THE IMPACTS OF DROUGHT ON SPECIES AT RISK AND THEIR HABITAT IN THE NORTHERN MIXED GRASS PRAIRIES

A Thesis

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Susan Michelle Rever, candidate for the degree of Master of Science in Interdisciplinary Studies in Biology and Geography, has presented a thesis titled, ***The Impacts of Drought on Species at Risk and Their Habitat in the Northern Mixed Grass Prairies,*** in an oral examination held on April 23, 2009. The following committee members have found the thesis acceptable in form and content, and that the candidate demonstrated satisfactory knowledge of the subject material.

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ABSTRACT

Climatologists suggest that global warming will bring higher temperatures and more frequent and extreme droughts to areas such as the West Block of Grasslands National Park (GNP). Since drought is closely linked to land degradation, future management of mixed prairie grasslands will require an improved understanding of past and future trends in regional aridity. The objectives of my research were: 1) to spatially analyze temporally discrete data for climate and grassland productivity from 1978 to 2006; 2) to develop statistical models of climate-vegetation relationships for the West Block of Grasslands National Park; 3) to assess past and predict future aridity; 4) to forecast the probability of future drought using Monte Carlo analysis; 5) to assess the effects climate change will have on the eight species-at-risk (SAR) chosen for my study; and 6) to develop management options and risk analysis for the eight SAR.

Past grassland productivity analyses show that vegetation index (numerical indicator that analyzes radiometric measurements that indicate relative abundance and activity of green vegetation) averages were typically lower during drought years, except for the moisture stress index (MSI), which is an inverted vegetation index. In this case, higher values indicate greater water stress. During a severe drought, photosynthesis is significantly reduced, which decreases grassland productivity.

I found that the normalized difference vegetation index (NDVI) and soil adjusted vegetation index (SAVI) are negatively correlated with temperature, while the normalized difference moisture index (NDMI) is positively correlated with precipitation and aridity, and negatively correlated with potential evapotranspiration (PET). The MSI is positively correlated with PET, and negatively correlated with precipitation and aridity. This means that vegetation indices are strongly associated with climate variables. The multiple linear regression models, which evaluated how accurately the vegetation index variables can be predicted by precipitation, temperature, and PET, for the NDMI and MSI vegetation indices, were significant.

Past aridity measurements for the West Block of GNP indicate that this area was a semi-arid ecoregion during 1978 to 2006. If current trends continue, GNP will fall into the arid classification by 2020, for the month of July. By 2050 and 2080, GNP will be classified as arid for both July and August.

Based on the Palmer Drought Severity Index (PDSI), the West Block of GNP was affected by droughts during the 1980s. Mild droughts also occurred in 2001 and 2006. The NDVI, SAVI and NDMI are positively correlated with the PDSI, while the MSI is negatively correlated with the PDSI. The simple linear regression models, which evaluated how accurately the vegetation index variables can be predicted by the PDSI, for the NDVI and SAVI vegetation indices, were significant.

When estimates of future conditions of density and vigour of vegetation were calculated, all three global climate models (GCMs) (CGCM2 A21, CSIROMk2b B11 and HadCM3 B21) predict that the amount of vegetation within the West Block of GNP will remain relatively stable until 2020. By 2050, all three GCMs predict a significant decrease in density and vigour of vegetation. By the year 2080, all three GCMs predict that most of the above ground biomass (plant matter) will decrease in density and vigour.

A decrease in grassland productivity, vegetation density, vigour and canopy water content, along with a more arid climate, will have a considerable impact on the vegetation communities that currently dominate the West Block of GNP. This highlights the importance of monitoring SAR population sizes, and their vegetation and food requirements during prolonged droughts and times of increased aridity. Management options will need to be adopted to help protect mixed prairie grasslands and ensure viable populations of SAR to prevent future extinctions.

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1. INTRODUCTION

1.1 Introduction

Climatologists suggest that global warming, the anticipated shift in the climate due to the greenhouse effect (the accumulation of heat in the lower atmosphere through the absorption of longwave radiation from the earth's surface), will cause the mixed grass prairie to experience higher temperatures and more frequent and extreme droughts. These effects are predicted to become increasingly evident within the next 50 years (Allen 1996, Carson 1996, Cutforth et al. 1999, Hengeveld 2000, Clark et al. 2002).

Many climate change projections for the mixed grass prairie suggest that temperatures in Saskatchewan could warm by 3 to 5°C by 2080 (de Groot et al. 1995, Herrington et al. 1997, Gan 2000, Canadian Institute for Climate Studies 2005). Climate change is more than a warming trend; it will lead to changes in many aspects of weather, such as wind patterns, the amount and type of precipitation, and the types and frequency of severe weather events that may be expected to occur in an area. If these changes occur, they would be the largest and most rapid in the last 10,000 years and could cause significant portions of the mixed grass prairie to shift from a sub-humid/semi-arid to semi-arid/arid ecosystem (dynamic system consisting of living organisms and their physical environment). This could have major consequences on the ecological function and structure of living organisms and their environment (Gan 2000, Clark et al. 2002).

Estimates of future climate change are based on scenarios taken from global climate models (GCMs). However, the nature of the environmental systems concerned, and the gaps or errors in our scientific understanding of climate change, generates uncertainty about such estimates or predictions (Mitchell 2003). Climate change is occurring based on a number of observations, such as increases in global average air and ocean temperatures, and melting of snow and ice (Crowley 2000, Hengeveld 2000, Hughes 2000, Jin and Dickinson 2002, Root et al. 2002, Scott 2003, Labat et al. 2004, Loehle 2004, IPCC 2007).

More than any other single climatic factor, vegetation growth and distribution on the mixed grass prairie is determined by precipitation (Henckel 1964, Crafts 1968, Gerakis et al. 1975, Kramer 1983, Yordanov et al. 2000, Flexas and Medrano 2002, Yordanov et al. 2003, Kochy and Wilson 2004, Iijima et al. 2008). Precipitation patterns change from one season to the next and from year to year. When drought sets in, the entire ecosystem is affected.

The mixed grass prairie includes a significant area that spans northeastern Montana, southeastern Alberta and southwestern Saskatchewan. This area is prone to drought, partly because it lies on the lee side of the western mountains, and is located in the middle of the continent, far from the moderating effects of oceans or other large bodies of water. This region experiences a continental climate characterized by extreme temperatures, cold dry winters, and hot summers. The average low in January is -22°C, while the average daily July temperatures are 28°C (Environment Canada 2006).

Global climate model (GCM) forecasts of increased drought have major implications for biodiversity in the mixed grass prairie. Water stress is one of the leading contributors for the distribution of diverse vegetation types (McCarty 2001). As precipitation patterns change, plant growth patterns may be altered. The water-use efficiency of plants depends on several variables, including soil characteristics and climate. Prolonged periods of low precipitation and soil moisture levels lower a plants ability to tolerate disturbance (Wheaton 1990, Dale 1997). Water deficits also inhibit photosynthesis and growth (Crafts 1968, Gerakis et al. 1975, Yordanov et al. 2000, Flexas and Medrano 2002, Yordanov et al. 2003, Iijima 2008).

Humans have affected most living species by interfering with their reproduction, destroying habitat, causing pesticide or herbicide poisoning, or accidentally causing mortality (Hulme et al. 1999). In Saskatchewan, agricultural activities are one of the largest causes of habitat destruction, pesticide or herbicide poisoning and accidental deaths. Agricultural activities also divide natural ecosystems into separate fragments isolated from each other by crop land or pasture. This spatially divides populations of plant and animal species (Peters 1991, deGroot et al. 1995).

The mixed grass prairie supports a large number of species-at-risk, including the eight species-at-risk chosen for this study, the black-tailed prairie dog, Burrowing Owl, Ferruginous Hawk, Greater Sage Grouse, Loggerhead Shrike, Short-eared Owl, Sprague's Pipit and swift fox. These species are grassland (mixed and short) specialists. Specialists are deemed to be at elevated risks of extinction because they have unique adaptations to grassland systems (Smith 1996, Leemans 1999). The greater the specialization, the more vulnerable a species is to becoming rare and ultimately going extinct (Peters 1991, Parmesan 1996; McGradysteed et al. 1997, Travis 2003). For example, the Sprague's Pipit, Ferruginous Hawk, swift fox and black-tailed prairie dog are entirely, or almost entirely restricted to the grasslands for a critical part of their life cycle. Black-tailed prairie dogs are often referred to as keystone species given that dozens of other species are adapted to live in and around prairie-dog towns, including Ferruginous Hawks, and Burrowing Owls (McGradysteed et al. 1997).

Since drought is closely linked to land degradation, future management of grassland ecosystems requires an improved understanding of past and future trends in regional aridity. Both drought and aridity deplete soil and surface water supplies; however, drought occurs when rainfall falls below a minimum moisture threshold, and is only a temporary climatic feature of a region (seasons to years) (Wheaton 1990; Le Houerou 1996, Cutforth et al. 1999). Aridity is a permanent feature of climate and is characteristic of regions with low rainfall (Sauchyn 2002). Throughout history, the mixed grass prairie has been impacted by drought. Over the past century, severe droughts affected the mixed grass prairie in 1961 and during the 1930s. Recently, severe droughts occurred in 2001-02 and during the 1980s. The grassland ecosystems were able to tolerate these severe drought spells because the dry periods only lasted for one or two years. The droughts predicted to occur in the future are of longer duration (e.g. decadal), which will likely exceed the grassland ecosystems' threshold of resilience (Ripley 1988; Cutforth et al. 1999; Sauchyn et al. 2003).

The extent of damage caused by drought in the mixed grass prairie will depend on the resilience of the individual animal species and plant life found there, and the health of the grassland ecosystem in which they live. Climate change could affect many species by lowering their food supply and habitat cover, making it more difficult for them to find food and avoid predators. The spatial arrangement of biodiversity and habitat found in this mixed grass ecoregion will play a major role in their success or failure, as well as how quickly they can adapt to climate change (Dale 1997, Halpin 1997, Hulme et al. 1999; Travis 2003, Savage 2004).

1.2 Thesis Rationale

Landscape ecology is the study of how landscape structure affects the abundance and distribution of organisms. This entails an understanding of how landscape pattern is related to the functioning of the landscape system. For instance, natural ecotones (transition zone between two structurally different communities) represent limits to many species' ranges (Smith 1996). These limits are often controlled by climate (Halpin 1997). Another important feature to consider is that human-influenced landscapes, like cropland, may form significant barriers to individual species movements (Halpin 1997). Such barriers are prevalent in Saskatchewan due to the extensive coverage of agricultural lands. Thus interdisciplinary studies are necessary for scientists to determine the degree to which species are affected by habitat configuration and the structure of the environment in between. To address this need, my research integrated knowledge from two different disciplines: biology and geography (Dale 1997; Hannah et al. 2002, Opdam et al. 2002).

Scientists need to produce models at spatial scales effective for estimating the state of biological systems (Dale 1997, Leemans 1999, Westervelt and Hopkins 1999). This requires collecting information on how climate change will affect the spatial distribution of natural vegetation; the distribution of animal species movements; and the distribution and frequency of disturbances, such as drought (Dale 1997; Hannah et al. 2002, Opdam et al. 2002).

Climate, along with other environmental factors, has been implicated in determining vegetation patterns. Species-environment relationships represent the core for predictive geographical modelling in ecology (Leemans 1999, Westervelt and Hopkins 1999, Guisan and Zimmerman 2000). By conducting a multi-species study, it is possible to compare different species in the same landscape, and obtain information about interspecific species interactions in response to landscape variation in temperature, precipitation, and food and nutrient availability (Opdam et al. 2002). This integration is necessary to protect healthy ecological landscapes.

1.3 Purpose and Objectives

The implications of climate change, increased aridity and more severe drought on the management and recovery of northern mixed grass prairie species-at-risk was assessed through the following six objectives:

1. To spatially analyze temporally discrete data for climate and grassland productivity from 1978 to 2006 using geographic information systems (GIS) and remote sensing;
2. To develop statistical models of climate-vegetation relationships for the West Block of Grasslands National Park to evaluate how accurately the vegetation index variables can be predicted by climate variables;
3. To assess past and predict future aridity (precipitation/evapotranspiration);

4. To forecast the probability of future drought using Monte Carlo analysis;
5. To assess the effects climate change will have on the eight species-at-risk chosen for my study; and
6. To develop management options and risk analysis for these eight species.

2. STUDY AREA

My study area is Grasslands National Park (Figure 1 and 2), located in southwestern Saskatchewan along the Montana border (49°15'N, 107°0'W). The park is composed of two separate blocks of land, 27 km apart, with a combined area of 906 square km (Davidson and Csillag 2001, Parks Canada 2006). The park was established by a provincial and federal government agreement in 1988.

Grasslands National Park (GNP) is situated on a vast tilted plain. The flat terrain is interrupted by eroded badlands, sand dunes, coulees, rocky canyons, potholes, hills and river valleys (Figure 3). Chernozemic and solonetzic soils are the most common soils found within the park. Chernozemic soils are characterized by a dark colour and high organic matter. Solonetzic soils are lighter in colour and have a high salt concentration, and are typically associated with areas subject to drought and high evaporation (Michalsky and Ellis 1994, Clark 1997).

Grasslands National Park is part of a mixed prairie ecoregion, consisting of both tall and short grasses. The grassland communities are divided into upland, sloped, and valley communities. The upland grasslands are dominated by speargrass (*Stipa comata*), blue grama grass (*Bouteloua gracilis*), junegrass (*Koeleria cristata*) and western wheatgrass (*Agropyron smithii*). Sloped grasslands, which occur along valley slopes, are dominated by western wheatgrass, blue grama grass, speargrass, and green needle grass (*Stipa viridula*), as well as microphytic communities of small non-vascular plants consisting of lichens and mosses. Valley grasslands, which occur at lower elevations within the park, are characterized by blue grama grass, speargrass, blue grasses and wheat grasses, and have a higher density of shrubs and a few trees (Michalsky and Ellis 1994, Clark 1997, Mitchell and Csillag 2001, Savage 2004, Zhang 2006).

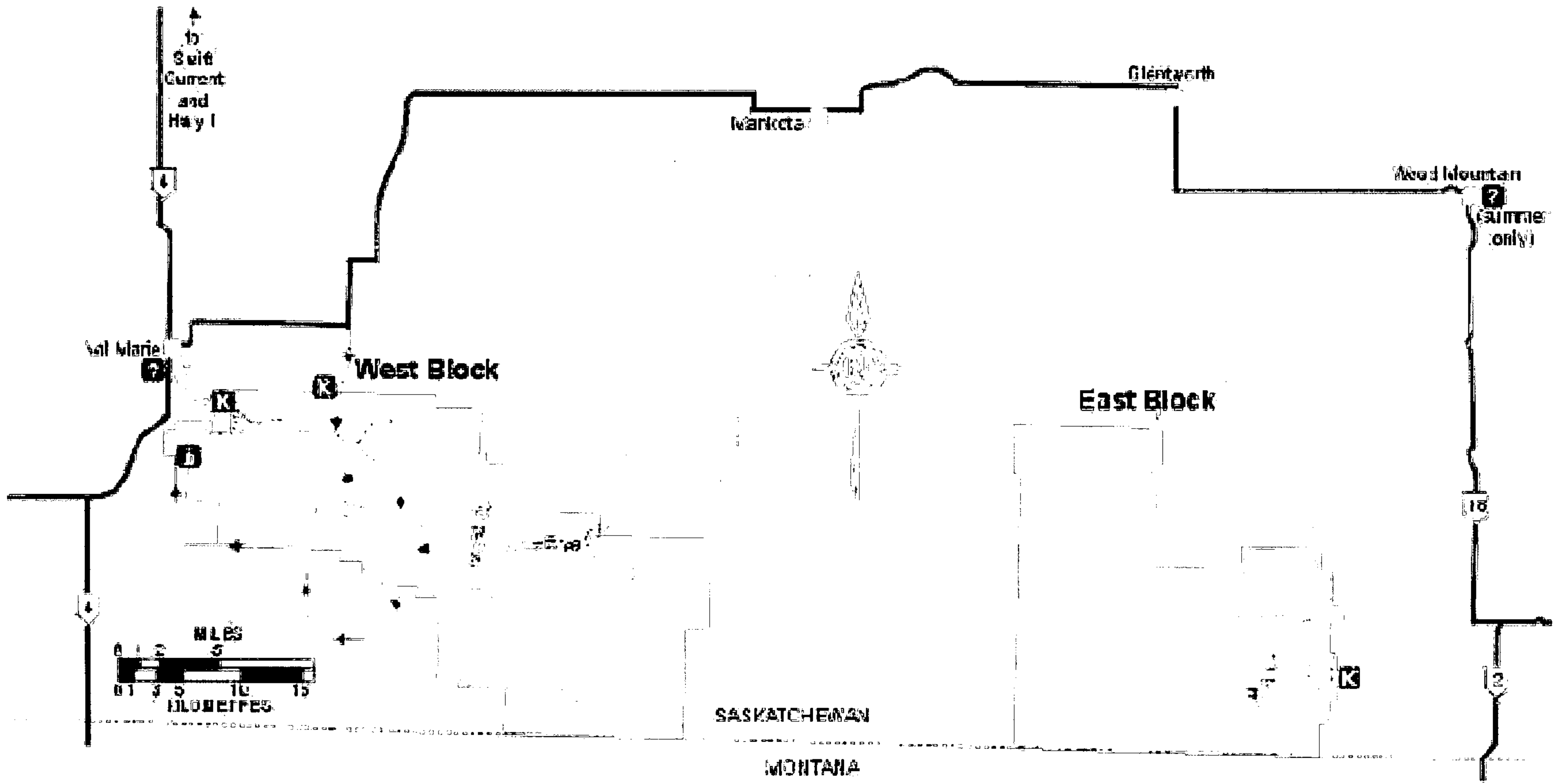


Figure 1. Grasslands National Park (Parks Canada 2006)

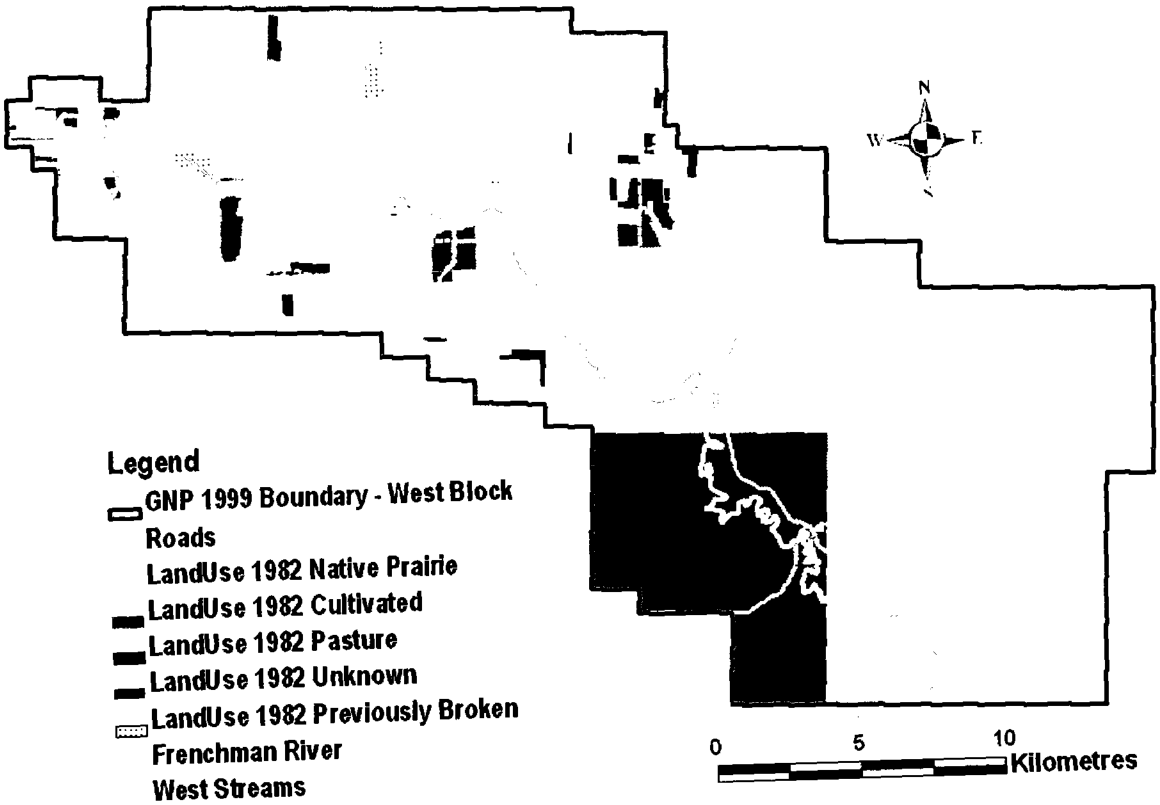


Figure 2. Landuse map of the West Block of Grasslands National Park.

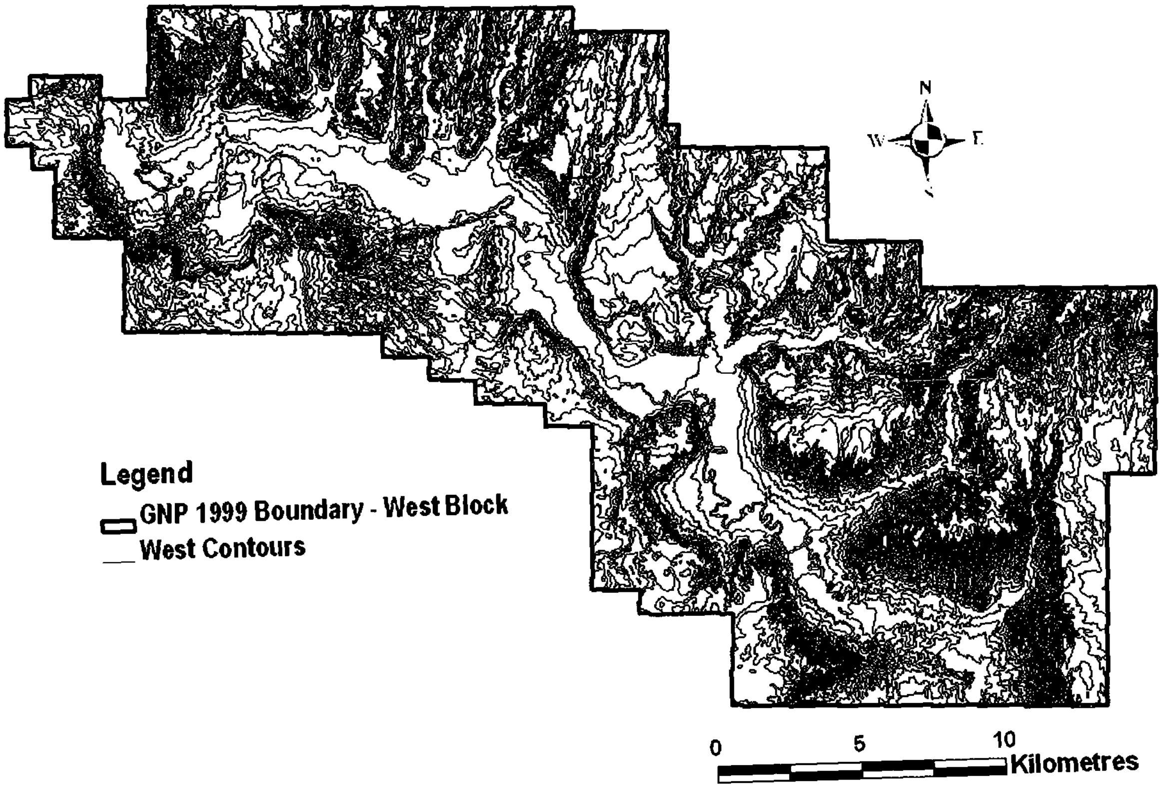


Figure 3. Contours map of the West Block of Grasslands National Park.

Total annual precipitation (which includes both rainfall and snowfall) for the GNP area averages 348 mm per year. Rainfall averages 262 mm per year, with less than 100 mm falling during drought years (Environment Canada 2006).

I selected the West Block of GNP as my study area for four reasons. First, the plant and animal species, soils, topography and land uses found in the West Block have been well documented. Second, both digital topographic and remotely sensed data were available for the area. Third, the area is prone to drought. Fourth, the park supports many endangered, threatened or special concern species that are either non-migratory or are almost entirely dependent on the mixed grass prairie for a critical part of their life cycle.

3. METHODS

3.1 Objective 1: Past Grassland Productivity

3.1.1 Satellite Imagery

To assess the impacts of recent droughts on grassland productivity in the West Block of Grasslands National Park (GNP), I used a remote sensing dataset spanning four decades of Landsat MSS, TM and ETM+ images. Images included drought and non-drought years. The coverage dates of the Landsat MSS images were 15 July 1978 and 29 June 1981, with a 79 m spatial resolution. The rest of the images have a 30 m spatial resolution. The coverage dates of the Landsat TM images were 24 June 1986, 11 and 27 June 1987, 15 July 1988, 2 July 1989, 17 June 1995, 24 July 1997, 27 July 1998, 25 June 2004, 14 and 30 July 2005, and 17 July 2006, while 6 July 1999 is a Landsat ETM+ image. All of the images were geometrically corrected, using nearest neighbour resampling, to the Universal Transverse Mercator (UTM) projection with an accuracy of better than 1.0 pixel and then trimmed to the extent of the region around the West Block of GNP.

3.1.2 Vegetation Indices

Vegetation indices (VIs) are numerical indicators that analyze radiometric measurements to indicate relative abundance and activity (photosynthetic material) of green vegetation. They are constructed from spectral reflectance measurements taken in two or more wavelengths. VIs are useful for analyzing specific characteristics of vegetation, such as the total leaf area or water content (Jensen 2007).

The most commonly applied vegetation index (VI) is the normalized difference vegetation index (NDVI), which is a broadband greenness VI (measures density and vigour of green vegetation). The NDVI has an index that ranges from -1 to 1, with green vegetation ranging from 0.2 to 0.8. Although the NDVI has been widely applied in a diverse range of environments, it has been shown to be influenced by the reflective properties of the soil background in areas, such as the mixed grass prairie, where vegetation patchiness frequently leaves segments of bare ground exposed (Henebry 1993, Braswell et al. 1997, Tieszen et al. 1997, Davidson and Csillag 2001, Wylie et al. 2002, Ji and Peters 2004).

The soil adjusted vegetation index (SAVI) was developed to reduce this soil background effect (Huete 1988). The SAVI uses a soil adjustment factor, L, to account for soil background variations. For vegetation with intermediate density, such as found in the mixed grasslands, an adjustment factor of L = 0.5 has been shown to be effective (Huete 1988, Qi et al. 1994, Rondeaux et al. 1996, Purevdorj 1998, Price et al. 2002, Rundquist 2002, Zhang 2006). Like the NDVI, the SAVI has an index range of -1 to 1, with green vegetation ranging from 0.25 to 0.95.

Vegetation water content is also an important measurement because higher water content is generally associated with healthier vegetation, which is likely to grow faster. Two spectral VIs that have been developed to estimate vegetation water content are the normalized difference moisture index (NDMI); also known as the normalized difference water index (NDWI), and the moisture stress index (MSI). The NDMI has an index range of -1 to 1, with green vegetation ranging from -0.1 to 0.4. The MSI is an inverted index, however, with higher values indicative of greater water stress and less water content. The MSI ranges from 0 to more than 3.0, with green vegetation ranging from 0.4 to 2.0 (Hunt and Rock 1989, Gao 1996, Jackson et al. 2004, Davidson et al. 2006).

I used all four indices in this study because they have been successfully used in past studies of grassland ecosystems to estimate percent vegetation cover and water content (Huete 1988, Hunt and Rock 1989, Henebry 1993, Qi et al. 1994, Gao 1996, Rondeaux 1996, Braswell et al. 1997, Tieszen et al. 1997, Purevdorj et al. 1998, Davidson and Csillag 2001, Price et al. 2002, Rundquist 2002, Wylie et al. 2002, Jackson et al 2004, Ji and Peters 2004, Davidson et al. 2006, Zhang 2006). The NDVI, SAVI, NDMI and MSI were calculated using the following formulas:

$$NDVI = NIR - RED / NIR + RED$$

$$SAVI = (1 + L) * (NIR - RED) / NIR + RED + L$$

$$NDMI = NIR - MIR / NIR + MIR$$

$$MSI = MIR / NIR$$

where the RED, NIR and MIR correspond to visible red, near-infrared and mid-infrared reflectances, respectively. For the Landsat MSS sensor, the wavelength ranges of these spectral bands were: 0.6 to 0.7 μm (red), 0.7 to 0.8 μm (near-infrared) and 0.8 to 1.1 μm (near-infrared). The Landsat MSS did not have a mid-infrared band or channel, so the NDMI and MSI could not be calculated from these data. The Landsat TM and ETM+ data were measured in spectral bands from 0.63 to 0.69 μm (red), to 0.76 to 0.90 μm (near-infrared) and 1.55 to 1.75 μm (mid-infrared).

3.1.3 Past Grassland Productivity Trends

To examine past trends in the grasslands within the West Block of GNP, I conducted three different analyses:

1. I analyzed the changes in grassland productivity that occurred during 1978-2006 within the West Block of GNP using remote sensing and GIS;
2. I assessed climate averages (temperature and precipitation) during 1978-2006; and
3. I created a change detection map in order to show the differences in spectral reflectance between a normal (1999) and drought (1988) year during 1978-2006.

First, I used remote sensing and geographic information system (GIS) technology to examine the changes in grassland productivity that have occurred since 1978 in the West Block of

GNP. To accomplish this, 266 pixel points (single points in a graphic image) were randomly selected using their UTM coordinates within the West Block of GNP. These consisted of 180 grassland community pixel points and 86 shrubland community pixel points. I calculated all four vegetation indices: NDVI, SAVI, NDMI and MSI to collect data for each of the 266 pixel points in each satellite image. Only the NDVI and SAVI were able to be derived from the 1978 and 1981 Landsat MSS images since they do not use the mid-infrared band in their calculations. The data from each of the 266 pixel points from each satellite image were then averaged. I constructed scatterplots of date versus mean for each vegetation index to assess how grassland productivity changed at each date.

I then assessed climate averages during 1978-2006 to examine the changes in temperature and precipitation during drought and non-drought years. The growing season (April through August) averages were calculated for both temperature and precipitation (Appendix C). Temperature and precipitation values were obtained from the Val Marie climate station, which is adjacent to the West Block of GNP.

Finally, I created a change detection map showing the difference between a normal and drought year using the NDVI, which measures density and vigour of green vegetation. Change detection analysis calculates the difference in pixel values between two satellite images. The 6 July 1999 and 17 July 2006 satellite images were chosen because 1999 was moderately wet, while mild drought conditions occurred in 2006. Several pixel difference thresholds were evaluated: one standard deviation from the mean ($\mu \pm 1.0\sigma$), two standard deviations from the mean ($\mu \pm 2.0\sigma$), and three standard deviations from the mean ($\mu \pm 3.0\sigma$). ENVI (4.4; ITT Visual Information Solutions 2007) and ArcGIS (9.2; ESRI 2006) were used to conduct the analysis.

3.2 Objective 2: Climate-Vegetation Relationships

I used the Pearson product moment correlation to assess the strength of association between the vegetation index variables (NDVI, SAVI, NDMI and MSI) and precipitation, temperature, potential evapotranspiration (PET) and aridity. I used a one-tailed test with $\alpha = 0.05$.

I used a multiple linear regression analysis to determine how accurately the vegetation index variables can be predicted by precipitation, temperature, and PET. The independent variables used in this analysis were precipitation, temperature, and PET, while the dependent variable was the vegetation index. The coefficient of determination, R^2, is the percent of variance in the dependent variable explained collectively by all of the independent variables. An F-test was used to test the significance of the R^2 value. The Durbin-Watson test was used to make sure no autocorrelation existed among the regression residuals. Aridity was excluded from this analysis due to the presence of multicollinearity. I calculated a multiple linear regression for each vegetation index (NDVI, SAVI, NDMI and MSI). SPSS (16.0; SPSS Inc. 2008) was used to conduct all statistical tests.

3.3 Objective 3: Past and Future Aridity

Both drought and aridity deplete soil and surface water supplies; however, drought occurs when rainfall falls below a minimum moisture threshold, and is only a temporary climatic feature of a region (seasons to years) (Wheaton 1990; Le Houerou 1996, Cutforth et al. 1999). Aridity is a permanent feature of climate and is characteristic of regions with low average rainfall or available water (Rosenberg 1978, Sauchyn 2002). However, arid regions are usually the most drought prone because they are naturally moisture deficient and typically have highly variable rainfall.

An aridity index (AI) is a numerical indicator of the degree of dryness of the climate at a given location (Table 1). A simple AI can be derived as the ratio P / PET, where P is the average annual precipitation (mm) and PET is the potential evapotranspiration (mm; Sauchyn et al. 2002).

Table 1. Aridity Index Classifications (Sauchyn et al. 2002)

Classification	Aridity Index
Hyperarid	AI < 0.05
Arid	0.05 < AI < 0.20
Semi-arid	0.20 < AI < 0.50
Dry Subhumid	0.50 < AI < 0.65

Evapotranspiration is the sum of evaporation and plant transpiration from the earth's land surface to atmosphere. Potential evapotranspiration is a representation of the environmental demand for evapotranspiration. I used the Thornthwaite formula to calculate PET. It is based on the empirical relationship between mean monthly temperature and evapotranspiration (Thornthwaite 1931, Thornthwaite 1948, Thornthwaite and Mather 1957, Mather 1985). Mean monthly values of temperature and the latitude of the climate station must be known. PET (Appendix A) was calculated using the formula (Thornthwaite 1948):

$$PET = 1.6 \left(\frac{T}{I}\right)^{a}$$

where PET is the potential evapotranspiration (cm $month^{-1}$), T is the mean monthly air temperature (°C) and the exponent, a, is derived as:

$$a = (6.75 \times 10^{-7})\, I^{3} - (7.71 \times 10^{-5})\, I^{2} + (1.79 \times 10^{-2})\, I + 0.49.$$

The annual heat index, I, was estimated as

$$I = \sum_{i=1}^{12} \left(\frac{Ti}{5}\right)^{1.514}.$$

Monthly PET is corrected for seasonal and latitudinal differences in daylength (Thornthwaite 1931, Thornthwaite 1948, Thornthwaite and Mather 1957, Mather 1985, Hogg 1994, Sauchyn et al. 2002). The Thornthwaite method was used since solar radiation and wind data are only collected at a few climate stations throughout Saskatchewan. It also works well at mid-latitude continental climates (Sauchyn et al. 2002).

I calculated historic (1978-2006) aridity for the West Block of Grasslands National Park based on PET and average annual precipitation and mean monthly temperature values obtained from the Val Marie climate station.

To calculate future aridity (for 2020, 2050 and 2080), I used the projected temperature and precipitation data from three global climate model (GCM) scenarios: the Coupled General Circulation Model (Canada) second generation - CGCM2 A21; the Commonwealth Scientific and Industrial Research Organization Model (Australia) - CSIROMk2b B11; and the Hadley Centre Couple Ocean-Atmospheric Model (United Kingdom) third generation - HadCM3 B21. These GCMs were chosen because they predict different outcomes for the future (IPCC 2007). The CGCM2 A21 predicts a hot and dry future, the HadCM3 B21 predicts a cool and wet future, and the CSIROMk2b B11 predicts an intermediate future (Appendix B). The GCM scenario data were obtained from the Canadian Climate Impacts and Scenarios project website (http://www.cics.uvic.ca/scenarios/).

I used a statistical downscaling model (SDSM) to obtain local-scale weather data (temperature and precipitation) from the coarser GCM scenarios. SDSM calculates statistical relationships based on multiple linear regression techniques between large scale (the predictors) and local (the predictand) climate. The statistical relationships are developed using observed weather data. Local future weather data are generated using the GCM-derived predictor variables and the statistical relationships between large scale and local climate (Wilby et al. 2002). Over- and underestimations in local future weather data can occur.

3.4 Objective 4: Past and Future Drought

Drought is a recurring complex natural disaster that has major environmental consequences for the prairies through the depletion of soil and surface water supplies. Its impact depends on the timing, severity and duration of the water shortage, as well as the size and vulnerability of the affected area (McKay 1986). In 1965, Palmer developed a soil moisture algorithm based on the supply and demand concept of the water balance equation and calibrated it for relatively homogeneous regions (Weber and Nkemdirim 1998). The Palmer Drought Severity

Index (PDSI) is calculated using precipitation, temperature, and available water content (AWC) of the soil. Palmer based his index on a two-layered model for soil moisture. The top soil layer (the plough layer) is assumed to have a field capacity of 25 mm (Weber and Nkemdirim 1998; Keyantash and Dracup 2002, Quiring and Papakryiakou 2003, Szep et al. 2005). Moisture is not transferred to the underlying layer (the root zone) until the top layer is saturated (Heim 2002). Precipitation represents the input of moisture into the soil, while actual evapotranspiration and runoff represents the output of moisture from the soil. Water is extracted from the soil by evapotranspiration when PET exceeds P (precipitation for the month) (Quiring and Papakryiakou 2003). If precipitation exceeds PET, then supply exceeds demand. A surplus of water is added to the storage layers until both soil layers become saturated. If precipitation is less than PET, then demand exceeds supply, and moisture is drawn out of the soil. Recharge of soil moisture is the net gain in soil moisture for the month (Weber and Nkemdirim 1998, Szep et al. 2005).

I used the PDSI to look at the severity and duration of droughts that have occurred in the past (1978-2006) in GNP. The data were obtained from the Prairie Farm Rehabilitation Administration (PFRA) of Agriculture and Agri-Food Canada. This drought index was chosen for several reasons: it is widely used in North America; the data were available; it takes into account the normal weather of a region so that comparisons can be made between locations and between durations; and the index was designed to examine drought conditions in semiarid and dry sub-humid regions.

The Palmer Drought Severity Index values generally range between -6.0 and +6.0 (Table 2). Negative PDSI values indicate dry conditions, while positive values indicate wet conditions.

Table 2. Palmer Drought Severity Index Categories (Hayes 2005)

Moisture Category	**PDSI**
Extremely wet	≥ 4.00
Very wet	3.00 to 3.99
Moderately wet	2.00 to 2.99
Slightly wet	1.00 to 1.99
Incipient wet spell	0.50 to 0.99
Near normal	0.49 to -0.49
Incipient drought	-0.50 to -0.99
Mild drought	-1.00 to -1.99
Moderate drought	-2.00 to -2.99
Severe drought	-3.00 to -3.99
Extreme drought	≤ -4.00

3.4.1 PDSI-Vegetation Relationships

I used the Pearson product moment correlation to measure the strength of association between the vegetation index variables (NDVI, SAVI, NDMI and MSI) and PDSI. I used a one-tailed test with $\alpha = 0.05$.

I used a simple linear regression analysis to assess how accurately the vegetation index variables can be predicted by the PDSI. The independent variable used in this analysis was the PDSI, while the dependent variable was the vegetation index. I calculated a simple linear regression for each vegetation index (NDVI, SAVI, NDMI and MSI).

3.4.2 Vegetation Change Scenarios

I used Monte Carlo analysis to identify areas in the West Block of GNP where vegetation density, vigour and water content are expected to decrease based on GCM predictions of increased drought. The NDVI and MSI vegetation indices were chosen for this purpose because they were normally distributed and they had the highest correlations with precipitation, temperature, PET and aridity of the four vegetation indices used in this study. The NDVI and MSI values from each of the 266 pixel points from each satellite image were used. Additional input included the precipitation, temperature, PET and aridity values from each corresponding year of the dataset and the projected monthly temperature and precipitation changes predicted by the CGCM2 A21, CSIROMk2b B11 and HadCM3 B21 GCMs, along with the projected PET and aridity changes expected for 2020, 2050 and 2080. I used the Monte Carlo simulation software, @RISK for Excel (5.0; Palisade Corporation 2008), for this analysis, which uses probability distributions to describe the uncertain values.

For each year in the dataset, the input variable values were randomly sampled 1000 times for each of the 266 pixel points in the spatial model. This produced a series of empirical models linking climate and vegetation variables. Each of the 266 pixel points was associated with a predicted probability of change. The pixel point values predicted to occur in 2020, 2050 and 2080 (Appendix D) from each GCM and vegetation index were then added as layers in ArcGIS 9.2. I used ordinary kriging (prediction map, exponential semivariogram, anisotropy and 6 neighbours) to generate vegetation change scenario maps. Exponential semivariograms are applied when spatial autocorrelation decreases exponentially with increasing distance. Anisotropy is a characteristic of a random process that shows higher autocorrelation in one direction than another (ESRI 2006). This interpolation method was chosen because it produced the lowest root-mean-square (RMS) errors. The maps were then exported to a vector using filled contours and clipped to the West Block GNP park boundary. A vegetation stress threshold value of 0.2 was used for the NDVI, while 1.85 was used for the MSI. Vegetation pixel values lower than 0.2 indicate low vegetation density and vigour for the NDVI. MSI is an inverted index, so vegetation pixel values higher than 1.85 indicate water stress and low water content. The threshold values were based on the 266 pixel point averages and the dataset averages from the NDVI and MSI, as well as the differences between the averages for drought and non-drought years.

4. RESULTS

4.1 Past Grassland Productivity Trends

My analysis of past grassland productivity trends in GNP indicated that during drought years precipitation averages were lower, while temperature averages were higher (Figure 4) than in non-drought years. The vegetation indices averages varied considerably over the study period (Figures 5 and 6). Typically, vegetation indices values were lower during drought years indicating a decrease in grassland productivity. During non-drought years on warm and dry days, plants can experience stress due to water deficiencies because they lose water by transpiration faster than it can be restored by uptake from the soil. All of the low MSI and NDMI averages (see Figure 5) correspond with warm and dry days or weeks during the months of June and July. The SAVI had lower values during 2006, suggesting reduced vegetation density and vigour (Figure 7). The darker tones of the 2006 MSI image (Figure 8) indicate areas of water stress and low water content. The maps illustrate that much of the vegetation in the West Block of GNP becomes stressed during drought years, decreasing productivity.

During a mild drought, vegetation density and vigour are significantly reduced, which decreases productivity. This is illustrated in the change detection map (Figure 9) which shows the difference in pixel values between the 1999 (non-drought year) and 2006 (drought year) satellite images based on the NDVI. Lighter areas indicate a significant negative change in vegetation density and vigour (productivity). The change detection map demonstrates how the overall amount and quality of photosynthetic material in vegetation declines during a drought year relative to a non-drought year.

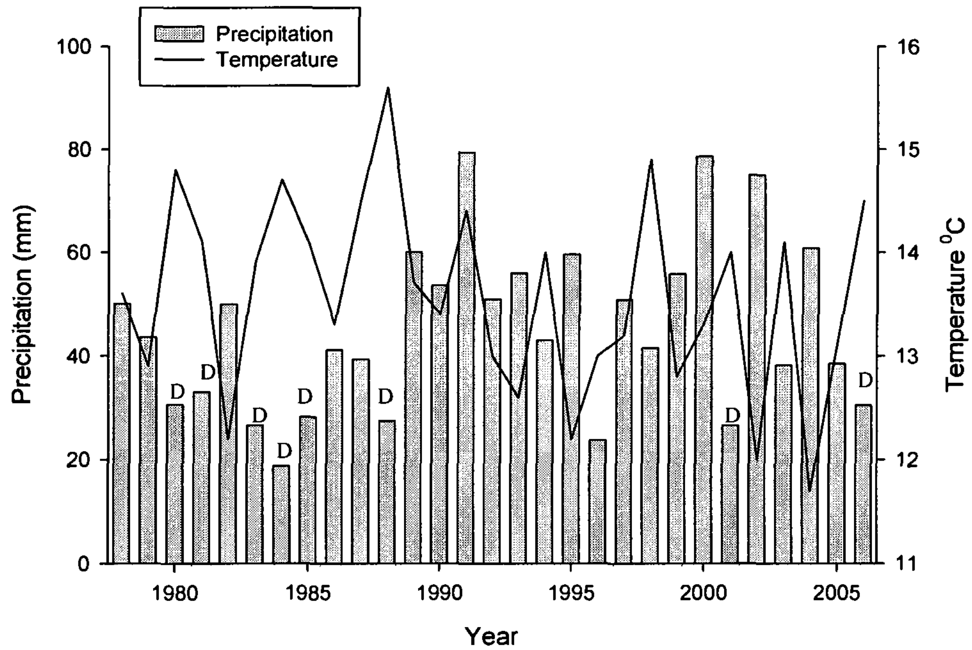


Figure 4. Precipitation and temperature for the Val Marie climate station (adjacent to Grasslands National Park) from 1978-2006 for the growing season (April through August). Drought years are indicated by the letter D.

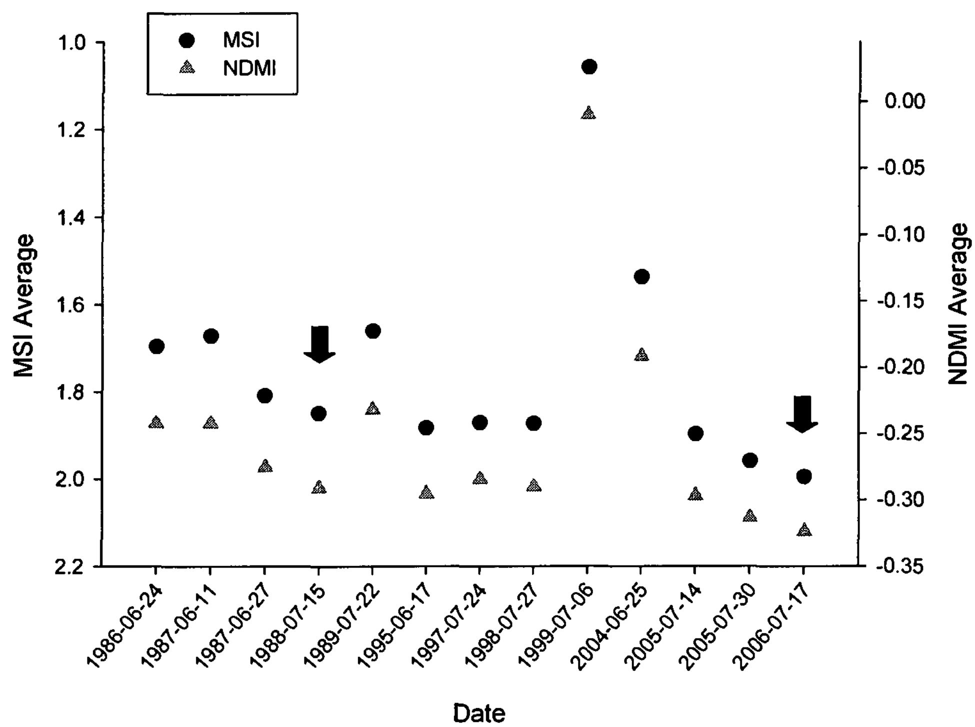


Figure 5. Mean MSI and NDMI vegetation indices values for the 266 pixel points vs. date of satellite images. Drought years are indicated by an arrow.

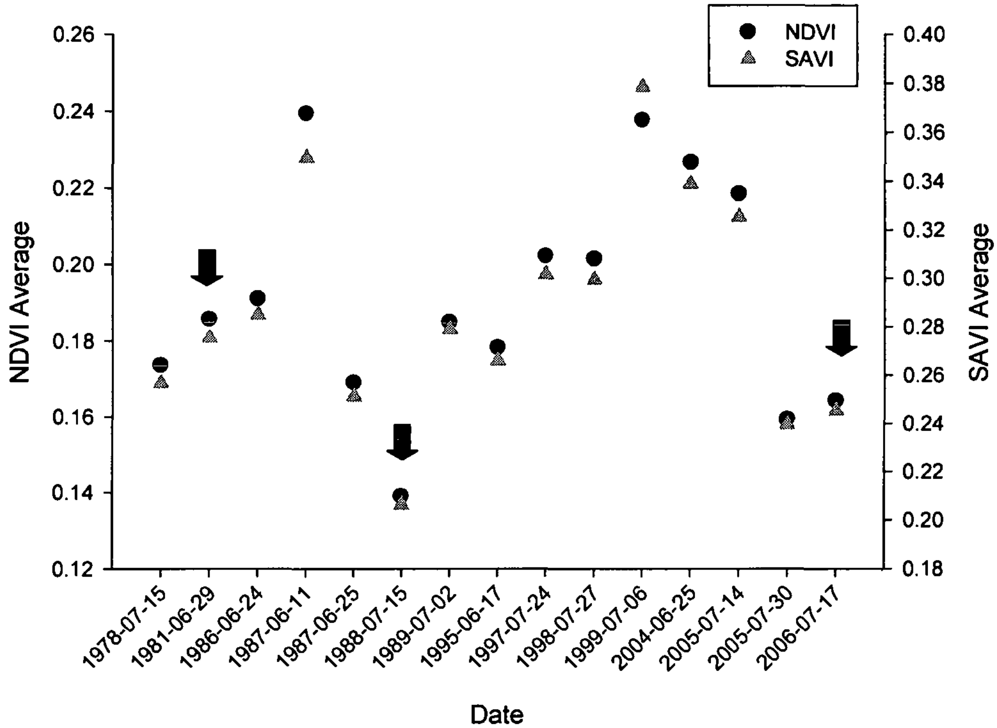


Figure 6. Mean NDVI and SAVI vegetation indices values for the 266 pixel points vs. date of satellite images. Drought years are indicated by an arrow.

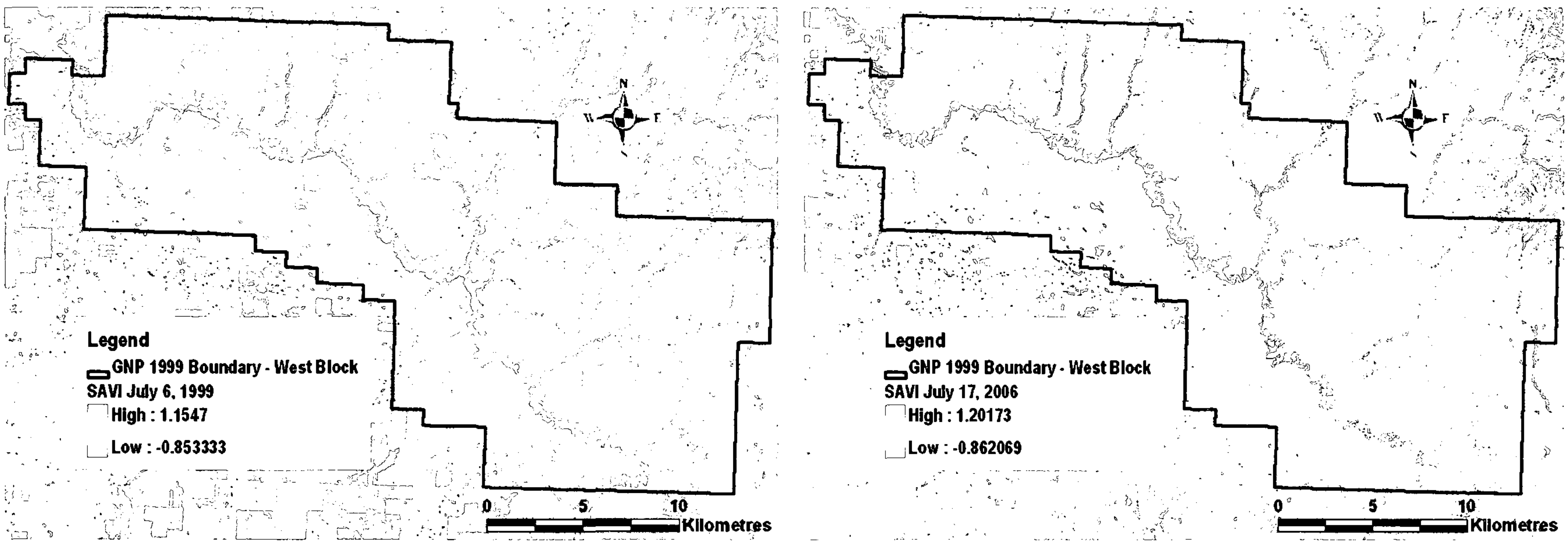


Figure 7. Vegetation density and vigour during drought and non-drought years based on the SAVI vegetation index. 1999 was a moderately wet year, while 2006 was a mild drought year. Darker areas indicate lower vegetation density and vigour.

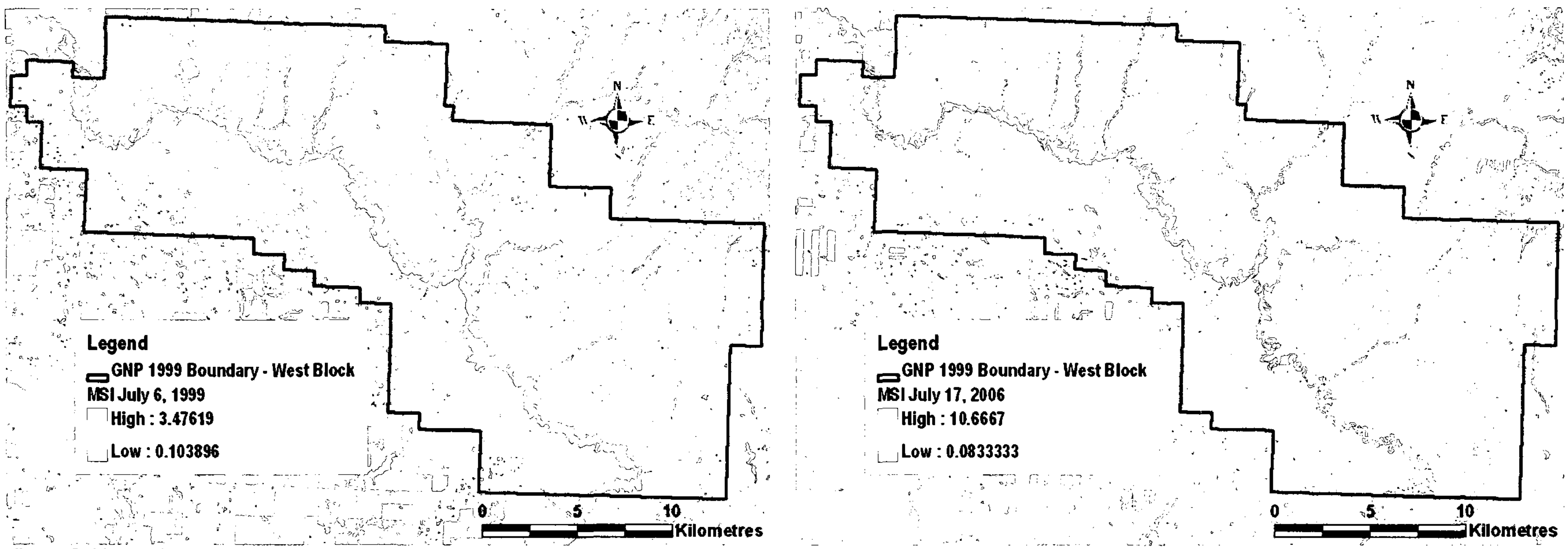


Figure 8. Vegetation canopy water content during drought and non-drought years based on the MSI vegetation index. 1999 was a moderately wet year, while 2006 was a mild drought year. Darker areas indicate water stress and low water content.

