RESEARCH ARTICLE

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Continent-Scale Landscape Conservation Design for Temperate Grasslands of the Great Plains and Chihuahuan Desert

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ABSTRACT: In support of natural resource agencies in Canada, the United States, and Mexico, we report on a series of component analyses and an updated Landscape Conservation Design for temperate grassland conservation. We targeted 12 major grassland ecosystem types that occur across the Great Plains and Chihuahuan Desert regions. Component analyses included (1) documenting long-term trends in extent by grassland type, (2) identifying species of concern associated with the major grassland types, (3) documenting current protected areas including each grassland type, (4) assessing landscape intactness and connectivity among grassland areas, and (5) identifying Grassland Potential Conservation Areas (GPCAs) to advance grassland conservation. Most severe declines in grassland extent have occurred in tallgrass prairie types, followed by mixed-grass, shortgrass, and semi-desert grasslands. Similar trends by type were documented for landscape intactness and connectivity. Some 174 species of vertebrates, invertebrates, and plants considered by NatureServe as critically imperiled, imperiled, or vulnerable are strongly associated with these grassland types, and 103 are listed under protective legislation in one or more countries. Just 1.2% of historic extent for all types combined is currently found within designated protected areas. A total of 177 GPCAs were identified to represent grassland type diversity in areas least likely to conflict with other land uses. Within identified GPCAs, type-specific representation varied from a low of just 1% of historic extent for Texas Blackland Tallgrass Prairie to a high of 27% for Western Great Plains Sand Prairie. Combined across all 12 grassland types, 15% of historic extent is represented.

Index terms: Aichi Target 11, conservation land investments, Landscape Conservation Design, long-term trends in extent, temperate grassland types

INTRODUCTION

Due to land use intensification (Hoekstra et al. 2005) and projected impacts of climate change (Sala et al. 2000), temperate grasslands are considered among the most threatened biomes worldwide. North American prairies and desert grasslands have sustained extensive loss to land conversion and degradation since the 1800s due to agricultural conversion, overgrazing, and infrastructure development (Buffington and Herbel 1965). Those grasslands, extending from the Canadian prairie provinces of Manitoba, Saskatchewan, and Alberta, south across the US Great Plains and through the Chihuahuan Desert of Northern Mexico, have experienced similar declines to others found worldwide. Significant portions of the vast trinational area (3M km^2) are considered a "breadbasket of the world" with some of the most productive and intensively cultivated croplands and pasture lands (Gauthier et al. 2003).

Wildlife has paid a steep price for this agricultural output. Grassland birds have seen sharp declines with increasingly fragmented and converted habitat (With et al. 2008; Hill et al. 2014), as have many other grassland-dependent plants and animals. For example, the grassland avian community is among the highest conservation concern due to rapidly declining populations (NABCI 2016). Species that migrate from the Great Plains to Mexico's Chihuahuan Desert grasslands have declined by almost 70% since 1970. Among the diverse herbivores of the grasslands, the black-tailed prairie dog (*Cynomys ludovicianus* Ord), often considered a "keystone" species in these grasslands, has experienced dramatic population decline due to multiple factors including use of poison, habitat conversion, and sylvatic plague, and was recently considered for listing under the Endangered Species Act (Hoogland 2013).

Regional patterns in climate (from cool and moist to hot and dry) and soils explain much of the natural variation in major temperate grassland types. Tallgrass prairies occur in a north–south belt from Manitoba to east Texas. Mixed-grass prairies dominate the Canadian prairies, extending south throughout the central Great Plains to central Texas. Both shortgrass and sand prairies, occurring on loamy and sandy soils, respectively, predominate the western and southern Great Plains. Finally, semi-desert grasslands occur throughout the Chihuahuan Desert in southern Arizona, New Mexico, and west Texas, and extend south and east to San Luis Potosí and Nuevo León, Mexico (Figure 1).

Patterns in habitat loss vary among grasslands and are also related to climate and soils, which influence agricultural potential. By combining agricultural potential

