LONG-TERM MONITORING OF POST-FIRE VEGETATION RECOVERY: A CASE STUDY IN WINNEMUCCA DISTRICT, NEVADA

by

Christine Dougherty
A Thesis
Submitted to the
Graduate Faculty
of
George Mason University
in Partial Fulfillment of
The Requirements for the Degree
of
Master of Science
Geographic and Cartographic Sciences

Committee:

_______________ Dr. Richard Medina, Thesis Director

_______________ Dr. Ruixin Yang, Committee Member

_______________ Dr. John Qu, Committee Member

_______________ Dr. Anthony Stefanidis, Department Chairperson

_______________ Dr. Donna M. Fox, Associate Dean, Office of Student Affairs & Special Programs, College of Science

_______________ Dr. Peggy Agouris, Dean, College of Science

Date: _______________ Summer Semester 2014
George Mason University
Fairfax, VA

Long-Term Monitoring of Post-Fire Vegetation Recovery: A Case Study in Winnemucca District, Nevada

A Thesis submitted in partial fulfillment of the requirements for the degree of Master of Science at George Mason University

by

Christine Dougherty
Bachelor of Arts
George Washington University, 2007

Director: Richard Medina, Professor
Department of Geographic and Cartographic Sciences

Summer Semester 2014
George Mason University
Fairfax, VA

ACKNOWLEDGEMENTS

I would like to thank those that made my pursuit of this degree possible. To my coworkers and supervisors for their flexibility and support while I went to classes and maintained an irregular work schedule. To my family and friends who have been encouraging and understanding. And finally, to the fellow GMU community of students, professors and staff without whom this would not have been possible.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF EQUATIONS

LIST OF ABBREVIATIONS

AWiFS .... Advanced Wide Field Sensor
BAER .... Burned Area Emergency Rehabilitation
BARC .... Burned Area Reflection Classification
BLM .... Bureau for Land Management
dNBR .... Differenced Normalized Burn Ratio
EROS .... USGS National Center for Earth Resources Observation and Science
ESR .... Emergency Stabilization and Rehabilitation
EPA .... Environmental Protection Agency
ETM+ .... Enhanced Thematic Mapper Plus
EVI .... Enhanced Vegetation Index
GIS .... Geographic Information System
GPS .... Global Positioning System
IRS .... Indian Remote Sensing
LANDFIRE .... Landscape Fire and Resource Management Planning Tools Project
LandTrendr .... Landsat-Based Detection of Trends in Disturbance and Recovery
LISS .... Linear Imaging Self-scanner Systems
LTDL .... Land Treatment Digital Library
LTSS .... Landsat Time Series Stack
MODIS .... Moderate Resolution Imaging Spectroradiometer
MSAVI .... Modified Soil Adjusted Vegetation Index
MSAVI2 .... Modified Soil Adjusted Vegetation Index Second Version
MSS .... Multispectral Scanner
MTBS .... Monitoring Trends in Burn Severity
NAD .... North American Datum
NASA .... National Aeronautic and Space Administration
NBR .... Normalized Burn Ratio
NDVI .... Normalized Vegetation Index
NOAA .... National Oceanographic and Atmospheric Administration
PDSI .... Palmer Drought Severity Index
PMSI .... Palmer Modified Severity Index
PVI .... Perpendicular Vegetation Index
RAVG .... Rapid Assessment of Vegetation Condition after Wildfire
RdNBR .... Relative Differenced Normalized Burn Ratio
RSAC .... U.S. Forest Service Remote Sensing Applications Center
SAVI .... Soil Adjusted Vegetation Index

SPOT.. Satellite Pour l'Observation de la Terre (French satellite)
TM...Thematic Mapper
TSAVI.. Transformed Soil Adjusted Vegetation Index
UAV ....Unmanned Aerial Vehicle
UTM...Universal Transverse Mercator
USDA... United States Department of Agriculture
USGS .... United States Geological Survey
VCT.. Vegetation Change Tracker
WGS... World Geodetic System
WiFS ....Wide Field Sensor

ABSTRACT

LONG-TERM MONITORING OF POST-FIRE VEGETATION RECOVERY: A CASE STUDY IN WINNEMUCCA DISTRICT, NEVADA

Christine Dougherty M.S.

George Mason University, 2014

Thesis Director: Dr. Richard Medina

The ability of vegetation to recover from a fire event occurs at different rates depending on environmental conditions and land management techniques. Immediately following a fire, short-term vegetation monitoring helps land managers plan for and apply appropriate land treatments. Long-term post-fire vegetation assessments are less common, but are also needed to understand the impact of management techniques on vegetation recovery over time. A challenge to long-term monitoring is that traditional field assessments can be resource intensive. The purpose of this study is to examine the ability of remote sensing based vegetation indices to capture annual and long-term vegetation recovery for three fire sites in the Winnemucca District of Nevada. The study uses Landsat Thematic Mapper imagery from 1985-2005 to calculate the Normalized Difference Vegetation Index (NDVI) and a version of the Modified Soil Adjusted Vegetation Index (MSAVI2) for the three fire sites. The results of this study suggest that annual differences in

vegetation indices provide an indication of changing vegetation response, but on their own are insufficient to categorize whether this signifies a change in phenology or vegetation type. The study concludes seasonal intra-annual analysis is necessary as a first step to identifying the different stages of plant phenology before comparison of vegetation change can occur across years. The long-term trend analysis used in this study identified areas experiencing a long-term pattern of change after fourteen years, but not after twenty. Further studies would be required to confirm whether a long-term trend corresponds to a change in vegetation type.

CHAPTER ONE: INTRODUCTION

The ability of a landscape to recover from a fire event occurs at different rates depending on environmental conditions and land management techniques. The efficient and accurate assessment of post-fire conditions is important so land managers can plan for and apply appropriate land management practices. While focus is often on land management practices implemented immediately after a fire, long-term post-fire assessments are also necessary for effective land management. Long-term assessments help land managers and land management agencies understand the impact of fires on a landscape over time and decide whether post-fire management techniques achieved short- and long-term objectives.

In the United States, the Department of Interior's Bureau for Land Management (BLM) manages approximately 245 million acres of public lands -- more land than any other federal agency ("About the BLM"). As part of its management program, the BLM provides Emergency Stabilization and Rehabilitation (ESR) funding to address the impact of wildfires and monitor the effectiveness of post-fire treatments. Originally, ESR funding was available for a maximum of three years after fire containment ("Burned Area Handbook," 2007). Conditions, though, do not always facilitate full recovery within this time period. A more recent policy now requires local BLM offices to continue monitoring burned areas after three-years, a requirement which can be burdensome for offices.

The purpose of this study is to examine the ability of remote sensing based vegetation indices to monitor long-term (5-20 years) vegetation recovery in the Winnemucca District of Nevada. Remote sensing provides a relatively quick method to assess vegetation on a recurring basis. Information derived from remote sensing can be analyzed for areas which may otherwise be too difficult or burdensome to access or visit in person. The combination of vast, federally managed space and Winnemucca District's susceptibility to wildfires make it an appropriate case study for long-term, post-fire vegetation recovery techniques.

The research analyzes recovery rates for three fire sites annually and then compare results across long-term intervals extending to twenty years after a fire occurred. The study will use statistical analysis to compare the outcomes of applying two vegetation indices, NDVI and MSAVI2, to these areas. The focus will be limited to assessing post-fire vegetation conditions as the first step to understanding recovery conditions. Attributing these conditions to biological factors or management techniques is outside the scope of this study. The information from this study provides the basis for further studies to determine whether long-term statistical analysis is an indicator of vegetation change.

Vegetation Management

Fires can have both positive and negative impacts on an environment. Fire is an integral part of many ecosystems and a specific branch of ecology exists, fire ecology, to look at the effects of wildland fires on landscapes. One potential benefit fires can have is that they return nutrients to the soil and expose mineral-rich soils. Replenishment of soils creates conducive conditions for seeds and allows for new plant growth. Another positive impact of recurring fires is that they can eliminate fuel loads and invasive species. Without fires, these materials can build up and potentially cause more damaging, harder to control fires.

While fires are beneficial in some environments, they can also have devastating effects. In addition to the direct damage fires can cause to life and property, fires also result in the loss of habitat important to specific species. Secondary effects of fires make soils more susceptible to erosion further threatening infrastructure and the environment. Post-fire management focuses on minimizing the negative effects of fires while also recognizing the integral role that fires have in sustaining ecosystems.

Post-fire vegetation recovery is dependent both on ecological conditions and management practices. A number of ecological factors contribute to vegetation recovery including fire severity, stage of ecological succession, the rate of species regrowth and atmospheric conditions (Cocke et al., 2005; Lentile et al., 2006). Human activities, and in particular, management techniques also influence post-fire vegetation recovery. Management techniques vary depending on the initial post-fire assessment and can range from building a fence to prevent grazing to reseeding (drill, aerial, etc.) with native or non-native species. The current preferred practice is to seed with native species to maintain the ecological structure of an area. Previously, introducing non-native species was a common approach by land managers due to the lower costs associated with purchasing non-native materials and the tendency of some non-native species to have quicker regrowth rates that help prevent erosion (Richards et al., 1998). However, these practices have become less common with the understanding of how the use of non-native species can cause substantial changes to an ecosystem. Introduction of some non-native and invasive species has shown to affect an area's fire fuel properties which consequently alter fire behavior (Brooks and Lusk, 2008). Of particular consequence are non-native species which cause increased fire frequency, intensity, length and severity. As a result, practices have changed which de-emphasize the use of non-native species.

Recommendations by land management agencies, such as the U.S. Fish and Wildlife Service which publishes the Handbook on Fire Management and Invasive Species, state fire managers should attempt to prevent the dispersal of invasive species by ensuring seed for re-vegetation is weed free (Brooks and Lusk, 2008). The use of non-native species does still exist, particularly if there is need for quick reestablishment, but it is generally not the preferred method (Richards et al., 1998).

Historical Context

Land managers require reliable scientific information on vegetation and vegetation change to assess ecosystem health. Historically, vegetation has been examined using field surveys. These surveys may consist of samples collected using line transects, quadrats, points or by monitoring individual plants. While these techniques provide *in situ* information for a particular area, they are resource intensive. Because these techniques require a large input of time to survey a relatively small area, they are less practical for detecting change over large areas. More recently vegetation recovery has been monitored using remote sensing and geographic information systems (GIS). These techniques are particularly useful in detecting land cover changes over large areas due to the spatial and temporal scales of the sensors collecting information.

CHAPTER TWO: REMOTE SENSING PLATFORMS AND SENSORS FOR VEGETATION MONITORING

Aerial photography was historically the main remote sensing technique used to gather vegetation data. Over time, as technologies advanced, additional methods emerged including the use of satellites to collect spaceborne data. This section will provide an overview of the different sensors and platforms used for remote sensing vegetation. The basic process for monitoring vegetation is the same for both airborne and spacebrone platforms. First a study area is selected, and then imagery or photography is acquired, processed and analyzed. This section will highlight some of advantages and disadvantages of data collected using each technique.

Aerial Photography

Aerial photography is one of the oldest forms of remote sensing (Morgan et al., 2010). Traditionally, aerial photography has been acquired using piloted aircraft, but recently unmanned aerial vehicles (UAVs) have also gained popularity. Once photographs are acquired, manual interpretation is typically used to identify spatial patterns and types of vegetation in a particular area.

An advantage to collecting aerial photography is that startup costs are relatively cheap compared to the cost of launching a satellite. If desired, off-the-shelf camera equipment can be used. Another advantage to aerial photography is that platforms can be deployed relatively quickly to collect information over a specific area. Unlike satellites which require years of preparation to launch, aircraft or UAVs can often be deployed with relatively little notice assuming regulatory approval has been secured.

While aerial photography has a number of advantages, using this method also poses a number of challenges. A major challenge to processing aerial photography is that it is often collected at oblique angles. Oblique photography tends to introduce geometric distortions, which can be difficult and time consuming to eliminate in post-processing (Campbell and Wynne, 2011). Because of this, attempting to assemble photo mosaics and register aerial photographs can be challenging and time consuming, especially because aircraft flight lines and altitude are often not constant.

In terms of monitoring vegetation, the spatial and temporal scales of aerial photography are limited. While this is suitable and potentially preferable for analyzing smaller ecosystems, aerial photography alone is not adequate when analyzing large spatial extents. To monitor vegetation it is preferable to have data which is systematically collected, to ensure collection at the desired stage of the vegetation's phenological cycle. Systematic records of aerial photography over a number of years for a specific site location tend to be rare because of the costs associated with flying each mission.

Another issue with the use of aerial photography is that interpretation is often subjective and relies on the knowledge of individual users (Morgan et al., 2010). Even if interpreters are highly trained, the perceptions of the person analyzing the photograph may influence the interpretation. For these reasons, aerial photography alone is not practical for assessing changes in vegetation over large spatial extents. Instead, this study will use primarily spaceborne remote sensing methods which are more suitable to vegetation monitoring over large areas.

Spaceborne Remote Sensing

Spaceborne remote sensing has a number of advantages over aerial photography. One of the major advantages in using spaceborne remote sensing data for analyzing vegetation change is that satellites have been collecting data continuously for decades, providing a consistent record for analysis. Another advantage to using satellite imagery for vegetation monitoring is the synoptic view satellite images provide – spaceborne imagery has the ability to collect data over a large area with relatively few images. This section will review the different types of platforms and sensors available for vegetation monitoring, with a focus on those which provide data that are freely and publicly available.

Landsat

Landsat is a joint program between the United States Geological Survey (USGS) and the National Aeronautics and Space Administration (NASA). The program was originally designed and implemented to collect a consistent record of land imagery. Landsat platforms have continuously collected information across the globe since the launch of Landsat-1 (previously known as the Earth Resource Technology Satellite) in 1972. The Landsat program has one of the longest continuous records of moderate resolution imagery from a spaceborne remote sensing platform. Landsat platforms have a near polar, sun-synchronous orbit which means they cross the equator, or any other latitude, at approximately the same time every day.

The program continues to collect information today from the Landsat-8 platform which was launched in 2013. Data collected from sensors onboard the Landsat platforms are particularly useful in examining historical vegetation change because of the continuity of the mission's sensors, which helps to minimize spatial, spectral, temporal and radiometric variations. Data from all the Landsat missions are freely and publicly available through the USGS EarthExplorer website. The following section will provide information on the different sensors used on the Landsat satellites.

Multi-Spectral Scanner (MSS)

MSS is a whiskbroom sensor and was the primary sensor on Landsat 1-3. While the MSS was also onboard Landsat 4-5, the Thematic Mapper (TM) was considered the primary sensor on those platforms. MSS data was originally collected at a roughly 80-meter spatial resolution, but has since been resampled to approximately 60 meters. One MSS scene is approximately 185 km in the east-west direction by 170 km in the north-south direction (Campbell and Wynne, 2011). MSS data was collected in four spectral bands: visible red, green and two near-infrared bands (Table 1). The sensor initially had a 6-bit radiometric resolution, which was improved to 8-bit for later missions. The revisit period, or the time it took for the sensor to re-image the same area of the Earth, was 18 days on the Landsat 1-3 and 16 days on the Landsat 4-5.

Table 1 MSS Sensor Band Descriptions

Band	Resolution	Wavelength (µm)	Description
4	60m	0.5-0.6	Green
5	60m	0.6-0.7	Red
6	60m	0.7-0.8	Near Infrared
7	60m	0.8-0.9	Near Infrared

Thematic Mapper (TM)

TM is a whisk broom scanner that improved upon the spatial and spectral resolutions of the MSS. The TM sensor has a roughly 30-meter spatial resolution and seven spectral bands (Table 2). TM scenes are approximately 170 km by 183 km and have an 8-bit radiometric resolution ("Landsat Thematic Mapper"). TM was first launched on Landsat-4 in 1982 and was operational on Landsat-5 which was decommissioned in 2013. The continuity of the sensor's operation from 1982-2013 provided consistent data collection, which helped minimize change detection error due to sensor calibration variations (Munyati, 2009). The continuity of the sensor and the minimization of calibration variations make TM useful for analyzing historical trends in vegetation change.

