUC. This indicates that the predicted model was accurate in its trial predictions about 97% of the time, making it a very good prediction. Based on these results it can be concluded that if the climatic predictions are correct, there will be a substantial increase in suitable habitat for *D. annulatum* into northern areas of the United States and Mexico.

From the results obtained it can be concluded that the formulated hypothesis was rejected because the area of suitability did not experience a shift in distribution. The distribution of the invasive grass, *Dichanthium annulatum*, will only expand in distribution. Relative to its current distribution, areas to the north will now become suitable and areas to the south will also become suitable, based on these models. As shown by the percent contribution from each variable, this increase in distribution could be mainly due to the increase in temperatures. Since *D. annulatum* is native to arid and semi-arid areas, the models indicate it will do well in areas with increased temperatures. It was predicted, in both the CCCMA and the CSIRO models that areas such as central/south Texas and south Arizona will experience an expansion in range, and that areas already suitable will gain a greater suitability.

Contrary to the prediction, there are no areas where the species seems to be retreating. Although these two predictions are slightly different, they both show the upcoming threat *D. annulatum* will increase. Therefore, based on these results *D. annulatum* poses a potential threat to southern parts of the Texas and Arizona, so these should be the areas of greater concern. Unlike the suitable habitat shift seen from other invasive species (Cheung, W. W. *et al.,* 2009; Hitch & Leberg, 2007; Salazar *et al.,* 2007), for *D. annulatum* the habitat suitability was predicted only to expand, partially rejecting my hypothesis.

Aside from these results, it is important to remember that other extraneous factors can also influence the distribution of a species: for example, soil composition, species competition, dispersal limitations such as geological barriers, availability of areas for dispersal, and the capacity of a species to evolve and adapt to new conditions. Those factors were not included in this analysis due to a lack of data, yet their importance in a species distribution should still be noted. Also, lack of distribution data can make an area under-represented, which can cause the maps to miss some important climatic associations.

Another important consideration is the effectiveness of modeling techniques. Although there were biotic and abiotic aspect that could not be incorporated into this prediction, a highly accurate prediction (based on evaluations from MaxEnt) was made with the information that was collected. Therefore, the predictive models generated from this study have a high possibility of being accurate in its predictions.

In summary, it is important to continue the research on *Dichanthium annulatum* in order to better understand its response to climate change. Biotic research of its interactions with other grasses and fauna, along with abiotic aspects such as soil type tolerances could be helpful to better understand this species' behavior. Prevention of further invasion can now be possible if the public and public officials are informed of the possible threat *D. annulatum* posses on our ecosystem.

Some recommendations for further work could include the study of *D. annulatum's* temperature and precipitation tolerances in its invasive and native occurrence, to better understand its climatic limitations. Also, further field work is needed to more accurately represent the areas already invaded by *D. annulatum.* Future modeling could also include other factors such as species interactions, soil types, and anthropogenic factors. Another possible approach to this model could be the selection of specific climatic variables (most relevant, based on literature).

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BIOGRAPHICAL SKETCH

Cynthia Isabel Garcia was born in Tamaulipas, Mexico on December 19, 1987. At the age of 4 she moved to Brownsville, Texas with her family where she attended J.T Canales Elementary, Cummings Middle School and Gladys Porter High School. In high school she was among the top 10 percent of her class all four years and obtained numerous awards and nominations including the National Honor Roll Society, The National Society of High School Scholars, All-American Scholar, Who's Who Among American High School Students and graduated in 2006 with a Distinguished Diploma. In 2005 she was among the members who started a choir group in Our Lady of Guadalupe Church in Brownsville, Texas for the 5 o'clock mass, which needed a choir. This commitment became a very important part of her spiritual and religious life at the age of seventeen, and she continues to attend every Saturday since then.

She attended The University of Texas-Pan American in 2006 with the help of scholarships. There she participated in organizations, worked under the HHMI program doing cancer research for some time and was elected to become part of the Golden Key International Honour Society. In 2010 she graduated with a Bachelor in Science. She continued her studies in UT-Pan American expanding her knowledge and experience by working as a Graduate Assistant teaching general biology laboratory courses in the university and twice with the USDA as a lab technician. In 2013 she graduated with a Masters in Biology and currently resides in 1540 Garfield St. in Brownsville, Texas.