Ocean of Grass: A Conservation Assessment for the Northern Great Plains

Addendum:

Climate Change Impacts and Adaptation Strategies

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Section I: Statement of the Problem and General Adaptation Guidance

Statement of the Problem

Climate change is impacting all corners of the planet to varying degrees and is changing the face of conservation in the process. While much of the focus on impacts has been and continues to be on systems that represent climatic extremes, such as mountainous and polar regions, the high biodiversity and ecosystem services that are present in temperate grasslands suggest that focusing attention on climate impacts and adaptation strategies in these areas is also highly valuable. Based on recent scientific research, the speed of climate change in the world's temperate grasslands is likely to outpace the amount of protected area currently available, leaving grasslands more vulnerable to change than other ecosystems (Loarie et al., 2009).

This report provides an overview of climate change impacts to the Northern Great Plains Ecoregion, as defined in Forrest et al. (2004; Fig. 1), and suggests general adaptation techniques that will be beneficial in this region. The analysis and literature review contained within this report is meant to provide regional-scale data on the exposure of species and systems to historical and predicted future climate change, as well as provide information from the scientific literature that can serve as a qualitative vulnerability analysis for the region as a whole. The purpose of this report is to suggest priorities for conservation work in the Northern Great Plains with a focus on potential climate change impacts, much in the same way that the Ocean of Grass Conservation Assessment (for which this report is an addendum). This report uses the priority landscapes and species identified in Ocean of Grass as a basis for understanding climate change impacts and prioritizing adaptation actions.

General Guiding Adaptation Principles

Climate change scientists have long grappled with how climate change fits into the larger conservation agenda. The newest and best climate science has begun to converge on a number of adaptation principles that can be broadly applied in most conservation settings and will help to guide the work of conservationists on the ground.

Many of the most commonly recommended adaptation principles rely on the concept of large landscape conservation for successful implementation. The majority of these principles are dependent upon having large landscapes that are managed for similar conservation goals across jurisdictional boundaries and provide habitat both within reserve-like core areas and in the surrounding matrix. Using these principles requires moving beyond the classic reserve model to envision a unified landscape that is managed for biodiversity across public and private boundaries, allowing for connectivity among core areas (Heller and Zavaleta 2009, Mawdsley et al. 2009). In addition, many of these adaptation strategies integrate the concepts of resistance, resilience and response of ecosystems to change. As defined by Millar et al. (2007):

- Resistance strategies hope to "forestall impacts and protect highly valued resources";
- Resilience strategies attempt to "improve the capacity of ecosystems to return to desired conditions after disturbance";

- Response strategies “facilitate the transition of ecosystems from current to new conditions”.

Reducing non-climate stressors: Reducing non-climate stressors is one of the most commonly recommended climate change adaptation principles. These stressors may include invasive species, habitat fragmentation, pollution, loss of habitat, disease, alteration of aquatic regimes, as well as many others. Removal of stressors that are exacerbated by climate change may be especially important, particularly because many common stressors may be intensified under certain climate change scenarios. For example, in many landscapes, the impacts of climate change on other stressors (e.g., water availability) may have more direct, short-term implications than those of climate change alone.

Increasing protected areas: Increasing protected areas is another common adaptation strategy, which may come in the form of an increased number of reserves or an increase in the extent of reserves. Improving representation and replication within already established protected areas may also enhance the capacity of the land to provide habitat for a variety of species. This concept is illustrated through initiatives such as Saskatchewan’s Representative Areas Network (Saskatchewan Environment 2005) and other projects that seek to preserve “the stage instead of the actors”.

Maintaining or improving connectivity: Maintaining or improving connectivity is another strategy for adapting to climate change, mainly due to its ability to provide movement corridors through which species may migrate to new areas. Often, corridors lie between protected areas and, thus, require creative ways of working with private landowners to ensure that species will be protected as they move through these areas. Connectivity may also require restoration of species and/or processes. In aquatic systems, restoring connectivity may necessitate removal of aquatic barriers, such as dams. In riparian corridors, restoration of vegetation for shade cover may allow species to use habitat on a more local scale, thus connecting landscapes on a broader spatial scale. For other species, linear terrestrial corridors may not be as important as habitat islands or stopover areas. These areas may be managed by flooding fields at specific times to coincide with migratory behavior. However, movement-based corridors may not completely satisfy the adaptation needs for certain species. Some species will experience more gradual range shifts and even “setbacks” and, thus, need additional protection so that habitat requirements are met as they respond to overall shifts in their range, as opposed to seasonal migrations.

Increasing landscape permeability: Increasing permeability of the landscape is a form of increasing landscape connectivity. Enhancing landscape permeability may be as simple as fence modification or removal or may require more complicated land management, such as providing buffers along fields for pollinators or managing a complex grazing scheme across a matrix of private lands.

Translocating species: Translocation of species into new areas that they have not previously inhabited, also known as assisted migration or managed relocation, is one of the more controversial adaptation techniques. This method is primarily targeted at species that are limited by dispersal and, thus, face an imminent threat of extinction. Species are generally moved or planted outside of their current range, but within areas that are predicted to be climatically suitable in the future. Assisted migration may have unintended consequences, such as a risk of invasion, and is sometimes criticized for its heavyhandedness in the management of species. This method is also very resource intensive and the potential success of these projects is unknown in many cases.

Dynamic landscape planning: While reserves form an essential part of the conservation equation throughout the world, they represent static protection of a land base in a dynamic world. Building landscape conservation plans that take dynamic systems into account will likely be a more successful strategy into the future. Such planning must incorporate different land uses and ensure that species can move among landscapes both now and in the future. These plans tend to be data intensive and require predictions of how spatial elements are likely to change in the future, which can be a stumbling block to implementation.

Cross-jurisdictional collaborations: Climate adaptation techniques that require large landscapes almost always necessitate collaboration across jurisdictional boundaries. These landscapes typically include a mixture of state, provincial, federal and privately held lands. Due to the complicated nature of planning processes and management plans, and the influence of the political atmosphere, finding common ground across jurisdictions is often one of the key limitations to successful large landscape conservation. Increasing and/or continuing monitoring programs is one of the best ways that multi-jurisdictional collaborations can aid in climate adaptation. Increasing the availability of baseline data and continuing funding for already-established monitoring programs ensures that detection of change will be possible and early warning signs will lead to action.

In addition to these principles, other guidance on conservation in light of climate change suggests a five-part approach. This approach largely pulls from the above principles, but also makes use of concrete analyses to guide the implementation of general adaptation techniques, and it suggests integration of these techniques into long-term planning (from Game et al. 2010):

- Identify climate refugia;
- Conserve the geophysical stage (e.g., elevational gradients, geological substrates, etc.);
- Enhance regional connectivity;
- Sustain ecosystem process and function;
- Take advantage of emerging opportunities from climate change with implications for conservation.

These general principles provide a useful starting point for conservationists dealing with climate change; however, in practice it is often difficult to connect broad principles with on-the-ground actions. Therefore, additional approaches, including the Adaptation for Conservation Targets framework (Cross et al. *in prep*) and other scenario-planning processes and vulnerability assessments can be used to connect the dots between climate change impacts, general adaptation principles and on-the-ground actions.

Section II: Historical Trends and Future Predictions for Climate Change

Historical Trends in Climate

Global average surface temperatures warmed by 0.74°C (1.3°F) during the 20th century (National Oceanic and Atmospheric Administration [NOAA] 2010a). Twenty of the warmest years in the past century have occurred since 1981, and ten of the last 12 years have been the warmest on record (NOAA 2010a). Precipitation changes have varied spatially during this period, but droughts and floods have become more common overall (Solomon et al. 2007). Arctic sea ice is declining, which could have substantial impacts and glaciers are receding. Combined, these changes are leading to increased sea levels (Intergovernmental Panel on Climate Change 2007).

Historical Trends in Climate in the Northern Great Plains

The climate of the Northern Great Plains is changing, with northern states and provinces experiencing greater and faster changes than southern areas (Mitchell and Jones 2005, Meehl 2007). While averages cannot accurately depict changes in variability and extreme events, they can be useful for monitoring trends in key variables. For instance, based on spatially interpolated climate trend data from 1951-2002, average annual temperatures increased by up to 2.6°C (4.68°F), with greater increases in the northern and eastern portions of the ecoregion. Spring and winter temperatures appear to be increasing more quickly than summer and fall temperatures (Fig. 2). Averaged over the entire year, precipitation is increasing most in the southeastern portion of the ecoregion, by up to 130 mm (5.12 in.) in areas of South Dakota and Nebraska. These increases in precipitation are primarily occurring in spring and fall. Areas along the Montana-North Dakota border have seen decreases in precipitation over the 51-year period, some by as much as 80 mm (3.15 in.; Fig. 3)[*].

Temperature and precipitation trends across the ecoregion are spatially variable. For instance, Conata Basin in South Dakota stands out as having experienced similar to decreasing average temperatures over the last half decade. Temperatures in this area have been the same to slightly cooler in all seasons except for fall, when temperatures were substantially cooler, by about 2°C (3.6°F) over the time period. Precipitation in the southeastern portion of the ecoregion has increased the most over the time period, with up to 78mm (3.07 in.) more precipitation falling in the spring and fall seasons. Summer precipitation changes have been the most spatially variable, with drier conditions along the Montana-North Dakota border and wetter conditions in the Montana Glaciated Plains, Big Open, Nebraska and along the eastern border in the Prairie Pothole Region. Winter precipitation trends have been relatively constant over the time period across the ecoregion. Annual averages show generally wetter conditions in the southeastern portion of the ecoregion, by up to 130 mm (5.12 in.), but precipitation has been relatively constant elsewhere in the region.

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Future Predicted Changes in Climate

Atmospheric-oceanic general circulation models (AOGCMs) are the principal tool used to predict future climate change on a global scale. These models integrate many physical processes, including interactions among the atmosphere, oceans, land surfaces and sea ice. The models build cloud formation, model precipitation and ocean mixing, and create the formation of water masses, among other processes, in order to simulate current and historic trends in climate and predict future climate changes. There are numerous AOGCMs to choose from and each model produces slightly different results depending upon parameterization of these physical processes.

AOGCMs generally produce results at about a 2 degree (approximately 220 km^2) resolution and are subsequently statistically downscaled to take into account regional variability in climate predictions due to physical factors like topography. For the purposes of this study, we used data that were downscaled to 50 km^2 resolution because we wanted to incorporate changes across the international US-Canada border. However, data is available within the US and Canada at finer resolutions (Mitchell and Jones 2005, Meehl et al. 2007). It is important to keep in mind that AOGCMs do a better job of predicting changes at coarser resolutions than at finer resolutions and that they predict temperature changes better than precipitation changes. The suite of AOGCMs used in this analysis also does not include bioclimatic variables, such as evapotranspiration, which would describe the combined effects of temperature on precipitation in the future.

For this analysis, we examined sixteen AOGCMs and two emissions scenarios (see box for general synopsis of chosen scenarios). All six emissions scenarios included in the most recent report of the Intergovernmental Panel on Climate Change (IPCC) predict an increase in temperatures; however, the

EMISSIONS SCENARIOS (IPCC, 2000)

A1B: The A1 storyline and scenario family describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building, and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system. The three A1 groups are distinguished by their technological emphasis: fossil intensive (A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1B).