Table 2 Thematic Mapper Sensor Band Descriptions

Band	Resolution	Wavelength (µm)	Description
1	30m	0.45-0.52	Blue
2	30m	0.53-0.61	Green
3	30m	0.63-0.69	Red
4	30m	0.78-0.90	Near Infrared
5	30m	1.55-1.75	Short-wave Infrared
6	60m	10.4-12.5	Thermal Infrared
7	30m	2.09-2.35	Short-wave Infrared

Enhanced Thematic Mapper (ETM+)

The ETM+ is a nadir-viewing whiskbroom sensor which collects data in eight spectral bands and has a 170 x 185 kilometer swath. The ETM+ has a 30-meter spatial resolution except for its panchromatic band which has a 15-meter spatial resolution. The sensor was launched on Landsat-7 in 1999 and was designed to provide continuity with the TM sensor. In 2003 the sensor experienced a problem with its scan-line corrector which resulted in gaps near the edges of images (Campbell and Wayne, 2011). Landsat-7 and the ETM+ sensor remain operational at present.

Terra & Aqua

The goal of the Terra & Aqua satellite missions is to improve understanding of global processes including changes occurring on land, in the oceans and in the lower atmosphere ("MODIS Website"). Launched in 1999 and 2002 respectively, the Terra and Aqua satellites are sun-synchronous and have polar orbits ("About Terra"). One difference between the satellites is that they cross the equator at different times in the day – Terra crosses in the morning while Aqua crosses in the afternoon ("MODIS Website"). Like the Landsat program, data from the Terra and Aqua satellites are freely and publicly available through NASA and USGS hosted websites.

Moderate Resolution Imaging Spectroradiometer (MODIS)

Both Terra and Aqua carry the MODIS sensor. MODIS acquires data in 36 spectral bands (Table 3) ("MODIS Website"). The sensor has three spatial resolutions 250-meter, 500-meter and 1-kilometer, which varies depending on the spectral band (Table 3).

Table 3 MODIS Sensor Band Descriptions ("MODIS Website")

Primary Use	Band	Bandwidth (micrometers)	Spatial Resolution (meters)
Land/Cloud/Aerosols Boundaries	1	620 - 670	250
	2	841 - 876	250
Land/Cloud/Aerosols Properties	3	459 - 479	500
	4	545 - 565	500
	5	1230 - 1250	500
	6	1628 - 1652	500
	7	2105 - 2155	500
Ocean Color/ Phytoplankton/ Biogeochemistry	8	405 - 420	1000
	9	438 - 448	1000
	10	483 - 493	1000
	11	526 - 536	1000
	12	546 - 556	1000
	13	662 - 672	1000
	14	673 - 683	1000
	15	743 - 753	1000
	16	862 - 877	1000
Atmospheric Water Vapor	17	890 - 920	1000
	18	931 - 941	1000
	19	915 - 965	1000
Surface/Cloud Temperature	20	3.660 - 3.840	1000
	21	3.929 - 3.989	1000
	22	3.929 - 3.989	1000
	23	4.020 - 4.080	1000
Atmospheric Temperature	24	4.433 - 4.498	1000
	25	4.482 - 4.549	1000
Cirrus Clouds Water Vapor	26	1.360 - 1.390	1000
	27	6.535 - 6.895	1000
	28	7.175 - 7.475	1000

Cloud Properties	29	8.400 - 8.700	1000
Ozone	30	9.580 - 9.880	1000
Surface/Cloud Temperature	31	10.780 - 11.280	1000
	32	11.770-12.270	1000
Cloud Top Altitude	33	13.185 - 13.485	1000
	34	13.485 - 13.785	1000
	35	13.785 - 14.085	1000
	36	14.085 - 14.385	1000

Sensor Selection

This study will use Landsat TM imagery. TM provides consistent collection and is the only Landsat-based sensor which covers the entire period of the study. While MODIS offers the ability to analyze data in a much greater number of spectral bands and like TM its data are also freely and publicly available, the MODIS sensor will not be used as the primary sensor in this study. MODIS was first was launched in 1999 and, therefore, did not collect data for the first fourteen years of the study. Another issue with the MODIS data is that the spatial resolution of the sensor tends to be more suitable for global or landscape level analyses, an inappropriate scale for this study which will focus on individual fire perimeters.

Other moderate spatial scale sensors with long-term continuous operation exist. One example is the high resolution visible imaging sensors on the Satellite Pour l'Observation de la Terre (SPOT) platforms. The SPOT sensor is highly correlated with TM in the visible and infrared bands, the bands commonly used for vegetation monitoring (Smits and Dellepiane, 1995). Additional moderate resolution imaging sensors include the linear imaging self-scanner systems (LISS I-IV), the Wide Field Sensor (WiFS), and the Advanced Wide Field Sensor (AWiFS) found on the Indian Remote Sensing Satellites (IRS). Imagery collected from TM is preferable to data from SPOT, LISS, WiFS and IRS sensors because TM data is freely and publicly available.

One disadvantage of the TM is that it needs cloud free days to collect useful data. The thermal band is the only band capable of producing imagery at night, but this band is not commonly used with vegetation indices. Another disadvantage is its sixteen-day revisit period. A sixteen-day revisit period means if one image is obscured by clouds, the next image would be collected sixteen days later. In interpreting vegetation, it is important to have data of the same phenological stage so obtaining imagery at the right phase of the cycle is of particular importance. Despite these challenges, TM still provides the best option because of its consistent data collection, appropriate spatial, radiometric and spectral resolutions and the availability of the data.

CHAPTER THREE: LITERATURE REVIEW

A number of studies have used remote sensing to monitor fires, fire behavior and the impact of fires on landscapes (Zhu et al., 2006). The definition of post-fire recovery is typically dependent on the purpose of the study and can be assessed in terms of economic, biological, or social impact. Assessments can be made on a micro-scale, looking only at the impact of a single fire or they can be regional and look at the overall impact across a larger area with multiple fires. The timeframe of an assessment can be across a single season or across a number of years. This study will assess recovery in terms of the vegetation regrowth of three fire sites in Winnemucca District over a period of twenty years.

Vegetation Indices

A common way to classify vegetation recovery using remote sensing techniques is to use indices that monitor surface-level vegetation changes. Vegetation recovery can be assessed in terms of the recovery of a specific species or class of vegetation or it can be assessed holistically based on the total amount of vegetative regrowth using a density measure. These vegetation indices are reliant on measuring reflectance, which is a ratio of the amount of electromagnetic radiation emitted from an object compared with the amount of radiation that strikes the object. The history and formulae for many of these indices are reviewed in Perry and Lautenschlager (1984). Some of these indices, like the Normalized

Burn Ration (NBR), are specific to assessing post-fire conditions, while others like the Normalized Difference Vegetation Index (NDVI) have wider applications. This literature review describes indices for assessing vegetation recovery with a focus on techniques used in arid and semi-arid environments. Since the scope of this study incorporates vegetation recovery over a period of years, this literature review also assesses methods to analyze changes in vegetation over time.

Vegetation indices are reliant on the physiological characteristics of vegetation and vegetation reflection properties. Healthy green vegetation tends to reflect large amounts of near infrared light and absorb large amounts of light in the red region. The structure of the plant is what causes this reaction. Chlorophyll of outer leaves typically absorbs red light and reflects green light, while mesophyll cells tend to reflect large amounts of NIR. As a result, areas that have large amounts of healthy green vegetation will have larger amounts of NIR reflectance. In areas with sparse vegetation, special considerations need to be made to address vegetation properties.

NDVI

One of the most common indices to monitor vegetation is NDVI. This index is often employed for global or continental scale calculations for its ability to compensate for illumination conditions, surface slope, and viewing angle (United States Geological Survey, 2013c). The algorithm is also applicable to smaller scale studies and has been widely used in part due to its simplicity. NDVI is a ratio that compares the proportion of reflectance in the near infrared and the visible red spectrums. The equation was developed by Rouse et al. (1974)

$$NDVI = \frac{NIR - RED}{NIR + RED} \tag{1}$$

where NIR is the measurement of the reflectance of the near infrared spectral band and RED is the measurement of the reflectance of the visible red spectral band. For TM data, NIR is Band 4 and VIS is Band 3

Calculating this ratio results in a number ranging from ± 1. The chlorophyll of healthy green vegetation absorbs visible red radiation and reflects infrared radiation. As a result, areas with large amounts of healthy green vegetation produce a number close to +1. Unhealthy or sparse vegetation reflects larger amounts of visible radiation and smaller amounts of near infrared radiation which will produce a lower, but still positive number closer to zero (Matsushita et al., 2007). Negative NDVI values represent clouds, water, and snow. Bare soils and rock tend to reflect moderate amounts of red and infrared radiation and tend to have values close to zero.

NDVI has a number of applications from estimating crop yields to estimating drought (Quarmby et al., 1993). A few selected studies that have used NDVI to look at pre- and post-fire vegetation recovery include: Diaz-Delgado et al. (2003) who used pre- and post-fire NDVI values to map fire severity in northeast Spain; Kushla et al. (1998) who used NDVI to assess fire effects in a forest landscape in Oregon; and Escuin et al. (2008) who used NDVI derived from Landsat TM/ETM+ data to assess pre- and post-fire severity measures in southern Spain.

The application of NDVI to arid and semi-arid environments has some challenges, though. Arid or semi-arid areas tend to have large amounts of non-photosynthetic vegetation (dry grass, leaf material, woody material) that produce limited amounts of chlorophyll which results in NDVI values lower than typical vegetation (Roberts, 1993; Huang et al., 2010). NDVI as a measure of greenness is an ephemeral characteristic which may not be present during certain times of the year when there are high amounts of brown biomass (Mullins, 1989). NDVI was also found to be inaccurate in areas immediately after vegetation burned and in areas that had little pre-fire vegetation (Cocke et al., 2005).

While NDVI was shown to be problematic in some studies, in other studies by Peters & Eve (1995) and Peters et al. (1997) NDVI was found to be useful in monitoring vegetation in arid and semi-arid environments. The studies by Peters & Eve (1995) and Peters et al. (1997) differentiated vegetation classes including shrubs and grasses in the Chihuahuan Desert in southern New Mexico. In these studies, they found it was feasible to derive certain information such as stress and growth of vegetation using NDVI despite issues normally associated with high soil to background ratios. The Peters & Eve study (1995) specifically focused on changing vegetation dynamics between shrub, scrub and grassland as indicators of desertification. Weiss et al. (2004) also used NDVI to assess vegetation over eleven years in an ecologically diverse semi-arid area of central New Mexico. Previous studies have shown the results of NDVI to be mixed in arid and semi-arid areas and other indices have been developed to address these issues.

Soil Adjusted Vegetation Index (SAVI)

SAVI is a vegetation index that addresses some of the deficiencies of NDVI by incorporating adjustments for soil reflectance (Qi et al., 1994). The following formula for SAVI was developed by developed by Huete (1988)

$$SAVI = \frac{NIR - RED}{NIR + RED + L} * (1 + L) \tag{2}$$

where L is a manually set correction factor ranging from 0 to +1. For TM data RED is Band 3 and NIR is Band 4. The soil adjustment factor L is subjectively set by the user to a value between 0 and +1, with +1 used for areas with low amounts of vegetation and 0 in areas with large amounts of vegetation (Baugh and Groeneveld 2006). L is commonly set to 0.5 for moderate amounts of vegetation or for vegetation that varies in density (Qi et al., 1994; Baugh and Groeneveld 2006). Like NDVI, SAVI has a scale of ± 1 with numbers closer to +1 representing healthy green vegetation.

In some studies SAVI has been shown to be highly correlated to NDVI (Elmore et al., 2000). However, in studies conducted by Pleniou and Koutsias (2013) and Veravebeke et al. (2012a), SAVI outperformed NDVI in delineating areas of burned versus unburned vegetation in homogenous areas with a single vegetation type. Conversely, in the study by Vevaverbeke et al (2012a) NDVI outperformed SAVI in estimating vegetation cover in areas with heterogeneous land cover.

One known issue with SAVI is that it has errors when used in areas with particularly low or high vegetation cover (Qi et al., 1994). The Modified Soil Adjusted Vegetation Index (MSAVI) and the Second Modified Soil Adjusted Vegetation Index (MSAVI2) try to address this issue with the following formulae:

$$MSAVI = \frac{(NIR - RED)(1 + L)}{NIR + RED + L} \tag{3}$$

$$L = 1 - \frac{2 * s * (NIR - RED) * (NIR - s * RED)}{NIR\_ + RED}$$

$$MSAVI2 = \frac{2*NIR+1-\sqrt{(2*NIR+1)^2-8(NIR-RED)}}{2} \qquad (4)$$

where s=slope of soil line. For TM data RED is Band 3 and NIR is Band 4. Whereas SAVI uses a manual adjustment L, in MSAVI the L factor is variable and self-adjusted (Purevdorj et al., 2010). MSAVI uses the slope of the line in a plot of red versus NIR values to calculate L. To calculate L this way requires plotting the red versus NIR values for each pixel in a space plot to get the slope of the soil line. MSAVI is typically used for areas with varying densities of vegetation (Ververabeke et al., 2012a). In a study by Qi et al. (1994) which compares the results of SAVI and MSAVI, using MSAVI resulted in better vegetation sensitivity. MSAVI2, developed by Qi et al., is a modified formula which eliminates the need for a feature space plot, simplifying the method of calculation.

Transformed SAVI (TSAVI) is another variation of SAVI which takes into consideration soil brightness by incorporating soil line slope and intercept values (Purevdorj et al., 1998). TSAVI uses the following formula:

$$TSAVI = \frac{s((NIR-s)*(RED-a))}{(a*NIR+RED-a*s+X*(1+s^2)} \qquad (5)$$

where s=slope of soil line and a=soil line intercept. For TM data RED is Band 3, NIR is Band 4. TSAVI incorporates soil line parameters and is used in areas with low density biomass. In a study by Purevdorj et al. (1998), the TSAVI index provided a more accurate estimate of vegetation cover than other variations of SAVI or NDVI when soil line information was available. Because soils are variable across time this equation requires calculating soil line information for each year of a study.

Enhanced Vegetation Index (EVI)

EVI is a standard NASA product derived from MODIS data which uses the following formula:

$$EVI = G * \frac{(NIR - RED)}{(NIR + C_1 * RED - C_2 * BLUE + L)} \qquad (6)$$

where G is gain factor, C_1, C_2 are coefficients for the aerosol resistance term and L is a canopy background adjustment. The index was created in response to some of the problems that exist with NDVI using the MODIS sensor. The EVI formula incorporates the blue band to compensate for certain atmospheric effects. EVI addresses the issue of saturation that occurs with NDVI and is an improvement on NDVI for areas with dense canopies and high biomass, typically forested regions.

Perpendicular Vegetation Index (PVI)

Richardson and Weigend (1977) developed the following formula to address the effects of soil reflectance when using remote sensing data to monitor vegetation:

$$PVI = \sin(a)NIR - \cos(a)RED$$

where a=angle between the soil line and the NIR axis. For TM data RED is Band 3 and NIR is Band 4. PVI incorporates the work of Kauth and Thomas (1976) who determined that soil reflection variation is limited to a line or plane and that the reflectance of vegetation growth is perpendicular to this plane. PVI measures the distance of a vegetation point to the soil line in a plot of MSS data. Richardson and Weigend found that PVI can serve as a measure of leaf area index (LAI), which measures plant density.

Vegetation Index Selection

This study uses the NDVI and MSAVI2 vegetation indices. These two indices are the most appropriate because they employ relatively simple formulae to calculate vegetation changes over time. The EVI index is not appropriate for this study because it is designed to prevent saturation, which is not a concern given the ecological environment of Winnemucca District. Winnemucca is dominated by shrubs and grasses so NDVI saturation is unlikely to occur. The PVI index will not be used because it is sensitive to atmospheric conditions. Because of this sensitivity, using the PVI index would make it difficult to determine what changes were due to atmospheric effects versus actual vegetation change.

NDVI will be used in this study despite the potential problem it has assessing vegetation immediately after a fire. Because the focus of this study will be on vegetation recovery in the five to twenty year period following a fire, the index is still applicable to the purpose of the study. NDVI also has a historical record of being used for vegetation monitoring in a variety of conditions. The previous studies which used NDVI provide useful information on the expected responses of NDVI in a variety of environments. This study will attempt to prevent against the problem NDVI has distinguishing vegetation in the late and non-growing seasons by using imagery from early spring, which was shown to have relatively uniform phenological characteristics across years (Weiss et al., 2004).

