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Spread of a Nonnative Grass Across Southern Arizona: Multiple Data Sources to Monitor Change

Abstract: In 1934, *Eragrostis lehmanniana* was introduced into southeastern Arizona to control erosion and provide forage for cattle. The earliest of these introductions took place on the Santa Rita Experimental Range (SRER) in 1937 and continued there until the early 1960s. Numerous researchers have observed a convincing association between an increased proportion of *E. lehmanniana* and decreasing species richness in these grasslands. This grass is both invasive and persistent: just 50 years after its introduction, the area occupied by *E. lehmanniana* had doubled. Published evidence indicates that variables such as elevation, summer precipitation, winter temperatures, and soils impact its abundance and distribution. We used these variables to generate a map of current predicted distribution of *E. lehmanniana*. Using over 600 presence/absence points amassed from eight agencies in Arizona, we selected among the guidelines to create a current distribution map for *E. lehmanniana* in Arizona. We then modified this map using two common general circulation models developed by the Hadley Centre for Climate Prediction and Research and the Canadian Centre for Climate Modeling and Analysis to predict the potential distribution of *E. lehmanniana* in Arizona in the year 2030.

Introduction

Nonnative plant species have the potential to alter species composition (across guilds), change hydrologic and nutrient cycles, and influence disturbance regimes (Mack and D'Antonio 1998). One particularly invasive species in southern Arizona is *Eragrostis lehmanniana* (Lehmann lovegrass). In the 1930s, *E. lehmanniana* was brought into the Southwestern United States to control erosion and provide forage for cattle. Numerous researchers have observed a convincing association between increasing proportion of *E. lehmanniana* and decreasing species richness in grasslands of southern Arizona (Cable 1971; Bock and others 1986; Medina 1988). In addition to decreased species richness, *E. lehmanniana* has been implicated with alteration of ecosystem processes (Cable 1971; Bock and others 1986; Williams and Baruch 2000), modification of community composition (Anable and others 1992; Kuvlesky and others 2002), and changes in fire regimes (Biedenbender and Roundy 1996; Burquez and Quintana 1994; Ruyle and others 1988). In the 50 years following its introduction, this species doubled the area to which it was originally sown (Cox and Ruyle 1986).

In the mid-1980s, two researchers mapped the then-current distribution of *E. lehmanniana* (Cox and Ruyle 1986) and suggested abiotic factors limiting its distribution. In that study, Cox and Ruyle (1986) predicted that *E. lehmanniana* had reached the limits of its range in many areas. Recently, several respected field ecologists have noted the spread of *E. lehmanniana* to areas well beyond these documented boundaries (D. Robinett 2002, personal communication; G. Ruyle 2002, personal communication). Its spread is expected to continue under current climate conditions and land-management practices (Anable and others 1992; McClaran and Anable 1992).

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Our objectives for this study were to (1) use the abiotic factors suggested by Cox and Ruyle (1986) and other researchers to predict the current distribution of *E. lehmanniana*, and (2) predict areas likely to become invaded by *E. lehmanniana* in the region of Arizona, U.S.A., under a variety of future climate conditions using two popular global circulation models (GCMs).

Methods

We gathered 641 data points from The Nature Conservancy, the USDA Natural Resource Conservation Service, the USDI Bureau of Land Management, Saguaro National Park, Fort Huachuca Military Reservation, Buenos Aires National Wildlife Refuge, the Santa Rita Experimental Range, and the U.S. Forest Service. The data points were coded as presence or absence of *E. lehmanniana*, latitude and longitude, and the date they were recorded.

A descriptive summary statistics analysis was completed (JMP IN Ver. 4.0.4, SAS Institute, Inc.) to identify relationships between abiotic factors and the presence or absence of *E. lehmanniana*. Explanatory variables included average total precipitation, average total summer precipitation (July through September), average total winter precipitation (December through February), average maximum and minimum temperature, elevation, aspect, and slope.