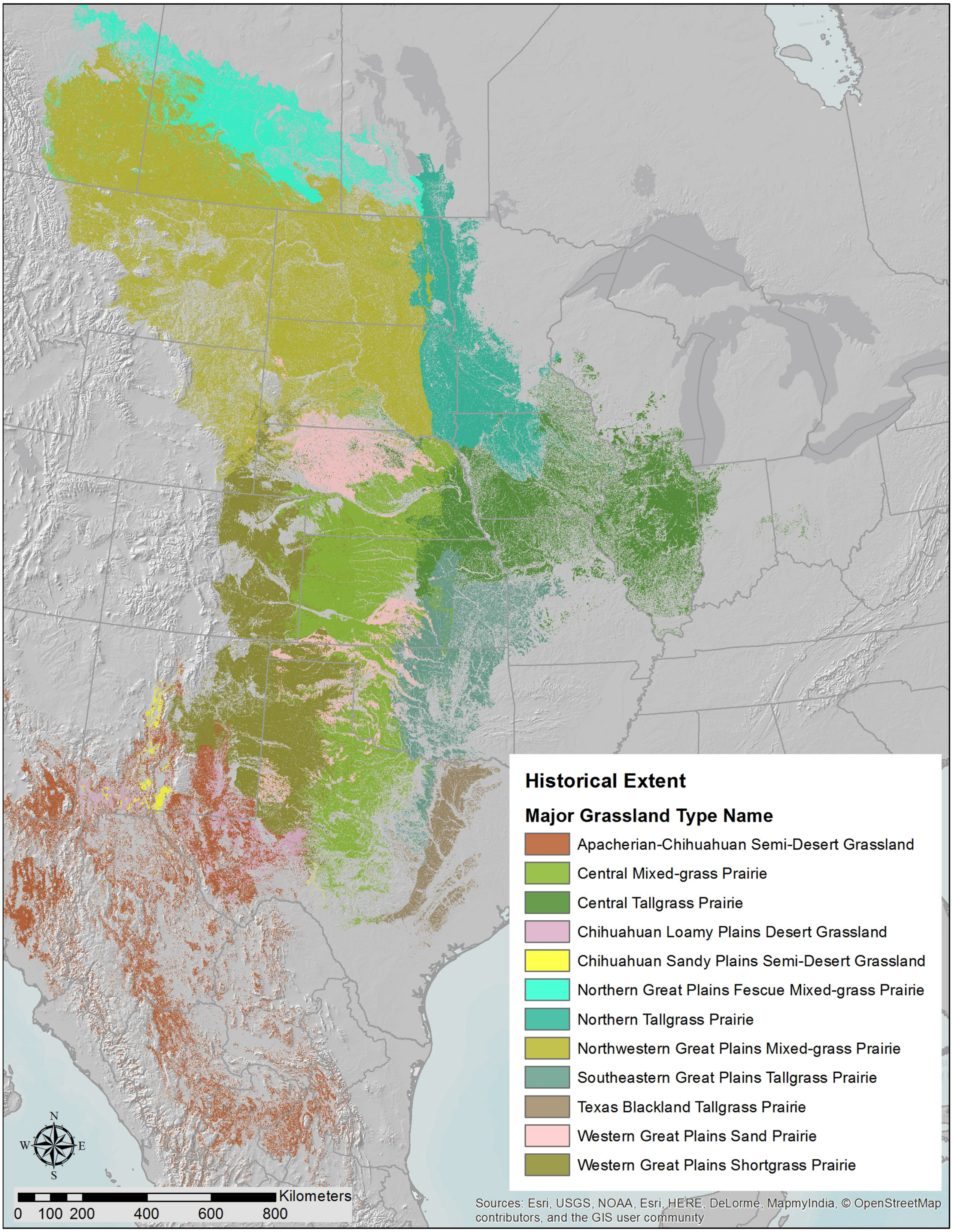

Figure 1. Approximate historical extent of 12 major temperate grassland types.

with distribution of infrastructure and access to markets, one can identify major trends of grassland conversion over the past century. More recent trends in agricultural intensification of the Chihuahuan Desert (Pool et al. 2014), biofuel production (Wright and Wimberly 2013), and energy development (Pruitt et al. 2009; Fargione et al. 2012) have introduced pockets of rapid change across the region (Drummond et al. 2012).

Prevailing patterns of land ownership shape conservation priorities and actions in these temperate grasslands. Privately held lands prevail throughout the Canadian and US prairies, while communal land ownership is more frequently encountered in Mexico. Private ownership predominates where agricultural productivity remains high, and so historic triggers for concentrated public ownership (e.g., tax-reversion of lands during the Great Depression) were limited to shortgrass prairie and desert grasslands (Gauthier et al. 2003; Samson et al. 2004). Given these ownership patterns, conservation largely takes place on lands controlled by private individuals, corporations, or communal land stewards. Consequently, a mix of public land acquisition, government subsidies for private conservation action, conservation easements, and multi-stakeholder partnerships (Gauthier et al. 2003; Drum et al. 2015) may be important for addressing pervasive and critical threats to these grasslands, and to achieving desired conservation outcomes.

In this context, agencies forming the North American Intergovernmental Committee on Cooperation for Wilderness and Protected Areas Conservation (NAWPA) recently agreed to examine the adequacy of the current North American conservation estate, considering key attributes of ecological representation, connectivity, and resilience. By assessing achievements and identifying gaps, efforts to restore and conserve functionally resilient landscapes can be enhanced. This paper presents results of analyses focused on North America's temperate grasslands.

Key elements to enhance landscape-scale conservation include assessing resiliency, as defined by adequate representation of intact habitat, establishing redundancy where needed, ensuring fine-scale and broad-scale connectivity for species and processes, providing refugia for species from rapid landscape change, and restoring targeted habitats and species. The project was designed to demonstrate the capacity of available data and analytical tools and approaches to identify priority conservation areas to focus individual decisions and conservation investments by agencies, and potential coordinated efforts. Below we report on a series of component analyses leading to an updated Landscape Conservation Design (LCD) identifying Grassland Potential Conservation Areas (GPCAs) as focal areas for conservation action.

Component analyses included:
(a) documenting long-term trends in extent of 12 major temperate grassland types;
(b) identifying species of concern associated with the major grassland types;
(c) documenting current protected areas including each grassland type;
(d) assessing landscape intactness and connectivity among grassland areas; and
(e) complete landscape conservation design to identify GPCAs to advance grassland resiliency.

Brief summaries of methods and results are provided with each component analysis.

TRENDS IN EXTENT OF MAJOR GRASSLAND TYPES

Temperate grasslands of this trinational area include types ranging from prairies dominated by tall grasses and forbs, to mixed-grass (tall and medium height grasses), to shortgrass prairies occurring in semi-arid climates of the southwestern plains, and semi-desert grasslands found throughout the Chihuahuan Desert. For this effort, we utilized grassland classification and map products based on the terrestrial ecological system classification of NatureServe (Comer et al. 2003). This classification integrates floristic composition and geophysical settings to define units that formed the basis for regional and national land cover mapping in the United States by federal interagency LANDFIRE (www.landfire.gov) and US Geological Survey's Gap Analysis Program (https://gapanalysis.usgs.gov/gaplandcover/; see type descriptions at http://explorer.natureserve.org/). Recent investments in continental-scale mapping have identified 12 major grassland types across this trinational area.

Within the United States, LANDFIRE has produced map products for "biophysical setting" of major upland ecological system type—effectively an estimate of potential/historical location and extent—using inductive modeling that utilizes field-based observations of each type and correlates these with mapped information on climate, landform, and soil (Rollins 2009). NatureServe then applied the same methods with data extending across temperate Canada and south across Mexico (Comer et al. unpub. data) to provide a complete distribution for each major grassland type at spatial resolutions of approximately 5-ha minimum map unit. Using these estimates of historical extent, the 12 most extensive grassland types were identified and served as the focus for this analysis. Figure 1 depicts predicted historical extent of each of the 12 major temperate grassland types. These grassland types range in estimated historical extent from a high of nearly 630,000 km^2 for Northwest Great Plains Mixed-grass Prairie, occurring from Nebraska north across southeastern Alberta, to a low of 8100 km^2 for Chihuahuan Sandy Plains Semi-Desert Grassland occurring in cross border region of Texas, New Mexico, and adjacent Chihuahua and Coahuila, Mexico (Table 1).

Long-term change in extent is estimated by comparing mapped current extent against these potential or historical estimates. Direct conversion for agricultural use explains much of the difference in areal extent for most types, with most extreme estimates of long-term loss found in Texas Blackland Prairie (98%), Northern Tallgrass Prairie (96%), Central Tallgrass prairies (92%), and Northern Fescue Mixed-grass Prairie (87%). These are types occurring on productive soils in areas with significant summer rainfall and have, therefore, been intensively utilized for their agricultural productivity. Using just this one criterion—specific to historic long-term trends in extent—from the International Union

Table 1. Long-term trends in extent and at-risk status of 12 major grassland types.

