POTENTIAL DISTRIBUTION OF THREE NATIVE AND ONE INTRODUCED GRASS SPECIES IN SEMIARID HIGHLANDS OF MEXICO USING GIS TECHNIQUES

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ABSTRACT

In the arid and semiarid region of Mexico, data on three native grasses growing in diverse ecological environments—*Muhlenbergia peruviana* (P. Beauv.) Steud., in temperate forests; *Bouteloua gracilis* (Kunth) Lag. ex Griffiths, in grasslands; *Muhlenbergia porteri* Scribn. ex Beal, in xeric regions; and one introduced nonnative species, *Melinis repens* (Willd.) Zizka (Zizka rose Natal grass)—were used in our essay analyzing their potential distribution, based on climatic factors. We took presence-only data applied to the Bioclim algorithm included in the Diva-GIS program. Using database bioclimatic WorldClim-Global Climate Data allowed us to make predictions of the distribution, and to determine the climatic characteristics that each species needs to grow. It generated a potential distribution of the four species under study, concluding that this method can be applied to other grass species from this geographic area in order to improve: a) knowledge of the actual distribution of species in their natural environment, b) knowledge related to biodiversity, and c) to create an indicator to support decisions related to conservation and management of grasses in Mexico. We concluded that possibly climatic requirements prevent the expansion of the introduced species (Zizka rose, Natal grass).

Key Words: semiarid region, Diva-GIS, Mexico, predicted distribution, Poaceae

RESUMEN

En la región árida y semiárida de México se realizó un ensayo con información de tres gramíneas que crecen en ambientes ecológicos diversos—*Muhlenbergia peruviana* (P. Beauv.) Steud., en bosque templado; *Bouteloua gracilis* (Kunth) Lag. ex Griffiths, en pastizal; *Muhlenbergia porteri* Scribn. ex Beal, en matorral xerófilo; y una especie introducida de África, *Melinis repens* (Wild.) Zizka (pasto rosado)—para analizar su distribución potencial en base a factores climáticos. Usamos datos de solo presencia aplicados al algoritmo Bioclim incluido en el programa Diva-GIS. Utilizando la base de datos bioclimáticos WorldClim–Global Climate Data, nos permitió hacer predicciones de la distribución y conocer las características climáticas que cada especie requiere para sobrevivir. Se generó un área potencial de distribución de las 4 especies en estudio, concluyéndose que este método puede ser aplicado a otras especies de esta área geográfica con el fin de mejorar a) el conocimiento de la distribución actual de las especies en su ámbito natural, b) conocer mejor la biodiversidad, y c) crear un indicador para la toma de decisiones en la conservación y manejo de las gramíneas en México. Concluimos que posiblemente los requerimientos climáticos de la especie introducida (pasto rosado) previenen su expansión.

INTRODUCTION

The distribution of the terrestrial surface of grasses, unlike any other living plants, follows a specific order since individuals are not randomly distributed on the ground but rather follow certain patterns. Since the majority of plants are immobile, they must satisfy their requirements "in situ": they must obtain the raw material for their sustenance from the surrounding environment which should also have adequate physical-chemical conditions. Different species require diverse conditions: some plants will be able to live within a specific area while others require a different one (Ederra 1997).

Floristic studies of the north central region of the country (Fig. 1) found nearly 500 species of grasses of the Poaceae family (Herrera 2001; Herrera & Peterson 2007; Herrera & Cortés 2009, 2010; Herrera et al. 2010; Cortés & Herrera 2011; Herrera et al., in prep); their distribution and diversity are due to the availability of their raw-material requirements and the suitable physical-chemical conditions of the environment.

Since the geographical distribution of grass species is determined by their requirements, eco-geographical modeling studies, understood as "… the process of merging information about taxonomy, genetic diversity,