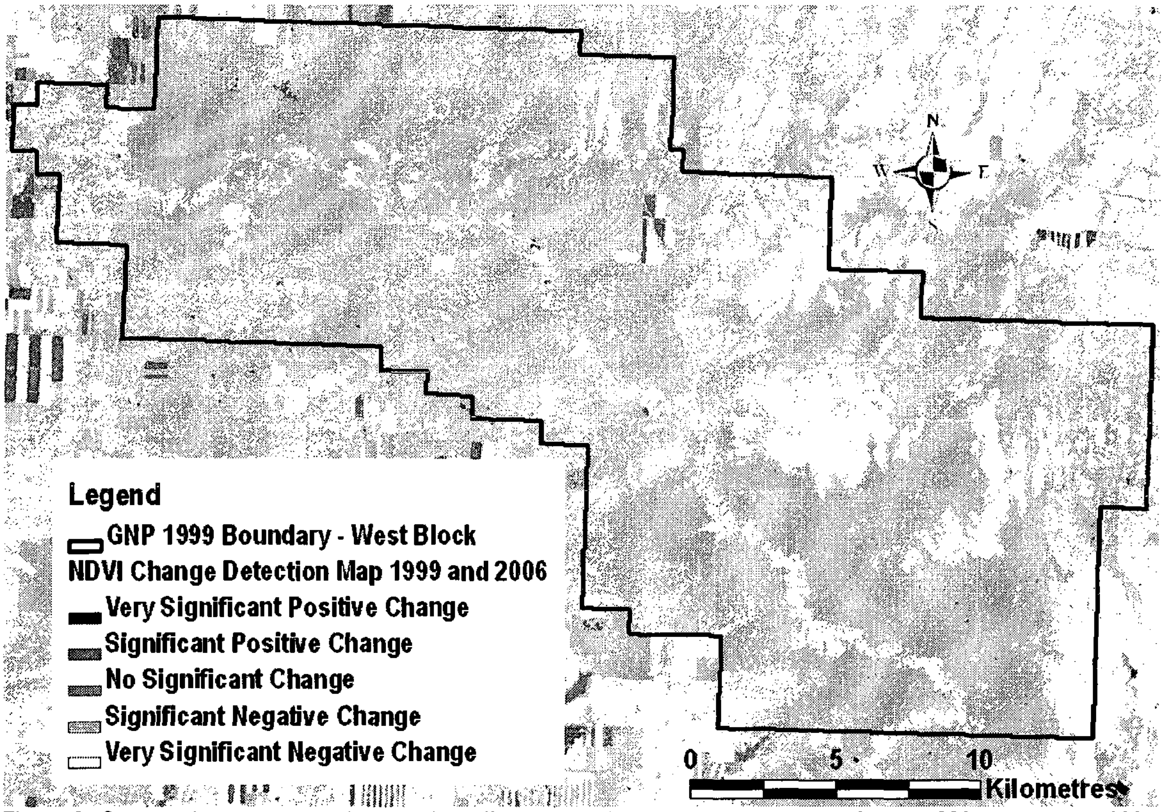


Figure 9. Change detection map showing the difference in pixel values between the 6 July 1999 and 17 July 2006 satellite images. 1999 was moderately wet, while 2006 was a mild drought year. No significant change corresponds to $\mu \pm 1.0\sigma$, a significant positive or negative change corresponds to $\mu \pm 2.0\sigma$, while a very significant positive or negative change corresponds to $\mu \pm 3.0\sigma$. Lighter areas indicate a significant negative change in vegetation density and vigour (productivity).

4.2 Climate-Vegetation Relationships

The correlation analyses between the VIs and the climate variables revealed that the NDVI was negatively correlated with temperature, but not with precipitation, PET or aridity. Likewise, the SAVI was negatively correlated with temperature, but not with precipitation, PET or aridity (Figure 10).

The NDMI was positively correlated with precipitation and aridity, and negatively correlated with PET. It was not significantly correlated with temperature. The inverted MSI was positively correlated with PET, and negatively correlated with precipitation and aridity. It was not significantly correlated with temperature (Figure 10).

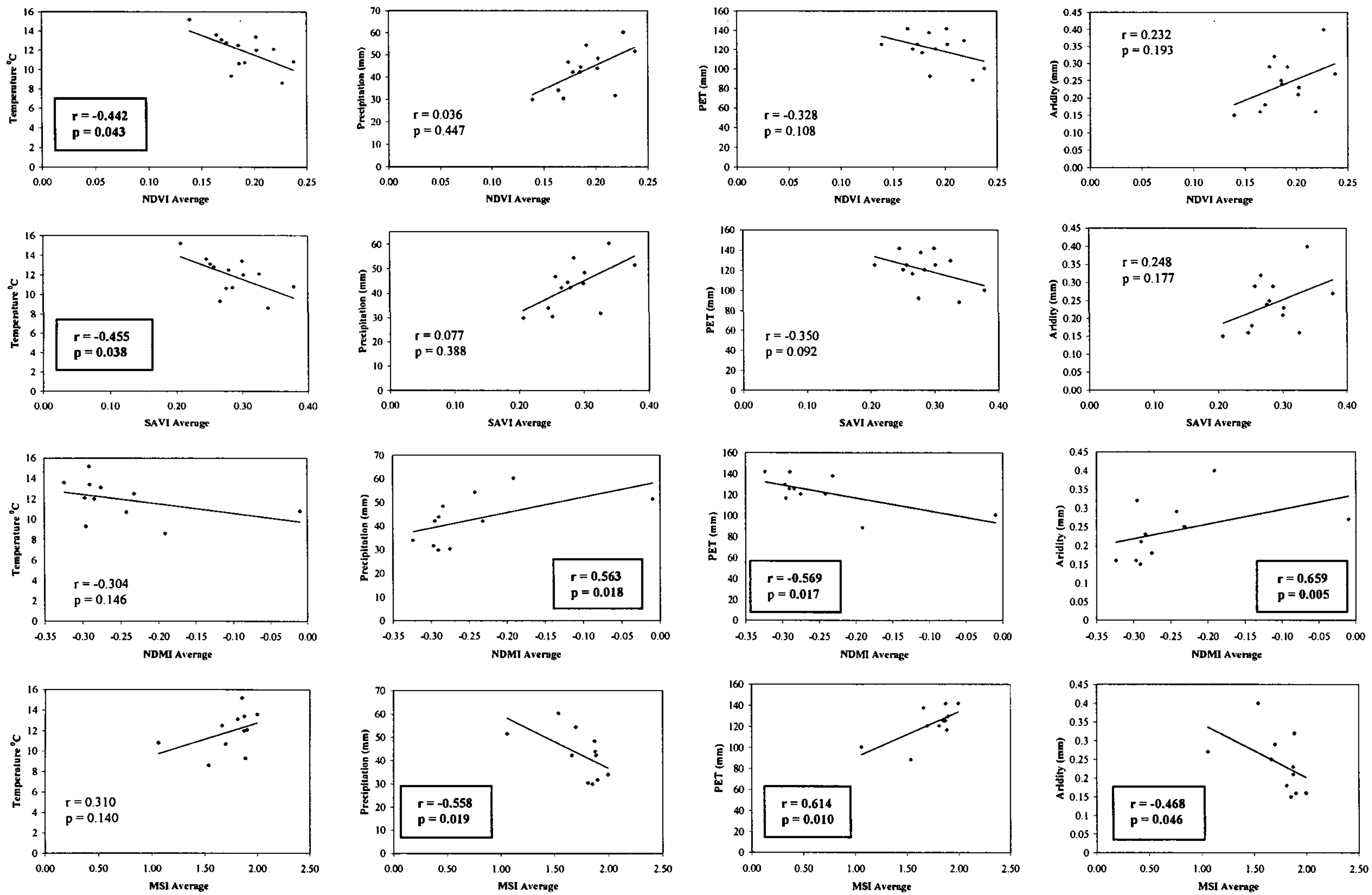


Figure 10. Scatterplot and correlation coefficients of NDVI, SAVI, NDMI and MSI relative to temperature, precipitation, PET and aridity. N = 15 for the NDVI and SAVI, and 13 for the NDMI and MSI. Values in plots represent correlation coefficients (r) and p-values. Significant values are indicated with a text box.

When all of the climate variables were analyzed together with each VI, the multiple linear regression models for the NDVI and SAVI were not significant (NDVI: $F_{1,12} = 0.022$, $p = 0.88$, $R^2 = 0.274$; SAVI: $F_{1,12} = 0.046$, $p = 0.83$, $R^2 = 0.266$). As shown in Tables 3 and 4, the multiple linear regression models for the NDMI and MSI were significant. These results suggest that over 50% of the variance in the moisture indices could be explained by a combination of temperature, precipitation and potential evapotranspiration. All the variance inflation factors (VIF) were less than 4.0 indicating that there was no multicollinearity among the climate variables. I found no autocorrelation among the regression residuals using the Durbin-Watson test.

Table 3. Coefficient estimates of the multiple linear regression model for NDMI

Variable	Coefficient	Standard Error	t-value	p-value	Variance inflation
Intercept	-0.199	0.248	-0.801	0.442	0
Precipitation	0.004	0.002	1.931	0.082	1.635
Temperature	0.025	0.016	1.521	0.159	2.460
PET	-0.004	0.002	-2.355	0.040	2.031
$R^2 = 0.560$, $R^2_{adj} = 0.428$ $F_{1,10} = 5.547$, p-value = 0.04					

Table 4. Coefficient estimates of the multiple linear regression model for MSI

Variable	Coefficient	Standard Error	t-value	p-value	Variance inflation
Intercept	1.576	0.755	2.088	0.063	0
Precipitation	-0.012	0.006	-1.962	0.078	1.635
Temperature	-0.080	0.050	-1.616	0.137	2.460
PET	0.013	0.005	2.465	0.033	2.031
$R^2 = 0.573$, $R^2_{adj} = 0.445$ $F_{1,10} = 6.077$, p-value = 0.03					

4.3 Past and Future Aridity

The aridity in May for Grasslands National Park averaged 0.39 for 1978-2006 (Appendix A). The values for June, July and August were 0.27, 0.22, and 0.25, respectively. This indicates that the growing season for GNP was generally semi-arid during this period.

By 2020, aridity in May is predicted to decrease to 0.32 based on the CGCM2 A21 GCM (Figure 11), but increase to 0.49 and 0.39 based on the CSIROMk2b B11 and HadCM3 B21 GCMs. For June, the CGCM2 A21 and HadCM3 B21 GCMs predict aridity should decrease to 0.23 and 0.26, but aridity should increase to 0.29 based on the CSIROMk2b B11 GCM. The month of July should see a decrease in aridity based on all three GCMs – 0.18 for the CGCM2 A21 GCM, 0.19 for the CSIROMk2b B11 GCM and 0.19 for the HadCM3 B21 GCM. August should also see a decrease in aridity based on all three GCMs – 0.22 for the CGCM2 A21 GCM, 0.22 for the CSIROMk2b B11 GCM and 0.22 for the HadCM3 B21 GCM.

By 2050, aridity in May is predicted to increase to 0.34 (Figure 11) based on the CGCM2 A21 GCM, and to 0.54 and 0.41 based on the CSIROMk2b B11 and HadCM3 B21 GCMs. For June, the CGCM2 A21 GCM predicts aridity should increase slightly to 0.24, but the CSIROMk2b B11 and HadCM3 B21 GCMs predict decreases to 0.27 and 0.24. The month of July should see a decrease in aridity based on all three GCMs – 0.17 for the CGCM2 A21 GCM, 0.16 for the CSIROMk2b B11 GCM and 0.18 for the HadCM3 B21 GCM. August will also see decreased aridity based on predictions from all three GCMs – 0.20 for the CGCM2 A21 GCM, 0.19 for the CSIROMk2b B11 GCM and 0.18 for the HadCM3 B21 GCM.

By 2080, aridity in May is predicted to increase to 0.35 based on the CGCM2 A21 GCM (Figure 11), but decrease to 0.50 and 0.39 based on the CSIROMk2b B11 and HadCM3 B21 GCMs. For June, the CGCM2 A21 and CSIROMk2b B11 GCMs predict aridity should decrease to 0.22 and 0.26, but increase to 0.27 based on the HadCM3 B21 GCM. The month of July sees a decrease in aridity to 0.13 and 0.14 based on the CGCM2 A21 and CSIROMk2b B11 GCMs, but stays at 0.18 as predicted by the HadCM3 B21 GCM. August sees a decrease in aridity to 0.17 and 0.15 based on the CGCM2 A21 and CSIROMk2b B11 GCMs, but remains at 0.18 based on the HadCM3 B21 GCM.

This means that by 2020, for even the wettest-coolest climate forecast (HadCM3 B21 GCM), GNP will fall into the arid classification during the month of July. By 2050 and continuing on to 2080, GNP will be classified as arid for both July and August.

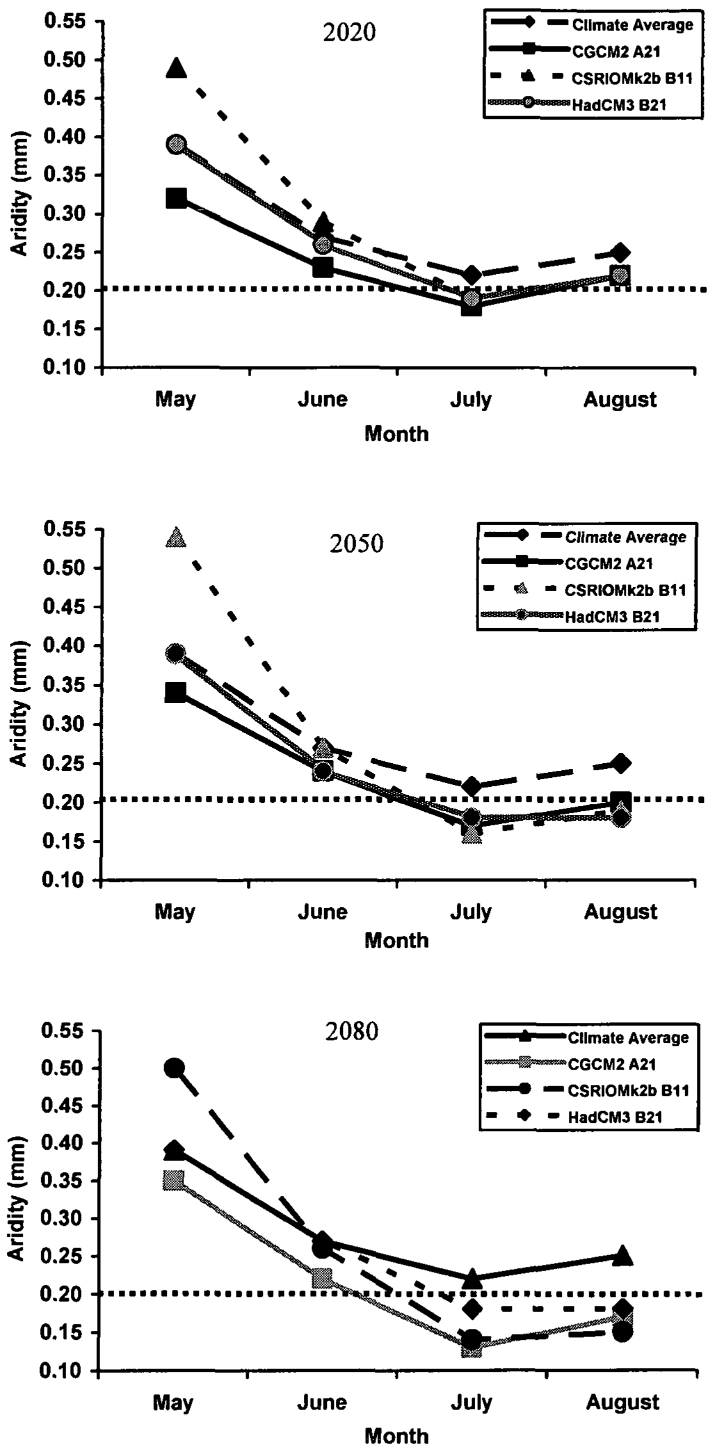


Figure 11. Future aridity during the growing season for GNP in 2020, 2050 and 2080 based on predictions by the CGCM2 A21, CSIROMk2b B11 and HadCM3 B21 GCMs. Dashed line indicates semi-arid/arid boundary.

4.4 Palmer Drought Severity Index

The Palmer Drought Severity Index (Figure 12) suggests that several droughts have occurred in GNP since 1978. Mild droughts occurred in 1980, 1983, 2001 and 2006. An incipient drought took place in 1986. There was a moderate drought in 1981 and severe droughts in 1984, 1985 and 1988.

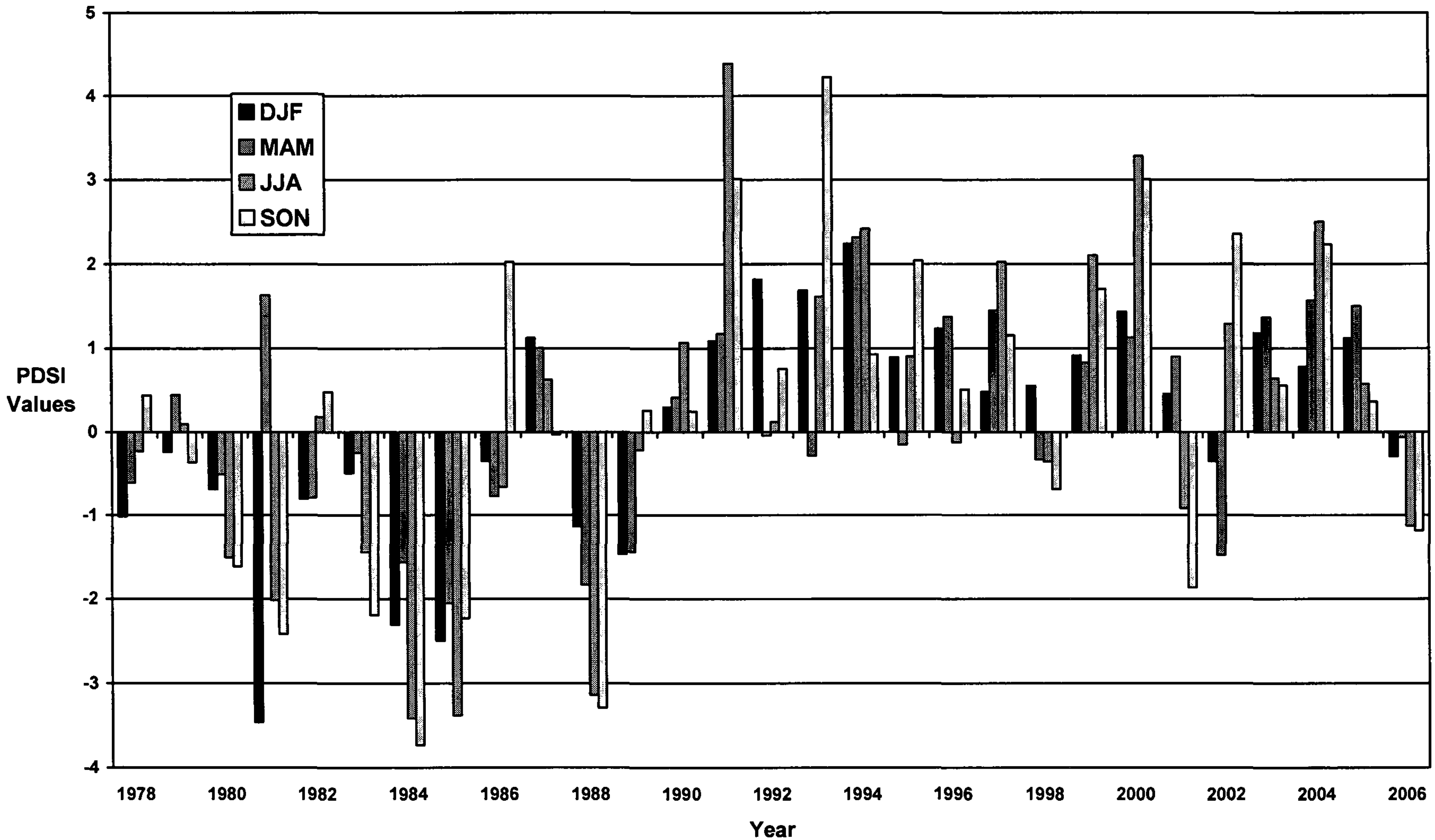


Figure 12. Palmer Drought Severity Index values for GNP for 1978-2006 for the winter (DJF), spring (MAM), summer (JJA) and fall (SON) seasons. Negative PDSI values indicate dry conditions, while positive values indicate wet conditions. -0.50 to -0.99 indicates an incipient drought, -1.00 to -1.99 a mild drought, -2.00 to -2.99 a moderate drought, and -3.00 to -3.99 a severe drought.

4.5 PDSI-Vegetation Relationships

The NDVI was positively correlated with the PDSI, as was the SAVI and NDMI. The MSI was negatively correlated with the PDSI (Figure 13).

The regression models for NDVI and SAVI were significant (Tables 5 and 6). The regression models for both the NDMI and MSI were not significant (NDMI: $F_{1,9} = 4.67$ and $p = 0.059$, $R^2 = 0.342$; MSI: $F_{1,9} = 4.31$ and $p = 0.068$, $R^2 = 0.324$).

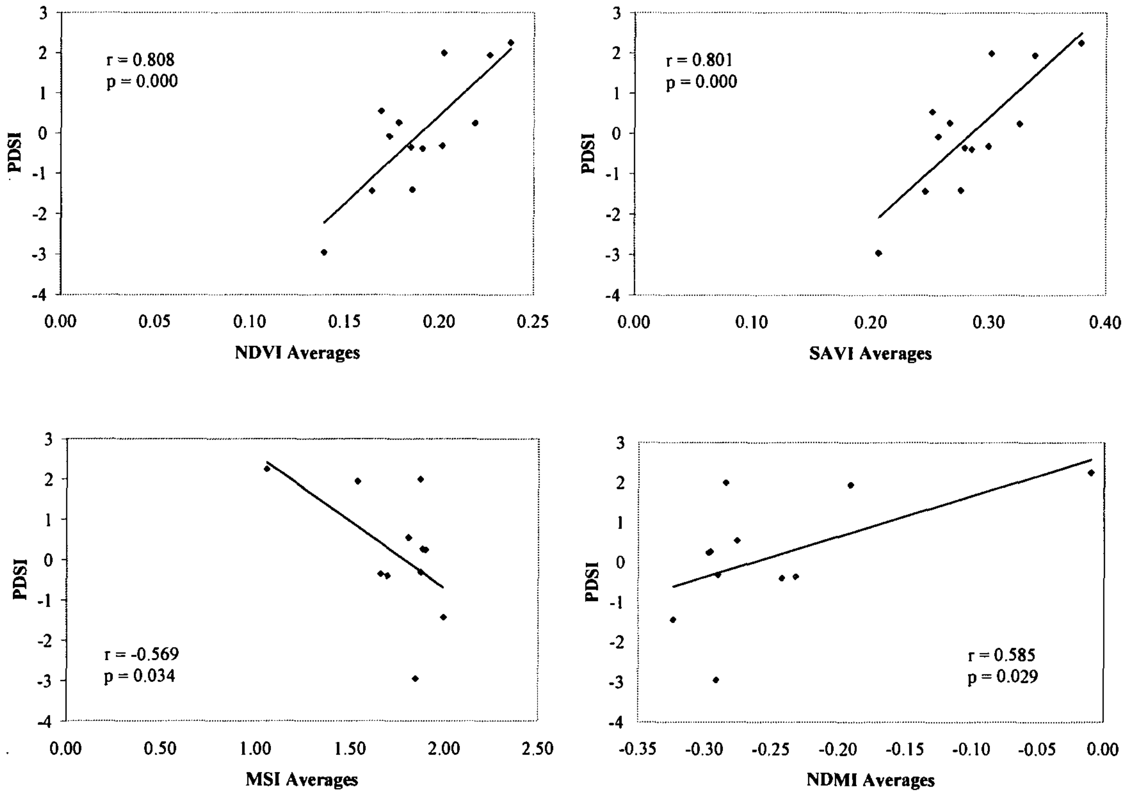


Figure 13. Scatterplot and correlation coefficients of NDVI, SAVI, NDMI and MSI relative to PDSI. N = 13 for the NDVI and SAVI, and 11 for the NDMI and MSI. Values in plots represent correlation coefficients (r) and p-values.

Table 5. Coefficient estimates of the simple linear regression model for NDVI

Variable	Coefficient	Standard Error	t-value	p-value	Variance inflation
Intercept	0.195	0.005	38.718	0.000	0
PDSI	0.016	0.004	4.552	0.001	0
$R^2 = 0.653$, $R^2_{adj} = 0.622$ $F_{1,11} = 20.724$, p-value = 0.001					

Table 6. Coefficient estimates of the simple linear regression model for SAVI

Variable	Coefficient	Standard Error	t-value	p-value	Variance inflation
Intercept	0.285	0.008	36.784	0.000	0
PDSI	0.024	0.005	4.444	0.001	0
$R^2 = 0.642$, $R^2_{adj} = 0.610$ $F_{1,11} = 19.749$, p-value = 0.001					

4.6 Vegetation Change Scenarios

Based on the predictions of the NDVI CGCM2 A21 GCM, the amount of vegetation within the West Block of GNP should remain more or less the same until 2020 (Figure 14). By 2050, the density and vigour of vegetation will decrease significantly. By 2080, the majority of the vegetation will decrease in density and vigour.

The predictions of the NDVI CSIROMk2b B11 GCM (Figure 15) are qualitatively similar to the CGCM2 A21 GCM. By 2020, the density and vigour of vegetation should be essentially the same, with a decrease by 2050. Most of the vegetation will have decreased in density by 2080, although not as significantly as predicted by the CGCM2 A21 GCM.

As for the NDVI HadCM3 B21 GCM (Figure 16), the density and vigour of vegetation will remain relatively stable until 2020. A notable decrease will occur by 2050, with nearly all the vegetation declining by 2080.

In regards to canopy water content, the MSI CGCM2 A21 GCM predicts the amount of canopy water content should decrease by 2020 (Figure 17). By 2050, a notable decrease in vegetation canopy water content will occur, with nearly all the vegetation canopy water content decreasing by 2080, indicating a hot and dry future for GNP.

The MSI CSIROMk2b B11 GCM predicts (Figure 18) a more intermediate future than the other two models. Vegetation canopy water content should still decrease by 2020 (as per the CGCM2 A21 GCM scenario), but with only slight decrease by 2050. No dramatic decrease should take place, as predicted by the CGCM2 A21 GCM 2050 map. By 2080, only a small decrease in canopy water content is predicted.

Predictions of the MSI HadCM3 B21 GCM suggest that canopy water content will remain more or less the same by 2020 (Figure 19). There will be a slight increase in canopy water content by 2050. By 2080, the amount of vegetation canopy water content will decrease. The decrease predicted by this GCM is the smallest of the three GCMs indicating a more cool and wet future for GNP.

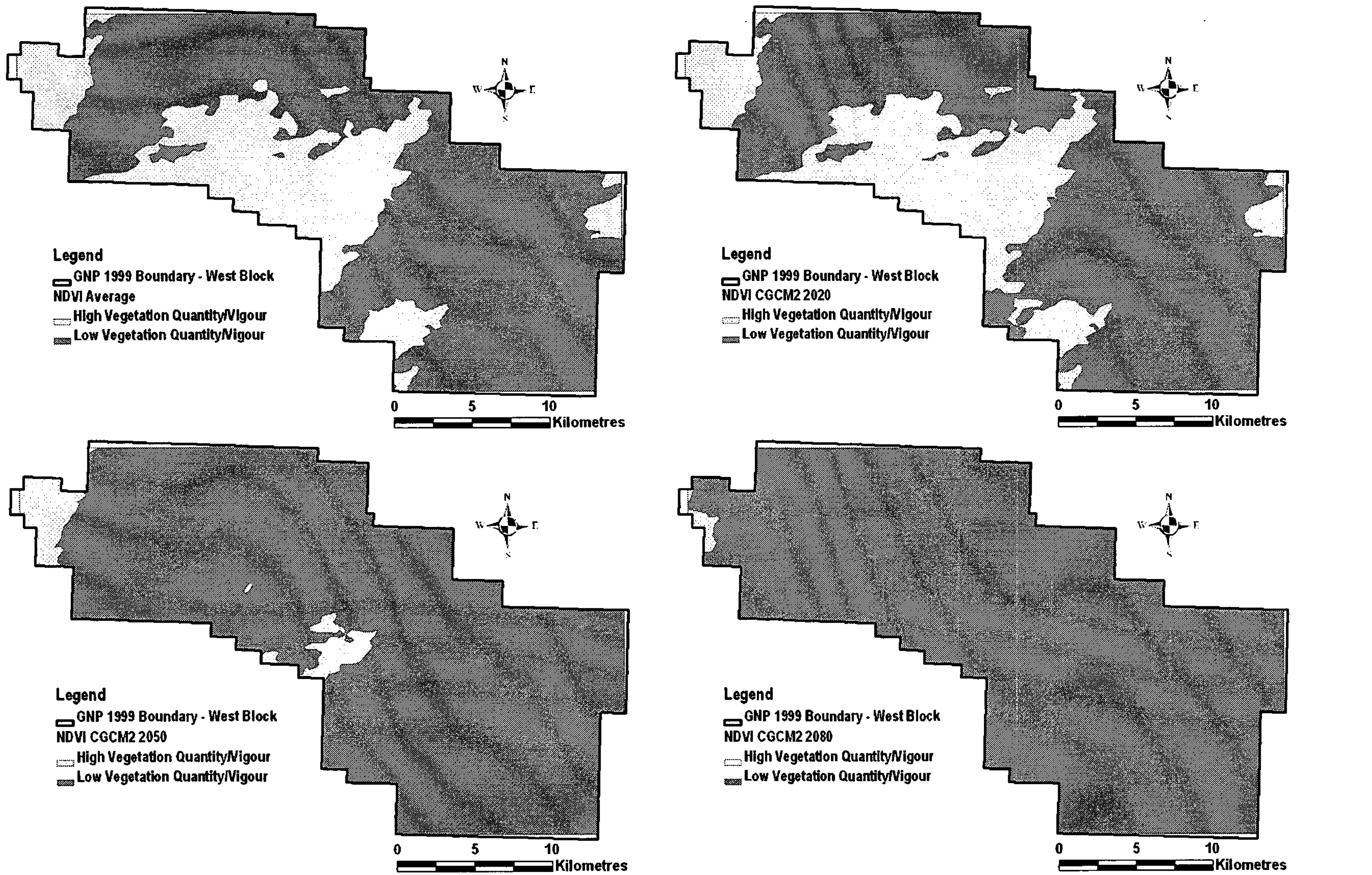


Figure 14. NDVI CGCM2 A21 GCM vegetation change scenarios for density and vigour of vegetation for the West Block of Grasslands National Park for 2020, 2050 and 2080.

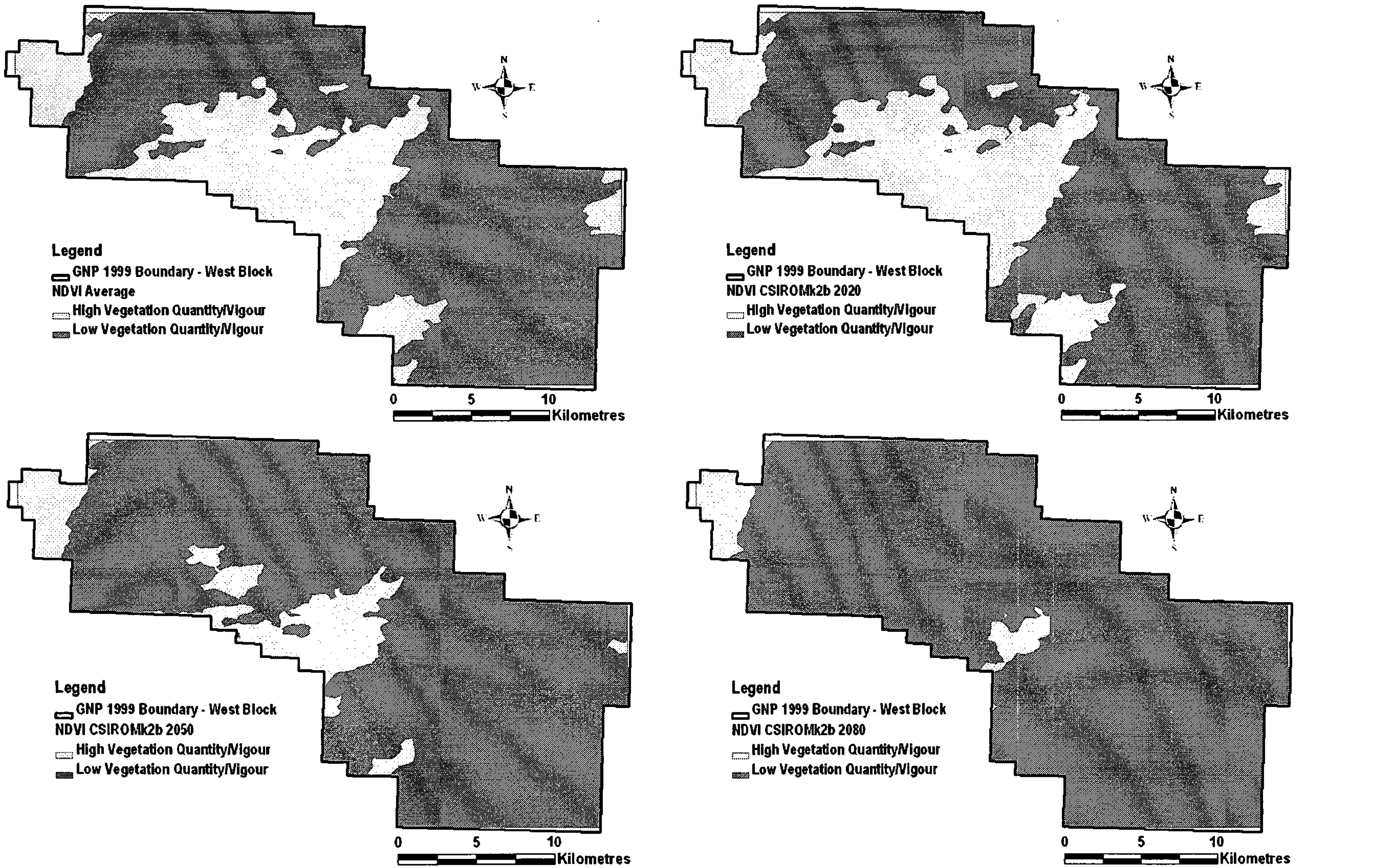


Figure 15. NDVI CSIROMk2b B11 GCM vegetation change scenarios for density and vigour of vegetation for the West Block of Grasslands National Park for 2020, 2050 and 2080.

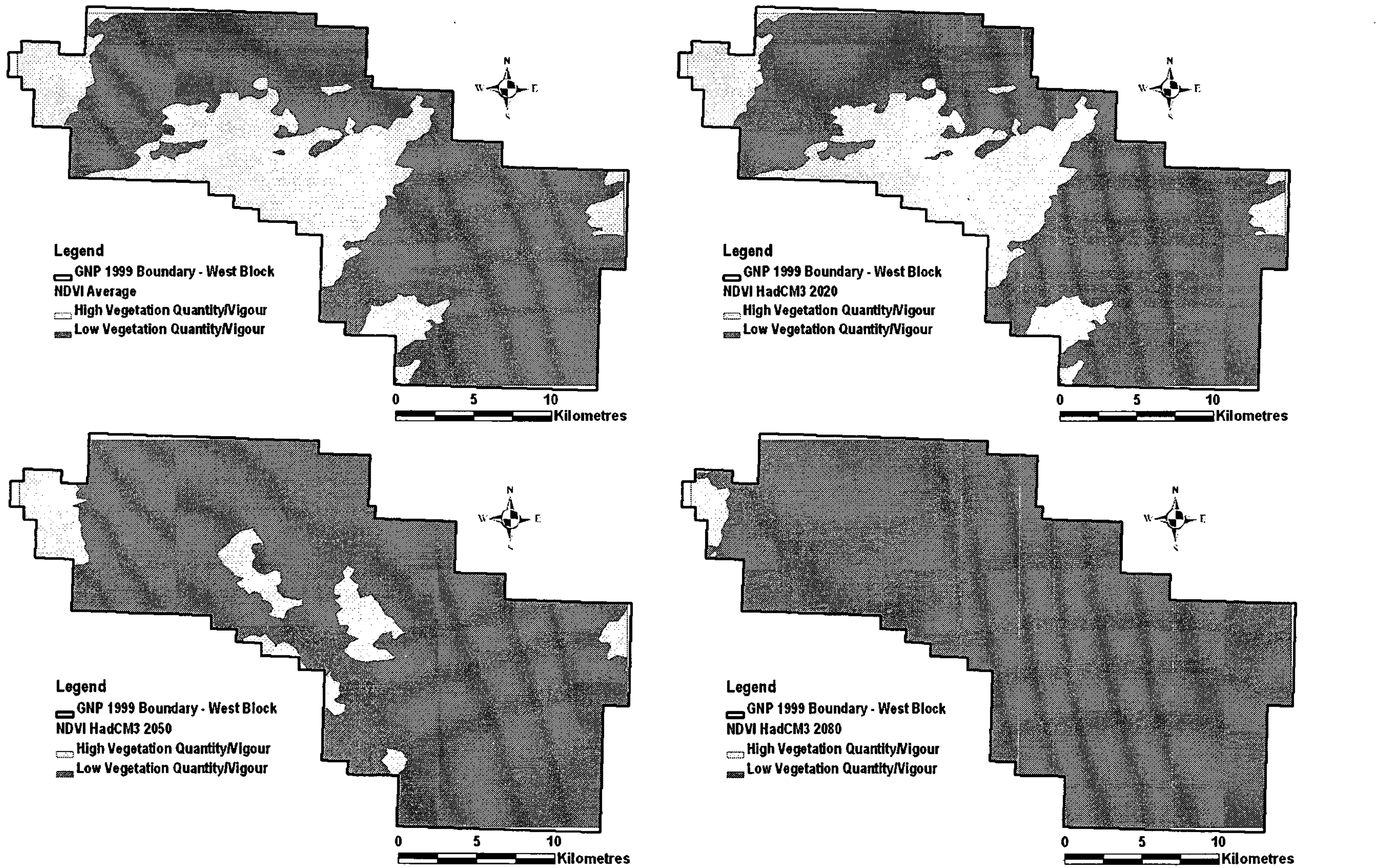


Figure 16. NDVI HadCM3 B21 GCM vegetation change scenarios for density and vigour of vegetation for the West Block of Grasslands National Park for 2020, 2050 and 2080.

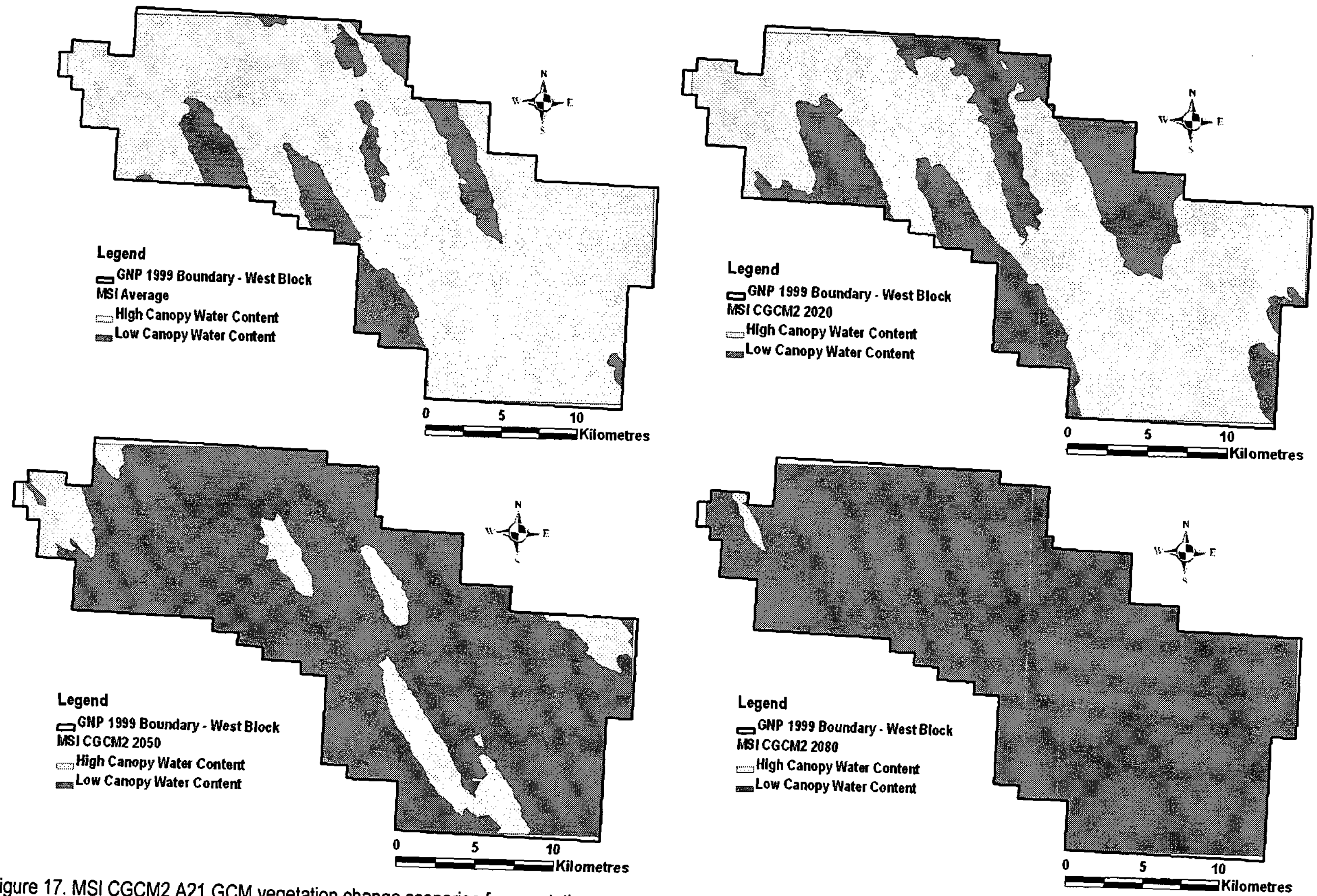


Figure 17. MSI CGCM2 A21 GCM vegetation change scenarios for vegetation canopy water content for the West Block of Grasslands National Park for 2020, 2050 and 2080.

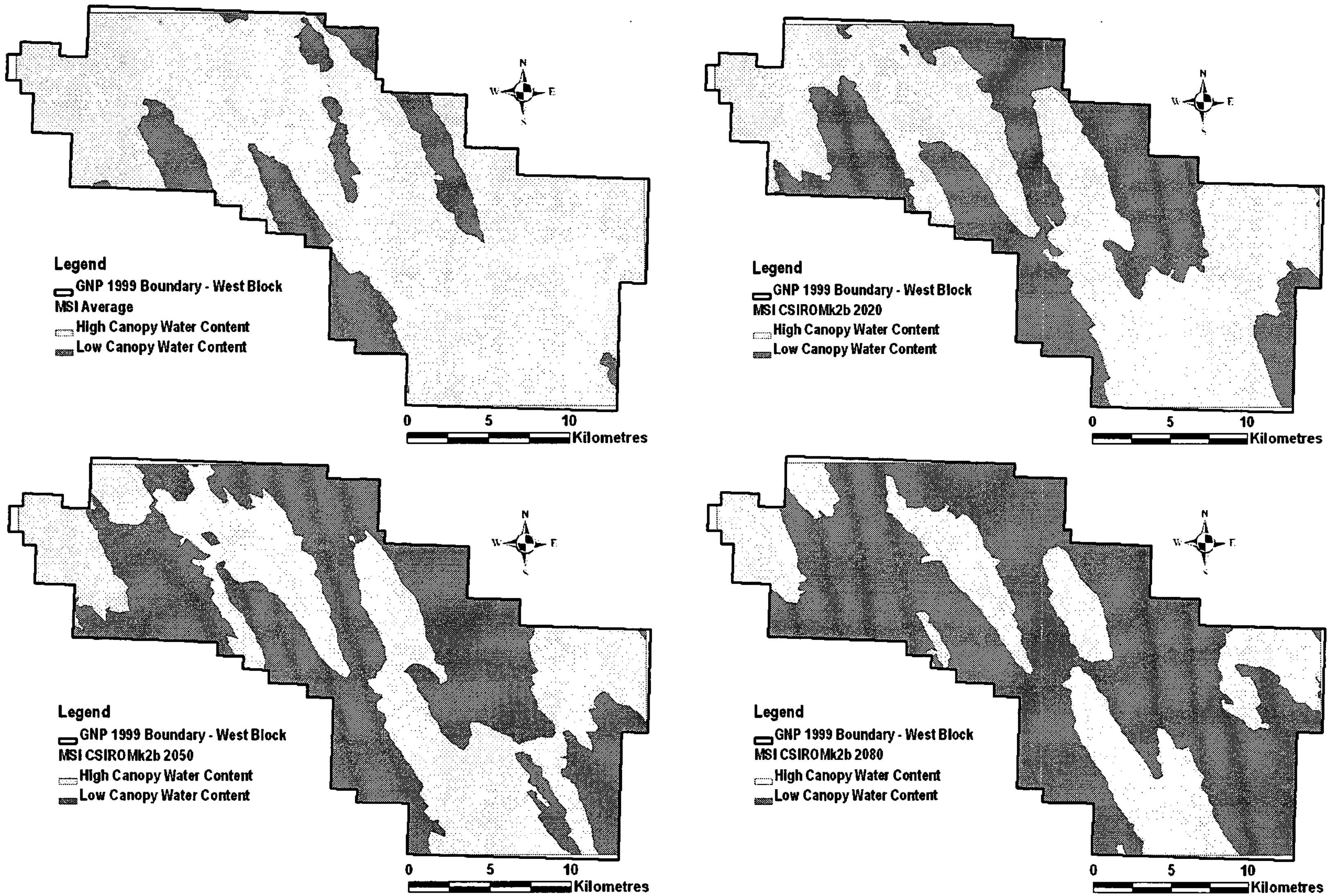


Figure 18. MSI CSIROMk2b B11 GCM vegetation change scenarios for vegetation canopy water content for the West Block of Grasslands National Park for 2020, 2050 and 2080.

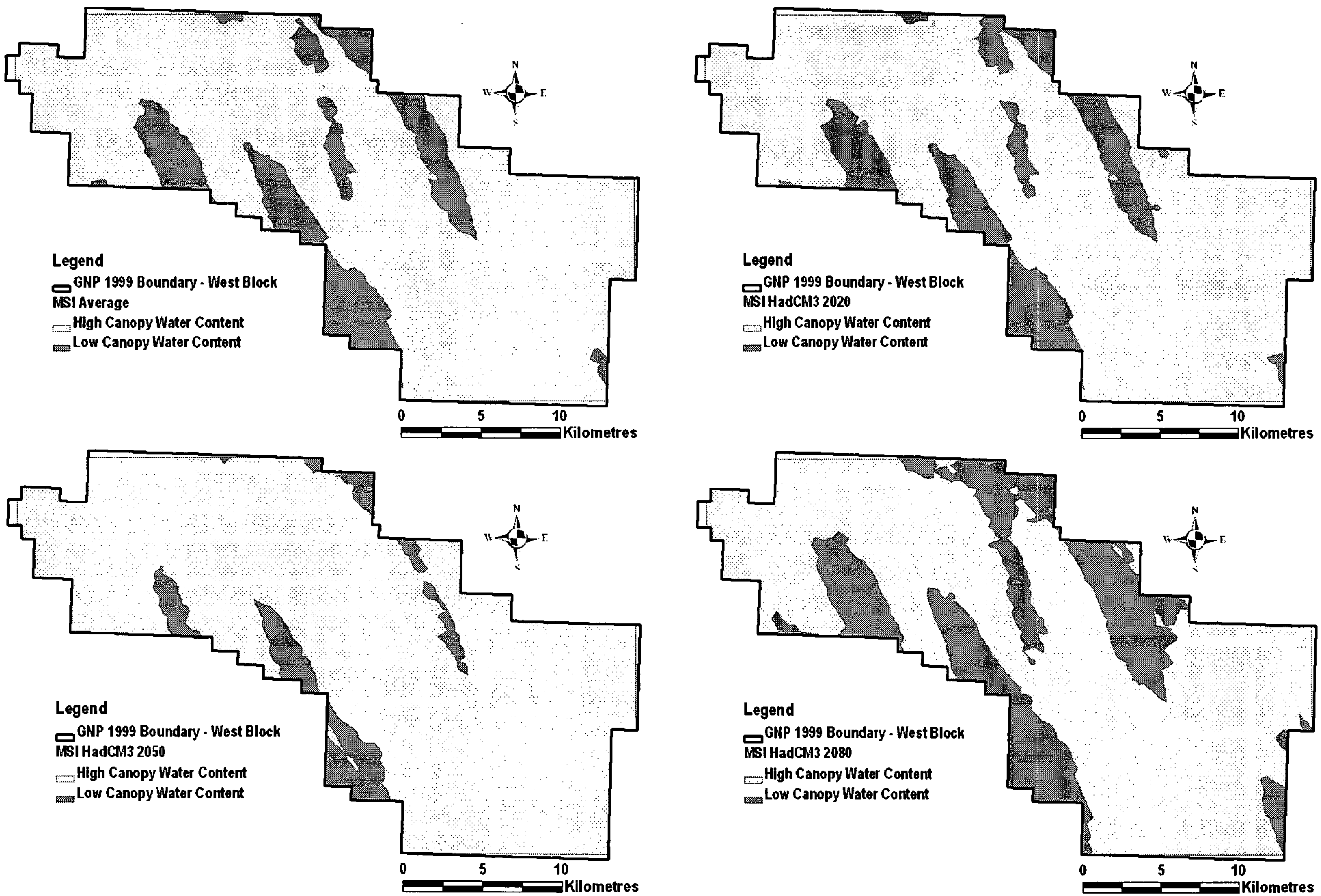


Figure 19. MSI HadCM3 B21 GCM vegetation change scenarios for vegetation canopy water content for the West Block of Grasslands National Park for 2020, 2050 and 2080.

5. DISCUSSION

5.1 Climate-Vegetation Values

My results show that both the NDVI and SAVI are negatively correlated with temperature, but can not be accurately predicted by precipitation, aridity and PET (Figure 10). This suggests that decreases in vegetation density and vigour of the mixed grass prairie are more closely related to increasing temperatures than to changes in precipitation.

The MSI is negatively correlated with precipitation and aridity, and positively correlated with PET, while the NDMI is positively correlated with precipitation and aridity, and negatively correlated with PET. Thus, both the NDMI and MSI can be accurately predicted by precipitation, aridity and PET, but are not strongly influenced by temperature (Figure 10). This suggests that the canopy water content indices are more closely related to moisture variables than to temperature.

The correlations further suggest that while it is possible to detect climate-vegetation relationships using the NDVI and SAVI, which use the RED and NIR spectral bands in their calculations, higher correlations can be obtained if data from the MIR spectral region are used, as in the NDMI and MSI. The MIR band seems to be more sensitive at detecting climate-vegetation relationships than the NIR band (Davidson et al. 2006, Zhang 2006). In the RED-NIR spectral region, radiation is strongly absorbed by leaves, but not directly by water in the leaf. However, in the NIR-MIR spectral region, radiation is strongly absorbed by water in the leaf.

Although other studies have demonstrated that NDVI is highly correlated with temperature and precipitation at a 1.1 km scale (Yang et al. 1997, Eklundh 1998, Richard and Poccard 1998, Suzuki et al. 2000, Gong and Shi 2003, Wang et al. 2003, Ji and Peters 2004), present research suggests that the NIR and RED bands are not sensitive enough to detect precipitation at smaller scales, especially because climate variables operate at much larger scales (Hunt and Rock 1989, Gao 1996, Jackson et al. 2004, Davison et al. 2005, Gu et al. 2007). However, there are other factors that likely affect the use of vegetation indices in detecting climate-vegetation relationships: 1) other climate and environmental factors that I did not look at in my study, such as solar radiation, wind speed, soil temperature and moisture, soil water holding capacity, and latent heat; and 2) errors induced by the sensor and data processing, including satellite navigation errors, view and zenith angle change, and atmospheric attenuation (Ji and Peters 2003, Ji and Peters 2004).

5.2 Palmer Drought Severity Index: Location of Grasslands National Park

Among all the vegetation indices tested, the strongest correlations to the PDSI occurred with the NDVI and SAVI (Figure 13). As for the regression analysis, I found that only the NDVI and SAVI can be accurately predicted by the PDSI (Tables 5 and 6).

The PDSI is calculated using data for precipitation, temperature, and the available water content of the soil. As for the climate-vegetation relationships, NDVI and SAVI are negatively correlated with temperature, whereas the MSI and NDMI are negatively/positively correlated with precipitation. The MSI and NDMI vegetation indices are indicative of water content in vegetation, not the available water content of the soil. They are not significantly correlated with temperature, which could explain the lack of significance in their regression models. Other studies suggest that the NDVI is strongly correlated with precipitation (Di et al. 1994, Paruelo and Lauenroth 1995 and 1998, Yang et al. 1998, Ji and Peters 2004). The PDSI takes into account the available water content of the soil and the water balance equation, which function at the landscape level. The Landsat images encompass similar scales. This may explain why the NDVI and SAVI detected more than just temperature and have stronger correlations with the PDSI, as well as their significance in their regression models.

I calculated the Palmer Drought Severity Index for each year during 1978-2006 for the winter, spring, summer and fall seasons in GNP (Figure 12). GNP was afflicted by droughts during the 1980s. Mild droughts occurred again in 2001 and 2006.

There are generally three contributors to drought on the prairies where GNP is located: equatorial Pacific sea surface temperatures, atmospheric circulation patterns, and its location. In regards to the equatorial Pacific sea surface temperatures and atmospheric circulation patterns, many of the dry years during the 1980s coincide with unusually intense El Niño-Southern Oscillation (ENSO) events (Nkemdirim and Weber 1998, Gan 2000). The cold (La Niña) phase of the ENSO cycle appears to be an important precursor for drought in the prairies. During La Niña years, a large anticyclone or high-pressure system often forms over the prairies, which inhibits the transport of moisture to the prairies and subsequent cloud formation and precipitation (Nkemdirim and Weber 1998, Khandekar 2004, Seager et al. 2005). The moisture received from the Pacific Ocean is important for the prairies. Without it, this ecoregion would be a desert (Quiring and Papakyriakou 2005). Another likely contributor is the Pacific Decadal Oscillation (PDO), which occurs on decadal to interdecadal time scales and is detected as warm or cool surface water in the Pacific Ocean north of 20°N. Warm phases of the PDO are correlated with El Niño years, whereas cool phases are correlated with La Niña years. A negative value of PDO along with a La Niña phase of the ENSO cycle may produce drought conditions in the prairies (Khandekar 2004, Breaker 2005).

Lastly, GNP is drought prone partly because of where it is located, within the Palliser Triangle (semi-arid triangular-shaped geographic area extending from southwestern Manitoba to southern Alberta), which is characterized by its aridity and annual water deficit. GNP lies on the lee side of the western mountains, and is located in the middle of the continent, far from the moderating effects of oceans or other large bodies of water. This mixed grassland ecoregion's climate is an interplay of three strong air masses: the Arctic, Pacific, and desert air masses, which typically collide in the middle latitudes where GNP is situated (Figure 20), producing its highly variable

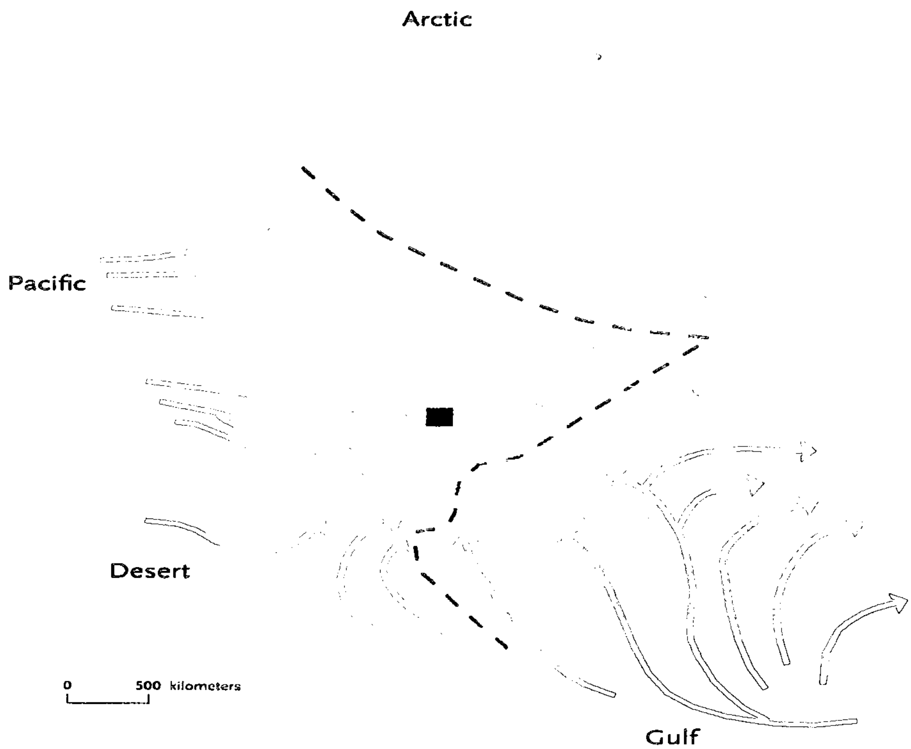


Figure 20. Major air masses affecting Grasslands National Park (Savage 2004). Grasslands National Park is indicated by a black rectangle.

precipitation patterns (Herrington et al. 1997, Gan 2000, Savage 2004, Raddatz 2005, Environment Canada 2006).