Major temperate grassland type	Historical extent estimate (km^2)	Current extent estimate (km^2)	Percent loss to conversion
Texas Blackland Tallgrass Prairie	41,400	670	98
Northern Tallgrass Prairie	157,200	6500	96
Central Tallgrass Prairie	242,000	20,100	92
Northern Great Plains Fescue Mixed-grass Prairie	137,000	18,000	87
Chihuahuan Sandy Plains Semi-Desert Grassland	8100	1600	80
Southeastern Great Plains Tallgrass Prairie	108,000	31,400	71
Central Mixed-grass Prairie	259,000	77,000	70
Western Great Plains Sand Prairie	107,300	38,000	65
Chihuahuan Loamy Plains Desert Grassland	38,300	14,400	62
Northwestern Great Plains Mixed-grass Prairie	620,900	307,500	50
Apacherian-Chihuahuan Semi-Desert Grassland and Steppe	249,400	152,200	39
Western Great Plains Shortgrass Prairie	259,000	188,000	27
Total	2,227,600	855,370	62
IUCN status based on long-term loss in extent	*Vulnerable*	*Endangered*	*Critically Endangered*

for Conservation of Nature (IUCN) Red List of Ecosystems (Keith et al. 2013), three types would be considered Critically Endangered, four types Endangered, and three types Vulnerable (Table 1). If assessed as one type of temperate grassland, a 62% estimated loss for these 12 types combined would qualify them as Vulnerable under this IUCN criterion.

SPECIES OF CONCERN ASSOCIATED WITH THE MAJOR GRASSLAND TYPES

Many plant and animal species that are dependent on these grassland types for core or seasonal habitat are increasingly at risk and identified on multiple lists of high-priority species for conservation attention. We used site-based occurrence data from Natural Heritage Programs in the United States and Canada, and expert knowledge of habitat associations in Mexican portions of the Chihuahuan Desert, to document species of concern that are associated with one or more of these 12 major grassland types. Because these are upland grassland types, all species known to be limited to aquatic and cave habitats were removed from analysis. Over 150,000 documented occurrences of 762 species tracked (i.e., considered of some conservation concern in at least a portion of the range) by Natural Heritage field inventories in the United States and Canada were overlain on current extent maps of the 12 major grassland types, and the relative proportion of each species' rangewide total was calculated. Table 2 summarizes numbers of species—grouped as birds, mammals, herptiles, invertebrates, and plants—tracked by NatureServe and IUCN Conservation Status categories, and under legal protection in Canada, the United States, and Mexico that use the 12 major grassland types. Eighty-three tracked bird species of concern are associated with these temperate grassland types, and 14 of these, such as mountain plover (*Charadrius montanus* Townsend), are listed as threatened under Canadian protective status and associated with several of these major grassland types extending south into Mexico. Fifty-two tracked mammal species are associated with these grasslands, and 12 of these, such as black-footed ferret (*Mustela nigripes* Audubon and Bachman), are listed under protective status in Canada, the United States, and Mexico. Twelve mammal species fall into the G1T1 (critically imperiled) to G3T3 (vulnerable) range of NatureServe Conservation status, including Preble's meadow jumping mouse (*Zapus hudsonius preblei* Krutzsch) [T2], associated with prairie along riparian zones along the Rocky Mountain front. Fifty-nine tracked herptiles (both amphibians and reptiles) are associated with these grasslands, including the Colorado checkered whiptail (*Aspidoscelis neotesselata* Walker, Cordes, and Taylor) [G2], which is found in shortgrass prairie and adjacent juniper savanna. Some 49 tracked invertebrates, primarily consisting of insects such as the Dakota skipper (*Hesperia dacotae* Skinner) [G2], are strongly associated with these prairie types. Of over 500 tracked plant species associated with these grassland types, 124 are categorized as G1–G3/T1–T3 range at species or subspecies levels by NatureServe. Some 16 are listed for protection in Canada, and 13 are listed within the United States. An example is Mead's milkweed (*Asclepias meadii* Torr. ex Gray) [G2, LT], a tallgrass prairie obligate, listed as Threatened in the United States.

Many at-risk species have been documented for the Canadian prairies, which have been extensively converted to agriculture. The vast area and diversity of circumstances across the US grassland types are indicated by varying numbers of at-risk species listed, and the relatively less in-

Table 2. Numbers of at-risk species* associated with 12 major grassland types.

Taxonomic group	G1 or T1 Critically Imperiled	G2 or T2 Imperiled	G3 or T3 Vulnerable	IUCN (CR, EN, VU, NT)	US ESA (LE, LT, Candidate)	COSEWIC (EN, T, SC, C, EX)	Mexico NOM-059 (EN, T, Prot. Espec.)
Birds	0	1	3	8	1	14	6
Mammals	2	1	7	8	4	6	8
Herptiles	2	2	6	8	3	10	6
Invertebrates	4	11	10	3	4	6	NA
Plants	21	49	54	3	13	16	6
Total	**29**	**65**	**80**	**30**	**25**	**52**	**26**

*NatureServe global status ranks G1–G3 indicate critically imperiled, imperiled, and vulnerable status at species and (T) subspecies levels.
IUCN Red List status: CR = Critically Endangered, EN = Endangered, VU = Vulnerable, NT = Near Threatened
US Endangered Species Act (ESA) status: LE = Listed Endangered, LT = Listed Threatened, Candidate for listing
Committee on the Status of Endangered Wildlife in Canada (COSEWIC): EN = Endangered, T = Threatened, SC = Special Concern, C = Candidate, EX = Extinct or Extirpated
Norma Official Mexicana 059 (NOM-059): EN = Endangered, T= Threatened, Protección Especial (Special Protection)

tensively developed and less intensively studied grasslands of northern Mexico indicate fewer documented at-risk species.

GRASSLAND TYPE REPRESENTATION IN CURRENT PROTECTED AREAS

The IUCN has established a measure of conservation land status that includes six protected areas categories. These six categories range from Category I representing "Strict Nature Reserve" to Category VI representing "Protected area with sustainable use of natural resources" (Dudley and Phillips 2006). However, many U.S. public and tribal lands that are strongly regulated under environmental protection, endangered species, and planning regulations are not included among IUCN categories, although their management is strongly regulated under environmental protection, endangered species, and planning regulations. Ongoing discussions among NAWPA partners aim to fully harmonize land management designations on a trinational basis.

Managed lands information (current in 2016) applicable to this trinational study area were standardized to IUCN categories by the USGS Gap Analysis Program and provided for our analysis. Overlay of land designations on current extent of the 12 major grassland types, and comparison of these areas with estimates of both historical extent and current extent, resulted in calculations found in Table 3.

Investments in North American conservation lands are known to be concentrated among ecosystems with limited potential for agriculture (Scott et al. 2001). These major temperate grasslands are minimally represented within designated conservation areas, with just 1.2% of the 2.2 million km^2 historical extent estimate, or just 3.1% of the 855,370 km^2 of estimated current extent, found within protected areas (Table 3). Major grassland types in the Chihuahuan Desert and surrounding region, including Apacherian-Chihuahuan Semi-Desert Grassland, appear to be most represented in designated protected areas, but the estimate of just 3% of historical extent for this type is still quite low as compared with other major vegetation types in temperate North America (Aycrigg et al.