A2: The A2 storyline and scenario family describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing global population. Economic development is primarily regionally oriented and per capita economic growth and technological change are more fragmented and slower than in other storylines.

magnitude of the change varies by scenario. For this analysis, we have chosen to examine the A1B and A2 scenarios based on their widespread use in modeling exercises and because they represent a “business as usual” scenario (A1B) and an increase in emissions (A2). To note, the A1B scenario suggests an increase in mean surface air temperature globally of 2.8°C (5.04°F), with a range from 1.7°C (3.06°F) to 4.4°C (7.92°F), by the 2050s. The A2 scenario predicts an increase of 3.4°C (6.12°F), with a range from 2.0°C (3.6°F) to 5.4°C (9.72°F), by the 2050s.

<u>Future Predicted Changes in Climate in the Northern Great Plains</u>

All future predicted changes in climate related below are for the 2050s, a time period that generally serves as an average for the thirty-year period from 2040-2069. We elected to look across all model outputs and emissions scenarios and within each emission scenario in order to better understand the differences among scenarios across all models. We then compared models within each emission scenario (A1B, A2). The results are presented in Table 1.

The model with the highest increase in predicted future temperatures in the region are represented by the GFDL CM2 0.1 model under both emissions scenarios (Figs. 4, 5). This model shows the greatest overall increases in temperature and average changes in precipitation. The CNRM CM3.1 model scenario shows the greatest overall decreases in precipitation for the A1B scenario, and the MIROC3 2 MEDRES.1 shows the greatest overall decreases in precipitation for the A2 scenario. However, neither of these models show the increases in temperature of the GFDL CM2 0.1 model.

Under the GFDL CM2 0.1 model, the Northern Great Plains is expected to experience increases of up to 5.7°C (10.26°F), with somewhat greater warming in the southern portion of the ecoregion, as compared to the northern portion of the ecoregion (Fig. 6). Falls are expected to be hotter and drier under both scenarios, and springs are expected to be hotter and wetter (with wetter springs under the A2 scenario as compared with the A1B scenario). Summers are expected to be hotter and wetter in eastern Montana, including the Montana Glaciated Plains and the Big Open, and hotter and drier elsewhere in the ecoregion under the A1B scenario. Summers are expected to be hotter and drier throughout the ecoregion under the A2 scenario. Warmer and drier winters are expected in the northern part of the region, and wetter winters are expected in the southern part of the region (Fig. 7). Averaged over the year, conditions are expected to be hotter and drier throughout most of the region (Figs. 4, 5).

In the MIROC3 2 MEDRES.1 model under the A2 emissions scenario, dry summers are prevalent across the NGP and are particularly dry in the Prairie Pothole Region, with annual average decreases in precipitation of up to 100 mm (3.94 in.) in the Nebraska Sandhills (Fig. 8). However, slightly wetter conditions are predicted for the northern portion of the NGP in Saskatchewan and Alberta. In the CNRM CM3.1 model for the A1B scenario, in contrast, precipitation is expected to decrease the most along the western border of the NGP and in the far northern reaches of the ecoregion. Wetter conditions are likely to exist in eastern Montana and in the Prairie Pothole Region. Overall decreases in annual precipitation are less severe in this model (Fig. 9).

Scenario	Variable	Value	Range	Season*
Both scenarios	Mean highest increase temperature	4.18°C (7.52°F)	2.5-5.7°C (4.5-10.26°F)	Summer
	Mean lowest increase temperature	1.46°C (2.63°F)	0.1-3.0°C (0.18-5.4°F)	Spring/Winter
	Mean increase precipitation	64 mm (2.52 in.)	31-106 mm (1.22-4.17 in.)	Spring
	Mean decrease precipitation	-41 mm (-1.62 in.)	-1-(-79) mm (-0.04-[-3.11] in.)	Summer
A1B	Mean highest increase temperature	4.3°C (7.79°F)	3.1-5.7°C (5.58-10.26°F)	Summer
	Mean lowest increase temperature	1.68°C (3.02°F)	0.6-3.0°C (1.08-5.4°F)	Spring/Winter
	Mean increase precipitation	65 mm (2.57 in.)	31-106 mm (1.22-4.17 in.)	Spring
	Mean decrease precipitation	-39 mm (-1.54 in.)	-1-(-79) mm (-0.04-[-3.11] in.)	Summer/Fall
A2	Mean highest increase temperature	4.02°C (7.42°F)	2.5-5.6°C (4.5-10.08°F)	Summer/Winter
	Mean lowest increase temperature	1.25°C (2.25°F)	0.1-2.5°C (0.18-4.5°F)	Spring/Winter
	Mean increase precipitation	63 mm (2.48 in.)	36-92 mm (1.42-3.62 in.)	Spring
	Mean decrease precipitation	-41 mm (-1.62 in.)	-10-(-78) mm (-0.39-[-3.07] in.)	Summer

Table 1: Predicted future changes in temperature and precipitation averaged across the Northern Great Plains Ecoregion by the 2050s. *Season corresponds to the season during which the majority of the models predict the amount of change will occur.

The changes predicted by these models suggest that overall climatic conditions in the Northern Great Plains will be more similar to current conditions in the northern part of the southern Great Plains by the middle of the century. For example, increases in temperature by 4°C (7.2°F) will put the Northern Great Plains roughly in the average annual temperature range of Kansas, northern Oklahoma and central New Mexico. Increasing precipitation will make conditions similar to current precipitation levels in eastern Nebraska and western Kansas (NOAA 2010b).

Some trends appear when looking across all models and are outlined below:

- The next forty years are expected to bring more substantial increases in temperature and changes in precipitation than the past fifty years, along with more variability overall;
- Some NGP priority landscapes are located in areas that have experienced less change (e.g., lower increases in temperature) than surrounding areas within the NGP; however, the Nebraska Sandhills are predicted to become warmer and drier overall than the other priority landscapes;
- On average (across models and emissions scenarios), predictions suggest an increase in average annual temperature of about 4°C (7.2°F) by the middle of the century and increases in spring precipitation by about 63 mm (2.5 in.);
- Warming in predicted to occur more during the summer and fall seasons, as opposed to the historical trends of warmer spring and winter seasons;
- Spring and winter seasons are expected to have the smallest increases in temperature, in the range of 2-3°C (3.6-5.4°F);
- No decreases in temperature are predicted;
- The largest decreases in precipitation will be during the summer season, and precipitation is likely to decrease by 38mm (1.5 in.), which represents a 50% decrease in the driest portions and a 15% decrease in the wettest portion of the ecoregion;
- Thus, hotter and drier summers are predicted across the region.

Section III: Impacts of Climate Change on Focal Systems and Species

Impacts of Climate Change to Grassland, Sagebrush and Wetland Systems

Grasslands in the Northern Great Plains have withstood droughts and floods for centuries and have co-evolved with grazing mammals and fire to produce a highly diverse system that is naturally resilient to both stochastic events and varying disturbance regimes. Paleoecological data on grasslands demonstrate that previous droughts led to decreases in productivity, increases in erosion and shifts in species composition, whereas humid periods lead to increases in productivity, abundant fuels for fire and stabilization of soils (Clark 2002). Future changes in the distribution of grasslands may come in a variety of forms that include changing species composition, directional shifts in movements (east-west or north-south) and range contractions. Some studies suggest a possible east-to-west shift in the forest-prairie transition zone due to increasing suitability for woody species to inhabit what is currently grassland and shrubland (Bachelet et al. 2003). Other modeling studies suggest a directional shift northward for many grassland vegetation types, given increases in temperatures and steady to slightly decreasing available moisture, which may lead to novel vegetative communities (Thorpe 2010)*.

Potential shifts in species composition may also come in the form of shifting plant functional groups. C_3 species tend to dominate the more northern reaches of the Northern Great Plains, including Montana, North Dakota, Alberta, Saskatchewan and parts of Wyoming. C_3 species are commonly referred to as cool-season, but their distribution relies on more than just temperatures. Epstein et al. (1997) found correlations with soil types and textures as well, while also predicting a potential decrease in distribution with a 2°C increase in mean annual temperature. Meanwhile, C_4 species are generally referred to as warm-season species and some studies have suggested that elevated summer temperatures and increased summer rainfall (but overall drier conditions) may lead to increased dominance of these species (Ehleringer et al. 1997). The impacts of increased carbon dioxide concentrations may call into question these assumptions, however, as increasing CO_2 is likely to benefit C_3 plants (Morgan et al. 2008). Overall, definite shifts from one functional type to another are uncertain; however, the possibility of increasing invasive species presence is likely with increased temperatures, carbon dioxide levels and winter precipitation (Morgan et al. 2008).

While grasslands generally are likely to persist in some form under future climate change, sagebrush systems may prove somewhat more vulnerable to predicted future climate change. Based on modeled species distributions under six future climate scenarios, increases in summer precipitation could lead to decreases in the overall extent of two species of sagebrush—Wyoming big sagebrush (*Artemisia tridentata* var. *wyomingensis*) and silver sagebrush (*Artemisia cana*)—by 2030. Decreases are predicted to be small—about 6% across Montana, North Dakota, South Dakota and Wyoming—but suggest that increasing moisture availability may lead to less overall suitable habitat for sagebrush. However, decreases in summer precipitation may lead to increases in the extent of habitat, although increases will be smaller—about 3-5% across the region (Schrag et al. 2010). The spatial distribution of sagebrush habitat is expected to shrink into the core of its range—southwestern Wyoming—as opposed to moving directionally (Fig. 10). This result suggests that habitats at the fringes currently are less likely to persist in the future (Neilson et al. 2005; Schrag et al. 2010). In addition, Wyoming big sagebrush is expected to be more significantly impacted than silver sagebrush.

Perhaps more importantly than the direct impacts of climate change on sagebrush is the interaction among climate change, fire, sagebrush and cheatgrass (*Bromus tectorum* L.). Cheatgrass is an invasive plant that leads to a reduction in fire return intervals (e.g., more frequent fires), native species diversity, forage quality and crop yields (Bradley 2009). Increases in fire return intervals and invasion of habitat are a double threat for species like sagebrush, which tend to be either fire intolerant or slow to repopulate areas after fire (Montana Natural Heritage Program 2007). Models of the distribution of cheatgrass across the western U.S. show maximum range expansion when there is a decrease in summer precipitation and suggest that the ideal range of precipitation for cheatgrass (0-50 mm during

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the summer season) overlaps substantially with the ideal range of precipitation for Wyoming big sagebrush (15-60 mm during the summer season; Bradley 2009, Schrag et al. 2010).

In addition to terrestrial impacts, climate change will also impact wetland and hydrological systems in the Northern Great Plains. The Prairie Pothole Region serves as the so-called ‘duck factory’ of North America—producing up to 7 million ducks annually during high-precipitation periods. Climate extremes have lead to high diversity in this region, with high-water events leading to a mix of open water and plants that emerge above the water surface (e.g., cattails). Meanwhile, droughts lead to increases in diversity and productivity by pulling new seeds from the seed bank and mobilizing nutrients (Johnson et al. 2005). Ducks have adapted to this variability on their annual migration routes by passing over areas that are experiencing drought. Although conditions may prove more favorable for duck production in the eastern portion of the range where warmer and wetter conditions could occur, this area is also most at risk of conversion to agriculture via draining of wetlands for croplands (Johnson et al. 2005). Some models suggest that temporary wetlands are more resilient to fluctuations in temperature and precipitation, and these wetlands could fill with water at historically high levels even under climate change scenarios. However, evapotranspiration rates may increase, which will shorten the period during which the wetland holds water. Meanwhile, models predict that semi-permanent wetlands will be disproportionately affected by increases in evapotranspiration rates, wherein groundwater recharge does not fully protect them from drying out under future scenarios. While groundwater support could boost resilience temporarily, some wetlands may become seasonal due to a lowered water table (Johnson et al. 2010)[*].