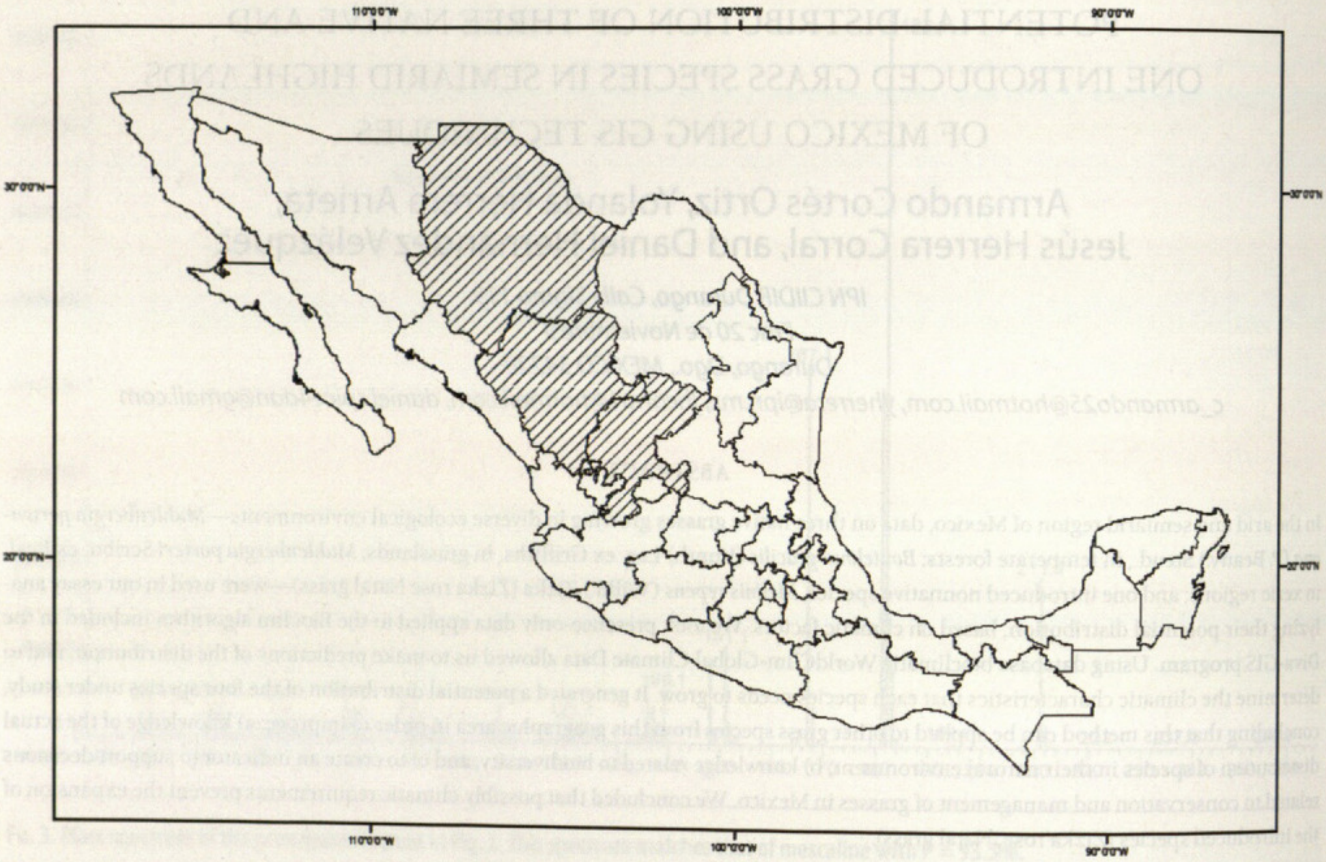

Fig. 1. Geographical location of the study area.

geographical distribution, ecological and ethnobotanical adaptation of a group of plants with geography, ecology, climate and human settlements... " (Guarino et al. 2002), can be used to analyze this distribution. Ecological and geographical information on species is fundamental for conservation, planning, and prediction (Ferrier 2002; Funk & Richardson 2002; Rushton et al. 2004), as well as to reach an understanding of factors which determine the patterns of spatial distribution of biodiversity (Elith et al. 2006; Ricklefs 2004). In general, occurrence data for the great majority of species are scarce and of presence-only since they generally come from random samplings that study flora and fauna. Therefore, determining the species distribution using data generated in such manner is inadequate for many applications (Cortés & Herrera 2011). Spatial distribution studies attempt to provide predictions of the distribution of species by connecting their presence with environmental factors. These have been applied in the study of relationships between environmental parameters and species richness (Herrera & Cortés 2010; MacNally & Fleishman 2004) and invasion by non-native species (Goolsby 2004). The present work attempts to analyze a large quantity of data compiled through flora and fauna studies in order to improve current knowledge of species distribution.

To this end, location data (latitude and longitude) for approximately 500 grass species have been obtained from floristic and diversity studies from the States of Chihuahua, Durango, and Zacatecas (Herrera 2001; Herrera & Peterson 2007; Herrera & Cortés 2009, 2010; Herrera et al. 2010; Cortés & Herrera 2011; Herrera et al., in prep.). This information was compiled and used to determine the climatic requirements for growth of the grass species. From these, a subset of 4 grasses from north central Mexico were chosen: 3 native and 1 introduced non-native species. The known distribution data of these 4 species indicate that they occupy diverse ecosystems, allowing the testing of the hypothesis that potential distribution of plants can be determined based on the climatic factors of the physical environment.

