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American Prairie Reserve: Climate Change Mitigation and Adaptation through Large-Scale Grassland Conservation

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EXECUTIVE SUMMARY

Climate change will be a major driver of land management decisions in the Great Plains of North America. This is a function of: (1) how to manage land to mitigate greenhouse gas (GHG) emissions and (2) how to adapt to the effects that a changing climate will have on agriculture and biodiversity. The effects of a changing climate (warmer and drier) in the Great Plains is already emerging and is expected to intensify under most climate change scenarios.

The biggest threat to GHG mitigation by grasslands is their conversion to croplands, which results in a rapid loss of soil carbon and increase in CO_2 and N_20 released to the atmosphere. Conversion to croplands reduces the ecosystem's capacity to adapt to climate change. Prioritizing large grassland ecosystems advances not only biodiversity conservation, but also mitigates GHG emissions and aids in adaptation to climate change of the region's human, plant, and animal communities.

American Prairie Reserve (APR) exists to build a grassland reserve of more than 3 million acres in the Northern Great Plains of northeast Montana, a region with a high rate of grassland conversion to cropland. APR's management policies and practices focus on four objectives: (1) stopping the conversion of grassland to cropland or any other form of land use; (2) restoring native prairie on agricultural croplands; (3) restoring native species, ecological processes and habitat heterogeneity; (4) scaling up these management actions to ever-larger landscapes.

APR has implemented a three-pronged approach to meet these objectives:

1. Management of deeded lands. As of June 2016, APR has acquired 86,018 acres of deeded land, of which 88% is in grassland and 12% in cropland. APR permits no cultivation of its intact grasslands, of which 37% are permanently protected by conservation easements, and it has begun grassland restoration on 40% of its cropland holdings.

2. Collaboration with public land agencies. APR holds grazing leases on 266,642 acres of Bureau of Land Management and Montana state trust lands for which APR's primary goal is, as on APR's deeded lands, to conserve native biodiversity and climate-change mitigation and adaptation functions. Moreover, by acquiring ranches with grazing leases on the C.M. Russell National Wildlife Refuge, APR has enabled the refuge to retire 63,777 acres of grazing leases and to fully devote management of this land to maintaining ecosystem health.

3. Technical assistance and financial incentives for private landowners. In 2014 APR established Wild Sky Beef, a for-profit subsidiary that offers technical assistance and financial incentives to private landowners who follow biodiversity-friendly management practices. Landowners enrolled in the Wild Sky Beef program are not allowed to convert grassland to cropland. As of June 2016, three landowners, representing 33,654 acres of native grasslands, had already enrolled.

To date, this three-pronged approach covers 450,000 acres. A rough estimate of the carbon stored in the soils of this land is 29.7 million t CO_2, equivalent to the CO_2 released annually by 6 – 7 million passenger vehicles or by 8.5 typical coal-fired power plants in the United States.

APR's largest contribution to mitigating GHG emissions and improving climate change adaptation, at least on a per-acre basis, is avoidance of grassland conversion to cropland and restoration of grassland on previous cropland. For calculations in this report, we assume that each acre of grassland converted to cropland in the APR region emits 33 t CO_2. Based on the U.S. government's estimate that the social cost of carbon is \$37/t CO_2, we estimate

the social cost to be $1,221 per acre of converted grassland in the APR region. These figures suggest that if the 96,081 acres of deeded grassland that APR has conserved to date through acquisition and Wild Sky Beef were cultivated, nearly 3.17 million t CO_2 would be released at a social cost of $117 million.

APR's progress in acquiring and conserving intact grasslands generates diverse environmental services—carbon sequestration, biodiversity, prevention of soil erosion, good water quality, recreation, education and others—all of which provide social benefit to the public. The estimated economic value of just one of these benefits—carbon sequestration—highlights the economic leverage of APR's investment in grassland conservation. The estimated net social benefit of $1,221 for acquiring and saving 1 acre of grassland from being plowed is roughly three times the per-acre cost of land in the APR region—a $3 return for every $1 invested. Although this ratio would shrink somewhat by including the cost of managing the land, that factor would be more than offset by including the monetary values of other environmental services from APR's grasslands and wildlife.

APR will continue to rapidly increase the acres of grasslands restored and conserved through its various approaches to land management. With each acre added, APR will restore and conserve more of the region's biodiversity, increase the ecosystem's capacity to adapt to climate change, and ensure that more carbon is permanently sequestered in the soils of the region's vast grasslands.

*About the Authors

Curtis Freese is a conservation biologist and was the founding executive director of American Prairie Reserve in 2001. In addition to launching World Wildlife Fund's Northern Great Plains Program, Curt's previous posts include vice president of International Programs for WWF, executive director of Yellowstone Ecosystem Studies, head of Latin American Programs for the U.S. Fish and Wildlife Service, biologist for Costa Rica's National Park Service, assistant professor at Rhodes College in Memphis and adjunct professor at Montana State University and University of Massachusetts. Curt has conducted research and conservation work throughout much of North America and Latin America, as well as in southern Africa and the Arctic. Among his publications is *Wild Species as Commodities: Managing Markets and Ecosystems for Sustainability*, one of three books he has published on the linkage between economics and biodiversity conservation. Curt received his B.S. from Iowa State University and Ph.D. from Johns Hopkins University. He currently lectures, writes and consults on conservation.

Kyran Kunkel, Lead Scientist for American Prairie Reserve, has more than a decade of experience building the Reserve and the region's wildlife populations. His role involves working with collaborators to restore the natural abundance of the Northern Plains, both on APR lands and neighboring ranchers participating in our wildlife-friendly beef program. This includes working alongside staff to restore Reserve lands according to the *Freese Scale for Grassland Biodiversity*, which he co-created with Curt Freese and Sam Fuhlendorf. Kyran has led a wide range of efforts including bison restoration with World Wildlife Fund, cougar conservation, swift fox reintroduction, wolf research, and tracking pronghorn migration routes. Earlier in his career, he studied moose, wolverines, and grizzly and black bears, and he has also served as the Senior Biologist for the Turner Endangered Species Fund. Kyran is also an Affiliate Professor in Wildlife Biology at the University of Montana.

Mark Sommer, Associate and Geographic Information Administrator for American Public Land Exchange, has worked with American Prairie Reserve since its inception, being involved in every land acquisition transaction APR has entered. Mark has more than two decades of experience in his field, including the Moab/Monticello Ranger District and the Red River Ranger District as a Minerals and Lands Administrator. Mark obtained his Master's Degree in Forest Soils from the University of Idaho.

INTRODUCTION

Climate change will increasingly be a major driver of land management decisions and of socioeconomic conditions in the grassland* ecosystems of North America's Great Plains. The Northern Great Plains has already experienced some of the greatest increases in temperature in the continental U.S. in recent decades, increases that are projected to continue with multiple effects on agriculture, biodiversity and the socioeconomic wellbeing of its residents (USGCRP 2014).

Land use—particularly agriculture, forest and rangeland management—contributes an estimated 24% of direct greenhouse gas (GHG) emissions and thus has a pivotal role in addressing climate change (IPCC 2014). Unlike energy systems, land use can affect GHG levels by not only altering emissions, but also by removing CO_2 from the atmosphere via photosynthesis and sequestering the carbon in organic material. GHG emissions from land use are projected to decline over the next few decades and, if we manage land wisely, terrestrial ecosystems may become a carbon sink before the end of the century. With rangelands covering 40% of the Earth's land surface, storing 50% more carbon than forests worldwide, and storing around 20% of global soil organic carbon (Conant 2010), their wise stewardship is central to realizing this goal.

Located in the glaciated plains of northeast Montana, American Prairie Reserve's (APR) mission is to create one of the largest wildlife reserves in North America. As APR becomes an increasingly prominent landowner and land manager in the Great Plains, it has an extraordinary opportunity to provide leadership in managing grasslands for climate change mitigation and adaptation on a large scale. We review in this white paper why and how APR is addressing this challenge.

The paper is divided into five sections:

1. Description of APR and the ecological and conservation significance of its location in northeast Montana.

2. Effects of climate change on ecosystems in the APR region, which highlight why climate change is of concern to APR and inform management priorities for ecological adaptation to climate change.

3. Effects of land use in the Great Plains, and particularly the APR region, on GHG emissions, which guide APR's strategy for implementing and promoting land management that mitigates emissions.

4. Review of APR's land management goals, progress toward meeting those goals, and resulting effects on climate change mitigation and adaptation.

5. Discussion and conclusion

*The terms "grassland," "rangeland" and "prairie" are used interchangeably here to refer to ecosystems where grass is the dominant vegetation at the landscape scale. Much of the grassland habitat of the APR region is often called "sagebrush steppe" because of the prominence of sagebrush.