<u>Adaptation recommendations and related research needs:</u>

- Reassessing management goals in light of climate change is a key planning action. Often, maintaining current composition of vegetation communities will be difficult to impossible under future conditions. Understanding future goals will help to prioritize adaptation actions. This will require managers to understand if their desired future condition is to maintain resiliency, resist change or respond to change.
- Restoration of sagebrush habitats can be quite difficult, especially for silver sagebrush, where studies have shown a successful seedling generation rate of 6% or less (US Forest Service 2010). Invasion by cheatgrass can make the restoration process more complicated. Conservation of current sagebrush habitats, and particularly silver sagebrush, should be a priority. To this end, a current map of sagebrush habitat is important for monitoring trends through time. In addition, treating small invasions of cheatgrass before they spread is critical in areas where the climatic conditions are conducive to spread in the future (Bradley 2009).
- Interagency collaboration—across state, provincial and international boundaries—is necessary for a variety of reasons. Northward movement of novel species or community types requires acknowledgement from other jurisdictions that species are not invasive but, rather, shifting their overall distribution. In addition, developing management objectives and setting thresholds

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for change is extremely difficult if different jurisdictions are monitoring resources using different methodologies.

- Use spatially explicit maps to guide conservation and restoration, ensuring that Farm Bill conservation programs, such as the Grassland Reserve Program, are directed to areas that currently have sagebrush habitat and are likely to have sagebrush habitat in the future. One example of successful execution of this type of spatially driven conservation is the Natural Resources Conservation Service's Sage Grouse Initiative, which is targeting conservation easements on lands that are of highest priority to sage grouse using the best-available scientific data.
- Direct other competing threats, such as oil, gas and wind development and tilling of native grasslands, away from high-priority sagebrush habitats and areas that may serve as corridors for sagebrush-dependent species under climate change. Corridors can help to link species to both areas of newly established sagebrush and areas that are likely to constitute refugia for sagebrush (e.g., southwestern Wyoming). Analyses that target wind development in areas that have already been disturbed can be quite helpful in siting new developments (Molvar 2008; Fargione et al. *in prep*).
- For grasslands, maintaining a diversity of structural types across the public-private continuum will ensure varied habitat for a variety of species. This can be accomplished by scaling up management recommendations to be at a landscape or larger scale, so that they are relevant to the scale at which climate change occurs. For example, a community pasture system may help to consolidate individual landowners so that grazing can be managed at a more appropriate scale.
- For both grassland and sagebrush systems, encouraging species diversity and planting of native species will enhance the resiliency of the system to invaders and increase carbon sequestration.
- As temperature thresholds are reached in the future, restoration projects may focus on warmer-season native plants to facilitate response to change and ensure that invasive species do not invade an area due to die-off of cooler-season plants.
- For wetland systems, protecting wetland 'complexes'—different types of wetlands within one area—may ensure greater resiliency under future climate change, as each type of wetland appears to respond in distinct ways to predicted changes. As with the sagebrush system mentioned above, using the results of current analyses on the interconnection among climate change, agriculture and wetlands (Skagen 2009) will help to direct the protection of these complexes so that they are resilient to both current and future conditions.
- Ensuring that federal agencies are taking into account climate change in their long-term planning will help to make sure large, core blocks of land serve as a safety net for some species.

Impacts to Focal Species

Climate change will directly and indirectly affect birds and other wildlife. Using species distribution models, Peterson (2003) predicted that bird species in the Great Plains were more likely than species in other regions of the US to experience both changes in the location of habitat as well as reductions in suitable habitat due to climate change (in some cases, up to 35%)*. However, historic trend data do not suggest that grassland birds are currently being heavily impacted by climate change. The annual State of the Birds Report (North American Bird Conservation Initiative 2009) suggests that grassland bird species are among the most threatened group of birds overall, but most grassland species show low or medium vulnerability to climate change (North American Bird Conservation Initiative 2010) and are the only group of birds that show a southward (as opposed to the predicted northward) latitudinal shift in their range over the last forty years, by about 10 miles on average. It is likely that a lack of information regarding what grassland birds are responding to on a site-by-site basis is contributing to the lack of ability to predict how climate change may impact grassland birds in the future.

Although the predicted impact of climate change on grassland bird species is still uncertain overall, impacts on sagebrush- and wetland-dependent birds are more concrete. One bird species that is likely to be particularly sensitive to changes due to climate change is the greater sage-grouse (*Centrocercus urophasianus*). Greater sage-grouse are expected to face not only contraction of sagebrush habitat throughout the Northern Great Plains (see Figs. 10, 11), but also expansion of West Nile virus. Mosquitoes transmit West Nile virus to sage-grouse after temperatures have reached a certain threshold for multiple days in a row. In the Northern Great Plains, this threshold is 82 degree days (Schrag et al. 2010). Given future predicted changes in temperature over the next two decades, West Nile virus will likely be transmitted to sage-grouse in higher-elevation areas (along the Rocky Mountain front), where it currently is not able to be transmitted due to insufficient temperatures, within the next two decades (Schrag et al. 2010; Fig. 11)*.

Ducks and other water-dependent birds experience fluctuations in population sizes correlated with precipitation. For example, in the Prairie Pothole Region of the Northern Great Plains, duck counts can fluctuate from 2.5 million to almost 7 million annually, depending on the number of filled ponds (Johnson et al. 2005). Shifts away from high levels of precipitation in the spring, as suggested by global circulation models for the Northern Great Plains, may lead to decreases in the number of ponds available as breeding grounds for water-dependent bird species in the future. Ducks have adapted to this variability already by passing over areas that are dry during their annual migrations, but the timing of these migrations may also start to shift in order to ensure that breeding grounds are available.

In addition to birds, some plains-associated mammals are likely to experience impacts from climate change. The Black-footed ferret is the most endangered mammal in North America and its populations are dependent upon vibrant prairie dog communities. These species are both susceptible to sylvatic plague, a disease that has decimated prairie dog communities across the Great Plains and western United States. The link between climate and plague is not completely understood, but some studies have shown a positive association between plague outbreaks and the previous year's spring precipitation (Collinge et al. 2005, Snall et al. 2008) and correlations between current and predicted climate and the spatial extent of the disease (Nakazawa et al. 2007). There also appears to be some

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association between plague outbreaks and temperature, where warm days are positively associated with outbreaks, while hot days are negatively associated with outbreaks (Collinge et al. 2005, Snall et al. 2008)[*]. In addition, during extreme droughts, such as the summer of 2011, prairie dogs in the southern Great Plains were observed hibernating, which they generally do not do at that latitude. This has cascading impacts on black-footed ferrets, since prairie dogs are their main prey species (Corn 2011).

Many mammals in the Northern Great Plains will be either directly or secondarily impacted by changes in grassland productivity caused by climate change. Models of grassland productivity for Saskatchewan have suggested potential decreases in the overall amount of grass produced under future climate scenarios (Thorpe et al. 2004). Decreases may occur more slowly in northern parts of the region, with steady production rates over the next two decades, followed by decreases later in the century, depending on the future climate scenario (Thorpe et al. 2004). Other studies predict steady production in the northern part of the region and decreasing production in the southern part of the region by 2030 under most climate-change scenarios, specifically in southwestern South Dakota (Schrag 2011). Some recent studies have shown that changes in the timing and amount of precipitation lead to decreases in the quality of forage, thus changing the number of animals that an acre of land can support. For instance, late-summer precipitation leads to more leaf and less stem in tallgrass prairies and, thus, weight gain in bison, whereas mid-summer precipitation results in the opposite effect (Craine et al. 2009). Reductions in the quality and/or quantity of forage may have major impacts on the number of wildlife and production animals that can be sustained by current habitat and protected areas, wherein more acreage may be needed to support the same number of animals in the future, at least in some parts of the ecoregion.

Another indirect impact of climate change on wildlife in the Northern Great Plains is the change in suitability for agriculture across the region (see also Section IV). Many areas have not been as suitable for growing crops as the southern Great Plains because of low temperatures and precipitation. However, climate change may make some areas in the Northern Great Plains more suitable for growing crops in the future (National Research Council 2010). Some mammals, including swift fox (*Vulpes velox*), which rely on contiguous blocks of land, may be negatively affected by these changes, as plowing up of native prairie will cause either direct destruction of their habitat or will fragment potential migration corridors. In addition, increasing temperatures may lead to earlier emergence of small mammal populations, changing the timing and movement patterns of the main prey source for swift fox. Repeated droughts could lead to substantial decreases in small mammal populations (Saskatchewan Planning Workshop *pers. comm.*). Conversion of native grasslands for crops would also have significant negative effects on a variety of grassland birds, including sprague's pipit (*Anthus spragueii*), mountain plover (*Charadrius montanus*) and greater sage-grouse. All three of these species have either been petitioned for listing under the Endangered Species Act or are currently listed as "warranted but precluded" (U.S. Fish and Wildlife Service 2010); thus, their dwindling population sizes make them more vulnerable to other disturbances, such as increasing farmland in the Northern Great Plains.

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Adaptation recommendations and related research needs

- Establish agreements with private landowners who own lands that have high levels of biodiversity or species at risk and also high likelihood of conversion, due to physical factors (e.g., soil suitability) and economic incentives, to conserve lands for the future.
- Alter field management practices, such as flooding fields for migratory birds (e.g., the Farming for Wildlife program through The Nature Conservancy) or changing the timing of harvests so that habitat is available during migration periods.
- Create buffer strips of native vegetation along the edges of agricultural fields to provide habitat and cover for small mammals, which will help increase prey diversity for some mammals of interest, like swift fox.
- Artificial sources of standing water (e.g., stock ponds, water on coalbed methane developments) should be prevented and/or removed in core sage-grouse areas because standing water serves as the primary breeding ground for mosquitoes, which transmit West Nile virus. For ponds that cannot be removed, aeration systems may be used to move water and decrease the breeding area for mosquitoes. Introducing mosquito-eating fish and re-engineering stock ponds and other water-retention systems may also provide a method for decreasing the number of mosquitoes.
- Keep areas around wetlands in native grasslands to enhance runoff and keep wetlands full that are not groundwater fed. Focusing conservation dollars (and government conservation programs) on areas surrounding these wetlands in order to prevent the elimination of native species for cropland is key to facilitating resiliency in this system.
- Continue efforts to “dust” and vaccinate prairie dog and ferret populations to enhance their natural resistance to disease. Support development of plague vaccinations and possibly grow prairie dogs with plague-resistant genes. In addition, pursue research on how climate change is affecting disease and which areas may best support populations in the future so that species reintroductions are occurring in the core of the potential future range, where species may have the best chance of survival.
- Research on changes to forage productivity due to climate change will help to guide stocking rates and develop management recommendations for wildlife carrying capacity under changed conditions.
- For many migratory birds, research on threats to their winter range can provide insights into the reasons for decreasing population sizes and potential adaptation techniques for these species.
- Research the potential for increasing temperatures to lead to increased agricultural production in the region. However, because the choice to switch from grassland to cropland is largely market-based, this research needs to be tied to information on market forces in the landscape.

Section IV: Impacts of Climate Change to Processes, Economic Interests and Threats

Impacts of Climate Change to Ecosystem Processes

Although the effects of climate change on many species in the Northern Great Plains may play out in an indirect manner, impacts to processes are likely to be direct and possibly more severe. For example, hydrological changes due to climate change may be profound in the streams of the Northern Great Plains. Small increases in temperature (1-2°C) and decreases in precipitation (5-10%) may lead to increased evapotranspiration, decreased surface discharge and increased salinity. Increased variability in temperature and precipitation and increased frequency of extreme events may lead to changes in flows of ephemeral streams, drying up of residual pools and loss of habitat for native fish. In addition, some native fish may suffer due to increased temperatures if they are already living at their thermal threshold. Warming groundwater and the diversion of surface water for other uses could lead to the complete loss of small prairie streams (Covich et al. 1997). In addition, water demand is predicted to outpace supply in many counties within the Northern Great Plains by 2050, leading to shortages for both human and agricultural uses (Natural Resources Defense Council 2010). If the total amount of water available decreases with climate change, increasing conflicts may arise among different land uses[*].