MATERIALS AND METHODS

Digital geo-referenced data of the selected grasses (*Muhlenbergia peruviana, Bouteloua gracilis, Muhlenbergia* *porteri*, and *Melinis repens*) collected in the study area were analyzed with Geographic Information Systems (GIS) software, specifically the DIVA-GIS 7.1.7.2 version (http://www.diva-gis.org/), and GVSIG 1.9 for Vista (http://www.gvsig.org/), using geo-statistics maps of the States of Chihuahua, Durango, and Zacatecas (INEGI geo-statistics framework) together with Bioclimatic data of 30-second arc resolution from the Worldclim database (http://worldclim.org/current). The GIS software packages were developed for the analysis of species diversity and distribution in order to clarify geographical, ecological, and genetic standards (Hijmans et al. 2004) and contain the necessary algorithms to generate the required data in a simple manner.

The study area encompasses the territory of the States of Chihuahua, Durango, and Zacatecas in the north central Mexico, occupying approximately 446,000 km^2 (Fig. 1) located between the extreme coordinates 21°02'24" to 31°46'48"N and 109°04'12" to 100°44'24"W.

This area is also located within the physiographical provinces of the Sierra Madre Occidental and Sierras del Norte, as well as partially within the Mesa del Centro (INEGI 2003b). As such, the topography of the study area is highly varied and rugged with altitude variations between less than 500 m and up to 3200 m. Its latitude position, the distance to and influence of the maritime zone, and the topographical characteristics of this zone determine strong variation in climatic factors such as temperature and precipitation. Within this region are low-altitude areas with an annual temperature ranging between 24 to 26°C and high-altitude areas with annual temperatures ranging between 8 and 10°C. In terms of precipitation the study area has dry zones with little annual precipitation (200 mm) as well as sub-humid zones that have an annual precipitation between 1000 and 1500 mm. Interrelations between these and other factors cause the study area to have varied plant communities and soil cover from zones with pine and oak forests to grasslands and xerophilus scrubs (microphyll desert scrub, rosette desert scrub, crassicaule scrub), as well as small pockets dominated by halophilous scrub communities or halophilous grasslands, due to salty soils (INEGI 2003a).

The potential distribution analysis was carried out using a subset of four (out of 500) species belonging to diverse environments in order to determine the potential distribution and climatic characteristics of the distribution area. A total of three native species were selected, *Muhlenbergia peruviana* from temperate semiarid forests; *Bouteloua gracilis* from grasslands; *Muhlenbergia porteri* from the xeric region; as well as one nonnative introduction, *Melinis repens* (Zizka rose Natal grass). The data used to carry out our analysis came from specimens kept at several herbaria in Mexico (CHAPA, CIIDIR, ENCB, HUAA, IEB, MEXU, SLPM) as well as abroad (TAES, US) that had been included in previous floristic inventories of the study area (Herrera 2001; Herrera & Peterson 2007; Herrera & Cortés 2009, 2010; Herrera et al. 2010; Cortés & Herrera 2011).

Potential species distribution prediction was carried out using the Bioclim model included in the Diva-GIS program applied to Global Climate Data from the WorldClim bioclimatic database (http://www.worldclim.org/current). In brief, the Bioclim model identifies patterns of geographical distribution of species from 19 bioclimatic variables (contained in the database) and determines areas where species could thrive. Unlike other models, this model uses presence-only data (Kenth & Carmel 2011; Rodríguez-Soto et al. 2011), characterizing the areas which are within the climate cover that have environmental characteristics similar to those occupied by the species under study. Bioclim can be used to describe the environment in which a certain species has been previously found in order to identify other areas where the species can live in the current condition as well as to identify areas where the same species could be present if the climate landscape alters.

The WorldClim bioclimatic database is a set of global climate layers (raster format) with a spatial resolution of about one kilometer. It can be used to generate maps or create a spatial model in GIS or other computer software. This database was generated by the interpolation of observed and representative data from the years 1950 to 2000 (Hij-mans et al. 2005).

Creation of prediction maps of distribution.—Potential distribution maps were generated for the four grass species with the Bioclim model, initially classifying the area into the following categories of probability of occurrence: Unsuitable, Low (0–3.5 percentiles), Medium (3.5–5 percentiles), High (5–10 percentiles), Very High (10–20 percentiles), and Excellent (20–34 percentiles). In order to determine the main climatic characteristics relevant to the species distribution, the maps were remodelled so that only cells/areas with high, very high and excellent probability were shown.

Creation of temperature and precipitation maps for each species.—Maps of the mean annual temperature and annual precipitation of the study area were generated from the climate database using Diva-GIS functions. Afterwards, using overlapping map functions, annual precipitation and mean annual temperature maps were generated for the high-probability distribution areas of each species.

Crossing of temperature and precipitation maps.—The annual precipitation and mean annual temperature maps were cross-mapped so that for every species, each high-probability distribution map cell also showed the precipitation and temperature values. Furthermore, the cell frequency for the various precipitation and temperature values was obtained.