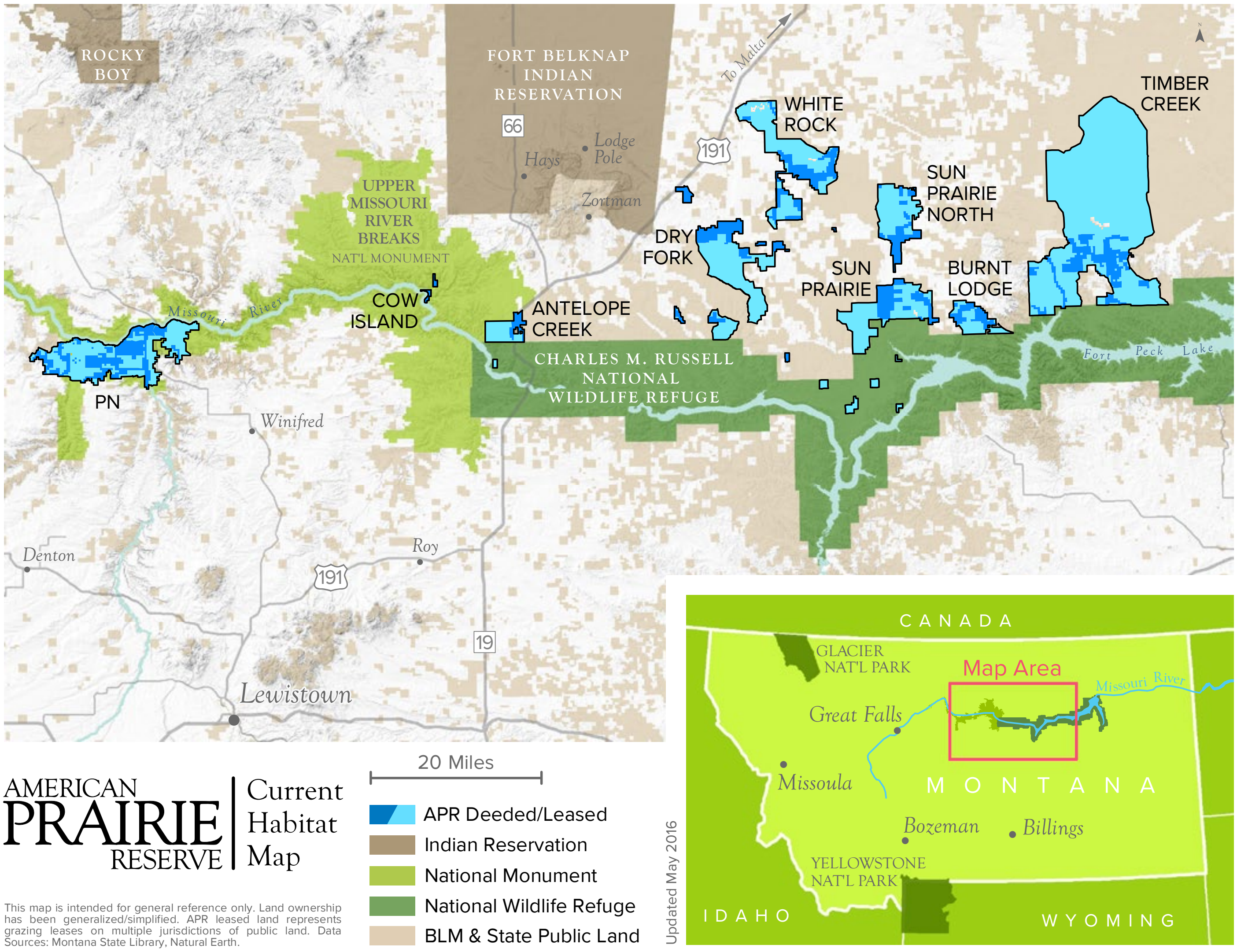

Figure 1. American Prairie Reserve and its primary region of interest.

AMERICAN PRAIRIE RESERVE

APR is a nonprofit organization whose mission is to build, restore and conserve for public benefit a prairie-based wildlife reserve of more than 3 million acres by managing private lands it acquires and collaborating in management of neighboring public lands (APR 2015). This mission responds to the precarious national and global status of temperate grassland ecosystems. Forty-six percent of the temperate grasslands, savannas and shrublands biome has been converted to other land uses, among the highest conversion levels of any terrestrial biome globally, while just 4.6% is protected for biodiversity conservation, the lowest of any biome (Hoekstra et al. 2005). The Great Plains fares even worse, with just 1% protected (CEC and TNC 2005).

APR is located on the glaciated plains of northeast Montana (Figure 2), a region of climatic extremes. Temperatures in winter may register –30° F and in summer more than 100° F. Average annual precipitation is 12 inches, but varies widely with multi-year droughts not uncommon. Mixed-grass prairie/sage-brush steppe is the primary habitat (Figure 1). The Missouri River and rugged Missouri River Breaks run through this region. Livestock ranching and wheat farming are the primary land management activities. The Bureau of Land Management (BLM) leases extensive grazing lands to ranchers and APR in and around the APR region. The Charles M. Russell National Wildlife Refuge (CMR Refuge), at 1.1 million acres, protects a large swath of the region.

The APR region stands out as a national and international priority for grassland conservation because of its intactness and extraordinary biodiversity. Roughly 90% of the region remains in native or semi-native habitat (Figure 3). Among various biodiversity values, the region lies within the Great Plains hot-spot for grassland bird diversity (Knopf 1996), is a priority area for endangered

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Figure 2. Mixed-grass prairie and sage-brush steppe are the dominant plant communities of the APR region.

species and other species of concern such as the black-footed ferret, greater sage-grouse, Sprague's pipit, Baird's sparrow, chestnut-collared longspur, McCown's longspur, golden eagle and pallid sturgeon (USFWS 2015b), and harbors important populations of all ungulates found here before EuroAmerican settlement—bison, elk, deer, pronghorn and bighorn sheep.

APR began acquiring ranch properties in 2004 and now owns and holds grazing leases on 266,642 acres of land. In addition, by purchasing ranches that held grazing leases on the CMR Refuge, APR has enabled the refuge to retire 63,777 acres from livestock grazing (Figure 4).

To meet its long-term goal of more than 3 million acres protected for biodiversity, over the next few decades APR plans to acquire roughly an additional 1.6 million acres of private lands and their public land grazing leases. Moreover, to foster sound land stewardship in the region, in 2014 APR created Wild Sky Beef, which pays participating ranchers to restore and maintain grassland habitat and wildlife.

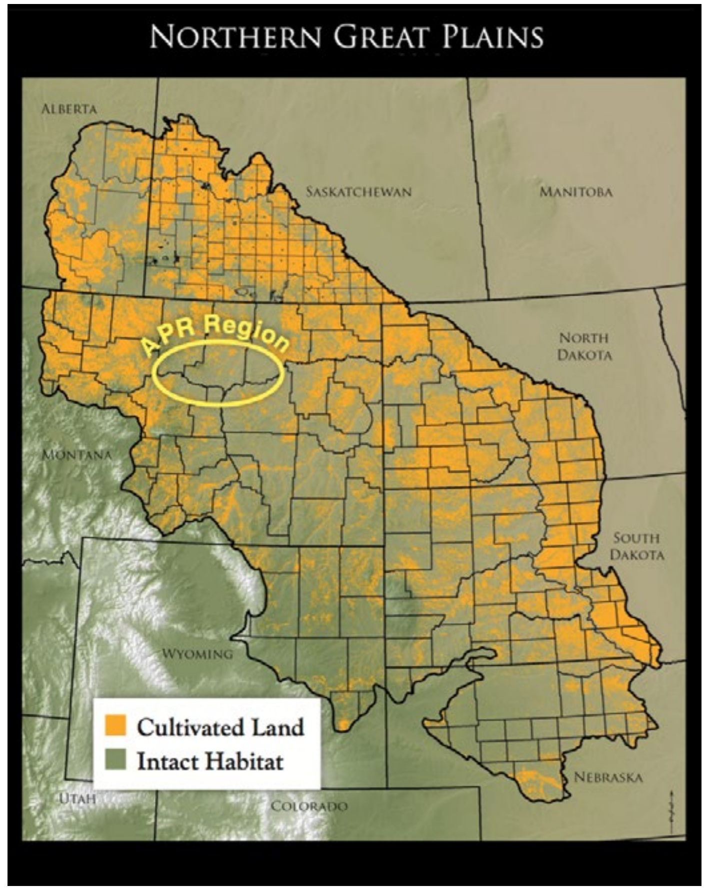

Figure 3. Intact habitats of Northern Great Plains. Approximately 90% of lands in the APR region remain in native habitat. (Source: Gage et al., In press)