Wildfires are also likely to be directly impacted by climate change. A recent study showed that the relationship between the extent of historic fires and climate variables was strong throughout the western ecoprovinces, especially in the Great Plains (which included both the Northern Great Plains and portions of the southern Great Plains to northern Texas). In the Great Plains, precipitation that fell during the year of the fire had the strongest correlation with the extent of the area burned (Littell et al., 2009). The model predicts that increasing temperatures by 1°C (1.8°F) will increase the median annual area burned by 393% in the Great Plains (National Research Council 2010). As mentioned in Section III above, increases in fire may lead to overall decreases in the amount of sagebrush habitat in the Northern Great Plains. Using a spatial vegetation succession model that incorporates fire, one study suggested that increases in fire of only 2-48% in the Northern Great Plains could lead to decreases of up to 5 million ha of sagebrush habitat (Ritter *unpublished data*). Cheatgrass, a rapid invader after fire, may outcompete and suppress sagebrush.

Annual migrations also may be affected by climate change. Many species migrate over short or long distances to find wintering habitat. Migrations in the Northern Great Plains vary from relatively short distance, such as the greater sage-grouse migration from Saskatchewan to northern Montana (Tack 2006), to much longer distances, including many migratory birds that winter in the Chihuahuan desert of Mexico (CEC and TNC 2005). While much of the research on climate change and migrations has been related to long-term migrations of plant species across the landscape, animals will also be impacted by these changes. Climate change is likely to be heterogeneous across North America; thus, signaling cues that birds and mammals use in order to time their migrations with food sources may be mismatched in their summer and winter habitats. In addition, increasing frequency of extreme events, such as significant snowfall in prairie landscapes, can completely stop normal migration and/or alter timing of movements. Such changes have already been documented in the Northern Great Plains (D. Jorgensen *pers. comm.*) and southern Rocky Mountains (Inouye et al. 2000). Mismatched timing between plants and pollinators in agricultural regions are likely to have economic effects as well (see Section IV for more information).

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Adaptation recommendations and related research needs:

- Removal of artificial water diversions (e.g., dams, stock ponds) will restore natural flows to prairie streams and increase functionality of water bodies, although at a cost to landowners and producers. Connecting small streams to larger water bodies (larger rivers) is important as drought may cause smaller streams to "blink out" at varying intervals and interconnectivity allows fish to repopulate these streams during wetter periods. Incentives for landowners to maintain water in streams may help to ensure that both people and fish have sufficient water under changed climatic conditions.
- Collaboration and cooperation among upstream and downstream users on policy issues that affect the quantity of water available in prairie streams is necessary. Understanding how climate change may influence those policies is integral to water management in the future.
- Removing artificial barriers to movement for migrating species will ensure that species are able to move across the landscape based on natural cues.
- In areas where sagebrush is being restored, experimental planting of sagebrush species that are more fire tolerant may help to ensure that habitat will be available if fires become more frequent.

Impacts of Climate Change to Economic Interests

Many of the major industries in the Northern Great Plains are likely to be affected to some degree by climate change. Agriculture, ranching, hunting, fishing and other recreational activities are all more likely to be impacted than industries that are not so closely tied to climatic variables.

The impacts of climate change on agricultural crops are likely to vary both spatially and by crop type. Research has shown that crops that use the C_3 photosynthetic pathway, such as wheat, are likely to experience increases in yield under increased carbon dioxide concentrations. Increased CO_2 concentrations stimulate photosynthesis in these crops and cause stomata (i.e., pores on the leaves) to shrink, which decreases water loss. Recent research suggests that increases in yield of up to 14% may be seen if atmospheric carbon dioxide levels reach 580 parts per million (ppm); the current level is 388 ppm (National Research Council 2010). However, when increasing temperatures are taken into account, the positive effects of increases in CO_2 concentrations are negated for C_3 crops once the warming reaches 2-3°C (3.6-5.4°F). In contrast, crops that use the C_4 photosynthetic pathway, like corn, are likely to experience steady to slightly decreasing yields (National Research Council 2010). For C_4 plants, any increase in temperature is likely to drive down crop yields (National Research Council 2010). In addition, pollinators are likely to be affected by mismatched timing between their phenology (e.g., timing of migration) and that of flowering plants (Memmott et al.

EXAMPLES OF C_3 AND C_4 CROPS
(common to the Northern Great Plains)

C_3: wheat, barley, potatoes, soybeans, sugar beets, oats, rye, peas

C_4: corn, sorghum, lentils

2007), and this could have significant impacts on agriculture in the region. Increasing nighttime temperatures may also lead to smaller fruits and grains, and some crops may experience an increased risk of episodic frost damage due to generally warmer temperatures, which lead to earlier spring-time growth before the frost-free period begins (Prasad et al. 2008)[*]. As described in Section III, changes in the amount of grass available as forage for production animals will impact ranching operations in the Northern Great Plains. In addition, an increasing threat of heat stress on cattle may occur due to more extreme summer temperatures (U.S. Global Change Research Program 2009).

Hunting and fishing also produce significant revenues in the region. Revenue gained through hunting and fishing permits funds many state wildlife agencies, and small communities throughout the region experience an economic boost from hunting-related tourism. Total revenue spent on hunting, fishing and wildlife watching in the five U.S. states in the Northern Great Plains was $1.1 billion in 2006 (Freese et al. 2009). Climate change is expected to impact both hunting and fishing industries in the Northern Great Plains. Greater variability in extreme precipitation events may decrease populations of some sport fish, as fluctuations in lake levels caused by flooding and droughts decrease the survival of eggs, larvae and young (Bipartisan Policy Institute, 2008). Because prairie fish are often said to be "living on the edge," small increases in temperatures may push them over their thermal threshold and cause die-offs due to stress on their metabolic activities and lower dissolved oxygen in the water (Bipartisan Policy Institute 2008). Fish may also be impacted by invasive plants, including Eurasian milfoil, which has recently invaded the Missouri in Montana and is present in the other U.S. states within the Northern Great Plains except for Wyoming (U.S. Geological Survey 2010).

Big game populations are likely to be impacted by climate change in a variety of ways. Some diseases that have yet to hit northern populations may be facilitated by warming temperatures (Bipartisan Policy Institute 2008). Decreasing forage quality may affect carrying capacities for many game species, as grasses become more fibrous and less nutrient-dense. Possible shifts in populations, with fewer mule deer (*Odocoileus hemionus*), which require nutrient-dense food sources, and more elk (*Cervus elaphus*), which are more adaptable to marginal habitat and food sources, may occur (Bipartisan Policy Institute 2008). White-tailed deer (*Odocoileus virginianus*) are not expected to experience much of a change in occurrence due to climate change, unless widespread changes in habitat occur (Bipartisan Policy Institute 2008).

<u>Adaptation recommendations and related research needs:</u>

- Ensure that agricultural fields have buffer strips of native species that can provide habitat for pollinators.
- Alter timing of harvest to provide habitat for migratory species and small mammals.
- Fish and wildlife agencies should plan proactively to set thresholds and establish monitoring programs for changing climatic conditions that drive hunting and fishing seasons, fishing regulations and sale of permits and tags.

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- Active removal of competing threats to the health of aquatic systems, including water diversions and invasive species, is essential.
- Plant riparian vegetation to provide shade and lead to lower stream temperatures and decreased erosion in shallow prairie streams. Vegetation types that are planted should be resilient under changed climate conditions.
- Conduct outreach to fisherman and hunters about the identification and spread of invasive species.
- Collect baseline data on species composition in prairie streams so that changes can be monitored through time. Modeling potential refugia will allow for identification of highest priority streams for adaptation actions.

Impacts of Climate Change to Environmental Stressors

Environmental stressors (threats) are prevalent in all conservation landscapes, and in the Northern Great Plains many of these threats are or may be influenced by climate change. We consider a few of the major threats to the landscape and the impacts of climate change on those threats here.

Energy development is prevalent throughout the Northern Great Plains, in the form of oil, gas, coalbed methane, coal, geothermal and wind energy. Climate change may influence oil, gas, coal and coalbed methane development primarily through federal regulatory structures. Yet, mitigating the effects of these developments will be one of the major climate adaptation challenges in specific priority landscapes. See Section III for information about impacts of these types of energy development on greater sage-grouse. Conversely, wind energy development may be directly impacted by climate change. Predictive studies for the Great Falls, Montana, area suggest that wind power may decrease by up to 45% during the summer months in the future (Sailor 2008). This may mean that areas where current wind potential is on the lower end of the necessary range for development may no longer be viable and developers may need to seek out areas with higher wind potential.

Climate change is also likely to impact the threat of tilling native grasslands to plant crops. As temperatures increase, historically temperature-limited areas like the northern parts of the Northern Great Plains could experience a boom in agricultural development as crops that traditionally grow well in southern areas are able to thrive (National Research Council 2010). As described above, yields of some crops may increase as carbon dioxide concentrations increase, which could provide an incentive for growing crops in new areas (National Research Council 2010). Conversely, as the total amount of water available decreases due to evapotranspiration, some crops may reach a threshold wherein they no longer are producing at a sufficient level. However, technological advances, such as drought-resistant strains of corn and wheat, may allow farmers to overcome this moisture deficit (Lutey 2009).

Climate change is also likely to impact invasive species and diseases. The major plants (cheatgrass) and diseases (plague, West Nile virus) of concern are examined in Section III above; however, other species and diseases may become important. For instance, species that are native in the southern portion of the Northern Great Plains (or even further south) may move northward and colonize new areas.

Establishing protocols for how to manage these new, climate-driven 'invasions' are essential for planning and management at the ecoregional scale.

Adaptation/mitigation recommendations:

- Due to possible decreases in wind potential for this region, wind developments should be sited in areas with higher wind potential than previously thought in order to prevent the development of wind farms in areas that are not viable long term. These developments also should be prevented in areas of high biodiversity, particularly with respect to bird species that are sensitive to tall structures or moving windmills.
- Understanding the distribution of biophysical characteristics (e.g., temperature, soil type, precipitation, etc.) that make land suitable for tillage will allow for targeted efforts to reduce the threat in those areas. Putting into place conservation easements in these areas will ensure that future development does not occur.

Section V: Recommendations for Focusing Conservation Effort and Dollars in the Face of Climate Change

Implementing all of the adaptation recommendations mentioned throughout this addendum will enhance the resiliency of a region that may experience great change over the next few decades. However, assuming that time, effort and dollars are not limitless, a few recommendations stand out as particularly necessary to improve the health of the Northern Great Plains under changed climatic conditions:

- Aquatic resources are likely to be the system that is most directly impacted by climate change over the next few decades, due to likely overall increases in frequency of extreme events and decreases in water availablility. Baseline data on species, streamflows and water quality must be collected and monitored. Immediate actions that may facilitate resiliency, such as planting riparian vegetation to provide shade and decrease erosion or removing aquatic diversions, are 'no-lose' strategies in smaller prairie streams. Removing invasive species in both small and large streams and rivers should also be a priority. And, planting or maintaining native vegetation—as opposed to invasive species or cropland—around wetlands will protect runoff and water quality in wetland systems. Conservation plans that prioritize wetland 'complexes' should be used in order to increase biocomplexity in the system and protect high biodiversity in the future.
- Sagebrush systems and greater sage-grouse also need to be prioritized for climate adaptation actions. Because sage-grouse are already threatened by other immediate causes, such as energy development, their populations are more sensitive to fluctuations in climate than other species. Preventing further development in 'core areas' is important for maintaining habitat and connectivity of populations. Other activities on the ground may also allow existing sage-grouse populations stabilize or increase. For instance, sage-grouse are currently being infected by West Nile virus, but mortality is relatively localized in extent; preventative measures should be taken in areas where it is likely to spread under future increased temperatures. Invasive species should also be heavily

controlled in core areas to prevent these habitats from becoming dominated by non-sagebrush species.