5.3 Past and Future Grassland Productivity: Climate Change, Drought and Aridity

During drought years, temperatures are normally higher and precipitation is lower than during non-drought years (Figure 4). These changes were captured by all the vegetation indices averages, which showed a general decrease in photosynthetic activity and grassland productivity during drought years (Figures 5, 6, 7, 8, and 9).

My aridity models predict that by 2020, the aridity classification of Grasslands National Park will change from semi-arid to arid in July. By 2050 and continuing on to 2080, GNP will be categorized as arid in both July and August (Figure 11).

For the vegetation change scenarios (Figures 14, 15 and 16), all three GCMs (CGCM2 A21, CSIROMk2b B11 and HadCM3 B21) suggest that the density and vigour of vegetation within the West Block of GNP will remain relatively stable until 2020. By 2050, all three GCMs predict that there should be a significant decrease in vegetation density and vigour. By 2080, all three GCMs suggest that most above ground biomass will decrease in vegetation density and vigour.

The canopy water content CGCM2 A21 scenarios (Figure 17) predict a decrease in the amount of water by 2020, with a significant decrease by 2050. By 2080, the majority of the canopy water content will decrease. As for the CSIROMk2b B11 GCM (Figure 18), the canopy water content will decrease by 2020, but with only a slight decrease by 2050. By 2080, there is only a small decrease in canopy water content. However, the HadCM3 B21 GCM (Figure 19) predicts the canopy water content will remain more or less the same by 2020, with a slight increase by 2050. By 2080, the canopy water content decreases.

Decreases in grassland productivity, vegetation density, vigour and canopy water content, coupled with a more arid climate, predicted by my aridity models and vegetation change scenarios, should change the vegetation communities that currently dominate GNP. Drought affects almost every plant process, including seed germination, water and mineral absorption, photosynthesis, respiration and growth (Mattson and Haack 1987, Haddad et al. 2002). A water shortage also affects soil biota, mineralization and nitrogen cycling. Plants under water stress lead to higher mortality (Henckel 1964). High temperatures, which generally accompany droughts, can cause injury to plants by increasing evapotranspiration and water stress demands, while causing decreased photosynthetic activity (Julander 1945, Henckel 1964, Yordanov et al. 2000, Flexas and Medrano 2002, Yordanov et al. 2003, Breshears et al. 2005, Zavalloni et al. 2008). Available water capacity (AWC) represents the water that is available to plants. The availability of soil water is determined by the amount of water drawn from the soil by plant transpiration and by direct evaporation relative to the amount of water replaced in the soil by precipitation. Root growth and nutrient uptake also generally decrease with increasing moisture stress (Gerakis et al. 1975)

GNP is currently a mixed grassland ecoregion, dominated by C_3 (cool-season) grasses, with an accompanying spring/early summer growing season and associated precipitation pattern (Sims and Singh 1978b, Singh et al. 1982, Heitschmidt and Vermeire 2006). C_3 grasses have the ability to exploit and deplete early season moisture, colonize faster and establish a dense root system (Weaver and Albertson 1943, Campbell 1996, Raven et al. 1999), out competing shrubs and trees early in the growing season. During spring drought cycles, grass productivity (C_3 and C_4) declines (Clark et al. 2002). As soil moisture decreases during the summer due to high levels of evapotranspiration and lack of precipitation, the soil moisture in the deeper layers becomes an important resource for plant growth during this period (Iijima et al. 2008). If the annual precipitation pattern in GNP shifts from a dominant spring/early summer precipitation to a dominant summer precipitation, there will most likely be a shift from C_3 to C_4 (warm-season) grasses and increased forb/shrub/tree activity (Mattson and Haack 1987, Le Houerou 1996, Clark et al. 2002, Baldocchi et al. 2004, Kochy and Wilson 2004, Heitschmidt and Vermeire 2006). However, plant responses to drought and increased aridity will also depend on the timing, length and severity of the drought period; air temperatures during the drought; individual plant species, and the ability of the plant to lie dormant or die back when stressed (Martin et al. 1991).

Prolonged droughts and increased aridity can have a pronounced effect on vegetation diversity and quality (low moisture and nutrient content). Droughts can cause the local extinction of many rare plant species, which reduces diversity (Le Houerou 1996, Clark et al. 2002, Hannah et al. 2002). After a drought, recolonization is often slow (Henckel 1964, Tilman and Haddi 1992, Haddad et al. 2002). An increase in the frequency and intensity of droughts will most likely lead to decreased plant species richness. Annual grasses and forbs are more likely to decline than perennials, due to their shallow root systems (Clark et al. 2002). However, annuals may be able to survive as seeds produced in wet years (Tilman and Haddi 1992). When shrubs replace grassland, a greater percentage of the soil is bare, and the temperatures of the soil surface and the air near the ground increase. This leads to an increase in soil erosion by wind and water, as well as nutrient loss. Plants also differ in competitive abilities, migration rates, and responses to disturbance such as drought. Migration for most plants is determined by how far they can distribute their seeds. Migration rates in plants are slow, which means it may not be possible for a plant population to keep pace with a changing climate (Allen 1996). Invasive exotic species may expand in range during climate change and will compete with the native species currently located in GNP for water and nutrients, since they possess traits which make them highly adaptable to climate change. Invasive species can tolerate a wide range of environmental conditions, grow and disperse rapidly, and are resistant to human disturbances (McCarty 2001, Hannah et al. 2002).

The climate of any given region is a combination of patterns of temperature and moisture, influenced by latitude and location in the continental land mass. However, the specific climatic conditions under which organisms live vary considerably within an area. These variations, or microclimates, are influenced by vegetation, soil, topography, and aspect (Kirkby 1995, Smith 1996).

The ability of soil to retain moisture is important for plant growth. Texture plays an important role. Heavy clays and clay loams retain more moisture than light sandy soils. AWC is lowest in coarse-textured soils like sand (0.05 to 2.0mm) and maximum in medium-textured soils like silt (0.002 to 0.05mm; Smith 1996, Strahler and Strahler 1998). The amount of organic matter in the soil also adds to a soil's water holding capacity. Soil properties also influence microclimates. Dark-coloured soils are better absorbers of heat than light-coloured soils because light-coloured soils reflect heat. Dry soils are poorer conductors of heat than moist soils. If the climate is very dry, then vegetation growth is very slow or absent (Kirkby 1995, Smith 1996, Strahler and Strahler 1998, Baldocchi et al. 2004).

Vegetation influences microclimates, especially near the ground. Temperatures at ground level in the shade are lower than areas exposed to the sun and wind. With little to no vegetation, temperature increases sharply near the soil surface, but as plant cover increases in height and density, the leaves of the plants intercept more solar radiation. Vegetation also deflects wind flow up and over its top (Smith 1996, Baldocchi et al. 2004, Chen et al. 2007).

Topography, including the steepness and direction of the slopes, influences soil development because of the way it distributes rainfall and sunlight over the ground. This leads to more plant growth and deeper soil development in the lower portions of a hillside compared to the upper portions (Kirkby 1995, Chen et al. 2007, Bennie et al. 2008). The aspect of a slope (direction a slope faces) also affects soil development. North facing slopes are cooler and retain more moisture than the south facing slopes. This may lead to the establishment of different plant communities and the formation of different soils on opposite sides of a hill. Slopes covered by vegetation also reduce soil erosion. (Kirkby 1995, Smith 1996, Chen et al. 2007, Bennie et al. 2008).

6. GENERAL BIOLOGY OF SPECIES-AT-RISK

6.1 Black-tailed Prairie Dog

The black-tailed prairie dog (*Cynomys ludovicianus*) is a diurnal, burrowing rodent found primarily in short and mixed grass prairies of the North American Great Plains (broad expanse of prairie which lie east of the Rocky Mountains in the United States and Canada; Stapp 1998). Grasslands National Park and its immediate surroundings are the only places in Canada where black-tailed prairie dogs occur (Savage 2004). Unlike other species of the genus *Cynomys*, black-tailed prairie dogs do not hibernate.

Prairie dogs have been identified as a keystone species, meaning that they are critical for other species that depend on them for food, burrows, and the plant communities they graze (Stapp 1998, Hof et al. 2002). Approximately 170 vertebrate species rely to some degree on prairie dogs, thus reductions in prairie dog populations could cause secondary extinctions, reducing overall biological diversity (Agnew et al. 1986, Sharps and Uresk 1990, Miller et al. 1994, Miller et al. 2000). For example, it is hypothesized that the eradication of prairie dogs has caused the near extinction of black-footed ferrets (*Mustela nigripes*), Mountain Plovers (*Charadrius montanus*), Ferruginous Hawks (*Buteo regalis*), and swift foxes (*Vulpes velox*). In addition, Ferruginous Hawks and swift foxes exploit prairie dogs as prey (Campbell and Clark 1981, Stapp 1998, Barko et al. 1999, Miller et al. 2000, Smith and Lomolino 2004). Burrowing Owls (*Athene cunicularia*) use abandoned burrows for nesting.

Agnew et al. (1986), Cincotta et al. (1987), and Sharps and Uresk (1990) concluded that avifaunal richness and abundance tends to be higher around prairie dog colonies because they provide heterogeneous plant cover, concentrated prey species, increased seed production, and lower vegetation height which creates greater visibility. King (1955) and Koford (1958) found that vegetation parameters, including height and species composition were key factors in separating colonies from surrounding prairie.

Site characteristics such as vegetation, soil type, slope, water availability, previous use by prairie dogs, proximity to existing prairie dog colonies, elevation, and any natural or man-made barriers at colonies are important determinants of prairie dog success (Koford 1958, Reading and Matchett 1997).

Black-tailed prairie dogs prefer flat or gently sloping terrain for burrows with vegetation shorter than 30 cm, which they clip to enhance visibility over the landscape (Clippinger 1989, Reading and Matchett 1997, Roe and Roe 2002, Roe and Roe 2003). Grasses are typically the preferred food. Western wheatgrass (*Agropyron smithii*), blue grama (*Bouteloua gracilis*), and buffalo grass (*Buchloe dactyloides*) are most frequently consumed (Clippinger 1989, Stapp 1998, Roe and Roe 2002, Roe and Roe 2003). Forbs are also an important part of prairie dog diets, such as plains prickly pear cactus (*Opuntia polyacantha;* Roe and Roe 2004). Diet appears to be influenced by plant phenology. Black-tailed prairie dogs prefer grasses and sedges in the spring and summer, but eat mostly forbs during the late summer and fall. They do not require a source of standing water and usually obtain water from the vegetation they eat (Clippinger 1989).

Soil structure is important for prairie dog burrows. Colonies typically do not occur on sand, loamy sand, and rocky/gravely soils, since these soil types do not promote stable burrows or allow burrows to go deep enough to allow protection from predators. Silty loam clay soils tend to be the best for tunnel construction, as they provide stability and facilitate good drainage. Black-tailed prairie dogs will burrow on slopes less than 10% (Koford 1958, Clippinger 1989, Reading and Matchett 1997, Roe and Roe 2002, Roe and Roe 2003, Roe and Roe 2004). Population density depends on the availability of food, and opportunities for colony expansion. Natural population densities on prairie dog colonies range between 4 to 23 prairie dogs per km^2 (Clippinger 1989, Roe and Roe 2002).

Altered vegetation composition and structure, along with a decline in vegetation quality, will most likely have a negative impact on prairie dog colonies. Collier and Spillett (1975) found a correlation between the presence of water and Utah prairie dog density. Prairie dogs obtain their water through the amount of moisture in the vegetation. Populations were almost completely eliminated by drought in the mid 1950s and during the 1930s drought (Collier and Spillett 1972; 1975). Scott-Morales et al. (2005) found an association between the density of the Mexican prairie dog and vegetation cover. Higher densities were found in areas with at least 45-50% vegetation cover. They also found that vegetation had an effect on the body mass and reproduction of Mexican prairie dogs. Areas that had more food (vegetation) contributed to faster growth of juveniles and improved reproduction. Barko et al. (1999) reported the absence of heterogeneous plant cover and increased seed production during drought months in 1996 in the Oklahoma panhandle. More than 90% of the dominant grasses, such as buffalo grass (*Buchloe dactyloides*) and blue grama (*Bouteloua gracilis*), were dormant in and around prairie dog colonies. Currie and White (1982) found prolonged drought killed or severely reduced stands of a number of grasses in the Northern Great Plains in Montana. Schmidt and Schuctz (1985) found buffalo grass production declined approximately 80% in Texas during a drought. Buffalo grass and blue grama are the most frequently consumed grasses of the black-tailed prairie dog. Frank and McNaughton (1992) found a 19% reduction in aboveground primary production of some dominant grass species during the 1988 drought in Yellowstone National Park. The drought also affected herbivores by reducing the duration of nutritious forage late in the season.

6.2 Burrowing Owl

Burrowing Owls (*Athene cunicularia*) are small birds of prey found on dry, open, short grass, treeless plains. They do not excavate their own burrows, but use existing ones created and abandoned by fossorial (an organism adapted to digging and life underground) mammals, including ground squirrels (*Spermophilus* spp.), badgers (*Taxidea taxus*), and prairie dogs (*Cynomys* spp.; Sissons 2003, Skiftun 2004, Lantz et al. 2007). In the Great Plains, Burrowing Owls are strongly associated with black-tailed prairie dogs (Desmond and Savidge 1996, Sheffield and Howery 2001). Lantz et al. (2007) found that out of the 105 burrowing owl nests they located in northeastern Wyoming, 82 were within active prairie dog colonies. They found that Burrowing Owl nests were selected based on certain habitat features: the structure of the burrow (burrows with longer tunnels); the area surrounding the nest burrow (high burrow density and low shrub cover); characteristics of the prairie dog colony (colonies with more prairie dog activity); and features within the surrounding landscape (sites close to water). Prairie dog colonies provide heterogeneous plant cover, high densities of prey species, high seed production, low vegetation height, and good visibility of prey and predators (Sheffield and Howery 2001, Skiftun 2004, Lantz et al. 2007). Soil types are also related to the nesting habitat of Burrowing Owls in that they prefer sandy loam, loam or silty loam soils. The amount of shrub and tree cover affects Burrowing Owls as well, since it limits their line of sight, making them more vulnerable to predators (MacCraken et al. 1985, Plumpton and Lutz 1993). Burrowing Owl prey varies seasonally. Mammalian prey, such as deer mice (*Peromyscus maniculatus*) and meadow voles (*Microtus pennsylvanicus*), seem to be the most important early in the nesting period before insects become available and again in the fall (Restani et al. 2001, Sissons 2003). During the summer, insects, such as beetles and grasshoppers, are the primary food source of Burrowing Owls. Food availability and predation limit burrowing owl populations (Desmond and Savidge 1996, Restani et al. 2001). Burrowing Owls are prey for a number of species, such as the Ferruginous Hawk (*Buteo regalis*), coyotes (*Canis latrans*), Golden Eagles (*Aquila chrysaetos*) and Great Horned Owls (*Bubo virginianus*).

Burrowing Owl nesting habitat should be managed at the scale of the prairie dog colony. It is critical for Burrowing Owl conservation to maintain prairie dog activity, burrow and food availability, and low vegetation cover.

Variation in temperature and precipitation can affect bird populations (higher mortality rates and lower reproduction) either indirectly through habitat change, or directly through heat stress or water restriction (Wiens 1974, Smith 1982, Morrison 1986). Wichmann et al. (2003) found that a decrease in mean annual precipitation and an increase in inter-annual variation caused decreases in raptor populations in arid savannas. Smith (1982) found that the number of breeding bird species declined during a drought, insect species composition and densities changed, and many bird species experienced water stress. Hawkins and Holoyoak (1998) found a widespread drought caused simultaneous crashes of insect populations across the United States, affecting diverse taxa from butterflies to sawflies to grasshoppers. Garcia and Arroyo (2001) showed that low levels of rainfall, during Hen Harrier breeding season in central Spain, reduced annual fledging success, likely mediated through a decline in food abundance. Additionally, the proportion of eggs that did not hatch in each clutch increased with higher temperatures during the incubation period. Aumann (2001) found raptor productivity during the 1996 drought in Australia was 6 to 15 times lower. Declines in territory occupancy, breeding density, breeding success and the number of young fledged per active nest are characteristic responses to the drought by most raptor species. Baker-Gabb (1983) found few diurnal raptor species bred during the severe drought of 1982 in Australia.

Drought can have negative impacts on natural populations of Burrowing Owl prey. Lewellen and Vessey (1998) showed that high temperatures, low precipitation and drought reduced white-footed mouse (*Peromyscus leucopus*) densities. Turchin and Ostfeld (1997) found that severe drought depressed population growth rates and density of meadow voles (*Microtus pennsylvanicus*). Nelson and Desjardins (1987) found water restriction impaired sperm production in deer mice in South Dakota, which may reduce reproduction during the peak of their annual breeding season. Nelson (1993) found reproductive function was significantly depressed in water restricted deer mice, while Nelson et al. (1995) showed that water restriction also reduced reproductive organ masses and plasma levels of prolactin, and may be an environmental cue to terminate breeding in male California mice.

6.3 Ferruginous Hawk

Raptors play an important role in ecosystems since they are at the top of their food web, have a direct effect on prey communities, cover wide home-range areas, and changes in their population structure may reflect large scale environmental changes (Gilmer and Stewart 1983). Ferruginous Hawks (*Buteo regalis*) are the largest hawk in North America. They occupy open habitats, such as grassland, shrubsteppe and desert in the western part of North America (Tomback and Murphy 1981, Travsky and Beauvais 2005). Habitat quality is strongly tied to prey availability. Viable populations of Ferruginous Hawks depend on large expanses of native grass and shrubs that support abundant prairie dogs, ground squirrels, and jackrabbits (*Lepus* spp.; Lokemoen and Duebbert 1976, Woffinden and Murphy 1977, Jasikoff 1982, Gilmer and Stewart 1983). They tolerate minimal human disturbance during the breeding season.

Ferruginous Hawks nest in flat to rolling terrain dominated by grass or shrubs in the Great Plains. Trees typically occur only in small and scattered stands. They will nest directly on the ground, but appear to prefer elevated features and landforms, such as boulders, creek banks, and buttes, when available. Large shrubs, isolated trees, haystacks and utility poles are also used (Lokemoen and Duebbert 1976, Tomback and Murphy 1981, Jasikoff 1982, Gilmer and Stewart 1983, Taylor 2004, Travsky and Beauvais 2005). Shrubs taller than 1 m in height can support a nest. Average territory size is approximately 2.6 to 7.7 km^2, with a diameter of 1.6 to 4 km (Jasikoff 1982).

Ferruginous Hawks eat mostly ground squirrels, especially Richardson's ground squirrels (*Spermophilus richardsonii*). Other small mammals, birds, reptiles, and large invertebrates, such as locusts, are also eaten. Several studies report synchronous fluctuations between populations of Ferruginous Hawks and major prey species, especially ground squirrels (Woffinden and Murphy 1977, Kirk and Hyslop 1996, Plumpton and Anderson 1998, Seery and Matiatos 2000, Taylor 2004).

Low, dense vegetation is correlated with lower prey abundance, but increased accessibility for Ferruginous Hawks. Different combinations of average vegetation heights and densities provide optimum prey levels. Habitats with vegetative heights of 15 cm provide optimum food when vegetative densities approach 100% canopy cover (Jasikoff 1982, Travsky and Beauvais 2005).

The major limiting factor for Ferruginous Hawk populations is low reproductive output. This is usually associated with habitat loss due to cultivation and cheatgrass (*Bromus tectorum*) invasion, reduced distribution and abundance of prey (especially prairie dogs), and high levels of disturbance during nesting. Gilmer and Steward (1983) found that summer storms were a major cause of nest loss, with nests in trees particularly vulnerable. The primary predator of nestlings is the Great Horned Owl (*Bubo virginianus*), but Common Ravens and American Crows also eat eggs and nestlings (Travsky and Beauvais 2005).

High temperatures, decreases in precipitation and a reduction in prey can negatively affect raptor populations (Wiens 1974, Smith 1982, Morrison 1986). Tomback and Murphy (1981) found that underfed Ferruginous Hawk nestlings were vulnerable to heat stress. They concluded that the combined effects of inadequate amounts of food and high temperatures resulted in high nestling mortality in years when prey populations were low. Steenhof et al. (1997) showed that weather conditions during the nesting season influenced Golden Eagle (*Aquila chrysaetos*) reproduction. Mean brood size at fledging and the proportion of pairs that laid eggs were positively related to jackrabbit abundance and inversely related to the number of hot spring days. High temperatures during incubation and hatching periods reduced chick survival. Mooij et al (2007) found snail availability during droughts is dramatically reduced, increasing the probability of Florida Snail Kites (*Rostrhamus sociabilis*) dying from starvation. The longer the drought persisted, the greater the reduction in kites. Reproduction was also dramatically reduced. Hoffman and Smith (2003) found drought increased raptor starvation and mortality in western North America. Wichmann et al. (2003) found that decreased mean annual precipitation and increased inter-annual variation caused dramatic decreases in raptor populations in arid savannas.

Drought can have negative impacts on Ferruginous Hawk prey species. Sherman and Runge (2002) argued that the ultimate collapse of the northern Idaho ground squirrel (*Spermophilus brunneus*) resulted from inadequate food resources, particularly seeds, due to drying of the habitat and changes in plant species composition. Van Horne et al. (1997) found that the demographic effects of drought and a prolonged winter lasted through the subsequent breeding season in Townsend's ground squirrel (*Spermophilus townsendii*). Rogowitz (1992) found reproductive output declined during a late summer drought in Wyoming. Low ova production and high prenatal mortality reduced mean litter size. Van Horne et al. (1998) found a drought in 1992 caused lower body mass and survival in Townsend's ground squirrels.

6.4 Greater Sage Grouse

Sage Grouse (*Centrocercus urophasianus*) are the largest grouse in North America. They are non-migratory and found almost exclusively within the range of sagebrush (*Artemisia* spp.) throughout the year; which they depend on for food and shelter (Aldridge 1998, Aldridge 2000, Connelly et al. 2000, Braun et al. 2005). Sagebrush leaves are eaten by Sage Grouse year round and comprise 99% of their winter diet. During the spring mating season, leks (breeding display grounds) typically occur in flat, open areas (Aldridge 1998, Aldridge 2000, Connelly et al. 2000) with sparse vegetation, surrounded within 100 to 200 m by tall sagebrush , which provide escape cover (Braun et al. 2005). Nesting habitat is primarily associated with dense sagebrush and abundant forbs. Connelly et al. (2000) found the distances between nests and leks vary from 1.1 to 6.2 km. Nesting habitats have abundant (15 to 30% canopy cover) taller (30 to 80 cm) sagebrush plants with more than 15% ground cover of taller (40 to 80 cm) grasses and forbs (Connelly et al. 2000, Braun et al. 2005). In early summer, brood-rearing habitats are concentrated in areas with high plant species richness, moisture, and taller grasses and forbs within 100 m to 1 km of nesting sites (Aldridge 1998, Aldridge 2000, Connelly et al. 2000, Braun et al. 2005). As sagebrush desiccate, Sage Grouse move to more mesic (habitat with more moisture) sites during June and July. These sites include a variety of habitats, such as sagebrush, wet meadows, and farmland (Aldridge 1998, Aldridge 2000, Connelly et al. 2000, Braun et al. 2005).

Sage Grouse use a variety of habitats during the fall and winter, usually consisting of dense (more than 20% canopy cover) taller (more than 25 cm) sagebrush (Connelly et al. 2000, Braun et al. 2005). South and southwest facing slopes are important attributes of wintering areas, as they are relatively snow free (Aldridge 1998, Aldridge 2000, Braun et al. 2005).

Sagebrush constitutes 62% of their year round diet (Aldridge 1998, Aldridge 2000). The majority of forbs consumed are the common dandelion (*Taraxacum officinale*), common salsify (*Tragopogon dubius*) and prickly lettuce (*Lactuca serriola*). Insects, including grasshoppers, beetles and ants also make up an important part of the juvenile diet (Aldridge 1998, Aldridge 2000). Sage Grouse obtain most of their water from the vegetation and insects they consume, but during dry years they will drink from standing water sources.

The factors limiting Sage Grouse populations are loss, fragmentation or degradation of habitat; industrial development; human disturbance; noxious weeds and invasive plants; grazing; predation; disease and parasites; and weather. Cold and wet weather during incubation and hatching periods can reduce chick survival. Drought reduces the abundance of herbaceous vegetation. Harsh winters can limit an individual's ability to find food (Aldridge 1998, Aldridge 2000).

Drought can have negative impacts on Sage Grouse populations by reducing food availability, chick survival and habitat cover. Flanders-Wanner et al. (2004) found lack of soil moisture indirectly restricted Sharp-tail Grouse (*Tympanuchus phasianellus*) production by limiting the availability of food plants and vegetative cover. They also found heat stress affected chick survival. Lusk et al. (2007) found drought and high temperatures reduced the length of the laying season, the percentage of hens laying, and the total reproductive effort in a breeding season of Bobwhite (*Colinus virginianus*) and Scaled Quail (*Callipepla squamata*) populations in Texas. Saab and Marks (1992) found the summer habitat of Sharp-tailed Grouse in western Idaho was significantly reduced during drought years. Moss et al. (1993) found Red Grouse (*Lagopus lagopus scotica*) chicks' condition and survival declined after a decline in the biomass of green heather during the spring. Swenson et al. (1994) found the availability of nutritionally rich food and the ability of female Hazel Grouse (*Bonasa bonasia*) to obtain it during the prelaying period determined their reproductive success.

6.5 Loggerhead Shrike

Loggerhead Shrikes (*Lanius ludovicianus*) differ from other songbirds because they regularly eat small vertebrates. Shrikes are also called "butcher birds" because they impale their prey on sharp objects such as thorns or barbed wire fences. Loggerhead Shrikes prefer open habitat interspersed with scattered trees and shrubs, which provide nesting and perching sites

(Brooks and Temple 1990, Dechant et al. 1998, Prescott and Bjorge 1999, Esely Jr. and Bollinger 2001, Bellar and Maccarone 2002, Lauver et al. 2002, Downey 2004). In Saskatchewan, Shrike habitat usually is dominated by thorny buffaloberry (*Shepherdia argentea*), willow (*Salix*), common caragana (*Caragana arborescens*), Manitoba maple (*Acer negundo*) or silver sagebrush (*Artemesia cana*). This songbird uses a variety of habitats, including pastures, prairies, riparian areas, shelterbelts, farmsteads and abandoned railroad rights-of-way (Dechant et al. 1998, Prescott and Bjorge 1999, Esely Jr. and Bollinger 2001, Downey 2004). Territories are usually 6 to 9 ha in size (Dechant et al. 1998, Downey 2004).

Shrikes seem to prefer habitats with slopes between 0-25%, and vegetation cover of at least 80% graminoids (a grass or grass-like plant) and 5% shrubs. Chabot et al. (2001) reported Shrikes select nest sites based more on the degree of cover provided than on particular tree or shrub species. As shrub density increases, foraging space decreases. Lauver et al. (2002) showed the most important variable in predicting shrike habitat suitability was the number of potential nesting trees. They reported that shrikes selected grassland habitats that contain low to moderate levels of isolated tree cover. Esely Jr. and Bollinger (2001) stated that selection of a particular habitat may be influenced by proximate cues such as habitat structure, as well as long term food availability. Farmyards can act as island refuges for shrikes and other shrub nesting birds (Downey 2004).

Bjorge and Prescott (1999) found that the number of breeding pairs was significantly higher (6.6 pairs vs. 2.3 pairs) in seven 41.5 square kilometre blocks containing more than 100 clusters of trees or shrubs than in 12 blocks containing less than 50 clusters. Collister (1994) reported that shrikes preferred to nest in buffaloberry habitat within territories averaging 52% native pasture, 33% right-of-way, 8% tame pasture (forage crops), 5% fallows, and 2% cropland. Prescott and Collister (1993) found shrikes using shrubby areas interspersed with grass and forbs and often nested in thorny buffaloberry more than or equal to 1.8 m tall. They also found that sites occupied by shrikes had a greater percentage of tall (more than or equal to 20 cm) grass (24.1% vs. 2.5%) and higher mean grass height (20.0 cm vs. 15.8 cm) than unoccupied sites. Telfer (1992) reported shrikes preferred native grassland and land seeded with introduced grasses and legumes. Sprunt (1965) found Loggerhead Shrikes nesting in cottonwoods (*Populus*) and willows along waterways.

Loggerhead Shrikes are opportunistic foragers, taking a variety of vertebrate and invertebrate prey. Invertebrates, such as grasshoppers and beetles, are consumed during the spring and summer. Vertebrates make up a larger part of the shrike's winter diet, dominated by small mammals and birds. Occasionally, reptiles and amphibians are consumed (Dechant et al. 1998, Prescott and Bjorge 1999, Downey 2004).

Badgers, Burrowing Owls, Ferruginous Hawks and Richardson's ground squirrels can be found in similar habitats as Loggerhead Shrikes. Shrikes compete for suitable nesting habitat with Eastern and Western Kingbirds, and Brewer's Blackbirds (Downey 2004).

Factors limiting shrike populations include habitat alteration, intraspecific competition, toxic contaminants (pesticides), weather/climate, human disturbance and predation. Chabot et al. (2001) concluded that mortality from fledging through independence is high. Low survival rates of fledglings, climate change and inclement weather are likely contributing to their decline. Lauver et al. (2002), and Brooks and Temple (1990) both suggest loss of breeding habitat is a limiting factor. Bellar and Maccarone (2002) propose that the loss of quality nesting sites, perch sites, and foraging habitat have contributed to the declining numbers.

Drought can have negative impacts on populations of Loggerhead Shrike and their prey species. Dittami and Knauer (1986) found that severe droughts inhibit reproductive activity and correspondingly the secretion of gonadal steroids in Fiscal Shrikes (*Lanius Collaris*) in Kenya. Giralt and Valera (2007) found the number of breeding pairs of Lesser Grey Shrikes (*Lanius minor*) in Girona during 1989-2002 was explained by climate variables, such as thermal oscillations during May and June. They found the larger the thermal oscillation, the lower the number of breeding pairs. LeFranc (1993) considered climate to be the most significant factor contributing to continent wide declines of Lesser Grey Shrikes. Yosef (1994) found climate variation coupled with a decrease of prey populations to be important causes of declines in shrike populations. Breshear et al. (2005) found the soil water content in the months preceding pine tree mortality across southwestern North American woodlands was sufficiently low to have produced high plant water stress and cessation of transpiration and photosynthesis. Insect, mice and vole populations are negatively influence by drought (refer to Burrowing Owl section 6.2).

6.6 Short-eared Owl

Short-eared Owls (*Asio flammeus*) are highly nomadic raptors that prefer open areas with low vegetation, such as grasslands and wetlands, for nesting and foraging. Short-eared Owls usually choose breeding sites based on the amount of prey available (Clark 1975, Herket et al. 1999, Clayton 2000). These owls are one of the few North American species that routinely nest on the ground. Clark (1975) reported that among 63 nest sites found in Saskatchewan, 55% were in grassland, 24% in grain stubble, 14% in hayland, and 6% in shrubs, like buckbrush (*Symphoricarpos occidentalis*). Clark also reported that Shored-eared Owls nest on drier ground. Herket et al. (1999) found that owls usually nest in areas with shorter vegetation . Nests are often located in grasslands where vegetation was less than 50 cm tall. Holt and Leasure (1993) found that 85% of nests were surrounded by grasses, 8% by herbs, and 7% by herbs/grasses. Ninety percent of the vegetation around these nests were less than 0.5 m tall, 9% were 0.5 to 1.0 m, and 1% was more than 1.0 m.

There have been relatively few studies done on foraging habitat. Martinez et al. (1998) reported that throughout the year, Short-eared Owls in an agricultural landscape in southern Chile, concentrated their hunting along roadsides, in ungrazed meadows, and untilled lands. Unfortunately, this study did not employ radio-telemetry, and habitat preferences were not tested statistically. Wintering habitat is similar to breeding habitat. Winter roosts are typically on the ground among grasses 30 to 40 cm tall (Clark 1975, Walk 1998). Short-eared Owls usually avoid urban areas and are area sensitive, grassland areas of 50 ha or larger offer the best breeding and wintering habitat (Tate 1992).

The diet consists mainly of small mammals, which make up more than 95% of prey items. Meadow voles are the predominant species in most cases, along with deer mice (*Peromyscus* maniculatus; Clayton 2000). However, Clark (1975) suggested that owls take whatever prey is most available. There is a strong correlation between Short-eared Owl abundance and peaks in vole populations (Gorman and Reynolds 1993).

Limiting factors of Short-eared Owl populations are habitat loss and degradation, food abundance and pesticides. Holt (1992) found that habitat loss and degradation through agriculture, grazing and development was probably the single most important factor in population declines. Sibling cannibalism has been reported when food resources are low, resulting in brood reduction (Ingram 1959). In the Canadian prairies, meadow vole populations are characterized by cyclic fluctuations in density, which are influenced by climate, food quality, and predators (Clayton 2000). Short-eared Owls are also ground nesters, making them susceptible to high nest mortality.

Altered vegetation composition and structure, a decline in vegetation quality, variation in temperature and precipitation, and drought will most likely have a negative impact on Short-eared Owl populations and their prey (refer to Burrowing Owl and Ferruginous Hawk sections 6.2 and 6.3).

6.7 Sprague's Pipit

Sprague's Pipit (*Anthus spragueii*) is a ground nesting songbird endemic to the Canadian prairies. Pipits are usually found in native grassland habitats, containing little to no woody vegetation. They tend to avoid heavily grazed areas and deep leaf litter or dense vegetation, and are negatively associated with shrubs 20 to 100 cm tall. Sprague's Pipits are positively associated with intermediate vegetation height and litter depth, with narrow leafed grasses equal to or less than 10 cm tall. Nesting habitat consists of dense and tall grasses, with low shrub and forb density (Prescott 1997, Sutter 1997, Prescott and Murphy 1999, COSEWIC 2002, Landry 2004).

Pipits are predominantly insectivorous. In May, beetles comprise over 40% of the adult diet, with grasshoppers making up 91% of their diet in September (Prescott 1997, Landry 2004).

The major limiting factors for Pipits are loss of native prairie, habitat fragmentation, livestock grazing, and haying during the nesting season. Several studies suggest that densities of grassland birds are influenced by the structure and coverage of vegetation (Cody 1968, Wiens 1969; 1973).

Variation in temperature and precipitation, along with a decline in food availability can affect bird populations (Wiens 1974, Smith 1982, Morrison 1986). George et al. (1992) found declines in species richness and diversity, including the Sprague's Pipit, during the 1988 drought in western North Dakota. The grassland bird community shifted from a relatively diverse grouping of common and uncommon species to one dominated by fewer, widespread, common species. George et al. (1992) concluded that increased nest abandonment and termination of breeding occurring during the drought was due to a combination of heat stress and declining food availability. Dale (1984) observed a similar shift in community composition in grassland bird communities in response to dry weather. Grzybowski (1982) found fewer grassland birds, such as the Sprague's Pipit, present during the winter of 1976 to 1977 in Oklahoma and Texas. The year 1976 was a drought year. Bock and Bock (1999) found drought and short-duration grazing in southeastern Arizona negatively affected a variety of resident and migratory birds dependent on ground cover and seed production for over-winter survival. Niemuth et al. (2008) found the dispersion of seven grassland species in North Dakota was influenced by moisture levels. Stiles (1992) found lek activity of males of the Long-tailed Hermit (*Phaethornis superciliosus*) in the Caribbean was reduced during a drought, successful breeding by females declined, and masses of both sexes dropped due to a flower shortage.

6.8 Swift Fox

The swift fox (*Vulpes velox*) is the smallest member of the Canid (dog) family and named for its speed. During the 20th century, it disappeared from the wild in Canada. It was reintroduced in 1983 (Downey 2004). Swift foxes prefer open, sparsely vegetated short or mixed grass prairie, which provides visibility. This allows them to detect and elude predators. Uresk and Sharps (1986) found the vegetation associated with den sites in South Dakota were buffalograss, western wheatgrass, blue grama, needleleaf sedge (*Carex duriuscula*), and scarlet globemallow (*Sphaeralcea coccinea*). They also found that swift foxes did not select dens within specific soil types, but Downey (2004) concluded that swift foxes prefer loam, silty loam, silt, silty or sandy clay loam, and clay loam.

Uresk et al. (2003) found that den sites had less western wheatgrass canopy, and that vegetation surrounding the dens was denser, which may relate to use of screening cover for burrow entrances and greater security; however, they detected no difference in canopy cover between foraging and denning sites. Cutter (1958) observed that dens in northern Texas were all in open, sparsely vegetated habitats, on sloping plains, hill tops, or other well-drained places. The majority of occupied dens were in overgrazed pastures. Hines and Case (1991) reported that proximity to roads was important for den selection, when suitable habitat was available. They found that dens usually had east and west exposures. Uresk and Sharps (1986) also reported easterly exposures. Kilgore (1969) observed almost half of the 35 dens he found during his study in the Oklahoma panhandle were in cultivated fields, while 15 were in native shortgrass pastures.

Swift foxes are opportunistic predators and primarily hunt at night. They eat mostly mice, cottontail rabbits and carrion, as well as other small mammals, birds, insects, reptiles and amphibians (Downey 2004). Hines and Case (1991) found swift fox scats in Nebraska contained 48% prairie vole, 38% cattle, 25% jackrabbit and 31% western harvest mouse. In addition, 56% of scats contained insect remains, mostly Orthoptera and Coleoptera, 54% plant material, and 40% birds. Uresk and Sharps (1986) found the most frequent items in scats in western South Dakota were mammals (49%), followed by insects (27%), plants (13%), and birds (6%). Prairie dogs, grasshoppers, and beetles were the major components of their diet. Insects were also abundant in the diets of swift fox in Uresk et al.'s (2003) study, along with cottontail rabbits (*Sylvilagus* spp.), pocket mice (*Perognathus* spp.) and thirteen-line ground squirrels (*Spermophilus tridecemlineatus*). Kilgore (1969) noted the contents of 488 scats comprised mostly of mammals, such as cottontails. Insects and plant materials were also found.

Home ranges of swift foxes seem to vary seasonally. In Alberta, their home range is approximately 34 km^2 (Downey 2004), while Olson and Lindzey (2002) reported the annual home-range size to be 18.6 plus or minus 1.6 km^2 for swift foxes in southeastern Wyoming. They found that home-range increased from the pup-rearing period to the dispersal period, likely reflecting the fact that adults were no longer tied to natal dens or the need to find prey. Hines and Case (1991) found home-ranges of seven swift fox averaged 32.3 plus or minus 9.8 km^2.

Swift fox depend on other mammals, like badgers and Richardson's ground squirrels, for escape burrows and den sites. Burrowing Owls may compete for these burrows. Red foxes (*Vulpes vulpes*), Ferruginous Hawks and Sprague's Pipits can be found in similar habitat. Red foxes may compete with swift foxes for prey and denning sites. Coyotes, eagles, Red-tailed Hawks, and Rough-legged Hawks all depredate swift foxes (Downey 2004).

Factors limiting swift fox populations are human disturbance (poisoning, trapping and hunting), predators, diseases, habitat loss and degradation, livestock grazing and prey abundance. Livestock grazing can reduce prey. High numbers of coyotes can significantly reduce swift fox populations (Uresk and Sharp 1986, Olson and Lindzey 2002, Downey 2004). Olson and Lindzey (2002) found a positive relationship between number of young observed and proportion of sage vegetation, a relationship likely driven by prey abundance. Moehrenschlager and Moehrenschlager (2001) found the lower numbers of swift foxes in GNP was related to higher mortality, lower reproduction and higher net dispersal from the region.

Altered vegetation composition and structure, along with a decline in vegetation quality, could have a negative impact on the den sites of swift fox (refer to Burrowing Owl section). Drought can have negative impacts on swift fox populations and their prey species. McIlroy et al. (2001) found female red fox reproductive performance decreased during a drought in Australia. Ralls and White (1993 and 1995) found a reduction in kit fox (*Vulpes macrotis*) reproduction in California due to reduced prey availability during a drought. Salvatori et al. (1999) found culpeo fox (*Lycalopex culpaeus*) populations declined as a consequence of drought, along with their prey populations. Callie et al. (1996) found proportionately fewer female kit foxes successfully reared young and densities of kit fox decreased significantly during a drought in California. Mice, vole and ground squirrel populations are negatively influenced by drought (refer to Burrowing Owl and Ferruginous Hawk sections 6.2 and 6.3).

7. RISK ANALYSIS

The SAR risk analysis maps (Figures 21 to 62) were created using the vegetation change scenario maps (Figures 14 to 19) to assess the effects climate change will have on the eight species-at-risk chosen for my study. The SAR distributions were obtained from Parks Canada. A k-means unsupervised classification was used to create the SAR habitat, which calculated initial class means evenly distributed in the data space and then clustered the pixels into the nearest class using a minimum distance technique. ENVI (4.4; ITT Visual Information Solutions 2007) and ArcGIS (9.2; ESRI 2006) was used to conduct the analysis.

The vegetation change scenario maps were used to categorize vegetation into three different classes: healthy, stressed and highly stressed. For the NDVI vegetation change scenario maps, NDVI values between 0.0 and 0.1 were classified as highly stressed vegetation; NDVI values between 0.1 and 0.2 were classified as stressed vegetation; and NDVI values between 0.2 and 0.5 were classified as healthy vegetation. For the MSI vegetation change scenario maps, MSI values between 1.0 and 1.85 represented healthy vegetation; MSI values between 1.85 and 2.0 represented stressed vegetation; and MSI values between 2.0 and 2.5 represented highly stressed vegetation. The SAR habitat and distributions were then laid over the vegetation change scenario maps to determine the likely affects climate change will have on SAR and their habitat in 2020, 2050 and 2080. Altered vegetation composition and structure, along with a decline in vegetation quality, will likely have a negative impact on SAR.

The information obtained from the SAR risk analysis maps was used to produce Table 7. Decreases in grassland productivity, vegetation density, vigour and canopy water content, coupled with a more arid climate, predicted by my aridity models and vegetation change scenarios, could have a negative impact on the SAR by altering vegetation composition and structure, and causing habitat loss, heat stress, water stress, a decline in food availability and mortality. In turn, invasive exotic species may expand in range with climate change further altering vegetation composition and structure. Each source of stress listed in Table 7 will either have a high, medium or low risk of negatively affecting the SAR based on their life history, biology and diet.

Vegetation change and loss means a decrease in habitat diversity and suitability for many animal species. Habitat loss can substantially diminish a species ability to keep pace with a changing climate. SAR are more likely to become extinct if they occupy a small geographic range or if they depend on a threatened plant species for food, shelter or breeding sites (Bazzaz and Fajer 1992). The eight SAR chosen for this study are grassland (mixed and short) specialists. Specialists are deemed to be at an elevated risk of extinction because they have unique adaptations to grassland systems (Smith 1996, Leemans 1999). For example, the Sprague's Pipit, Ferruginous Hawk, swift fox and black-tailed prairie dog are entirely, or almost entirely restricted to the grasslands for a critical part of their life cycle. SAR located in GNP are also at the northern edge of their range. As the distance to the edge of the range for a species decreases, individuals often experience increasingly stressful climatological conditions resulting in fewer, smaller patches of suitable habitat, or in decreased reproductive success (Grace 1987, Root 1988a, Parmesan et al. 2000). Even if habitat conditions become favourable farther north, it will take time for them to evolve adaptations and will depend on suitable habitat cover to provide food and shelter. Thus, they will be heavily influenced by the spatial configuration of their habitat, especially since their habitat in GNP is surrounded by agriculture (Opdam and Wascher 2004). The configuration, density, and quality of landscape elements, such as foraging and nesting habitat, required by the SAR to reproduce and find prey will likely be altered in response to increased aridity (Peters 1991, deGroot et al. 1995, Opdam and Wascher 2004). In addition, SAR could experience higher mortality rates and lower reproduction in response to higher temperatures and water stress. In turn, a reduction in habitat cover will make individual species more susceptible to predation (Opdam and Wascher 2004).

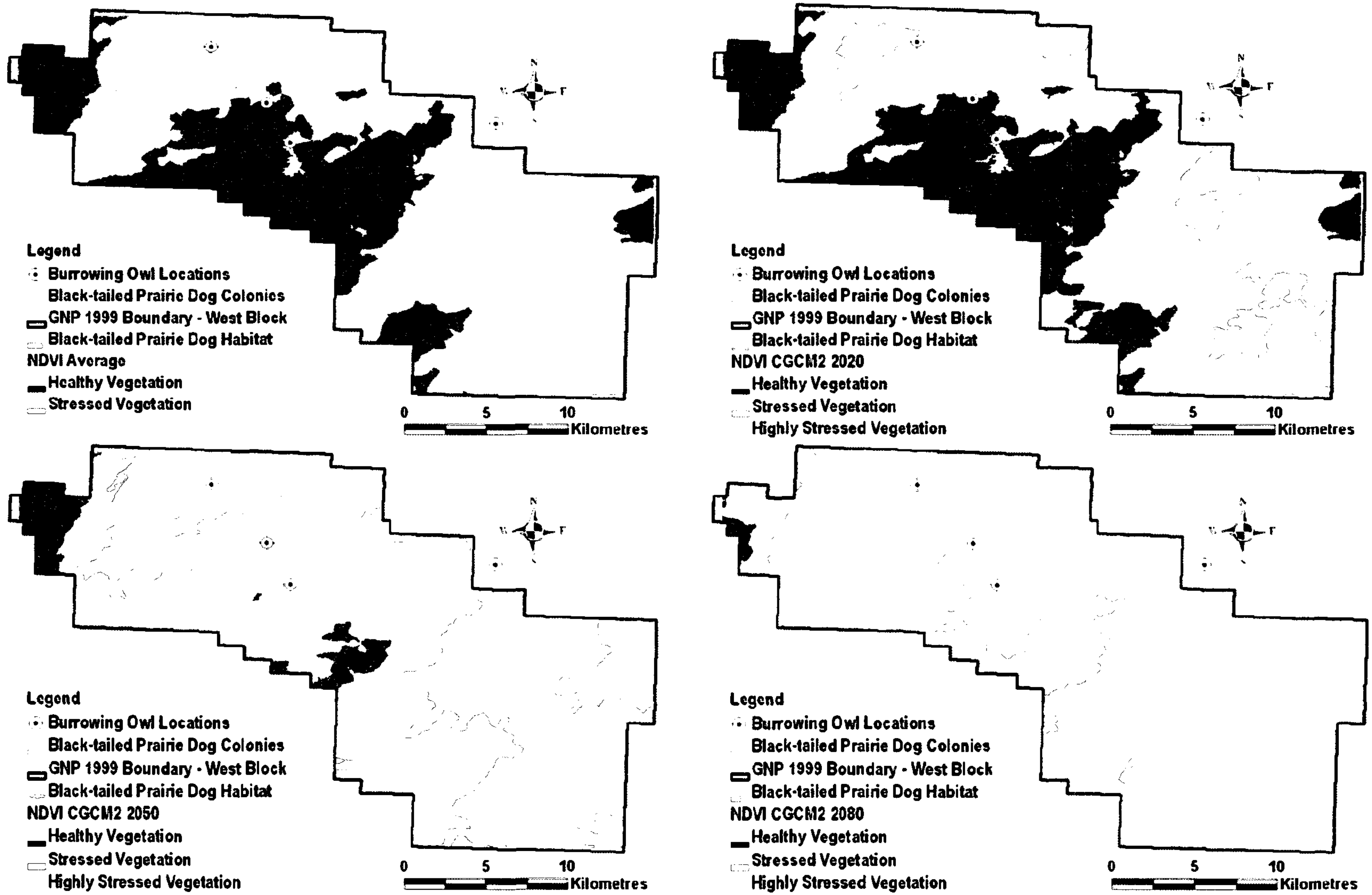


Figure 21. Risk analysis of black-tailed prairie dog and Burrowing Owl habitat and distributions for the NDVI CGCM2 A21 GCM vegetation change scenarios for the West Block of Grasslands National Park for 2020, 2050 and 2080.

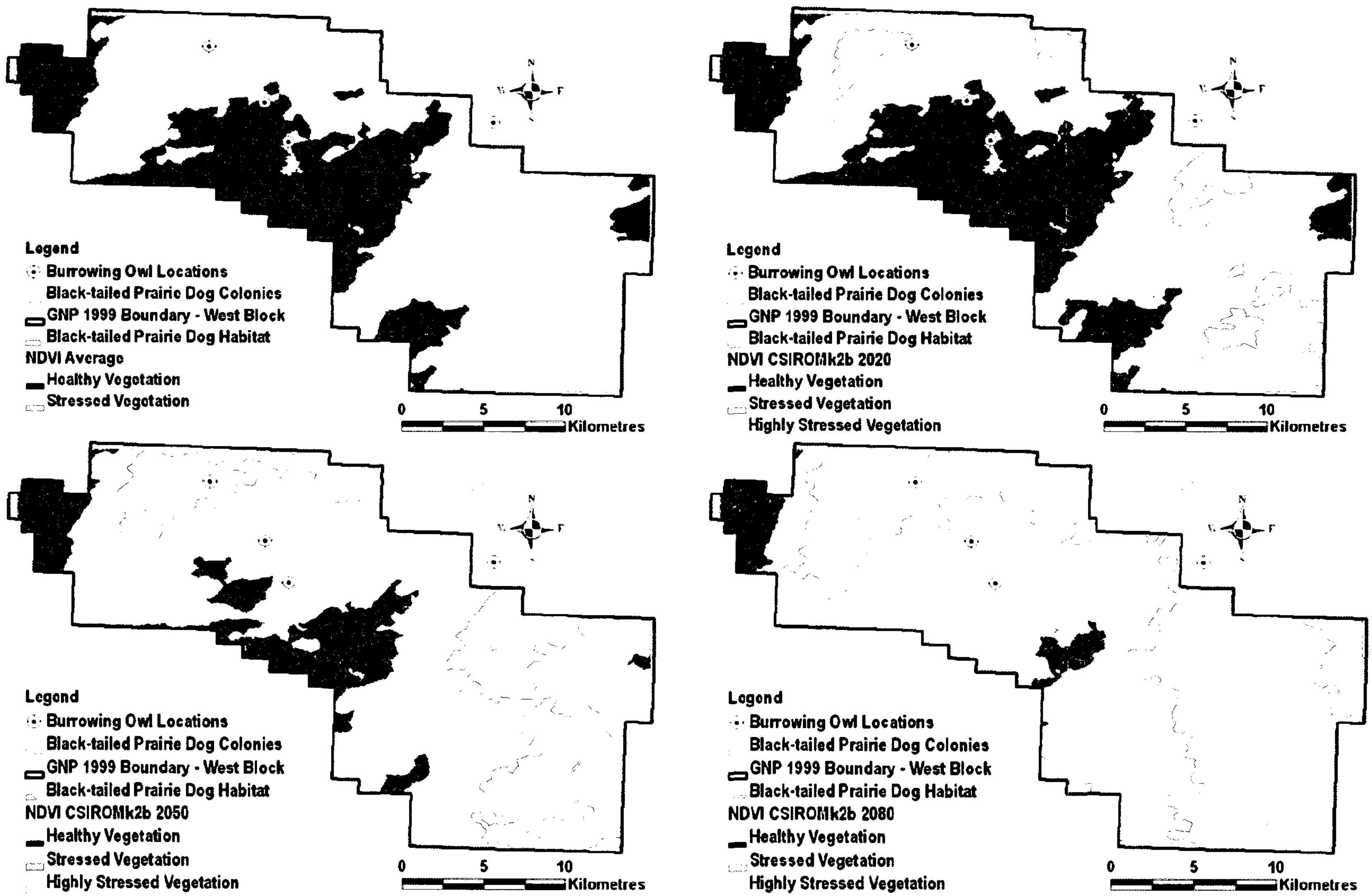


Figure 22. Risk analysis of black-tailed prairie dog and Burrowing Owl habitat and distributions for the NDVI CSIROMk2b B11 GCM vegetation change scenarios for the West Block of Grasslands National Park for 2020, 2050 and 2080.

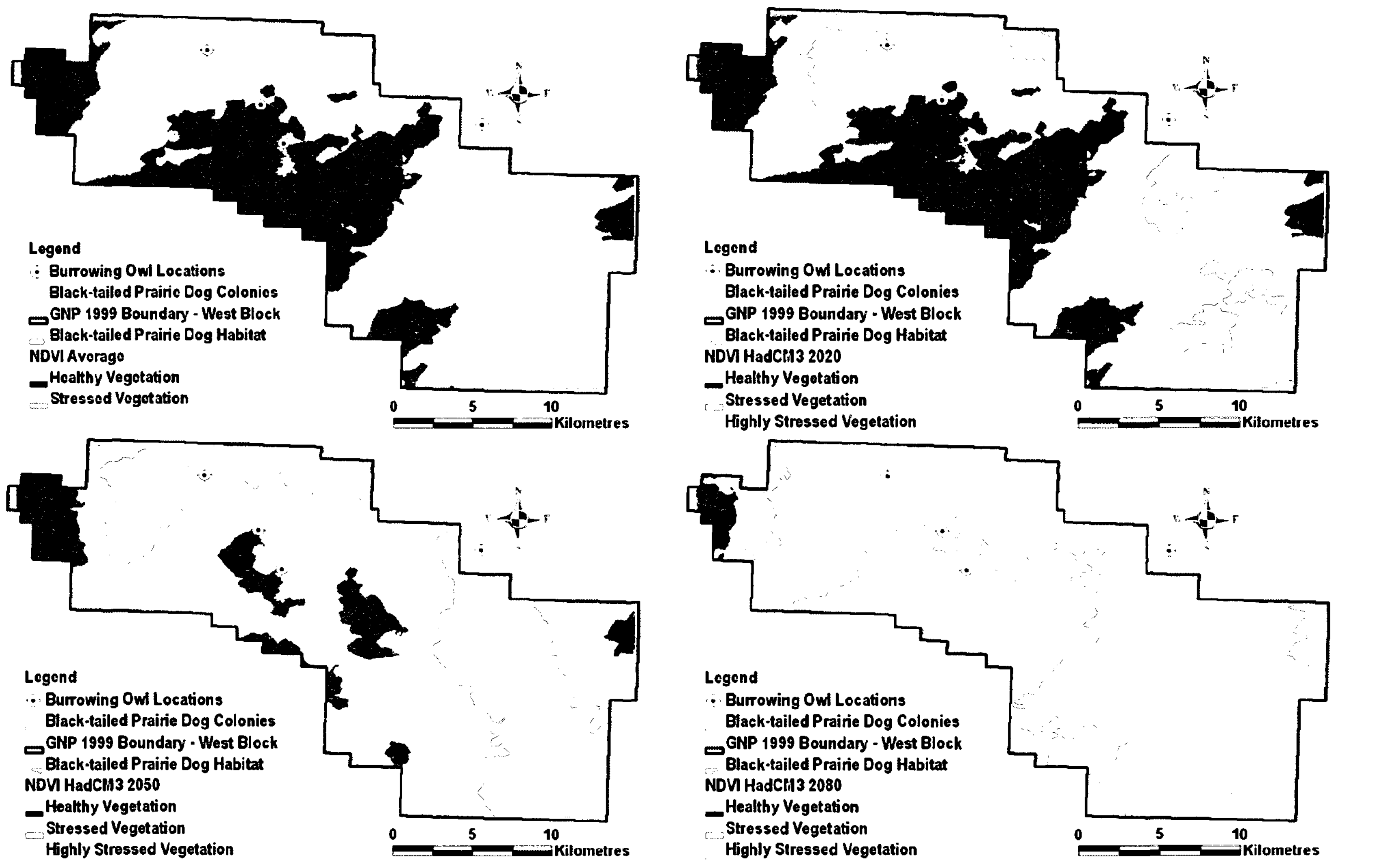


Figure 23. Risk analysis of black-tailed prairie dog and Burrowing Owl habitat and distributions for the NDVI HadCM3 B21 GCM vegetation change scenarios for the West Block of Grasslands National Park for 2020, 2050 and 2080.