Table 3. Proportion of historical and current extent of each major grassland types represented in protected lands, as defined by IUCN Categories I-VI (as of 2016).

Major temperate grassland type	Historical extent estimate (km^2)	% in IUCN Category I–VI lands	Current extent estimate (km^2)	% in IUCN Category I–VI lands
Apacherian-Chihuahuan Semi-Desert Grassland and Steppe	249,400	3	152,200	4.9
Chihuahuan Sandy Plains Semi-Desert Grassland	8100	3	1600	15
Northern Great Plains Fescue Mixed-grass Prairie	137,000	2	18,000	15
Northwestern Great Plains Mixed-grass Prairie	620,900	2	307,500	4
Chihuahuan Loamy Plains Desert Grassland	38,300	1	14,400	2.6
Western Great Plains Sand Prairie	107,300	1	38,000	2.8
Northern Tallgrass Prairie	157,200	0.4	6500	9.6
Western Great Plains Shortgrass Prairie	259,000	0.4	188,000	0.5
Southeastern Great Plains Tallgrass Prairie	108,000	0.3	31,400	1
Central Mixed-grass Prairie	259,000	0.1	77,000	0.3
Central Tallgrass Prairie	242,000	0.1	20,100	1.2
Texas Blackland Tallgrass Prairie	41,400	0.1	670	6
All Types Combined	**2,227,600**	**1.2**	**855,370**	**3.1**

2013). The estimated historical extent of eight in twelve of these major temperate grassland types are represented by 1% or less in designated protected areas, as defined by IUCN Categories I-VI. Two types that have experienced extremely high proportional loss due to past land conversion, such as Northern Great Plains Fescue Mixed-grass Prairie and Northern Tallgrass Prairie, appear to have relatively high proportions of their current extent (15% and 9.6%, respectively) found within protected areas. For contrast, many forest types occurring across the western states and northeast regions are represented in percentages ranging from 5% up to over 30%. Similar ranges are found among desert scrub vegetation types across the West.

LANDSCAPE INTACTNESS AND CONNECTIVITY AMONG GRASSLANDS

Land conversion and subsequent land protection tell only one part of the story of trends in temperate grassland biodiversity. A common consideration in landscape design for biodiversity conservation is to document the relative condition or intactness, and key ecological processes such as connectivity, in any given area in order to influence their selection for conservation attention (Groves 2003). High condition or intact vegetation retains expected composition, structure, and dynamic process characteristics of sites that have not been altered by prior human land uses (Parrish et al. 2003). Substantial environmental degradation—due to wildfire suppression, soil compaction, overgrazing, and climate change—or disruption of biotic composition and processes, due to invasive species introductions and landscape fragmentation disrupting native species dispersal, have had substantial (albeit varying) impacts on each grassland type (Samson et al. 2004).

We developed two spatial models, first to address ecological intactness of current grassland areas, and second, to gauge relative connectivity among major grassland patches. Practical measures of landscape intactness often utilize remotely sensed data, which allow mapping landscape features that result in habitat fragmentation and degradation (Woolmer et al. 2008; Theobald et al. 2012). For example, fragmentation of natural habitat by human activities can be modeled spatially, and used to identify intact core areas and quantify the relative permeability of intervening areas. For this effort, we used the NatureServe landscape condition model (Hak and Comer 2017). This model builds on the growing body of published methods for ecological effects assessment and spatial modeling, all aiming to characterize relative fragmentation effects on the ecological condition of landscapes (Riitters and Wickham 2003; Leu et al. 2008; Theobald 2013). It integrates data representing roads, land uses, and mapped expressions of altered vegetation to predict relative intactness in any given area. This approach enables users to express assumptions at the site level about the relative ecological effect that each land use type has (called a *Site Impact Score*) and the potential effect as it diminishes with distance from the site (called a *Decay Score*). Mapped information available for across the trinational area was compiled and standardized into 20 categories, organized by (a) *Transportation*, (b) *Urban and Industrial Development*, and (c) *Managed and Modified Land Cover*, each at 90-m pixel resolution. The resulting spatial index combines the scores of all input layers and their per-pixel values. Values close to 1.0 imply relatively little ecological impact from surrounding land use. The result is a wall-to-wall grid surface of landscape condition values falling between 0.0 and 1.0 (**Figure 2**). Independent data sets, including field observations of invasive species and Natural Heritage Program field surveys, were used to calibrate and validate the model. See Hak and Comer (2017) for additional detail on the model.