- Rethinking both long-term planning and specific actions, such as species reintroductions, in the face of climate change will be essential. Most species plans are currently based upon historic distributions and/or carrying capacities may change based on the availability of forage and habitat. Targeting species reintroductions and conservation in the areas where they are most likely to persist in the future is likely to allow species to flourish under changed climatic conditions.
- Cross-jurisdictional collaboration will be of utmost importance. Collaborating across the public-private continuum, international and state borders, and federal and state agencies is essential for making climate adaptation work. Many adaptation techniques are similar to 'conservation as usual', but must be applied at a much larger scale in order to be effective under changed climatic conditions. Using networks and cooperatives (e.g., Landscape Conservation Cooperatives) to tackle issues that stretch across boundaries may be one effective way of dealing with this issue.

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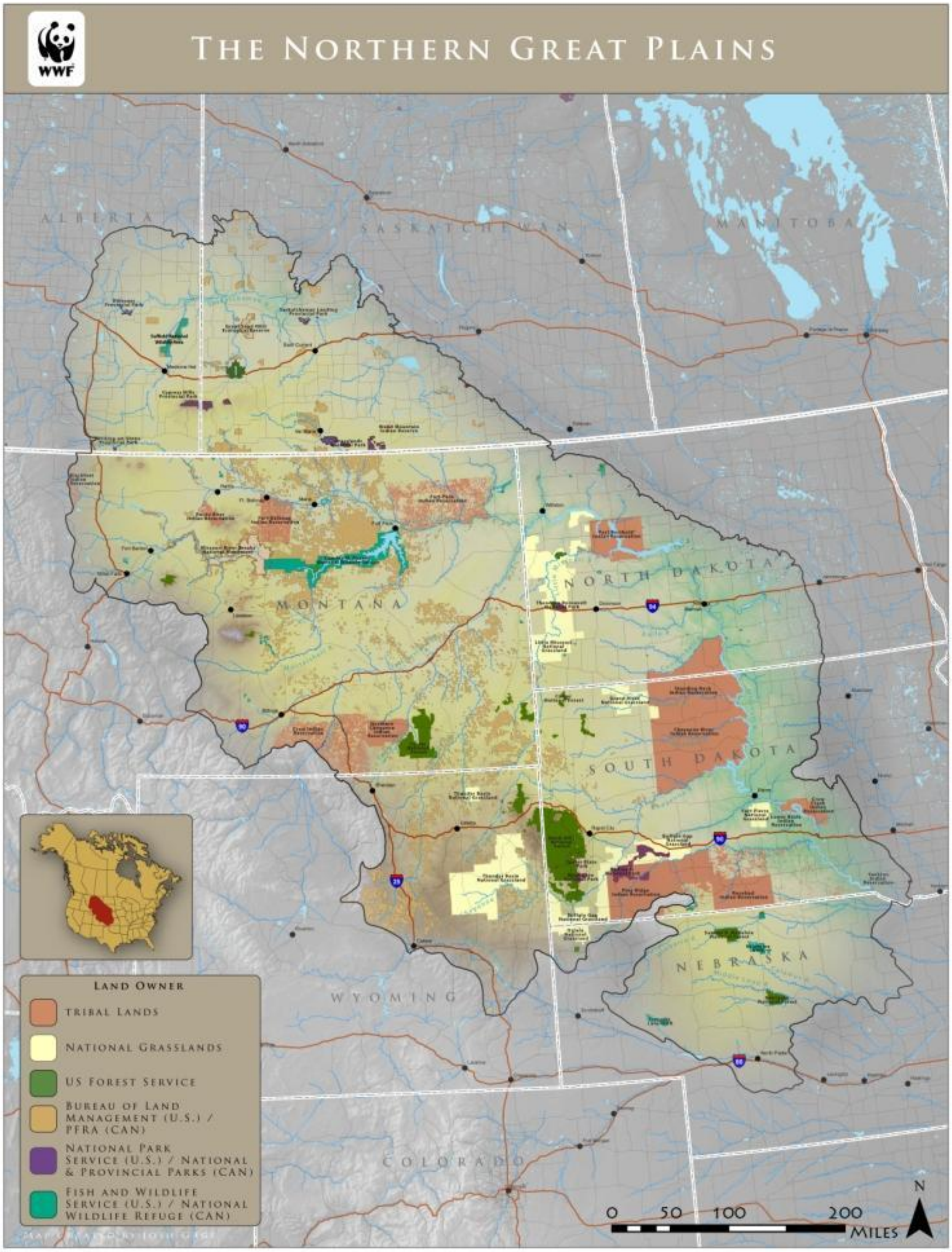

Figure 1: Map of the Northern Great Plains Ecoregion.

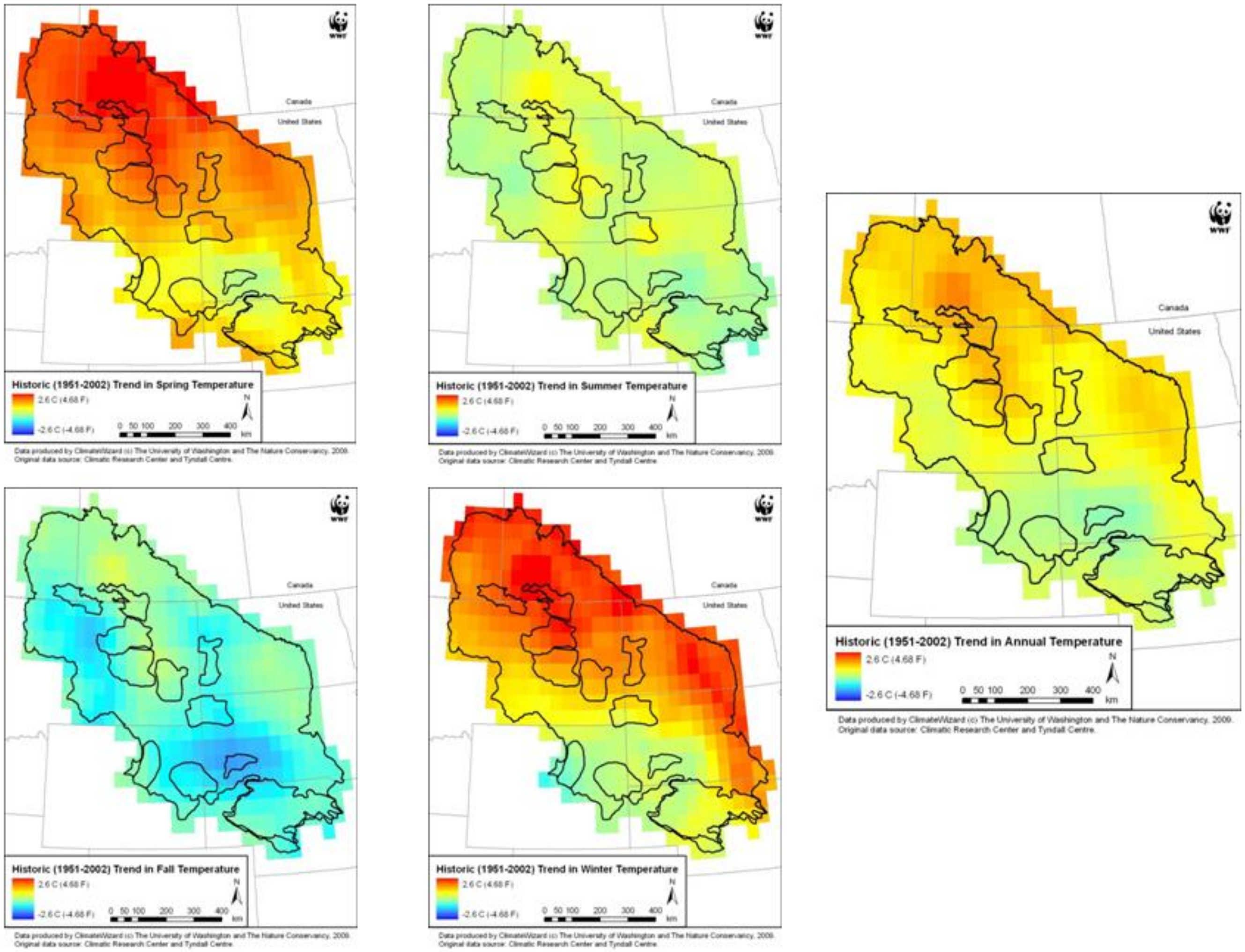

Figure 2: Historic trends in seasonal and annual temperatures from 1951-2002 in the Northern Great Plains. **Data produced by Climate Wizard © The University of Washington and The Nature Conservancy, 2009. Original data sources: Climate Research Center and Tyndall Centre.**

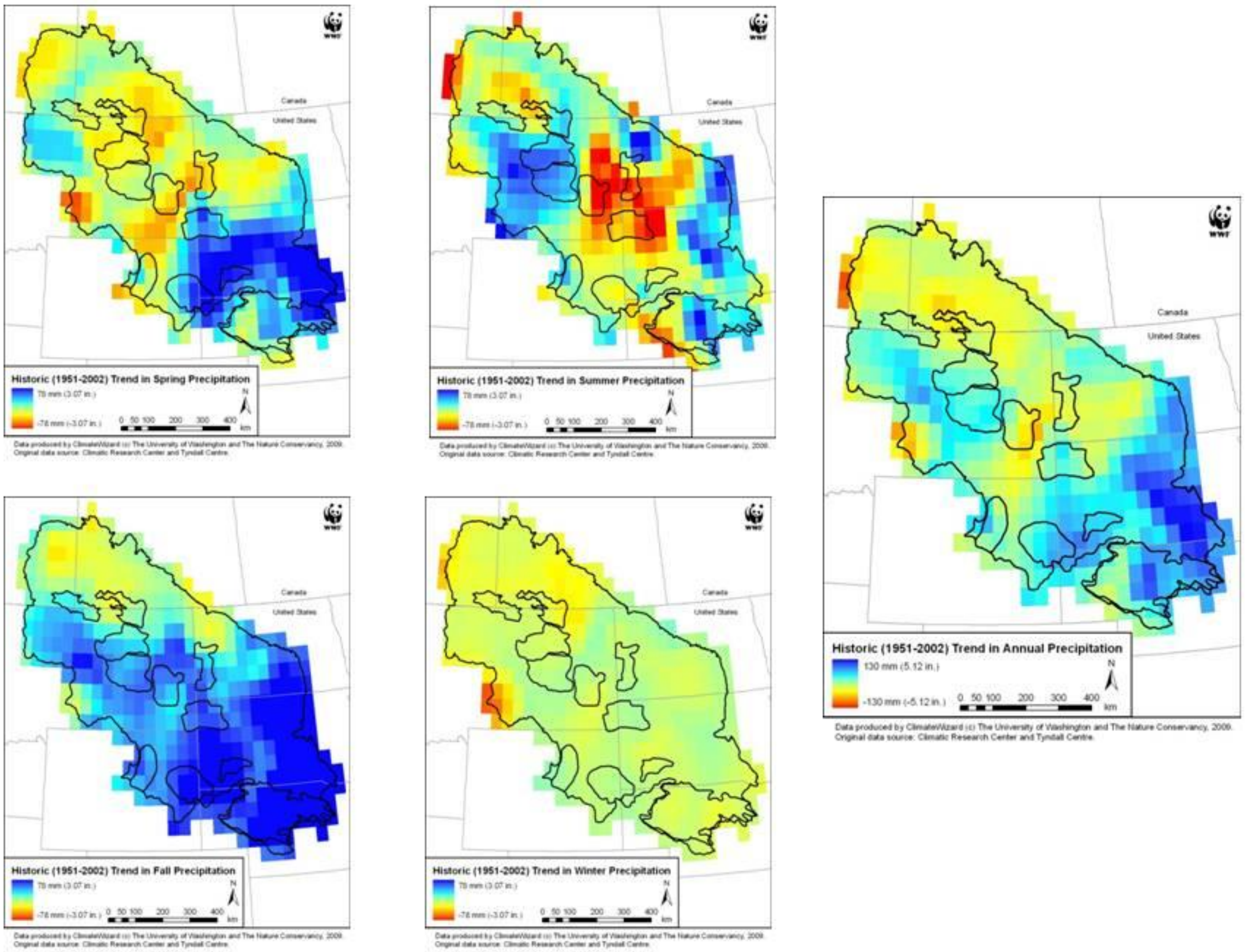

Figure 3: Historic trends in seasonal and annual precipitation from 1951-2002 in the Northern Great Plains. **Data produced by Climate Wizard © The University of Washington and The Nature Conservancy, 2009. Original data sources: Climate Research Center and Tyndall Centre.**