Cox and Ruyle (1986) predicted spread of *E. lehmanniana* to be limited to areas between 800 and 1,500 m in elevation, with summer rainfall exceeding 150 mm in 40 days, and temperatures rarely falling below 0 °C. In earlier research, Crider (1945) suggested a minimum temperature bound for *E. lehmanniana* of –3 °C. We compared our presence/absence points to the distribution suggested by the abiotic factors described by Cox and Ruyle (1986) and Crider (1945). The current distribution of *E. lehmanniana* was modeled using grid arithmetic within ArcView GIS software. Spatial data sets of long-term climatic averages for minimum January temperature (Thornton and others 1997), annual precipitation (Thornton and others 1997), and corresponding elevation models (GLOBE 1999) were obtained for the study area at 1-km resolution. Based on the ranges of these abiotic factors believed to be tolerated by *E. lehmanniana* (Cox and Ruyle 1986; Crider 1945), spatial grids were coded as either appropriate or inappropriate habitat. When intersected, these grids resulted in a map of the predicted current distribution of *E. lehmanniana* (fig. 1).

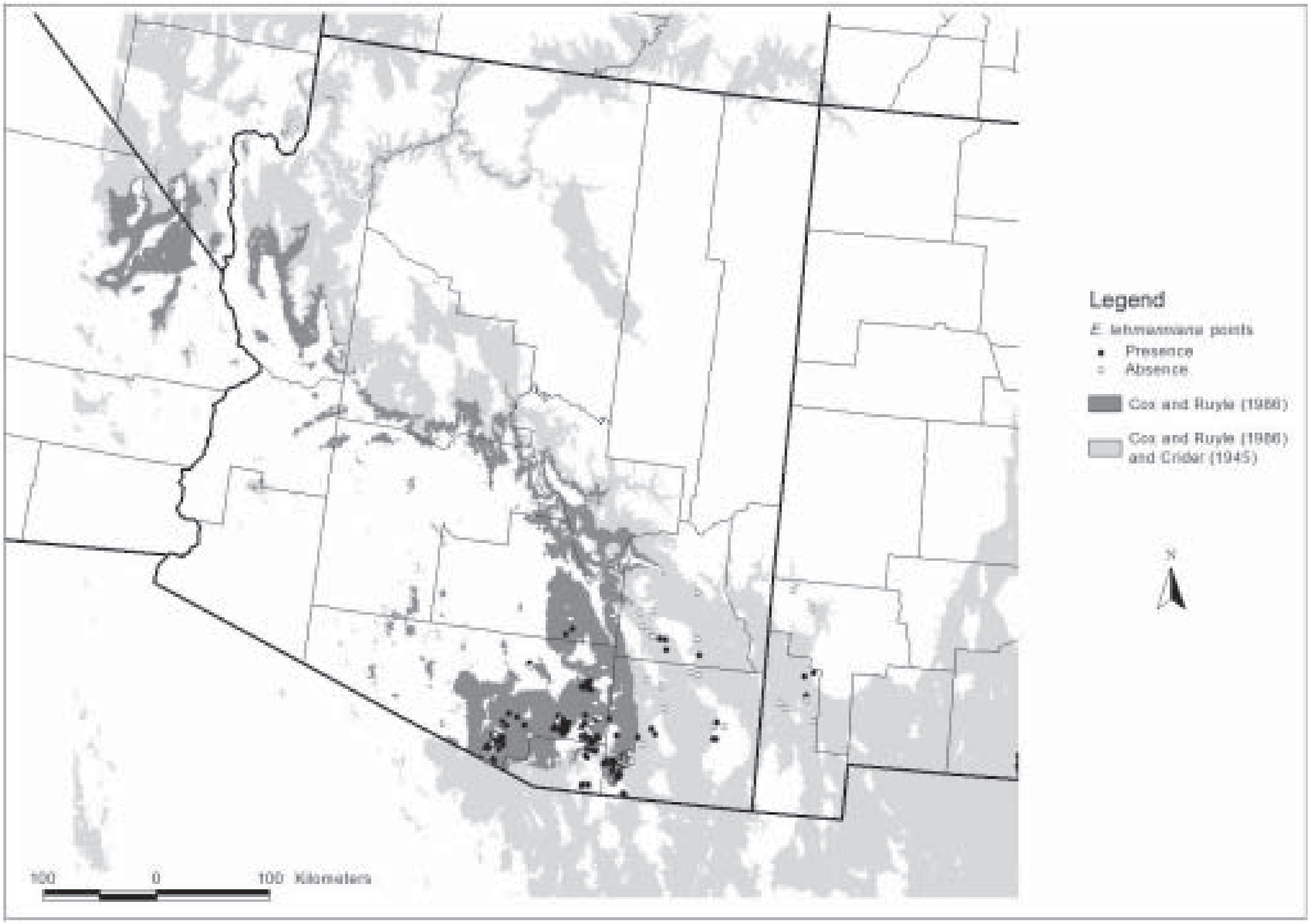

Figure 1—Potential current distribution of *Eragrostis lehmanniana* (Lehmann lovegrass) in Arizona, U.S.A., using abiotic factors suggested by Cox and Ruyle (1986) and Crider (1945).

Potential future distributions of *E. lehmanniana* were predicted using two common general circulation models developed by the Hadley Centre for Climate Prediction and Research and the Canadian Centre for Climate Modeling and Analysis. The long-term climatic data sets for winter temperature and annual precipitation were modified to reflect the changes in winter temperature and annual precipitation predicted for 2030 by each of these models. The Hadley Centre model predicts an