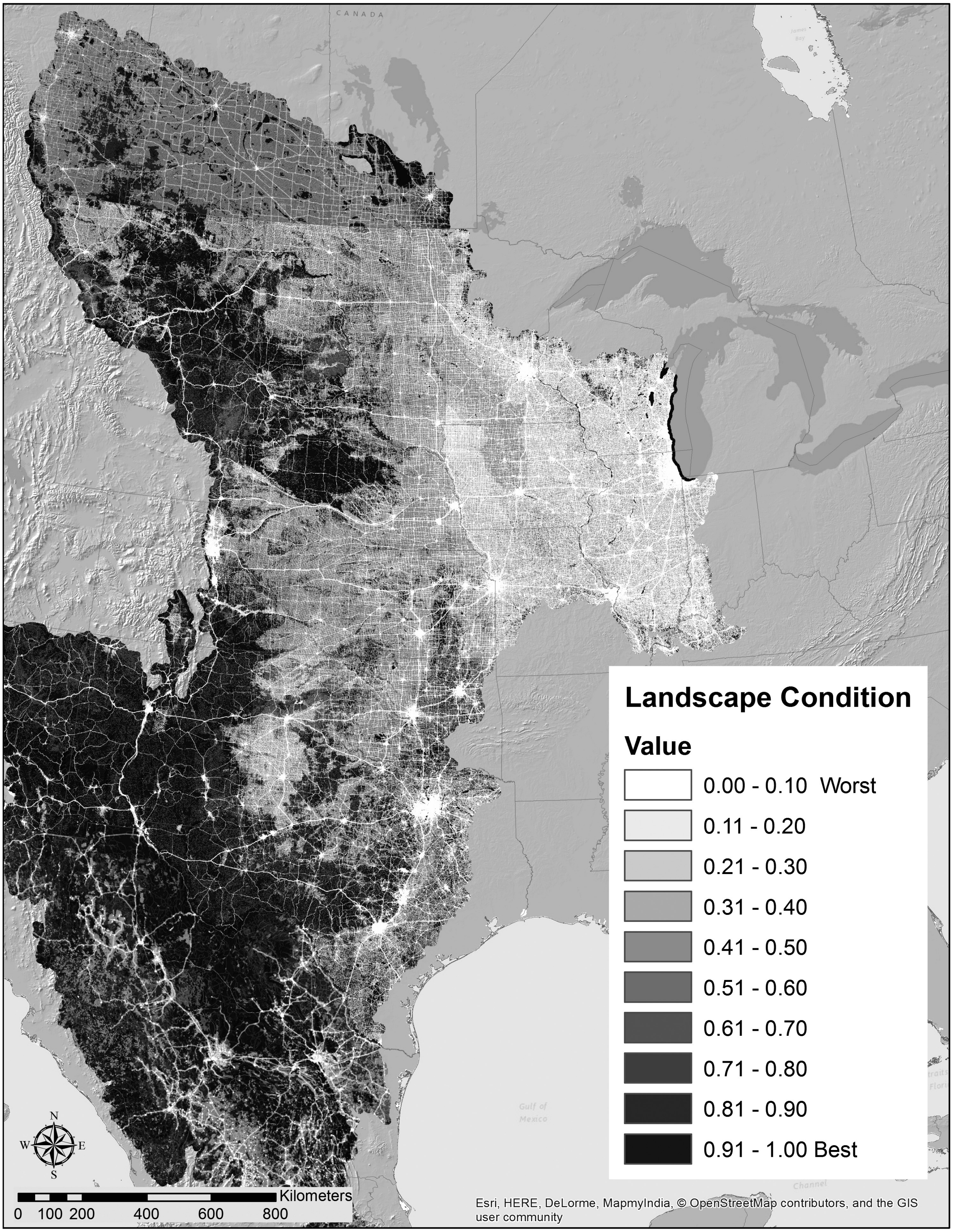

Figure 2. NatureServe landscape condition model applied to ecoregions currently supporting major grassland types, predicting a range of grassland quality.

By segmenting the landscape condition model evenly across the 0.0–1.0 scale range, and overlaying the spatial model on current grassland distributions, we summarized proportions of each grassland type falling along the continuum of predicted landscape condition (Table 4). Based on analyses reported in Hak and Comer (2017), grassland areas scoring within the 0.61–1.0 range of landscape condition are most likely to serve as "core areas" for grassland conservation. Among desert, semi-desert, and shortgrass types, a relatively high proportion of the current extent occurs in better condition categories, as compared with other types. As anticipated, tallgrass prairie types tended to score most poorly over greater proportions of their current extent than other types. Tallgrass types occur in areas with lowest landscape condition categories (0.40–0.00), and will tend to be most challenging for ecological restoration.

The second of the two models aimed to measure relative connectivity among grassland patches. We used the NatureServe landscape condition model as a "resistance" surface to model relative connectivity among grassland patches using methods and tools designed by Theobald et al. (2012). That is, with increasing landscape fragmentation, there is increasing "resistance" to lateral movement by species across a given landscape. These models produced a per-pixel value for both intactness and relative connectivity across the entire trinational study area. These scores facilitate documentation of current conditions, and were fed into subsequent landscape conservation design to assist with selecting representative grassland areas with highest potential for restoring and maintaining ecological resilience.

LANDSCAPE CONSERVATION DESIGN

Grassland Priority Conservation Areas (GPCAs) define areas where conservation attention could be concentrated to advance biodiversity conservation goals. Their identification does not imply any particular conservation action, or suggest change in ownership. However, the lands within identified GPCAs present conservation opportunities to be considered, along with current and established management priorities, to strive for compatibility with biodiversity values they support today, or could feasibly support through ecological restoration. Grassland Priority Conservation Areas have been previously identified across this trinational area (PCAP 1998; Gauthier et al. 2003; Pool and Panjabi 2011), each with a primary focus on conserving grassland species. Similar efforts to identify and prioritize places for conservation across portions of this trinational area have included state wildlife action plans (Mawdsley et al. 2016), and across political jurisdictions produced by The Nature Conservancy (Groves 2003; Neely et al. 2006), the Nature Conservancy of Canada (Riley et al. 2007), Fish and Wildlife Joint Ventures (Giocomo et al. 2009), and Landscape Conservation Cooperatives (Olliff et al. 2016).

New information and policy priorities among NAWPA agencies led to the desire to revisit GPCA identification in this region. First, much new mapped information pertaining to grassland types and landscape conditions became available, enabling a focus of grassland diversity to complement prior efforts emphasizing grassland bird species. Second, there was a common desire to enable national reporting of progress toward "Aichi Targets" under the United Nations Convention on Biodiversity (CBD). Nations who signed on to the Convention met in Nagoya, Aichi Prefecture, Japan, in 2010 and committed to a series of national conservation targets. Aichi Target 11 states that "By 2020, at least 17 percent of terrestrial and inland water areas… especially areas of particular importance for biodiversity and ecosystem services, are conserved through effectively and equitably managed, ecologically representative

Table 4. Proportion of current extent of each major grassland types predicted to occur across a range of quality and condition, based on the NatureServe landscape condition model.

Grassland type	0.81–1.0 (*best condition*)	0.61–0.80 (*moderate–good*)	0.41–0.60 (*moderate*)	0.21–0.40 (*moderate–poor*)	0.00–0.20 (*worst condition*)
Chihuahuan Sandy Plains Semi-Desert Grassland	72%	19%	6%	2%	1%
Chihuahuan Loamy Plains Desert Grassland	61%	24%	8%	5%	3%
Apacherian-Chihuahuan Semi-Desert Grassland and Steppe	57%	23%	13%	5%	2%
Western Great Plains Sand Prairie	51%	15%	16%	13%	6%
Western Great Plains Shortgrass Prairie	45%	22%	15%	13%	6%
Northwestern Great Plains Mixed-grass Prairie	36%	23%	24%	12%	5%
Northern Great Plains Fescue Mixed-grass Prairie	28%	20%	40%	11%	2%
Southeastern Great Plains Tallgrass Prairie	18%	13%	23%	28%	19%
Central Mixed-grass Prairie	10%	17%	28%	29%	16%
Texas Blackland Tallgrass Prairie	6%	10%	18%	30%	36%
Central Tallgrass Prairie	4%	7%	28%	34%	28%
Northern Tallgrass Prairie	3%	9%	28%	35%	25%
All Types Combined	*39%*	*20%*	*20%*	*14%*	*7%*

and well-connected systems of protected areas and other effective area-based conservation measures, and integrated into the wider landscape and seascape." The specific forms of defining "17 percent" and "ecologically representative" area is left to each reporting country.

We used mapped information on each major grassland type to assess relative representation in conservation investments under Aichi Target 11. We also utilized estimates of historical extent of each grassland type to assist with gauging progress relative to the Aichi Target 17% percent-area milestone. Grassland Priority Conservation Areas (GPCAs) were identified to build upon existing conservation lands, and to use Aichi Target 11 as one practical milestone for temperate grassland representation. This approach in landscape conservation design helped to reflect the diversity of major grassland-dominated landscapes and habitat requirements for many associated species.