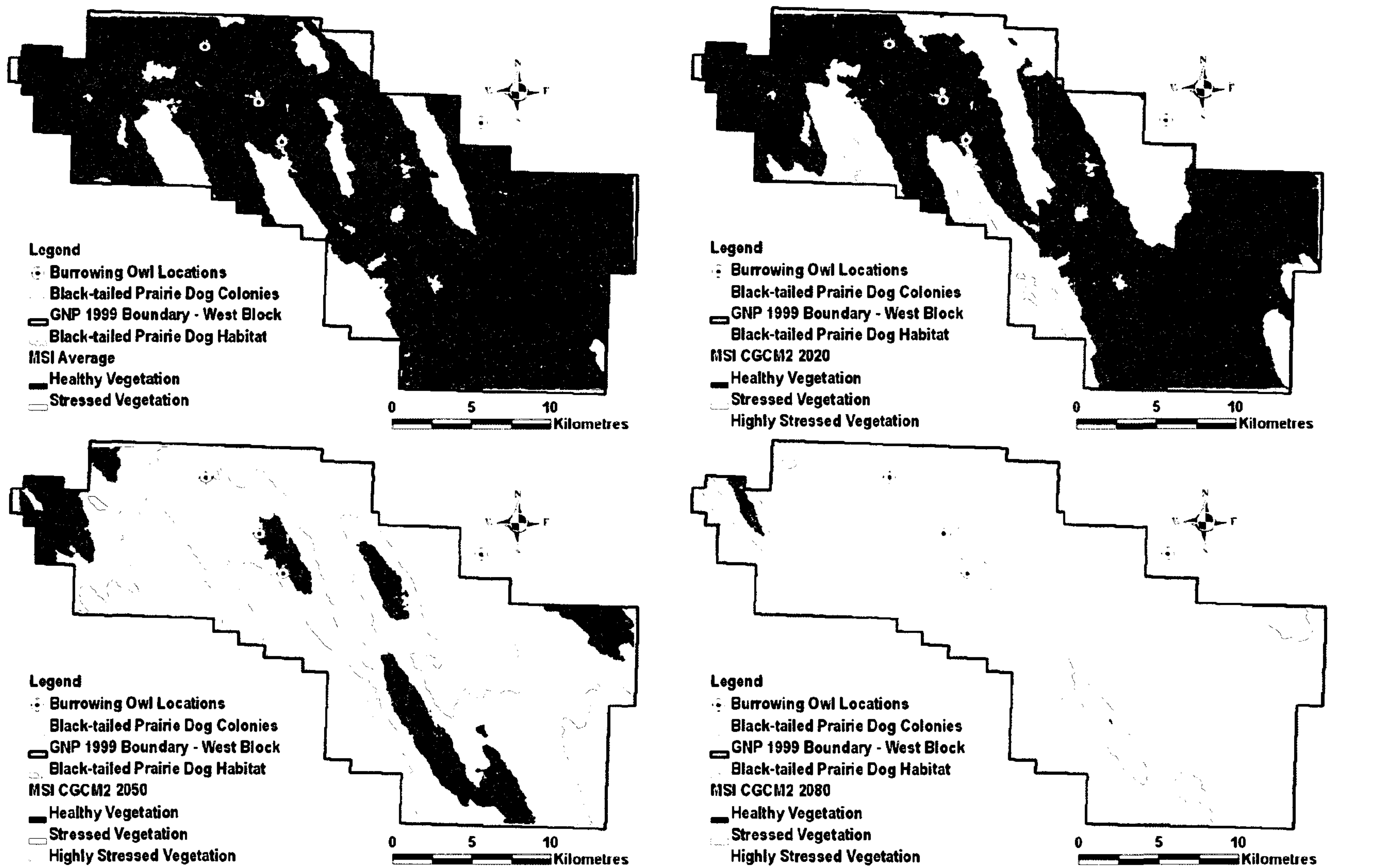


Figure 24. Risk analysis of black-tailed prairie dog and Burrowing Owl habitat and distributions for the MSI CGCM2 A21 GCM vegetation change scenarios for the West Block of Grasslands National Park for 2020, 2050 and 2080.

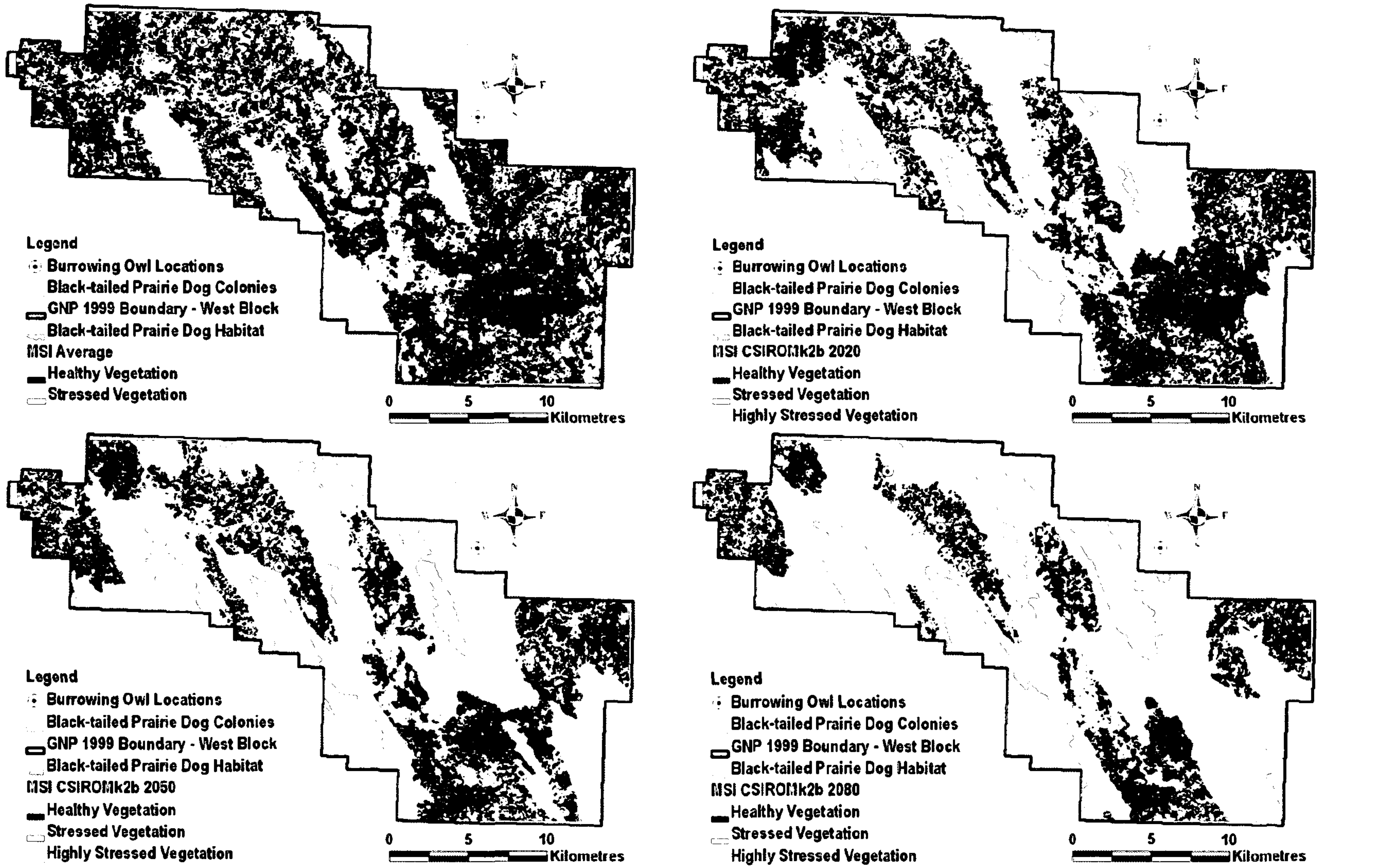


Figure 25. Risk analysis of black-tailed prairie dog and Burrowing Owl habitat and distributions for the MSI CSIROMk2b B11 GCM vegetation change scenarios for the West Block of Grasslands National Park for 2020, 2050 and 2080.

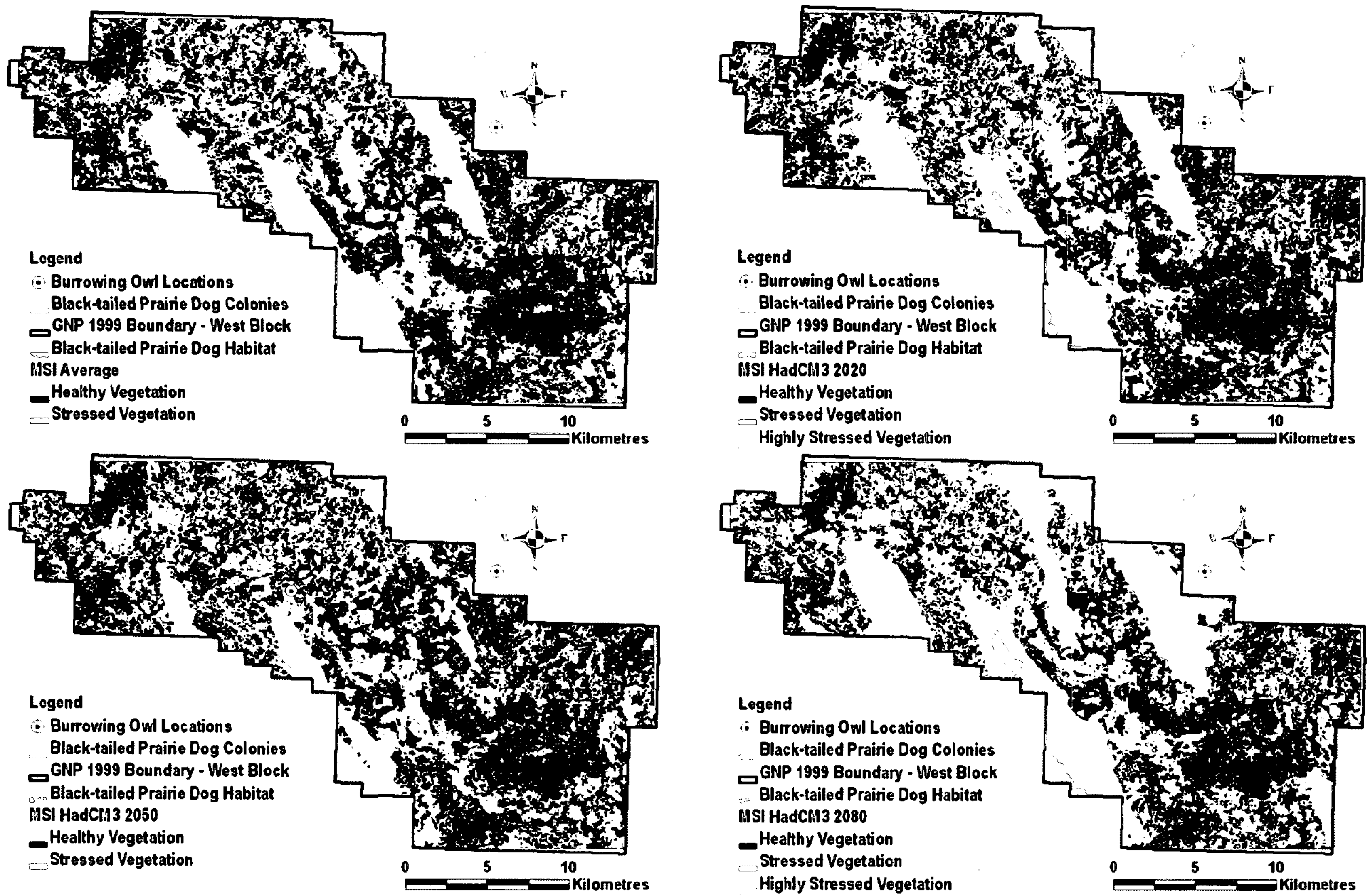


Figure 26. Risk analysis of black-tailed prairie dog and Burrowing Owl habitat and distributions for the MSI HadCM3 B21 GCM vegetation change scenarios for the West Block of Grasslands National Park for 2020, 2050 and 2080.

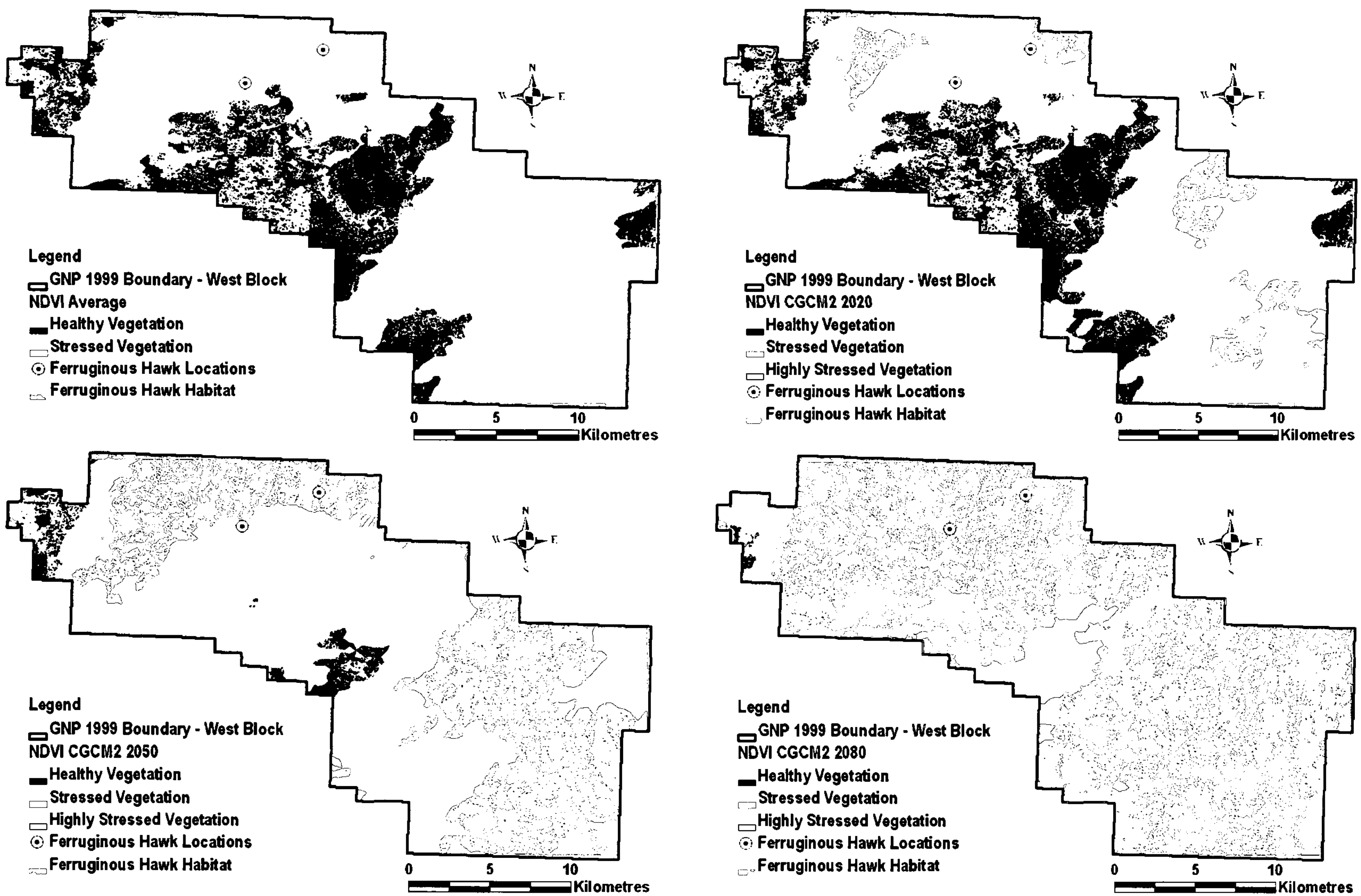


Figure 27. Risk analysis of Ferruginous Hawk habitat and distributions for the NDVI CGCM2 A21 GCM vegetation change scenarios for the West Block of Grasslands National Park for 2020, 2050 and 2080.

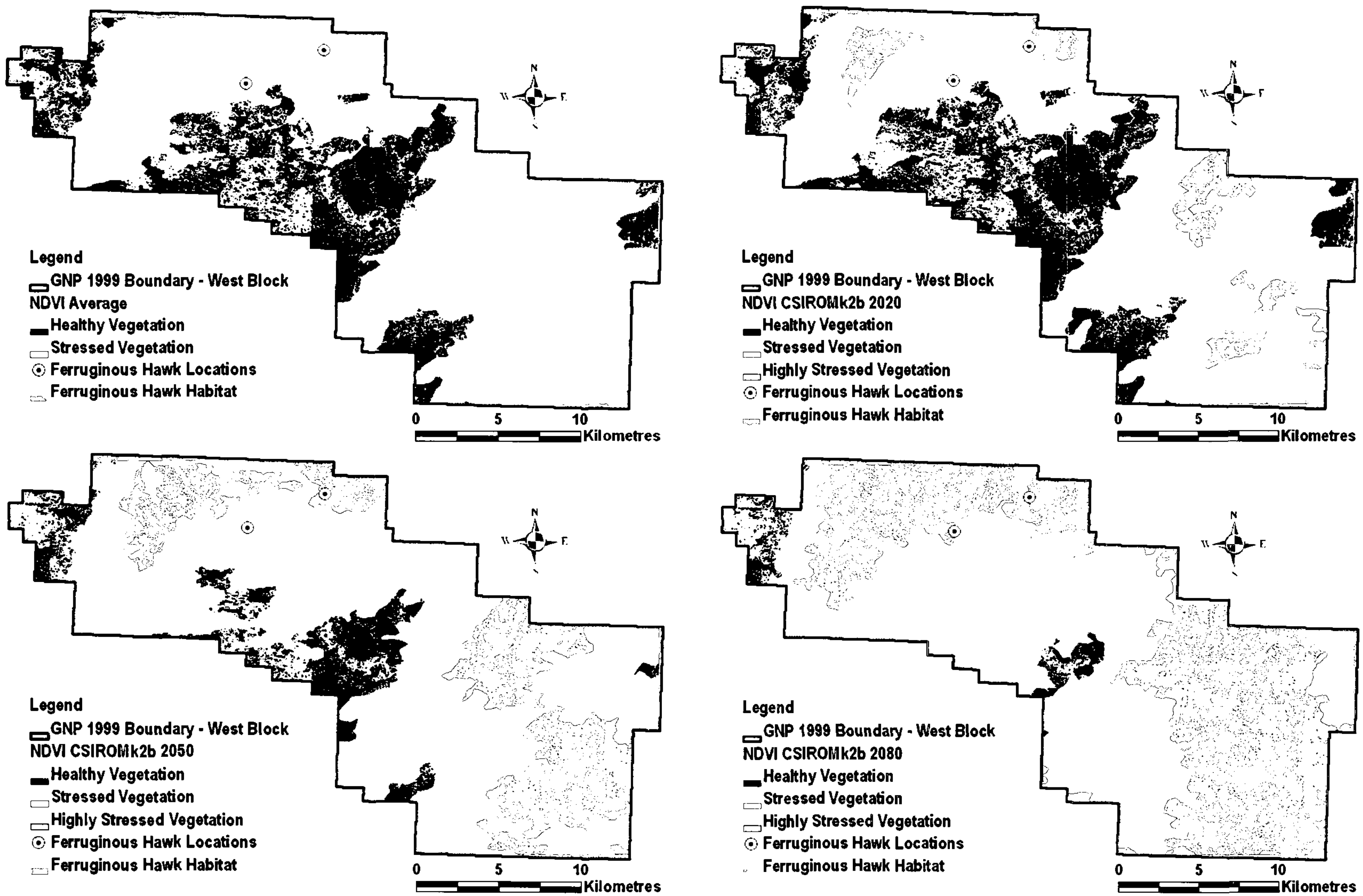


Figure 28. Risk analysis of Ferruginous Hawk habitat and distributions for the NDVI CSIROMk2b B11 GCM vegetation change scenarios for the West Block of Grasslands National Park for 2020, 2050 and 2080.

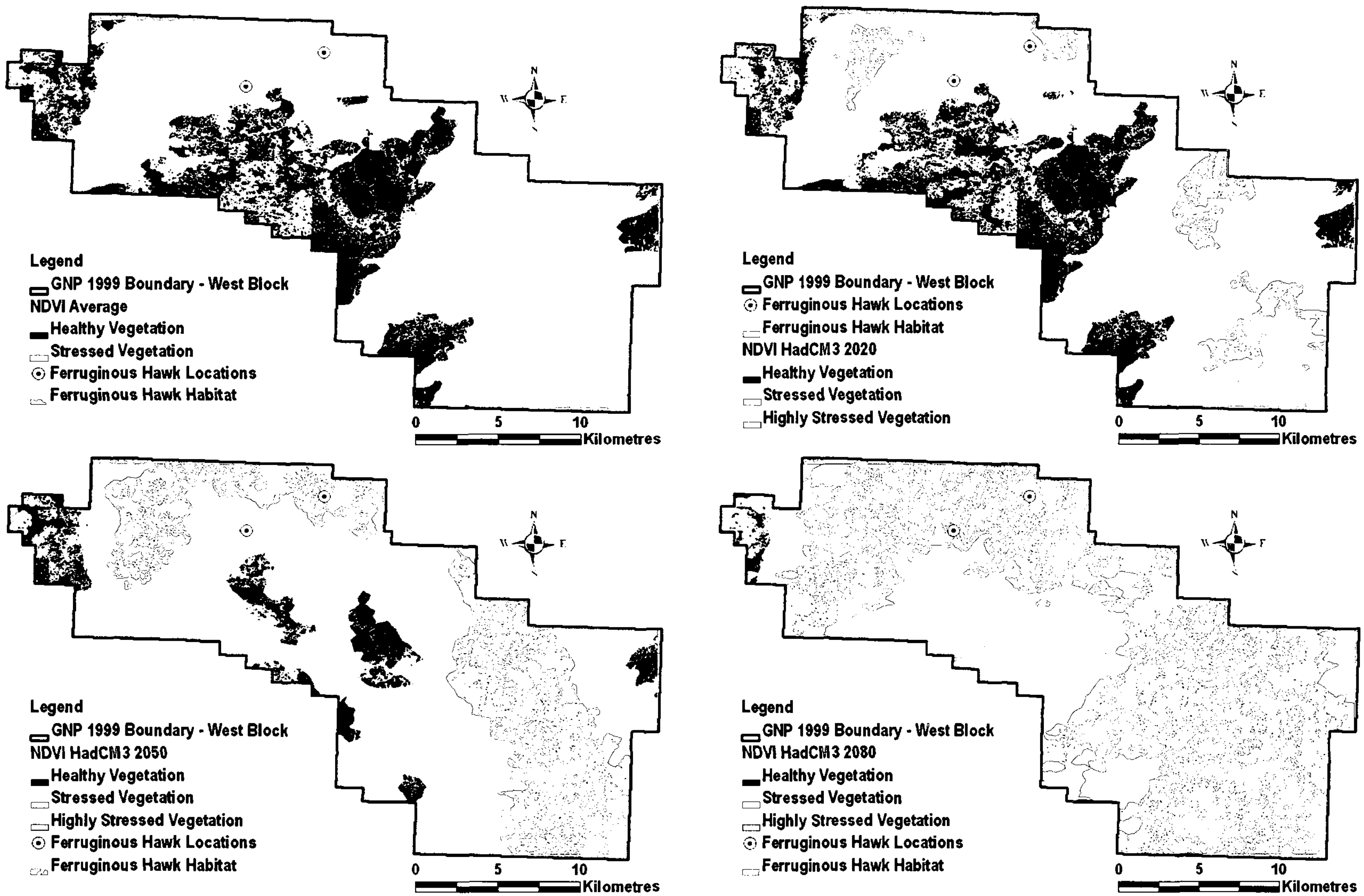


Figure 29. Risk analysis of Ferruginous Hawk habitat and distributions for the NDVI HadCM3 B21 GCM vegetation change scenarios for the West Block of Grasslands National Park for 2020, 2050 and 2080.

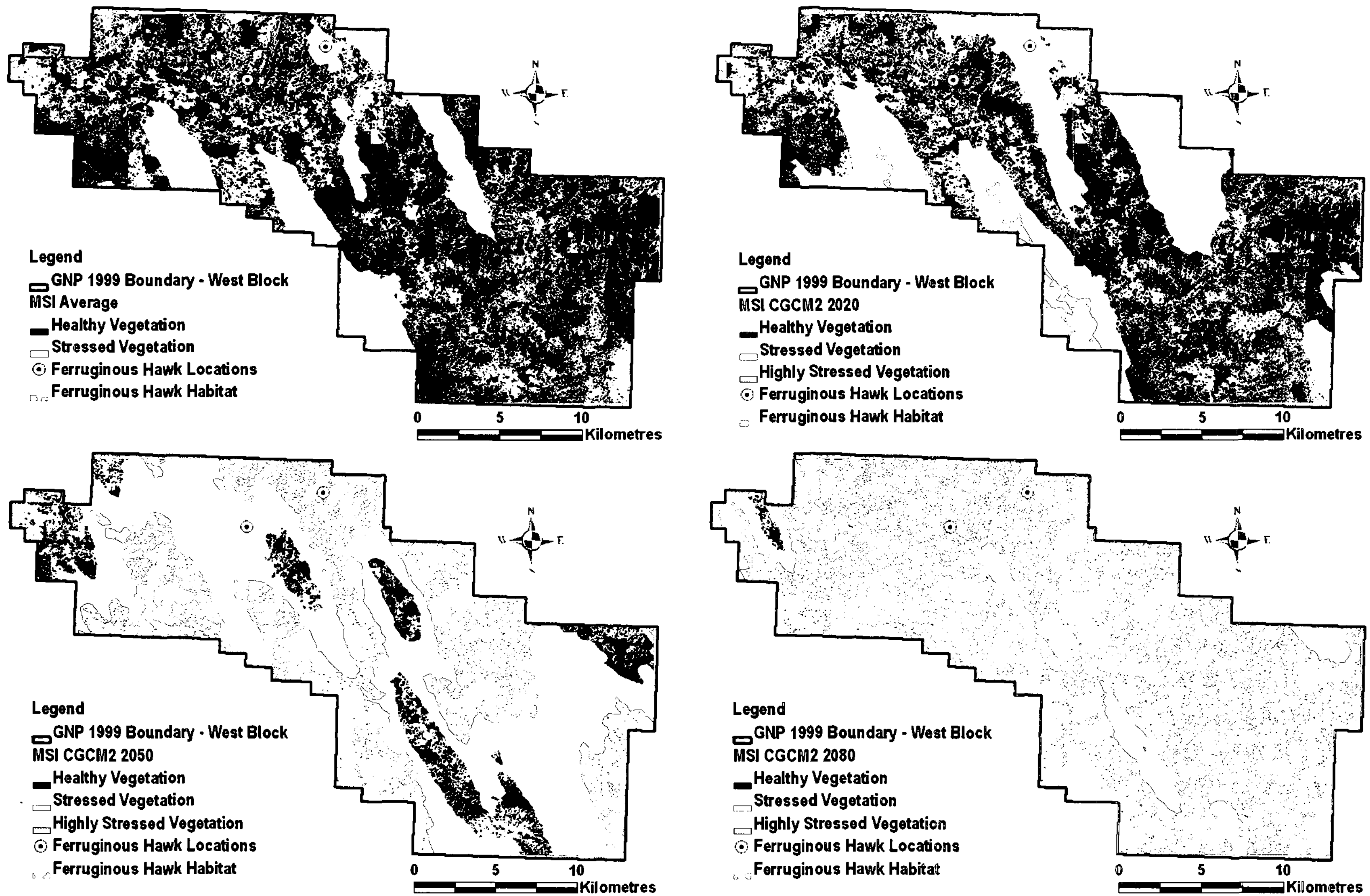


Figure 30. Risk analysis of Ferruginous Hawk habitat and distributions for the MSI CGCM2 A21 GCM vegetation change scenarios for the West Block of Grasslands National Park for 2020, 2050 and 2080.

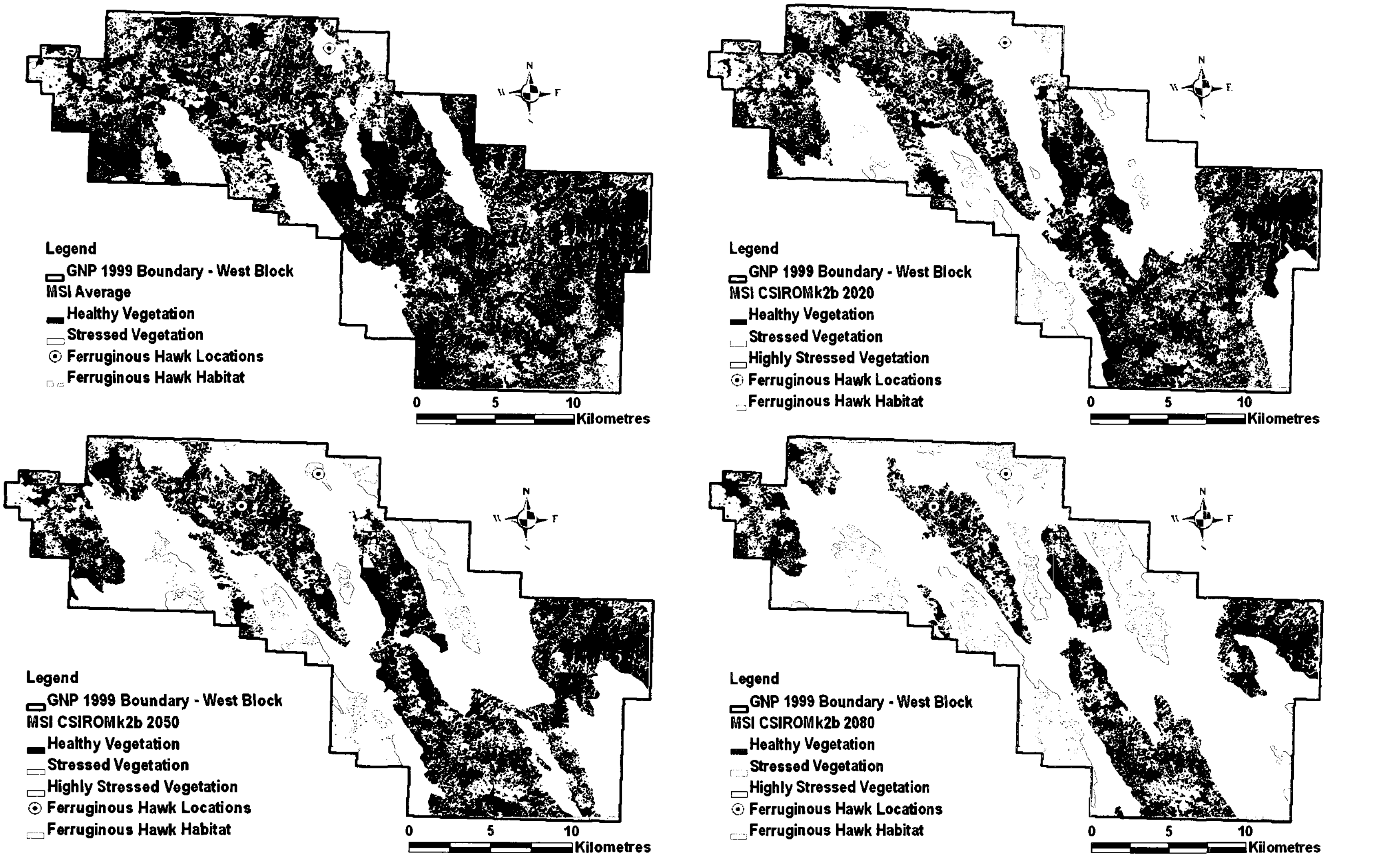


Figure 31. Risk analysis of Ferruginous Hawk habitat and distributions for the MSI CSIROMk2b B11 GCM vegetation change scenarios for the West Block of Grasslands National Park for 2020, 2050 and 2080.

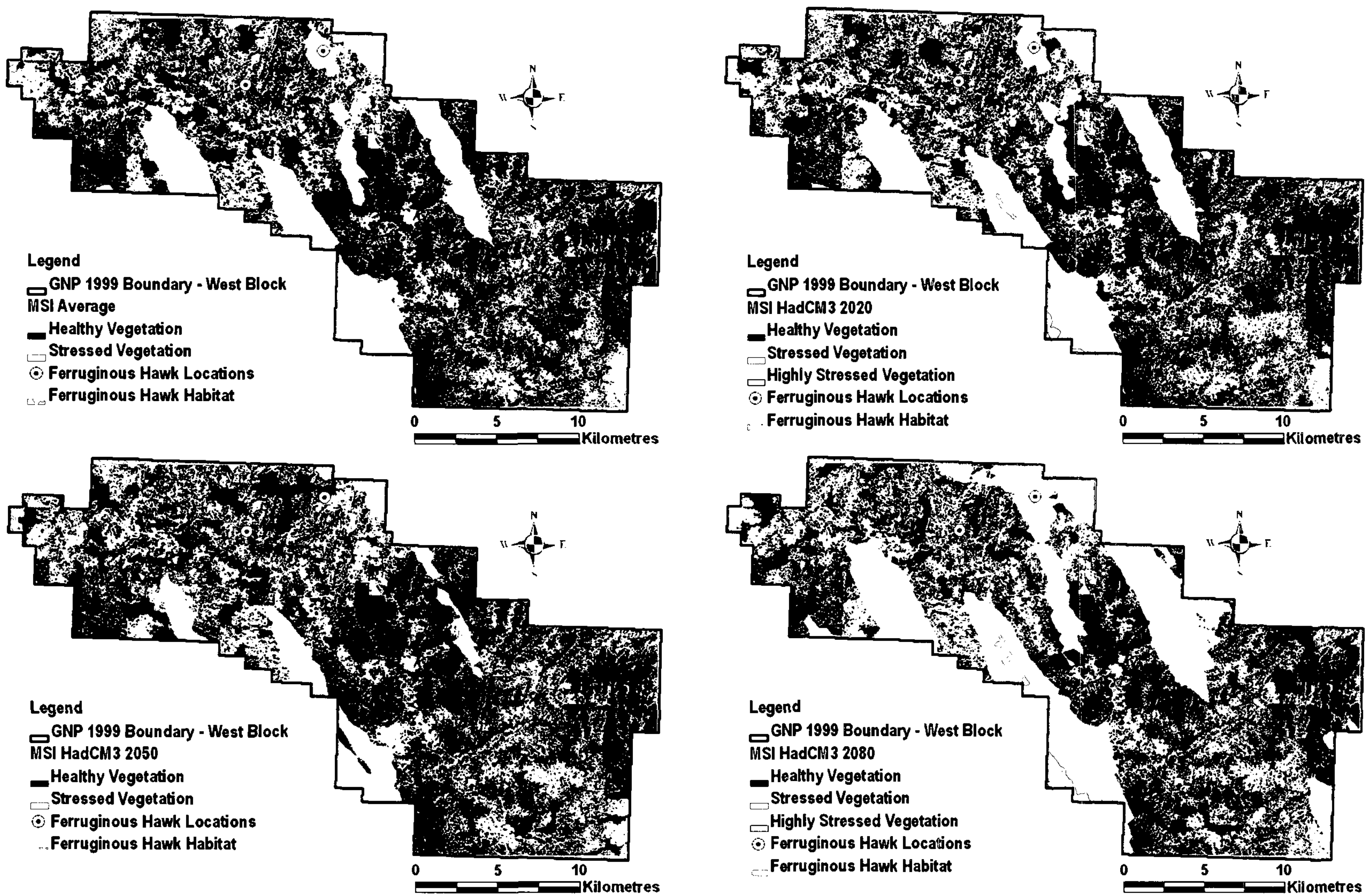


Figure 32. Risk analysis of Ferruginous Hawk habitat and distributions for the MSI HadCM3 B21 GCM vegetation change scenarios for the West Block of Grasslands National Park for 2020, 2050 and 2080.

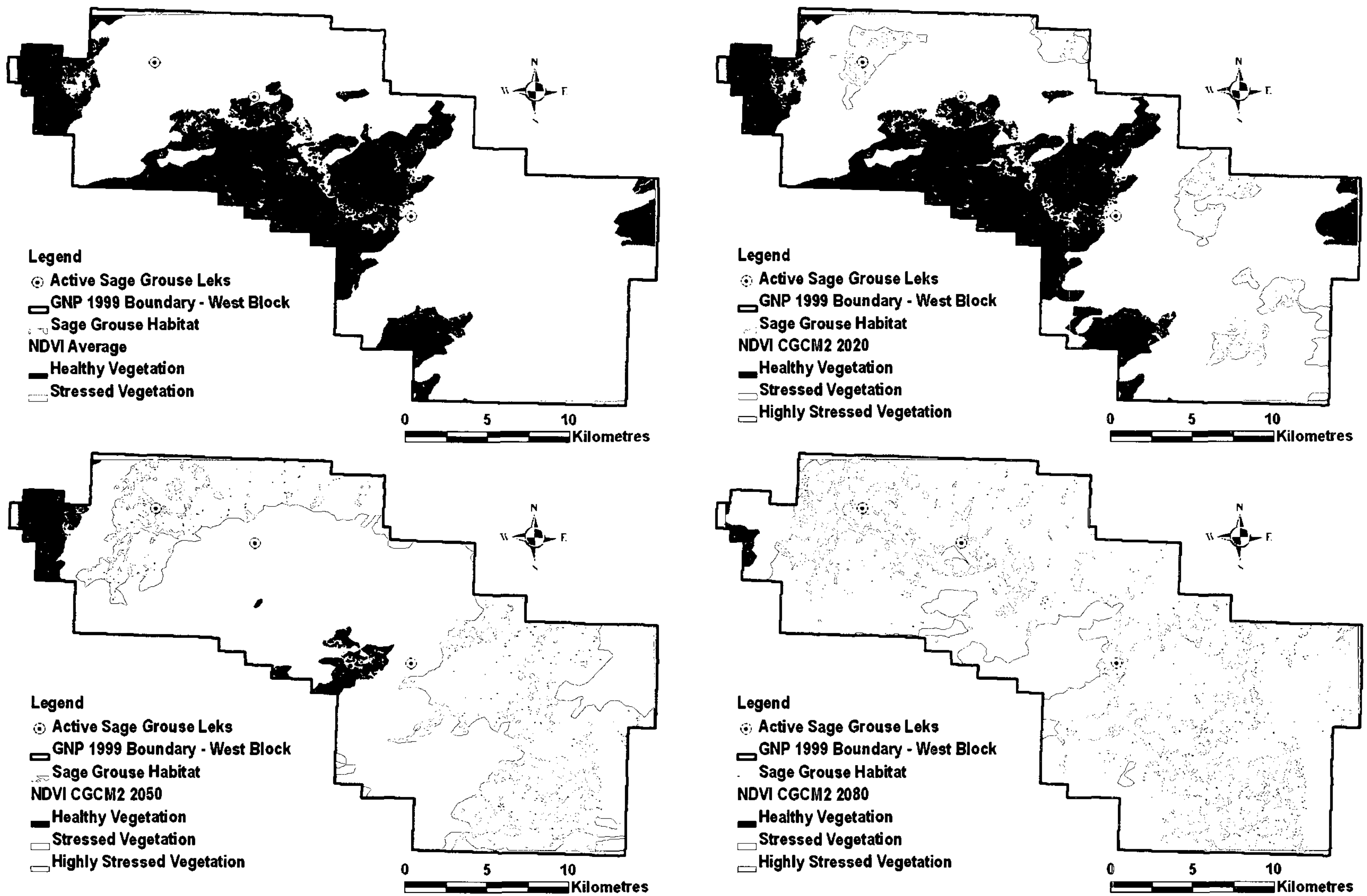


Figure 33. Risk analysis of Greater Sage Grouse habitat and distributions for the NDVI CGCM2 A21 GCM vegetation change scenarios for the West Block of Grasslands National Park for 2020, 2050 and 2080.

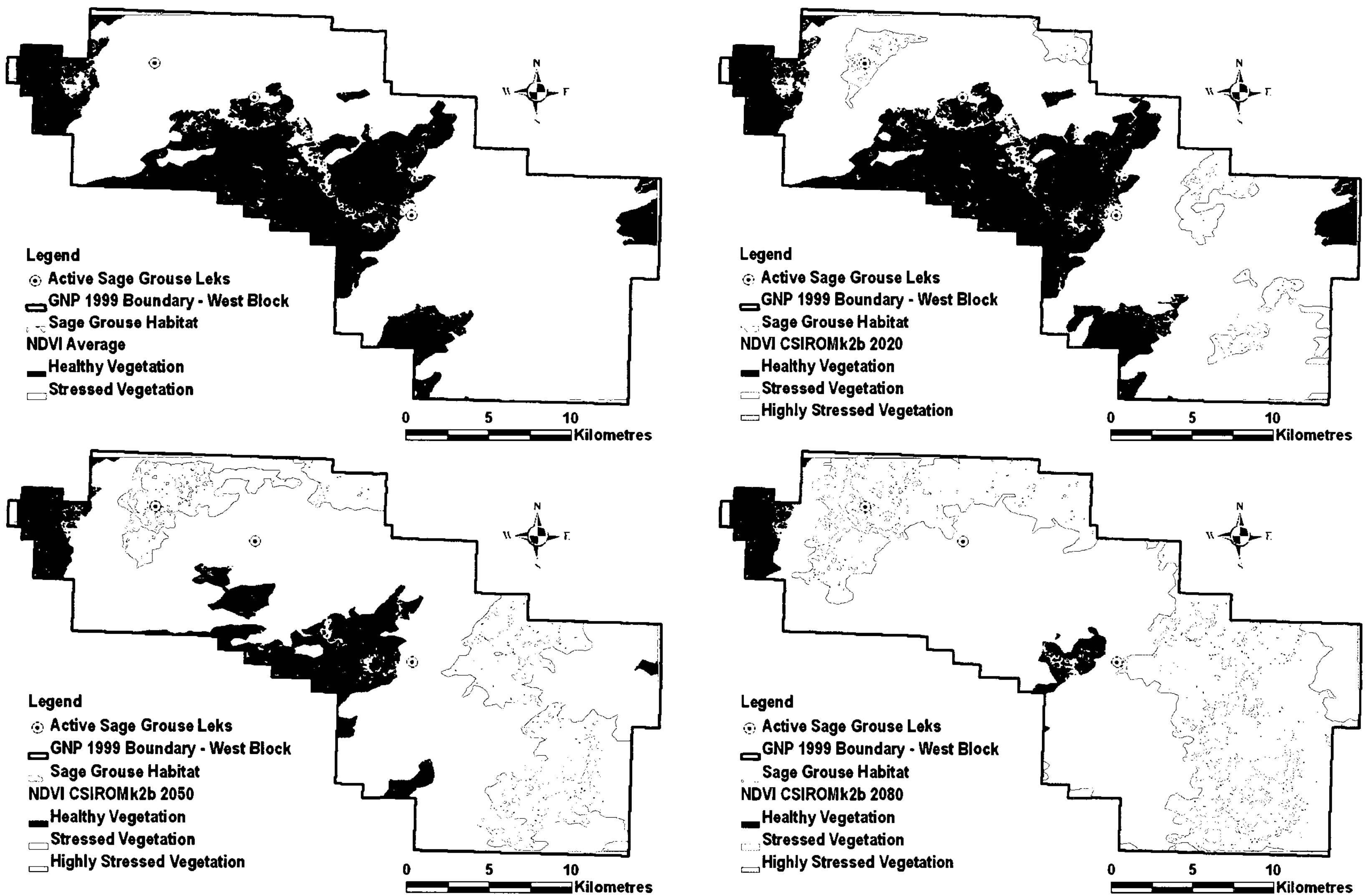


Figure 34. Risk analysis of Greater Sage Grouse habitat and distributions for the NDVI CSIROMk2b B11 GCM vegetation change scenarios for the West Block of Grasslands National Park for 2020, 2050 and 2080.

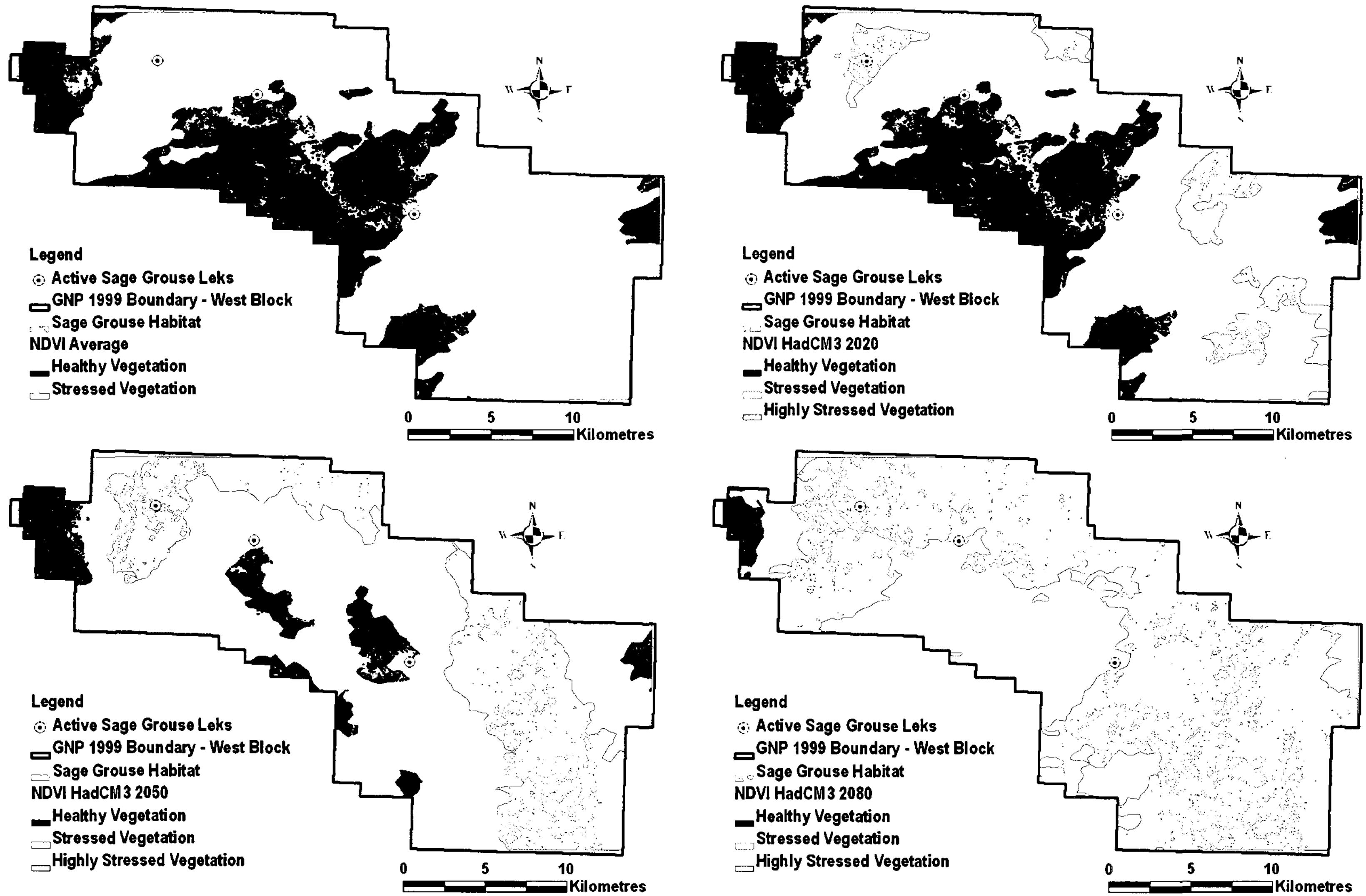


Figure 35. Risk analysis of Greater Sage Grouse habitat and distributions for the NDVI HadCM3 B21 GCM vegetation change scenarios for the West Block of Grasslands National Park for 2020, 2050 and 2080.

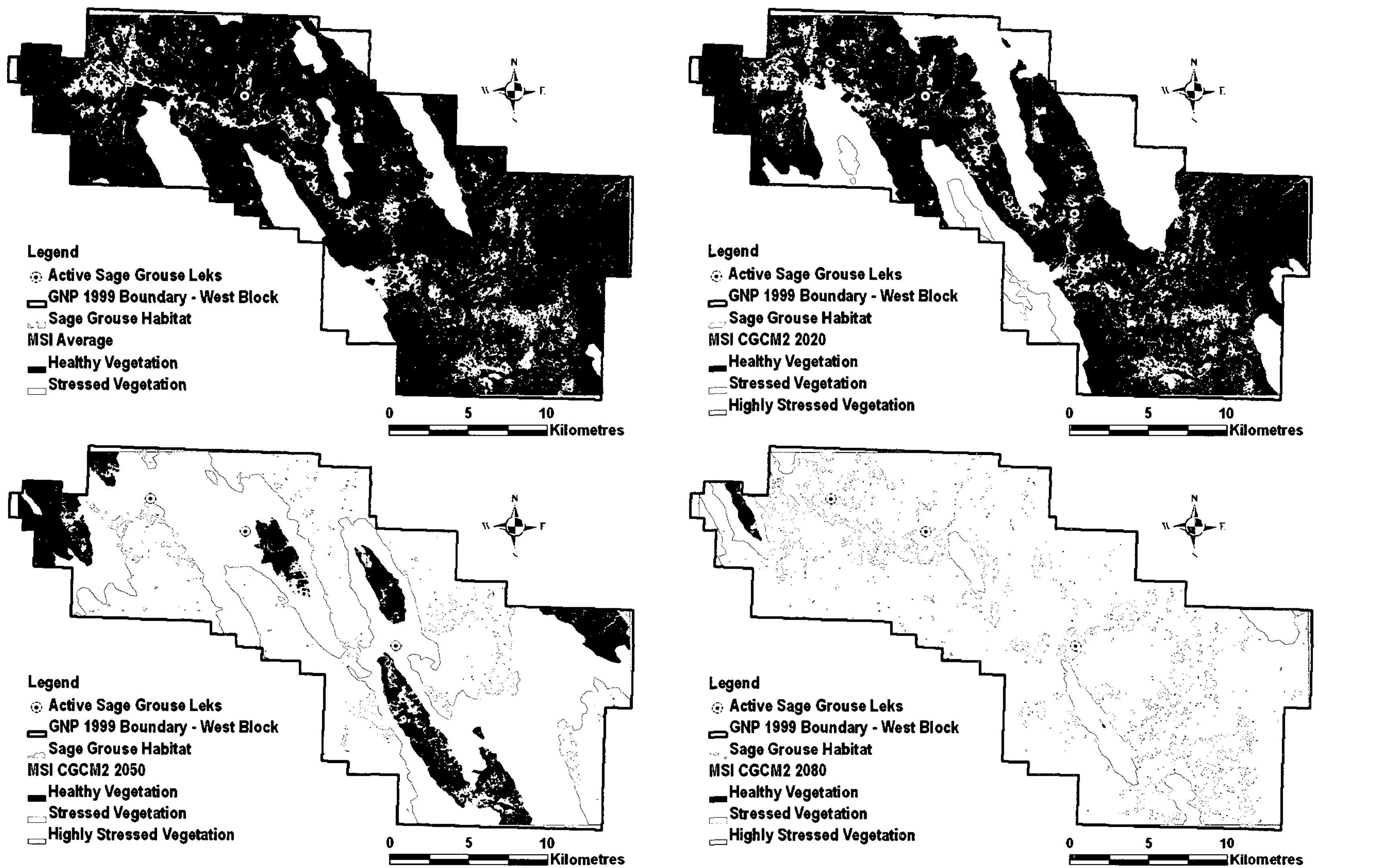


Figure 36. Risk analysis of Greater Sage Grouse habitat and distributions for the MSI CGCM2 A21 GCM vegetation change scenarios for the West Block of Grasslands National Park for 2020, 2050 and 2080.

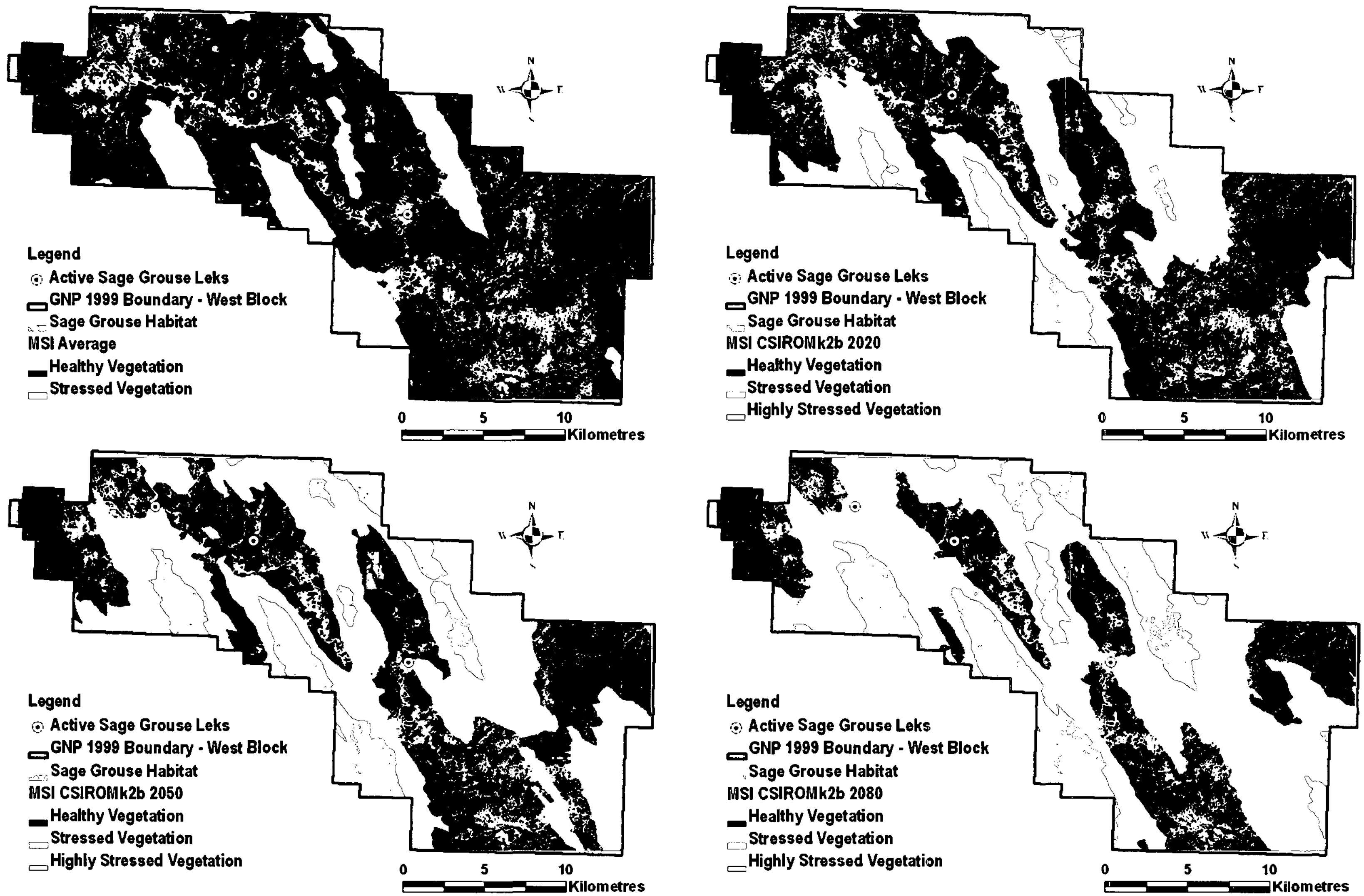


Figure 37. Risk analysis of Greater Sage Grouse habitat and distributions for the MSI CSIROMk2b B11 GCM vegetation change scenarios for the West Block of Grasslands National Park for 2020, 2050 and 2080.