RESULTS

Maps of the predicted distribution of four grass species were generated with the Diva-GIS Bioclim algorithm. The selected species were *Muhlenbergia peruviana, Muhlenbergia porteri, Bouteloua gracilis*, and *Melinis repens*, which were chosen because they have been collected in different ecosystems and our results show the variety of climate conditions in which they can develop. Said maps show the level of probability of occurrence for each of the species in the study area (Guarino et al. 2002; Hijmans et al. 2004).

Muhlenbergia peruviana is listed as a species commonly distributed in pine-oak forest communities and the potential distribution map that was generated (Fig. 2) shows that areas of the Sierra Madre Occidental have greater probability of occurrence for this species.

When the mean annual temperature and total precipitation maps of high, very high and excellent probability of distribution areas of *M. peruviana* were obtained, we found that this species is located in areas with a relatively low mean annual temperature between 12 and 17°C, particularly at 14°C. Furthermore, the annual precipitation ranged between 600 and 1000 mm, notwithstanding the fact that the largest area was comprised in places with 600 mm (Tables 1 and 2). With this in mind, it is possible to establish that the distribution of *M. peruviana* is within areas with low temperatures and relatively high precipitation.

The potential distribution map of *Bouteloua gracilis*, which is known to be mainly distributed in natural grasslands and within some xerophilus scrubs (Fig. 3), shows a large area with high to excellent values of potential distribution.

The distribution area of *B. gracilis*, with greater likelihood values, had annual precipitations ranging from 400 to 800 mm, with an average of 560 mm although the most common precipitation values (mode) were 500 and 600 mm (these had the highest percentage of surface area). The mean annual temperature established in our model showed a range between 13 and 19°C, with an average of 16.2°C and a mode located at 17°C.

The potential distribution map of *Muhlenbergia porteri* (Fig. 4), which is known to be present within xerophilus scrubs (Fig. 4), placed this species within the driest regions of the study area.

The area with the highest predicted distribution of *M. porteri* had a mean annual temperature ranging between 12 and 21°C, with the mean located at 17.8°C and the mode at 18°C, while the annual precipitation ranged between 300 and 900 mm with a mean centered at 482 mm and a mode of 400 mm.

Climatic requirements for each of the three native species are summarized in Table 3, showing that, as expected, they belong to different ecosystems.

The potential distribution map of the nonnative introduced grass *Melinis repens* (Fig. 5) showed that it had the smallest area of likely distribution. It is possible that these results are influenced by the fact that this species was represented in low numbers with all collections used in this study.

Nevertheless, the distribution area with the highest likelihood of having *Melinis repens* showed mean annual temperatures ranging between 14 and 18°C, with an average of 16°C and a mode also at 16°C. Also, the annual precipitation reached an average of 609 mm, with a range between 500 to 800 mm and a mode of 600 mm.

DISCUSSION

Results from previous inventories of grass species carried out in the arid and semiarid regions in northern Mexico (Herrera 2001; Herrera & Peterson 2007; Cortés & Herrera 2010; Herrera & Cortés 2010, 2011; Her-