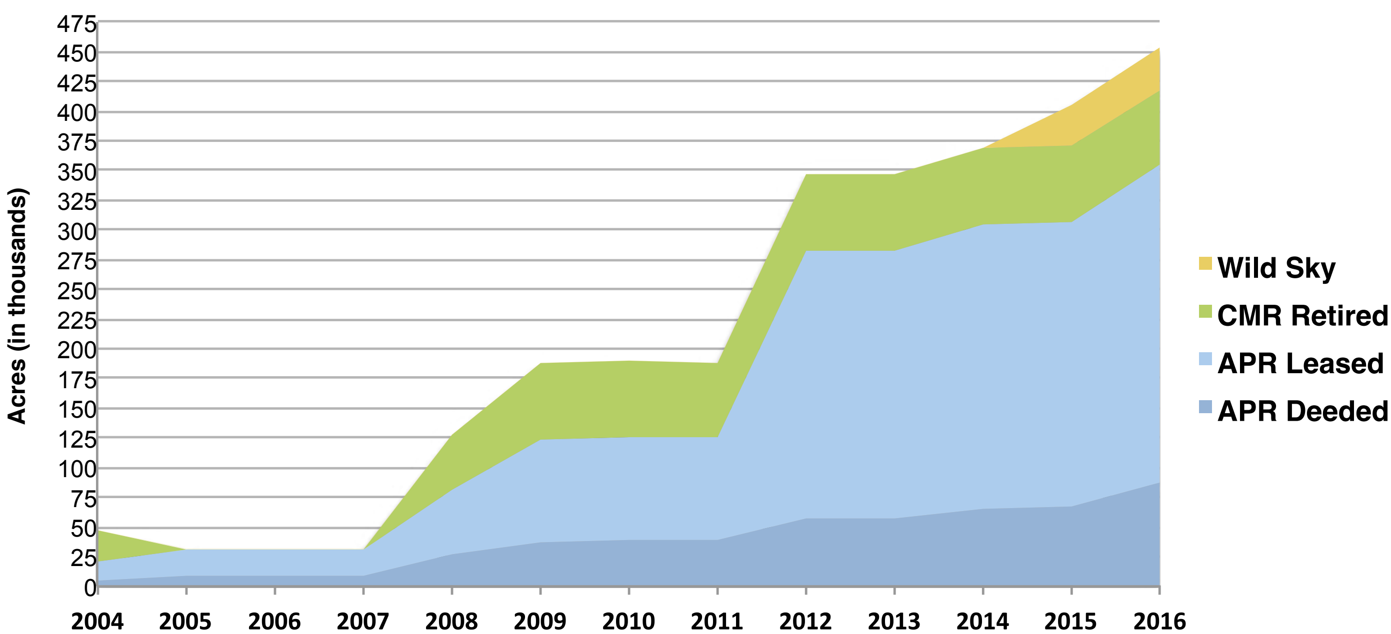

Figure 4. Growth in APR deeded lands and leased public lands, in CMR Refuge lands that APR acquisitions have enabled the refuge to retire from livestock grazing, and in private lands enrolled in the Wild Sky Beef program that began in 2014.

EFFECTS OF CLIMATE CHANGE ON ECOSYSTEMS IN THE APR REGION

The National Climate Assessment (USGCRP 2014) cautions that "The interaction of climate and land-use changes across the Great Plains promises to be challenging and contentious." Even under scenarios of reduced GHG emissions, the Northern Great Plains, including the APR region, can expect significant climatic change, with complex and potentially far-reaching effects on ecosystems and agriculture (Table 1).

The most obvious effects of climate change in the region will largely stem from an increasing water deficit. The daily, seasonal and inter-annual ebbs and flows of water availability—dictated by wide precipitation and temperature fluctuations—is the single largest driver of plant and animal ecology and ecosystem processes in the region (Samson et al. 2004). A projected 10% increase in precipitation in the Northern Great Plains, mostly in winter and spring, may favor early season crop growth, but is likely to be more than offset by a projected increase in temperature resulting in higher evapotranspiration rates and drier summer and fall conditions (USGCRP 2014). The Northern Great Plains has already experienced some of the greatest average winter temperature increases in the United States (Figure 5) and substantial increases in summer temperatures are predicted under future climate change scenarios (Figure 6). Lands that are now marginally arable may become largely non-arable. An increase in severe precipitation events, which has already begun, will lead to greater flooding, soil erosion and nutrient loss, with downstream consequences as far away as the dead zone at the mouth of the Mississippi River in the Gulf of Mexico (USGCRP 2014).

Livestock production in the APR region may decline due to a combination of more heat stress and reduction in forage quantity and quality; drier conditions reduce plant growth while higher temperatures and CO_2 levels

	Higher Average Temperature	**Overall Drier Conditions** (increased evapotranspiration expected to more than offset increased precipitation)
Agriculture	• Lengthened growing season of crops • Insect pests & invasive plants may experience higher winter survival rates • Reduced livestock production due to heat stress & accelerated soil N loss that reduces forage quality • Forage productivity & quality likely affected if ratio of C_3 to C_4 plants changes • Earlier phenology of crop pollinators or crop flowering may disrupt crop pollination if pollinators or crops do not adapt to maintain synchrony; maintenance of high pollinator diversity may mitigate this potential problem	• Marginally productive lands may become non-arable & increase in severe precipitation events may increase flooding, erosion & nutrient loss; however, increased winter/spring precipitation may enhance early-season crop growth • Lower grassland productivity will reduce cattle production, perhaps exacerbated by higher CO_2 reducing N content of plants, though may be partially offset by higher CO_2 levels increasing water-use efficiency of plants
Native Habitats & Plants	• May cause shift in plant communities; e.g., C_4 grasses likely to increase relative to C_3 grasses, climate for sagebrush steppe may become less suitable in southern & more suitable in northern APR region • Wetlands, especially in nearby prairie pothole region, will disappear & cause decline in some wetland birds species that frequent APR region • Phenology of pollinated plants likely to advance, but uncertain if pollinators will remain synchronous; if not, could be disruptive of plant reproduction and alter plant communities	• Overall decline in stream flow combined with more floods caused by increased severe precipitation events likely to alter associated aquatic & riparian habitats • Likely shifts in composition of plant communities & distribution of habitats; e.g., C_4- versus C_3-dominated grasslands & prominence of open grasslands versus sagebrush steppe.
Native Animals	• Earlier arrival of migratory birds on breeding grounds may precede food production & expose young to lethal inclement weather • Birds & other animals may shift ranges into or out of APR region in response to changing climate & habitats; some populations may increase, but others likely to decline & become imperiled if climatically suitable areas become scarce; change in prominence of sagebrush versus open grasslands would affect many species that depend on one of these habitats • Phenological advance of pollinators, primarily bees, likely. If pollinator-host plant synchrony widely disrupted, could deleteriously affect pollinator & host plant populations with cascading effects via food chain on herbivores & predators	• Drier conditions combined with higher temperatures may result in major shifts in bioclimatically suitable habitat for many species, with APR region become more suitable for some and less suitable for others resulting in species range shifts • Native ungulates, particularly bison, may be little affected as they display tolerance of climatic extremes • Drier conditions & higher temperatures will likely change transmission & infection rates of animal pathogens such as West Nile virus & sylvatic plague

Table 1. Effects of predicted higher temperatures and drier conditions on agriculture and biodiversity in APR region.

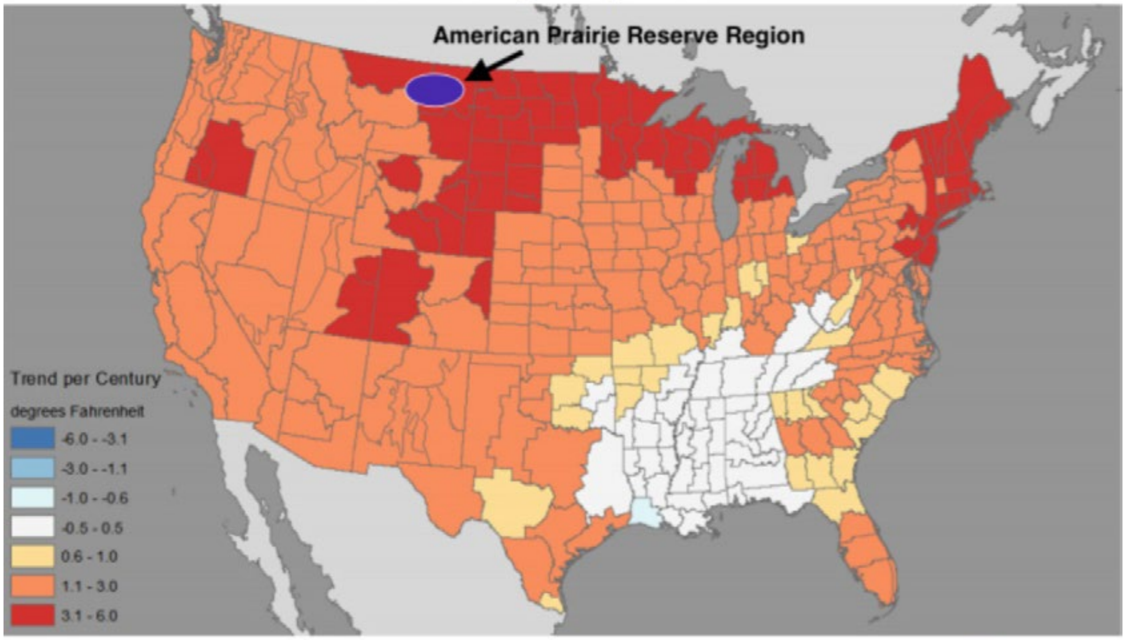

Figure 5. Average winter temperature change in U.S. regions, 1895/96 – 2013/14 (NOAA National Climatic Data Center 2015).

accelerate soil nitrogen loss and lower plant nitrogen uptake, respectively (Craine 2013, Feng et al. 2015, USGCRP 2014). The reaction of C_3 (cool season) grasses and the less common C_4 (warm season) grasses to climate change in the APR region may be important but is difficult to predict. Higher temperatures will favor an increase in C_4 over C_3 grasses, but higher CO_2 concentrations will reduce plant sensitivity to aridity and favor C_3 grasses and forbs over C_4 grasses. Changes in relative abundance of C_3 and C_4 grasses could alter biotic diversity, forage productivity and quality, and carbon sequestration rates, among other effects (Derner et al. 2006, Soussana and Lüsher 2007, von Fischer et al. 2008).

"The interaction of climate and land-use changes across the Great Plains promises to be challenging and contentious."