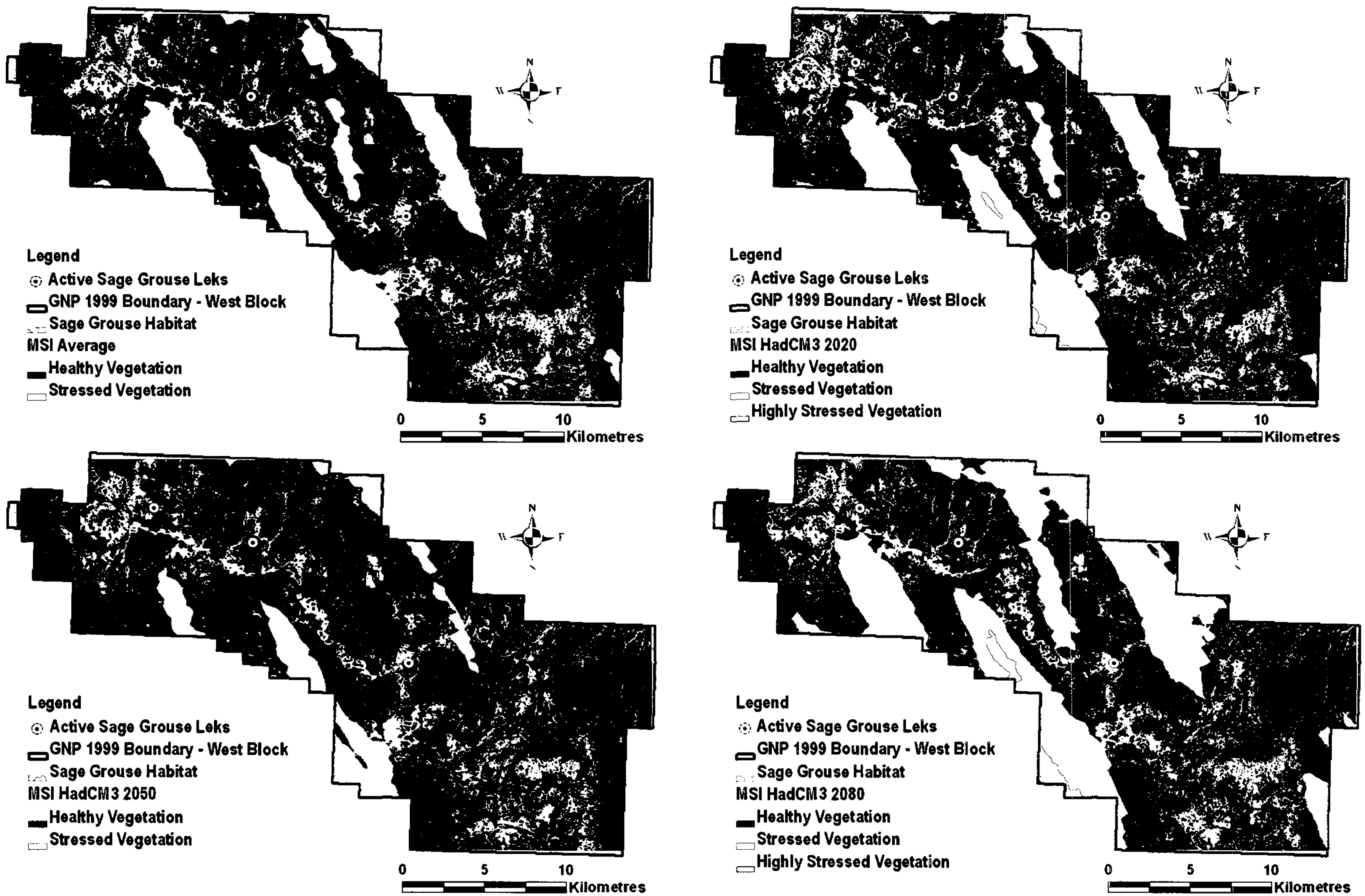


Figure 38. Risk analysis of Greater Sage Grouse habitat and distributions for the MSI HadCM3 B21 GCM vegetation change scenarios for the West Block of Grasslands National Park for 2020, 2050 and 2080.

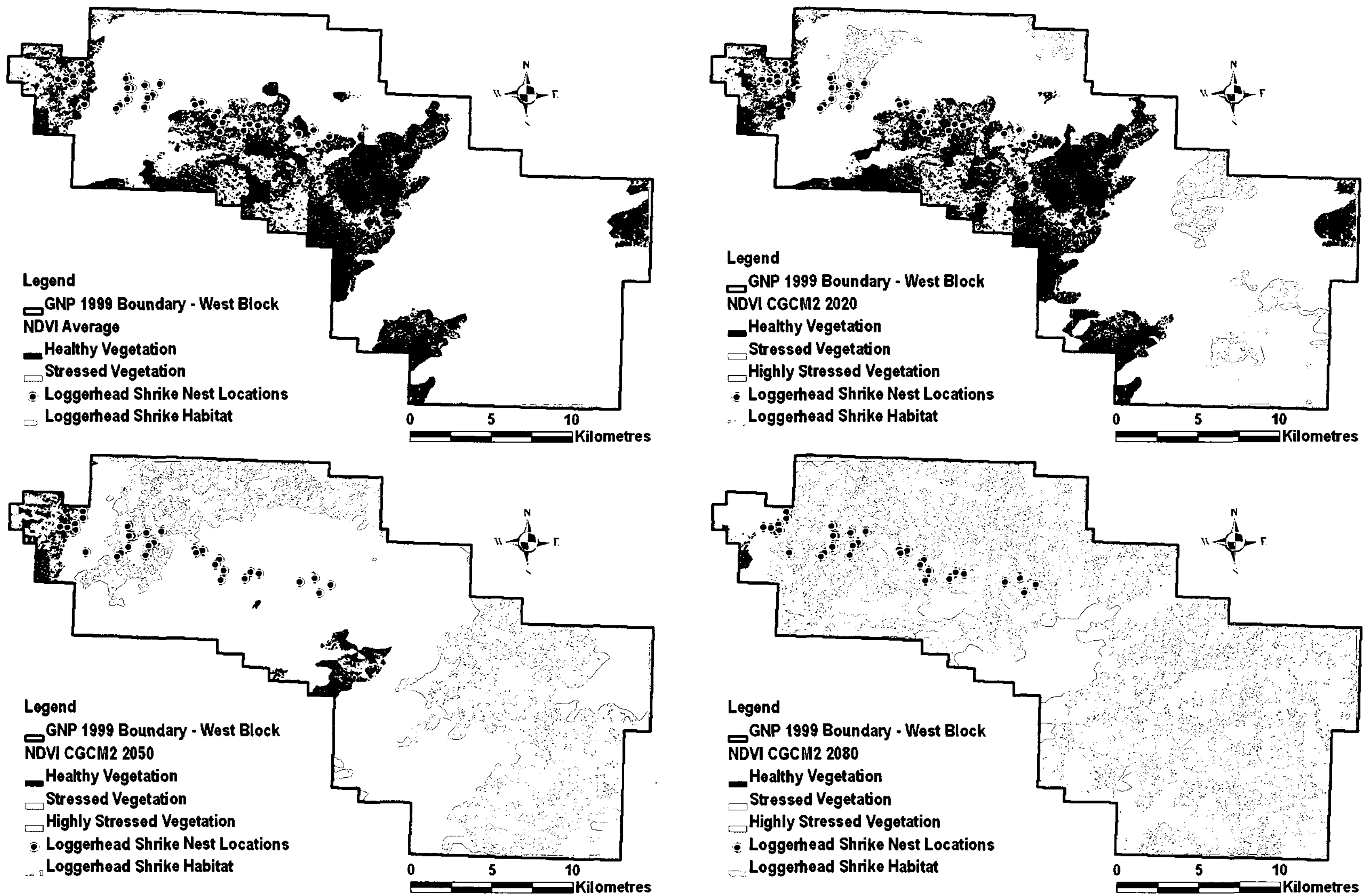


Figure 39. Risk analysis of Loggerhead Shrike habitat and distributions for the NDVI CGCM2 A21 GCM vegetation change scenarios for the West Block of Grasslands National Park for 2020, 2050 and 2080.

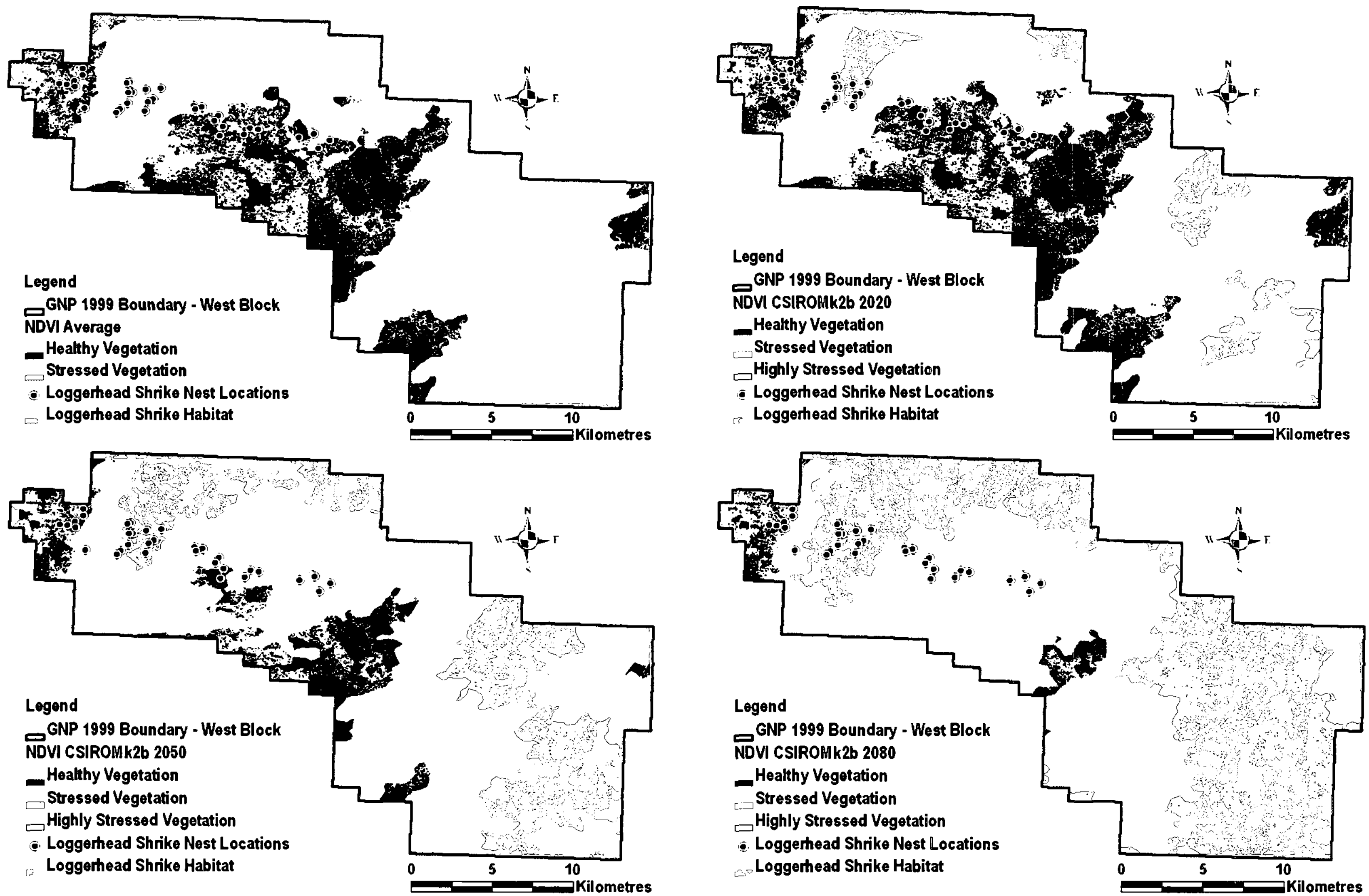
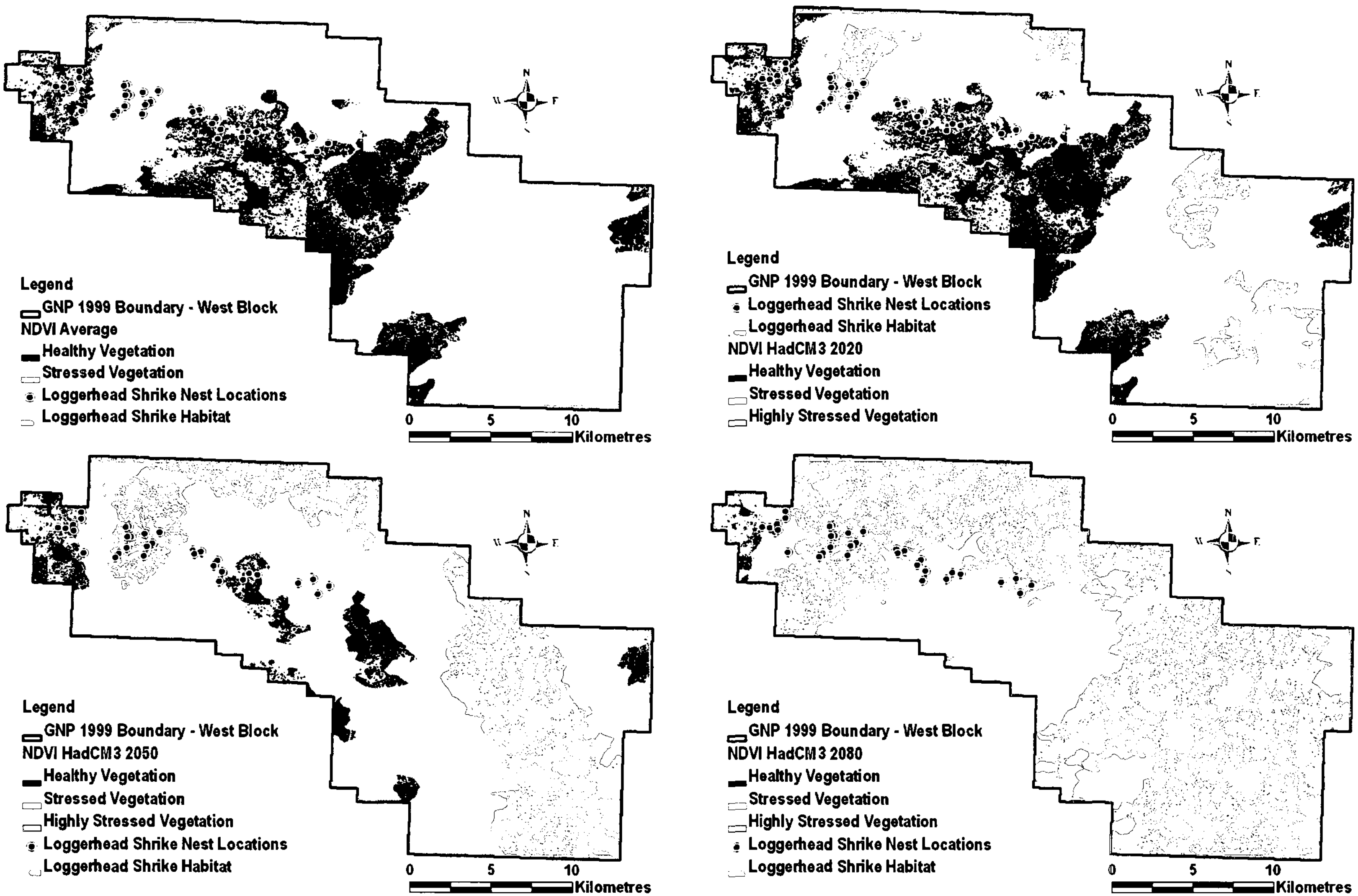


Figure 40. Risk analysis of Loggerhead Shrike habitat and distributions for the NDVI CSRIOMk2b B11 GCM vegetation change scenarios for the West Block of Grasslands National Park for 2020, 2050 and 2080.



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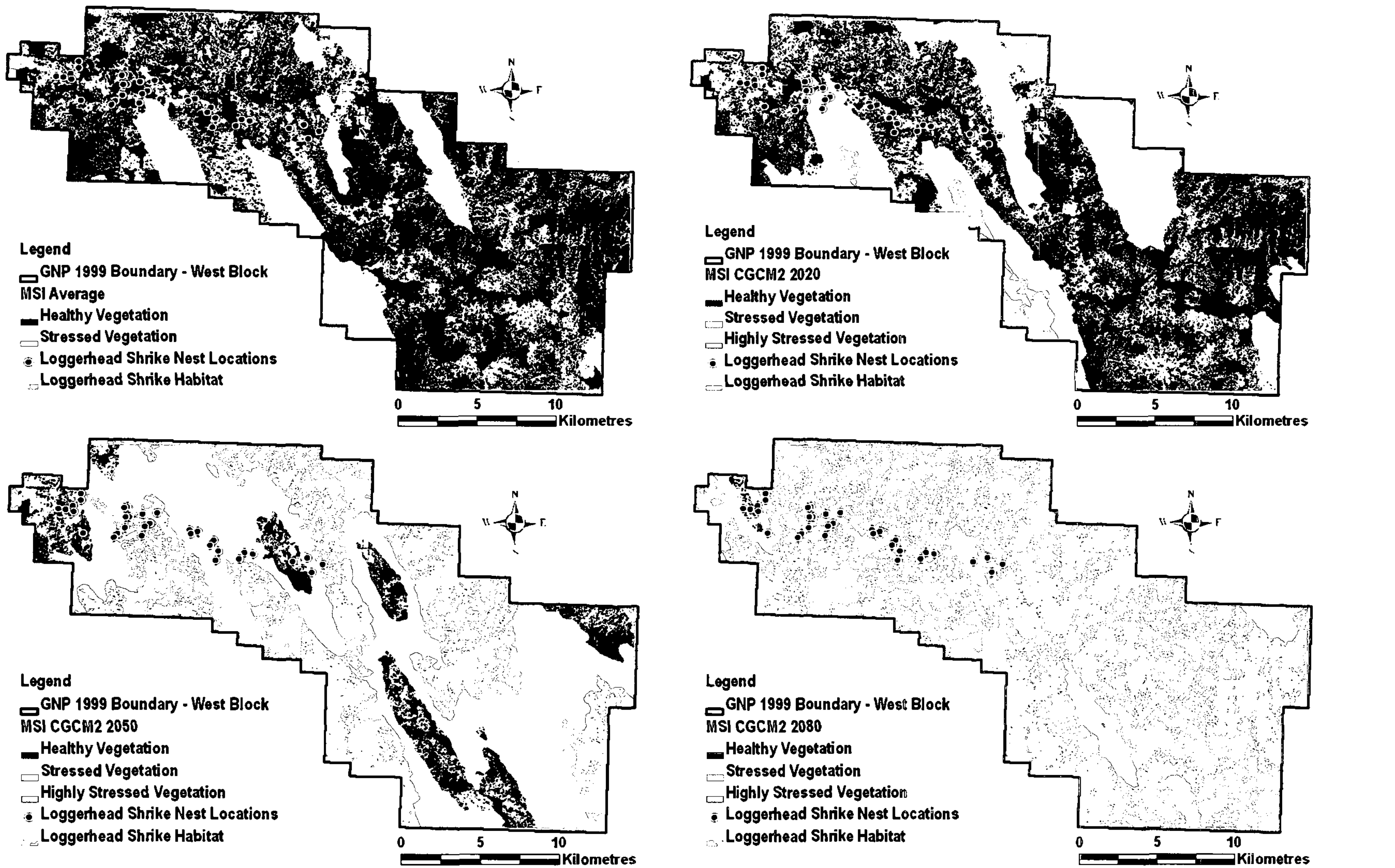

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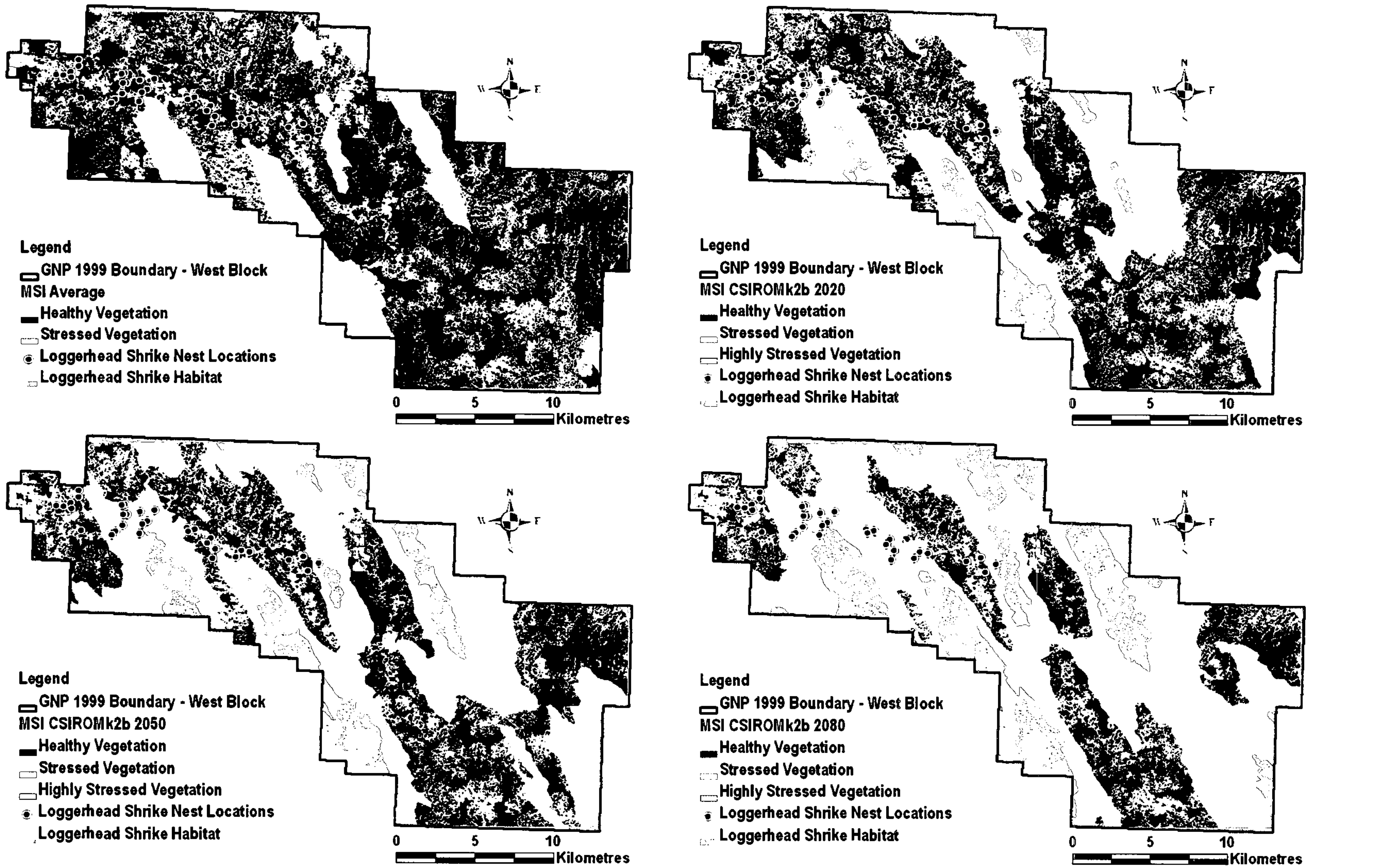


Figure 43. Risk analysis of Loggerhead Shrike habitat and distributions for the MSI CSRIOMk2b B11 GCM vegetation change scenarios for the West Block of Grasslands National Park for 2020, 2050 and 2080.

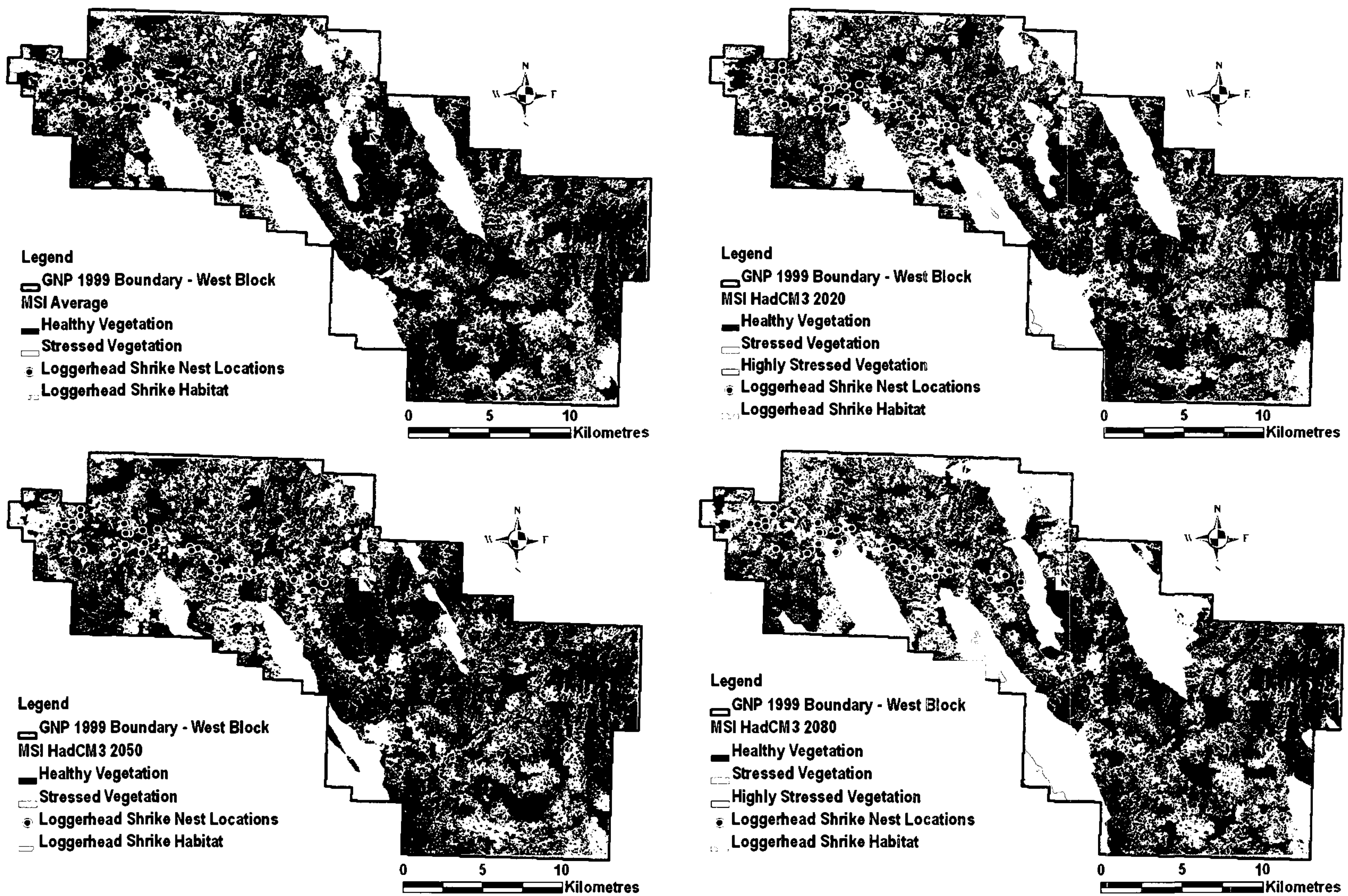


Figure 44. Risk analysis of Loggerhead Shrike habitat and distributions for the MSI HadCM3 B21 GCM vegetation change scenarios for the West Block of Grasslands National Park for 2020, 2050 and 2080.

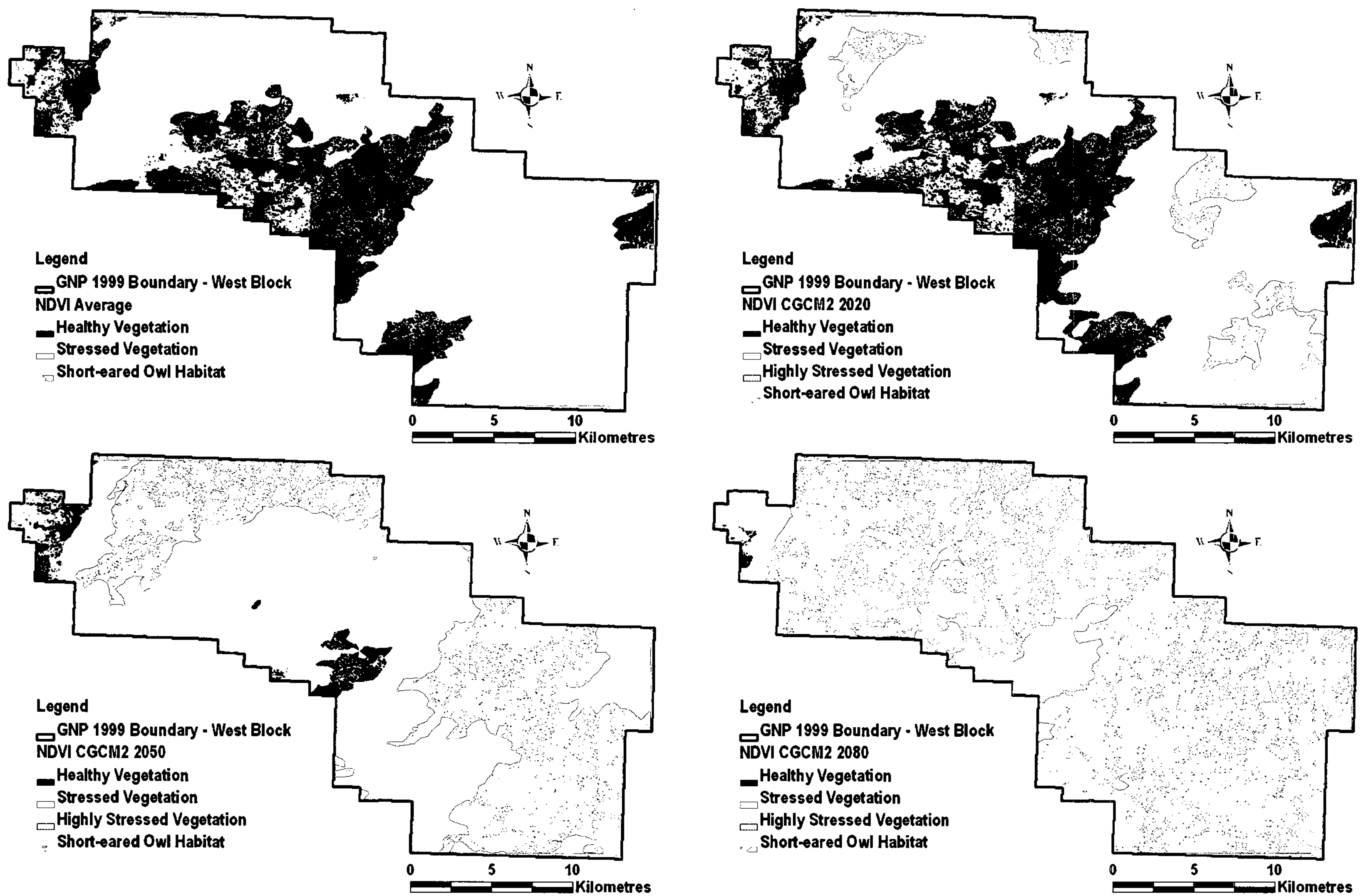


Figure 45. Risk analysis of Short-eared Owl habitat for the NDVI CGCM2 A21 GCM vegetation change scenarios for the West Block of Grasslands National Park for 2020, 2050 and 2080.

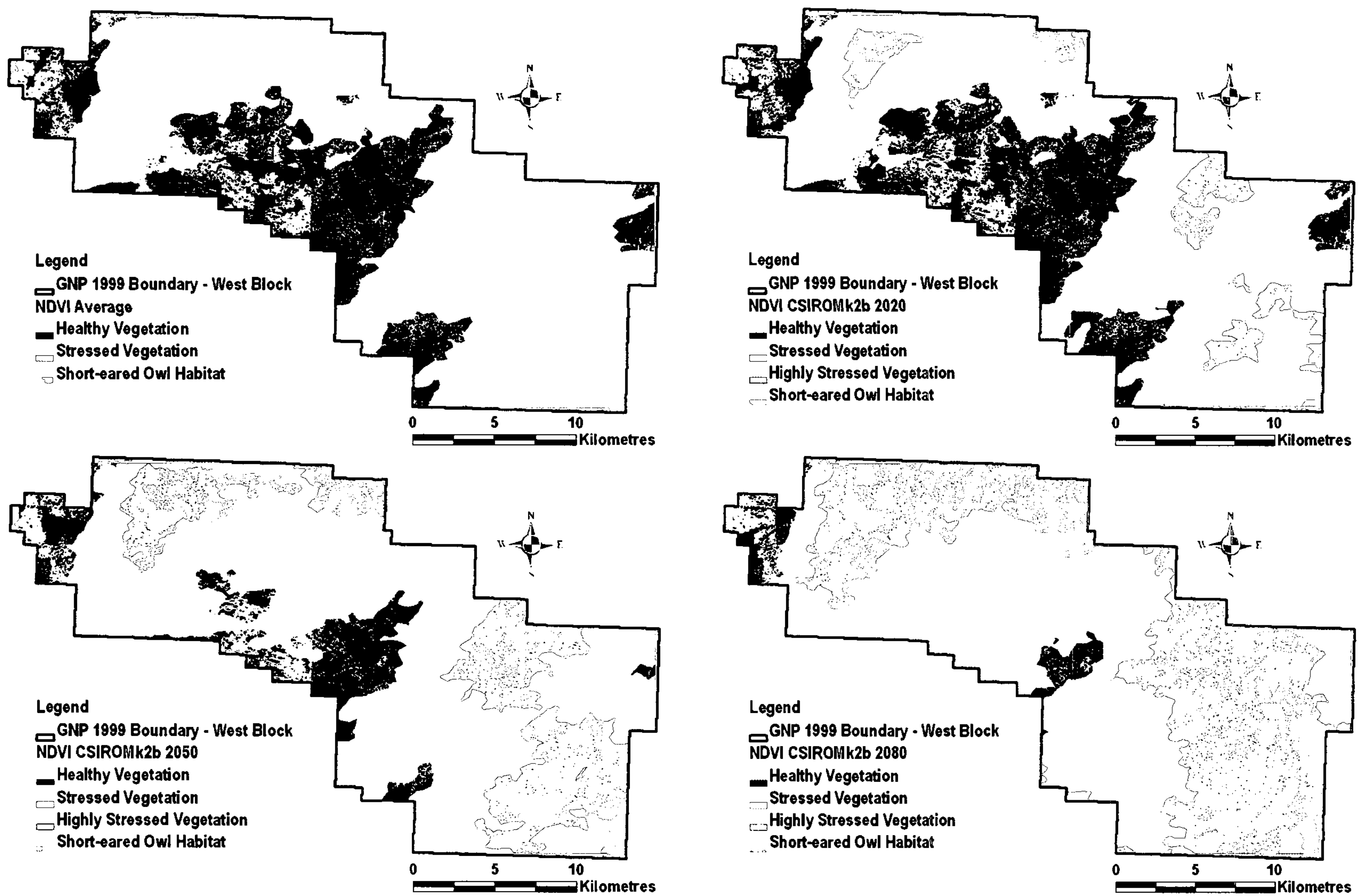
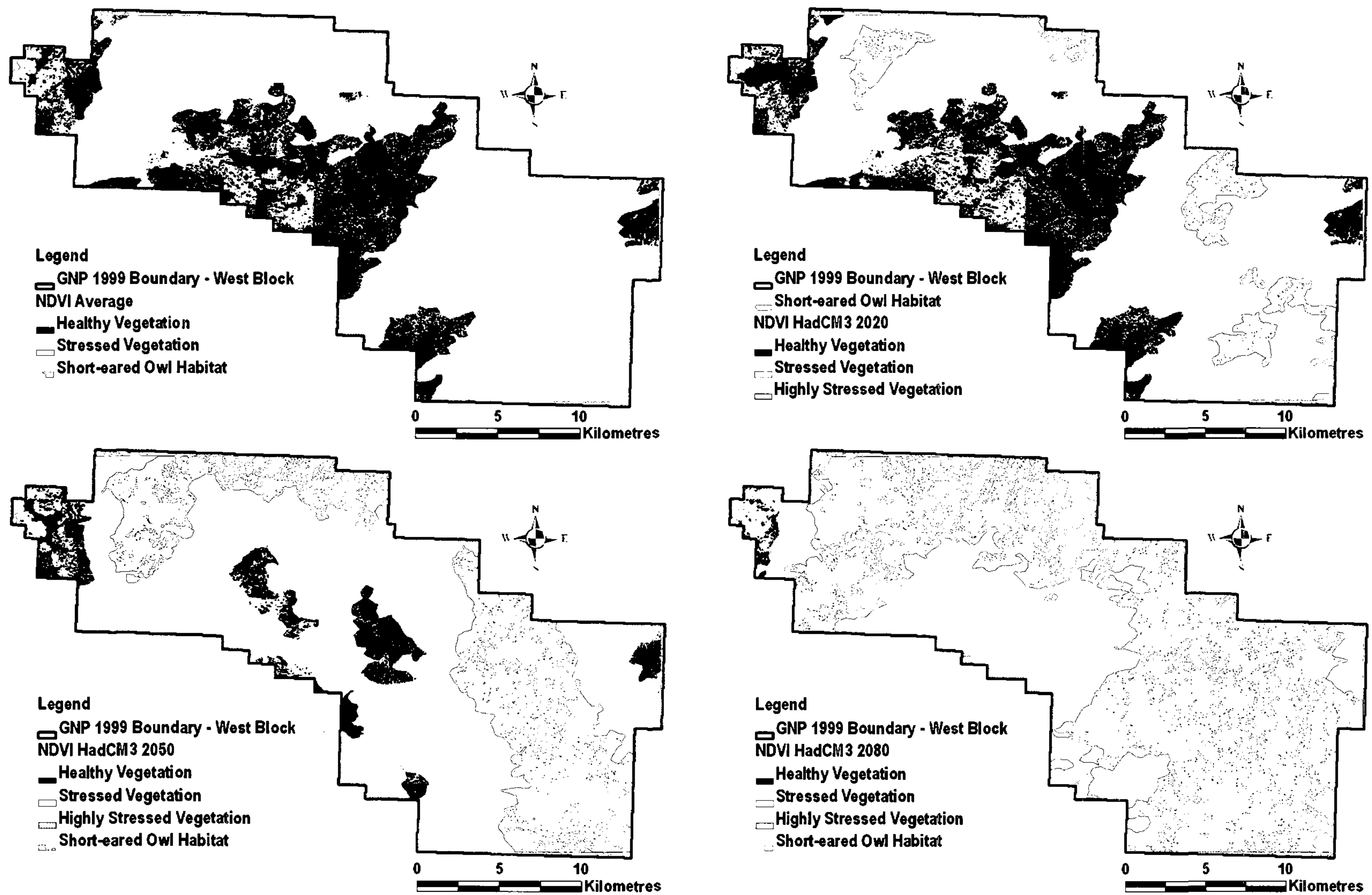


Figure 46. Risk analysis of Short-eared Owl habitat for the NDVI CSIROMk2b B11 GCM vegetation change scenarios for the West Block of Grasslands National Park for 2020, 2050 and 2080.



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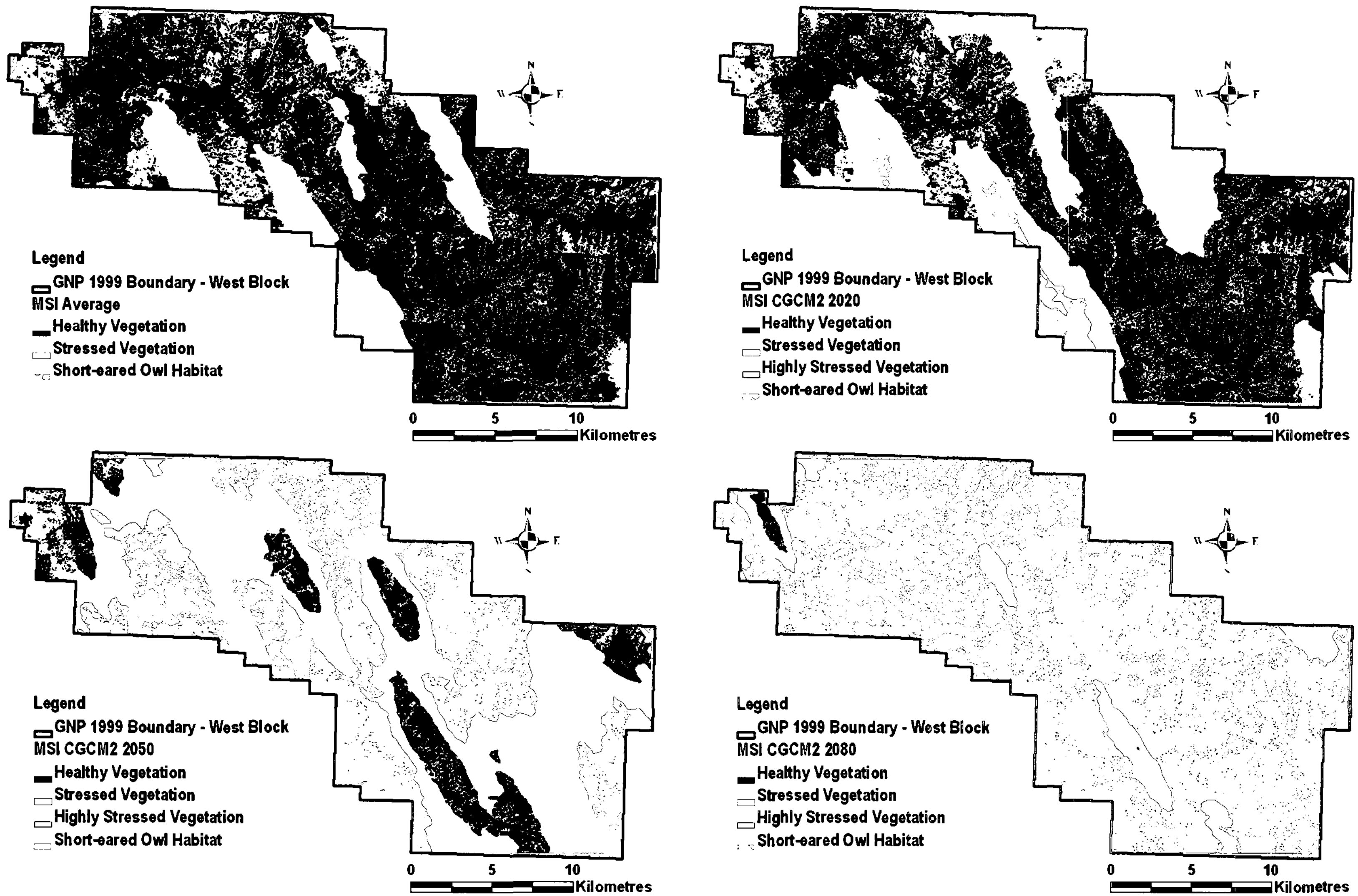

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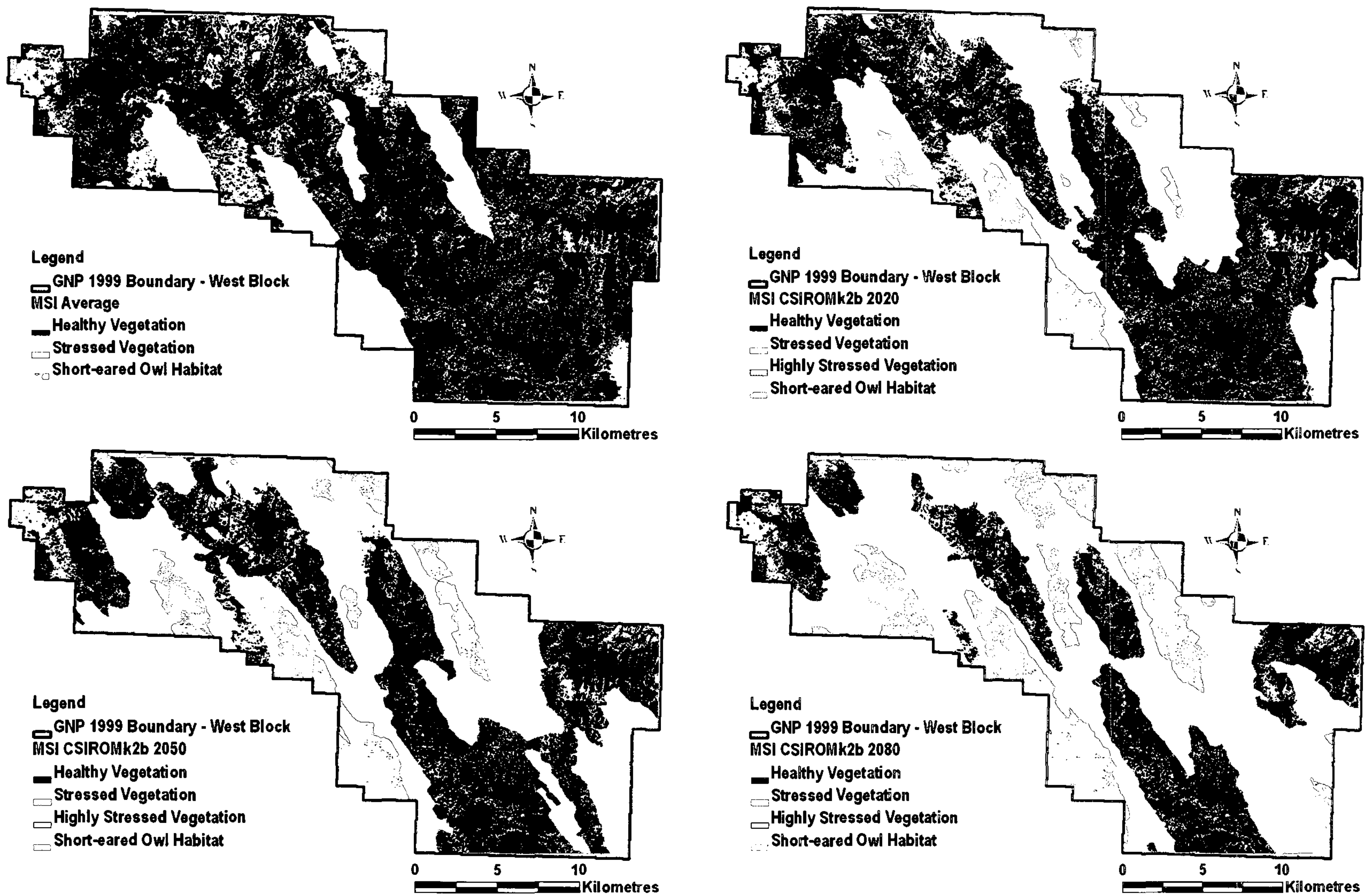

Figure 49. Risk analysis of Short-eared Owl habitat for the MSI CSIROMk2b B11 GCM vegetation change scenarios for the West Block of Grasslands National Park for 2020, 2050 and 2080.

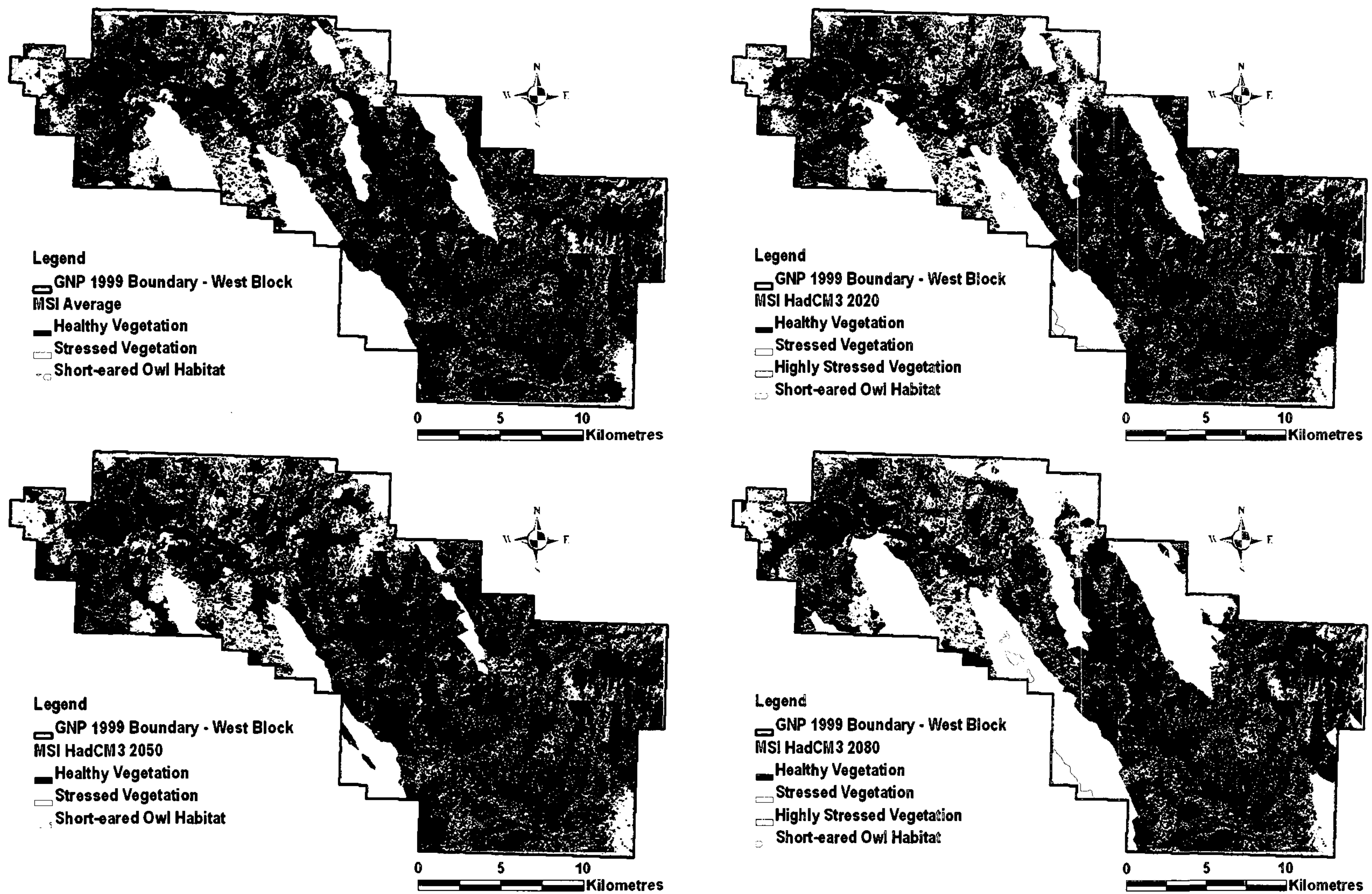

Figure 50. Risk analysis of Short-eared Owl habitat for the MSI HadCM3 B21 GCM vegetation change scenarios for the West Block of Grasslands National Park for 2020, 2050 and 2080.

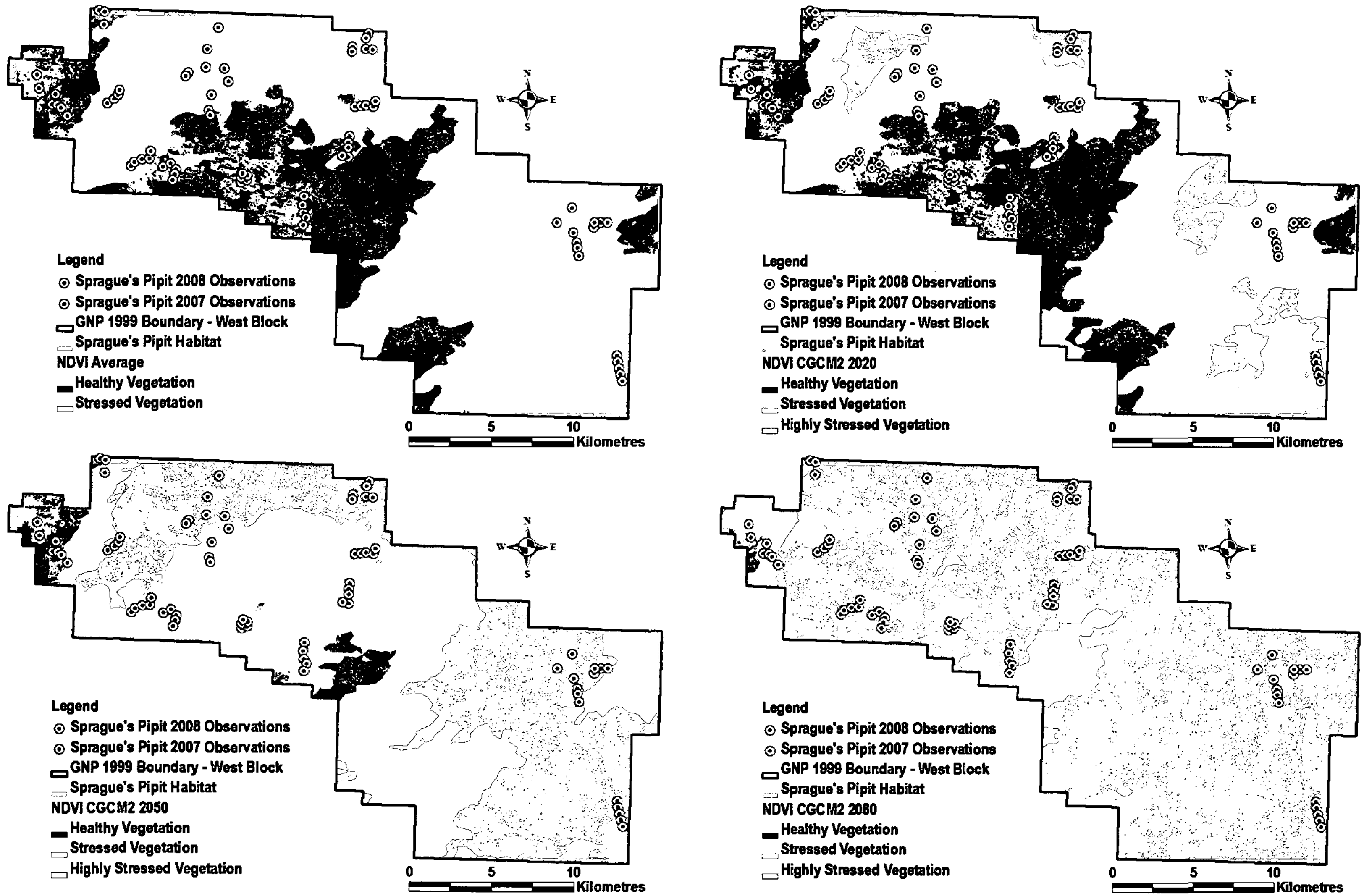

Figure 51. Risk analysis of Sprague's Pipit habitat for the NDVI CGCM2 A21 GCM vegetation change scenarios for the West Block of Grasslands National Park for 2020, 2050 and 2080.