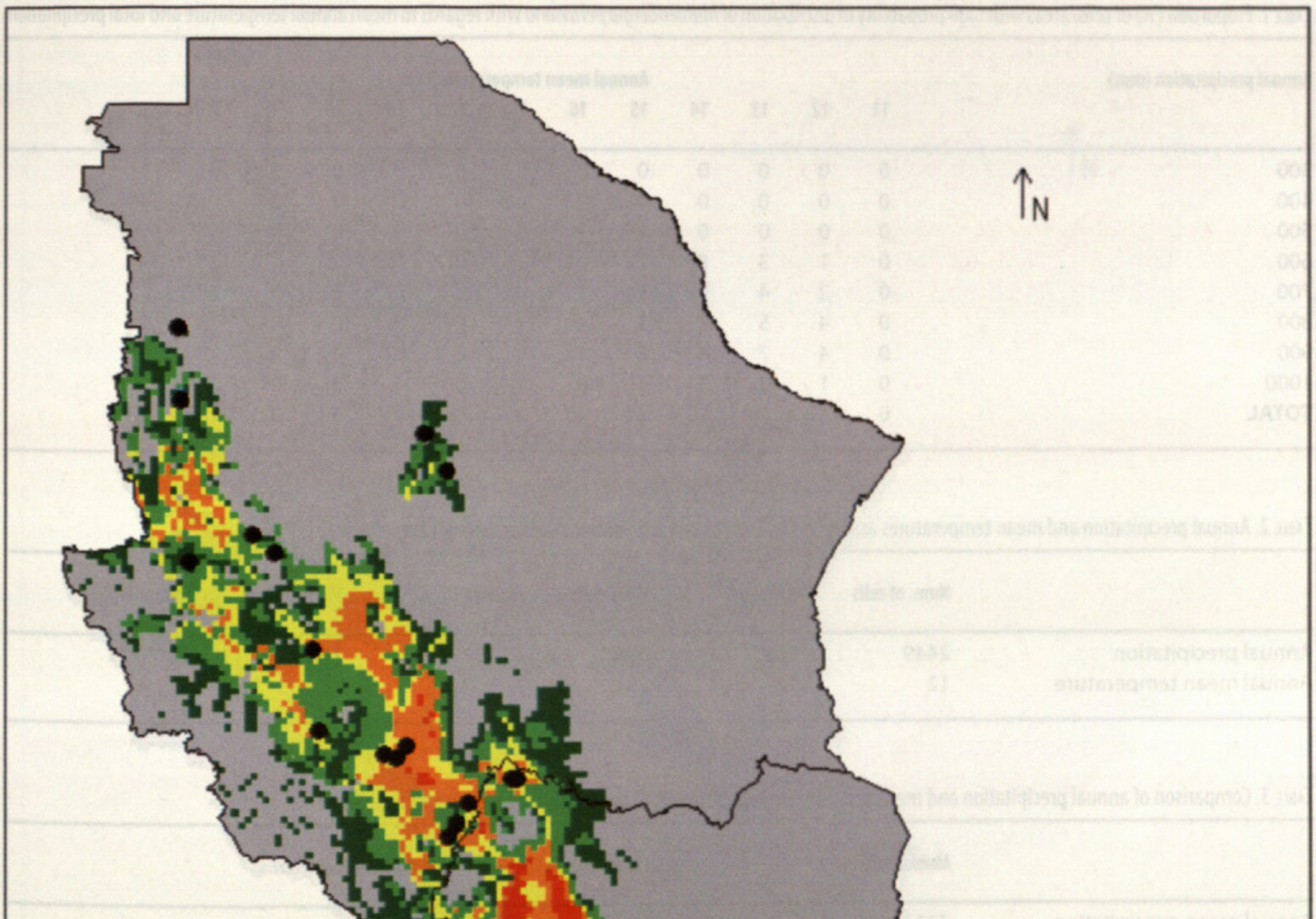

Fig. 2. Map of the potential distribution of *Muhlenbergia peruviana* obtained with Bioclim.

rera et al. 2010; Herrera et al. in prep) allowed us to construct probable distribution maps of close to 500 species of which the actual areas of distribution are known; this work shows the results from a subset of four selected species. The distribution of grass species in northern Mexico is mainly determined by climatic factors (Rzedowski 1978); therefore it can be assumed that this same analysis applied to the remainder of the grass species within this area has a very high probability of increasing our knowledge on their potential distribution.

Table 1. Proportion (%) of cells/areas with high probability of distribution of *Muhlenbergia peruviana* with regards to mean annual temperature and total precipitation.

Annual precipitation (mm)	Annual mean temperature (° C)										
	11	12	13	14	15	16	17	18	19	20	21	TOTAL
300	0	0	0	0	0	0	0	0	0	0	0	0
400	0	0	0	0	0	0	0	0	0	0	0	0
500	0	0	0	0	1	0	0	0	0	0	0	1
600	0	1	3	8	12	10	2	0	0	0	0	36
700	0	2	4	8	5	1	0	0	0	0	0	20
800	0	4	5	7	3	1	0	0	0	0	0	20
900	0	4	7	4	2	1	0	0	0	0	0	18
1000	0	1	2	1	1	0	0	0	0	0	0	5
TOTAL	0	12	21	28	24	13	2	0	0	0	0	100

Table 2. Annual precipitation and mean temperatures associated with potential distribution of *Muhlenbergia peruviana*.

	Num. of cells	Minimum	Máximum	Mean	Standar desv.	Moda
Annual precipitation	2449	500	1000	733	142	600
Annual mean temperature	12	17	14	1.32	15	

Table 3. Comparison of annual precipitation and mean temperature requirements of the three native species analyzed.

	Muhlenbergia peruviana	*Bouteloua gracilis*	*Muhlenbergia porteri*
Annual mean precipitation	733 mm	560 mm	482 mm
Annual mean temperature	14°C	16.2°C	17.8°C

In this study we modeled the potential distribution of four grass species from the arid and semiarid regions in northern Mexico, allowing us to predict the area in which it is more likely to find each of them as well as to determine the main climatic characteristics necessary for each species to be present.

The maps of potential distribution of *Muhlenbergia peruviana, Bouteloua gracilis, Muhlenbergia porteri,* and *Melinis repens,* generated with the Bioclim model using 19 bioclimatic variables, show the probability of distribution of these species within the study area in regard to their bioclimatic characteristics. These maps allowed us to determine the annual precipitation and mean annual temperature conditions in which each species has been found. The possible distribution areas can be considered to be critical for further fieldwork as these show similarities in the main climatic characteristics with those areas where these species are distributed.