average increase in winter temperature of 2.5 °C and winter precipitation of 1.0 mm per day by 2030 for the Southwestern United States. Summer temperature is predicted to increase by 1 °C and 0.25 mm per day, on average, by the Hadley Centre model. The Canadian Climate Centre model predicts an average increase in winter temperature of 3 °C and winter precipitation of 1.5 mm per day by 2030 for the Southwestern United States. Summer temperature is predicted to increase by 1.5 °C and 0 mm per day, on average, by the Canadian Centre model.

The current climate grids were then coded as appropriate or inappropriate habitat for *E. lehmanniana* based on the ranges provided by Cox and Ruyle (1986) and Crider (1945). When intersected with the grid of elevations appropriate for *E. lehmanniana*, two scenarios of predicted distribution of *E. lehmanniana* in 2030 were generated (fig. 2).

Results

Summary statistics of the 641 data points revealed that *E. lehmanniana* was present in 326 and absent in 227. Sites where *E. lehmanniana* was present were, on average, 265 m lower than sites where it was absent (table 1). Slopes averaged 5.5 percent steeper on sites where *E. lehmanniana* was absent than where it was present (table 1). Sites where *E. lehmanniana* was present received, on average, 6.4 mm less total precipitation annually than sites where it was absent (table 1). Average summer precipitation was 10.2 mm higher for sites where *E. lehmanniana* was absent than sites where it was present (table 1). Average winter precipitation was 2.8 mm higher, on average, for sites where *E. lehmanniana* was absent than sites where it was present (table 1).

The predicted current extent of *E. lehmanniana* using the abiotic factors suggested by Cox and Ruyle (1986) and Crider (1945) appears in figure 1. Areas shaded in dark gray depict