(National Climate Assessment 2014)

Although higher winter temperatures will extend the crop-growing season, insect pests and invasive plant species may experience higher winter survival rates. Even more difficult to understand is how climate change will affect pathogen-vector-host relationships, both in agricultural and natural systems. For example, prevalence of West Nile virus and sylvatic plague are strongly influenced by climatic conditions, but it remains hard to predict how climate change will affect their impacts on species and public health (Ben-Ari et al. 2011, Schrag et al. 2011, Snäll et al. 2008).

Hotter and drier conditions will also affect aquatic ecosystems and wildlife in a variety of ways. The prairie pothole region (PPR) is of particular concern because of its importance to North American waterbirds and other wildlife, as well as to maintaining water quality and flow, recharge of groundwater, and other ecological services, including carbon sequestration. Though the APR region lies largely outside the southwestern edge of the PPR, loss of these wetlands will affect wildlife, especially migratory waterbirds, whose ranges and migration routes span the region. Warmer temperatures are projected to have the greatest effect on the drier western edge of the PPR (Johnson et al. 2010) and, in fact, wetland drying appears to have already begun in this region (Werner et al. 2013).

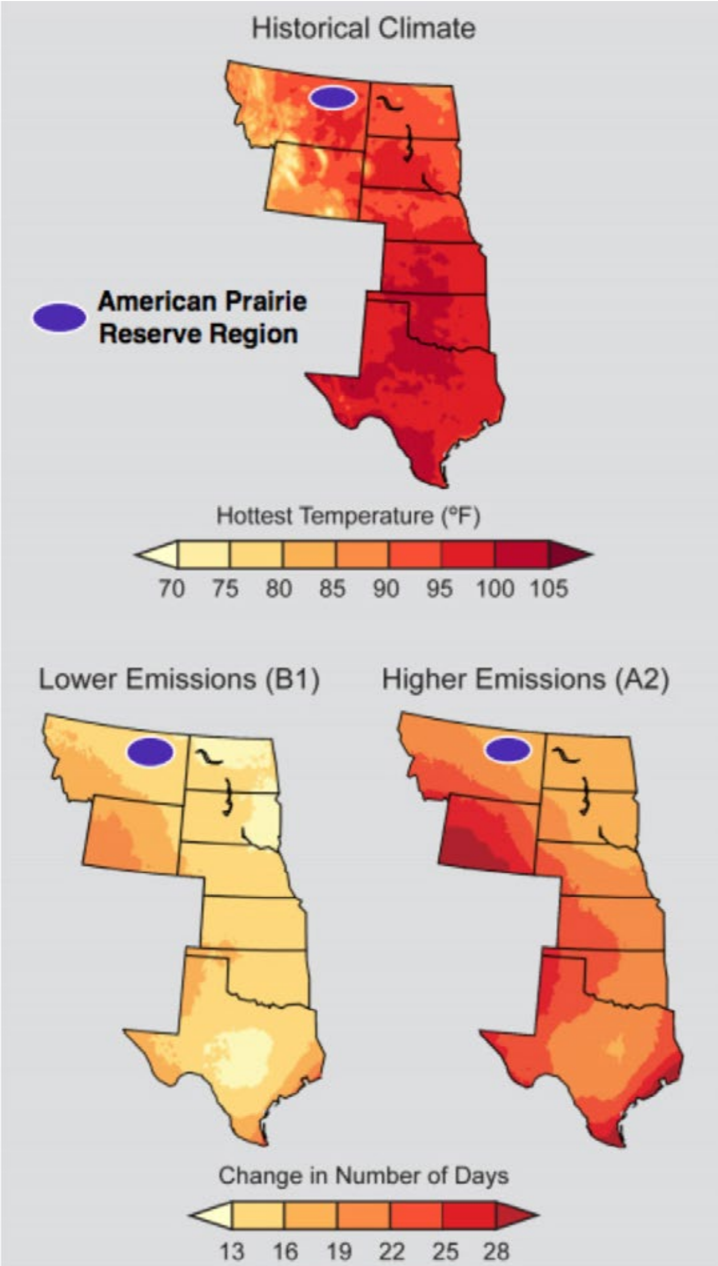

Figure 6. Top: Historical distribution of temperature for the hottest 7 days each year, 1971 - 2000. Bottom: Projected change in number of hot days in the Great Plains by mid-Century (2041 – 2070) under lower emissions scenario (B1) and higher emission scenario (A2) (USGCRP 2014).

Great Plains fish evolved under conditions of extreme variation in water flow and temperature and thus most species may be resilient to climate change. Some species, however, may be inhibited by human-erected barriers from making climate-change-induced movements to more favorable stream locations; nearly 12,000 dams and more than 800,000 road-stream crossings in the Missouri River drainage present serious obstacles to fish migration (Pracheil et al. 2014).

Climate change has already begun to alter biodiversity patterns in the Northern Great Plains. Phenological changes are the most obvious effects, but we have only begun to understand how these changes affect ecosystem processes and the adaptive response of organisms to climate change. A comparison of flowering phenology for 178 plant species over the last 100 years in North Dakota and Minnesota found 24 – 41 % exhibited large shifts in flowering dates, with spring flowers tending to bloom earlier and fall flowers later (Dunnell and Travers 2011).

The extent to which pollinators can maintain synchrony with their host plants is of concern, but there are indications that some pollinators can adjust. Phenology of ten bee species in northeastern North America has advanced an average of 10 days in apparent response to earlier host plant flowering dates (Bartomeus et al. 2011). APR's goal of conserving high native plant diversity and thus pollinator diversity may help maintain plant-pollinator synchrony for both crops and natural habitats (Bartomeus et al. 2013).

Recent evidence also suggests that pollinators, particularly because of their relatively short generation times, may under undergo rapid evolution in adaptation to changes in flowering phenology (Miller-Struttmann 2015). Again, APR's goal of large-scale conservation and, accordingly, of restoring large and genetically diverse populations of species, increases the potential for species to rapidly evolve adaptations to climate change (Sgrò et al. 2011).

Several studies have documented that most species of migratory birds of the Northern Great Plains are arriving earlier on their breeding grounds and/or shifting their breeding ranges further north (Hitch and Leberg 2007, Johnsgard 2015, Swanson and Palmer 2009, Travers et al. 2015). A sample of Great Plains and eastern U.S. bird species found an average 1.46 miles/yr northward shift of breeding ranges (Hitch and Leberg 2007). The centers of winter ranges of 305 widespread species of North American birds have shifted north an average of more than 35 miles over the last 40 years. This broad trend, how-

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ever, masks important differences among bird guilds and individual species. Among inland land birds, woodland birds experienced the greatest average shift (74 miles) whereas grassland birds showed on average no significant change in latitude. However, 10 of the 26 grassland species moved significantly north while 9 moved south (Niven et al. 2009).

The APR region is within the North American center of diversity of grassland-obligate birds (Knopf 1996). National Audubon Society's recent analysis projects that, if current climate change trends continue, by 2080 six species of grassland-obligate species found in the APR region will have a little or no climatically suitable summer breeding habitat remaining (NAS 2015). Moreover, even if climatically more favorable conditions existed to the north, breeding range shifts to the north may not be an option for these species due to the extensive conversion of grasslands to wheat fields in central Alberta and Saskatchewan (Figure 2).

Migratory birds of the Northern Great Plains are arriving earlier on their breeding grounds and/or shifting their breeding range further north.

Compared to phenological shifts, it is much more difficult to evaluate how climate change will affect reproduction and survival of grassland and wetland birds. Changes in habitat are likely to have the greatest impact. For example, loss of wetlands will lead to declines in many water-bird species (Steen et al. 2014) and climate-induced changes in the distribution of sage-brush (Homer et al. 2015) will directly affect populations of the sage sparrow, sage thrasher and greater sage-grouse. Negative effects, however, may occur via other mechanisms. Earlier spring arrival on the nesting grounds may expose newborn young to more inclement weather and thus high mortality, as has been documented for white pelicans in North Dakota (Sovada et al. 2014). Warmer temperatures are predicted to increase the frequency and extend the range of the mosquito-borne West Nile virus, which infects more than 300 species of birds, including dozens of Great Plains species, with often debilitating or lethal effects (Harrigan et al. 2014, Hofmeister 2011). The virus is particularly lethal to the greater sage-grouse, a species common in the APR region that until recently was proposed for listing under the U.S. Endangered Species Act (Schrag et al. 2011).

Because Great Plains ecosystems and species evolved under boom-and-bust climatic conditions, the region's biodiversity, to some degree, may be pre-adapted to withstand the greater extremes that climate change portends. Compared to the relatively ecologically homogenized landscape of agriculture—particularly of crop production—a biologically diverse landscape offers the best chance for ecological adaptation to climate change. The diversity of native grasses and forbs may be crucial for enabling pre-adaption and thereby for creating ecosystem resilience to climate change. Grass species in grassland systems display a broad range of tolerance to drought—up to a ten-fold difference among species. Where high grass diversity is maintained, grasslands may be resilient to climate change because drought-tolerant species can replace less drought-tolerant species as drier conditions prevail. Thus high grass diversity may be crucial for maintaining ecosystem function, including the capacity for GHG mitigation (Craine et al. 2013).

Similarly, compared to livestock, native ungulates demonstrate greater tolerance to climatic extremes

High grass diversity may be crucial for maintaining ecosystem function, including the capacity for GHG mitigation.

and should exhibit greater resilience to projected climate change in the Northern Great Plains. Bison in particular demonstrate much greater tolerance to temperature extremes than cattle and are far better adapted to water scarcity (Christopher et al. 1978, Kohl et al. 2013).