Our analysis clearly shows that the three native species that were selected grow under very different climatic conditions, lending support to our initial decision of selecting species from different ecological regions. Nevertheless, *Melinis repens* (the introduced species) was shown to share a large ecological niche with *Bouteloua gracilis* (the grasslands species) since the former has climatic requirements similar to those of the latter. This fact could mean that this African species would not be able to invade other communities, such as forests or xerophytic scrubs, only posing a problem for grasslands. With our model it is possible to appreciate the actual distribution shared between a native species and an introduced species.

The replacement of native species with less desirable introduced species affects biodiversity. The hypothesis that biodiversity has an influence on productivity and stability of the grassland ecosystem has been previously tested in European grasslands by Hector et al. (1999) and in North American grasslands by Tilman et al. (1997). Both groups agree that the loss of biodiversity directly affects productivity and stability of grasslands.

One of the grasses that was studied in our work, *Melinis repens* (Zizka rose Natal grass), is an invasive species and the prediction of critical areas of future expansion is an important issue in order to prevent an in-

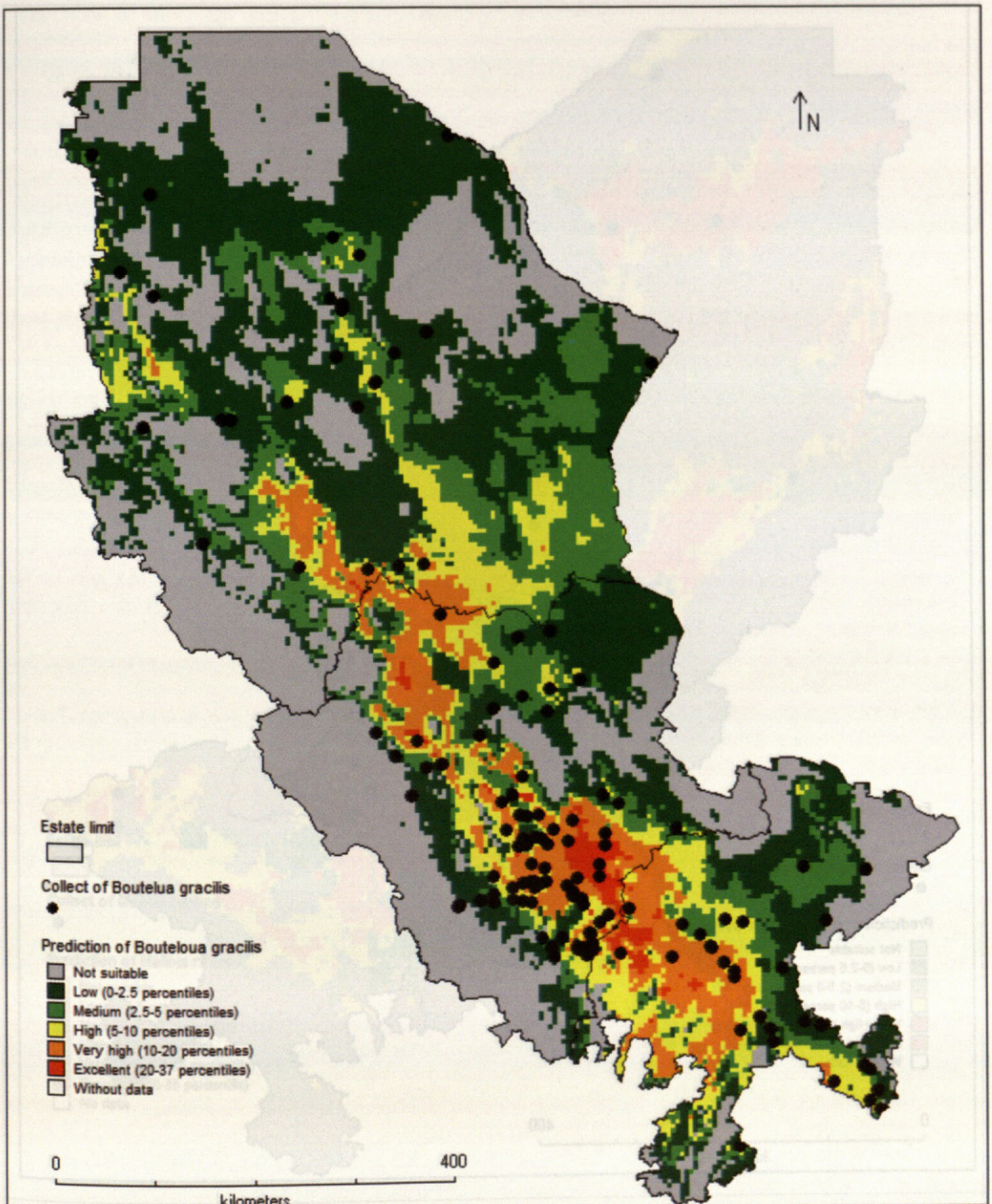

Fig. 3. Map of the potential distribution of *Bouteloua gracilis* obtained with Bioclim.

vasion and later displacement of native grassland species in Mexico. *Melinis repens* is an African grass that was recently introduced into Mexico (less than 50 years ago), first found at the edge of roads, a fact that possibly helped this species to spread, and it now invades and displaces native species in grasslands in northern Mexico (Herrera Arrieta et al. 2011; Herrera Corral et al. 2011). This grass is highly aggressive and this characteristic could be allowing it to increase its cover and dominate the distribution areas of *Bouteloua gracilis* (blue grass).