Two major site selection strategies were used:
1) Efficient type representation strategy for grassland types that retain large proportional area and/or relatively large intact blocks based on current grassland condition and connectivity.
2) Emphasis on consolidation of high-value sites for restoration of types that have experienced extreme loss through land conversion since 1800.

Landscape design was completed by using a grid of nearly 48,000 hexagonal spatial analysis units, each 100 km^2 in size. Given the trinational scale of analysis, areas identified were no smaller than 100 km^2, with the presumption that subsequent planning decisions would bring local knowledge to specify areas for conservation action. We applied common systematic conservation planning methods (Groves and Game 2016) and spatial optimization algorithms (Ball et al. 2009) augmented by expert review and refinement. In the first and primary step, for each hexagon, a measure of grassland extent (standardized to 0.0–1.0) was divided by the inverse of the landscape intactness score (also on the scale of 0.0–1.0) to provide a relative index of their potential contribution toward grassland conservation goals. That is, hexagons with high areal grassland extent and high landscape intactness scored highest for initial site selection. Highest-scoring hexagons were selected preferentially in sufficient numbers to initially advance toward the 17% representation goal. Grassland experts from each jurisdiction reviewed and refined site selection. Existing managed areas, land use intensity and connectivity maps, and at-risk species distributions, and already identified priority conservation areas, were all used as ancillary information to refine areas selection aiming to efficiently represent each grassland type in landscapes of greatest complementary conservation value. Once selected, hexagons were finalized, and adjacent clusters were systematically identified and labeled to form 177 distinct GPCAs.

Results include representative areas for all 12 types, and achieve levels of representation that meet, or surpass, Aichi Target 11 (Figure 3). Others that do not achieve those levels of representation are included in landscapes with at least some substantial potential for successful restoration. Table 5 includes a high-level summary of grassland type representation within the newly identified GPCAs. The Nebraska Sand Hills includes an extensive and contiguous area of Western Great Plains Sand Prairie, so it is feasible to represent the highest proportion of this type. Our results indicate that about 27% of estimated historical extent of this type occurs within identified GPCAs. Six other major grassland types met or surpassed the 17% milestone of Aichi Target 11. These include Northwestern Great Plains Mixed-grass Prairie (21%), Chihuahuan Loamy Plains Desert Grassland (19%), Central Mixed-grass Prairie (18%), Southeastern Great Plains Tallgrass Prairie (18%), Western Great Plains Shortgrass Prairie (17%), and Apacherian-Chihuahuan Semi-Desert Grassland (17%). These types dominate the relatively dry-to-arid portions of the study area across the western Great Plains and extending throughout the Chihuahuan Desert. Only the Southeastern Great Plains Tallgrass Prairie represents tallgrass prairie types in this group. It occurs in relatively humid areas of eastern Kansas and Oklahoma, but relatively shallow soils with extensive rock outcrops in its core distribution of the Flint Hills has limited intensive conversion of this type for agriculture. Occurring in relatively small and fragmented areas, the Chihuahuan Sandy Plains Semi-Desert Grassland was not represented at or above the 17% milestone. As anticipated, it was also quite challenging to adequately represent other tallgrass prairie types occurring across the more humid, eastern portions of the region, as these types have been extensively converted for agriculture (Table 1). Identified GPCAs encompass Central Tallgrass Prairie (4%), Northern Great Plains Fescue Mixed-grass Prairie (4%), Northern Tallgrass Prairie (2%), and Texas Blackland Tallgrass Prairie (1%). Undoubtedly, these types bring the greatest challenges for restoration and representation of habitat conditions for the high diversity of species they each support. Taken together, approximately 15% of estimated historical extent of all 12 major temperate grassland types occurs in newly identified GPCAs (Table 5). While just below the 17% Aichi Target 11 milestone, the selection of GPCAs still represents all major grassland types in areas most likely to support successful conservation.

Tables 6–8 provide a high-level summary of conditions associated with the 177 identified GPCAs, again organized by the predominant grassland type they contain. Table 6 summarizes spatial information used in the landscape condition model. The table is sorted based on the estimated total area of each grassland type occurring within identified GPCAs. While purposely designed to avoid and minimize overlap with current intensive—and potentially threatening—land uses, each GPCA will inevitably include a footprint of some level of current land use. Knowledge of these patterns can be helpful for clarifying conservation strategies. Patterns in the occurrence and abundance of different road types, development intensity, wells and mines, current croplands, pasture and ruderal vegetation, and major centers of invasive plant species are summarized. On average, the GPCAs avoid primary roads and highways, but all include varying levels of more local and unpaved road networks. Current cropland makes up a substantial component of GPCAs that represent mixed-