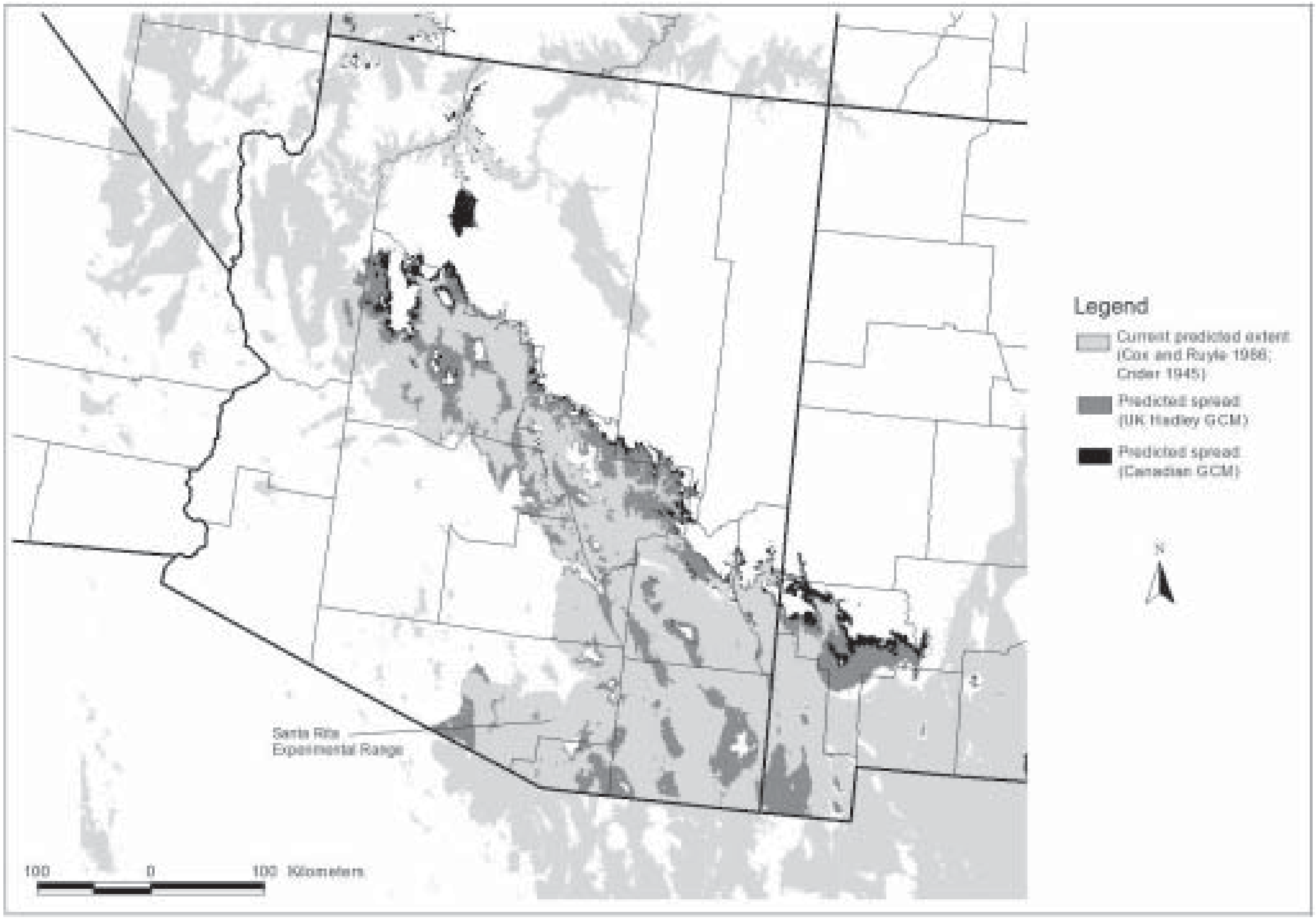

Figure 2—Potential future distribution of *Eragrostis lehmanniana* (Lehmann lovegrass) in Arizona, U.S.A., based on the Hadley Centre for Climate Prediction and Research and the Canadian Centre for Climate Modeling and Analysis general circulation models.

Table 1—Mean values of variables affecting presence of *Eragrostis lehmanniana* in southern Arizona.

E. lehmanniana **status**	**Variable**	**n**	**Mean**	**SE**
Present	Elevation	326	1,241 m	11 m
Absent	Elevation	227	1,510 m	31 m
Present	Slope	326	2.3 percent	0.13 percent
Absent	Slope	227	7.8 percent	0.65 percent
Present	Total precipitation	326	505.4 mm	5.5 mm
Absent	Total precipitation	227	511.8 mm	6.2 mm
Present	Average summer precipitation	326	163.7 mm	3.5 mm
Absent	Average summer precipitation	227	173.9 mm	4.8 mm
Present	Average winter precipitation	326	134.8 mm	1.5 mm
Absent	Average winter precipitation	227	137.6 mm	1.6 mm

the range of *E. lehmanniana* using the limits of abiotic factors suggested by Cox and Ruyle (1986). Areas shaded in light gray represent areas that also are predicted to be invaded by *E. lehmanniana* when the minimum cold temperature is changed from 0 °C, as suggested by Cox and Ruyle (1986), to –3 °C, as suggested by Crider (1945). The dark gray areas encompass 63 percent of the 326 presence points we collected; the dark gray and light gray areas together capture 76 percent of the presence points.