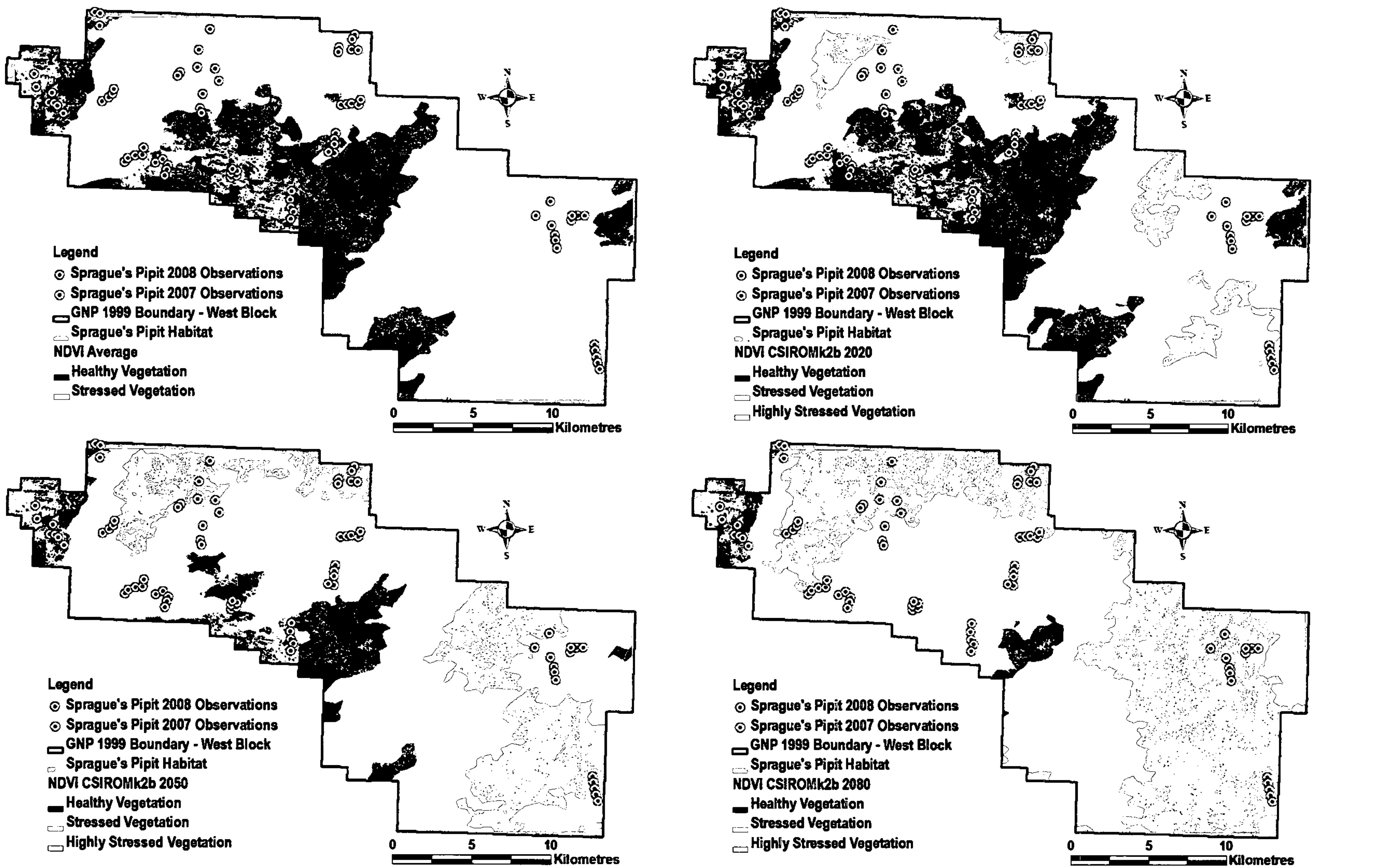

Figure 52. Risk analysis of Sprague's Pipit habitat for the NDVI CSIROMk2b B11 GCM vegetation change scenarios for the West Block of Grasslands National Park for 2020, 2050 and 2080.

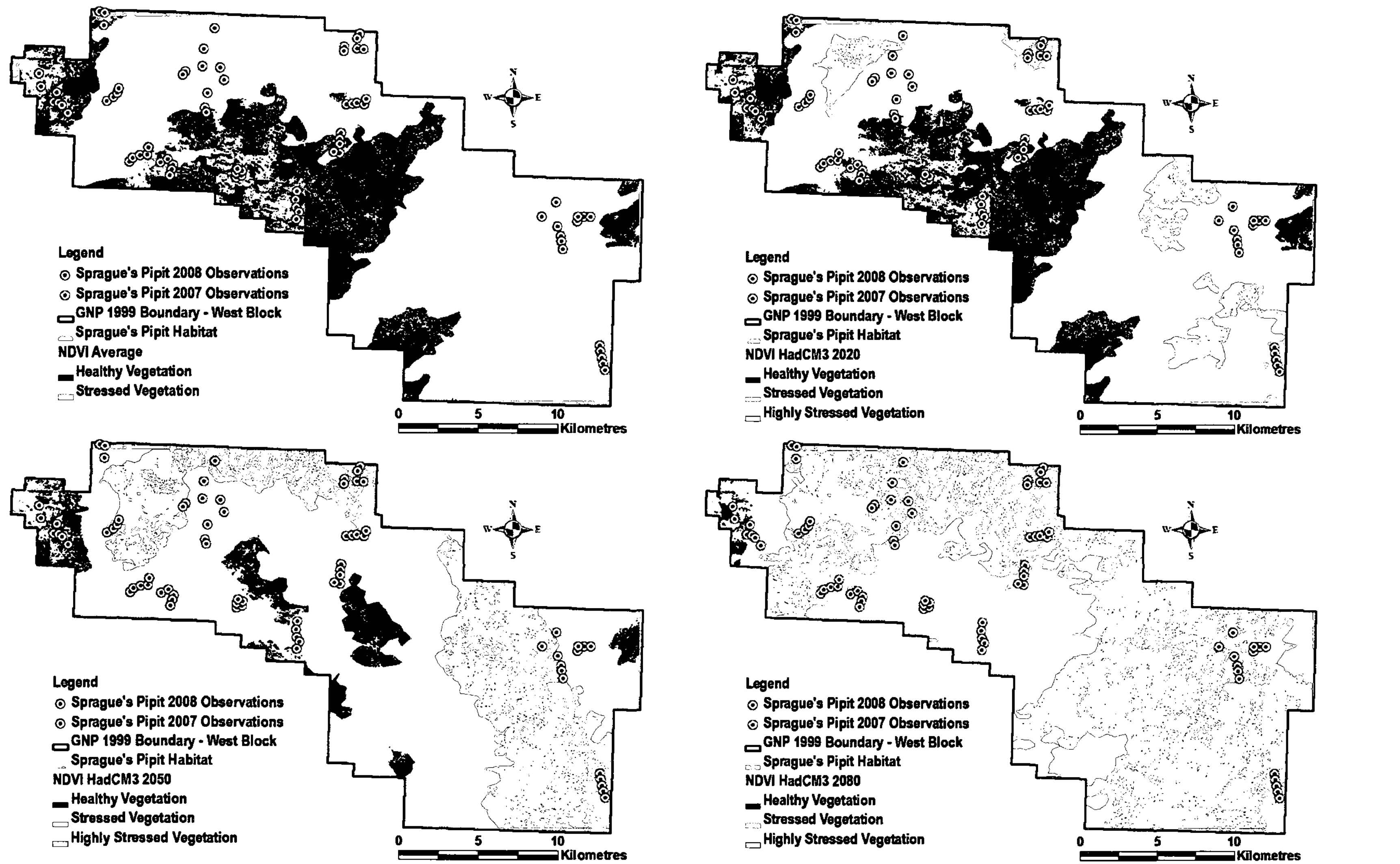

Figure 53. Risk analysis of Sprague's Pipit habitat for the NDVI HadCM3 B21 GCM vegetation change scenarios for the West Block of Grasslands National Park for 2020, 2050 and 2080.

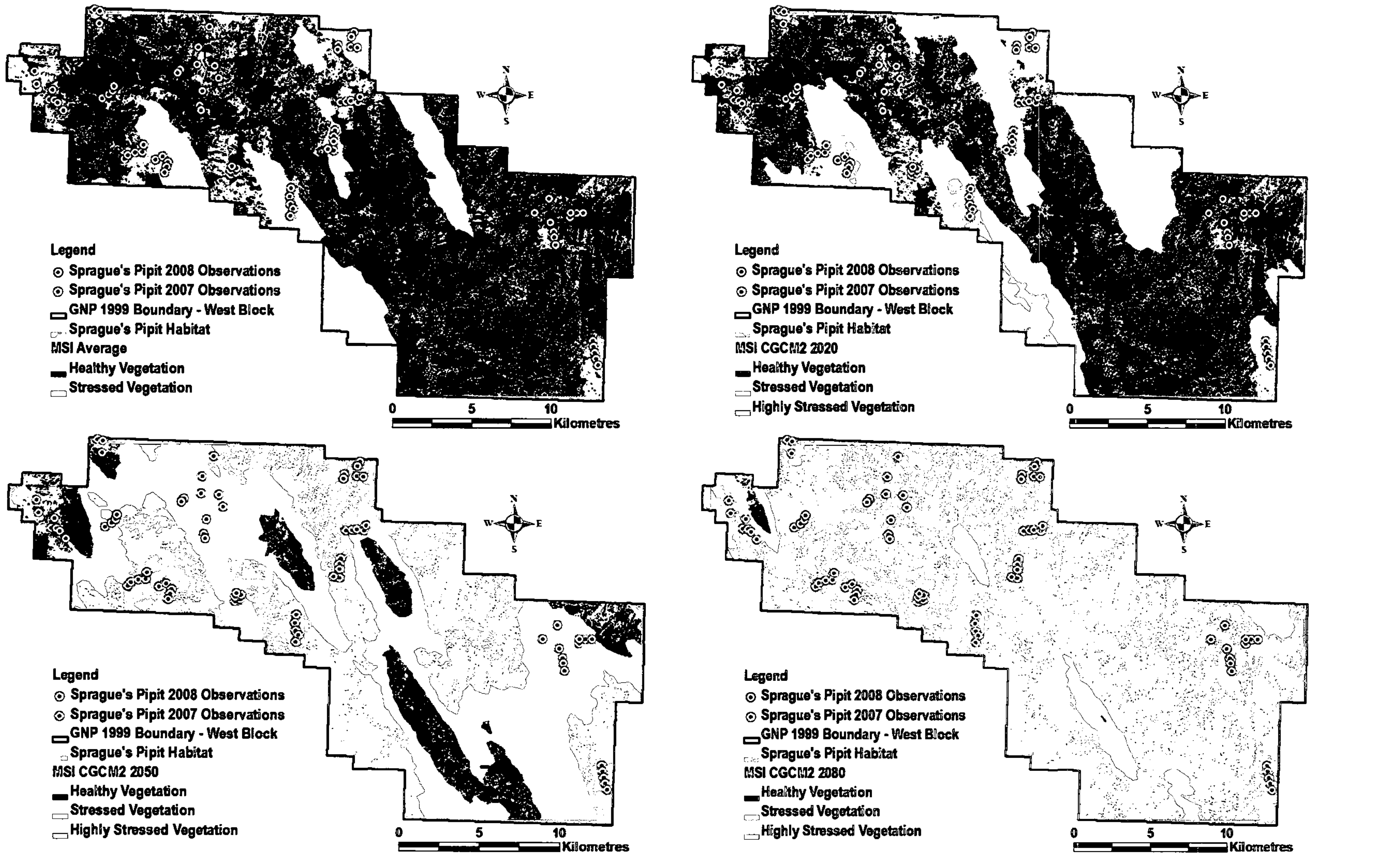

Figure 54. Risk analysis of Sprague's Pipit habitat for the MSI CGCM2 A21 GCM vegetation change scenarios for the West Block of Grasslands National Park for 2020, 2050 and 2080.

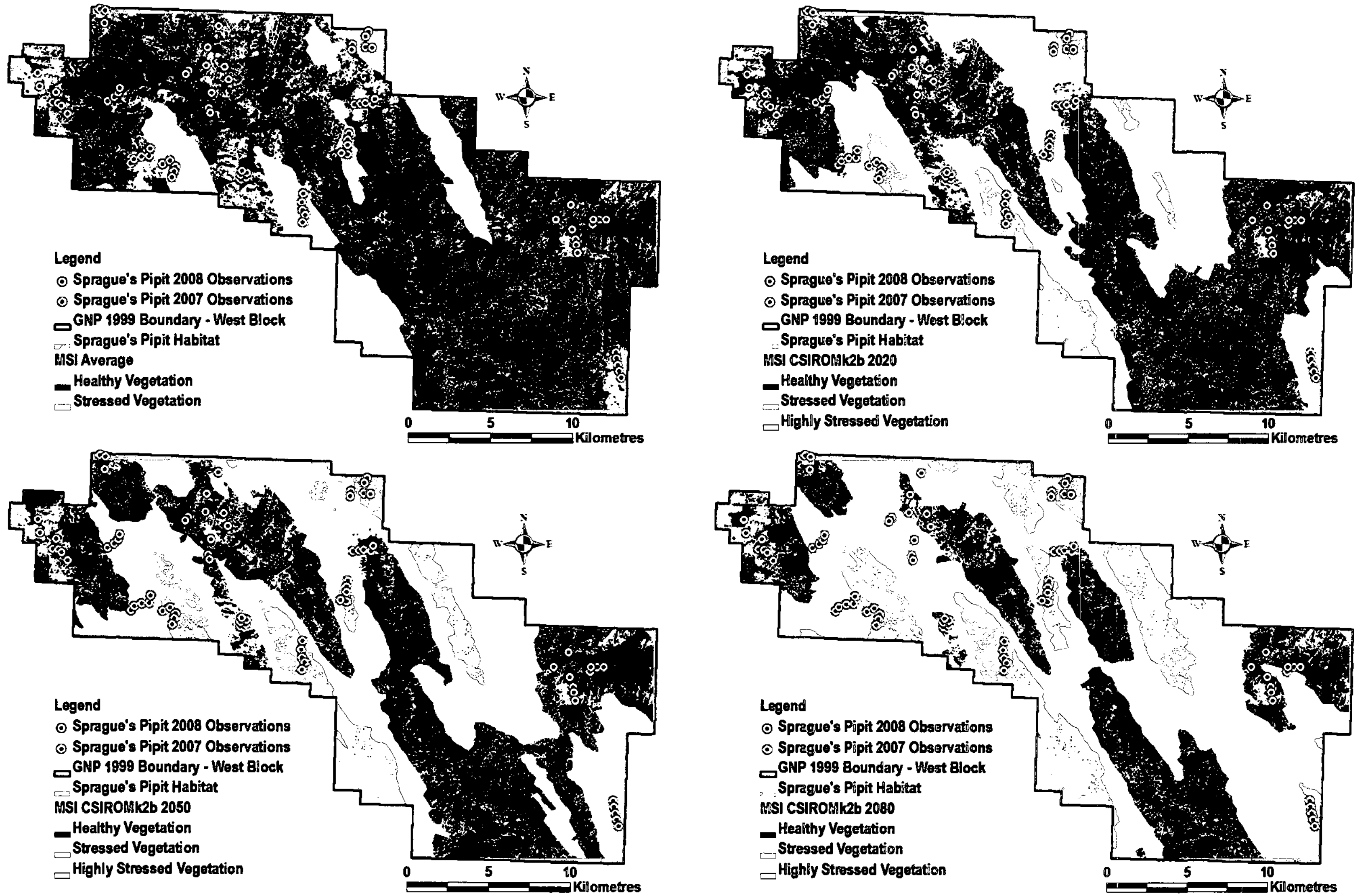

Figure 55. Risk analysis of Sprague's Pipit habitat for the MSI CSIROMk2b B11 GCM vegetation change scenarios for the West Block of Grasslands National Park for 2020, 2050 and 2080.

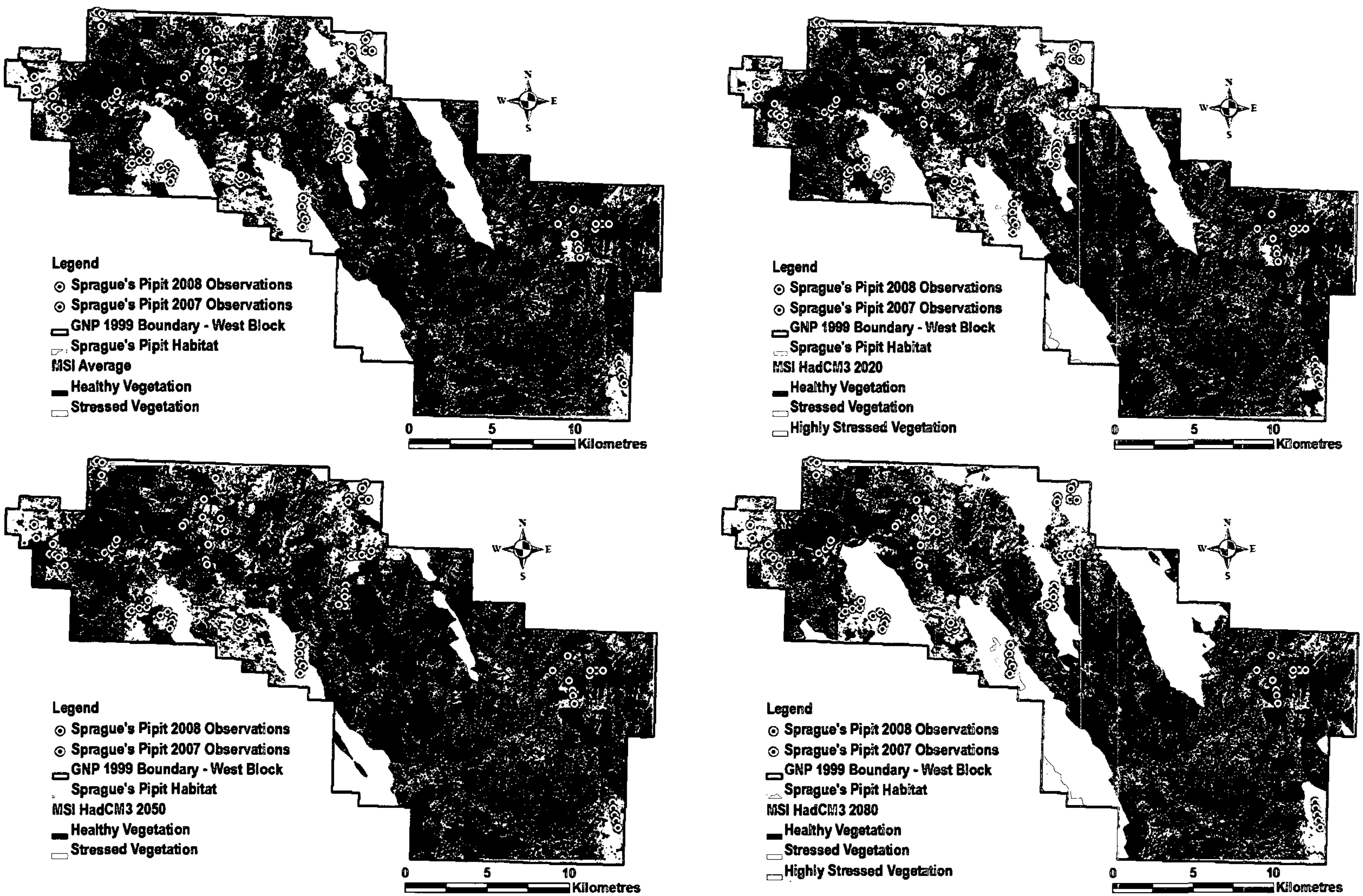

Figure 56. Risk analysis of Sprague's Pipit habitat for the MSI HadCM3 B21 GCM vegetation change scenarios for the West Block of Grasslands National Park for 2020, 2050 and 2080.

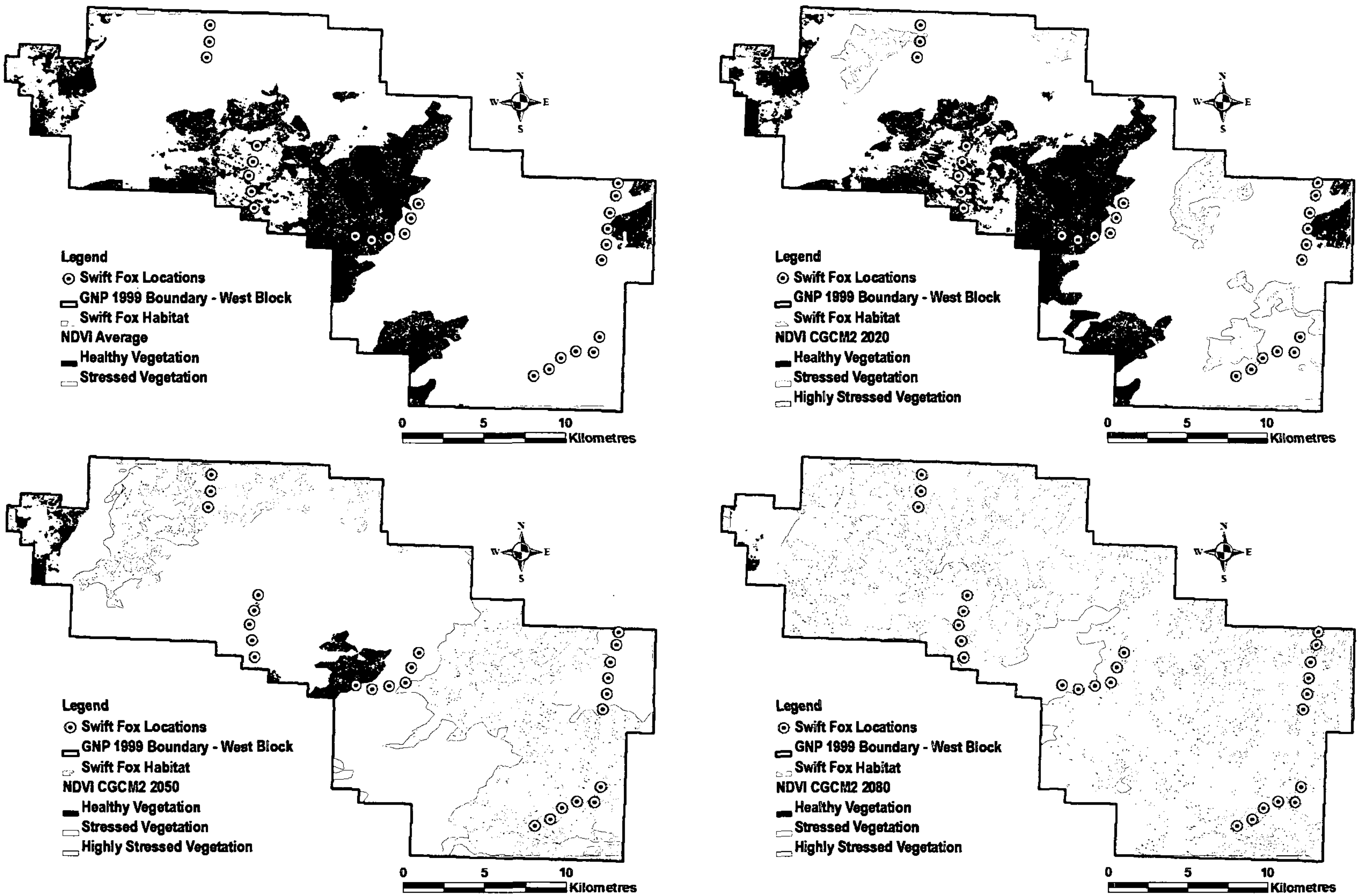

Figure 57. Risk analysis of Swift Fox habitat for the NDVI CGCM2 A21 GCM vegetation change scenarios for the West Block of Grasslands National Park for 2020, 2050 and 2080.

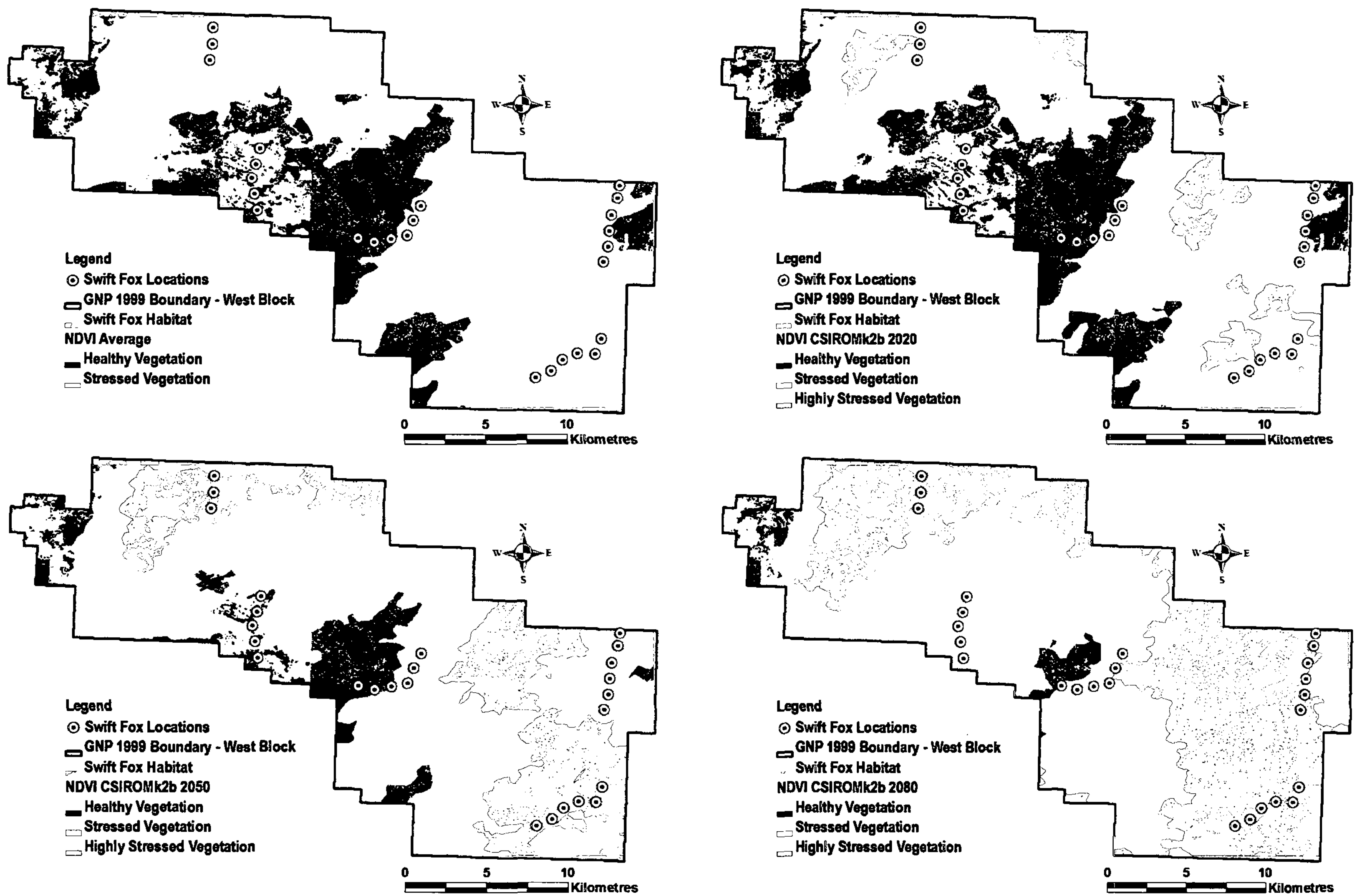

Figure 58. Risk analysis of Swift Fox habitat for the NDVI CSIROMk2b B11 GCM vegetation change scenarios for the West Block of Grasslands National Park for 2020, 2050 and 2080.

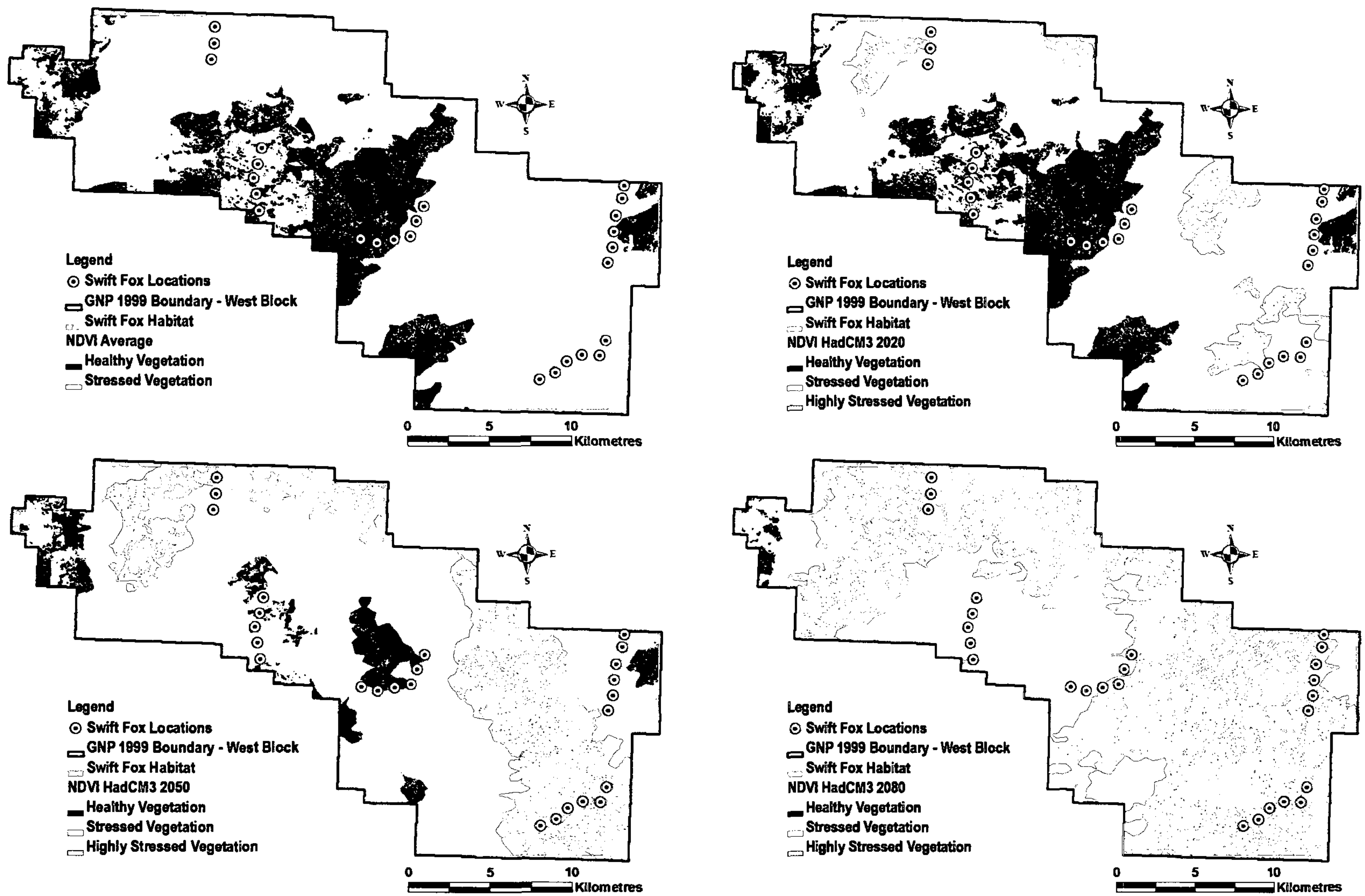

Figure 59. Risk analysis of Swift Fox habitat for the NDVI HadCM3 B21 GCM vegetation change scenarios for the West Block of Grasslands National Park for 2020, 2050 and 2080.

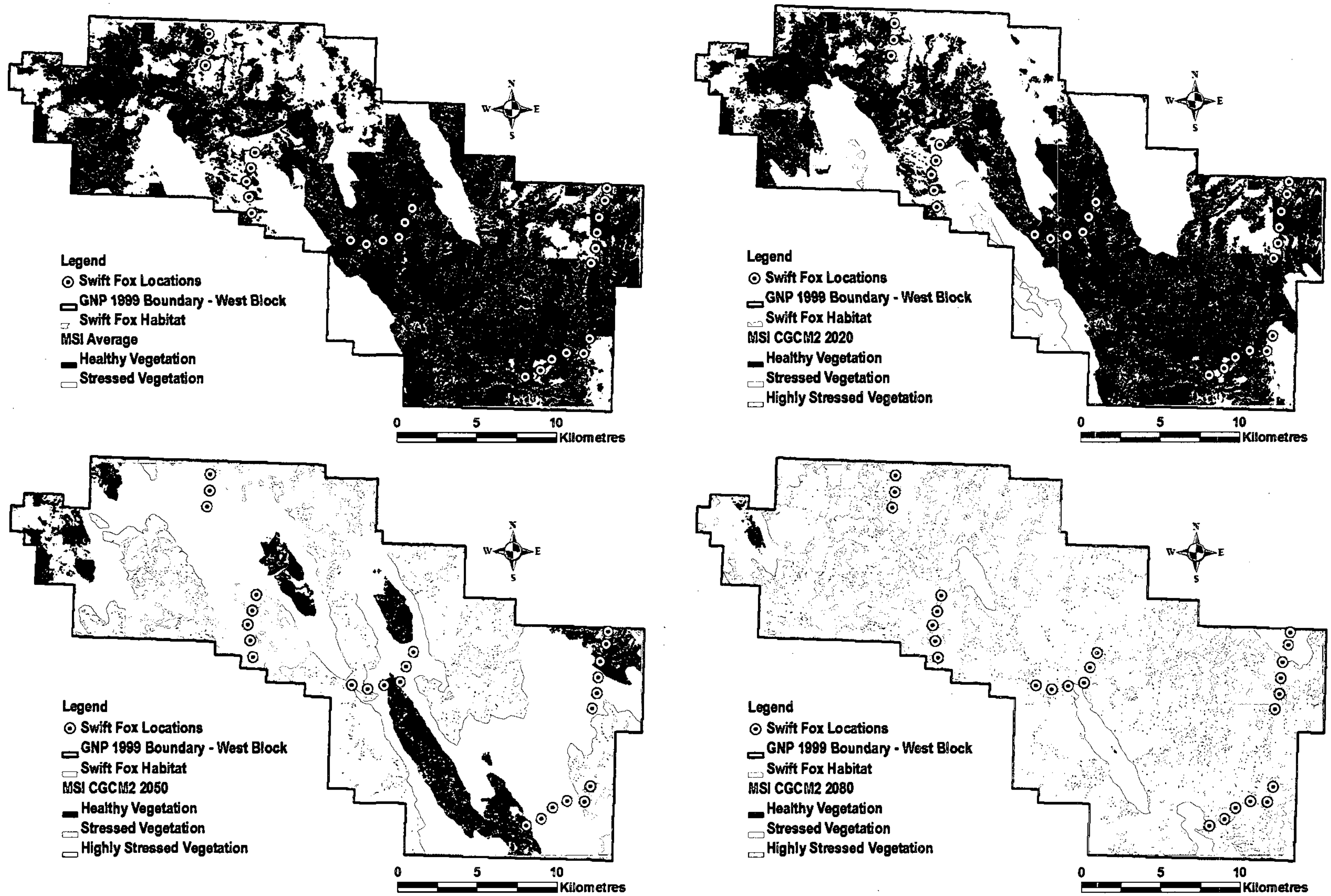

Figure 60. Risk analysis of Swift Fox habitat for the MSI CGCM2 A21 GCM vegetation change scenarios for the West Block of Grasslands National Park for 2020, 2050 and 2080.

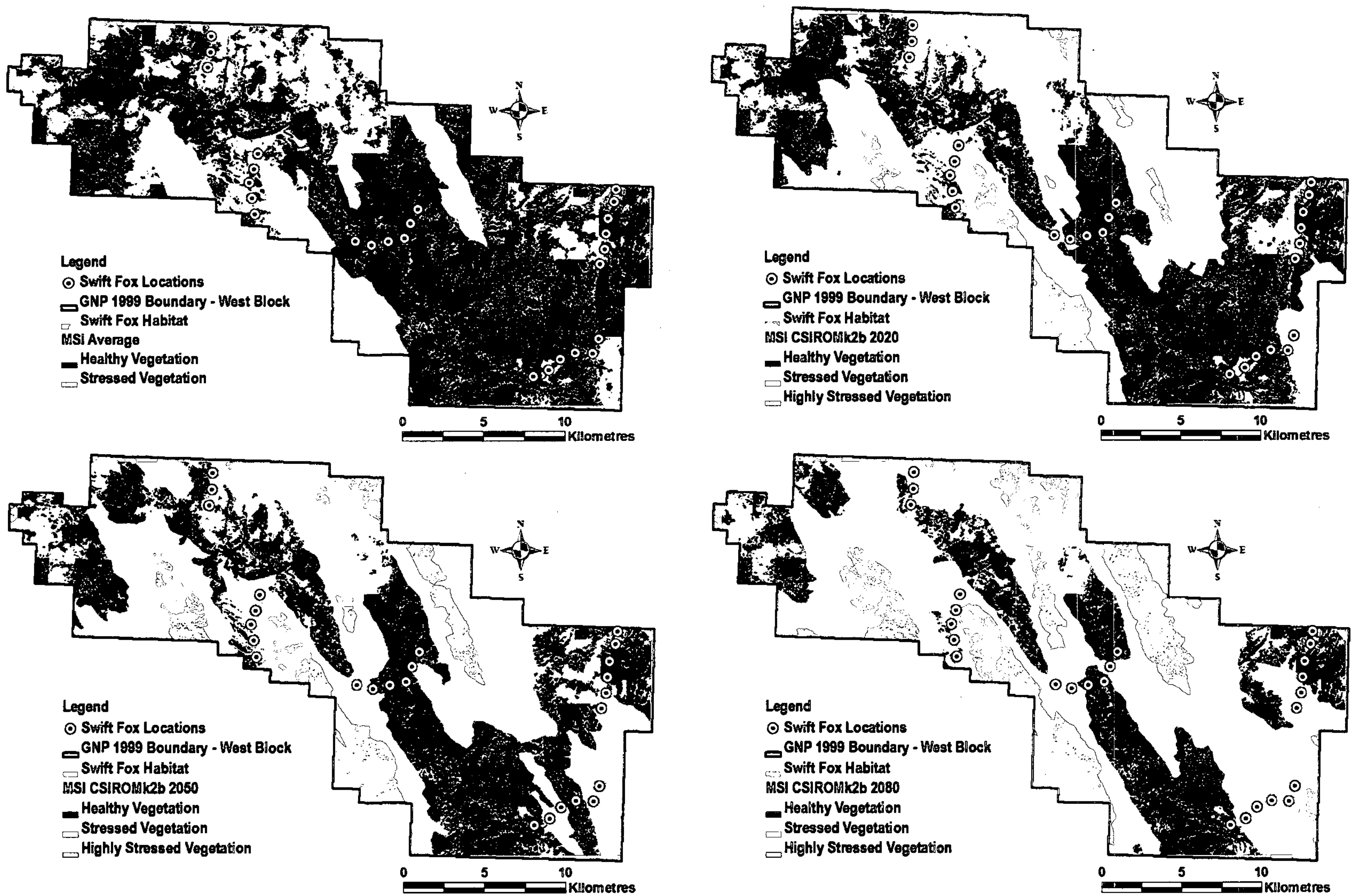

Figure 61. Risk analysis of Swift Fox habitat for the MSI CSIROMk2b B11GCM vegetation change scenarios for the West Block of Grasslands National Park for 2020, 2050 and 2080.

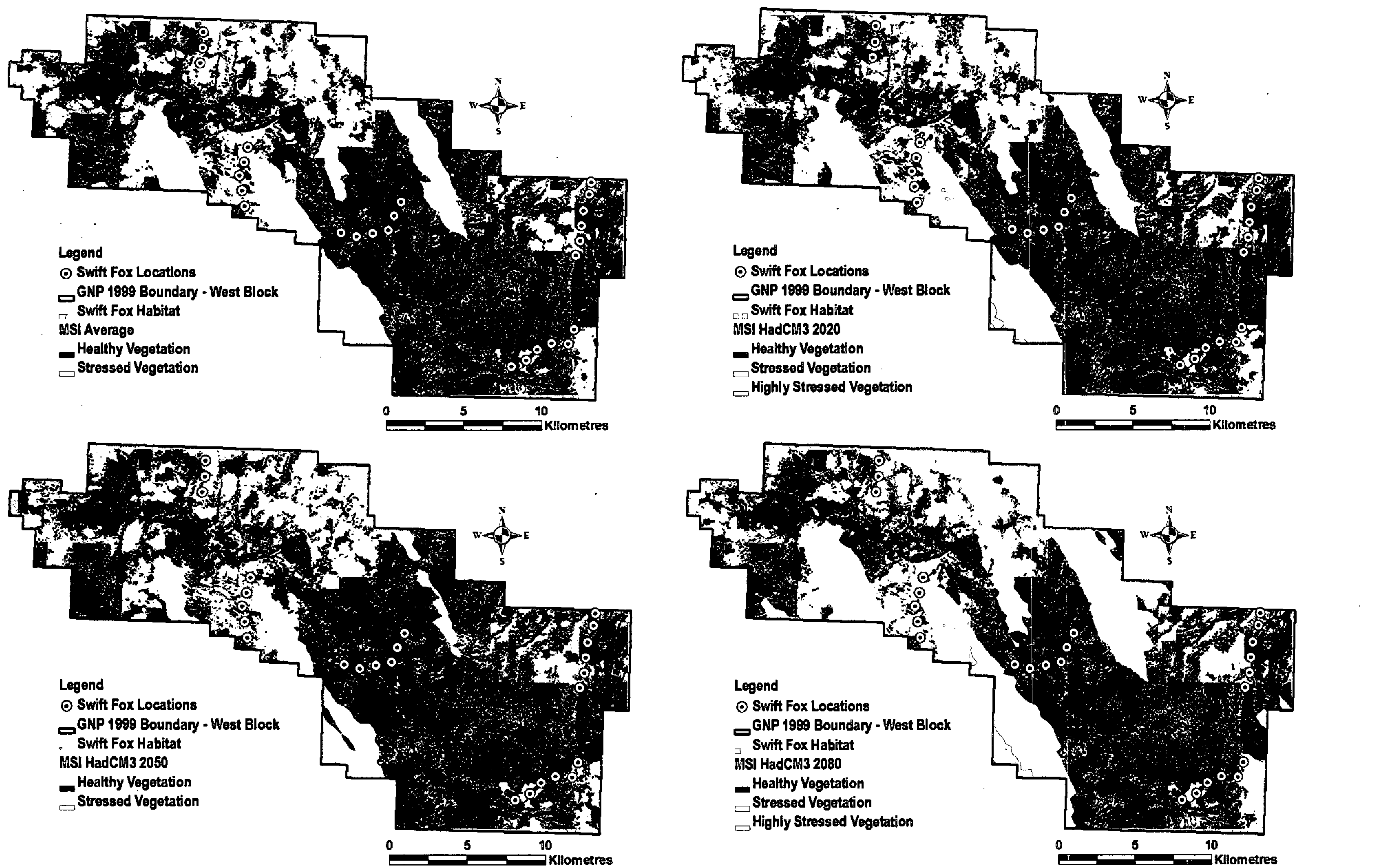

Figure 62 Risk analysis of Swift Fox habitat for the MSI HadCM3 B21 GCM vegetation change scenarios for the West Block of Grasslands National Park for 2020, 2050 and 2080.

Table 7. Risk analysis for eight SAR, invasive/alien species invasion, increased aridity & prolonged/more severe droughts based on the vegetation change scenarios and future aridity for all three GCMs for 2020, 2050 and 2080 and the potential impacts changes in vegetation and future aridity could have on the eight SAR and invasive/alien species by altering vegetation composition/structure, and causing habitat loss, heat stress, water stress, a decline in food availability and mortality.

Sources of Stress	Altered Vegetation Composition and Structure	Habitat Loss	Heat Stress	Water Stress	Decline in Food Availability	Mortality
Black-tailed Prairie Dog	High	Medium	Medium	Medium-High	High	Medium
Burrowing Owl	High	Medium-High	Medium	Medium	High	Medium-High
Ferruginous Hawk	High	Medium	Medium-High	Medium	High	Medium-High
Greater Sage Grouse	High	Medium-High	Medium-High	Medium-High	High	High
Loggerhead Shrike	High	Medium	Medium-High	Medium	Medium-High	Medium
Short-eared Owl	High	Medium-High	Medium-High	Medium	High	Medium-High
Sprague's Pipit	High	Medium-High	Medium-High	Medium	Medium-High	Medium-High
Swift Fox	High	Medium	Medium	Medium	High	Medium
Invasive/Alien Species	High					
Increase Aridity	High	High		High	High	
Prolonged and More Severe Droughts	High	High		High	High	

Altered Vegetation Structure and Composition – change in vegetation height and threat from invasive/alien species, such as crested wheat grass

Habitat Loss – destruction of native mixed grass prairie

Heat Stress – high temperatures during incubation and hatching periods, and high temperatures resulting in high chick/ fledging/pup mortality

Water Stress – decrease in vegetation canopy water content and standing water sources

Decline in Food Availability – decline in prey species, such as Richardson's ground squirrels, voles, mice, and rabbits, and sage spp.

8. MANAGEMENT OPTIONS

Decreases in grassland productivity, vegetation density, vigour and canopy water content, coupled with a more arid climate, as predicted by my aridity models and vegetation change scenarios, will likely change the vegetation communities that currently dominate GNP. During the 1930s, drought in the Great Plains killed most of the vegetation, creating large areas of bare ground. In addition, large numbers of grasshoppers consumed much of the remaining vegetation. When rain occurred, a proliferation of weeds occurred in bare areas (Weaver et al. 1935; 1940, Weaver and Albertson 1936; 1940; 1943, Albertson 1937, Robertson 1939, Albertson and Weaver 1942; 1944a; 1944b, Weaver and Mueller 1942, Weaver and Bruner 1945, Albertson et al. 1957). Albertson and Weaver (1944b) found that *Sphaeralcea coccinea* (scarlet globemallow), an abundant plant found in the western part of the mixed grass prairie, was extremely drought resistant. This species, along with *Opuntia* (prickly pear), were two of the non-weedy forbs which increased during the 1930s drought. Maintaining and re-establishing native mixed grass prairie during and after a drought will be important, since vegetation change and loss means a decrease in habitat diversity and suitability for many species. In turn, reduction in habitat cover will make individual species more susceptible to predation.

Variation in temperature and precipitation can affect bird populations either through habitat change, heat stress or water restriction, or a decline in food availability (Wiens 1974, Smith 1982, Morrison 1986). Li and Brown (1999) found that yearly variation in the amount of precipitation in the southwestern United States is related to annual reproductive success of Mexican Jays. Precipitation in March and April, during the laying season, can have an effect on the food supply of jays by promoting growth of herbaceous plants. Burbidge and Fuller (2007) found birds declined in abundance as drought progressed in the Gibson Desert. Blake et al. (1989) found annual variations in bird populations were correlated with drought in Wisconsin and Michigan. Mice, vole, insect and ground squirrel populations are negatively impacted by drought (refer to Burrowing Owl and Ferruginous Hawk sections 6.2 and 6.3 under general biology).

Thus, future management for SAR needs to consider the effects drought has on the diet, nesting and foraging habitat, disease, life cycles, predator-prey relationships and other interspecific relationships of the listed species.

8.1 Management Recommendations

1) Restoration of native prairie (grassland and shrubsteppe) should include sagebrush, thorny buffaloberry, willow, native forbs (especially legumes) and native grasses (bunchgrasses) or other native drought resistant or tolerant plants. The impacts of drought can be reduced by maintaining a protective vegetative cover which guards against high soil temperatures and water loss (Julander 1954). If the annual precipitation pattern in GNP shifts from a dominant spring/early summer precipitation to a dominant summer precipitation, there will most likely be a shift from C_3 to C_4 (warm-season) grasses and increased forb/shrub/tree activity (Mattson and Haack 1987, Le Houerou 1996, Clark et al. 2002, Baldocchi et al. 2004, Kochy and Wilson 2004, Heitschmidt and Vermeire 2006). Mamolos et al. (2001) found C_4 grasses to have high drought tolerance because they are able to photosynthesize at higher rates with low stomatal conductances. Willms et al. (2005) found monocultures of two native species, green needlegrass and blue grama, were productive under drought conditions. The western wheatgrass monoculture and the western wheatgrass-blue grama mixture experienced the greatest yield reduction as a result of drought. Mueller and Weaver (1942) found the short grasses, such as blue grama and buffalo grass, were the most drought resistant within a greenhouse at the University of Nebraska. Briske and Wilson (1980) found drought may affect the capacity for root development from blue grama seedling crowns by reducing seedling leaf areas, and

delaying root initiation and inhibition of root growth. Planting must be initiated when soil moisture is high, and the probability of precipitation and favourable temperatures is high.

Seed hardening is another recommendation. Julander (1945) found drought hardened plants had higher food reserves than unhardened plants and were more resistant to heat injury. Buffalo grass was the most resistant.

Water management, use of nitrogen fertilizers (except in areas infested by annual weeds), mechanical chopping of certain types of vegetation, removal of invasive/alien plant species, such as crested wheat grass (*Agropyron cristatum*), suppression of wildfire, and use of prescribed fires may also be necessary to enhance and restore native prairie. In addition, enhancing nest and forage areas for species, such as the Ferruginous Hawk, should be considered.

Management for Sage Grouse populations should include protecting and maintaining existing habitats, and restoring degraded habitats (Connelly et al. 2000, Braun et al. 2005). Connelly et al. (2000) suggested brush beating (restoration technique which removes dead plant material and allows herbaceous vegetation to increase) in strips or patches 4 to 8 m wide where the sagebrush overstory (greater than or equal to 35% shrub cover) is intact but the understory has been degraded, interseeded with native grasses and forbs, as an option. A variation in sagebrush size and distribution contributes to the health and resilience of shrublands. Brush beating should mimic small, low intensity fires that historically occurred in an area. To restore sage spp., Bai et al. (1995) concluded that seed germination and seedling emergence of fringed sage are controlled by environmental factors such as soil moisture and temperature. Romo and Grilz (2002) found that silver sagebrush seedlings emerged early in the growing season. The emergence of silver sagebrush is greatest from about the 2 to 5 mm depth. Romo and Young (2002) found that seeding of silver sagebrush in early spring is recommended to maintain high viability and germination of seeds in this shrub, since germination of silver sagebrush declined as temperatures increased during the spring. Silver sagebrush seeds are not known to exhibit dormancy and establish primarily by sprouting from rhizomes. In naturally occurring silver sagebrush stands in Saskatchewan, shrub densities range from 0.3 to 1.0 m^{-2} (Romo and Grilz 2002). The conditions at time of seedling establishment are therefore of high importance (Kreyling et al. 2008). Brock and Galen (2005) found native dandelions to be more drought tolerant than their hybrids, but have less water use efficiency.

Management of loggerhead shrike populations should include preserving and providing native prairie in breeding and wintering areas of adequate size; maintaining low, thick shrubs and trees along abandoned farmyards, fence lines and throughout open pastures and fields; controlling grazing practices in areas with taller vegetation; maintaining herbaceous cover by trimming excessive amounts of woody vegetation; and reducing the use of pesticides (Dechant et al. 1998).

2) Modelling how climate and prey factors interact to better understand how these two factors interrelate. Long-term studies are needed to determine how prey populations or other food sources consumed by the species, like sagebrush and insects, and prolonged droughts and increased aridity are correlated. Turchin and Ostfeld (1997) found that severe drought depressed population growth rates and densities of meadow voles (*Microtus pennsylvanicus*). Sherman and Runge (2002) argued that the ultimate collapse of the northern Idaho ground squirrel (*Spermophilus brunneus*) was inadequate food resources, particularly seeds, due to drying of the habitat and changes in plant species composition. Hawkins and Holoyoak (1998) found a widespread drought caused simultaneous crashes of insect populations across the United States, affecting diverse taxa

from butterflies to sawflies to grasshoppers. Many SAR, such as the Ferruginous Hawk and Short-eared Owls, fluctuate synchronously with their major prey species, such as ground squirrels and voles.

3) Long-term studies of climate (including measures of drought and increased aridity) are needed in the context of species demography. Physiological effects of environmental 'crunches' on animals may persist several years afterwards, reducing reproductive success and growth rates of future offspring. Studies need to assess microhabitat and microclimate selection and use, since the habitat and climate in the immediate vicinity of a plant or animal will differ from the habitat and climate over a large geographical area.

4) Continued long-term climate (prolonged droughts and increased aridity) studies need to evaluate the relationship between breeding productivity, precipitation and temperature. SAR will likely respond differently to drought. Smith (1982) found that the number of breeding bird species declined during a drought, insect species composition and densities changed, and many bird species experienced water stress. Dittami and Knauer (1986) found that severe droughts inhibit reproductive activity and correspondingly the secretion of gonadal steroids in Fiscal Shrikes in Kenya. George et al. (1992) found declines in species richness and diversity, including the Sprague's Pipit, during the 1988 drought in western North Dakota. Monitoring should include as many species as possible to provide reliable information on entire communities.

5) More research is needed about the effects of disease and parasites on some of the SAR, and their relation to climate (increased aridity), such as the black-tailed prairie dog, swift fox and Sage Grouse. For example, studies need to assess the effects of sylvatic plague on infected and recovering black-tailed prairie dog populations. Stapp et al. (2004) found a link between extinctions of colonies of black-tailed prairie dogs attributed to plague

(*Yersinia pestis*) and climate fluctuations associated with El Niño Southern Oscillation events that promote the growth of flea vector and rodent host populations. Walker et al. (2007) found the impacts of West Nile virus on Greater Sage Grouse in the Powder River Basin of Montana and Wyoming in the future will likely depend on annual variation in temperature and changes in vector distribution.

6) Alternative water sources for species, such as the Sage Grouse, need to be maintained in response to increased aridity and prolonged droughts.

7) Ongoing surveys are required to assess the population status and habitat conditions of the species and their prey.

8) Future research should concentrate on habitat features and land uses with suspected negative and positive influence on the species. Future growths or declines in abundance and distribution need to be monitored.

9) Vegetation and soil surveys need to be completed within GNP.

8.2 Other Research

1) Identify proximate cues migratory birds use to select breeding habitat, as well as understand the spatial scales at which the cues elicit selection.

2) Disturbance to nesting birds needs to be minimized, such as Ferruginous Hawks and Short-eared Owls.

3) Initiate studies on the distribution, numbers, habitat use and prey populations of 'Canadian' subpopulations on their nonbreeding grounds in Texas, Mexico, Central America and South America. To identify nonbreeding areas, satellite radiotelemetry will likely prove invaluable.

4) Educate the public about the value of ecosystem conservation, and the links between animals and human habitat. Reduce direct human-caused mortality of SAR.

5) Conduct research on the effects agricultural change and increased applications of new pesticides have on SAR and their prey populations.

6) Devise habitat models for each species, defining crucial habitat parameters.

7) Develop landowner stewardship incentives to help protect the species.

8) More information is needed on the intensity and duration of grazing in the context of vegetation structure and composition. Effective black-tailed prairie dog habitat management should include grazing systems focused on maintaining and enhancing native shortgrass conditions. Grazing should be monitored carefully, since it can have negative impacts on prey populations and compact the soil.

9) Develop population viability models for each species, identifying primary threats that could lead to extinction and develop estimates of minimum viable population size.