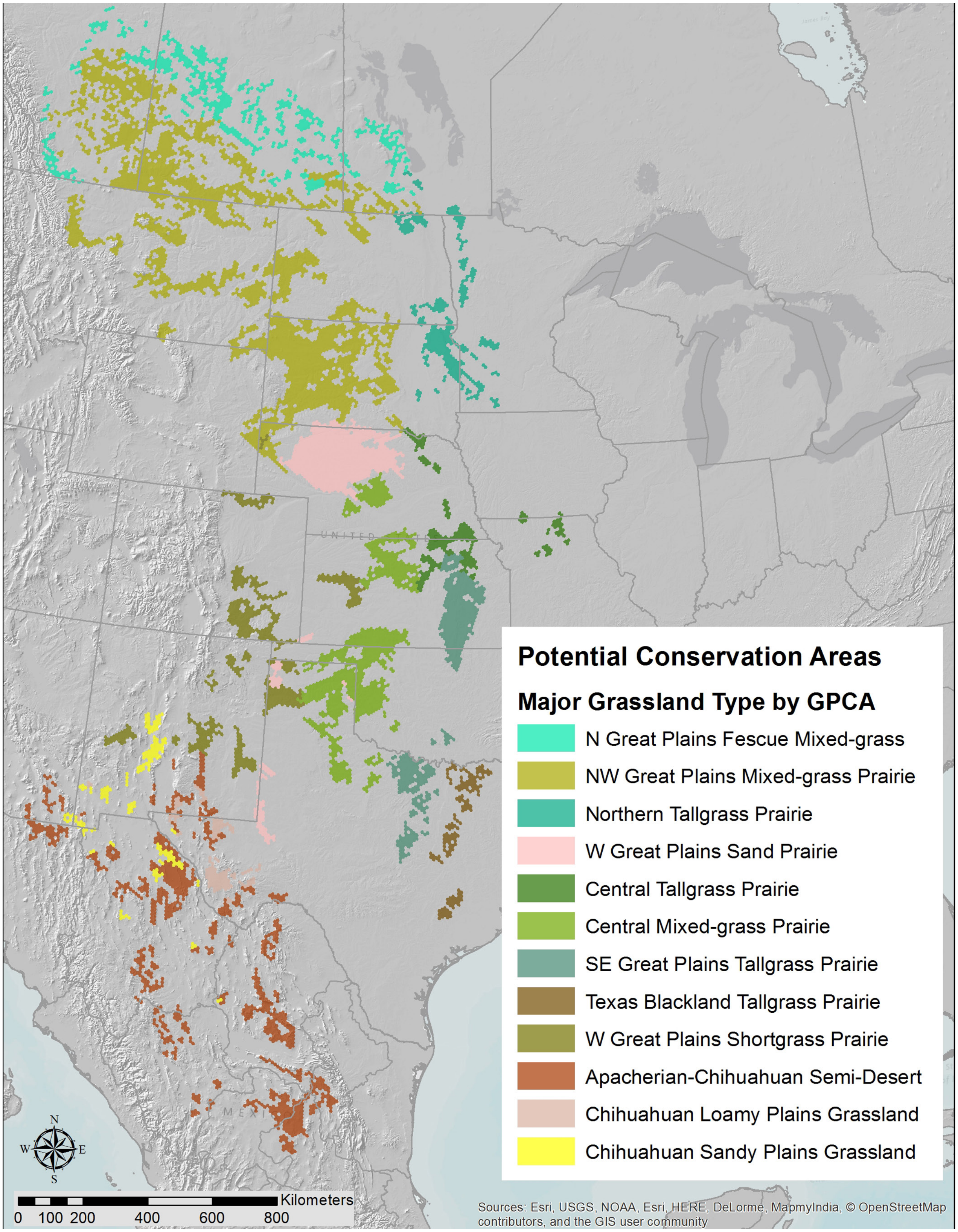

Figure 3. Grassland Potential Conservation Areas (GPCAs) based on representation of 12 major temperate grassland types (ordered north to south).

Table 5. Proportion of historical extent of each major grassland types represented in identified Grassland Potential Conservation Area (GPCA).

Grassland type	Historical extent estimate (km^2)	Current extent estimate (km^2)	Number of GPCAs	Grassland km^2 within GPCAs	% Historical extent in GPCAs
Western Great Plains Sand Prairie	107,300	38,000	7	29,200	27
Northwestern Great Plains Mixed-grass Prairie	620,900	307,500	26	128,400	21
Chihuahuan Loamy Plains Desert Grassland	38,300	14,400	10	7300	19
Central Mixed-grass Prairie	259,000	77,000	9	39,200	18
Southeastern Great Plains Tallgrass Prairie	108,000	31,400	5	19,300	18
Western Great Plains Shortgrass Prairie	259,000	188,000	14	50,700	17
Apacherian-Chihuahuan Semi-Desert Grassland and	249,400	152,200	34	42,000	17
Chihuahuan Sandy Plains Semi-Desert Grassland	8100	1600	16	1000	12
Central Tallgrass Prairie	242,000	20,100	8	10,000	4
Northern Great Plains Fescue Mixed-grass Prairie	137,000	18,000	29	5400	4
Northern Tallgrass Prairie	157,200	6500	15	3500	2
Texas Blackland Tallgrass Prairie	41,400	670	4	400	1
Total	**2,227,600**	**855,370**	**177**	**342,400**	**15%**

grass prairie types, as these large GPCAs tend to occur in landscapes supporting both cropland and pasture. This mixture of current land uses is exemplified by Northwestern Great Plains Mixed-grass Prairie. GPCAs representing this type extend across the northern Great Plains where the mix of land use is well supported.

Table 7 summarizes existing protected areas as they contribute to the GPCAs. Following from Table 3, a relatively small proportional area of the newly identified GPCAs are currently protected under one of the I–VI categories from IUCN, with 1.2%, or a total of 40,496 km^2, occurring in lands designated into at least one of the IUCN status categories. Of these, IUCN category VI (*Protected area with sustainable use of natural resources*) is most common with 23,133 km^2, or 54% of the total GPCA lands, designated as such.

Table 8 summarizes information on complementary conservation investments and priorities related to the newly identified GPCAs associated with each major grassland type. "Other Conservation Areas" tend to include US public lands that have a clear multiple-use mandate, but do not fall within any of the IUCN protected land categories. These areas, such as National Grasslands managed by the US Forest Service, encompass over 46,500 km^2 and could be reviewed within each GPCA to determine where additional levels of biodiversity conservation could be emphasized. Conservation easements represent the transfer of development rights for the benefit of conservation values. While relatively small, these areas are currently most concentrated in Northwestern Great Plains Mixed-grass Prairie, Northern Tallgrass Prairie, and Western Great Plains Shortgrass Prairie, respectively. If one combines these current conservation investments, they amount to over 52,000 km^2, or about 15% of the newly identified GPCA area.

The priority areas already identified by The Nature Conservancy and the Nature Conservancy of Canada include substantial lands and encompass fully 84% of the land area in newly identified GPCAs. This result was to be expected in that the purpose and intent of those planning processes overlaps substantially with the goals of this effort, and their mapped boundaries were taken into account as sites were identified.

BUILDING ON THIS ANALYSIS

While this process followed common methods and best practices used in regional-scale landscape conservation design, it was intended as a relatively rapid, subcontinental-scale analysis, and so there are several key considerations for building on these results to advance conservation and build resiliency.

First, since we focused primarily on major grassland types, there are many less abundant ecosystem types not yet treated. We anticipate that most characteristic upland ecosystems, as well as needs for most grassland birds, have been represented within the GPCAs. However, much complementary analysis and priority-setting in this region has centered on wetland ecosystems and the diversity of species they support (e.g., Beyersbergen et al. 2004). Similarly, systematic prioritization, assessment, and monitoring of lake and stream ecosystems (e.g., Stagliano 2006) could provide another important complement to this analysis.

Second, this effort did not directly address the rates of landscape change or use forecasting to gauge the risk of future land use patterns. While land use change tends to follow existing patterns, and those patterns were used directly in GPCA selection, there can be land use trends that are difficult to foresee, such as trends in energy development stimulated by changes in technology or policy. For example, concentrated renewable energy development

Table 6. Summary information on land uses and threats within GPCAs associated with each major grassland types (linear features expressed as km distance, areal features as km²).