Any pre-adaption to climate change by grassland species, however, will be readily neutralized by ongoing habitat degradation and fragmentation by dams, energy development, conversion of grassland to cropland, fences and highways, among other threats. APR is addressing these threats by restoring and maintaining large, intact habitats with robust connectivity among them. This is crucial for conserving species migrations, for allowing shifts in species distributions, and for enabling ecological processes such as stream flow, grazing and fire to operate at large scales, a key to ecological resiliency (Fuhlendorf et al. 2012). Fortunately, as the next section describes, what's good for adaptation to climate change in the APR region is also good for mitigating GHG emissions.

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Figure 7. American Prairie Reserve is a priority area for conservation of the imperiled greater sage-grouse. Prevalence of West Nile virus, which is lethal to sage-grouse and other species of grassland birds, is projected to increase with warmer temperatures.

What's good for adaptation to climate change in the APR region is also good for mitigating GHG emissions.

EFFECTS OF LAND USE IN THE GREAT PLAINS AND APR REGION ON GREENHOUSE GASES

Land use in the Great Plains has undergone massive changes since EuroAmerican colonization. In 1850 the region was largely characterized by natural ecological processes, a full suite of native species, and wildlife-based tribal economies. Today, roughly 1% of the region is in protected areas that strive to conserve natural processes and native species (CEC and TNC 2005) while more than 90% of the land area is primarily devoted to an agricultural economy of livestock ranching and crop farming (Samson et al. 2004). This has resulted in the loss or decline of many native species and habitat and the degradation of many natural ecological processes. APR is interested in how these changes have affected GHG emissions and how to integrate GHG mitigation and climate change adaptation into its restoration goals and methods.

Conversion from Grassland to Cropland

Before plow-up of native grassland for crop production in the late 1800s and early 1900s, Great Plains grasslands were probably modest carbon sinks or near equilibrium (Zhang et al. 2011). Conversion of grasslands to croplands quickly altered this balance by initiating large increases in both CO_2 and N_2O emissions (Hartman et al. 2011).

Cultivation of native grassland disrupts soil structure, increases decomposition rates and accelerates soil erosion (Ogle et al. 2005). Because soils contain roughly 90% of all carbon in grassland ecosystems, changes in soil organic carbon (SOC) are of paramount concern regarding GHG emissions. On average, plowing of native grasslands and long-term crop production result in approximately a 50% loss of SOC (Hartman et al. 2011), although this varies widely depending on ecological conditions, cultivation practices and other variables. While a review of studies of temperate drylands under long-term cultivation found an average of 18% SOC loss (Ogle et al. 2005), in the short-grass steppe region of northeast Colorado 60 years of cultivation resulted in 62% less SOC in the upper 15 cm (6 inches) compared to native rangeland. More than half of this loss occurred in the first 3 years of cultivation (Bowman et al. 1990).

Whereas SOC is rapidly lost after grasslands are first cultivated, cultivated lands left fallow may require hundreds of years to reach pre-cultivation SOC levels. Active grassland restoration accelerates carbon sequestration but, depending in part on how long a site has been cultivated, achieving pre-cultivation carbon levels still requires decades (Conant et al. 2001, Fuhlendorf et al. 2002).

N_2O, a GHG with 300 times greater global-warming potential than CO_2 and 12 times greater than NH_4, is naturally released into the atmosphere from Earth's ecosystems including, at relatively low levels, from temperate grasslands. Soil disruption when native grasslands are first plowed causes a surge in N_2O emissions (Grandy and Robertson 2006). Of much greater long-term importance, however, is the increased emission of N_2O caused by the application of nitrogen fertilizers (Venterea et al. 2012, EPA 2015b). Globally, more nitrogen fertilizer is applied in the production of wheat, the primary crop of the APR region, than any other crop (Snyder et al. 2014).

On average, plowing of native grasslands and long-term crop production result in approximately a 50% loss of soil organic carbon.

The conversion of grasslands to croplands in the Great Plains during 1860 – 2003 resulted in an estimated net release of 1.87 billion t CO_2e (Hartman et al. 2011). Dryland cropping, typical of the APR region, was an important contributor to this net GHG release. The greatest release of CO_2 and N_2O and overall net release of GHG emissions was in the first few years after plow-up when soil nutrient levels were still high. But SOC, nitrogen and other nutrients quickly declined, resulting in ever lower productivity and reduced release of CO_2 and N_2O so that, by the 1960s, net emissions were close to zero or negative (Figure 8).

The advent of commercial production of nitrogen fertilizer in the 1950s led to a rapid increase in nitrogen fertilizer application which, when combined with new crop varieties and farming practices, resulted in a surge in both crop production and N_2O releases. However, under semi-arid conditions of dryland farming as found in the APR region, SOC increased only modestly despite increased productivity. N_2O emissions have continued to grow in recent years, leading to an increase in net GHG emissions where dryland farming is practiced in the Great Plains. Meanwhile, SOC levels of cropland remain far below those found in soils that have never been cultivated (Hartman et al. 2011).

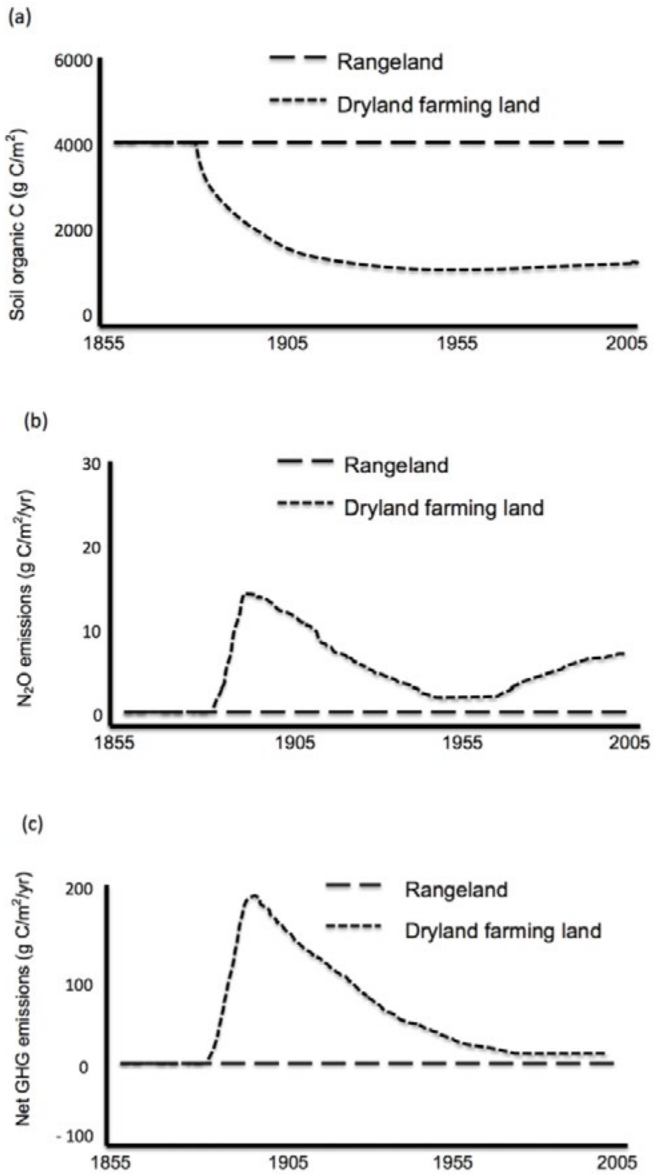

Figure 8. General trends in (a) SOC, (b) N_2O emissions and (c) net GHG emissions in CO_2 equivalents, 1855 – 2005, for lands maintained in grassland and lands converted to dryland farming in semi-arid regions of Great Plains. Based on simulated trends for Yuma and Weld counties, Colorado (Hartman et al. 2011).

The U.S. federal government's Conservation Reserve Program (CRP) and other government-sponsored soil conservation programs led to some semi-arid cropland being converted back to grasslands in the Great Plains, especially since the 1980s. Because CRP lands are not fertilized, this change reduced the rate of N_2O emissions from these lands while likely increasing carbon sequestration (Hartman et al. 2011).

Over the last 10 – 20 years rising prices for agricultural commodities, technological advances in crop production and perverse federal farm policies, particularly biofuel mandates, crop subsidies and disaster payments, and lower caps on lands enrolled in CRP have created what appears to be a new surge in conversion of grasslands to croplands (Classen et al. 2011, ERS 2015, Lark et al. 2015). Nationally, from 2008 – 2012, 7.34 million acres of grassland that had never been cultivated or were uncultivated since 2001 were converted to cropland, while 4.36 million acres of cropland were removed from production, of which 85% went into CRP. Seventy-seven percent of all new croplands were on grasslands, primarily in the Great Plains (Lark et al. 2015).

This analysis was recently corroborated by data from the Northern Great Plains and APR region. During the 2-year period 2011 – 2013, grassland habitat in the U.S. portion of the Northern Great Plains was lost at the rate of 1%, or 1.3 million acres, annually. In three of the Montana counties with APR lands (Blaine, Phillips and Valley), 53,221 acres—equivalent to nearly 40,000 football fields—of grassland habitat were cultivated during this period. This includes lands that may be in pasture or hay or have been in CRP a few years and is based on the Cropland Data Layer from USDA National Agricultural Statistics Service (Gage et al., In press). Most was placed into wheat production.