10) Create a corridor for safe travel between the West and East Block of GNP. Management of swift fox populations should include accurate assessments of swift fox distributions (use of home-ranges) and understanding swift fox habitat requirements. Moehrenschlager and Moehrenschlager (2001) suggest future presence/absence assessments should concentrate on the apparent gaps between the eastern and western regions of GNP and adjacent regions in Montana. They also suggest a need to understand the factors that have increased swift fox populations recently, like high prey abundance, favourable weather conditions, or low predator numbers.

11) Discuss the importance of buffer zones with landowners.

9. CONCLUSIONS

The implications of climate change, increased aridity and more severe drought on the management and recovery of northern mixed grass prairie species-at-risk was assessed through the following six objectives: 1) to spatially analyze temporally discrete data for climate and grassland productivity from 1978-2006; 2) to develop statistical models of climate-vegetation relationships for the West Block of Grasslands National Park; 3) to assess past and predict future aridity; 4) to forecast the probability of future drought using Monte Carlo analysis; 5) to assess the effects climate change will have on the eight species-at-risk (SAR) chosen for my study; and 6) to develop management options and risk analysis for the eight SAR.

As in other studies, I show that the relationship between climate and vegetation can be analyzed using vegetation indices. I found that both the NDVI and SAVI can be used to detect climate-vegetation relationships, but other vegetation indices have higher correlations with climate and vegetation. I suggest that the best approach for predicting aridity, precipitation and PET is to use the NDMI and MSI.

My data are consistent with the idea that drought indices, like the Palmer Drought Severity Index (PDSI), can be used to assess past droughts in an area. Grasslands National Park (GNP) had moderate to severe droughts during the 1980s, as well as in 2001 and 2006.

I found all four vegetation indices are strongly correlated with the PDSI; however, the highest correlations occurred between the NDVI and SAVI vegetation indices. The NDVI and SAVI are also the best vegetation indices for predicting the PDSI.

During droughts, temperatures are normally higher and precipitation is lower than during non-drought years. The vegetation indices averages were usually lower during drought years. Overall, grassland productivity, including photosynthetic activity, decreased during drought years.

A decrease in grassland productivity, vegetation quantity, vigour, and canopy water content, coupled with a more arid climate, as predicted by my aridity models and vegetation change scenarios, will likely change the vegetation communities that currently dominate the West Block of GNP. Drought affects almost every plant process, including seed germination, water and mineral absorption, photosynthesis, respiration and growth (Mattson and Haack 1987, Haddad et al. 2002). High temperatures, which generally accompany droughts, can cause injury to plants by increasing evapotranspiration and water stress demands, while causing decreased photosynthetic activity (Julander 1945, Henckel 1964, Yordanov et al. 2000, Flexas and Medrano 2002, Yordanov et al. 2003, Breshears et al. 2005, Zavalloni et al. 2008). Root growth and nutrient uptake also generally decrease with increasing moisture stress (Gerakis et al. 1975). If the annual precipitation pattern in GNP shifts from a dominant spring/early summer precipitation to a dominant summer precipitation, there will most likely be a shift from C_3 to C_4 (warm-season) grasses and increased forb/shrub/tree activity (Mattson and Haack 1987, Le Houerou 1996, Clark et al. 2002, Baldocchi et al. 2004, Kochy and Wilson 2004, Heitschmidt and Vermeire 2006). Droughts can also cause the local extinction of many rare plant species, which reduces diversity (Le Houerou 1996, Clark et al. 2002, Hannah et al. 2002). An increase in the frequency and intensity of droughts will most likely lead to decreased plant species richness. This means a decrease in habitat diversity and suitability for many animal species. The configuration, density, and quality of landscape elements, such as foraging and nesting habitat, required by the SAR to reproduce and find prey will likely be altered in response to increased aridity (Peters 1991, deGroot et al. 1995, Opdam and Wascher 2004). In addition, SAR could experience higher mortality rates and lower reproduction in response to higher temperatures and water stress. In turn, a reduction in habitat cover will make individual species more susceptible to predation (Opdam and Wascher 2004).

This makes monitoring population sizes and the vegetation and food requirements for each species to detect changes in response to prolonged droughts and increased aridity important. Land owners and park managers will also want to make sure that these requirements are available farther north, since the SAR are at their northern range within GNP. Management is needed to protect remaining mixed prairie grasslands and ensure viable SAR populations. This includes grassland restoration, conducting long-term climate (prolonged drought and increased aridity) studies involving habitat comparisons of species demography and the relationship between prey populations and climate, maintaining dense and widespread populations of prey, and maintaining alternative water sources.

Models, GIS and remote sensing technologies are now used in many disciplines and together these techniques can be used to characterize landscape degradation. It is important for scientists to cross the boundaries of knowledge and integrate disciplines to allow multidisciplinary approaches to solving problems.

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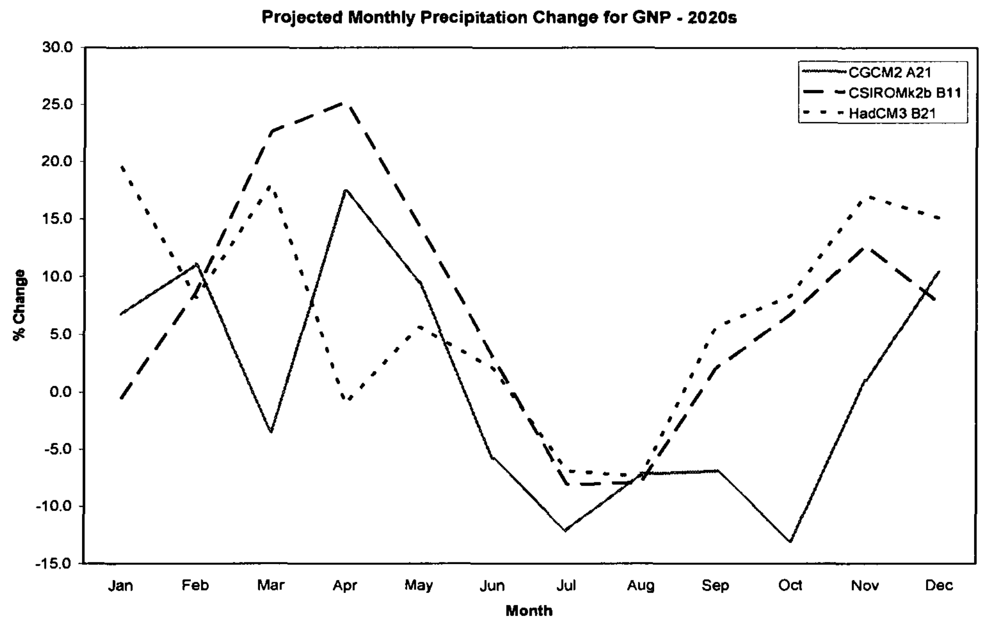
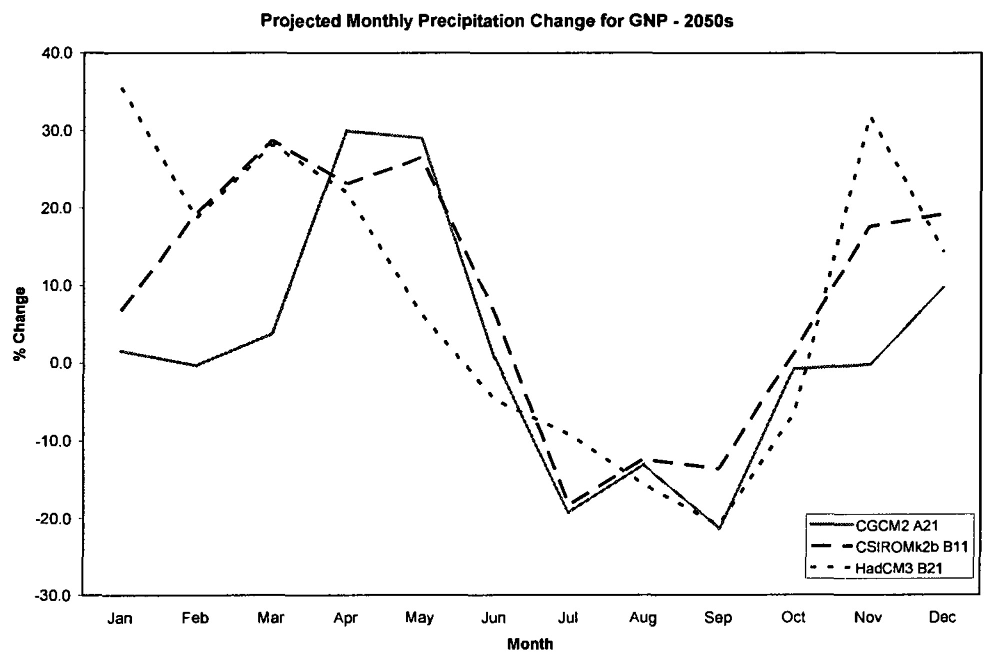
11. APPENDICES

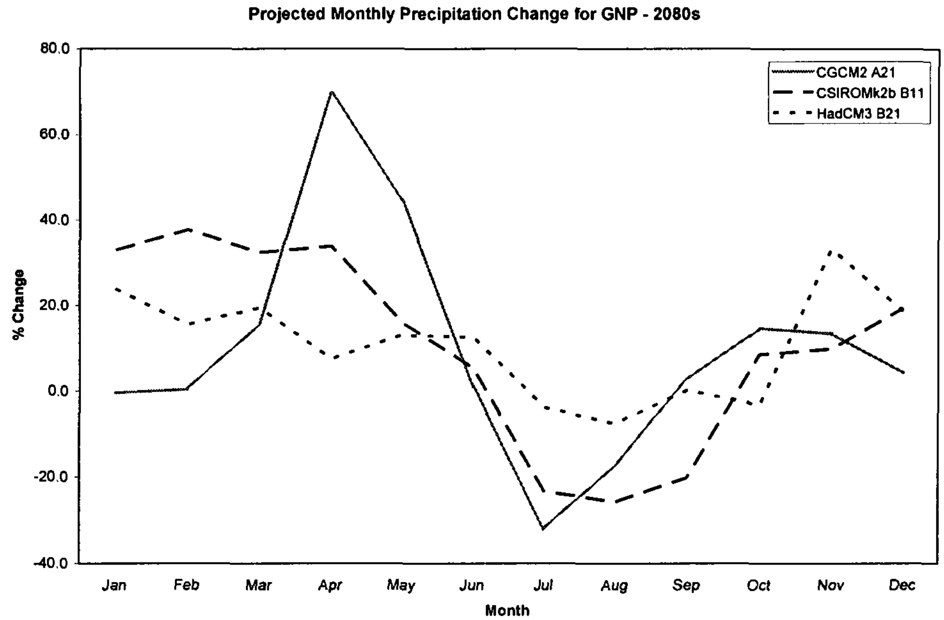
Appendix A. Heat index, unadjusted PET, adjusted PET and aridity values for 1978 to 2006 for May, June, July and August for the West Block of Grasslands National Park. The heat index, unadjusted PET and adjusted PET values were calculated using the Thornthwaite method.

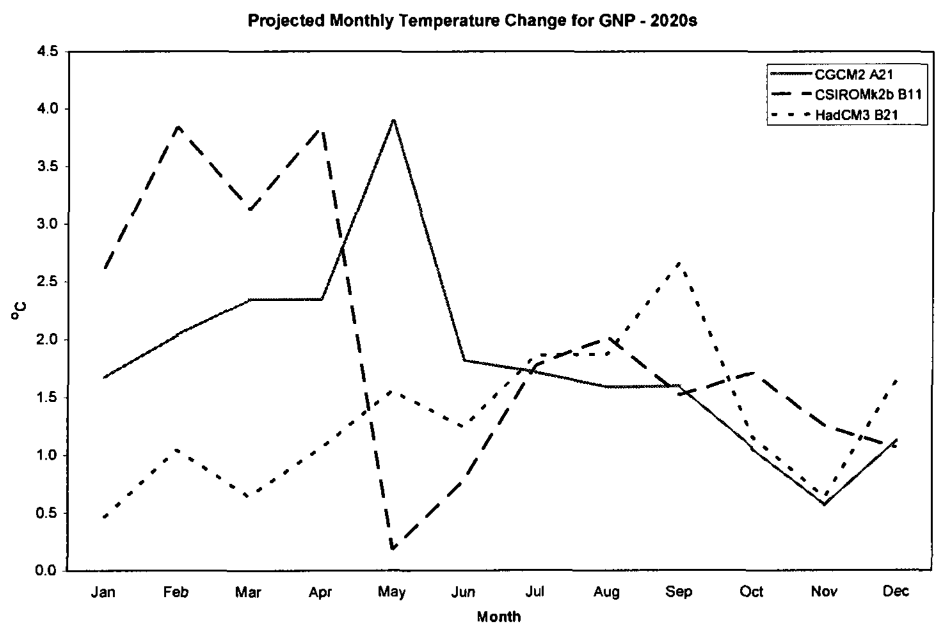
	May			June			July			August			Aridity (P/PET)				
Date	Heat Index (I)	Unadj PET (mm)	Adj PET (mm)	Heat Index (I)	Unadj PET (mm)	Adj PET (mm)	Heat Index (I)	Unadj PET (mm)	Adj PET (mm)	Heat Index (I)	Unadj PET (mm)	Adj PET (mm)	May	June	July	August	Average
1978	29.29	1.9	75.24	29.29	2.8	112.56	29.29	3.1	125.55	29.29	2.9	107.88	0.48	0.32	0.29	0.34	0.36
1979	30.45	1.5	59.40	30.45	2.8	112.56	30.45	3.4	137.70	30.45	3.1	115.32	0.42	0.22	0.18	0.22	0.26
1980	31.17	2.4	95.04	31.17	2.8	112.56	31.17	3.2	129.60	31.17	2.6	96.72	0.26	0.22	0.19	0.26	0.23
1981	30.76	2.1	83.16	30.76	2.3	92.46	30.76	3.2	129.60	30.76	3.4	126.48	0.26	0.24	0.17	0.17	0.21
1982	25.60	1.7	67.32	25.60	2.7	108.54	25.60	3.2	129.60	25.60	3.1	115.32	0.45	0.28	0.23	0.26	0.31
1983	30.07	1.6	63.36	30.07	2.6	104.52	30.07	3.4	137.70	30.07	3.5	130.20	0.30	0.18	0.14	0.15	0.19
1984	29.17	1.7	67.32	29.17	2.7	108.54	29.17	3.5	141.75	29.17	3.5	130.20	0.24	0.15	0.11	0.12	0.16
1985	27.65	2.4	95.04	27.65	2.4	96.48	27.65	3.5	141.75	27.65	2.9	107.88	0.26	0.25	0.17	0.23	0.23
1986	27.94	2.0	79.20	27.94	3.0	120.60	27.94	3.0	121.50	27.94	3.0	111.60	0.48	0.29	0.29	0.32	0.35
1987	30.66	2.3	91.08	30.66	3.0	120.60	30.66	3.2	129.60	30.66	2.5	93.00	0.24	0.18	0.17	0.23	0.21
1988	34.05	2.5	99.00	34.05	3.6	144.72	34.05	3.1	125.55	34.05	3.0	111.60	0.19	0.13	0.15	0.17	0.16
1989	28.94	1.9	75.24	28.94	2.7	108.54	28.94	3.4	137.70	28.94	3.0	111.60	0.45	0.31	0.25	0.30	0.33
1990	29.32	1.8	71.28	29.32	2.8	112.56	29.32	3.0	121.50	29.32	3.2	119.04	0.43	0.27	0.25	0.25	0.30
1991	30.61	1.9	75.24	30.61	2.8	112.56	30.61	3.2	129.60	30.61	3.5	130.20	0.55	0.37	0.32	0.32	0.39
1992	26.27	2.3	91.08	26.27	2.9	116.58	26.27	2.8	113.40	26.27	2.8	104.16	0.31	0.24	0.25	0.27	0.27
1993	24.92	2.3	91.08	24.92	2.7	108.54	24.92	2.7	109.35	24.92	2.8	104.16	0.44	0.37	0.37	0.39	0.39
1994	31.16	2.1	83.16	31.16	2.6	104.52	31.16	3.2	129.60	31.16	3.1	115.32	0.32	0.25	0.20	0.23	0.25
1995	25.76	1.8	71.28	25.76	2.9	116.58	25.76	3.1	125.55	25.76	3.0	111.60	0.53	0.32	0.30	0.34	0.37
1996	27.35	1.4	55.44	27.35	2.8	112.56	27.35	3.2	129.60	27.35	3.3	122.76	0.50	0.25	0.21	0.23	0.30
1997	29.47	1.8	71.28	29.47	2.9	116.58	29.47	3.1	125.55	29.47	3.1	115.32	0.41	0.25	0.23	0.25	0.29
1998	34.13	2.0	79.20	34.13	2.3	92.46	34.13	3.5	141.75	34.13	3.5	130.20	0.38	0.32	0.21	0.23	0.29
1999	26.06	1.9	75.24	26.06	2.5	100.50	26.06	2.8	113.40	26.06	3.3	122.76	0.41	0.31	0.27	0.25	0.31
2000	27.77	1.9	75.24	27.77	2.5	100.50	27.77	3.3	133.65	27.77	3.1	115.32	0.54	0.40	0.30	0.35	0.40
2001	30.57	1.9	75.24	30.57	2.5	100.50	30.57	3.3	133.65	30.57	3.3	122.76	0.23	0.17	0.13	0.14	0.17
2002	24.41	1.6	63.36	24.41	2.9	116.58	24.41	3.4	137.70	24.41	2.8	104.16	0.65	0.35	0.30	0.39	0.42
2003	30.26	1.7	67.32	30.26	2.5	100.50	30.26	3.3	133.65	30.26	3.5	130.20	0.45	0.30	0.23	0.23	0.30
2004	23.06	1.6	63.36	23.06	2.2	88.44	23.06	3.1	125.55	23.06	2.7	100.44	0.56	0.40	0.28	0.35	0.40
2005	27.16	1.7	67.32	27.16	2.6	104.52	27.16	3.2	129.60	27.16	3.0	111.60	0.32	0.20	0.16	0.19	0.22
2006	29.75	2.1	83.16	29.75	2.7	108.54	29.75	3.5	141.75	29.75	3.0	111.60	0.28	0.21	0.16	0.21	0.22
Average	28.75	1.92	76.20	28.75	2.71	108.82	28.75	3.20	129.74	28.75	3.09	114.81	0.39	0.27	0.22	0.25	0.28

Appendix B. CGCM2 A21, CSRIOMk2b B11, and HadCM3 B21 GCM projected changes of temperature and precipitation for Grasslands National Park for the years 2020, 2050 and 2080.

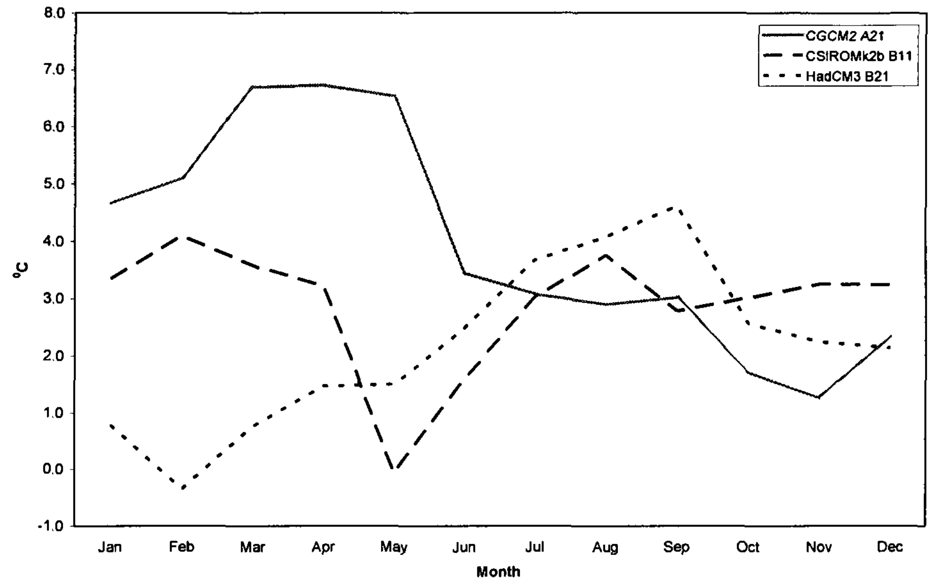




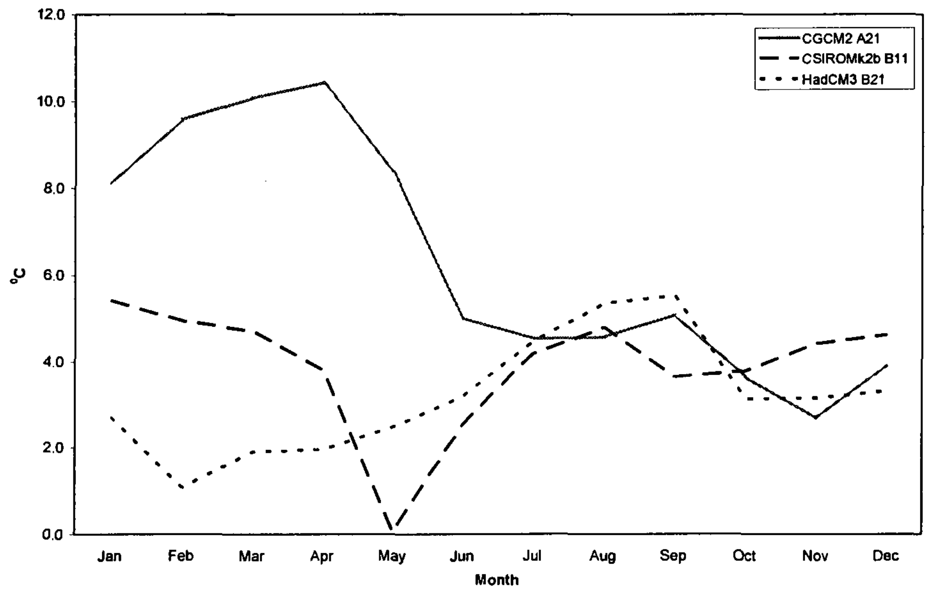

Projected Monthly Precipitation Change for GNP - 2080s
% Change
80.0
60.0
40.0
20.0
0.0
-20.0
-40.0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
CGCM2 A21
CSIROMk2b B11
HadCM3 B21


Projected Monthly Temperature Change for GNP - 2020s
°C
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
CGCM2 A21
CSIROMk2b B11
HadCM3 B21

Projected Monthly Temperature Change for GNP - 2050s



Projected Monthly Temperature Change for GNP - 2080s



Appendix C. Temperature and precipitation averages from 1978 to 2006 for GNP.

Temperature Averages 1978-2006 for GNP													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
1978	-20.2	-16.2	-6.0	5.7	11.3	16.1	18.1	16.8	12.5	6.5	-7.9	-14.7	1.8
1979	-20.2	-18.2	-4.4	1.6	8.9	16.2	19.7	18.3	14.4	7.6	-4.3	-6.2	2.8
1980	-16.2	-12.5	-5.6	9.6	13.8	16.1	19.1	15.3	11.9	5.6	-0.5	-12.0	3.7
1981	-5.4	-6.1	1.1	6.3	12.1	13.4	19.0	19.8	13.4	4.8	0.3	-10.6	5.7
1982	-22.6	-13.1	-6.0	1.8	9.0	14.9	17.7	17.4	11.1	5.0	-6.6	-8.4	1.7
1983	-7.5	-4.7	-1.6	4.0	9.6	15.3	19.7	20.7	10.9	6.3	-2.1	-22.9	4.0
1984	-9.2	-1.7	-3.1	6.8	9.9	15.6	20.4	20.6	7.9	1.9	-4.8	-16.2	4.0
1985	-12.8	-15.2	-2.2	6.7	13.4	13.7	20.0	16.5	7.8	4.4	-15.0	-10.4	2.2
1986	-4.8	-13.0	3.2	4.2	11.0	17.2	17.1	16.9	9.1	6.9	-7.3	-7.6	4.4
1987	-7.4	-3.1	-1.2	8.3	13.3	17.6	18.5	14.7	13.0	4.2	-0.3	-6.6	5.9
1988	-13.4	-9.3	-0.7	5.0	15.1	21.6	18.8	17.6	11.1	5.2	-4.7	-9.3	4.8
1989	-10.5	-16.3	-6.3	4.3	10.9	15.8	20.0	17.7	11.3	4.3	-2.3	-11.6	3.1
1990	-6.5	-9.8	0.1	4.3	10.6	15.9	17.8	18.5	14.2	3.9	-3.5	-13.2	4.4
1991	-12.9	-1.1	-3.0	6.1	11.0	15.9	18.7	20.2	12.2	3.9	-5.6	-5.7	5.0
1992	-4.4	-3.4	1.7	5.5	12.5	16.0	15.6	15.2	10.5	5.1	-2.6	-14.8	4.7
1993	-19.1	-14.4	0.0	5.8	12.3	14.7	15.1	15.3	10.1	4.9	-7.2	-6.5	2.6
1994	-14.4	-15.9	1.3	5.7	12.3	15.0	19.0	18.2	14.1	5.6	-3.4	-7.5	4.2
1995	-12.3	-6.4	-3.7	1.1	9.6	16.0	17.3	17.0	10.7	5.2	-4.4	-13.4	3.1
1996	-18.9	-9.4	-8.3	3.6	7.5	16.2	18.5	19.2	11.0	4.1	-17.5	-15.9	0.8
1997	-16.8	-6.8	-4.1	3.0	10.3	16.7	18.1	17.9	14.1	5.3	-3.3	-4.6	4.2
1998	-15.2	-2.1	-4.2	6.9	12.2	14.1	20.4	20.8	15.3	6.0	-1.3	-12.8	5.0
1999	-12.2	-4.1	-1.0	5.1	10.1	14.0	16.2	18.8	9.9	5.4	1.0	-4.2	4.9
2000	-11.8	-9.6	-0.3	4.5	10.5	13.9	19.3	18.1	11.6	4.4	-6.8	-15.1	3.2
2001	-6.6	-14.8	-1.9	4.8	11.3	14.8	19.6	19.4	14.1	3.2	0.1	-3.3	5.1
2002	-10.8	-7.6	-14.1	1.5	8.0	15.9	19.3	15.2	11.1	0.0	-1.4	-6.6	2.5
2003	-11.4	-11.4	-5.3	5.9	9.7	14.6	19.5	20.6	10.7	6.9	-11.1	-10.0	3.2
2004	-15.0	-11.1	-1.0	6.0	8.3	12.0	17.2	15.1	11.0	4.0	-2.2	-0.5	3.7
2005	-15.7	-4.9	0.4	5.3	9.3	15.1	18.4	16.6	11.3	5.1	-1.3	-9.2	4.2
2006	-4.1	-8.7	-4.9	7	12	15.4	20.5	17.8	10.7	2.6	-6.2	-9	4.4
Average	-12.4	-9.3	-2.8	5.0	10.9	15.5	18.6	17.8	11.6	4.8	-4.6	-10.0	3.8

Precipitation Averages 1978-2006 for GNP													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Sum
1978	12.2	65.9	10.1	23.4	53.0	68.7	75.1	29.8	44.5	12.4	26.2	15.7	437.0
1979	4.0	24.7	6.2	45.5	39.6	39.0	78.4	15.2	18.2	25.0	0.0	6.6	302.4
1980	34.4	8.8	19.2	5.0	26.0	82.8	16.2	23.0	21.2	28.8	3.0	28.3	296.7
1981	2.6	3.6	8.6	6.6	54.6	71.9	30.0	2.0	14.0	37.8	11.0	21.0	263.7
1982	24.5	7.2	17.2	9.2	87.7	35.4	99.4	17.7	34.4	21.0	1.4	4.6	359.7
1983	14.2	6.6	29.6	5.8	57.0	18.2	44.6	7.2	25.2	1.6	3.6	16.2	229.8
1984	11.8	7.8	24.2	4.8	24.8	46.6	4.0	14.0	19.8	8.8	6.6	20.8	194.0
1985	3.6	8.6	16.4	25.2	58.6	7.0	9.9	40.4	48.0	19.8	38.8	16.4	292.7
1986	6.8	16.2	10.6	26.8	96.2	56.2	19.8	6.4	128.8	26.2	29.0	2.2	425.2
1987	10.2	3.0	21.8	9.0	46.8	38.8	79.2	22.8	19.2	3.8	2.2	4.8	261.6
1988	4.8	9.2	11.0	0.0	6.4	71.0	55.8	4.2	29.0	2.0	12.0	16.4	221.8
1989	28.0	10.6	4.0	16.0	64.2	87.8	67.0	65.0	19.8	16.6	17.8	10.6	407.4
1990	14.8	4.8	25.8	32.4	65.2	45.0	98.2	27.2	2.4	7.2	19.2	21.4	363.6
1991	9.0	20.0	26.0	42.2	60.0	208.8	44.0	42.0	10.4	17.4	6.4	8.8	495.0
1992	6.0	6.2	0.8	5.2	17.6	96.4	78.4	57.0	19.0	13.6	21.8	12.8	334.8
1993	3.4	9.8	17.6	10.0	10.0	5.2	83.0	171.6	113.2	32.4	20.2	6.8	483.2
1994	39.8	14.4	1.6	19.6	61.4	97.0	17.0	20.0	4.4	29.2	5.8	6.0	316.2
1995	4.6	3.6	16.6	49.8	24.2	104.2	75.0	45.0	37.4	46.4	22.6	25.0	454.4
1996	29.4	8.7	20.8	9.2	43.4	37.8	13.8	14.8	81.6	12.2	31.4	30.8	333.9
1997	12.6	1.8	38.2	40.0	46.1	95.6	32.0	40.4	13.0	17.0	10.4	1.0	348.1
1998	11.2	2.4	25.0	11.2	12.1	121.8	32.6	30.0	18.6	33.6	42.0	19.0	359.5
1999	23.0	10.4	10.0	26.4	87.8	82.2	53.2	29.4	22.0	18.8	0.6	10.0	373.8
2000	12.2	11.8	19.0	39.8	103.8	62.6	157.2	29.6	33.4	3.2	7.4	7.5	487.5
2001	3.0	15.6	17.5	15.7	25.2	41.9	48.4	2.0	17.2	10.0	11.0	3.3	210.8
2002	17.0	13.0	32.0	3.6	32.4	154.0	73.6	111.2	31.0	9.6	10.0	4.6	492.0
2003	27.6	12.0	13.0	41.9	51.4	71.0	9.6	17.0	48.4	28.4	21.6	20.0	361.9
2004	57.0	5.0	9.2	3.0	131.8	46.1	82.8	40.2	23.0	8.0	6.0	15.6	427.7
2005	9.0	2.0	19.0	7.2	22.6	89.4	14.8	55.8	24.8	15.8	9.4	5.0	274.8
2006	14.0	12.0	9.0	32.2	37.7	64.2	11.0	7.6	50.2	23.6	13.6	2.5	277.6
Average	15.5	11.2	16.6	19.5	49.9	70.6	51.9	34.1	33.5	18.3	14.2	12.5	347.8

Appendix D. NDVI and MSI *Monte Carlo simulation averages from the 266 pixel points for the years 2020, 2050 and 2080 for all three GCMs* (CGCM2 A21, CSIROMk2b B11 and HadCM3). The NDVI & MSI vegetation change scenarios were calculated using the averages from the dataset.

				CGCM2 A21 (warm-dry)			CSIROMk2b B11 (mid-range)			HadCM3 B21 (cool-wet)	
Easting	Northing	Average	2020	2050	2080	2020	2050	2080	2020	2050	2080
301900.000	5451700.000	0.164052	0.123002	0.065402	-0.013390	0.126910	0.096364	0.062687	0.122486	0.085801	0.024638
318500.000	5442100.000	0.168537	0.131002	0.073402	-0.005390	0.136424	0.105878	0.072201	0.132000	0.095315	0.034152
338100.000	5432150.000	0.213574	0.228002	0.170402	0.091606	0.231959	0.201413	0.167737	0.227535	0.190850	0.129687
310175.000	5449575.000	0.152686	0.099002	0.041402	-0.037390	0.102800	0.072254	0.038577	0.098376	0.061691	0.000528
307775.000	5450050.000	0.022403	-0.176998	-0.234600	-0.313390	-0.173565	-0.204110	-0.237790	-0.177989	-0.214670	-0.275840
318800.000	5446625.000	0.332313	0.480002	0.422402	0.343606	0.483836	0.453290	0.419613	0.479412	0.442727	0.381564
334750.000	5432100.000	0.093211	-0.026998	-0.084600	-0.163390	-0.023363	-0.053910	-0.087580	-0.027787	-0.064470	-0.125630
314500.000	5445425.000	0.223113	0.248002	0.190402	0.111606	0.252194	0.221648	0.187971	0.247770	0.211085	0.149922
314425.000	5449475.000	0.117406	0.024002	-0.033600	-0.112390	0.027961	-0.002580	-0.036260	0.023537	-0.013150	-0.074310
312750.000	5451150.000	0.150127	0.093002	0.035402	-0.043390	0.097371	0.066825	0.033149	0.092947	0.056262	-0.004900
312725.000	5449425.000	0.427857	0.683002	0.625402	0.546606	0.686509	0.655964	0.622287	0.682085	0.645401	0.584238
308325.000	5450775.000	0.042990	-0.133798	-0.191400	-0.270190	-0.129894	-0.160440	-0.194120	-0.134318	-0.171000	-0.232170
315350.000	5450575.000	0.369120	0.558002	0.500402	0.421606	0.561913	0.531367	0.497691	0.557489	0.520804	0.459641
314800.000	5447975.000	0.368246	0.556002	0.498402	0.419606	0.560059	0.529513	0.495837	0.555635	0.518950	0.457787
318550.000	5447400.000	0.315266	0.444002	0.386402	0.307606	0.447674	0.417129	0.383452	0.443250	0.406566	0.345403
333250.000	5431900.000	0.471871	0.775002	0.717402	0.638606	0.779875	0.749329	0.715652	0.775451	0.738766	0.677603
332575.000	5443325.000	0.096692	-0.019998	-0.077600	-0.156390	-0.015978	-0.046520	-0.080200	-0.020402	-0.057090	-0.118250
333050.000	5430475.000	0.376184	0.573002	0.515402	0.436606	0.576897	0.546352	0.512675	0.572473	0.535789	0.474626
305525.000	5448875.000	0.394612	0.612002	0.554402	0.475606	0.615988	0.585442	0.551766	0.611564	0.574879	0.513716
332025.000	5442600.000	0.041341	-0.136998	-0.194600	-0.273390	-0.133392	-0.163940	-0.197610	-0.137816	-0.174500	-0.235660
312075.000	5450075.000	0.053312	-0.111998	-0.169600	-0.248390	-0.107999	-0.138540	-0.172220	-0.112423	-0.149110	-0.210270
317775.000	5452475.000	0.028003	-0.165998	-0.223600	0.302390	-0.161686	-0.192230	-0.225910	-0.166110	-0.202790	-0.263960
319675.000	5453375.000	0.135333	0.062002	0.004402	-0.074390	0.065989	0.035443	0.001767	0.061565	0.024880	-0.036280
313850.000	5447250.000	0.148934	0.091002	0.033402	-0.045390	0.094841	0.064295	0.030618	0.090417	0.053732	-0.007430
333700.000	5442525.000	0.217451	0.236002	0.178402	0.099606	0.240183	0.209637	0.175961	0.235759	0.199074	0.137912
336375.000	5431350.000	0.082479	-0.049998	-0.107600	-0.186390	-0.046128	-0.076670	-0.110350	-0.050552	-0.087240	-0.148400
306875.000	5451300.000	0.074134	-0.067998	-0.125600	-0.204390	-0.063830	-0.094380	-0.128050	-0.068254	-0.104940	-0.166100
316275.000	5449475.000	0.142235	0.077002	0.019402	-0.059390	0.080630	0.050084	0.016408	0.076206	0.039521	-0.021640
304600.000	5450450.000	0.411561	0.648002	0.590402	0.511606	0.651941	0.621396	0.587719	0.647517	0.610833	0.549670
333650.000	5432225.000	0.057969	-0.101998	-0.159600	-0.238390	-0.098120	-0.128670	-0.162340	-0.102544	-0.139230	-0.200390
316125.000	5446975.000	0.123339	0.037002	-0.020600	-0.099390	0.040547	0.010001	-0.023680	0.036123	-0.000560	-0.061720
323250.000	5448350.000	0.202125	0.204002	0.146402	0.067606	0.207673	0.177127	0.143450	0.203249	0.166564	0.105401
302850.000	5451775.000	0.220735	0.243002	0.185402	0.106606	0.247149	0.216604	0.182927	0.242725	0.206041	0.144878
324550.000	5450075.000	0.141562	0.075002	0.017402	-0.061390	0.079203	0.048657	0.014980	0.074779	0.038094	-0.023070
305925.000	5449350.000	0.177118	0.151002	0.093402	0.014606	0.154626	0.124080	0.090404	0.150202	0.113517	0.052355
318250.000	5445425.000	0.116626	0.022002	-0.035600	-0.114390	0.026307	-0.004240	-0.037920	0.021883	-0.014800	-0.075960
311100.000	5450975.000	0.117596	0.024002	-0.033600	-0.112390	0.028364	-0.002180	-0.035860	0.023940	-0.012740	-0.073910
306825.000	5454700.000	0.417981	0.662002	0.604402	0.525606	0.665560	0.635014	0.601338	0.651136	0.624451	0.563288
320175.000	5449850.000	0.146727	0.086002	0.028402	-0.050390	0.090159	0.059613	0.025937	0.085735	0.049050	-0.012110
308225.000	5444150.000	0.215557	0.232002	0.174402	0.095606	0.236165	0.205620	0.171943	0.231741	0.195057	0.133894
312750.000	5448850.000	0.165730	0.127002	0.069402	-0.009390	0.130469	0.099925	0.066247	0.126045	0.089360	0.028198
316250.000	5442700.000	0.335312	0.486002	0.428402	0.349606	0.490197	0.459651	0.425975	0.485773	0.449088	0.387926
301425.000	5450675.000	0.425331	0.677002	0.619402	0.540606	0.681151	0.650605	0.616929	0.676727	0.640042	0.578880
332500.000	5442825.000	0.107590	0.003002	-0.054600	-0.133390	0.007139	-0.023410	-0.057080	0.002715	-0.033970	-0.095130
304700.000	5448400.000	0.139485	0.071002	0.013402	-0.065390	0.074797	0.044251	0.010574	0.070373	0.033688	-0.027470
328275.000	5448500.000	0.163103	0.121001	0.063402	-0.015390	0.124897	0.094351	0.060674	0.120473	0.083788	0.022625
334625.000	5430175.000	0.148900	0.091002	0.033402	-0.045390	0.094768	0.064223	0.030546	0.090344	0.053660	-0.007500
317250.000	5449525.000	0.328921	0.473002	0.415402	0.336606	0.476640	0.446094	0.412418	0.472216	0.435531	0.374369
304075.000	5448075.000	0.293125	0.397002	0.339402	0.260606	0.400708	0.370162	0.336485	0.396284	0.359599	0.298436
306725.000	5453125.000	0.192274	0.183002	0.125402	0.046606	0.186776	0.156230	0.122554	0.182352	0.145667	0.084504
303900.000	5450475.000	0.319175	0.452002	0.394402	0.315606	0.455966	0.425421	0.391744	0.451542	0.414858	0.353695
333725.000	5431200.000	0.176658	0.150002	0.092402	0.013606	0.153650	0.123105	0.089428	0.149226	0.112542	0.051379
338025.000	5440600.000	0.140318	0.073002	0.015402	-0.063390	0.076564	0.046018	0.012341	0.072140	0.035455	-0.025710
322175.000	5450400.000	0.145593	0.084002	0.026402	-0.052390	0.087753	0.067208	0.023531	0.083029	0.046645	-0.014520
311025.000	5446050.000	0.136977	0.066002	0.008402	-0.070390	0.069477	0.038931	0.005254	0.065063	0.028368	-0.032790
315700.000	5454175.000	0.191886	0.182002	0.124402	0.045606	0.185953	0.155407	0.121731	0.181529	0.144844	0.083681
310775.000	5454575.000	0.148628	0.090002	0.032402	-0.046390	0.094191	0.063646	0.029969	0.089767	0.053083	-0.008080
309675.000	5447800.000	0.281174	0.371002	0.313402	0.234606	0.375356	0.344811	0.311134	0.370932	0.334247	0.273085
307700.000	5448850.000	0.322646	0.459002	0.410402	0.322606	0.463329	0.432784	0.399107	0.458905	0.422220	0.361058
307700.000	5447475.000	0.151971	0.097002	0.039402	-0.039390	0.101283	0.070737	0.037060	0.096859	0.060174	-0.000990
308275.000	5446625.000	0.220472	0.243002	0.185402	0.106606	0.246591	0.216046	0.182369	0.242167	0.205483	0.144320
304750.000	5449675.000	0.556125	0.955002	0.897402	0.818606	0.958600	0.928054	0.894377	0.954176	0.918714	0.856328
303875.000	5448925.000	0.333773	0.483002	0.425402	0.346606	0.486933	0.456387	0.422710	0.482509	0.445824	0.384661
303800.000	5452250.000	0.361346	0.542002	0.484402	0.405606	0.545422	0.514876	0.481200	0.540998	0.504313	0.443151
302975.000	5448825.000	0.283395	0.376002	0.318402	0.239606	0.380068	0.349522	0.315845	0.375644	0.338959	0.277796
303050.000	5448075.000	0.343550	0.504002	0.446402	0.367606	0.507672	0.477126	0.443450	0.503248	0.466563	0.405401
302200.000	5452650.000	0.288958	0.388002	0.330402	0.251606	0.391868	0.361322	0.327646	0.387444	0.350759	0.289597
308675.000	5453750.000	0.165799	0.127002	0.069402	-0.009390	0.130616	0.100070	0.066393	0.126192	0.089507	0.028344
309325.000	5454500.000	0.152670	0.099002	0.041402	-0.037390	0.102766	0.072220	0.038543	0.098342	0.061657	0.000494
310325.000	5452575.000	0.235220	0.274002	0.216402	0.137606	0.277876	0.247330	0.213653	0.273452	0.236767	0.175604
312800.000	5453300.000	0.141760	0.076002	0.018402	-0.060390	0.079623	0.049077	0.015400	0.075199	0.038514	-0.022650
314200.000	5451175.000	0.411736	0.648002	0.590402	0.511606	0.652313	0.621767	0.588090	0.647889	0.611204	0.550041
312550.000	5453900.000	0.198180	0.195002	0.137402	0.058606	0.199304	0.168758	0.135082	0.194880	0.158195	0.097033
316300.000	5451850.000	0.114399	0.016002	-0.039600	-0.118390	0.021583	-0.008960	-0.042640	0.017159	-0.019530	-0.080690
317800.000	5454525.000	0.101661	-0.008998	-0.066600	-0.145390	-0.005438	-0.035980	-0.069660	-0.009862	-0.046550	-0.107710
318825.000	5451325.000	0.160711	0.116002	0.058402	-0.020390	0.119823	0.089277	0.055600	0.115399	0.078714	0.017551
321675.000	5451825.000	0.227052	0.258924	0.199402	0.120606	0.260549	0.230004	0.196327	0.256125	0.219441	0.158278
323500.000	5453150.000	0.164890	0.125002	0.067402	-0.011390	0.128687	0.098142	0.064465	0.124263	0.087579	0.026416
323950.000	5449675.000	0.261131	0.329002	0.271402	0.192606	0.332840	0.302294	0.268618	0.328416	0.291731	0.230568
318200.000	5448250.000	0.427151	0.681002	0.623402	0.544606	0.685012	0.655484	0.620789	0.680588	0.643903	0.582740
323725.000	5447250.000	0.177670	0.152002	0.094402	0.015606	0.155797	0.125251	0.091575	0.151373	0.114688	0.053526
325725.000	5446175.000	0.376542	0.574002	0.516402	0.437606	0.577657	0.547111	0.513435	0.573233	0.536548	0.475385
325150.000	5449000.000	0.209422	0.219002	0.161402	0.082606	0.223151	0.192606	0.158929	0.218727	0.182043	0.120880
328800.000	5449225.000	0.234669	0.273002	0.215402	0.136606	0.276707	0.246161	0.212485	0.272283	0.233559	0.174435

325375.000	5444425.000	0.369760	0.559002	0.501402	0.422606	0.563270	0.532725	0.499048	0.558846	0.522162	0.460999
328890.000	5446225.000	0.186994	0.172002	0.114402	0.035606	0.175576	0.145030	0.111353	0.171152	0.134467	0.073304
330950.000	5445750.000	0.182173	0.161002	0.103402	0.024606	0.165349	0.134803	0.101127	0.160925	0.124240	0.063078
333300.000	5440500.000	0.125908	0.042002	-0.015600	-0.094390	0.045996	0.015451	-0.018230	0.041572	0.004888	-0.056280
338675.000	5443100.000	0.493223	0.821002	0.763402	0.684606	0.825168	0.794622	0.760946	0.820744	0.784059	0.722896
334825.000	5440250.000	0.187937	0.174002	0.116402	0.037606	0.177576	0.147030	0.113354	0.173512	0.136467	0.075305
339575.000	5441650.000	0.212141	0.225002	0.167402	0.088606	0.228919	0.198373	0.164697	0.224495	0.187810	0.126648
340225.000	5444050.000	0.240719	0.286002	0.228402	0.149606	0.289541	0.258995	0.225318	0.285117	0.248432	0.187269
336900.000	5439775.000	0.219011	0.240002	0.182042	0.103606	0.243492	0.212946	0.179270	0.239068	0.202383	0.141221
335150.000	5438050.000	0.222890	0.248002	0.190402	0.111606	0.251721	0.221175	0.187498	0.247297	0.210612	0.149449
330225.000	5437200.000	0.485469	0.805002	0.747402	0.668606	0.808720	0.778174	0.744497	0.804296	0.767611	0.706448
335700.000	5434350.000	0.188912	0.176002	0.118402	0.039606	0.179644	0.149099	0.115422	0.175220	0.138536	0.077373
338150.000	5434275.000	0.219809	0.241002	0.183402	0.104606	0.245185	0.214639	0.180963	0.240761	0.204076	0.142913
335625.000	5430650.000	0.127635	0.046002	-0.011600	-0.090390	0.049660	0.019114	-0.014560	0.045236	0.008551	-0.052610
330800.000	5432800.000	0.311991	0.437002	0.379402	0.300606	0.440727	0.410181	0.376505	0.436303	0.399618	0.338456
327100.000	5430375.000	0.391725	0.606002	0.548402	0.469606	0.609864	0.579318	0.545642	0.605440	0.568755	0.507592
326100.000	5430800.000	0.206453	0.213002	0.155402	0.076606	0.216853	0.186308	0.152631	0.212429	0.175745	0.114582
327475.000	5431975.000	0.220254	0.242002	0.184402	0.105606	0.246129	0.215583	0.181907	0.241705	0.205020	0.143857
328100.000	5433025.000	0.163051	0.121002	0.063402	-0.015390	0.124786	0.094241	0.060564	0.120362	0.083678	0.022515
329150.000	5433425.000	0.311029	0.435002	0.377402	0.298606	0.438687	0.408141	0.374464	0.434263	0.397578	0.336415
328275.000	5434300.000	0.455050	0.740002	0.682402	0.603606	0.744193	0.713647	0.679971	0.739769	0.703084	0.641921
328075.000	5435425.000	0.427286	0.681002	0.623402	0.544606	0.685298	0.654752	0.621076	0.680874	0.644189	0.583027
327175.000	5436575.000	0.501739	0.839002	0.781402	0.702606	0.843233	0.812687	0.779010	0.838809	0.802124	0.740961
330225.000	5437200.000	0.485469	0.805002	0.747402	0.668606	0.808720	0.778174	0.744497	0.804296	0.767611	0.706448
333675.000	5436925.000	0.220577	0.243002	0.185402	0.106606	0.246814	0.216268	0.182592	0.242390	0.205705	0.144543
326475.000	5437225.000	0.319287	0.452002	0.394402	0.315606	0.456204	0.425658	0.391982	0.451780	0.415095	0.353932
325174.000	5437175.000	0.397440	0.618002	0.560402	0.481606	0.621987	0.591441	0.557765	0.617563	0.580878	0.519715
328725.000	5440025.000	0.213679	0.228002	0.170402	0.091606	0.232182	0.201635	0.167959	0.227758	0.191073	0.129910
325075.000	5439650.000	0.462146	0.755002	0.697402	0.618606	0.759245	0.728700	0.695023	0.754821	0.718137	0.656974
321600.000	5438575.000	0.277940	0.365002	0.307402	0.228606	0.368496	0.337950	0.304274	0.364072	0.327387	0.266225
326825.000	5442325.000	0.267753	0.343002	0.285402	0.206606	0.345887	0.316341	0.282665	0.342463	0.305778	0.244615
324675.000	5441125.000	0.461970	0.755002	0.697402	0.618606	0.758872	0.728326	0.694650	0.754448	0.717763	0.656600
323150.000	5441975.000	0.280773	0.371002	0.313402	0.234606	0.374506	0.343960	0.310283	0.370082	0.333397	0.272234
319850.000	5440825.000	0.240943	0.286002	0.228402	0.149606	0.290016	0.259470	0.225793	0.285592	0.248907	0.187744
325225.000	5443600.000	0.411819	0.649002	0.591402	0.512606	0.652489	0.621943	0.588266	0.648065	0.611380	0.550217
324550.000	5445700.000	0.336065	0.488002	0.430402	0.351606	0.491795	0.461249	0.427572	0.487371	0.450686	0.389523
321350.000	5442150.000	0.433741	0.695002	0.637402	0.558606	0.698991	0.668445	0.634769	0.694567	0.657882	0.596719
320425.000	5443325.000	0.415021	0.655002	0.597402	0.518606	0.659281	0.628735	0.595059	0.654857	0.618172	0.557009
322425.000	5446725.000	0.274284	0.357002	0.299402	0.220606	0.360741	0.330195	0.296518	0.356317	0.319632	0.258469
320725.000	5447050.000	0.124430	0.039002	-0.018600	-0.097390	0.042861	0.012315	-0.021360	0.038437	0.001752	-0.059410
317225.000	5447175.000	0.320451	0.455002	0.397402	0.318606	0.458673	0.428127	0.394451	0.454249	0.417564	0.356402
313650.000	5445400.000	0.262389	0.332002	0.274402	0.195606	0.335508	0.304963	0.271286	0.331084	0.294400	0.233237
315375.000	5444800.000	0.236449	0.277002	0.219402	0.140606	0.280483	0.249937	0.216261	0.276059	0.239374	0.178211
312325.000	5445250.000	0.213005	0.227002	0.169402	0.090606	0.230752	0.200206	0.166530	0.226328	0.189643	0.128480
302675.000	5450625.000	0.174712	0.146002	0.088402	0.009606	0.149522	0.118977	0.085300	0.145098	0.108414	0.047251
303075.000	5449825.000	0.253299	0.312002	0.254402	0.175606	0.316226	0.285680	0.252004	0.311802	0.275117	0.213956
304475.000	5451775.000	0.308031	0.428002	0.370402	0.291606	0.432327	0.401781	0.368105	0.427903	0.391218	0.330055
305775.000	5451750.000	0.030894	-0.159498	-0.217100	-0.295890	-0.155553	-0.186100	-0.219780	-0.159977	-0.196660	-0.257820
305825.000	5450975.000	0.059450	-0.098998	-0.156600	-0.235390	-0.094978	-0.125520	-0.159200	-0.099402	-0.136090	-0.197250
306700.000	5448025.000	0.128174	0.047002	-0.010600	-0.089390	0.050803	0.020257	-0.013420	0.046379	0.009694	-0.051470
306375.000	5447300.000	0.081631	-0.051998	-0.109600	-0.188390	-0.047927	-0.078470	-0.112150	-0.052351	-0.089040	-0.150200
306975.000	5446800.000	0.079321	-0.056998	-0.114600	-0.193390	-0.052827	-0.083370	-0.117050	-0.057251	-0.093940	-0.155100
307600.000	5446100.000	0.159327	0.113002	0.055402	-0.023390	0.116887	0.086341	0.052665	0.112463	0.075778	0.014615
307200.000	5445150.000	0.187194	0.172002	0.114402	0.035606	0.176000	0.145454	0.111778	0.171576	0.134891	0.073728
306075.000	5444525.000	0.214757	0.231002	0.173402	0.094606	0.234468	0.203923	0.170246	0.230044	0.193360	0.132197
306025.000	5444125.000	0.194220	0.187002	0.129402	0.050606	0.190904	0.160358	0.126682	0.186480	0.149795	0.088632
305275.000	5445250.000	0.193409	0.185002	0.127402	0.048606	0.189184	0.158638	0.124961	0.184760	0.148075	0.086912
305300.000	5446425.000	0.177968	0.153002	0.095402	0.016606	0.156429	0.125884	0.092207	0.152005	0.115320	0.054158
304975.000	5447475.000	0.114509	0.018002	-0.039600	-0.118390	0.021816	-0.008730	-0.042410	0.017392	-0.019290	-0.080460
306075.000	5454075.000	0.190462	0.179002	0.121402	0.042606	0.182932	0.152387	0.118710	0.178508	0.141824	0.080661
308400.000	5454600.000	0.169515	0.135002	0.077402	-0.001390	0.138498	0.107952	0.074276	0.134074	0.097389	0.036227
307775.000	5453250.000	0.132245	0.056002	-0.001600	-0.080390	0.059439	0.028893	-0.004780	0.055015	0.018330	-0.042830
306900.000	5449700.000	0.015055	-0.193098	-0.250700	-0.329490	-0.189152	-0.219700	-0.253370	-0.193576	-0.230260	-0.291420
308800.000	5449450.000	0.156340	0.107002	0.049402	-0.029390	0.110551	0.080005	0.046328	0.106127	0.069442	0.008279
308550.000	5448350.000	0.175792	0.148002	0.090402	0.011606	0.151813	0.121268	0.087591	0.147389	0.110705	0.049542
309425.000	5446825.000	0.173663	0.143002	0.085402	0.006606	0.147297	0.116751	0.083075	0.142873	0.106188	0.045026
308700.000	5445650.000	0.280955	0.371002	0.313402	0.234606	0.374892	0.344346	0.310669	0.370468	0.333783	0.272620
309175.000	5444600.000	0.189693	0.177002	0.119402	0.040606	0.181301	0.150755	0.117079	0.176877	0.140192	0.079030
309975.000	5444050.000	0.207170	0.214002	0.156402	0.077606	0.218374	0.187829	0.154152	0.213950	0.177266	0.116103
310600.000	5445225.000	0.166842	0.129002	0.071402	-0.007390	0.132828	0.102282	0.068606	0.128404	0.091719	0.030557
311175.000	5444125.000	0.212951	0.227002	0.169402	0.090606	0.230637	0.200092	0.166415	0.226213	0.189529	0.128366
312425.000	5444200.000	0.202487	0.205002	0.147402	0.068606	0.208441	0.177895	0.144218	0.204017	0.167332	0.106169
313350.000	5443950.000	0.199791	0.199002	0.141402	0.062606	0.202722	0.172176	0.138499	0.198298	0.161613	0.100450
315475.000	5443775.000	0.302467	0.417002	0.359402	0.280606	0.420524	0.389979	0.356302	0.416100	0.379416	0.318253
314775.000	5446500.000	0.175091	0.148002	0.088402	0.009606	0.150326	0.119781	0.086104	0.145902	0.109218	0.048055
316600.000	5446075.000	0.151626	0.097002	0.039402	-0.03939	0.100551	0.070005	0.036329	0.096127	0.059442	-0.001720
316825.000	5445050.000	0.179037	0.155002	0.097402	0.018606	0.158697	0.128151	0.094475	0.154273	0.117588	0.056425
318425.000	5444350.000	0.192996	0.184402	0.126802	0.048006	0.188308	0.157762	0.124085	0.183884	0.147199	0.086036
317500.000	5443400.000	0.173540	0.143122	0.085522	0.006726	0.147036	0.116491	0.082814	0.142612	0.105928	0.044765
317225.000	5442025.000	0.180725	0.158372	0.100772	0.021976	0.162278	0.131732	0.098055	0.157854	0.121169	0.060006
319425.000	5444425.000	0.082939	-0.049068	-0.106670	-0.185460	-0.045152	-0.075700	-0.109370	-0.049576	-0.086260	-0.147420
319875.000	5442450.000	0.165127	0.125280	0.067680	-0.011120	0.129190	0.098644	0.064968	0.124766	0.088081	0.026919
321425.000	5446075.000	0.147301	0.087468	0.029866	-0.048930	0.091377	0.060831	0.027154	0.086953	0.050268	-0.010900
320575.000	5444975.000	0.139168	0.070214	0.012614	-0.066180	0.074124	0.043579	0.009902	0.069700	0.033015	-0.028150
321575.000	5444825.000	0.169693	0.134965	0.077365	-0.001430	0.138876	0.108330	0.074654	0.134452	0.097767	0.036604
321975.000	5443250.000	0.144184	0.080854	0.023254	-0.055540	0.084765	0.054219	0.020542	0.080341	0.043656	-0.017510
323125.000	5444325.000	0.149206	0.091507	0.033907	-0.044890	0.095418	0.064872	0.031195	0.090994	0.054309	-0.006850
324125.000	5443025.000	0.168270	0.131947	0.074237	-0.004450	0.135857	0.105312	0.071635	0.131433	0.094748	0.033586
324000.000	5442125.000	0.103947	-0.004499	-0.062100	-0.140900	-0.000589	-0.031130	-0.064810	-0.005013	-0.041700	-0.102860
321700.000	5440150.000	0.198465	0.195998	0.138398	0.059602	0.199909	0.169363	0.135686	0.195485	0.158800	0.097637
323850.000	5439925.000	0.174227	0.144583	0.086983	0.008187	0.148494	0.117948	0.084271	0.144070	0.107385	0.046222
323125.000	5438350.000	0.066221	-0.084526	-0.142130	-0.220920	-0.080615	-0.111160	-0.144840	-0.085039	-0.121720	-0.182890
322075.000	5437325.000	0.117514	0.024280	-0.033320	-0.112120	0.028191	-0.002360	-0.036030	0.023767	-0.012920	-0.074080