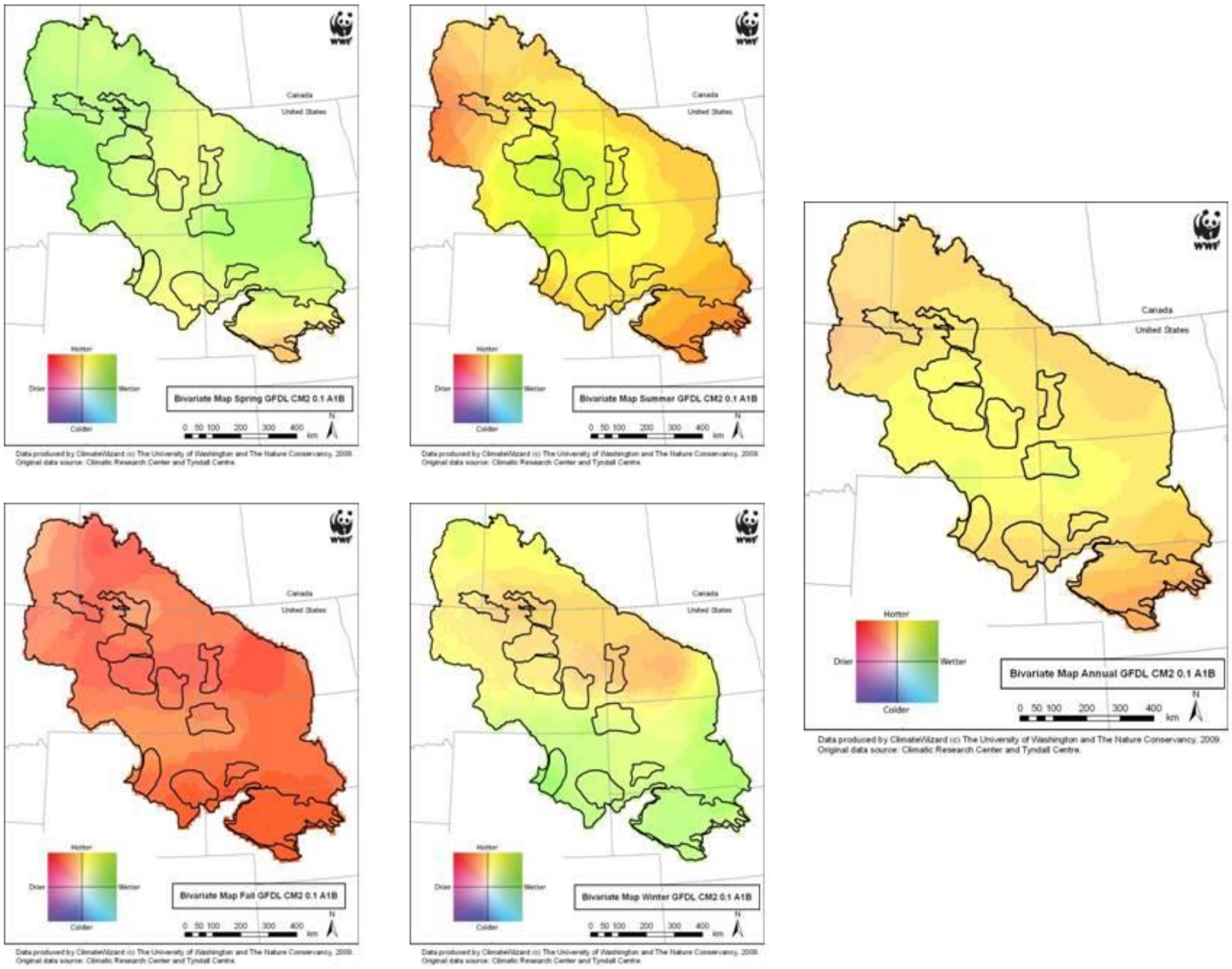

Figure 4: Future predicted changes under model GFDL CM2 0.1 for the A1B scenario in seasonal and annual temperature and precipitation for the 2050s in the Northern Great Plains presented as a bivariate map (effects shown are combined changes in temperature and precipitation across the region). Data produced by Climate Wizard © The University of Washington and The Nature Conservancy, 2009. Original data sources: Climate Research Center and Tyndall Centre.

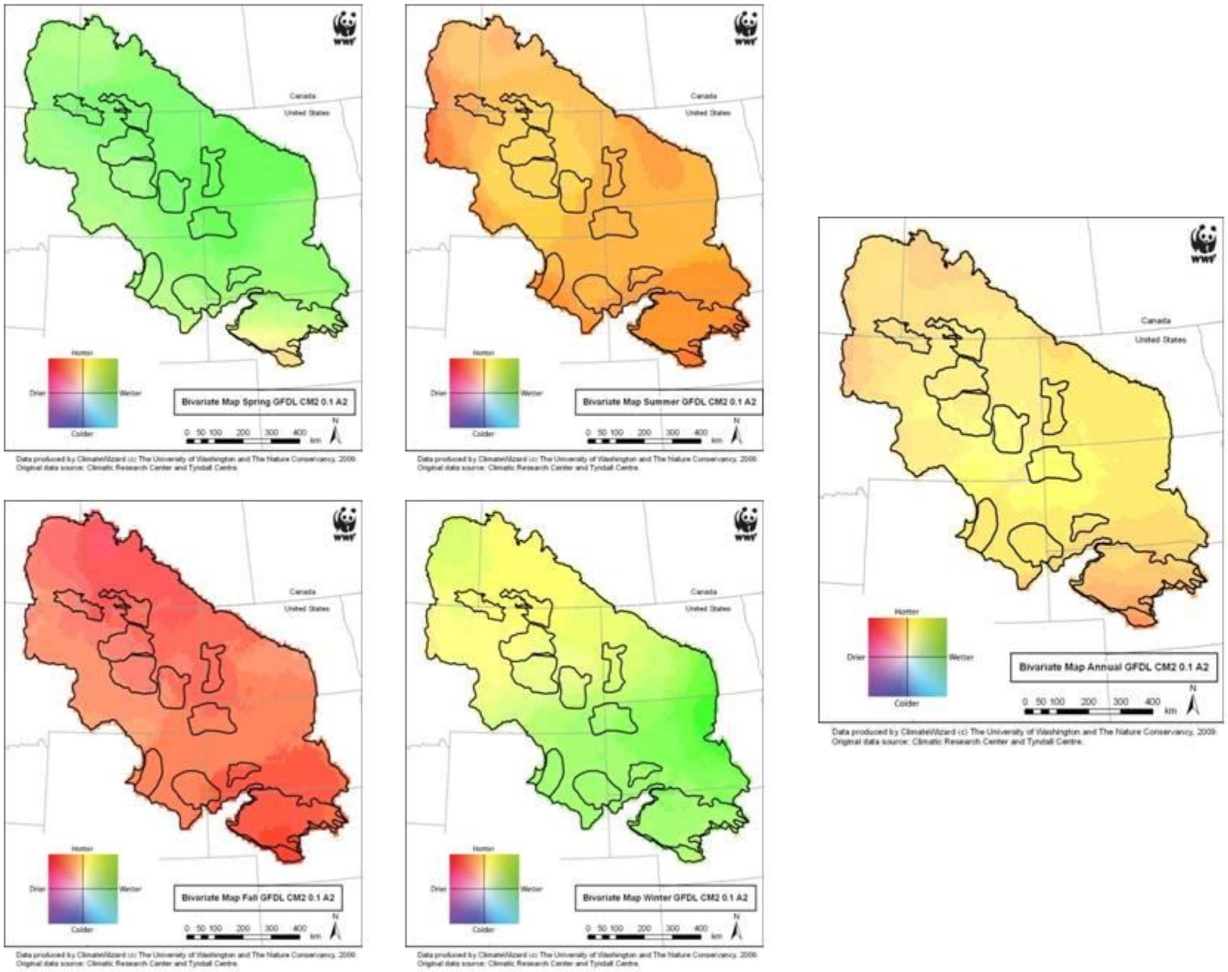

Figure 5: Future predicted changes under model GFDL CM2 0.1 for the A2 scenario in seasonal and annual temperature and precipitation for the 2050s in the Northern Great Plains presented as a bivariate map (effects shown are combined changes in temperature and precipitation across the region). **Data produced by Climate Wizard © The University of Washington and The Nature Conservancy, 2009. Original data sources: Climate Research Center and Tyndall Centre.**