MSAVI2 is the other vegetation index this study uses. The index compensates for some of the deficiencies in the NDVI index, such as adjustments for soil reflectance and increased sensitivity to vegetation. MSAVI2 is preferable to other variations of SAVI because of its ability to account for areas with sparse amounts of vegetation and its relatively simple formula which makes it easy to apply across time. The study uses a combination of vegetation indices to compensate for the deficiencies of the other index. MSAVI2 compensates for soil reflectance and sparse vegetation better than NDVI and NDVI has been shown to be more effective in areas with heterogeneous vegetation.

Fire-related Indices

While this study primarily uses vegetation indices, it is important to acknowledge other fire-related indices also exist. Many of these indices focus on short-term changes within a growing season or between two growing seasons. As a result, their intent is not necessarily applicable to long-term monitoring. Two of the most common fire indices are the Normalized Burn Index (NBR) and the differenced Normalized Burn Ratio (dNBR) which are discussed in the following section. This study will use products derived from these indices as measures of fire severity, but not for long-term vegetation monitoring purposes. Fire perimeter data derived from these indices will also be compared to field collected fire perimeter data to ensure consistency and agreement of fire perimeters.

Normalized Burn Index & Differenced Normalized Burn Index

NBR is a measure of fire severity developed in 1991 by Lopez-Garcia and Casselles (Lentile et al., 2006). NBR uses the following formula which uses the reflectance in the NIR and MIR regions as an indication of the amount of moisture in vegetation (Veraverbeke et al., 2011):

$$NBR = \frac{(NIR-MIR)}{(NIR+MIR)} \tag{8}$$

For TM data NIR is Band 4 and MIR is Band 7. NBR ranges from ±1. Post-fire areas tend to have increased levels of reflectance in the RED and MIR regions and a decrease in NIR reflectance due to a decrease in chlorophyll and soil moisture (Escuin et al., 2008).

The dNBR index is a measure of change in the value of NBR at two points in time:

$$\Delta NBR = NBR_{pre-fire} - NBR_{post-fire} \qquad (9)$$

Negative dNBR represents vegetation growth and positive dNBR is an indication of vegetation mortality (Eidenshenk et al, 2007). The advantage to using dNBR as opposed to NBR is that it is easier to distinguish which areas have been effected by fire than using a single image, particularly for areas with sparser vegetation (Veraverbeke et al., 2011). The NBR and its variation dNBR are commonly used at the landscape level as a measure of fire severity in the United States and are incorporated into many of the databases which monitor the effects of fires (Lentile et al., 2006).

Long-Term Remote Sensing Techniques for Vegetation Monitoring

Volgemann et al. (2012) describe four types of vegetation changes: abrupt, seasonal, gradual ecosystem and short-term inconsequential change. The focus of this paper will be on interannual and long-term land cover changes. A number of methods have been developed using Landsat Time Series Stacks (LTSS) to monitor land cover change over time. Two of these methods are described below:

Landsat-Based Detection of Trends in Disturbance and Recovery (LandTrendr)

Kennedy et al., (2001) developed LandTrendr which uses temporal segmentation algorithms to examine changes to landscapes over time using Landsat imagery. This method relies on NBR and the Tasseled Cap wetness index to categorize the status of vegetation change. Land Trendr incorporates vegetative cover into change models to develop segmentations that capture both short- and long-term changes. For long-term changes it uses a smoothing method that reduces the impact of ephemeral changes due to phenological characteristics, illumination differences or geometric conditions. The study by Kennedy et al. (2001) determined this method is useful to capturing abrupt changes as well as long-term recovery of forested areas.

Vegetation Change Tracker

Huang et al. (2009) developed the Vegetation Change Tracker (VCT) algorithm to assess changes in national forests over time. The algorithm uses a series of Landsat imagery for the same location to map disturbances. This process is similar to that used by Kennedy et al. with LandTrendr (Huang et al., 2009). Overall accuracy for the Huang study using VCT was about 80% with slightly lower producer's accuracy (50-75%) which was assessed as being a result of minor changes in disturbances that were captured by human analysts that the algorithm did not detect.

Existing Management Tools

A number of database and management systems have been developed by the United States government to organize and display GIS products used to monitor fires and the impact fires have on landscapes. Included in these management systems are tools geared to analyze conditions at different stages of the fire cycle. Some tools focus on short-term impacts while others model potential changes over hundreds of years. The purposes of the management tools vary and the tools themselves are intended to be applied at different scales. Overviews of four of the main programs are provided in the following section. Because fire recurrence and severity often depend on changing environmental conditions and in particular, changing vegetation conditions, a noticeable gap in these databases is in specific information related to changing vegetation conditions.

Burned Area Reflection Classification

The Burned Area Reflection Classification (BARC) system is employed as part of the Burned Area Emergency Response (BAER) program. The purpose of the BAER program is to identify and mitigate the potential for fires to cause further impact beyond damage caused by the initial burn (Lentile et al., 2006). BAER teams address secondary effects of fire, such as soil erosion, which potentially threaten an area's stabilization (Lentile et al., 2006). BARC maps are based on data derived from remote sensing platforms. They use either the NBR or the dNBR to classify vegetation into the following impact categories: low, moderate, high and unburned[1] ("RSAC"). BAER teams use these severity maps to determine where to focus their efforts and then the teams provide ground truth information to update maps derived from the remote sensing information.

Rapid Assessment of Vegetation Condition after Wildfire (RAVG)

[1] An additional product is available from the Remote Sensing Applications that has 256 classes. This information is known as BARC256. Typical BARC maps include only four classes.

Another system used to assess short-term fire effects is RAVG. This system is employed by the United States Forest Service and classifies basal area loss (change in relative area of live tree cover) using the relative differenced normalized burn ratio (RdNBR) calculated from Landsat TM images ("What is RAVG"). RAVG is utilized for thirty days following fire containment to monitor affected by fires that affected areas greater than 1000 acres ("What is RAVG"). RAVG is specifically used on National Forest Service lands and intended to complement BAER reports.

Landscape Fire and Resource Management Planning Tools Project (LANDFIRE)

LANDFIRE is an interagency program designed to provide information on fires. LANDFIRE incorporates information from MTBS, RAVG and BARC. Two unique features of the LANDFIRE website are that it provides training on how to use the products it produces and it offers users the opportunity to contribute their own data. The amount of information, including the information incorporated from other databases, and the interactive components of the site make it the most comprehensive site dealing with fire and fire-related vegetation information.

Over twenty layers of fire-related geospatial data are contained in the LANDFIRE database. The database includes information on: historical vegetation types, vegetation surveys (Gap Analysis Surveys), fuel loads, fire regimes, disturbance maps and a number of other topics. LANDFIRE vegetation information consists of a number of layers related to existing and potential vegetation. The existing vegetation data layer is derived from a variety of sources including imagery, topographic information, field collection and other surveys such as the National Land Cover Database. While a lot of information is available, most of the existing vegetation data layers are for 2001, 2008 and 2010. Only information for 2001 is within the scope of the study. In addition to containing existing vegetation information, potential vegetation information is also contained in LANDFIRE. Available potential vegetation includes estimated historical dominance of vegetation dating back to pre-Euro American settlement and potential vegetation which could be supported by a specific environment. LANDFIRE contains a variety of information on fire-related vegetation information, but for the purposes of this study most of the information is too recent to be extensively incorporated into the study.

Monitoring Trends in Burn Severity (MTBS)

The USGS National Center for Earth Research Observation and Science (EROS) and the U.S. Forest Service's Remote Sensing Application Center (RSAC) developed the MTBS project to monitor national trends in fire severity. MTBS aims to provide consistent information on changes in burn severity across the United States. A goal of MTBS was to establish common definitions. MTBS defines burn severity as, "degree to which a site has been altered or disrupted by a fire; loosely, a product of fire intensity and residence time" (Eidenshenk et al., 2007). MTBS compiles information for fires larger than 500 acres in the eastern United States and 1000 acres for other areas ("Mapping Burn Severity"). The database hosts a number of products including pre- and post-fire imagery, maps of NBR/dNBR/RdNBR indices for individual fires, fire perimeter information, and thematic burn severity information. Information from historical fires continues to be updated in the database.

Land Treatment Digital Library (LTDL)

Unlike the other databases reviewed in this section, the primary focus of the LTDL is not on fire data. The database contains information related to fires including fire perimeter data, but the primary purpose of the LTDL is to provide land treatment information for western lands managed by the BLM (Pilliod and Welty, 2013). Unlike MTBS and LANDFIRE, the information contained in the LTDL is not publicly available. Access can be obtained by land managers or scientific researchers, but it must first be requested and granted before the majority of information stored in the database can be accessed. For the purposes of the study, the LTDL will be used for comparison of fire perimeter data and for information regarding which post-fire treatments were applied.

CHAPTER FOUR: STUDY SITE, DATE AND FIRE PERIMETER SELECTION

The focus of this research is on the BLM District of Winnemucca (Figure 1) located in northwestern Nevada. Winnemucca is composed of all of Humboldt and Pershing counties, and portions of Washoe, Lyon and Churchill counties ("Winnemuca District Office"). The district covers approximately 11 million acres, of which approximately 8 million acres are classified as public lands ("Winnemucca District Office").

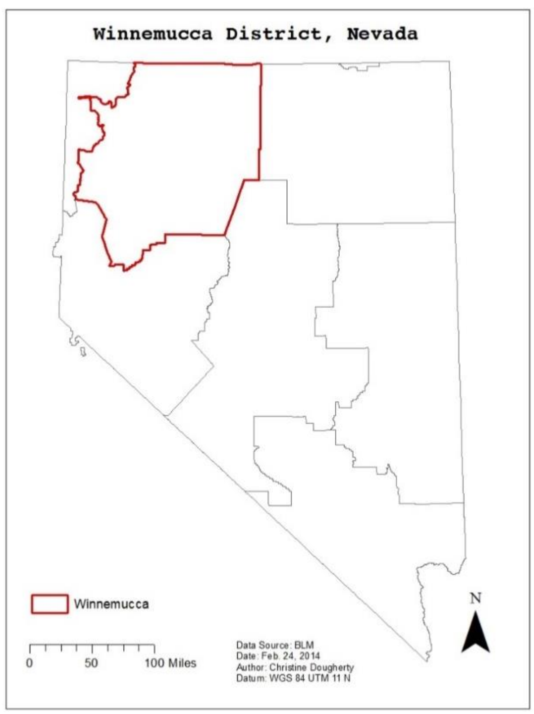

Figure 1 Winnemucca District

Winnemucca is part of the Environmental Protection Agency (EPA) Level III Northern and Central Basin and Range ecosystem (Figures 2 & 3). Dominant vegetation cover includes grasses, shrubs, and pinyon and juniper forests (“Winnemucca District Office”). Winnemucca District has a dry, semi-arid climate and conditions conducive to fire activity. Over 2.5 million acres of the Winnemucca District burned in a period of twenty years from approximately 1986-2006 (Eisworth et al., 2009).

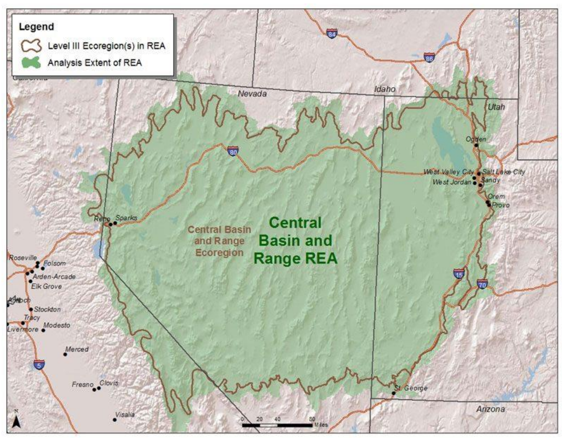

Figure 2 Central Great Basin

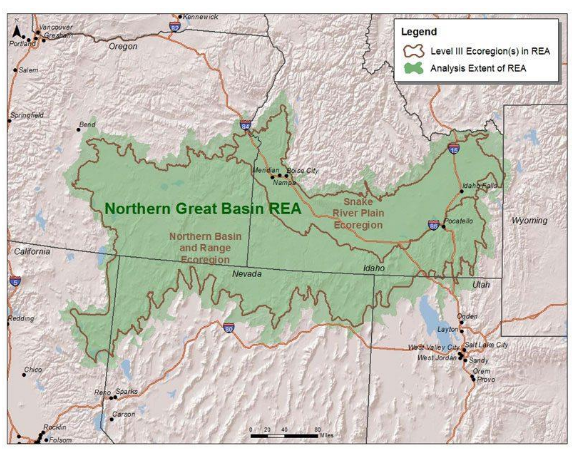

Figure 3 Northern Great Basin

A feature of the ecosystem is high variability of rainfall from year-to-year. The amount of precipitation in a wet year may be four times the amount received in a dry year and years of persistent drought may be followed by years of above average precipitation (Bradley and Mustard, 2005). These conditions can cause dramatic changes in the interannual response of vegetation. High interannual variability of production linked to precipitation is characteristic of annual grasses, and in particular, *Bromus tectorum* or cheatgrass (Figure 4) (Bradley and Mustard, 2005). Other types of vegetation, like shrubs and perennial grasses, have adapted to the ecosystem and their variability is much more limited.

Figure 4 *Bromus Tectorum* - cheatgrass ("Plants Profile for Bromus tectorum (Cheatgrass)"

Cheatgrass, a noxious annual grass also known as downy brome, is a concern for the region (Knapp, 1996). Cheatgrass is of particular concern for the following reasons: (1) after fires an area is particularly susceptible to cheatgrass invasion which can prevent natural vegetation recovery (Young and Evans, 1978) and (2) areas with cheatgrass tend to have higher frequency of fires due to increased fuel load (Knapp, 1996). In Winnemucca the natural vegetation of the Wyoming big sagebrush community has had extremely poor natural recovery rates after fires because of its susceptibility to cheatgrass (Knapp, 1996). Beginning in the early 1980s cheatgrass started to be found in areas of northern Nevada where it was not previously present (Knapp, 1996). With the spread of cheatgrass areas which had not previously been susceptible to fires started to experience them (Knapp, 1996).

Study Dates

The focus of this paper is on vegetation recovery following the 1985 fire season extending 20 years after containment. The year 1985 was chosen because it was a peak fire year in the Winnemucca District when over one million acres burned (Zielinski, 1992; Knapp, 1996). Image analysis will begin in 1985 prior to the fire season, therefore, imagery from 1985 will reflect pre-fire vegetation cover.

Imagery will be analyzed from early spring in an attempt to standardize phenology conditions. Cheatgrass growth starts in April, peaks in mid-May and then senesces until the next growing season (Bradley and Mustard, 2005). This phenology tends to precede other vegetation's phenology and USGS studies have shown there is a difference in the profile of cheatgrass and big sagebrush in early spring (mid-March – May) (Boyte et al., 2012). The ability to differentiate these vegetation types is important to classification.

This phenology timeframe is also supported in a report by Tedrow and Weber (2011) who studied southern Idaho rangeland. In their study, the time of maximum photosynthetic productivity occurred in early spring and late fall. Because of this, their recommendation is to acquire images in April or May, instead of the traditionally used June or July timeframe (Tedrow and Weber, 2011). The spring timeframe was also supported in a study by Weiss et al. (2004) that looked at vegetation in semi-arid New Mexico. In this study they found that there was almost uniform interannual phenological response during the spring period. Vegetation indices, particularly NDVI, are reliant on photosynthetic measurements so it is important to use an appropriate stage in the phenological cycle of the vegetation.

Fire Site Selection

For this study, the focus is on fires that occurred in the 1985 fire season in Winnemucca District. Previous research has identified fire perimeters, and this study will rely on this research to help identify fire locations. Given the vast number of fires that occurred in Winnemucca in 1985, restrictions were imposed to limit the number of fires to focus on to three.

Fire perimeter data populated by the Nevada State Office and downloaded from the BLM's Nevada Geospatial database is the primary source of fire perimeter data for this study. The perimeter information was gathered by Nevada and California BLM staff in the field using global positioning systems (GPS) or digitized from paper maps and checked by BLM staff ("Nevada BLM Geospatial Data"). Other databases, like the LTDL and the MTBS, also contain fire perimeter information for this time period. Unlike the Nevada BLM data, the primary method of collection for the LTDL and the MTBS is through algorithms applied to imagery. The information in these databases is similar to what is contained in the BLM managed geospatial database, but variations exist.