321275.000	5435900.000	0.168392	0.132206	0.074606	-0.004190	0.136116	0.105570	0.071894	0.131692	0.095007	0.033845
321900.000	5434625.000	0.180169	0.157188	0.099588	0.020792	0.161098	0.130552	0.096876	0.156674	0.119989	0.058827
322725.000	5435800.000	0.182944	0.163074	0.105474	0.026678	0.166985	0.136439	0.102762	0.162561	0.125876	0.064713
324925.000	5436175.000	0.058776	-0.100319	-0.157920	-0.236720	-0.096408	-0.126950	-0.160630	-0.100832	-0.137520	-0.198680
324200.000	5434100.000	0.144009	0.080843	0.023243	-0.055550	0.084393	0.053848	0.020171	0.079969	0.043285	-0.017880
325975.000	5435100.000	0.106261	0.000410	-0.057190	-0.135990	0.004320	-0.026230	-0.059900	-0.000104	-0.036790	-0.097950
326600.000	5436250.000	0.137425	0.066517	0.008917	-0.069880	0.070427	0.039881	0.006205	0.066003	0.029318	-0.031840
327000.000	5434550.000	0.151011	0.095336	0.037736	-0.041060	0.099246	0.068701	0.035024	0.094822	0.058138	-0.003030
326150.000	5432625.000	0.201091	0.201569	0.143969	0.065173	0.205479	0.174933	0.141257	0.201055	0.164370	0.103208
329225.000	5432275.000	0.030350	-0.160618	-0.218220	-0.297010	-0.156707	-0.187250	-0.220930	-0.161131	-0.197820	-0.258980
328750.000	5430850.000	0.043518	-0.132685	-0.190280	-0.269080	-0.128774	-0.159320	-0.193000	-0.133198	-0.169880	-0.231050
330600.000	5430475.000	0.110360	0.009105	-0.048490	-0.127290	0.013015	-0.017530	-0.051210	0.008591	-0.028090	-0.089260
330175.000	5431650.000	0.056483	-0.105183	-0.162780	-0.241580	-0.101272	-0.131820	-0.165490	-0.105696	-0.142380	-0.203540
331875.000	5431500.000	0.079718	-0.055895	-0.113490	-0.192290	-0.051985	-0.082530	-0.116210	-0.056409	-0.093090	-0.154260
337775.000	5431075.000	0.185491	0.168477	0.110877	0.032081	0.172388	0.141842	0.108165	0.167964	0.131279	0.070116
336825.000	5430400.000	0.117786	0.024857	-0.032740	-0.111540	0.028767	-0.001780	-0.035450	0.024343	-0.012340	-0.073500
336250.000	*5432625.000*	*0.208694*	*0.217697*	*0.160097*	*0.081301*	*0.221607*	*0.191061*	*0.157385*	*0.217183*	*0.180498*	*0.119036*
337025.000	5433650.000	0.167288	0.129864	0.072264	-0.006530	0.133774	0.103228	0.069552	0.129350	0.092665	0.031503
336425.000	5435550.000	0.130035	0.050840	-0.006760	-0.085560	0.054751	0.024205	-0.009470	0.050327	0.013642	-0.047520
336375.000	5437250.000	0.171613	0.139038	0.081438	0.002642	0.142949	0.112403	0.078726	0.138525	0.101840	0.040677
338050.000	5437000.000	0.203954	0.207642	0.150042	0.071246	0.211552	0.181007	0.147330	0.207128	0.170444	0.109281
338550.000	5438425.000	0.206816	0.213713	0.156113	0.077317	0.217623	0.187078	0.153401	0.213199	0.176515	0.115352
339925.000	5438250.000	0.189670	0.195341	0.137741	0.058945	0.181252	0.150707	0.117030	0.176828	0.140143	0.078981
338650.000	5439775.000	0.212680	0.226152	0.168552	0.089756	0.230063	0.199517	0.165840	0.225639	0.188954	0.127791
340050.000	5440875.000	0.181716	0.160469	0.102869	0.024073	0.164380	0.133834	0.100157	0.159956	0.123271	0.062108
336400.000	5440825.000	0.199482	0.198156	0.140556	0.061760	0.202066	0.171520	0.137844	0.196419	0.160957	0.099795
337675.000	5442100.000	0.236522	0.276727	0.219127	0.140331	0.280638	0.250092	0.216415	0.276214	0.239529	0.178366
337025.000	5444125.000	0.278318	0.365388	0.307788	0.228992	0.369298	0.338752	0.305076	0.364874	0.328189	0.267026
335225.000	5442475.000	0.135907	0.063296	0.005696	-0.073100	0.057207	0.036661	0.002985	0.062783	0.026098	-0.035060
333740.000	5443650.000	0.091302	-0.031322	-0.088920	-0.167720	-0.027412	-0.057960	-0.091630	-0.031836	-0.068520	-0.129680
331700.000	5444450.000	0.163880	0.122635	0.065035	-0.013760	0.126545	0.095999	0.062323	0.122121	0.085436	0.024273
332125.000	5445975.000	0.143473	0.079346	0.021746	-0.057050	0.083256	0.052711	0.019034	0.078832	0.042148	-0.019020
330375.000	5443500.000	0.101095	-0.010549	-0.068150	-0.146950	-0.006639	-0.037180	-0.070860	-0.011063	-0.047750	-0.108910
329950.000	5444800.000	0.141725	0.075636	0.018036	-0.060760	0.079548	0.049003	0.015326	0.075124	0.038440	-0.022720
329075.000	5443775.000	0.091921	-0.030009	-0.087610	-0.166410	-0.026099	-0.056640	-0.090320	-0.030523	-0.067210	-0.128370
327625.000	5443525.000	0.009891	-0.204000	-0.261600	-0.340400	-0.200106	-0.230650	-0.264330	-0.204530	-0.241210	-0.302380
328925.000	5445425.000	0.032035	-0.157043	-0.214640	-0.293440	-0.153133	-0.183680	-0.217360	-0.157557	-0.194240	-0.255400
326275.000	5444625.000	0.069867	-0.076792	-0.134390	-0.213190	-0.072881	-0.103430	-0.137100	-0.077305	-0.113990	-0.175150
327175.000	5446150.000	0.179070	0.154857	0.097257	0.018461	0.158767	0.128221	0.094545	0.154343	0.117658	0.056495
325725.000	5442950.000	0.169093	0.133693	0.076093	-0.002700	0.137603	0.107057	0.073381	0.133179	0.096494	0.035332
325400.000	5442000.000	0.103485	-0.005479	-0.063080	-0.141880	-0.001569	-0.032110	-0.065790	-0.005993	-0.042680	-0.103840
326475.000	5440425.000	0.117049	0.023294	-0.034310	-0.113100	0.027204	-0.003340	-0.037020	0.022780	-0.013900	-0.075070
325750.000	5438800.000	0.062973	-0.091416	-0.149020	-0.227810	-0.087505	-0.118050	-0.151730	-0.091929	-0.128610	-0.189780
327175.000	5439300.000	0.096025	-0.021304	-0.078900	-0.157700	-0.017393	-0.047940	-0.081620	-0.021817	-0.058500	-0.119660
327400.000	5438050.000	0.081922	-0.051220	-0.108820	-0.187620	-0.047309	-0.077860	-0.111530	-0.051733	-0.088420	-0.149580
328925.000	*5438600.000*	*0.170709*	*0.137121*	*0.079521*	*0.000725*	*0.141031*	*0.110485*	*0.076809*	*0.136607*	*0.099922*	*0.038759*
328550.000	5437050.000	0.057212	-0.103636	-0.161240	-0.240030	-0.099726	-0.130270	-0.163950	-0.104150	-0.140830	-0.202000
329800.000	5435625.000	0.077230	-0.061173	-0.118770	-0.197570	-0.057262	-0.087810	-0.121480	-0.061686	-0.098370	-0.159530
329425.000	5434600.000	0.061525	-0.094487	-0.152090	-0.230880	-0.090577	-0.121120	-0.154800	-0.095001	-0.131690	-0.192850
330900.000	5434150.000	0.105416	-0.001383	-0.058980	-0.137780	0.002527	-0.028020	-0.061690	-0.001897	-0.038580	-0.099740
332475.000	5434125.000	0.019355	-0.183941	-0.241540	-0.320340	-0.180030	-0.210580	-0.244240	-0.184454	0.022114	-0.282300
334575.000	5433725.000	0.020821	-0.180831	-0.238430	-0.317230	-0.176921	-0.207470	-0.241140	-0.181345	-0.218030	-0.279190
335450.000	5435850.000	0.059459	-0.098870	-0.156470	-0.235270	-0.094959	-0.125510	-0.159180	-0.099383	-0.136070	-0.197230
333800.000	5435850.000	0.123343	0.036645	-0.020950	-0.099750	0.040555	0.010010	-0.023670	0.036131	-0.000550	-0.061720
332600.000	5435950.000	0.096941	-0.019361	-0.076960	-0.155760	-0.015450	-0.046000	-0.079670	-0.019874	-0.056560	-0.117720
331300.000	5435900.000	0.146674	0.086136	0.028536	-0.050260	0.090047	0.059501	0.025824	0.085623	0.048938	-0.012230
332125.000	5437525.000	0.079400	-0.056570	-0.114170	-0.192970	-0.052659	-0.083210	-0.116880	-0.057083	-0.093770	-0.154930
333625.000	5438425.000	0.114598	0.018094	-0.039510	-0.118300	0.022005	-0.008540	-0.042220	0.017581	-0.019100	-0.080270
334150.000	5439375.000	0.094347	-0.024863	-0.082460	-0.161260	-0.020953	-0.051500	-0.851800	-0.025377	-0.062060	-0.123220
331950.000	5439300.000	0.050571	-0.117724	-0.175320	-0.254120	-0.113813	-0.144360	-0.178040	-0.118237	-0.154920	-0.216080
331625.000	5441075.000	0.041710	-0.136520	-0.194120	-0.272920	-0.132610	-0.163160	-0.196830	-0.137034	-0.173720	-0.234880
330250.000	5442625.000	0.147195	0.087241	0.029641	-0.049160	0.091152	0.060606	0.026929	0.086728	0.050043	-0.011120
328625.000	5442000.000	0.182077	0.161235	0.103635	0.024839	0.165146	0.134600	0.100923	0.160722	0.124037	0.062874
327250.000	5441050.000	0.161765	0.118148	0.060548	-0.018250	0.122058	0.091513	0.057836	0.117634	0.080950	0.019787
324950.000	5447675.000	0.144236	0.080964	0.023364	-0.055430	0.084875	0.054329	0.020653	0.080451	0.043766	-0.017400
326400.000	5448150.000	0.137556	0.066794	0.009194	-0.069600	0.070705	0.040159	0.006482	0.066281	0.029596	-0.031570
326700.000	5449300.000	0.162224	0.119121	0.061521	-0.017280	0.123032	0.092486	0.058810	0.118608	0.081923	0.020761
319625.000	5448475.000	0.064201	-0.088811	-0.146410	-0.225210	-0.084900	-0.115450	-0.149120	-0.089324	-0.126010	-0.187170
323375.000	5451775.000	0.124425	0.038940	-0.018660	-0.097460	0.042851	0.012305	-0.021370	0.038427	0.001742	-0.594200
318500.000	5449950.000	0.069269	-0.078060	-0.135660	-0.214460	-0.074150	-0.104700	-0.138370	-0.078574	-0.115260	-0.176420
320475.000	5451375.000	0.125817	0.041893	-0.015710	-0.094500	0.045803	0.015258	-0.018420	0.041379	0.004695	-0.056470
321275.000	5453200.000	0.211084	0.222767	0.165167	0.086371	0.226677	0.196131	0.162455	0.222253	0.185568	0.124405
316925.000	5450850.000	0.138784	0.069399	0.011799	-0.067000	0.073310	0.042764	0.009087	0.068886	0.032201	-0.028960
316900.000	*5453325.000*	0.150179	0.093571	0.035971	-0.042830	0.097482	0.066936	0.033259	0.093058	0.056373	-0.004790
314900.000	*5453200.000*	*0.132596*	*0.056273*	*-0.001330*	*-0.080120*	*0.060183*	*0.029638*	*-0.004040*	*0.055759*	*0.019075*	*-0.042090*
313975.000	5454400.000	0.137889	0.067501	0.009901	-0.068900	0.071411	0.040865	0.007189	0.066987	0.030302	-0.030860
313700.000	5452600.000	0.111948	0.012473	-0.045130	-0.123920	0.016384	-0.014160	-0.047840	0.011960	-0.024730	-0.085890
311725.000	5452425.000	0.156706	0.107417	0.049817	-0.028980	0.111327	0.080781	0.047105	0.106903	0.070218	0.009055
311550.000	5453125.000	0.123393	0.036751	-0.020850	-0.099650	0.040661	0.010116	-0.023560	0.036237	-0.000450	-0.061610
309925.000	5453725.000	0.147847	0.088624	0.031024	-0.04777	0.092535	0.061989	0.028312	0.086111	0.051426	-0.009740
309575.000	5451300.000	0.070504	-0.075440	-0.133040	-0.211840	-0.071530	-0.102080	-0.135750	-0.075954	-0.112640	-0.173800
308475.000	5452425.000	0.076505	-0.062711	-0.120310	-0.199110	-0.058880	-0.089350	-0.123020	-0.063224	-0.099910	-0.161070
321775.000	5448550.000	0.148200	0.089373	0.031773	-0.047020	0.093284	0.062738	0.029061	0.088860	0.052175	-0.008990
311150.000	5448300.000	0.103854	-0.004696	-0.062300	-0.141090	-0.000786	-0.031330	-0.065010	-0.005210	-0.041690	-0.103060
312700.000	5446750.000	0.125394	0.040996	-0.016600	-0.095400	0.044906	0.014360	-0.019320	0.040482	0.003797	-0.057370
329825.000	5441100.000	0.198463	0.195994	0.138394	0.059598	0.199905	0.169359	0.135682	0.195481	0.158796	0.097633
323525.000	5437225.000	0.040579	-0.138919	-0.196520	-0.275320	-0.135009	-0.165550	-0.199230	-0.139433	-0.176120	-0.237280
325675.000	5433650.000	0.183894	0.165089	0.107489	0.028693	0.169000	0.138454	0.104778	0.164576	0.127891	0.066728
330400.000	5438975.000	0.177632	0.151806	0.094206	0.015410	0.155717	0.125171	0.091494	0.151293	0.114608	0.053445
	Average	0.190070	0.178281	0.120705	0.044152	0.182101	0.151559	0.114997	0.177674	0.141904	0.077819

Easting	Northing	Average	CGCM2 A21 (warm-dry) 2020	2050	2080	CSIROMk2b B11 (mid-range) 2020	2050	2080	HadCM3 B21 (cool-wet) 2020	2050	2080
301900.000	5451700.000	2.002496	2.100280	2.298800	2.506050	2.136020	2.170810	2.210810	2.047290	1.996970	2.078330
318500.000	5442100.000	2.082030	2.200900	2.399420	2.605670	2.236630	2.271420	2.311420	2.147910	2.097580	2.178950
338100.000	5432150.000	1.913760	1.988030	2.186540	2.393800	2.023760	2.058550	2.098550	1.935040	1.884710	1.966070
310175.000	5449575.000	2.073310	2.189870	2.388380	2.595640	2.225600	2.260390	2.300390	2.136880	2.086550	2.167910
307775.000	5450050.000	1.935113	2.015040	2.213560	2.420810	2.050770	2.085570	2.125570	1.962050	1.911720	1.993090
318800.000	5446625.000	1.219903	1.110250	1.308770	1.516020	1.145990	1.180780	1.220780	1.057260	1.006940	1.088300
334750.000	5432100.000	1.833314	1.886260	2.084770	2.292030	1.921990	1.956780	1.996780	1.833270	1.782940	1.864300
314500.000	5445425.000	1.875540	1.939680	2.138190	2.345450	1.975410	2.010200	2.050200	1.886690	1.836360	1.917720
314425.000	5449475.000	1.984685	2.077750	2.276270	2.483520	2.113480	2.148280	2.188280	2.024760	1.974430	2.055800
312750.000	5451150.000	1.814978	1.863060	2.061580	2.268830	1.898790	1.933590	1.973590	1.810070	1.759740	1.841110
312725.000	5449425.000	1.268094	1.171220	1.369740	1.576990	1.206950	1.241740	1.281740	1.118230	1.067900	1.149270
308325.000	5450775.000	1.904009	1.975690	2.174210	2.381460	2.011420	2.046220	2.086220	1.922700	1.872370	1.953740
315350.000	5450575.000	1.259769	1.160690	1.359200	1.566460	1.196420	1.231210	1.271210	1.107700	1.057370	1.138730
314800.000	5447975.000	1.387022	1.321670	1.520190	1.727440	1.357400	1.392200	1.432200	1.268680	1.218350	1.299720
318550.000	5447400.000	1.410405	1.351250	1.549770	1.757020	1.386980	1.421780	1.461780	1.298260	1.247930	1.329300
333250.000	5431900.000	1.064353	0.900820	1.099340	1.306590	0.936560	0.971350	1.011350	0.847830	0.797500	0.878870
332575.000	5443325.000	1.716381	1.738330	1.936850	2.144100	1.774060	1.808860	1.848860	1.685340	1.635010	1.716380
333050.000	5430475.000	1.270490	1.174250	1.372770	1.580020	1.209980	1.244780	1.284780	1.121260	1.070930	1.152300
305525.000	5448875.000	1.247378	1.145010	1.343530	1.550780	1.180740	1.215540	1.255540	1.092020	1.041690	1.123060
332025.000	5442600.000	1.974419	2.064760	2.263280	2.470530	2.100500	2.135290	2.175290	2.011770	1.961450	2.042810
312075.000	5450075.000	1.809194	1.855740	2.054260	2.261510	1.891480	1.926270	1.966270	1.802750	1.752430	1.833790
317775.000	5452475.000	1.852800	1.910910	2.109430	2.316680	1.946640	1.981430	2.021430	1.857920	1.807590	1.888950
319675.000	5453375.000	1.839448	1.894020	2.092530	2.299790	1.929750	1.964540	2.004540	1.841030	1.790700	1.872060
313850.000	5447250.000	1.813970	1.861790	2.060300	2.267560	1.897520	1.932310	1.972310	1.808800	1.758470	1.839830
333700.000	5442525.000	1.407403	1.347450	1.545970	1.753220	1.383190	1.417980	1.457980	1.294460	1.244140	1.325500
336375.000	5431350.000	1.685286	1.698990	1.897510	2.104760	1.734720	1.769520	1.809520	1.646000	1.595670	1.677040
306875.000	5451300.000	1.678955	1.690980	1.889500	2.096750	1.726720	1.761510	1.801510	1.637990	1.587670	1.669030
316275.000	5449475.000	1.843635	1.899310	2.097830	2.305080	1.935050	1.969840	2.009840	1.846320	1.796000	1.877360
304600.000	5450450.000	1.119323	0.983010	1.181530	1.388780	1.018750	1.053540	1.093540	0.930020	0.879700	0.961060
333650.000	5432225.000	2.040748	2.148670	2.347190	2.554450	2.184410	2.219200	2.259200	2.095680	2.045360	2.126720
316125.000	5446975.000	1.910161	1.972660	2.171180	2.378430	2.019210	2.054000	2.094000	1.930480	1.880160	1.961520
323250.000	5448350.000	1.553517	1.532300	1.730810	1.938070	1.568030	1.602820	1.642820	1.479310	1.428980	1.510340
302850.000	5451775.000	1.681007	1.693580	1.892100	2.099350	1.729310	1.764110	1.804110	1.640590	1.590260	1.671630
324550.000	5450075.000	2.107184	2.232720	2.431240	2.638490	2.268450	2.303250	2.343250	2.179730	2.129400	2.210770
305925.000	5449350.000	1.832604	1.885360	2.083880	2.291130	1.921090	1.955880	1.995880	1.832370	1.782040	1.863410
318250.000	5445425.000	1.926018	2.003530	2.202050	2.409300	2.039270	2.074060	2.114060	1.950540	1.900220	1.981580
311100.000	5450975.000	1.656559	1.662650	1.861170	2.068420	1.698380	1.733180	1.773180	1.609660	1.559330	1.640700
306825.000	5454700.000	1.108292	0.969060	1.167580	1.374830	1.004790	1.039580	1.079580	0.916070	0.865740	0.947110
320175.000	5449850.000	1.983495	2.076250	2.274760	2.482020	2.111980	2.146770	2.186770	2.023260	1.972930	2.054290
308225.000	5444150.000	1.906259	1.978540	2.177050	2.384310	2.014270	2.049060	2.089060	1.925550	1.875220	1.956580
312750.000	5448850.000	2.030267	2.135420	2.333930	2.541190	2.171150	2.205940	2.245940	2.082420	2.032100	2.113460
316250.000	5442700.000	1.212639	1.101060	1.299580	1.506830	1.136800	1.171590	1.211590	1.048070	0.997750	1.079110
301425.000	5450675.000	1.161946	1.036930	1.235450	1.442710	1.072670	1.107460	1.147460	0.983940	0.933620	1.014980
332500.000	5442825.000	1.732601	1.758850	1.957370	2.164620	1.794580	1.829370	1.869370	1.705860	1.655530	1.736900
304700.000	5448400.000	1.902349	1.973590	2.172110	2.379360	2.009320	2.044120	2.084120	1.920600	1.870270	1.951640
328275.000	5448500.000	1.805549	1.851130	2.049650	2.256900	1.886870	1.921660	1.961660	1.798140	1.747810	1.829180
334625.000	5430175.000	1.743597	1.772760	1.971280	2.178530	1.808490	1.843290	1.883290	1.719770	1.669440	1.750810
317250.000	5449525.000	1.540941	1.516390	1.714900	1.922160	1.552120	1.586910	1.626910	1.463400	1.413070	1.494430
304075.000	5448075.000	1.449284	1.400440	1.598950	1.806210	1.436170	1.470960	1.510960	1.347450	1.297120	1.378480
306725.000	5453125.000	1.360710	1.288380	1.486900	1.694150	1.324120	1.358910	1.398910	1.235390	1.185070	1.266430
303900.000	5450475.000	1.504036	1.469700	1.668220	1.875470	1.505430	1.540230	1.580230	1.416710	1.366380	1.447750
333725.000	5431200.000	1.830025	1.882100	2.080610	2.287870	1.917830	1.952620	1.992620	1.829110	1.778780	1.860140
338025.000	5440600.000	1.870919	1.933830	2.132350	2.339600	1.969560	2.004360	2.044360	1.880840	1.830510	1.911880
322175.000	5450400.000	1.938348	2.019130	2.217650	2.424900	2.054860	2.089660	2.129660	1.966140	1.915810	1.997180
311025.000	5446050.000	1.963056	2.050390	2.248910	2.456160	2.086120	2.120910	2.160910	1.997400	1.947070	2.028440
315700.000	5454175.000	1.805557	1.851140	2.049660	2.256910	1.886880	1.921670	1.961670	1.798150	1.747820	1.829190
310775.000	5454575.000	1.803236	1.848210	2.046720	2.253980	1.883940	1.918730	1.958730	1.795220	1.744890	1.826250
309675.000	5447800.000	1.583152	1.569790	1.768300	1.975560	1.606520	1.640310	1.680310	1.516800	1.466470	1.547830
307700.000	5448850.000	1.405495	1.345040	1.543560	1.750810	1.380770	1.415570	1.455570	1.292050	1.241720	1.323090
307700.000	5447475.000	1.660759	1.667960	1.866480	2.073730	1.703700	1.738490	1.778490	1.614970	1.564650	1.646010
308275.000	5446625.000	1.641194	1.643210	1.841730	2.048980	1.678950	1.713740	1.753740	1.590220	1.539900	1.621260
304750.000	5449675.000	0.779403	0.552990	0.751510	0.958760	0.588730	0.623520	0.663520	0.500000	0.449680	0.531040
303875.000	5448925.000	1.391064	1.326780	1.525300	1.732550	1.362520	1.397310	1.437310	1.273790	1.223470	1.304830
303800.000	5452250.000	1.430322	1.376450	1.574960	1.782220	1.412180	1.446970	1.486970	1.323460	1.273130	1.354490
302975.000	5448825.000	1.524967	1.496180	1.694700	1.901950	1.531910	1.566700	1.606700	1.443190	1.392860	1.474230
303050.000	5448075.000	1.458553	1.412160	1.610680	1.817930	1.447890	1.482690	1.522690	1.359170	1.308840	1.390210
302200.000	5452650.000	1.530234	1.502840	1.701360	1.908610	1.538570	1.573370	1.613370	1.449850	1.399520	1.480890
308675.000	5453750.000	1.495996	1.459530	1.658050	1.865300	1.495260	1.530050	1.570050	1.406540	1.356210	1.437580
309325.000	5454500.000	1.868584	1.930880	2.129390	2.336650	1.966610	2.001400	2.041400	1.877890	1.827560	1.908920
310325.000	5452575.000	1.393682	1.330100	1.528610	1.735870	1.365830	1.400620	1.440620	1.277110	1.226780	1.308140
312800.000	5453300.000	1.634498	1.634740	1.833260	2.040510	1.670470	1.705270	1.745270	1.581750	1.531420	1.612790
314200.000	5451175.000	1.154137	1.027060	1.225570	1.432830	1.062790	1.097580	1.137580	0.974070	0.923740	1.005100
312550.000	5453900.000	1.501303	1.466240	1.664760	1.872010	1.501970	1.536770	1.576770	1.413250	1.362920	1.444290
316300.000	5451850.000	1.572920	1.556840	1.755360	1.962610	1.592570	1.627370	1.687370	1.503850	1.453520	1.534890
317800.000	5454525.000	1.732351	1.758530	1.957050	2.164300	1.794270	1.829060	1.869060	1.705540	1.655210	1.736580
318825.000	5451325.000	1.706390	1.724430	1.922940	2.130200	1.760160	1.794950	1.834950	1.671440	1.621110	1.702470
321675.000	5451825.000	1.809080	1.855600	2.064120	2.261370	1.891330	1.926130	1.966130	1.802610	1.752280	1.833650
323500.000	5453150.000	1.877626	1.942310	2.140830	2.348090	1.978050	2.012840	2.052840	1.889320	1.839000	1.920360
323950.000	5449675.000	1.481414	1.441080	1.639600	1.846850	1.476810	1.511610	1.551610	1.388090	1.337600	1.419130
318200.000	5448250.000	1.167163	1.043540	1.242050	1.449310	1.079270	1.114060	1.154060	0.990540	0.940220	1.021580
323725.000	5447250.000	1.538507	1.513310	1.711830	1.919080	1.549040	1.583830	1.623830	1.460320	1.409990	1.491350
325725.000	5446175.000	1.350771	1.275810	1.474330	1.681580	1.311540	1.346340	1.386340	1.222820	1.172490	1.253860
325150.000	5449000.000	1.638800	1.640180	1.838700	2.045960	1.675920	1.710710	1.750710	1.587190	1.536870	1.618230
328800.000	5449225.000	1.674608	1.685480	1.884000	2.091250	1.721220	1.756010	1.796010	1.632490	1.582170	1.663530
325375.000	5444425.000	1.410395	1.351240	1.549760	1.757010	1.386970	1.421760	1.461760	1.298250	1.247920	1.329280
328890.000	5446225.000	1.878452	1.943360	2.141880	2.349130	1.979090	2.013890	2.053890	1.890370	1.840040	1.921410
330950.000	5445750.000	2.006449	2.105260	2.303800	2.511050	2.141020	2.175810	2.215810	2.052290	2.001970	2.083330
333300.000	5440500.000	1.618942	1.615060	1.813580	2.020830	1.650800	1.685590	1.725590	1.562070	1.511750	1.593110
338675.000	5443100.000	0.951699	0.770960	0.969480	1.176730	0.806690	0.841480	0.881480	0.717970	0.667640	0.749010
334825.000	5440250.000	1.791536	1.833410	2.031920	2.239180	1.869140	1.903930	1.943930	1.780420	1.730090	1.811450
339575.000	5441650.000	1.816087	1.864460	2.062980	2.270230	1.900200	1.934990	1.974990	1.811470	1.761150	1.842510

340225.000	5444050.000	1.804292	1.849540	2.048060	2.255310	1.885270	1.920070	1.960070	1.796550	1.746220	1.827590
336900.000	5439775.000	1.694271	1.710360	1.908880	2.116130	1.746090	1.780880	1.820880	1.657370	1.607040	1.688410
335150.000	5438050.000	1.835607	1.889160	2.087680	2.294930	1.924890	1.959680	1.999680	1.836170	1.785840	1.867200
330225.000	5437200.000	0.980060	0.806840	1.005350	1.212610	0.842570	0.877360	0.917360	0.753850	0.703520	0.784880
335700.000	5434350.000	1.549273	1.526930	1.725440	1.932700	1.562660	1.597450	1.637450	1.473940	1.423610	1.504970
338150.000	5434275.000	1.855188	1.913930	2.112450	2.319700	1.949660	1.984450	2.024450	1.860940	1.810610	1.891980
335625.000	5430650.000	1.705325	1.724340	1.922860	2.130110	1.760080	1.794870	1.634870	1.671350	1.621030	1.702390
330800.000	5432600.000	1.343104	1.266110	1.464630	1.671880	1.301840	1.336640	1.376640	1.213120	1.162790	1.244160
327100.000	5430375.000	1.290610	1.199700	1.398220	1.605470	1.235440	1.270230	1.310230	1.146710	1.096380	1.177750
326100.000	5430800.000	1.809871	1.856600	2.055120	2.262370	1.892330	1.927130	1.967130	1.803610	1.753280	1.834650
327475.000	5431975.000	1.857234	1.916520	2.115030	2.322290	1.952250	1.987040	2.027040	1.863530	1.813200	1.894560
328100.000	5433025.000	1.781325	1.820490	2.019010	2.226260	1.856220	1.891010	1.931010	1.767500	1.717170	1.798530
329150.000	5433425.000	1.582900	1.569470	1.767980	1.975240	1.605200	1.639990	1.679990	1.516480	1.466150	1.547510
328275.000	5434300.000	1.128939	0.995180	1.193700	1.400950	1.024530	1.059320	1.099320	0.942190	0.891860	0.973230
328075.000	5435425.000	1.192982	1.076200	1.274710	1.481970	1.111930	1.146720	1.186720	1.023210	0.972880	1.054240
327175.000	5436575.000	1.047386	0.892010	1.090530	1.297780	0.927740	0.962530	1.002530	0.839020	0.788690	0.870060
330225.000	5437200.000	0.980060	0.806840	1.005350	1.212610	0.842570	0.877360	0.917360	0.753850	0.703520	0.784880
333675.000	5436925.000	1.832265	1.884930	2.083450	2.290700	1.920660	1.955460	1.995460	1.831940	1.781610	1.862980
326475.000	5437225.000	1.546530	1.523460	1.721970	1.929230	1.559190	1.593980	1.633980	1.470470	1.420140	1.501500
325174.000	5437175.000	1.383229	1.316870	1.515390	1.722640	1.352600	1.387400	1.427400	1.263880	1.213550	1.294920
328725.000	5440025.000	1.869114	1.931550	2.130060	2.337320	1.967280	2.002070	2.042070	1.878560	1.828230	1.909590
325075.000	5439650.000	1.119068	0.982690	1.181210	1.388460	1.018420	1.053220	1.093220	0.929700	0.879370	0.960740
321600.000	5438575.000	1.645829	1.649080	1.847590	2.054850	1.684810	1.719600	1.759600	1.596090	1.545760	1.627120
326825.000	5442325.000	1.720481	1.743520	1.942030	2.149290	1.779250	1.814040	1.854040	1.690530	1.640200	1.721560
324675.000	5441125.000	1.146991	1.016020	1.216530	1.423790	1.053750	1.088540	1.128540	0.965030	0.914700	0.996060
323150.000	5441975.000	1.708097	1.727850	1.926370	2.133620	1.763580	1.798380	1.838380	1.674860	1.624530	1.705900
319850.000	5440825.000	1.850491	1.907990	2.106500	2.313760	1.943720	1.978510	2.018510	1.855000	1.804670	1.886030
325225.000	5443600.000	1.250663	1.149170	1.347690	1.554940	1.184900	1.219690	1.259690	1.096180	1.045850	1.127210
324550.000	5445700.000	1.308675	1.222560	1.421070	1.628330	1.258290	1.293080	1.333080	1.169570	1.119240	1.200600
321350.000	5442150.000	1.224955	1.116650	1.315160	1.522420	1.152380	1.187170	1.227170	1.063650	1.013330	1.094690
320425.000	5443325.000	1.392435	1.328520	1.527040	1.734290	1.364250	1.399040	1.439040	1.275530	1.225200	1.306560
322425.000	5446725.000	1.433498	1.380470	1.578980	1.786240	1.416200	1.450990	1.490990	1.327470	1.277150	1.358510
320725.000	5447050.000	1.687239	1.701460	1.899980	2.107230	1.737200	1.771990	1.811990	1.648470	1.598150	1.679510
317225.000	5447175.000	1.426743	1.371920	1.570440	1.777690	1.407650	1.442450	1.482450	1.318930	1.268600	1.349970
313650.000	5445400.000	1.701103	1.719000	1.917520	2.124770	1.754730	1.789530	1.829530	1.666010	1.615680	1.697050
315375.000	5444800.000	1.797889	1.841440	2.039960	2.247210	1.877170	1.911970	1.951970	1.788450	1.738120	1.819490
312325.000	5445250.000	1.888322	1.955850	2.154360	2.361620	1.991580	2.026370	2.066370	1.902860	1.852530	1.933890
302675.000	5450625.000	1.942308	2.024140	2.222660	2.429910	2.059870	2.094670	2.134670	1.971150	1.920820	2.002190
303075.000	5449825.000	1.693539	1.709430	1.907950	2.115200	1.745170	1.779960	1.819960	1.656440	1.606120	1.687480
304475.000	5451775.000	1.377210	1.309260	1.507770	1.715030	1.344990	1.379780	1.419780	1.256270	1.205940	1.287300
305775.000	5451750.000	1.853103	1.911290	2.109810	2.317060	1.947020	1.981820	2.021820	1.858300	1.807970	1.889340
305825.000	5450975.000	1.896773	1.966540	2.165050	2.372310	2.002270	2.037060	2.077060	1.913550	1.863220	1.944580
306700.000	5448025.000	1.915221	1.989750	2.188270	2.395520	2.025610	2.060400	2.100400	1.936880	1.886560	1.967920
306375.000	5447300.000	1.809183	1.855730	2.054250	2.261500	1.891460	1.926260	1.966260	1.802740	1.752410	1.833780
306975.000	5446800.000	1.821157	1.870880	2.069390	2.276650	1.906610	1.941400	1.981400	1.817890	1.767560	1.848920
307600.000	5446100.000	1.572599	1.556440	1.754950	1.962210	1.592170	1.626960	1.666960	1.503450	1.453120	1.534480
307200.000	5445150.000	1.986183	2.079650	2.278160	2.485420	2.115380	2.150170	2.190170	2.026660	1.976330	2.057690
306075.000	5444525.000	1.899419	1.969880	2.168400	2.375650	2.005620	2.040410	2.080410	1.916890	1.866570	1.947930
305025.000	5444125.000	1.920233	1.996220	2.194730	2.401990	2.031950	2.066740	2.106740	1.943230	1.892900	1.974260
305275.000	5445250.000	1.894664	1.963870	2.162390	2.369640	1.999600	2.034390	2.074390	1.910880	1.860550	1.941920
305300.000	5446425.000	1.906167	1.978420	2.176940	2.384190	2.014150	2.048950	2.088950	1.925430	1.875100	1.956470
304975.000	5447475.000	1.776003	1.816280	2.014800	2.222060	1.852020	1.886810	1.926810	1.763300	1.712970	1.794330
306075.000	5454075.000	1.667289	1.676220	1.874740	2.082000	1.711960	1.746750	1.786750	1.623240	1.572910	1.654270
308400.000	5454600.000	2.038109	2.145340	2.343850	2.551110	2.181070	2.215860	2.255860	2.092350	2.042020	2.123380
307775.000	5453250.000	1.597513	1.587950	1.786470	1.993720	1.623690	1.658480	1.698480	1.534960	1.484640	1.566000
306900.000	5449700.000	2.003787	2.101920	2.300430	2.507690	2.137650	2.172440	2.212440	2.048930	1.998600	2.079960
308800.000	5449450.000	2.057103	2.169360	2.367880	2.575130	2.205100	2.239890	2.279890	2.116370	2.066050	2.147410
308550.000	5448350.000	1.944539	2.026960	2.225480	2.432730	2.062700	2.097490	2.137490	1.973970	1.923650	2.005010
309425.000	5446825.000	1.990544	2.085160	2.283680	2.490930	2.120900	2.155690	2.195690	2.032170	1.981850	2.063210
308700.000	5445650.000	1.559888	1.540360	1.738870	1.946130	1.576090	1.610880	1.650880	1.487370	1.437040	1.518400
309175.000	5444600.000	1.952302	2.036780	2.235300	2.442550	2.072520	2.107310	2.147310	1.983790	1.933470	2.014830
309975.000	5444050.000	1.904577	1.976540	2.175050	2.382310	2.012270	2.047060	2.087060	1.923550	1.873220	1.954580
310600.000	5445225.000	2.025974	2.353420	2.551940	2.759190	2.165720	2.200510	2.240510	2.076990	2.026670	2.108030
311175.000	5444125.000	1.829160	1.881000	2.079520	2.286770	1.916730	1.951530	1.991530	1.828010	1.777680	1.859050
312425.000	5444200.000	1.946984	2.030060	2.228570	2.435830	2.065790	2.100580	2.140580	1.977070	1.926740	2.008100
313350.000	5443950.000	1.893758	1.962720	2.161240	2.368490	1.998450	2.033250	2.073250	1.909730	1.859400	1.940770
315475.000	5443775.000	1.347854	1.272120	1.470640	1.677890	1.307850	1.342650	1.382650	1.219130	1.168800	1.250170
314775.000	5446500.000	2.041625	2.149780	2.348300	2.555550	2.185520	2.220310	2.260310	2.096790	2.046470	2.127830
316600.000	5446075.000	1.782594	1.822090	2.026100	2.227860	1.857830	1.892620	1.932620	1.769100	1.718780	1.800140
316825.000	5445050.000	2.074922	2.191910	2.390420	2.597680	2.227640	2.262430	2.302430	2.138920	2.088590	2.169950
318425.000	5444350.000	1.938077	2.018790	2.217310	2.424560	2.054520	2.089310	2.129310	1.965800	1.915470	1.996840
317500.000	5443400.000	2.097209	2.220100	2.418620	2.625870	2.255830	2.290630	2.330630	2.167110	2.116780	2.198150
317225.000	5442025.000	1.992276	2.087350	2.285870	2.493120	2.123090	2.157880	2.197880	2.034360	1.984040	2.065400
319425.000	5444425.000	1.920803	1.996940	2.195450	2.402710	2.032670	2.067460	2.107460	1.943950	1.893620	1.974980
319875.000	5442450.000	2.114820	2.242380	2.440900	2.648150	2.278110	2.312910	2.352910	2.189390	2.139060	2.220430
321425.000	5446075.000	2.119660	2.248500	2.447020	2.654270	2.284240	2.319030	2.359030	2.195510	2.145180	2.226550
320575.000	5444975.000	1.896117	1.965710	2.164220	2.371480	2.001440	2.036230	2.076230	1.912720	1.862390	1.943750
321575.000	5444825.000	2.104227	2.228980	2.427500	2.634750	2.264710	2.299500	2.339500	2.175990	2.125660	2.207030
321975.000	5443250.000	2.115643	2.243420	2.441940	2.649190	2.279150	2.313950	2.353950	2.190430	2.140100	2.221470
323125.000	5444325.000	2.009485	2.109120	2.307640	2.514900	2.144860	2.179650	2.219650	2.054570	2.005810	2.087170
324125.000	5443025.000	1.991211	2.086010	2.284520	2.491780	2.121740	2.156530	2.196530	2.033020	1.982690	2.064050
324000.000	5442125.000	1.896998	1.966820	2.165340	2.372590	2.002550	2.037350	2.077350	1.913830	1.863500	1.944870
321700.000	5440150.000	1.915955	1.990800	2.189320	2.396570	2.026540	2.061330	2.101330	1.937810	1.887490	1.968850
323850.000	5439925.000	1.933186	2.012600	2.211120	2.418370	2.048330	2.083130	2.123130	1.959610	1.909280	1.990650
323125.000	5438350.000	1.879436	1.944600	2.143120	2.350370	1.980340	2.015130	2.055130	1.891610	1.841290	1.922650
322075.000	5437325.000	1.974213	2.064500	2.263020	2.370270	2.100240	2.135030	2.175030	2.011510	1.961190	2.042550
321275.000	5435900.000	1.994457	2.090110	2.288630	2.495880	2.125850	2.160640	2.200640	2.037120	1.986800	2.068160
321900.000	5434625.000	1.985038	2.078200	2.276720	2.483970	2.113930	2.148720	2.188720	2.025210	1.974860	2.056240
322725.000	5435800.000	1.956846	2.042530	2.241050	2.448300	2.078270	2.113060	2.153060	1.989540	1.939210	2.020580
324925.000	5436175.000	1.850615	1.908140	2.106660	2.313910	1.943880	1.978670	2.018670	1.855150	1.804830	1.886190
324200.000	5434100.000	2.044600	2.153800	2.352320	2.559570	2.189530	2.224330	2.264330	2.100810	2.050480	2.131850
325975.000	5435100.000	1.737385	1.764900	1.963420	2.170670	1.800630	1.835430	1.875430	1.711910	1.661580	1.742950
326600.000	5436250.000	1.909572	1.982730	2.181250	2.388500	2.018460	2.053250	2.093250	1.929740	1.879410	1.960780

327000.000	5434550.000	1.632806	1.632600	1.831120	2.038370	1.668330	1.703130	1.743130	1.579610	1.529280	1.610650
326150.000	5432625.000	1.852105	1.910030	2.108550	2.315800	1.945760	1.980550	2.020550	1.857040	1.806710	1.888080
329225.000	5432275.000	1.699218	1.716620	1.915130	2.122390	1.752350	1.787140	1.827140	1.663630	1.613300	1.694660
328750.000	5430850.000	1.798690	1.842460	2.040970	2.248230	1.878190	1.912980	1.952980	1.789470	1.739140	1.820500
330600.000	5430475.000	1.914296	1.988700	2.187220	2.394480	2.024440	2.059230	2.099230	1.935710	1.885390	1.966750
330175.000	5431650.000	1.734323	1.761030	1.959540	2.166800	1.796760	1.831550	1.871550	1.708040	1.657710	1.739070
331875.000	5431500.000	1.758883	1.792100	1.990610	2.197870	1.827830	1.862620	1.902620	1.739110	1.688780	1.770140
337775.000	5431075.000	1.945055	2.027620	2.226130	2.433390	2.063350	2.098140	2.138140	1.974630	1.924300	2.005660
336825.000	5430400.000	1.730508	1.756200	1.954720	2.161970	1.791930	1.826730	1.866730	1.703210	1.652880	1.734250
336250.000	5432625.000	1.545060	1.521600	1.720110	1.927370	1.557330	1.592120	1.632120	1.468610	1.418280	1.499640
337025.000	5433650.000	1.977685	2.068900	2.267410	2.474670	2.104630	2.139420	2.179420	2.015910	1.965580	2.046940
336425.000	5435550.000	1.820380	1.869890	2.068410	2.275670	1.905630	1.940420	1.980420	1.816900	1.766580	1.847940
336375.000	5437250.000	1.512971	1.481000	1.679520	1.886770	1.516740	1.551530	1.591530	1.428010	1.377690	1.459050
338050.000	5437000.000	1.967970	2.056610	2.255120	2.462380	2.092340	2.127130	2.167130	2.003620	1.953290	2.034650
338550.000	5438425.000	1.842058	1.897320	2.095840	2.303090	1.933050	1.967840	2.007840	1.844330	1.794000	1.875370
339925.000	5438250.000	1.970380	2.059650	2.258170	2.465420	2.095390	2.130180	2.170180	2.006660	1.956340	2.037700
338650.000	5439775.000	1.788738	1.829870	2.028380	2.235640	1.865600	1.900390	1.940390	1.776880	1.726550	1.807910
340050.000	5440875.000	1.922314	1.998850	2.197360	2.404620	2.034580	2.069370	2.109370	1.945860	1.895530	1.976890
336400.000	5440825.000	1.722558	1.746140	1.944660	2.151910	1.781880	1.816670	1.856670	1.693150	1.642830	1.724190
337675.000	5442100.000	1.515407	1.484090	1.682600	1.889860	1.519820	1.554610	1.594610	1.431090	1.380770	1.462130
337025.000	5444125.000	1.385428	1.319650	1.518170	1.725420	1.355390	1.390180	1.430180	1.266660	1.216340	1.297700
335225.000	5442475.000	1.585530	1.572800	1.771310	1.978570	1.608530	1.643320	1.683320	1.519800	1.469480	1.550840
333740.000	5443650.000	1.777007	1.815030	2.013540	2.220800	1.850850	1.885640	1.925640	1.762040	1.711710	1.793070
331700.000	5444450.000	1.866923	1.928770	2.127290	2.334550	1.964510	1.999300	2.039300	1.875780	1.825480	1.906820
332125.000	5445975.000	2.057674	2.170090	2.368600	2.575860	2.205820	2.240610	2.280610	2.117100	2.066770	2.148130
330375.000	5443500.000	1.928467	2.006300	2.205150	2.412400	2.042360	2.077160	2.117160	1.953640	1.903310	1.984680
329950.000	5444800.000	1.690596	1.705710	1.904230	2.111480	1.741440	1.776240	1.816240	1.652720	1.602390	1.683760
329075.000	5443775.000	1.868834	1.931190	2.129710	2.336960	1.966920	2.001720	2.041720	1.878200	1.827870	1.909240
327625.000	5443525.000	1.952176	2.036620	2.235140	2.442400	2.072360	2.107150	2.147150	1.983630	1.933310	2.014870
328925.000	5445425.000	1.676036	1.687290	1.885810	2.093060	1.723020	1.757820	1.797820	1.634300	1.583970	1.665340
326275.000	5444625.000	1.723992	1.747960	1.946480	2.153730	1.783690	1.818480	1.858480	1.694970	1.644640	1.726000
327175.000	5446150.000	1.973970	2.064200	2.262710	2.469970	2.099930	2.134720	2.174720	2.011210	1.960880	2.042240
325725.000	5442950.000	1.978849	2.070370	2.268890	2.476140	2.106100	2.140890	2.180890	2.017380	1.967050	2.048410
325400.000	5442000.000	1.896356	1.966010	2.164530	2.371780	2.001740	2.036540	2.076540	1.913020	1.862690	1.944060
326475.000	5440425.000	1.912918	1.986960	2.165480	2.392730	2.022690	2.057490	2.097490	1.933970	1.883640	1.965010
325750.000	5438800.000	1.806771	1.852680	2.051200	2.258450	1.888410	1.923200	1.963200	1.799690	1.749360	1.830730
327175.000	5439300.000	1.830503	1.882700	2.081220	2.288470	1.918430	1.953230	1.993230	1.829710	1.779380	1.860750
327400.000	5438050.000	1.982594	2.075110	2.273620	2.480880	2.110840	2.145630	2.165630	2.022120	1.971790	2.053150
328925.000	5438600.000	1.997810	2.094360	2.292870	2.500130	2.130090	2.164880	2.204880	2.041360	1.991040	2.072400
328550.000	5437050.000	2.027592	2.132030	2.330550	2.537800	2.167760	2.202560	2.242560	2.079040	2.028710	2.110080
329800.000	5435625.000	1.586209	1.573650	1.772170	1.979430	1.609390	1.644180	1.684180	1.520660	1.470340	1.551700
329425.000	5434600.000	1.880462	1.945900	2.144420	2.351670	1.981630	2.016430	2.056430	1.892910	1.842580	1.923950
330900.000	5434150.000	1.908530	1.981410	2.179930	2.387160	2.017140	2.051940	2.091940	1.928420	1.878090	1.959460
332475.000	5434125.000	1.828856	1.880620	2.079130	2.286390	1.916350	1.951140	1.991140	1.827630	1.777300	1.858660
334575.000	5433725.000	1.866802	1.928620	2.127140	2.334390	1.964350	1.999150	2.039150	1.875630	1.825300	1.906870
335450.000	5435850.000	1.812654	1.860120	2.058640	2.265890	1.895850	1.930650	1.970650	1.807130	1.756800	1.838170
333800.000	5435850.000	1.713284	1.734410	1.932930	2.140180	1.770140	1.804940	1.844940	1.681420	1.631090	1.712460
332600.000	5435950.000	1.708225	1.728010	1.926530	2.133780	1.763740	1.798540	1.838540	1.675020	1.624690	1.706060
331300.000	5435900.000	1.796738	1.839990	2.038500	2.245760	1.875720	1.910510	1.950510	1.787000	1.736670	1.818030
332125.000	5437525.000	1.588296	1.576290	1.774810	1.982060	1.612030	1.646820	1.686820	1.523300	1.472980	1.554340
333625.000	5438425.000	1.816167	1.864570	2.063080	2.270340	1.900300	1.935090	1.975090	1.811580	1.761250	1.842610
334150.000	5439375.000	1.607829	1.601010	1.799520	2.006780	1.636740	1.671530	1.711530	1.548010	1.497690	1.579050
331950.000	5439300.000	1.655797	1.661690	1.860200	2.067460	1.697420	1.732210	1.772210	1.608700	1.558370	1.639730
331625.000	5441075.000	1.850922	1.908530	2.107050	2.314300	1.944260	1.979060	2.019060	1.855540	1.805210	1.886580
330250.000	5442625.000	1.907494	1.980100	2.178620	2.385870	2.015830	2.050630	2.090630	1.927110	1.876780	1.958150
328625.000	5442000.000	1.988374	2.082420	2.280940	2.488190	2.118150	2.152940	2.192940	2.029430	1.979100	2.050460
327250.000	5441050.000	1.717800	1.740130	1.938640	2.145900	1.775860	1.810650	1.850650	1.687130	1.636810	1.718170
324950.000	5447675.000	2.038461	2.145780	2.344300	2.551550	2.181510	2.216310	2.256310	2.092790	2.042460	2.123830
326400.000	5448150.000	1.985751	2.079100	2.277620	2.484870	2.114630	2.149630	2.189630	2.026110	1.975780	2.057150
326700.000	5449300.000	1.955793	2.041200	2.239720	2.446970	2.076930	2.111730	2.151730	1.988210	1.937860	2.019250
319625.000	5448475.000	1.534849	1.508680	1.707200	1.914450	1.544410	1.579210	1.619210	1.455690	1.405360	1.486730
323375.000	5451775.000	2.210932	2.363970	2.562490	2.769740	2.399700	2.434490	2.474490	2.310980	2.260650	2.342010
318500.000	5449950.000	1.789889	1.831320	2.029840	2.237090	1.867050	1.901850	1.941850	1.778330	1.728000	1.809370
320475.000	5451375.000	1.976081	2.066870	2.265380	2.472640	2.102600	2.137390	2.177390	2.013880	1.963550	2.044910
321275.000	5453200.000	1.827042	1.878320	2.076840	2.284090	1.914060	1.948850	1.988850	1.825330	1.775000	1.856370
316925.000	5450850.000	1.958765	2.044960	2.243480	2.450730	2.080690	2.115490	2.155490	1.991970	1.941640	2.023010
316900.000	5453325.000	1.941432	2.023030	2.221550	2.428800	2.058770	2.093560	2.133560	1.970040	1.919720	2.001080
314900.000	5453200.000	2.070050	2.185740	2.384260	2.591510	2.221480	2.256270	2.296270	2.132750	2.082430	2.163790
313975.000	5454400.000	1.988356	2.082400	2.280910	2.488170	2.118130	2.152920	2.192920	2.029400	1.979080	2.060440
313700.000	5452600.000	2.259699	2.425660	2.624180	2.831430	2.461390	2.496190	2.536190	2.372670	2.322340	2.403710
311725.000	5452425.000	1.728821	1.754070	1.952580	2.159840	1.789800	1.824590	1.864590	1.701080	1.650750	1.732110
311550.000	5453125.000	1.934322	2.014040	2.212560	2.419810	2.049770	2.084560	2.124560	1.961050	1.910720	1.992090
309925.000	5453725.000	1.960824	2.047570	2.246080	2.453340	2.083300	2.118090	2.158090	1.994580	1.944250	2.025610
309575.000	5451300.000	1.842180	1.897470	2.096990	2.303240	1.933210	1.968000	2.008000	1.844480	1.794160	1.875520
308475.000	5452425.000	1.578857	1.564350	1.762870	1.970120	1.600090	1.634880	1.674880	1.511360	1.461040	1.542400
321775.000	5448550.000	1.957155	2.042920	2.241440	2.448690	2.078660	2.113450	2.153450	1.989930	1.939610	2.020970
311150.000	5448300.000	1.849669	1.906950	2.105460	2.312720	1.942680	1.977470	2.017470	1.853960	1.803630	1.884990
312700.000	5446750.000	1.721523	1.744840	1.943350	2.150610	1.780570	1.815360	1.855360	1.691840	1.641520	1.722880
329825.000	5441100.000	1.942833	2.024810	2.223320	2.430580	2.060540	2.095330	2.135330	1.971820	1.921490	2.002850
323525.000	5437225.000	2.074587	2.191480	2.390000	2.597250	2.227220	2.262010	2.302010	2.138490	2.088160	2.169530
325675.000	5433650.000	1.923987	2.000960	2.199480	2.406740	2.036700	2.071490	2.111490	1.947970	1.897650	1.979010
330400.000	5438975.000	1.937997	2.018690	2.217210	2.424460	2.054420	2.089210	2.129210	1.965700	1.915370	1.996730
	Average	1.739038	1.767790	1.966329	2.173186	1.802701	1.837494	1.877494	1.713996	1.663674	1.745038