Transition From Native Ungulates to Livestock Ranching

Since EuroAmerican settlement, Great Plains grasslands have experienced a rapid and almost total transition from tens of millions of native ungulate grazers, most notably bison, but also elk, deer and pronghorn, that interacted at large scales with ecological processes such as fire and predation, to tens of millions of domestic livestock, primarily cattle, where both ecological processes and the animals are intensely managed. This transition could affect GHG emissions in three major ways (excluding GHG emissions associated with fossil fuel energy use in managing domestic livestock): (1) effect of grazing on carbon storage in grassland soils, (2) effect of suppression of grassland fires on soil carbon and GHG emissions, and (3) effect of a change in ruminants on CH_4 emissions.

Effect of grazing on carbon

Degradation of grasslands resulting from excessive stocking rates and inappropriate grazing management can reduce SOC and result in greater CO_2 emissions (Conant 2010). However, we have limited knowledge of the extent to which livestock grazing has degraded grasslands and affected SOC in the APR region and, more widely, the Great Plains (Olander et al. 2012). No record exists of grazing pressure on grasslands by wild ruminants before EuroAmerican settlement, though one assumes that "overstocking" of native ungulates would have been kept in check by both bottom-up (inadequate forage) and top-down (predation by wolves, coyotes, cougars and grizzly bears) factors as well as by catastrophic events (e.g., severe winters) and that carbon flux would have largely been in equilibrium (Wang et al. 2014). Where livestock grazing has degraded grasslands, rangeland scientists broadly agree that improved grazing management can lead to significant gains in carbon sequestration in rangeland soils (Fuhlendorf et al. 2002, Schuman et al. 2002, Conant 2010). However, where grassland is being restored on previously cultivated land, livestock grazing may retard carbon sequestration (Fuhlendorf et al. 2002).

During the 2-year period 2011 – 2013, grassland habitat in the U.S. portion of the Northern Great Plains was lost at the rate of 1%, or 1.3 million acres, annually.

Effects of grazing on SOC loss are highly variable under different ecological conditions and different grazing intensities and histories. Moderate to heavy grazing in semi-arid grasslands of the Great Plains, where there is an evolutionary history of large ungulate grazing, appears to often result in greater SOC storage compared to ungrazed areas (Conant et al. 2001, Derner et al. 2006, Reeder et al. 2004). No significant difference in carbon sequestration has


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Figure 9. Pronghorn on the move through recently plowed grassland in the APR region. In two years, 2011 – 2013, 53,221 acres—equivalent to 40,000 football fields—of grasslands were plowed in three of the counties where APR owns land.

been found between rest rotation and continuous grazing on native rangelands (Eagle et al. 2012).

Effects of grazing on SOC, however, are highly site specific and can vary widely among apparently similar sites. This has led to broad consensus that the interaction of abiotic factors—rainfall patterns, temperature, soil conditions, plant communities, grazing history and so on—will usually override the effects of grazing management on SOC. Consequently, except in circumstances where grazing has clearly degraded the grassland community and soil, grazing management is generally not considered a reliable method for managing carbon sequestration rates, especially over time periods of a few years (Derner and Schuman 2005, McDermot and Elavarthi 2014, McSherry et al. 2013, Wilcox et al. 2015).

Other ecological changes accompanied the shift to domestic livestock. In addition to the loss of native ungulate grazers, populations of two other important herbivores suffered major collapses. Gone—perhaps extinct—for unknown reasons is the Rocky Mountain locust, which, until EuroAmerican settlement, periodically descended from the mountains in massive plagues that denuded vast swaths of the Great Plains (Lockwood 2004). Also largely gone, occupying 2% of its estimated historic range of 80 – 100 million acres in the Great Plains, is the black-tailed prairie dog, a keystone species crucial to native grassland biodiversity and ecological processes (USFWS 2015a). There is no basis for assessing what the impacts of locust plagues may have had on SOC. Similarly, our knowledge is insufficient to draw general conclusions about the effects of prairie dogs on SOC either before EuroAmerican colonization or today. Effects of prairie dogs on plant diversity and biomass—and thus likely on SOC—are highly variable spatially and temporally according to local ecological conditions and the size and history of a prairie dog colony (Augustine and Springer 2013). The only published work on this question, based on research in the Chihuahuan Desert Ecoregion, reported that prairie dog towns generated more SOC than areas without prairie dogs (Martínez-Estévez et al. 2013). Given the insignificant portion of the prairie landscape that prairie dogs now occupy, restoring their keystone role in the prairie ecosystem remains of paramount concern.

Effect of suppression of grassland fires on GHG emissions

Fire, particularly its interaction with grazing, was a keystone ecological process that shaped Great Plains ecosystems (Anderson 2006, Fuhlendorf et al. 2009). Before EuroAmerican settlement, lightning-caused and anthropogenic fires occurred periodically in the Great Plains. Agriculture largely eliminated fire in the APR region and across the Great Plains (Twidwell et al. 2013).

Grassland fires can directly affect atmospheric conditions affecting climate by emitting CO_2, CH_4 and N_2O and by releasing particulate matter into the atmosphere. CO_2 emissions from grassland fires have been estimated to account for just 5% of biomass fire emissions in the United States (Wiedinmyer and Neff 2007). CO_2 flux should generally be near equilibrium, even over the short term, in a healthy grassland as an equivalent amount of CO_2 released by a fire is absorbed during subsequent plant growth on the nutrient-rich burned site within a year or two. CH_4 and N_2O from grassland fires are small compared to other sources; however, they are not reabsorbed through photosynthesis and thus may contribute to increased GHG levels in the atmosphere.

Black carbon (BC), resulting from incomplete combustion of biomass, is the most significant climate-forcing particulate matter released into the atmosphere (Bond et al. 2013). Though discerning the net effect of warming and cooling emissions is complicated, a recent modeling exercise indicates a significant net warming effect (Jacobsen 2014). This modeling does

Abiotic factors—rainfall patterns, temperature, soil conditions, plant communities, grazing history and so on—will usually override the effects of grazing management on SOC.

not account for CO_2 uptake by new plant growth after fire or for the long-term deposition of fire-generated BC in soil. Moreover, in contrast to forests, even in the absence of fire most carbon in above-ground growth in grasslands ends up in 1 – 2 years cycling through to the atmosphere as CO_2 via plant decomposition and consumption by herbivores (heterotrophic transpiration) (Follett 2001).

Grassland fires can alter carbon storage in soils through the deposition of BC and organic matter and through effects on primary productivity. Measurements in grasslands from various regions of the world show BC concentrations at 5 – 35% of total organic carbon. BC is relatively inactive biogeochemically and, consequently, some BC that was deposited in grassland soils thousands of years ago persists today (Dai et al. 2006, Rodionov et al. 2010). As Dai et al. (2005; p. 1879) note, "formation of BC transfers fast-cycling C from the atmosphere-biosphere system to much slower-cycling geologic forms that may persist for millennia, and therefore represent a sink for atmospheric CO_2." However, we understand very little about BC accumulation rates and persistence under different fire regimes and ecological conditions (Rodionov et al. 2010).

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Figure 10. APR is removing livestock and restoring wild bison as the principal grazer of its grasslands.

Fire may affect SOC by altering primary production and species composition, but few studies have investigated this and the effects are highly variable depending on fire frequency and local ecological conditions (Fuhlendorf et al. 2011). Burned plots showed a significant increase in SOC and nitrogen compared to unburned sites in a mixed-grass savanna in northern Texas (Dai et al. 2006). Where periodic fires and grazing are allowed to interact (pyric herbivory), primary productivity generally increases, which suggests maintenance or an increase in SOC (Fuhlendorf et al. 2011). Suppression of grassland fires may also influence carbon sequestration by favoring growth of trees. Grassland fires often kill woody plants and therefore are crucial for preventing encroachment by junipers and other trees into grasslands across much of the Great Plains. Although this is not a serious problem in the APR region, extensive areas of the central and southern Great Plains are now juniper woodlands because of fire suppression. Plant diversity declines more than 90% where this occurs and grassland birds largely abandon areas when juniper exceeds 10% of land cover (Twidwell et al. 2013). Uncertainty remains regarding effects of woodland encroachment on carbon sequestration. Ecosystem carbon response to woodland encroachment seems to be neutral or negative in semi-arid sites with precipitation similar to the APR region, but long-term effects are poorly understood. With as much as 90% of carbon stored in above-ground biomass in juniper woodlands, any gains in carbon are susceptible to rapid loss through wildfires, drought, disease and insect outbreaks (Barger et al. 2011, Twidwell et al. 2013).

Effect of change in ruminants on GHG emissions

Approximately 26% of CH_4 emissions in the United States are from enteric fermentation, primarily from ruminants (EPA 2015b). All native and nearly all domestic ungulate grazers in the Great Plains are ruminants. Thus, the switch in principal grazers—primarily from bison to cattle—has probably had a small effect on ungulate CH_4 emissions. One analysis estimated that pre-EuroAmerican-settlement emissions from bison, elk and deer were 86% of current emissions from livestock (assuming a pre-settlement bison population of 50 million) for the continental United States (Hristov 2015). Another estimated a 14% lower CH_4 emission rate from 30 million pre-settlement bison than from 36.5 million cattle currently in the historic range of bison (Kelliher and Clark 2010).

APR eliminates all feedlot conditions on its lands thereby eliminating the potential for significant CH_4 emissions from manure (EPA 2015b). We expect N_2O emissions from dung and urine deposition on rangelands, whether from bison or cattle, to be similar to pre-EuroAmerican settlement.