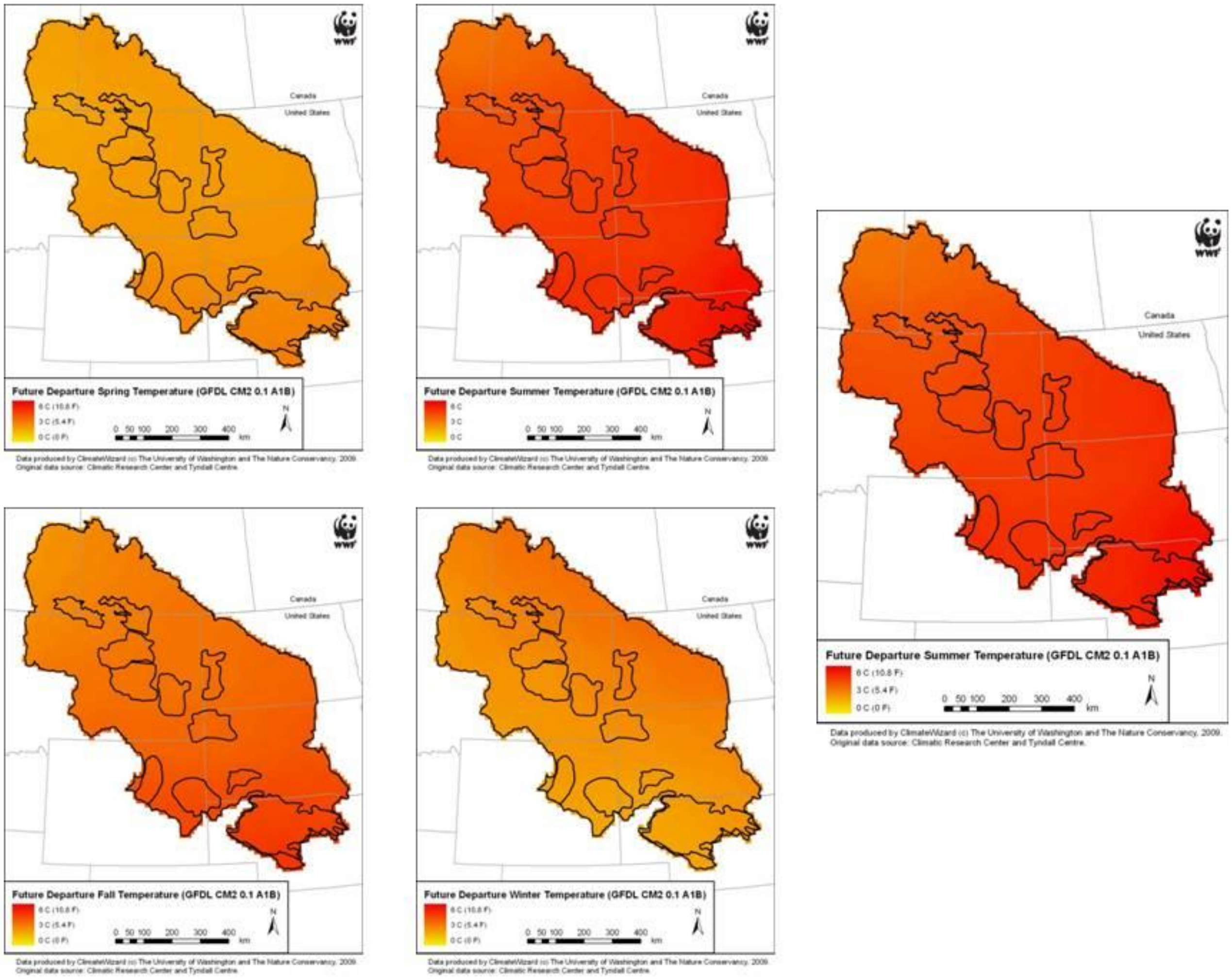

Figure 6: Future predicted changes under model GFDL CM2 0.1 for the A1B scenario in seasonal and annual temperature for the 2050s in the Northern Great Plains. **Data produced by Climate Wizard © The University of Washington and The Nature Conservancy, 2009. Original data sources: Climate Research Center and Tyndall Centre.**

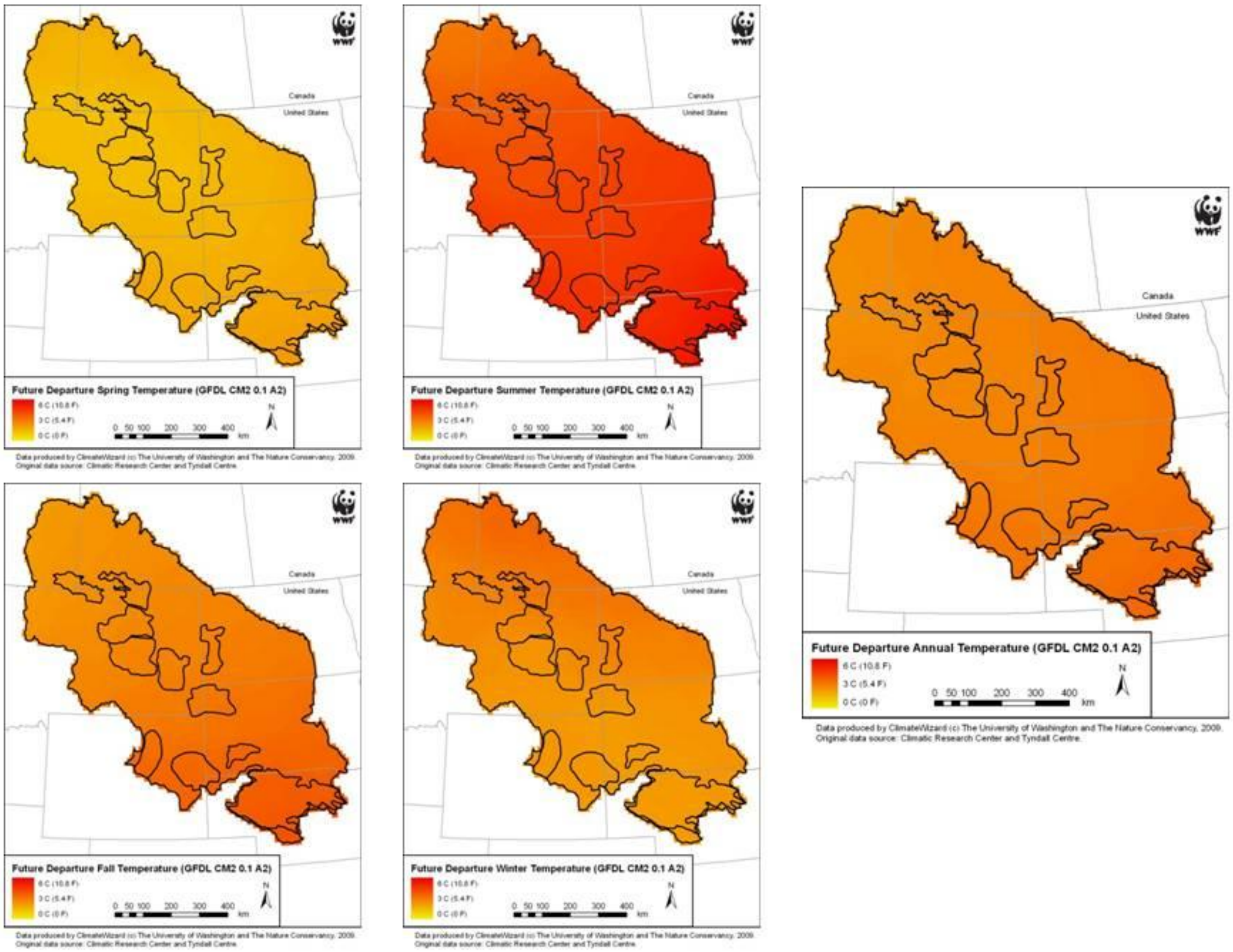

Figure 7: Future predicted changes under model GFDL CM2 0.1 for the A2 scenario in seasonal and annual temperature for the 2050s in the Northern Great Plains. **Data produced by Climate Wizard © The University of Washington and The Nature Conservancy, 2009. Original data sources: Climate Research Center and Tyndall Centre.**

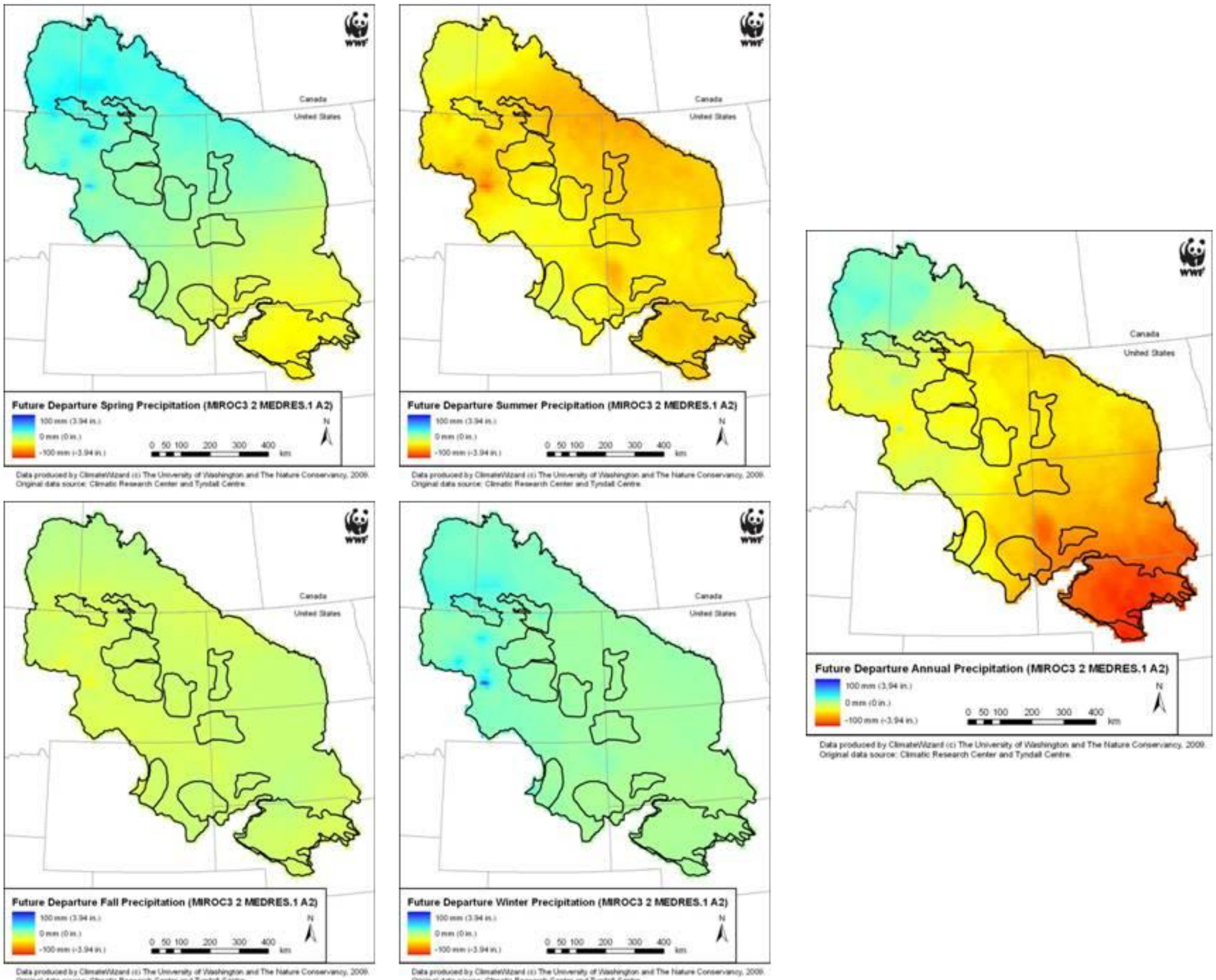

Figure 8: Future predicted changes under model MIROC3 2 MEDRES.1 for the A2 scenario in seasonal and annual precipitation for the 2050s in the Northern Great Plains. **Data produced by Climate Wizard © The University of Washington and The Nature Conservancy, 2009. Original data sources: Climate Research Center and Tyndall Centre.**