The BLM derived data provided by the Nevada State office was chosen as the primary source of fire perimeter data because the BLM manages approximately 75 per cent, or roughly 8 million acres, of the lands comprising the Winnemucca District. The assumption is that because the BLM is responsible for managing the majority of the land in the District they would be the most familiar with the on ground reality of burned areas and would, as a result, be able to provide the most accurate perimeter information. Historical fire perimeters dating from as early as 1910 through 2008 are available on the Nevada BLM Geospatial Data webpage. To select which fires to use for this study the number of fires was first narrowed by date and location (Figure 5).

The fire perimeter data from the BLM Nevada Geospatial website uses a geodatabase to organize fire perimeters by year. In addition to providing fire perimeter boundaries, total burned area and identifying name code information is contained in the shape file attribute table. Separate shape files are provided for each year. The primary shape file used in this study contained the fire perimeters for the 1985 fire year, but fire perimeter data from other years is also used to determine whether any areas experienced burns in later years of the study.

To narrow from the whole population of Nevada fires to 1985 Winnemucca fires, ArcGIS selection operators were applied to fire perimeter data supplied by the BLM. Some fires overlapped district boundaries, but in this study only fires contained completely within the administrative boundary of the Winnemucca District were considered.

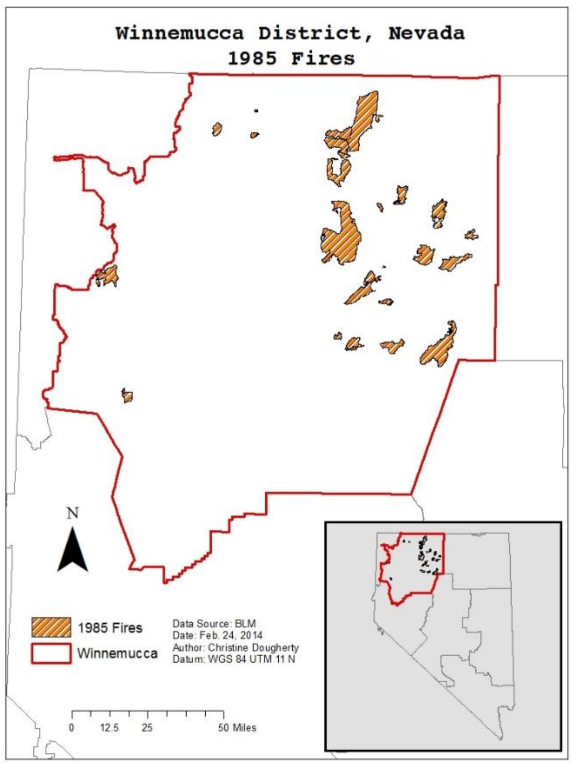

Figure 5 1985 Fires Contained Completely within Winnemucca District

A simple survey of the fires determined that most fires from the 1985 fire season were contained in the eastern portion of the district. The next step overlaid the footprint of the Landsat TM path/rows onto the 1985 Winnemucca fire perimeters to determine which imagery would need to be acquired. Geographically, the 1985 fires were dispersed evenly between the Landsat path/row 042/032 and 042/031 scenes. To simplify processing and limit the amount of data necessary for analysis, fires were chosen from a single Landsat scene. This decision was in part due to the size of the Landsat files – only having to download one set of files not only minimized the download time and space required to store these files, but it also meant that the images only had to be processed once.

To determine which scene to use, agreement of fire perimeters between the Nevada BLM database and the LTDL database along with proximity of fires to each other were used as a filter. To determine which fires had additional data available to support analysis and to cross-reference fire perimeter information, the dataset from the BLM website was cross-checked with the LTDL. This process required geographic boundary comparison. The LTDL contains fire names and codes, but these names are not contained within the Nevada BLM database. The fire codes in the Nevada BLM Database often only provide general information (e.g. NV-WID) and apply to multiple fires for that year. As a result, to determine which fires were contained both in the Nevada BLM Geospatial Database and the LTDL the geographic locations of the fires and their perimeters were compared. The LTDL had information on eleven fires in the Winnemucca District for the 1985fire season out of a total of twenty-seven fires listed on the Nevada BLM Geospatial Database.

Priority was given to fires that had consistent boundaries across the LTDL and the BLM sponsored databases. Preference was also given to fires which were not contiguous to ensure the fires could be treated as independent observations from each other. The result was the selection of the following three fires: Cosgrave Fire, Sheep Canyon Fire, and Dixie Fire (Table 4 & Figure 6).

Table 4 Selected Fire Information

Name	Code	Area (acres)	Date Contained
Cosgrave	J408	2961	Unknown - post-fire date 8/11/85
Dixie	J526	41706	7/9/1985
Sheep Canyon	J395	11340	8/20/1985

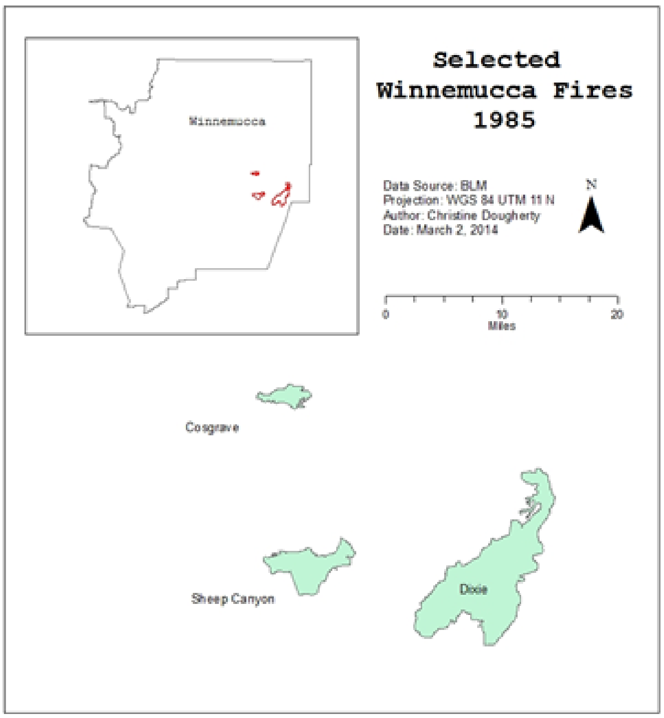

Figure 6 1985 Winnemucca Fires Selected for Study

CHAPTER FIVE: DATA ACQUISTION

This study uses data from the Landsat TM sensor which was chosen because it provides continuity across the full period of study and data from it are free and publicly available. The study specifically uses Landsat TM Climate Data Record Surface Reflectance imagery from the USGS's Earth Explorer website processed to a standard of Level 1T. Imagery processed to this standard has systematic geometric, radiometric and topographic accuracy and converted MODIS atmospheric correction routines applied ("Landsat Thematic Mapper"). Applying corrections to imagery is important particularly for time series analysis because it reduces the likelihood that changes detected will be a result of other variables besides vegetation change.

Datum & Projections

All imagery and map products use UTM 11 North projected coordinates and the World Geodetic System (WGS) 84 datum. WGS 84 is an earth-centered geodetic datum which is also used in global positioning devices. The Landsat imagery used in the study is in the WGS 84 datum with UTM 11 N coordinates while the fire perimeter data was originally on the Northern American Datum (NAD) 83. The two datums, WGS 84 and NAD 83, are relatively consistent with horizontal references in North America (Snay and Soler, 2000). Still, in order to ensure precise geographic positioning for analysis, the fire perimeters were transformed into WGS 84 and then reprojected into UTM 11 N coordinates. This method was chosen because the imagery was more numerous than other vector data used in the study and the WGS 84 datum is appropriate for the region of study.

Image Selection Criteria

Criteria used to select which imagery to download included: geographic specification of the 042/032 path/row, temporal restriction to April-May timeframe and less than 10% cloud cover. In some years multiple images were available that met these conditions, while in other years no imagery was available. The 10% cloud cover restriction was ultimately loosened to include more images within the specified timeframe. Additional processing took place to eliminate the effects of cloud cover on image interpretation which is discussed later. Even after relaxing the cloud cover restrictions, imagery was not available for every year in the study. Seasonal restrictions were applied to minimize the effects of phenological differences on vegetation indices. Instead of expanding the seasonal restrictions to include imagery from March and June, the decision was made to maintain the restrictions which meant a few years of the study did not have imagery.

Vegetation Data

Winnemucca District was chosen as a location both because of its historical record of wildfires and the belief that detailed field data would be available for this region. The Winnemucca BLM District Office was contacted at the beginning of the study to determine what vegetation and fire data exists. The Winnemucca District Office suggested contacting the USGS representatives who manage the LTDL to get access to the

LTDL database for additional vegetation information. While the LTDL contained information on fire perimeter data and the treatments applied after a fire, no specific information on what vegetation existed prior to the fire was available.

Vegetation information with precise locations is available for later years in the study through the National Gap Analysis Program, which produced vegetation maps for 1992 and 2001 (Figures 7 & 8). These surveys used field collected information as the basis of their land cover classification scheme ("Publications Gap Analysis"). The Gap Analysis maps provide useful information about what existed in these specific areas at an appropriate spatial scale at two points in time.

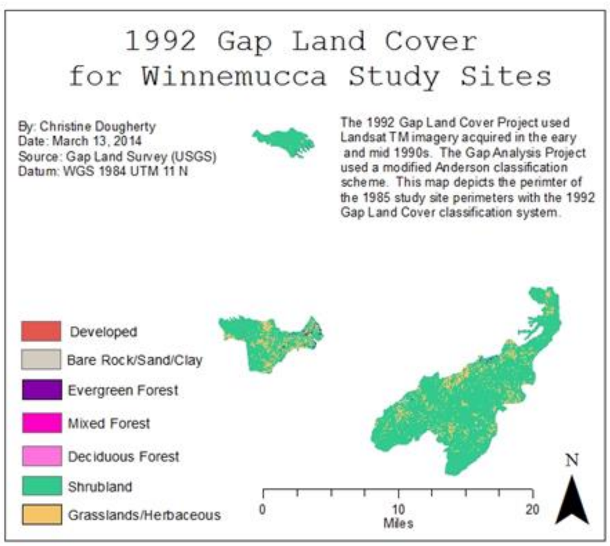

Figure 7 Gap Analysis (1992) Applied to Selected 1985 Fire Perimeters

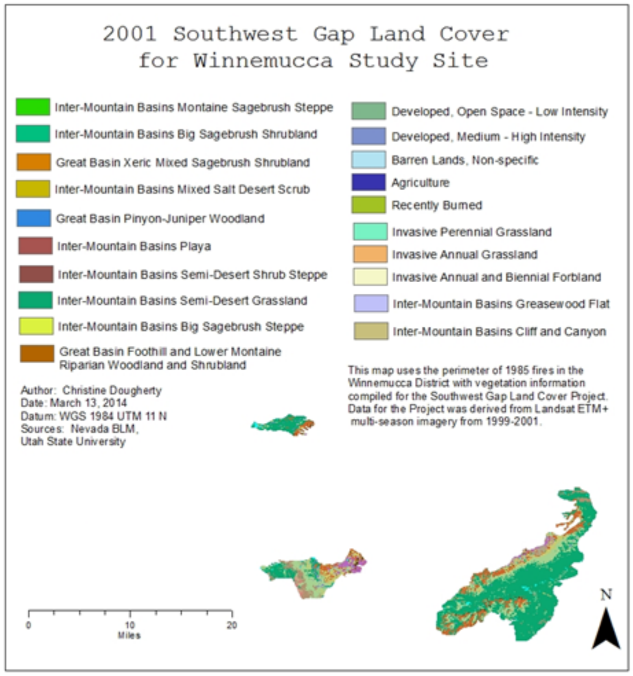

Figure 8 Southwest Gap Analysis (2001) Applied to Selected 1985 Fire Perimeters

Deriving what vegetation existed in 1985 from the Gap Analysis information is not practical because vegetation may have changed between 1985 and 1992. Another challenge in using these maps is that the classification schemes differ from the two dates of collection. The information from the 2001 survey could be smoothed to have consistent classification, but this would eliminate information such as whether an area had invasive annual or perennial grasses because fewer classes were used in the 1992 survey.

Ancillary Data

Additional ancillary data used in this study includes: historical climate data and drought data gathered from the National Oceanic and Atmospheric Administration (NOAA). NOAA has daily, monthly and annual climate data available for weather station locations across the country. The information is available for download from the Climate Data Online website and can be requested for a specific weather station. In Winnemucca, the airport weather station (station id: GHCND: USW00024128) has climate data dating back to 1877. This station was used for this study because it was the closest station to the study area and that information available for the duration of the study.

Historical drought index information from NOAA's National Climatic Data Center dating back to 1900 is also freely and publicly available. The site has two different measures for long-term drought monitoring – the Palmer Drought Severity Index (PDSI) (Palmer, 1965) and the Palmer Modified Severity Index (PMSI) (Heddinghaus and Sabol, 1991). The difference between the indices is in how they calculate the beginning of a wet or dry spell – the PMSI calculates on a continuous basis while the PDSI does not. After analyzing the dates and categorization of the two indices for the duration of the study, limited differences (Table 5) were found between the two indices for the northwestern Nevada region.

Table 5 Comparison of Palmer Drought Severity Indices (Source: NOAA Climate Data Center)

	PDSI		Modified PDSI	
Date	**April**	**May**	**April**	**May**
1985	MR	MR	MR	MR
1986	MR	MR	MR	MR
1987	MD	MR	MD	MR
1988	SD	SD	SD	SD
1989	SD	MD	SD	MD
1990	MD	MD	MD	MD
1991	SD	MD	MD	MR
1992	ED	ED	ED	ED
1993	MD	MD	MR	MR
1994	SD	SD	SD	SD
1995	VM	EM	VM	EM
1996	VM	EM	VM	EM
1997	MR	MR	MR	MR
1998	MR	VM	MR	EM
1999	MR	MR	MR	MR
2000	MD	MD	MD	MD
2001	SD	ED	SD	ED
2002	ED	ED	ED	ED
2003	ED	ED	ED	ED
2004	ED	ED	ED	ED
2005	MR	MM	MR	VM

*Gray denotes differences between PDSI and PMSI calculations

ED = Extreme Drought

SD = Severe Drought

MD = Moderate Drought

MR = Mid-Range

MM = Moderately Moist

VM = Very Moist

EM = Extremely Moist

CHAPTER SIX: METHODOLOGY

Classification

The initial aim of this study was to extract land cover classification classes for grass, shrubs (defined by the U.S. Department of Agriculture [USDA] as perennial, multi-stemmed woody plant that is usually less than 4 to 5 meters), tree and bare ground ("Growth Habits Codes & Definitions") at five year intervals. The study sites are predominantly bare ground, shrubs, and grasses, which is outlined in the post-fire monitoring reports. However, this information is not georeferenced to use for training or validation of vegetation classifications and discerning these vegetation types is difficult using the bands available on the Landsat TM imagery (Patil et al., 2006; Satterwhite and Henley, 1987). Because of the lack of georeferenced and ground truth data, classifying vegetation into distinct land cover types with reasonable accuracy was not possible. Instead of using land cover classifications, vegetation indices were applied to provide a general indication of whether vegetation change occurred.

Image Analysis

Three fires from the 1985 fire season were identified for this study (Table 4) to examine long-term vegetation recovery. For each fire study area selected, NDVI and MSAVI2 values are calculated annually when annual data is available or across two-years when annual data was not available. The 1985 data was used as a baseline because the date of the imagery precedes the fires for that year.

This study applies many of the pre-processing steps developed by Kennedy et al. (2010) for their tool LandTrendr. In the analysis, instead of using NBR and Tassled Cap Greenness Index though, NDVI & MSAVI2 are used. This study uses a different method to categorize vegetation change – analyzing changes annually and using a monotonic trend test to detect long-term change. The following steps are the method this study uses:

1) Prepare imagery
2) Apply a study area mask
3) Calculate Vegetation Indices
4) Difference and Classify Annual Images
5) Select Random Points to Calculate Statistical Change
6) Calculate Statistical Change Using Vegetation Indices at Longer-Term Intervals
7) Compare Vegetation Index Results

Results are assessed in terms of change over time for the two indices. Raw data derived from MSAVI2 and NDVI vegetation indices will compare annual and longer-term change for individual sites. The study will also compare the two indices to determine whether the vegetation response is the same for each index.