AMERICAN PRAIRIE RESERVE'S APPROACH TO CLIMATE CHANGE MITIGATION AND ADAPTATION

APR pursues several management objectives that address the dual needs of GHG mitigation and climate change adaptation. To achieve the scale, both financially and in terms of land, needed for these management objectives to have a significant impact, APR works across multiple forms of land ownership and employs several technical and financial tools. This, in turn, requires that APR collaborate with diverse stakeholders—ranchers, Indian tribes, university researchers, nonprofit organizations, donors, and county, state and federal land managers, among others.

We summarize here the four primary management objectives and describe progress to date and next steps.

Management Objectives

Innovative, landscape-scale approaches are required for grassland management to significantly alter the course of climate change. APR's goal to restore and conserve grassland habitats and their biodiversity on a large scale is fully supportive of the two major climate-change goals of grassland ecosystems—(1) mitigating GHG emissions by both reducing emissions and increasing carbon sequestration and (2) improving ecosystem adaptation to climate change. Because of a largely synergistic relationship between the goals of biodiversity conservation, GHG mitigation and climate change adaptation in grassland ecosystems, a single set of management objectives simultaneously addresses all three goals.

APR focuses on four major land management objectives:

Objective 1: Stop conversion of grasslands to croplands or any other form of land use

Plowing of native grasslands is the killer threat to GHG mitigation, ecosystem adaptation to climate change, and biodiversity conservation on grasslands. Consequently, this is a top priority for APR and thus no native prairie is converted to cropland on APR's deeded lands. As explained below, avoided grassland conversion is also central to our work with other landowners in the APR region.

Objective 2: Convert cropland back to native grassland

APR's long-term goal is to convert all cropland it acquires back to native grassland. APR also offers private landowners technical assistance and financial incentives for restoring native grassland. Restoring native vegetation and soil health to previously cultivated land is often a slow and expensive undertaking. APR generally begins the process by seeding 5 -10 native species of forbs and perennial grasses and then relying on natural seed dispersal into the area from nearby native grasslands to slowly enrich plant diversity. Higher levels of plant diversity are likely to result in an ecosystem more resistant or resilient to perturbations such as may be caused by climate change (Craine et al. 2013, Isbell et al. 2015,Tilman 1996) and with a higher capacity for carbon sequestration (Lange et al. 2015, Steinbeiss et al. 2008). Published rates of carbon sequestration during grassland restoration vary widely. A review by Diaz et al. (no date) found a range of 0 – 5.7 t CO_2/acre/yr for cool temperate dry grasslands (includes the APR region). APR's mixture of forbs and perennial grasses probably yields a sequestration rate somewhere between these extreme values.

Objective 3: Restore native ecological processes, habitat diversity and native species

Two key ecological processes APR focuses on are restoration of natural grazing patterns and of patch fires because the interaction of these processes creates habitat heterogeneity over large scales. Habitat heterogeneity is crucial for supporting a high diversity of grassland species and for creating resiliency to climate change (Freese et al. 2014, Fuhlendorf et al. 2009). Nearly all populations of species in the APR region can be restored without physical reintroduction once the right ecological processes and conditions are in place. In some cases, such as native-plant seeding, this process can be accelerated. In the few cases where the species has been extirpated from the region, such as bison and black-footed ferrets, restoration requires reintroduction.

Cattle and other domestic livestock are removed from APR deeded and leased public lands and replaced with bison as conditions and resources permit. As of June 2016, more than 600 bison had replaced cattle on 35,000 acres of APR. Properties where this change has not yet occurred are generally leased for grazing to neighboring ranchers under APR grazing guidelines. An overarching management guideline for APR lands that is crucial to maintaining rangeland health is to maintain low-to-moderate stocking rates of grazing animals and to periodically monitor and assess rangeland health.

Restoration of natural hydrological processes and conditions through dam removal and exclusion of cattle from riparian areas is also an APR priority. In addition to enhancing habitat and species diversity, restoration of riparian shrub and forest habitats will increase carbon sequestration. As noted earlier, high plant diversity helps ensure that those species best adapted to warmer and drier conditions predicted for the APR region are present to form new biotic communities and maintain ecological functions, including carbon sequestration (Craine et al. 2013). Large and genetically diverse populations of species also increase the potential for species to evolve adaptations and thereby enhance ecosystem resilience to a changing climate (Sgrò et al. 2011).

Objective 4: Scale up these management actions to ever-larger landscapes

Larger landscapes obviously translate directly into greater climate-change mitigation through more acres of native grassland conserved and of cropland restored to grassland. Less obvious perhaps are the ways that larger landscapes are important for meeting Objective 3. Larger landscapes will generally include more species of plants and animals and support larger species populations with greater genetic variation than smaller landscapes. Moreover, in semi-arid grassland ecosystems the integrity of ecological processes such as grazing, fire, stream flow, and nutrient cycling operate best at large scales of hundreds of thousands or millions acres. These processes interact with highly variable and localized soil conditions, precipitation patterns and other factors to create a shifting mosaic of habitats. Only very large areas can encompass this habitat heterogeneity and maintain long-term

Management Action	GHG Mitigation Effects	Climate Change Adaptation Effects	Environmental Co-Benefits
Stop conversion to cropland	• Avoids rapid release of CO2 & N_2O, & of loss of soil C & N • Averts use of N fertilizers & increased N_2O emissions	• Maintains ecological processes • Maintains species diversity • Reduces susceptibility to drought & other perturbations	• Avoids increased soil erosion • Maintains soil nutrients • Maintains water flow, quality & recharge • Resists invasive plants • Stops habitat fragmentation • Maintains most biodiversity • Maintains pollinator diversity
Restore grasslands on previous croplands	• Increases C sequestration, but may take decades for soil C to reach pre-cultivation levels • Eliminates N fertilizer use & rapidly reduces N_2O emissions • Increases ecosystem resilience & thus GHG mitigation function	• Begins to restore ecological processes & biodiversity • Increased biodiversity builds resilience to drought & other perturbations	• Reduces soil erosion • Improves natural soil fertility • Improves water flow, quality & groundwater recharge • Reduces habitat fragmentation • Begins to restore biodiversity • Increases diversity of pollinators
Restore ecological processes & habitat & species diversity	• Increases short- and long-term resiliency of ecosystem to climate change (see Adaptation Effects) & thus restores ecological function of GHG mitigation. • Replacing cattle with bison & other native herbivores has no effect or slightly reduces CH_4 emissions	• Use of moderate grazing pressure by native herbivores combined with patch fires restores/maintains grassland health • Greater species diversity, especially of plants, increases chance of ecosystem adapting quickly to warmer & drier conditions	• Enhances above benefits, plus: • Helps conserve endangered & other imperiled species such as Sprague's pipit, greater sage-grouse, black-footed ferret, plains bison, gray wolf, grizzly bears & others
Scaling up to larger landscapes	• Increases area of grasslands that will not be cultivated & thus maintains GHG mitigation at larger scales • Enables restoration of previous cropland & of grasslands degraded by overgrazing & thus slowly increases GHG mitigation • Larger areas more likely to ecologically adapt to climate change (see Adaptation Effects) & thus to maintain GHG mitigation functions	• Larger areas likely to include more species pre-adapted to future climatic conditions • Larger areas likely to support larger populations/greater genetic diversity of species, thereby increasing probability of evolutionary adaption of species & thus ecosystem to climate change	• Enables long-term conservation of fully intact, native ecosystem with viable populations of full suite of native species • Increases habitat connectivity—e.g., to Glacier, Yellowstone and Grasslands National Parks—for migration & gene flow, & for range shifts due to climate change

Table 2. Summary of the effects of APR management objectives on GHG mitigation, climate change adaptation and environmental co-benefits.

ecosystem health and GHG mitigation capacity (Fuhlendorf et al. 2009).

Table 2 summarizes these management objectives, their primary effects on climate change mitigation and ecosystem adaptation, and their other environmental co-benefits.

Progress to Date and Next Steps

To meet these four objectives, APR is focusing on three major approaches to maximizing the land base managed for conservation. These approaches cut across multiple forms of land ownership with the long-term goal of directly and indirectly improving management of millions acres of grasslands.

1. Test and implement methods for restoring and managing rangelands on APR deeded lands.
2. Improve management of public lands, especially those leased by APR, through collaboration with federal and state agencies.
3. Provide to private landowners technical assistance and economic incentives for improved land management.

Approach 1: Management of APR deeded lands

As of June 2016, APR has acquired 86,018 acres of private land, 88% of which is native/semi-native rangeland and 12% is cropland. Associated with APR's deeded land are 266,642 acres of public lands that APR leases (see next section), for a total of 352,660 acres of private and public lands.

APR's strategy is to maintain ownership of its deeded lands and to ensure their long-term ecological integrity by placing them under permanent conservation easements that prohibit conversion of the grassland to any other use. APR thus far has placed conservation easements on 8,912 acres of land. APR has also purchased 22,702 acres with conservation easements already in place, for a total of 31,614 acres, or 37% of its private land holdings, protected by conservation easements. Avoiding conversion of grassland to cropland is the single most important step that APR can take to mitigate GHG emissions and to conserve other environmental services from the land. In July 2015, Climate Action Reserve released the Grassland Project Protocol (Climate Action Reserve 2015), which provides the basis and guidelines for APR's potential participation in the voluntary carbon market.