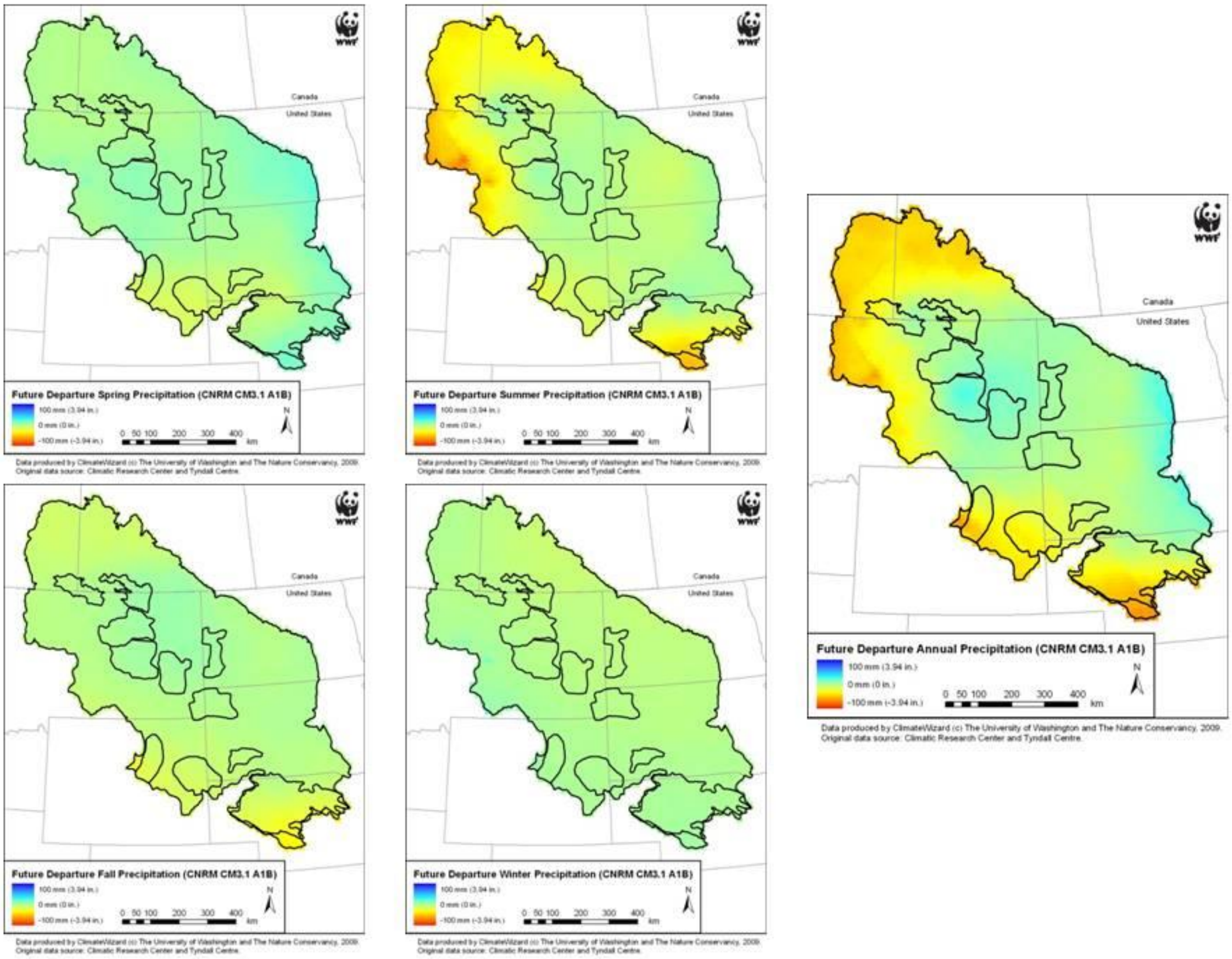

Figure 9: Future predicted changes under model CNRM CM3.1 for the A1B scenario in seasonal and annual precipitation for the 2050s in the Northern Great Plains. **Data produced by Climate Wizard © The University of Washington and The Nature Conservancy, 2009. Original data sources: Climate Research Center and Tyndall Centre.**

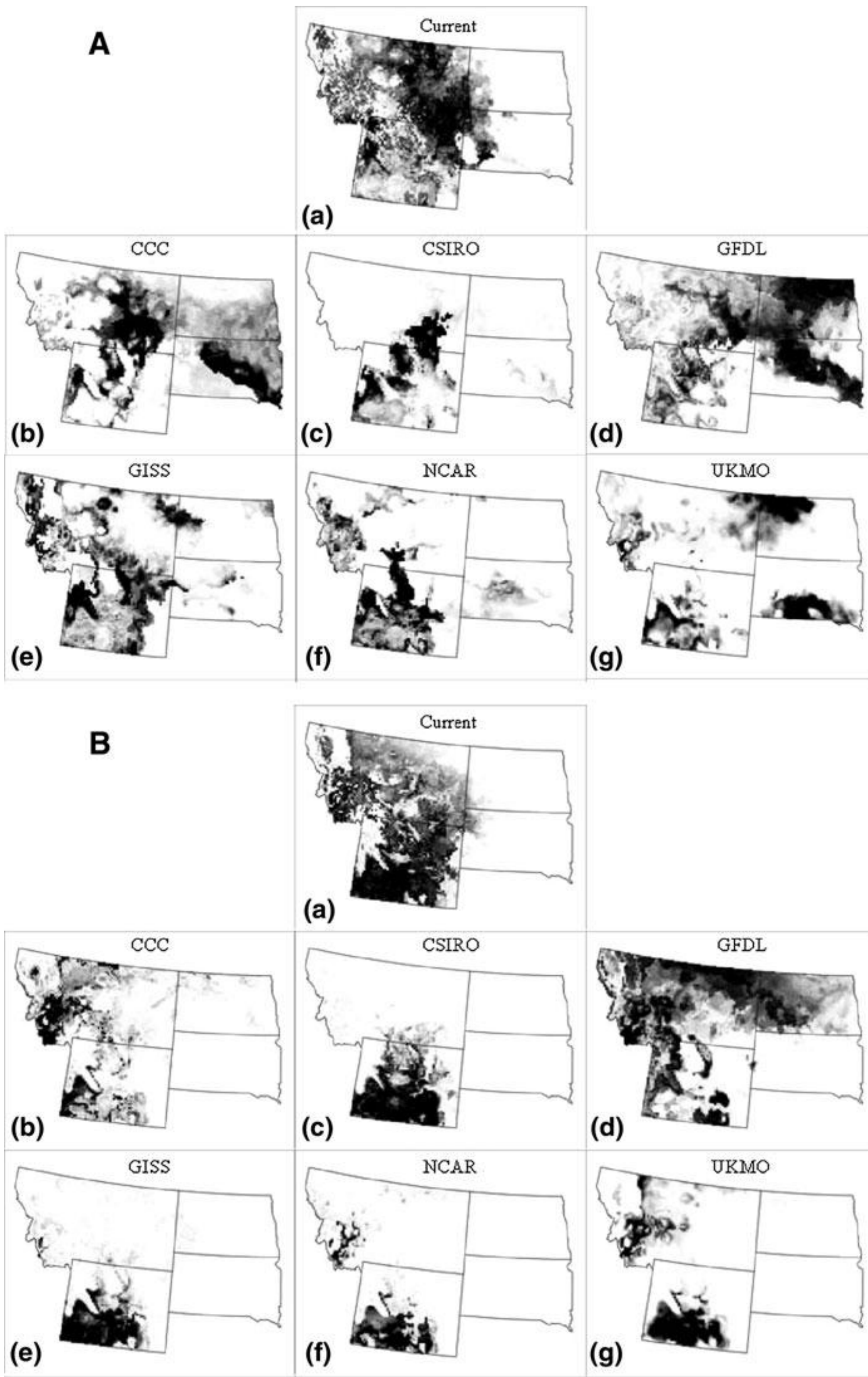

Figure 10: Models of current and future predicted climatically suitable conditions for silver sagebrush (A) and Wyoming big sagebrush (B) in 2030 using the Maxent modeling method, where black represents a probability of occurrence of 1.0 and white represents a probability of occurrence of 0.0, on a continuous scale of 0.0-1.0. Spatial resolution is 12 km^2. General circulation models used are as indicated in the labeled boxes. Adapted from Schrag et al. (2011).

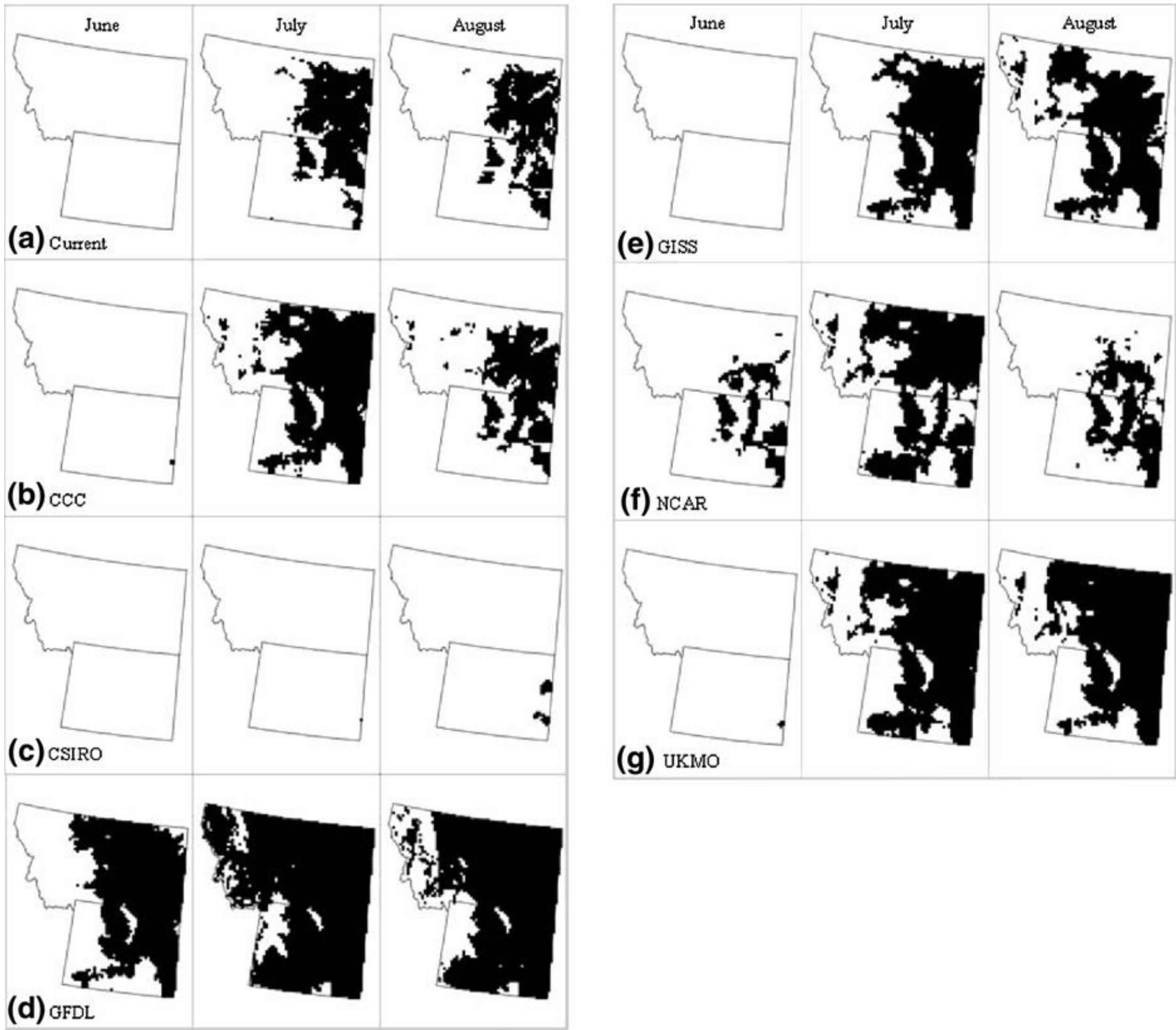

Figure 11: Models of current and future predicted risk of West Nile virus transmission in Montana and Wyoming using a degree-day model (see Schrag et al. *in press* for explanation of model), where black represents probably transmission risk and white represents no risk, on a binary scale of 0 and 1. Spatial resolution is 12 km^2. General circulation models used are as indicated in the labeled boxes. Adapted from Schrag et al. (2011).