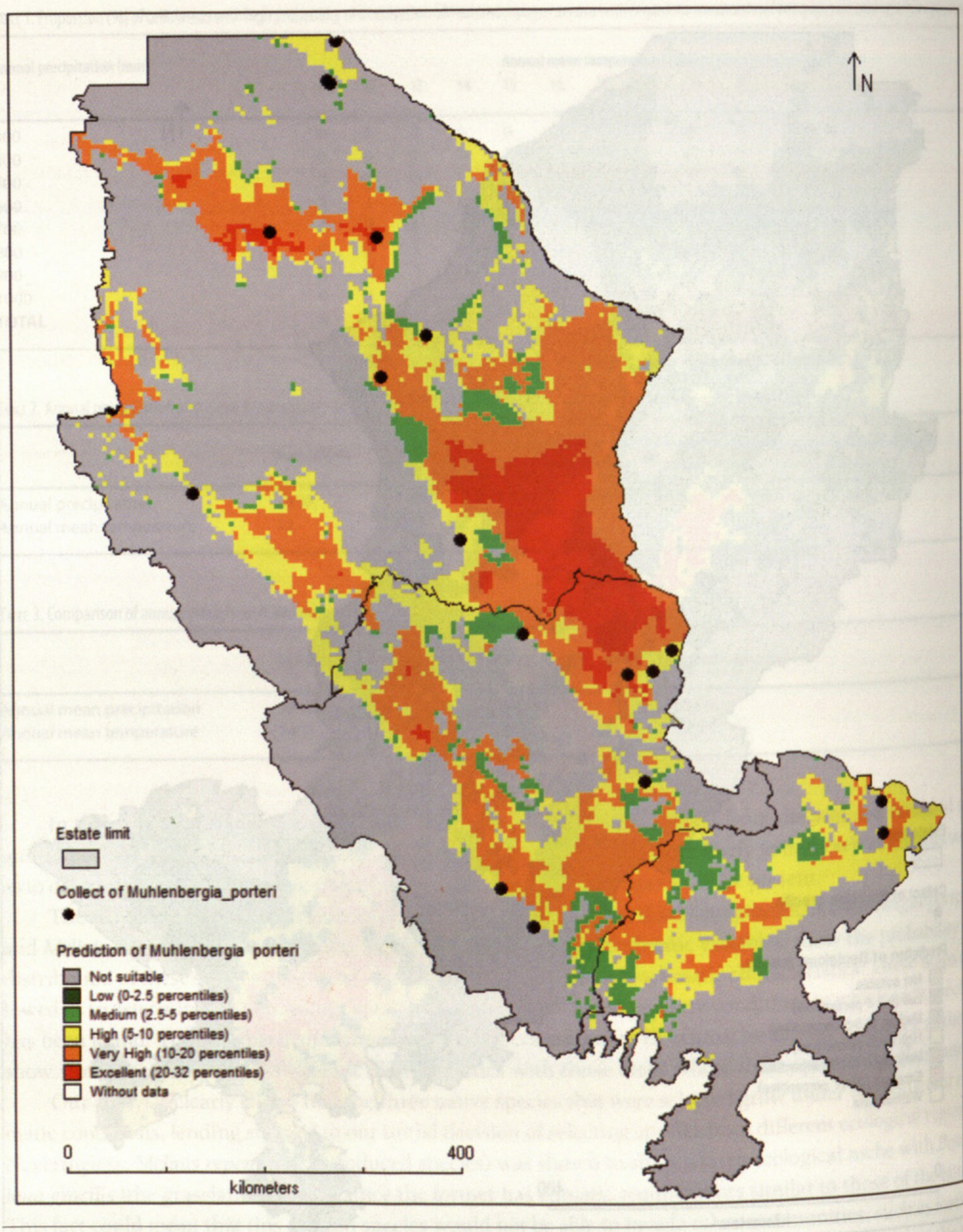

Fig. 4. Map of the potential distribution of *Muhlenbergia porteri* obtained with Bioclim.

However, Figure 5 shows that climatic conditions could be containing Zizka rose Natal grass from spreading into every space that blue grass now occupies within these grasslands (see Fig. 4).