Grassland type	Grassland area in GPCAs (km²)	Primary roads (km)	Secondary roads (km)	Local roads (km)	Unpaved roads (km)	Development (High–Low) (km²)	Agriculture cropland (km²)	Pasture & ruderal (km²)	Invasive plants (km²)
Northwestern Great Plains Mixed-grass Prairie	128,400	3650	59,365	79,285	67,232	1652	46,698	25,908	3915
Western Great Plains Shortgrass Prairie	50,700	200	2277	33,571	3821	598	3785	191	1784
Apacherian-Chihuahuan Semi-Desert Grassland and Steppe	42,000	656	710	11,062	11,321	46	99	4932	–
Central Mixed-grass Prairie	39,000	881	7218	90,084	2883	2369	13,757	2273	6156
Western Great Plains Sand Prairie	29,200	66	2946	25,990	4242	514	1988	319	720
Southeastern Great Plains Tallgrass Prairie	19,300	1127	6277	56,872	1203	2342	3342	3898	–
Central Tallgrass Prairie	10,000	234	3215	27,909	605	1059	6731	3254	–
Chihuahuan Loamy Plains Desert Grassland	7300	–	703	10,260	746	79	3	0	–
Northern Great Plains Fescue Mixed-grass Prairie	5400	2617	37,212	588	37,212	19	22,711	4767	7
Northern Tallgrass Prairie	3500	709	4693	39,188	3355	1700	16,167	3146	489
Chihuahuan Sandy Plains Semi-Desert Grassland	1000	352	364	6503	1317	47	45	343	–
Texas Blackland Tallgrass Prairie	400	480	2331	22,847	84	938	1467	5037	1
Total	**342,400**	**10,972**	**127,310**	**404,159**	**134,021**	**11,363**	**116,792**	**54,068**	**13,071**

can rapidly expand due to advances in technology and placement of transmission infrastructure (Lewis and Wiser 2007). Changes in commodity prices have also brought increasing unpredictability in patterns of land conversion in this region (Wright and Wimberly 2013). Furthermore, we have not specifically addressed potential near-term direct effects of climate change on grassland biodiversity or interactions of changing climate with other ecosystem stressors such as displacement of native species by invasive species expansion. Following emerging recommendations for best practices (Gillson et al. 2013; Comer 2018), additional steps could be applied to evaluate and potentially modify identified GPCAs to maximize their resilience in the face of climate change.

Third, we were limited to available spatial data and modeling to gauge relative intactness and connectivity among grasslands. There are undoubtedly land use legacies and current impacts not adequately reflected in spatial data (Gauthier et al. 2003). For example, grazing pressure on these grasslands has varied substantially over decades, and its effects may not always correlate well with current patterns in land use and infrastructure. Therefore, our measures of landscape intactness could mask true conditions on the ground where past land uses have severely degraded grassland condition in areas that are now extensive, contiguous, and remote. Regional-scale remote sensing indices (e.g., Muldavin et al. 2001) may prove valuable in further assessing landscape conditions where impacts are more diffuse.

All three of these areas should be considered and appropriate actions should be taken to make the most of our analysis. These results should be suitable for use by the NAWPA agencies as they engage with partners and stakeholders in conservation planning, protected area expansion, habitat restoration, and environmental monitoring. Specific conservation objectives for each GPCA may then be collaboratively developed based on grassland type, associated species, threats, relative cost of conservation action, associated stakeholder needs, and other factors.

Table 7. Summary information on current conservation investments within GPCAs associated with each major grassland types (km^2).

Grassland type	IUCN I *Strict Nature Reserve or Wilderness*	IUCN II *National Park*	IUCN III *Natural Monument or Feature*	IUCN IV *Habitat/Species Management Area*	IUCN V *Protected Landscape*	IUCN VI *Protected area with sustainable use of natural resources*	IUCN I-VI Combined
Apacherian-Chihuahuan Semi-Desert Grassland and Steppe	512	166	10	130	290	5317	5913
Central Mixed-grass Prairie	31	–	4	229	632	–	896
Central Tallgrass Prairie	–	–	13	48	489	–	550
Chihuahuan Loamy Plains Desert Grassland	–	–	–	–	245	–	245
Chihuahuan Sandy Plains Semi-Desert Grassland	625	–	–	730	525	816	2696
Northern Great Plains Fescue Mixed-grass Prairie	64	817	25	1219	122	5070	7317
Northern Tallgrass Prairie	0	–	73	235	1375	318	2001
Northwestern Great Plains Mixed-grass Prairie	1332	1537	36	2089	2696	11,612	19,302
Southeastern Great Plains Tallgrass Prairie	1	–	1	45	375	–	422
Texas Blackland Tallgrass Prairie	–	–	–	5	30	–	35
Western Great Plains Sand Prairie	173	–	–	405	470	–	1048
Western Great Plains Shortgrass Prairie	64	–	–	12	1487	–	1563
Total	2801	2520	161	5145	8736	23,133	42,496

CONCLUSIONS

We have demonstrated a systematic approach to use major grassland ecosystem type distributions as a novel approach for advancing toward, and beyond, Aichi Target 11 for ecosystem representation. Grassland Potential Conservation Areas can serve as one important focus for collaborative conservation action to build landscape resiliency in the face of accelerating environmental change.

Much of the Great Plains and Chihuahuan Desert is dominated by private lands. Conservation strategies throughout this region are inherently collaborative, often involving partnerships and programs aiming to provide technical assistance and financial incentives that encourage natural resource conservation. The emergence of ecosystem service markets across North America may provide additional opportunities to advance conservation within and among GPCAs where markets for soil carbon, water resources, and wetland or grassland habitat mitigation generate revenue for land owners and managers.

From this analysis, we have produced an online conservation atlas to share project data and provide input to subsequent agency and partner decision making processes (www.DataBasin.org). The site includes a series of maps, text, and tabular summaries to describe the GPCAs in terms of the grassland types, existing conservation investments, and threats associated with their conservation. It may be accessed by the public and partners interested in biodiversity conservation across this trinational area. Supplementary materials associated with this paper include descriptions of each major grassland type, tabular summaries of grassland associated species, and GPCA site summaries, and are found on the DataBasin site.

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Table 8. Summary information on Other Conservation Areas, conservation easements, and TNC or NCC conservation priorities in GPCAs associated with each major grassland types (km^2).

Grassland type	Other conservation area (km^2)	Conservation easement (km^2)	TNC or NCC priority (km^2)
Apacherian-Chihuahuan Semi-Desert Grassland and Steppe	5150	143	43,997
Central Mixed-grass Prairie	319	42	39,155
Central Tallgrass Prairie	34	224	7711
Chihuahuan Loamy Plains Desert Grassland	2065	244	7509
Chihuahuan Sandy Plains Semi-Desert Grassland	2472	534	7525
Northern Great Plains Fescue Mixed-grass Prairie	–	–	891
Northern Tallgrass Prairie	700	1166	7099
Northwestern Great Plains Mixed-grass Prairie	26,485	2145	68,031
Southeastern Great Plains Tallgrass Prairie	509	207	22,971
Texas Blackland Tallgrass Prairie	79	16	1781
Western Great Plains Sand Prairie	1484	252	53,411
Western Great Plains Shortgrass Prairie	7250	1002	35,727
Total	46,547	5975	295,807

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