Image Pre-Processing

Imagery was acquired from the EarthExplorer website and loaded into ENVI for processing. The first step in the process was to stack the bands contained in the Landsat TM files. The next step was to define the band wavelengths in the stacked images. . Once this process was complete, vegetation indices were applied. ENVI contains the formula for NDVI in its vegetation index calculator so once image bands were defined, ENVI automatically calculated NDVI for each image. MSAVI2 is not a supported vegetation index in ENVI. The MSAVI2 formula was manually input and saved in the band math calculator for MSAVI2. To check the formula, a calculation for a single cell was conducted manually and compared with the calculator to ensure the correct results were computed. Separate images were saved for each year after MSAVI2 and NDVI indices were applied to the imagery.

The next step was to apply a geographic mask and a cloud mask to the imagery that had been converted to NDVI and MSAVI2. This process was done in ArcMap, which allows raster files to be clipped using vector information. Fire perimeters for the three relevant fires were selected and exported as a shape file. This shape file was transformed to have the same projection as the imagery. Then the images were clipped using this geographic mask. A cloud mask layer was available from the original imagery package downloaded from the USGS EarthExplorer website. The cloud mask was developed by Zhu et al. (2012) and identifies pixels containing clouds, cloud shadows, water and snow. Because the original cloud mask from the imagery package includes a number of classifications, the cloud mask was reclassified into two categories – areas with cloud, cloud shadows, water or snow (areas within fmask) and areas without cloud, cloud shadows, water or snow (areas outside the fmask). Only areas outside the fmask will be considered for analysis because these are areas without known atmospheric obstructions. Pixels containing clouds, cloud shadows or other atmospheric effects will not be consistent across time and will have dramatic changes in spectral responses which are not due to vegetation change; therefore, they should not be included in analysis. These masks were applied for all available imagery.

In some years multiple images (see Appendix) were available for the area of study. If multiple images were available for the same year they were mosaicked to form a single composite image. Mosaicking was based on the median date of the imagery to determine which would be the primary image used. The primary image's pixels would be the first used within the fire perimeter. Any subsequent images would help to supplement the primary image by filling areas which were affected by atmospheric conditions in the primary image. For a given year, the image with the date closest to the median date across images was selected as primary. Each subsequent image was used in the order from the median date.

Annual Image Differences

To classify vegetation changes on an annual basis ArcGIS was used. The vegetation index images were differenced using band math. The workflow is based on two image inputs. For this study, the later image (either NDVI or MSAVI2) was always input as Image 1 while the earlier year was input as Image 2. In other words, the earlier year was subtracted from the later. A positive result would indicate an increase in the calculated vegetation response and a negative response would mean there was a decrease in vegetation response across years. Once the images were differenced a threshold was applied. A threshold of +/- 0.025 was selected as no change, and anything greater/less than that was characterized as change. Areas affected by clouds, cloud shadow or water are identified as no data. After the vegetation indices were calculated a low-pass filter was applied to the image. The filter smoothed the data using a 3x3 pixel filter eliminating anomalous pixels. The process was repeated annually for NDVI and MSAVI2.

Long-Term Monitoring

To monitor long-term vegetation change, the Mann-Kendall trend test was applied to a selection of sampled points for each fire using the program XLSTAT. The Mann-Kendall trend test has been used in a number of other ecological studies to determine whether there is change over time – often with water quality, but also with vegetation (Han et al., 2013; Hesl and Hirsch, 2002). The Mann-Kendall trend test is a non-parametric test, which means it is based on the relative ranking of data. The trend test uses a hypothesis, in this case that there is no trend for change in vegetation and an alternative hypothesis that there is a trend of vegetation change. A limiting factor with the test is that it looks at monotonic change – which means a pattern of increasing or decreasing values over time.

This study limited the number of images available to the April-May timeframe. This timeframe was chosen because according to studies by Tedrow and Weber (2013) and Boyte et al. (2012) cheatgrass growth begins April, peaks in May and then senesces. This cycle tends to precede the phenology of native vegetation. As a result of this temporal limitation, a limited number of images were available to use. The Mann-Kendall statistic will only be applied for long-term change detection because the number of observations required is too many for the number of images available for short-term changes. A relatively large value was used for statistical significance α=.1 because the null hypothesis is no trend detected. The risk of rejecting the hypothesis when it is true is not as much of a concern as not accepting an alternative hypothesis that may be true.

Validation

Existing databases to support the validation of time series data is limited – the primary database which is used in this study for interpretation of results is the LTDL. This database contains information on applied treatments, existing vegetation and assessed burn severity. Additional information from the Gap Program will also be used which provides known information on land cover type for 1992 and 2001. Ancillary sources including climate data and information from other vegetation studies will assist in determining whether the results reflect expectations.

CHAPTER SEVEN: ANALYSIS RESULTS

This study applies vegetation indices to post-fire sites annually and then at long-term intervals. For each method of comparison, annual and long-term, the MSAVI2 and NDVI indices are applied. For the annual comparisons, results are calculated for each of the three fire sites for each year that imagery is available. When sequential year imagery was not available the study compares changes across two years. The long-term results use a trend test to evaluate vegetation change after fourteen and then twenty years. The final section of the results compares the two vegetation indices to determine whether significant differences exist between the datasets.

Dixie Fire

The Dixie fire was caused by natural conditions and contained on July 9, 1985. Prior to post-fire project implementation vegetation was assessed as predominantly shadscale (60%) and big sagebrush (40%). The ecosystem is considered dry upland (69.6%) and mesic upland (36.3%). Post-fire land treatment applications included: seeding, fencing and cattle guards (Pilliod and Welty, 2013). Assessed burn severity was primarily low to moderate (Table 6 and Figure 9).

Table 6 Dixie Fire Burn Severity (Source: Pilliod and Welty, 2013)

Burn Severity	Acres	Percentage
Unburned - Low	5007	12.0
Low	19797	47.5
Moderate	16862	40.4
Severe	39	0.1

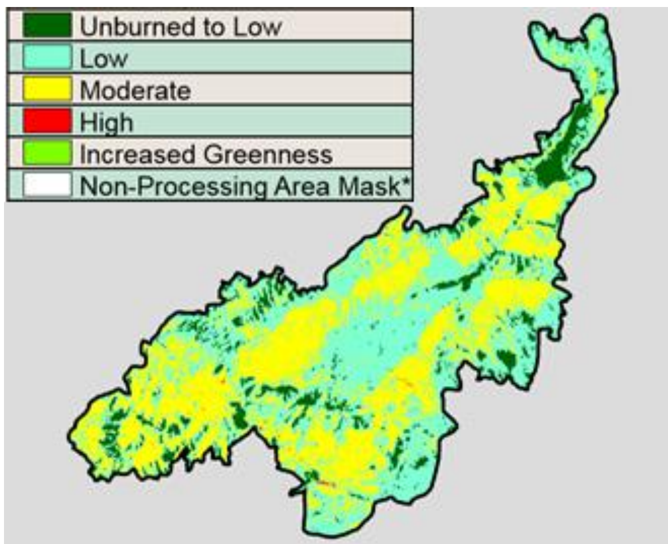

Figure 9 Dixie Fire Burn Severity Map (Source: "MTBS Individual Fire-Level Geospatial Data")

Cosgrave Fire

The Cosgrave Fire was caused by unknown conditions and was contained on August 19, 1985. Prior to post-fire project implementation vegetation was assessed as predominantly Wyoming big sagebrush (90%) and juniper sagebrush (10%). Assessed burn severity was primarily low to moderate (Table 7 and Figure 10). Post-fire land treatment applications included: ground seeding and fencing (Pilliod and Welty, 2013).

According to the burned area report, the area was left devoid of vegetation following the fire. Like the Dixie Fire, the area was seeded with Siberian wheatgrass.

Table 7 Cosgrave Fire Severity (Source: Pilliod and Welty, 2013)

Burn Severity	Acres	Percentage
Unburned - Low	248	8.4
Low	1350	45.6
Moderate	1245	42.1
Severe	117	4.0

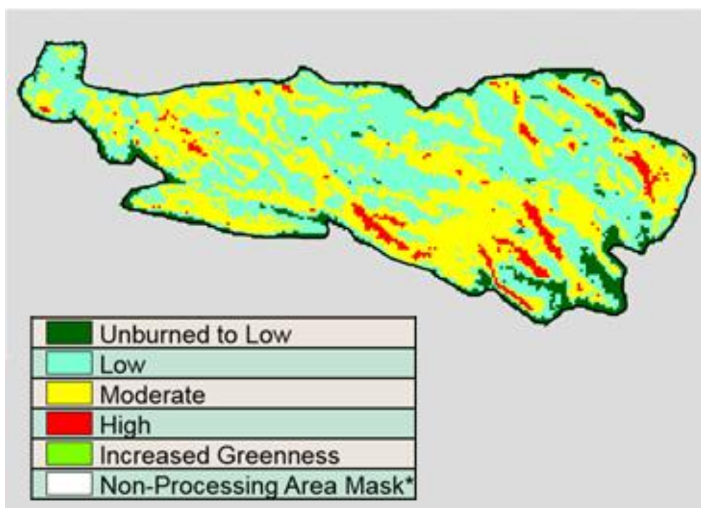

Figure 10 Cosgrave Fire Severity Map (Source: "MTBS Individual Fire-Level Geospatial Data")

Sheep Canyon Fire

The Sheep Canyon Fire was caused by natural conditions and was contained on August 20, 1985. Prior to post-fire project implementation vegetation was assessed as predominantly Wyoming big sagebrush (40%), shadescale (30%) and mountain big sage

(30%). Assessed burn severity was primarily low to moderate (Table 8 and Figure 11). Post-fire land treatment applications included: ground seeding, fencing and soil stabilization measures (Pilliod and Welty, 2013). Seeding contained a mixture of: Great Basin wildrye, Siberian wheatgrass, Lewis flax, Bluebunch wheatgrass and serviceberry (Pilliod and Welty, 2013).

Table 8 Sheep Canyon Fire Severity (Source: Pilliod and Welty, 2013)

Burn Severity	Acres	Percentage
Unburned - Low	934	8.2
Low	5309	46.8
Moderate	4747	41.9
Severe	282	2.5
Not Classified*	68	0.6

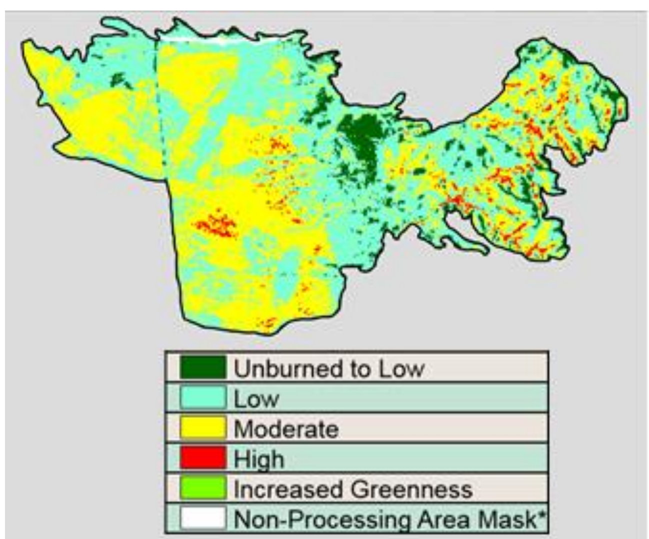

Figure 11 Sheep Canyon Fire Severity (Source: "MTBS Individual Fire-Level Geospatial Data")

Annual Changes in Vegetation Response

For this study, the threshold of ±0.025 was applied to signify change in annual image differences. Any change that falls within the ±0.025 threshold is classified as no change. This threshold level was chosen because the differences in the vegetation index responses of bare ground, shrub and grasses are small, particularly between bare ground and shrubs (Bradley and Mustard, 2005). In the years following the fire, the annual vegetation response was variable. This variability represents either a change in the phenology across years or a change in the type of vegetation.

While normally the expectation would be for the vegetation indices to decrease between pre-fire and post-fire season imagery – the results did not completely satisfy this expectation. NDVI & MSAVI2 increased in the year after the fire in some areas and decreased in other areas (Figures 12-17). One reason for the increase could be due to actual vegetation regrowth. On the other hand, vegetation indices and NDVI in particular, have in some instances shown to be problematic in accurately estimating vegetation immediately after fires. As a result, the identified change could also be an error (Cocke et al., 2012). Based on the pre- and post-fire imagery – the latter would likely be the reason for the increased NDVI in this study – a clear decrease in vegetation is visible in the false color composite image for the area with a positive NDVI response between the two years (Figure 18).

To determine whether any other identified changes in subsequent years may also be the result of fire, the Nevada Geospatial Database fire perimeter shape files were analyzed for the years spanning from 1986-2005. The perimeters for each year were overlain with the 1985 fire perimeter data. No significant overlap was found indicating changes in subsequent years are likely not a result of fire.

Prior to image analysis, the anticipation was that if an area experienced regrowth this change could be identified through an increasing pattern of vegetation index response across years. No consistent pattern of change emerged however. The variability in vegetation response is likely an indicator of the sensitivity of the indices to phenological changes given the chosen threshold and period of image acquisition.

The data used in the study are not accurate enough to compare vegetation differences across years. Increasing the threshold would identify areas experiencing greater change, but could potentially eliminate areas which changed from bare ground to shrub since their responses have been shown to be similar in other studies (Bradley and Mustard, 2005). Limiting the image acquisition dates could provide for more consistent phenological response, but would also eliminate imagery for a number of years. Another method is required to discern what constitutes vegetation change versus what changes are a result of phenology.