CONCLUSIONS

With this study we have shown that it is possible to carry out prediction modeling of the potential distribution or ecological niche of grass species based upon presence-only data (Kent & Carmel 2011; Rodríguez-Soto et al. 2011) that can be obtained from specimens collected with floristic inventory purposes.

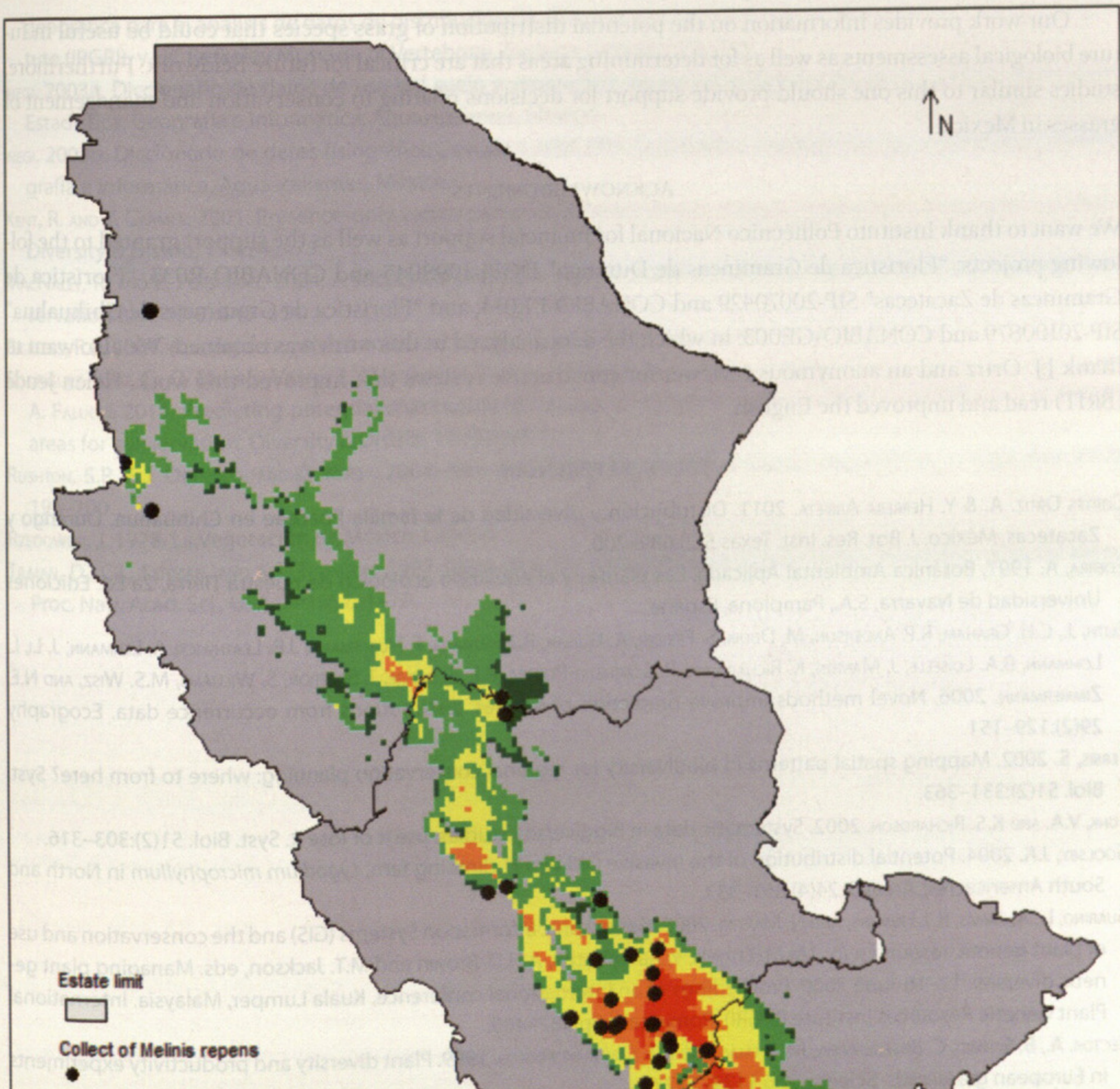

FIG. 5. Map of the potential distribution of *Melinis repens* obtained with Bioclim.

Also, this study demonstrates that the overlap in distribution between native and invasive species can be shown, providing valuable information that can be used for preventing the spread of invasive species and the displacement of native species. We also uncovered evidence that it is possible that climatic requirements are preventing the expansion of the African-introduced species *Melinis repens* (Zizka rose Natal grass), although it has spread into grasslands in northern Mexico during the last 40 years.

Our work provides information on the potential distribution of grass species that could be useful in future biological assessments as well as for determining areas that are critical for future fieldwork. Furthermore, studies similar to this one should provide support for decisions relating to conservation and management of grasses in Mexico.

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