Future spread maps, based on the Hadley Centre for Climate Prediction and Research and the Canadian Centre for Climate Modeling and Analysis GCM's are presented in figure 2. These models show the distribution of *E. lehmanniana* increasing, mainly by moving up in elevation. The Canadian Centre model predicts a slightly greater 2030 extent of *E. lehmanniana* than the Hadley Centre model.

Discussion

Several studies have pointed out the importance of average total summer precipitation in limiting the spread of *E. lehmanniana* (Anable 1990; Anable and others 1992; Cox and Ruyle 1986). In our analysis using more than 600 points, we found no meaningful difference between *E. lehmanniana* presence or absence and precipitation. However, elevation and slope substantially affected the presence of *E. lehmanniana*. Of the points we amassed, *E. lehmanniana* was present more often at lower elevations and less steep slopes. Of particular interest is our finding that the upper elevation limit suggested by Cox and Ruyle (1986), 1,500 m, appears to be too low. Of the 327 presence points analyzed in this study, 10 percent existed above the predicted limitation of 1,500 m.

Crider (1945) documented that *E. lehmanniana* could be found in areas with minimum temperature as low as –3 °C, but in these areas, it acted more like an annual plant, reproducing primarily from seed rather than previous years' vegetative growth. This finding may have influenced Cox and Ruyle (1986) when they selected 0 °C as the minimum temperature boundary for *E. lehmanniana*. It appears from the points we collected that *E. lehmanniana* is able to persist at these lower temperatures, as changing the minimum temperature from 0 to –3 °C improved our predictive power of presence points from 63 to 76 percent.

With the model we have constructed using limits of abiotic factors suggested by Crider (1945) and Cox and Ruyle (1986), we predict *E. lehmanniana* to be present in large areas expected to be absent. The map appearing in figure 1 is a representation of areas where the conditions are appropriate to host *E. lehmanniana*. However, myriad other factors play a role in the species' ability to inhabit an area. Factors such as competition, land use history, proximity to seed source, and microsite variability are likely affecting the presence or absence of *E. lehmanniana* in these areas.

The future extent maps (fig. 2) predict that *E. lehmanniana* will move up in elevation as average summer and winter temperatures increase. In addition, areas predicted to currently be invaded in the northwestern portion of the State are no longer predicted to be appropriate for *E. lehmanniana* under future climate conditions. The increase in *E. lehmanniana* presence in Arizona predicted by these is not dramatic compared to the extent already predicted in figure 1. Using the limits suggested by Cox and Ruyle (1986), *E. lehmanniana* is predicted to inhabit 25,680 km^2; using the minimum temperature suggested by Crider (1945), this area increases to 81,504 km^2. Under the Hadley Centre model, 62,314 km^{2}m are predicted to be appropriate for *E. lehmanniana*, and under the Canadian Centre scenario, 66,158 km^2 are predicted to potentially host this invasive grass.

The areas predicted to host *E. lehmanniana* in the future distribution models assume that viable seed is spread to these areas. However, whether *E. lehmanniana* reaches this area will depend on the spread of seed. It has been observed that vehicle traffic is a primary source for seed introductions (D. Robinett 2002, personal communication). Spread of *E. lehmanniana* will likely be driven, at least in part, by development of areas not currently invaded.

Our hope is that the maps we have generated will give a quick up-to-date reference guide for areas throughout the State that are currently occupied by *E. lehmanniana* to aid in planning efforts such as large-scale fire restoration. Additionally, land managers can use the maps to identify where they fall along the current and future distribution of *E. lehmanniana* and adjust management practices as necessary to decrease the spread of *E. lehmanniana* on their lands.

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