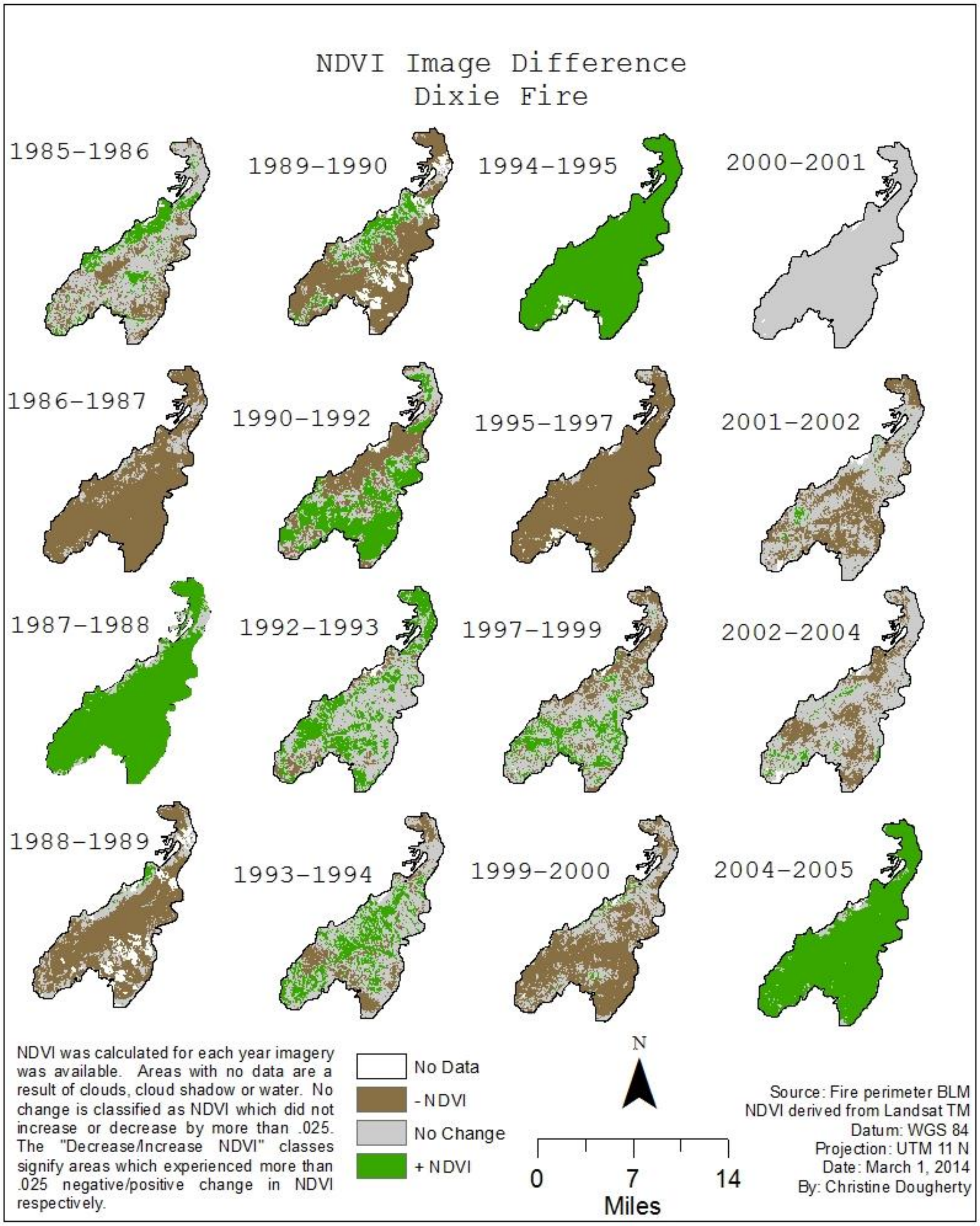

Figure 12 Dixie Fire 20-Year NDVI Annual Differencing

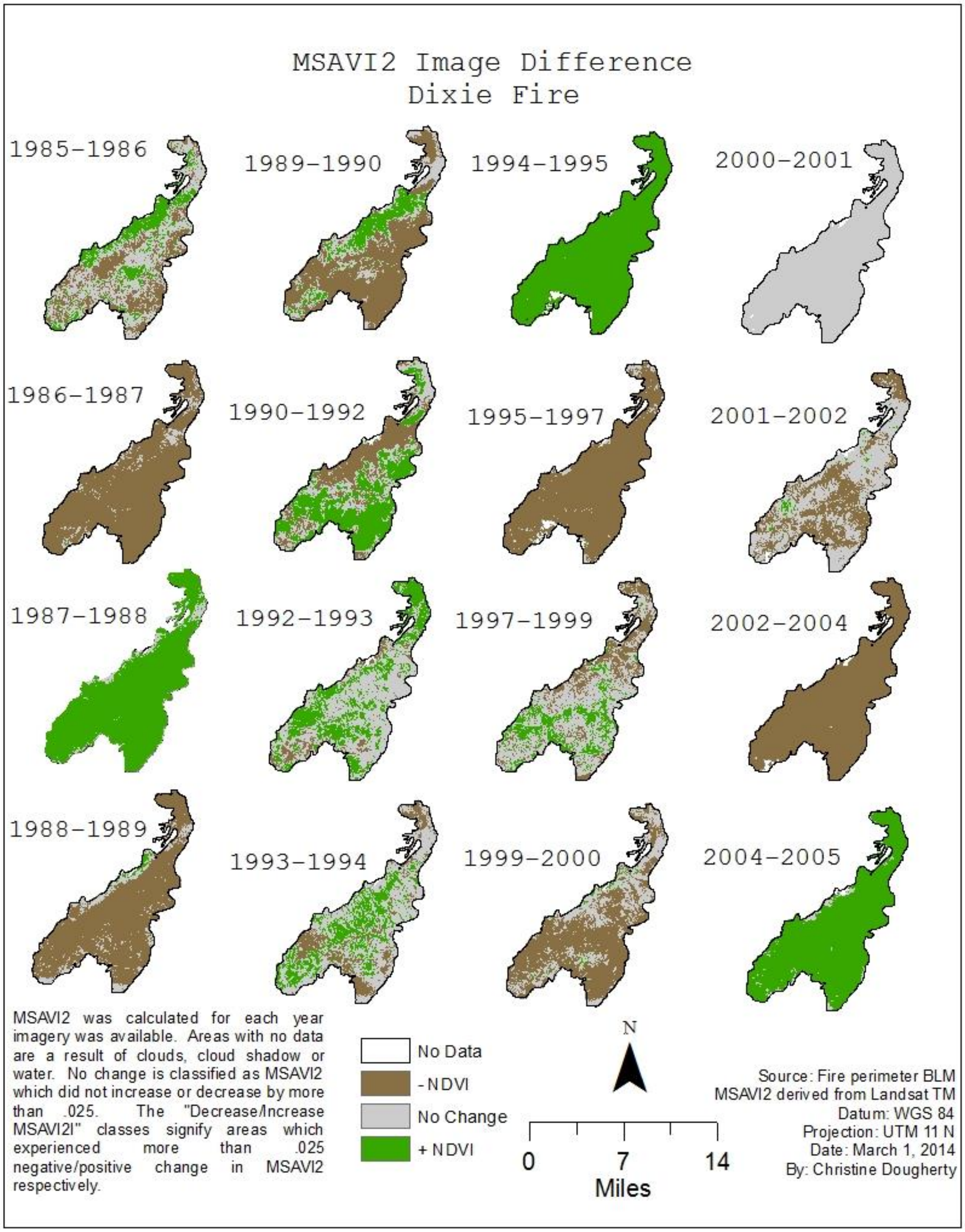

Figure 13 Dixie Fire 20-Year MSAVI2 Annual Differencing

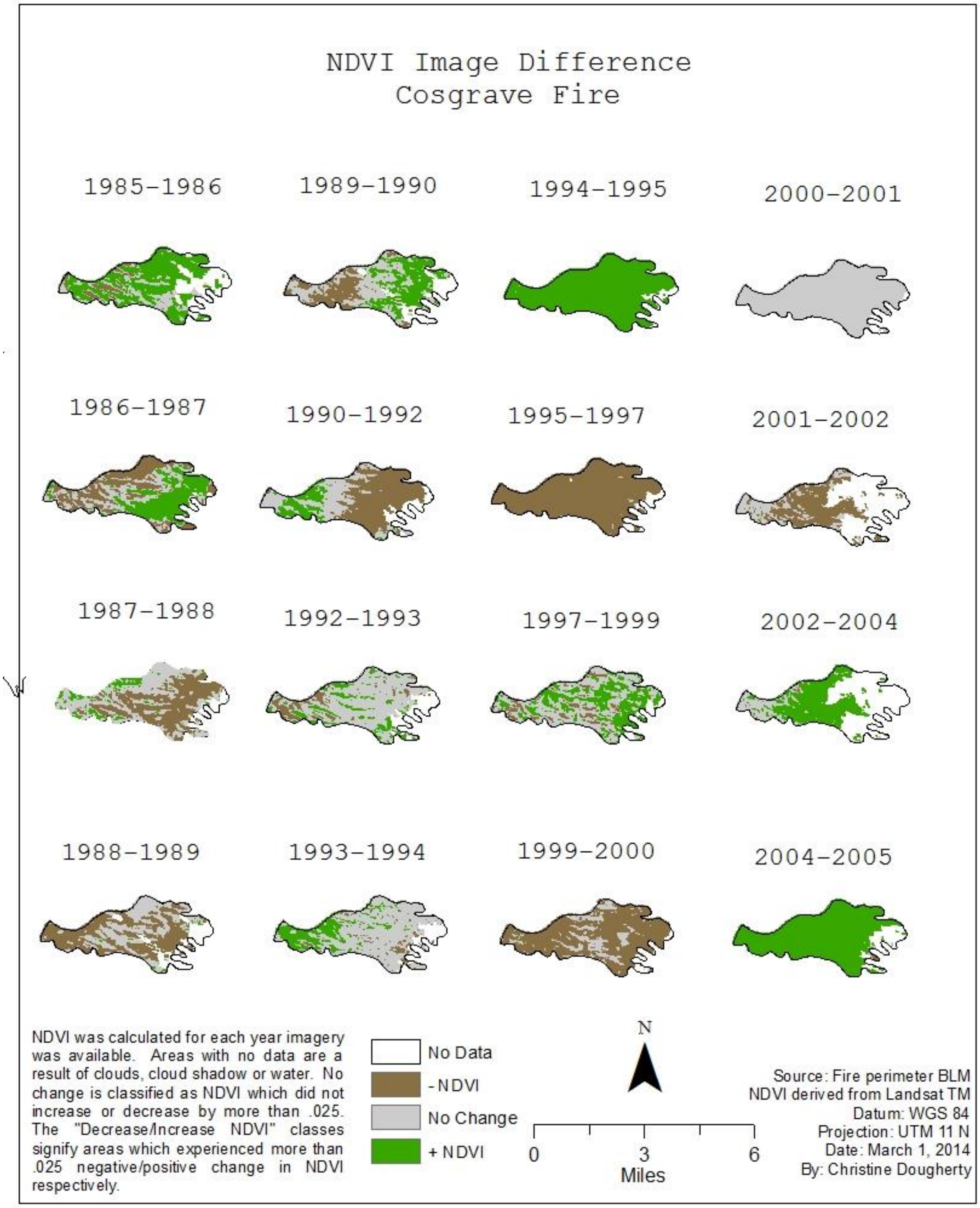

Figure 14 Cosgrave Fire 20-Year NDVI Annual Differencing

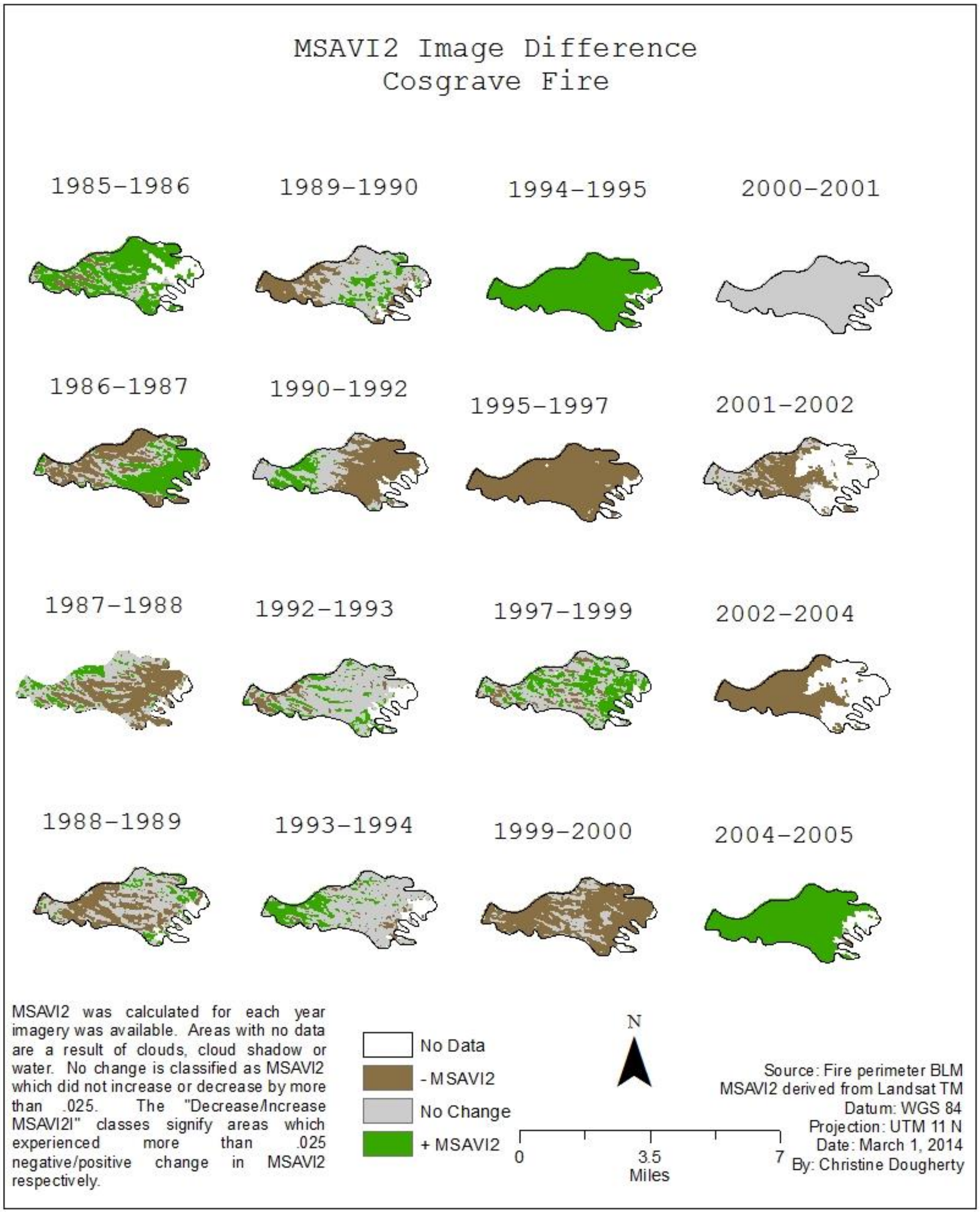

Figure 15 Cosgrave Fire 20-Year MSAVI2 Annual Differencing

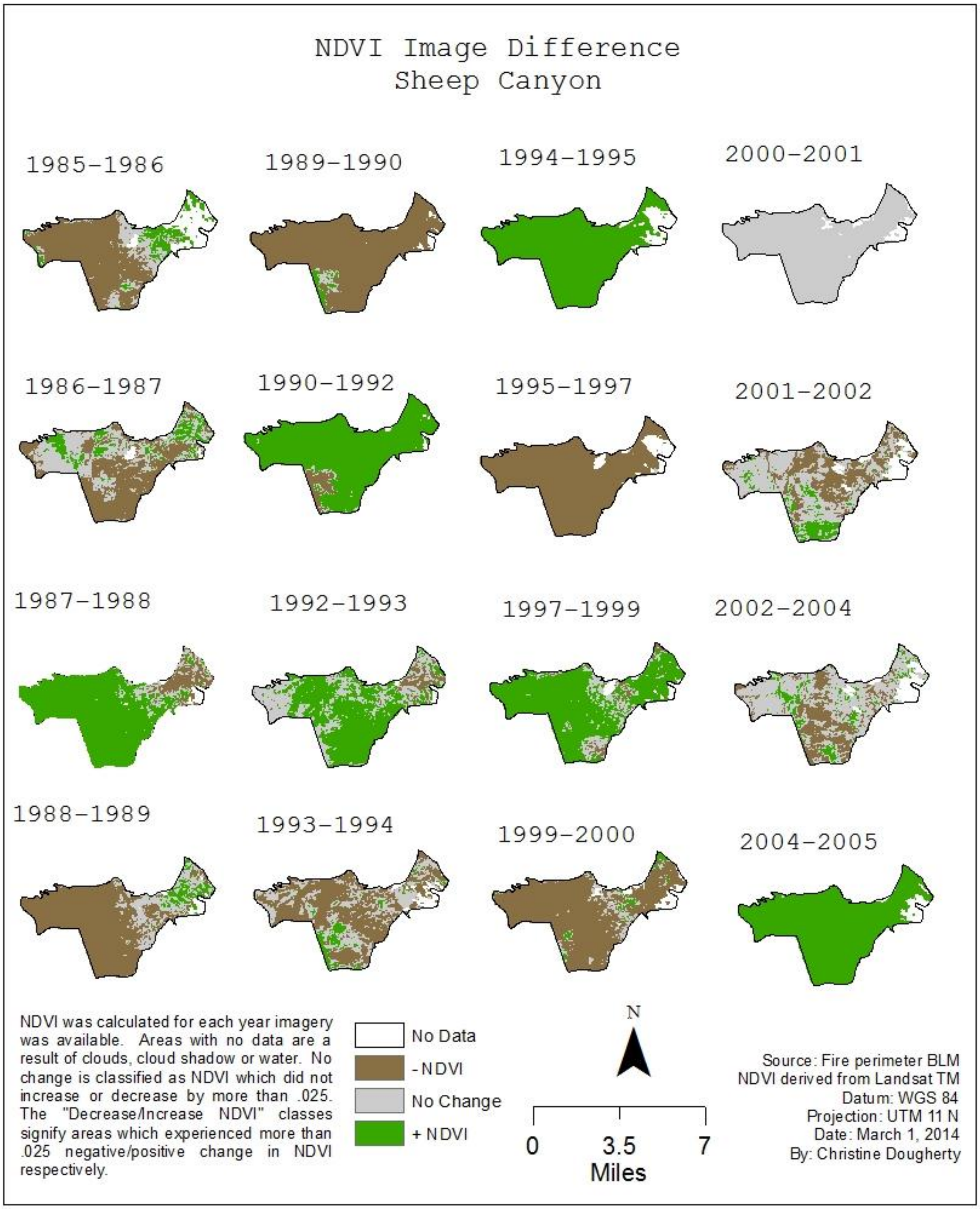

Figure 16 Sheep Canyon Fire 20-Year NDVI Annual Differencing

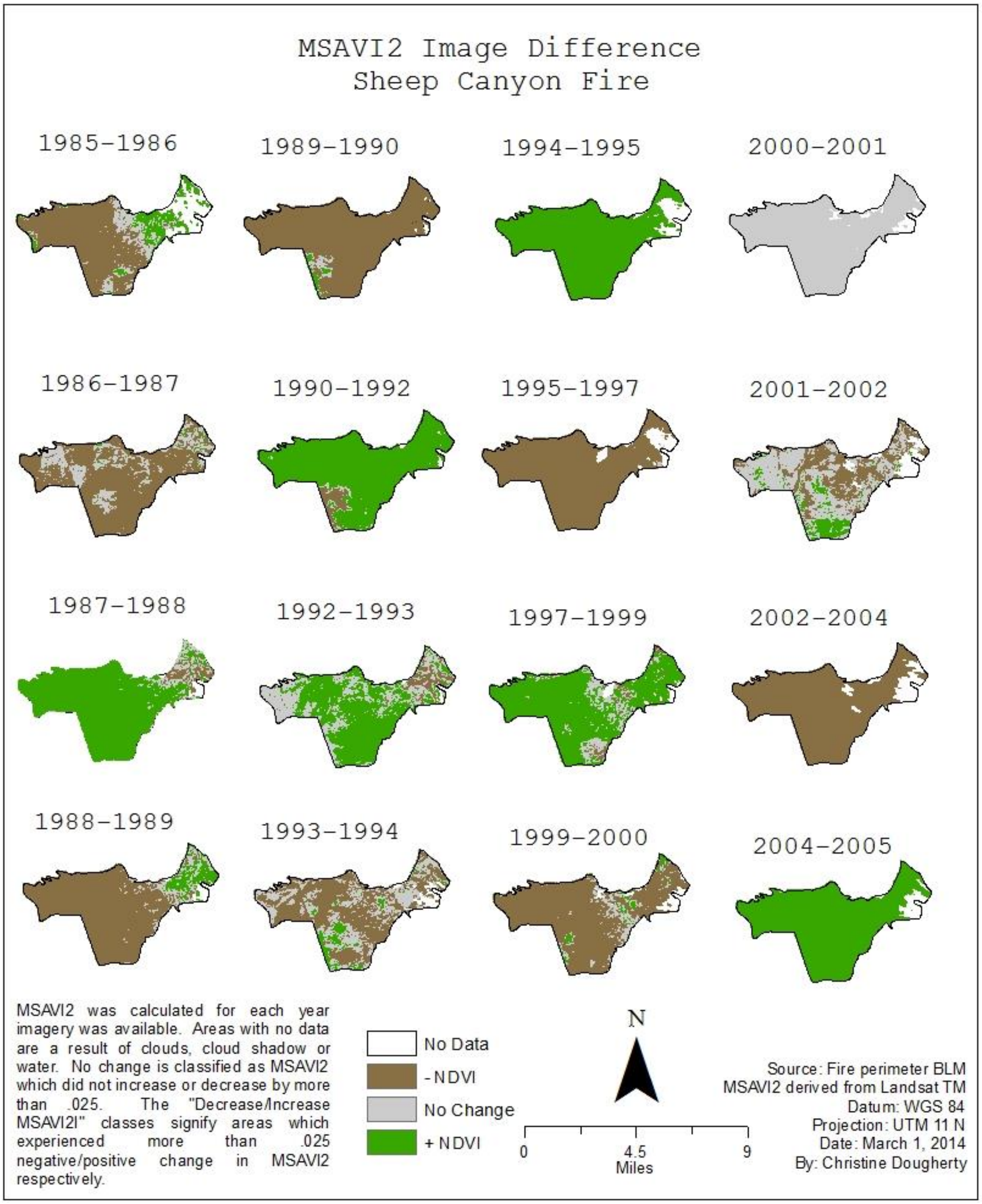

Figure 17 Sheep Canyon Fire 20-Year MSAVI2 Annual Differencing

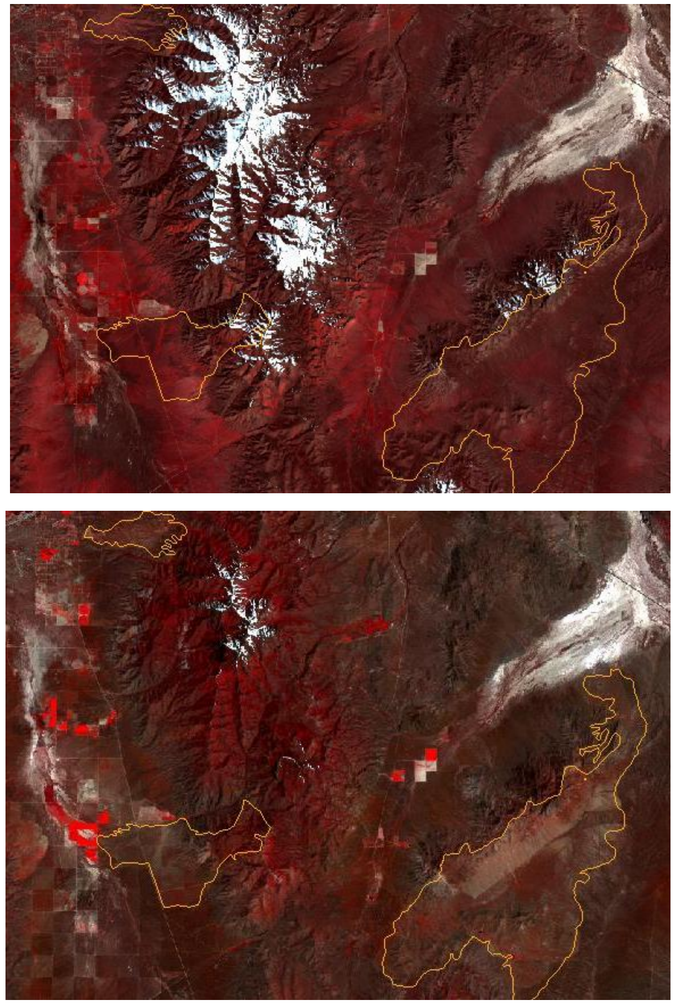

Figure 18 Landsat TM Images with 1985 Fire Perimeters
Pre-Fire Image 1985 (above) Post-Fire Image 1986 (below)
(RGB=432)

Long-term Changes in Vegetation Index Response

The long-term results seek to identify potential changes in vegetation based on trend data (Figures 19-24). The belief is that areas with a general trend of an increasing or decreasing response to a vegetation index over a number of years are an indicator of vegetation change versus phenological change. Responses of vegetation vary from year-to-year and do not necessarily show types of vegetation change, but if, excluding outliers, a monotonic trend exists the belief is it could be an indicator of changing vegetation.

Due to the limited number of images available in the April-May timeframe, only two long-term tests were conducted one after fourteen years and one after twenty. The results for the three fire sites were relatively similar. Generally, more areas of change were found in the fourteen year tests than in the twenty year tests. The twenty year MSAVI2 trend tests for the Dixie and Cosgrave fire sites resulted in no trend. The assumption is that if there is consistent change over a long period this indicates changing vegetation. At some point though, there may be a plateau in the vegetation response with only minor variations due to phenology. At that point, the increasing trend would stop. Very few twenty year trends were found in this study. This does not imply no change occurred, only that no consistent long-term change occurred. Shorter-term changes may have taken place, but they are not captured in this test though they would be captured in the annual image differences.

For the long-term results, when a trend was detected it was almost always an increasing trend – meaning the vegetation index increased over time. Further analysis would be required to determine though what this increasing trend indicates in terms of type of vegetation change. The result could be indicating the establishment of a species introduced with the purpose of re-vegetation, like Siberian wheatgrass, or the result could be an indicator of another species, like cheatgrass. Additional analysis would be required to determine what this specific change is. The area where the Siberian wheatgrass and other post-fire management techniques were implemented is unknown. If it were known, then the annual or long-term response could be tracked to provide an indication about how an area responded to the treatment.