APR has begun restoring grassland on 4,182 acres, representing 40% of the cropland it owns. Using a conservative sequestration rate in the range of 0.1 – 1.0 t CO_2/acre/yr (see Diaz et al., no date), this restoration may be sequestering 418 – 4,182 t CO_2/acre/yr. This is roughly equivalent to the average annual CO_2 emissions of 90 – 900 U.S. passenger vehicles (EPA 2015a). Cropland that is not yet being restored is leased out for crop production and management, crucial for avoiding invasion by non-native species until native plant restoration begins.

APR generally manages its deeded rangelands and adjacent leased public lands as a single unit to achieve greater scale; most management units range from 20,000 – 158,000 acres. Livestock fences are a major cause of habitat fragmentation that conflicts with achieving scale and that impedes the restoration of natural ecological processes such as animal migration. Grazing management plans prepared for the long-term ecological health of each grazing unit and all units are periodically monitored and assessed.

APR's goal over the next decade is to acquire many more properties with extensive acreages of intact grasslands. APR will continue to ensure the long-term conservation of these grasslands and their importance for climate change mitigation through the use of conservation easements, sound grazing management practices and other means.

Approach 2: Collaboration with public land agencies

APR's private lands are base properties for leasing 235,120 acres of BLM and and 31,522 acres of state trust lands. Federal law prohibits cultivation of BLM lands and thus our primary objective for these lands is to cooperate with BLM to ensure that grazing is maintained at low to moderate levels and that grassland health and diversity is maintained.

Montana law currently permits, with state approval, lessees of state trust lands that are in native grassland to convert them to cropland. Although the state has not issued such permits for several years (John Grassy, Montana Dept. of Natural Resource Conservation, pers. comm.), a reversal of this policy in the future poses a risk to these grasslands. APR's lease of 31,522 acres of state trust lands helps ensure that these lands will be maintained in grassland habitat.

CMR Refuge land cannot be cultivated. However, two-thirds of its land is leased for cattle grazing. By acquiring ranches with grazing leases on the refuge, APR has enabled the refuge to retire 63,777 acres of grazing leases and to fully devote management of this land to biodiversity conservation. This includes restoring more natural processes of fire and native ungulate grazing. Moreover, a major advantage for achieving seamless management across the landscape is that APR lands share a common boundary of 37 miles with the 1.1-million-acre refuge.

APR cooperation with public land managers is expected to expand substantially over the next decade as properties purchased will include sizeable BLM, state and CMR Refuge grazing leases. APR will continue to work closely with BLM and state land managers to ensure sound grazing practices on APR grazing allotments. If properties with CMR Refuge grazing leases are purchased, APR will continue to enable the refuge to retire those leases as the refuge deems necessary for grassland health.

Approach 3: Technical assistance and financial incentives for private landowners

No grassland reserve, no matter how large, can ignore how lands that surround it are managed. This is especially true in grassland ecosystems where ecological processes operate at such large scales. To address this, in 2014 APR established Wild Sky Beef, a for-profit subsidiary that offers technical assistance and financial incentives for carbon-friendly and wildlife-friendly land management of private ranchlands that have ecological linkages to APR lands. This generally includes ranchlands that surround APR and ranchlands that are potential corridors/linkages to other ecosystems for animal migration and other ecological processes. Ranchers who enroll in the Wild Sky Beef program receive payment for following a comprehensive suite of management guidelines. Better management performance is rewarded with higher payments.

Three ranches totaling 10,220 acres of deeded lands and 23,434 acres of leased public lands have thus far enrolled. Among the management criteria that landowners must meet to qualify for enrollment, no cultivation of grassland is one of the most important. Extra points are awarded for placing their grasslands in conservation easements and for restoring grasslands on previously cultivated lands. Again, the program offers the dual benefit of improving and maintaining carbon storage on

Figure 11. Stephen and Michelle Fox were the first ranch owners to sign a contract with APR's Wild Sky Beef, which pays them to maintain their grasslands and to conserve wildlife.

enrolled ranches while enhancing the adaptive capacity of the ecosystem to climate change. Also of importance to participating ranchers is that Wild Sky Beef diversifies their revenue sources from commodity production alone to include payments for environmental services.

Because Wild Sky Beef is a new initiative to expand APR's efficacy and reach in grassland conservation, a priority over the next few years is to evaluate and improve both the payment system and the management guidelines and metrics for improving and monitoring landowner performance and compliance. Our goal is to greatly increase the number of ranches under contract with Wild Sky Beef over the next 5 years and, as a result, to improve the management of thousands of additional acres of grasslands.

DISCUSSION AND CONCLUSION

APR's progress toward building a grassland reserve of more than 3 million acres to meet its goal of large-scale biodiversity conservation contributes to meeting the goals of GHG mitigation and climate change adaptation because large, intact grassland ecosystems (1) efficiently sequester large amounts of carbon and maintain a neutral flux—and may often be net sinks—of GHG, and (2) sustain the habitat heterogeneity, ecological processes, species diversity and genetic variation within species that should best enable ecological and evolutionary adaptation to climate change. This is largely a three-way synergistic relationship. What's good for mitigation is good for adaptation, and vice versa, and better mitigation and adaptation should provide a positive feedback to conserving biodiversity.

To date, roughly 450,000 acres are affected by APR's work on its deeded lands, leased public lands and Wild Sky Beef lands (Figure 4). If we use a figure of 66 t CO_2/acre (middle of the range that Diaz et al., no date, give for cool dry temperate grasslands), a rough estimate of the carbon stored in the soils of this land is 29.7 million t CO_2, equivalent to the CO_2 released annually by 6 – 7 million passenger vehicles or by 8.5 typical coal-fired power plants in the United States (based on emission figures from EPA [2015a] for passenger vehicles and from UCS [2015] for coal-fired plants).

The social cost of carbon (SCC), the estimated economic damage to property, agriculture, human health, and other values caused by an increase in CO_2, provides another perspective on the carbon stored in these 450,000 acres. The U.S. government currently uses an SCC of $37 per metric ton of CO_2 released into the atmosphere to assess the costs and benefits of rulemakings regarding climate change (The White House 2013). The accuracy of this SSC figure is widely debated, although economists generally view the figure as too conservative (Howard and Sylvan 2015, Moore and Diaz 2015). With these caveats, using a SSC of $37/t CO_2, the social cost of releasing all the carbon in these 450,000 acres would be more than $1 billion. This figure would be even higher if we included the N_2O that would be released if this land was plowed.

Such a release is obviously not going to happen, in large part because much of the land in the APR region is under federal ownership where grassland conversion to cropland is prohibited. Nevertheless, it highlights the importance of APR's work with federal agencies and others to maintain and, where needed, to improve grazing and associated management practices on these grasslands because of the large area and amounts of carbon involved. Increasing carbon sequestration by just 1% across the roughly 330,419 acres of public lands that APR leases and that APR has enabled the CMR Refuge to now manage for biodiversity without livestock grazing would amount to nearly 220,000 t CO_2; a 5% increase would equal nearly 1.1 million t CO_2. The net social benefit, based on an SCC of $37/t CO_2, would be, respectively, $8 million and $40 million.

Compared to public lands, the carbon in millions of acres of deeded land is at much greater risk because of the rapid rate of grassland conversion to cropland in the APR region. To derive a rough estimate of the SCC incurred if these grasslands are converted, we again use a figure of 66 t CO_2/acre and assume that one-half the soil carbon is lost to the atmosphere when grassland is converted to cropland. Under these assumptions, each acre of converted grassland emits 33 t CO_2 (a conservative estimate compared to Fargione et al.'s [2008] use of 54 t CO_2 /acre for conversion of U.S. central grasslands to corn). This yields a social cost of $1,221 per acre of converted grassland.

The magnitude of this cost becomes apparent if we apply these figures to grasslands being converted to cropland in the three counties cited above where APR owns land (Gage et al., In press). The 26,610 acres of land converted each year subsequently releases 878,130 t CO_2 at a social cost of $32.5 million.

As these figures suggest, APR's largest contribution to mitigating GHG emissions and improving climate change adaptation, at least on a per-acre basis, is avoidance of grassland conversion to cropland and restoration of grassland on previous cropland. APR's two main approaches to this—acquisition of deeded land and financial incentives for private landowners—have protected a total of 96,018 acres to date. Using the assumptions noted above, cultivation of these acres would release nearly 3.17 million t CO_2 with a social cost of $117 million.

APR's progress in acquiring and conserving intact grasslands generates diverse environmental services—carbon sequestration, biodiversity, prevention of soil erosion, good water quality, recreation, education and others—all of which provide economic benefit to the public. The economic value of just one of these benefits—carbon sequestration—highlights the economic leverage of APR's investment in grassland conservation. The estimated net social benefit of $1,221 for acquiring and saving 1 acre of grassland from being plowed is roughly three times the per-acre cost of land in the APR region—a $3 return for every $1 invested. Although this ratio would shrink somewhat by including the cost of managing the land, that factor would be more than offset by including the monetary values of other environmental services from APR's grasslands and wildlife.

APR will continue to apply its diverse and innovative approaches to grassland management to an expanding land base. With each acre added, APR will restore and conserve more of the region's biodiversity, increase the ecosystem's capacity to adapt to climate change, and ensure that more carbon is permanently sequestered in the soils of the region's vast grasslands.

The estimated net social benefit of $1,221 for acquiring and saving 1 acre of grassland from being plowed is roughly three times the per-acre cost of land in the APR region—a $3 return for every $1 invested.

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