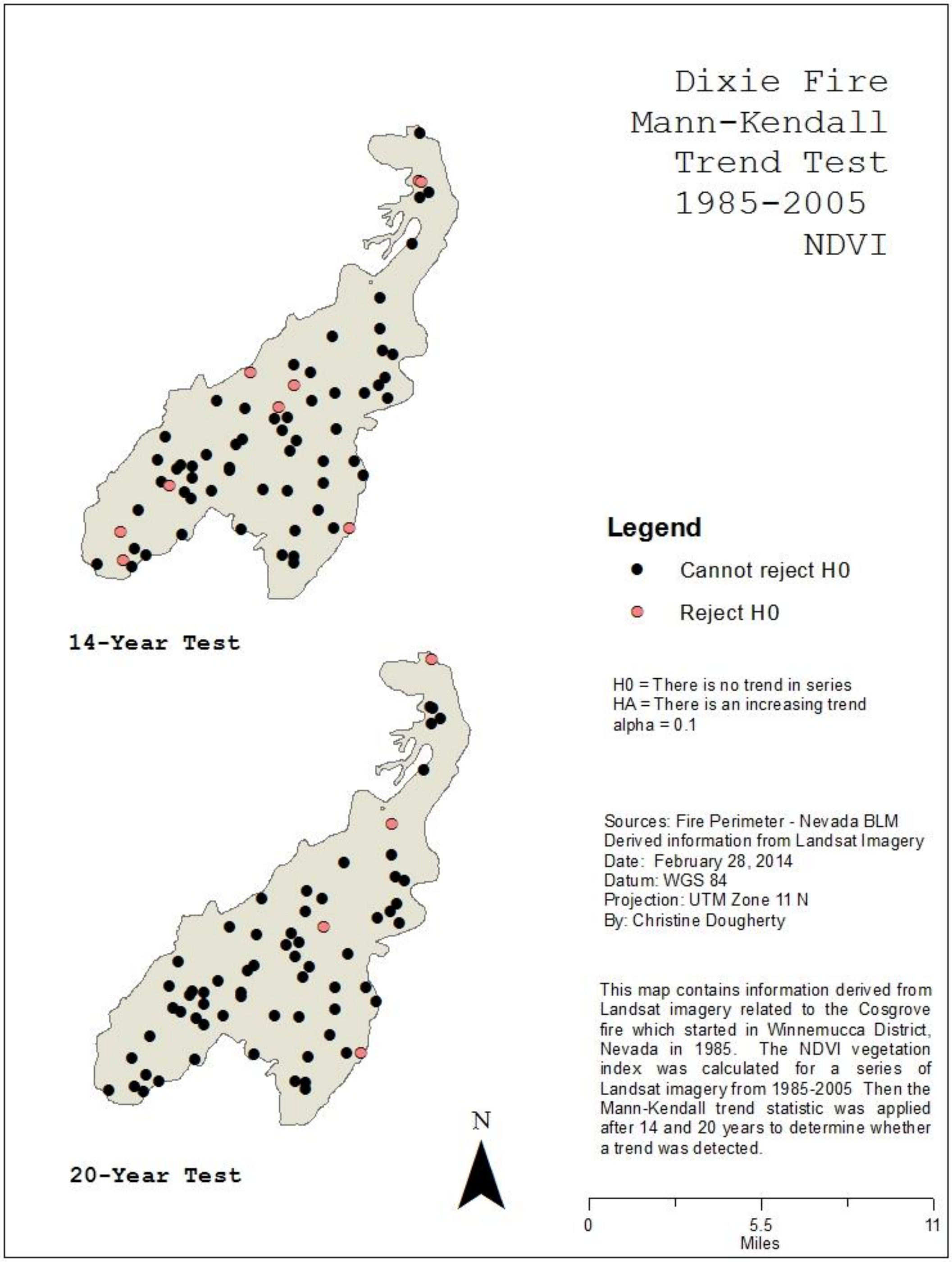

Figure 19 Long-Term NDVI Results Dixie Fire

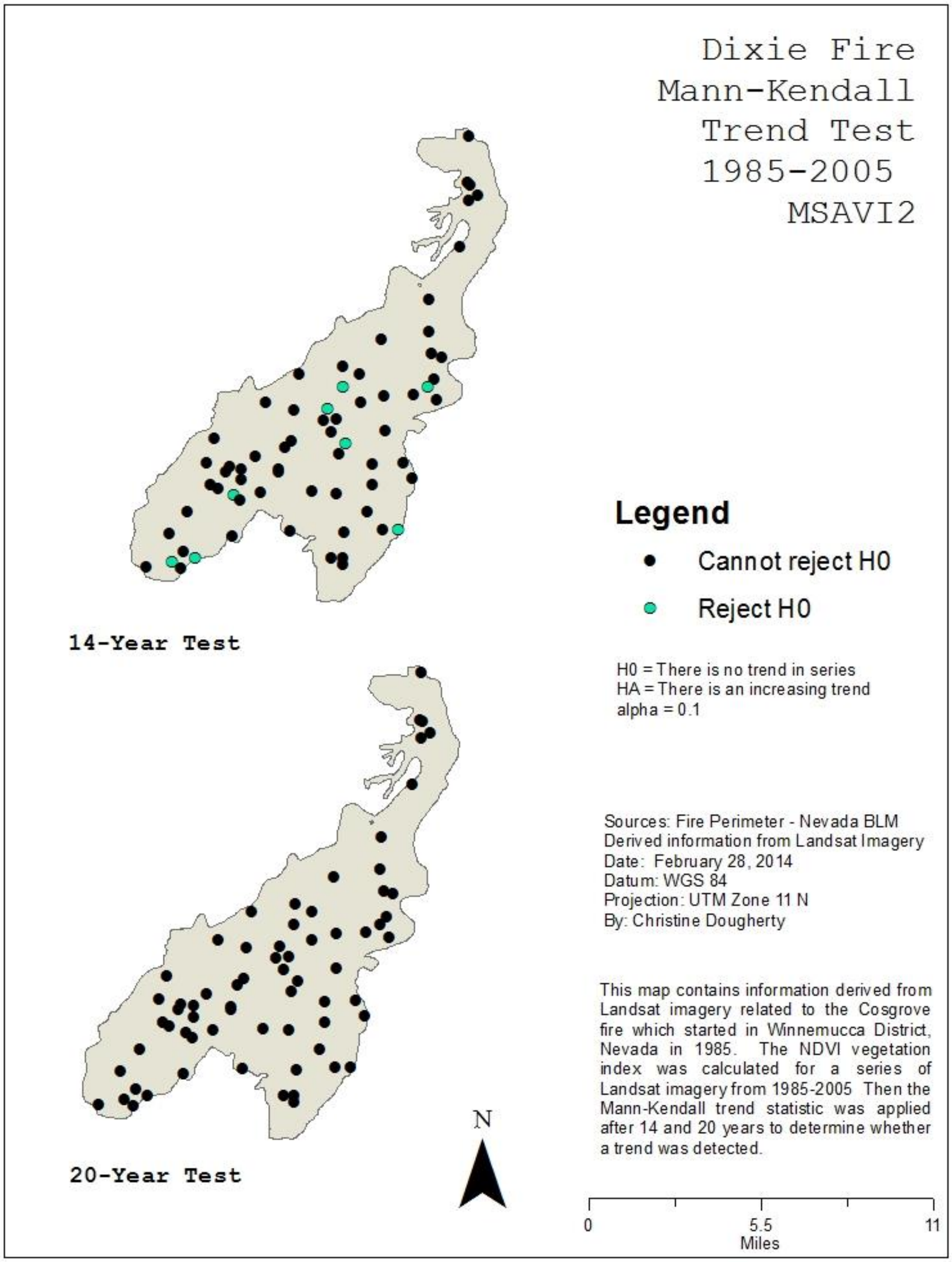

Figure 20 Longer-term MSAVI2 Results Dixie Fire

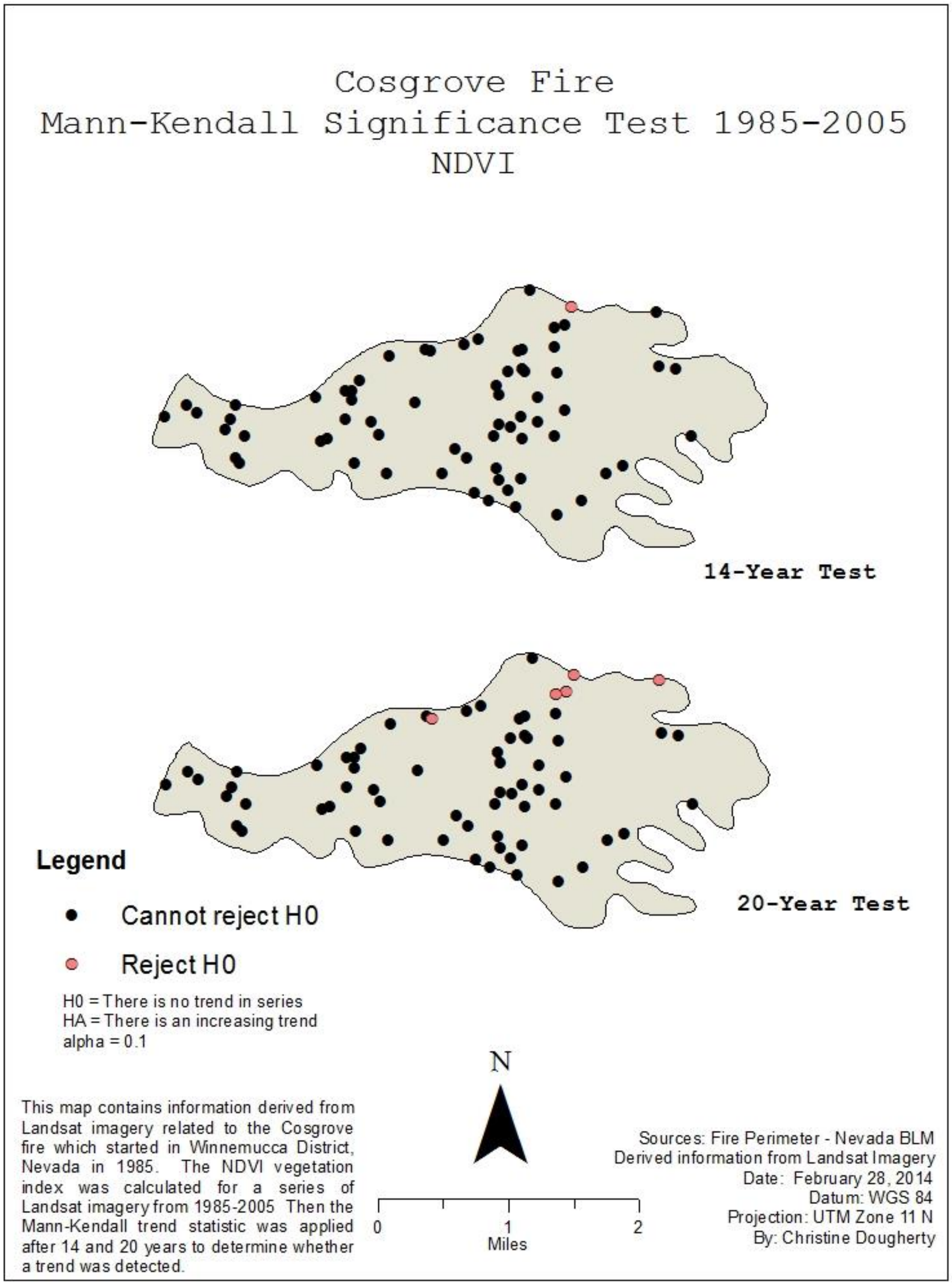

Figure 21 Long-Term NDVI Results Cosgrave Fire

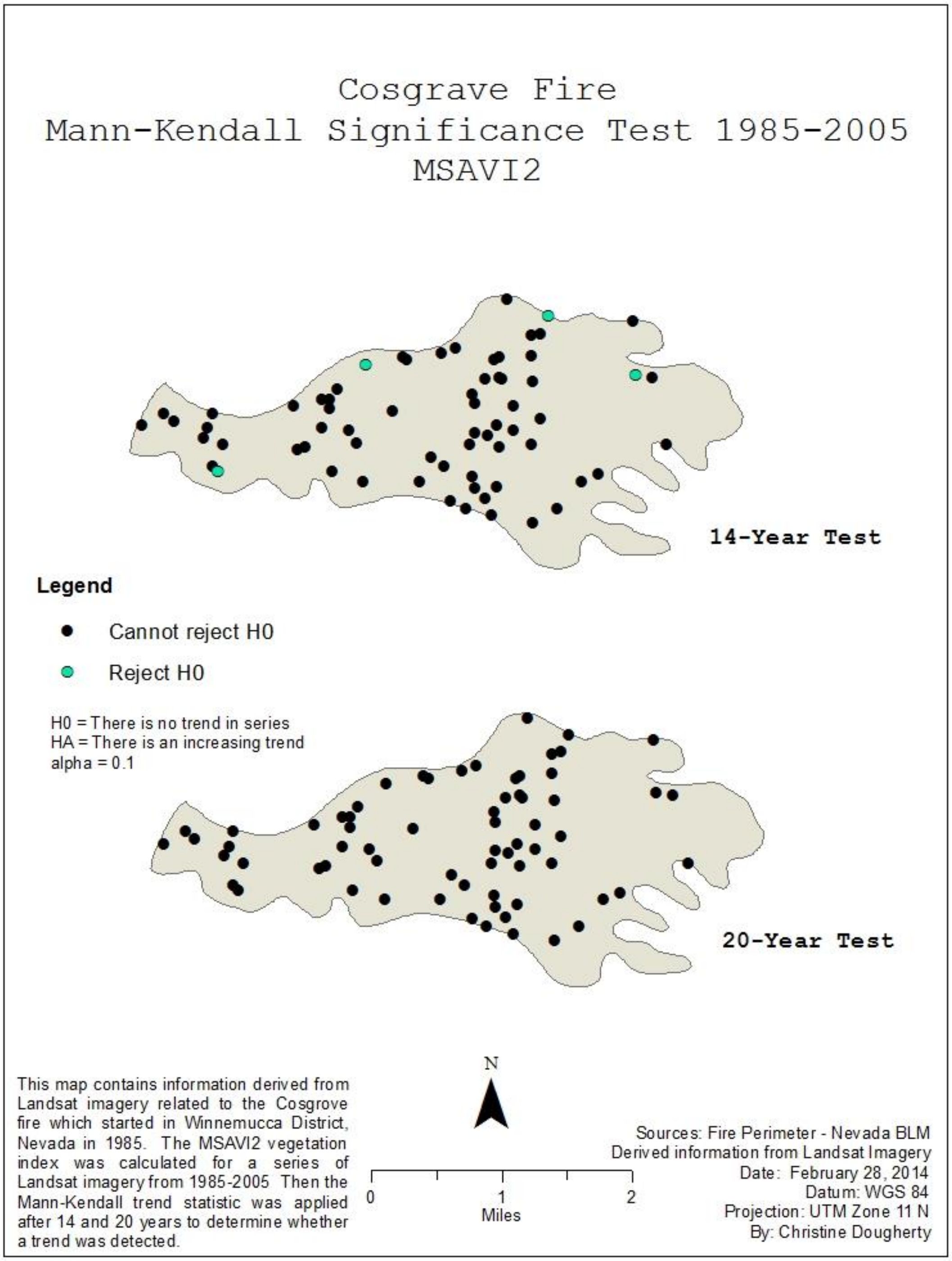

Figure 22 Long-Term MSAVI2 Results Cosgrave Fire

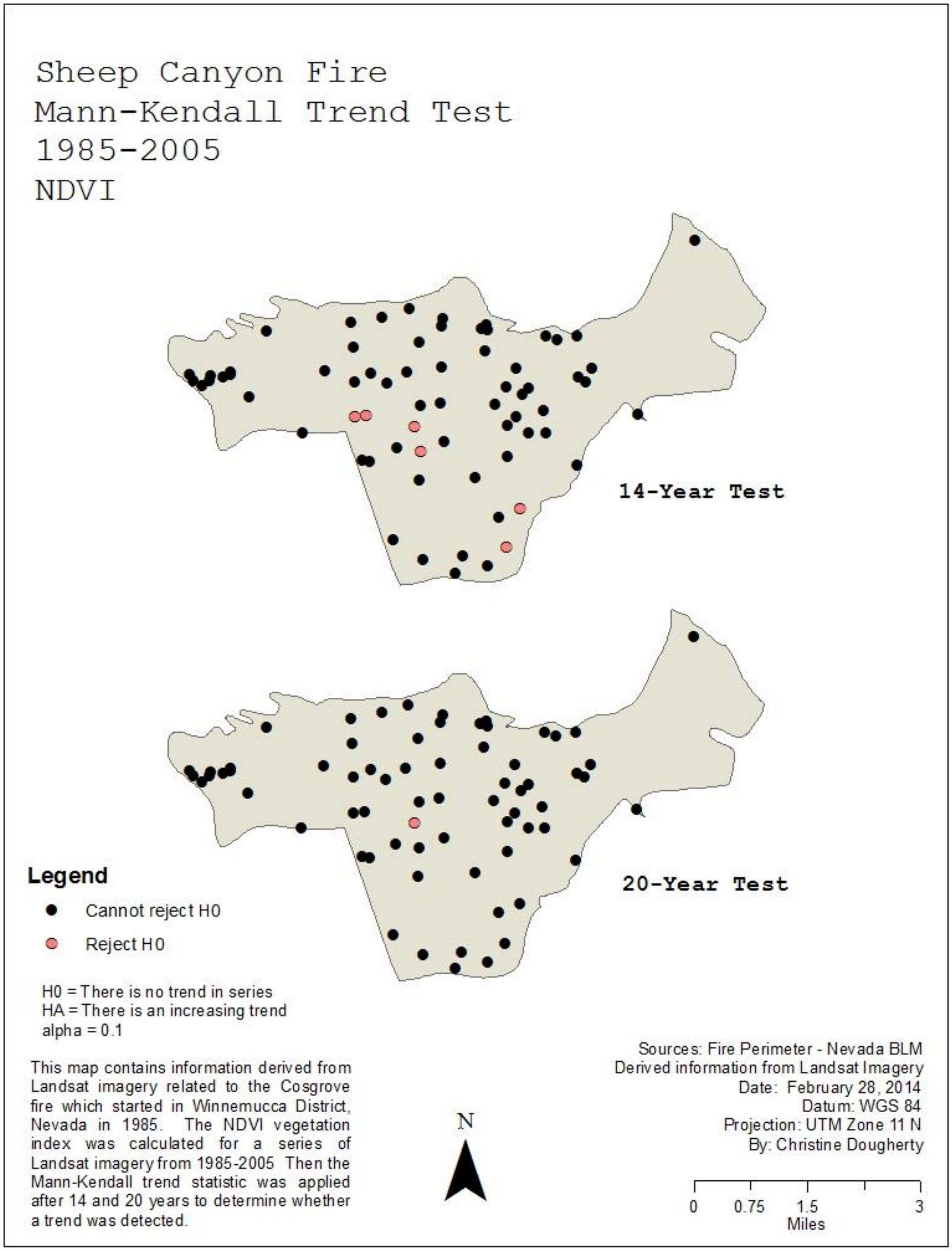

Figure 23 Long-Term NDVI Results Sheep Canyon Fire

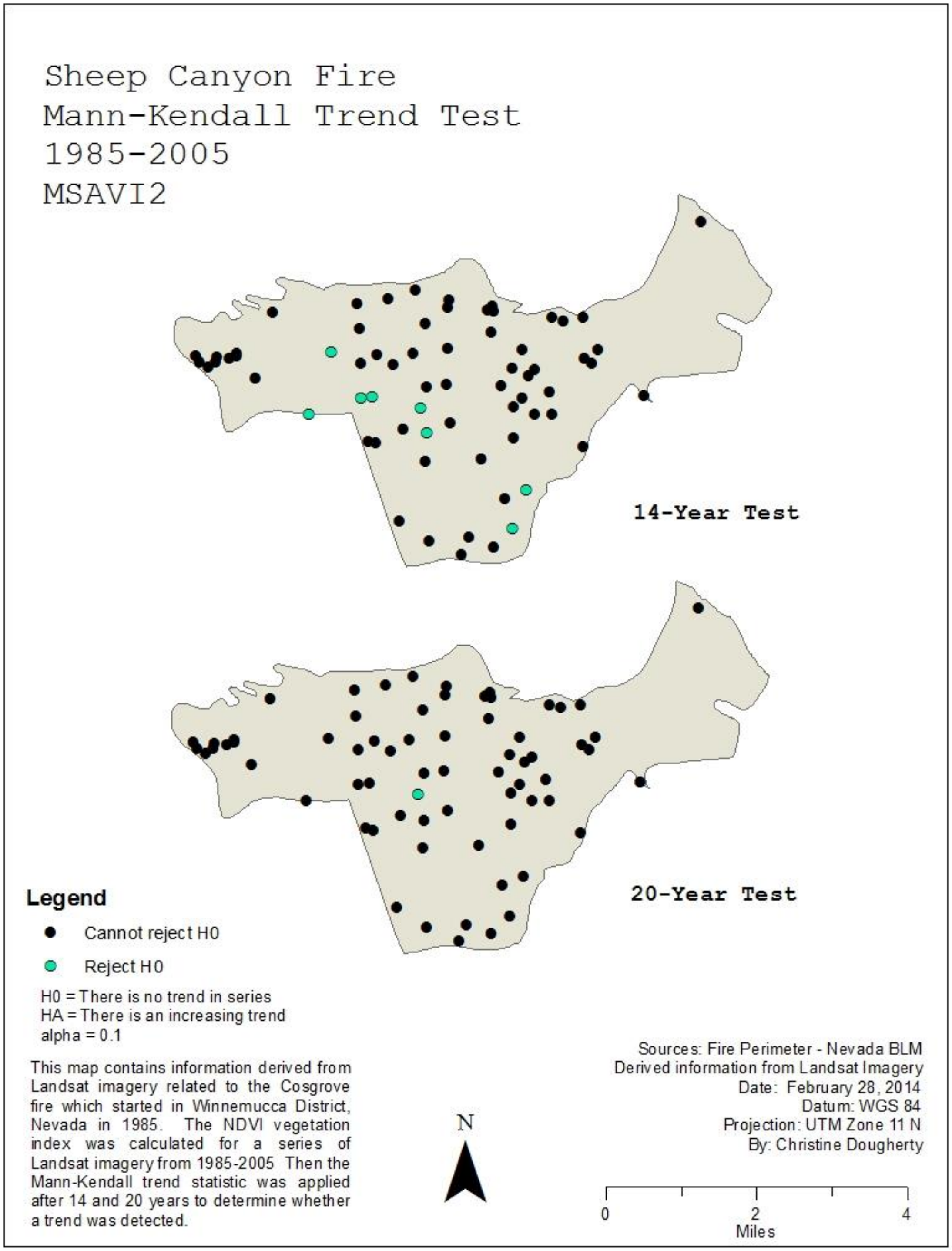

Figure 24 Long-Term MSAVI2 Results Sheep Canyon Fire

Vegetation Index Comparison

Two vegetation indices were used for this study -- MSAVI2 and NDVI. The expectation was that MSAVI2 would be less sensitive to soil reflectance than NDVI. NDVI was used because it had been shown in previous studies to be better in distinguishing between areas that did not have homogenous vegetation. The results from this study show the two to have quite similar results, particularly with annual changes in vegetation.

Side-by-side comparison was conducted for years with negative, positive and mixed response change (Figure 25-27). The patterns of vegetation response are almost exactly the same for NDVI and MSAVI2: a mixed response occurred from 1985-1986; a decrease in both MSAVI2 and NDVI occurred from 1995-1997; no significant change occurred for the majority of the fire site areas from 2000-2001. The one exception was for 2002-2004 image differences – the vegetation indices responded differently.

To further analyze the degree to which MSAVI2 and NDVI differed the original vegetation index calculations, not the differenced or classified indices, were compared for four years in ArcGIS using correlation matrices. The correlation matrices were generated using the Band Collection Statistics tool. Results confirmed the high degree of correlation – with strong, positive correlation in 1985, 1995 and 2000. In 2004 the correlation was weaker, but still positive and relatively high. Given the differences in the side-by-side comparison for the 2002-2004 image differences, the anticipation would be that there would be a negative correlation. As a result, MSAVI2 and NDVI correlation was also tested for 2002. The correlation for the 2002 image was 0.99807. That means both images in the 2002-2004 sequence are positively correlated. A difference exists between the correlation matrices results and the image difference results. The correlation matrices show the vegetation indices are highly correlated (Table 9) and the maps of annual vegetation differences (Figures 25-27) suggest less correlation. While these results seem to contradict each other, the result may be in part due to the “no change” threshold set for the annual image differences. The threshold was set manually to ±0.025 so if the values calculated for the vegetation index are relatively close then they may appear different on the MSAVI2 or NDVI annual difference map when the difference is actually quite small.

Table 9 NDVI & MSAVI Correlation Matrix

Year	Correlation
1985	0.9965
1995	0.9943
2000	0.9977
2004	0.87947

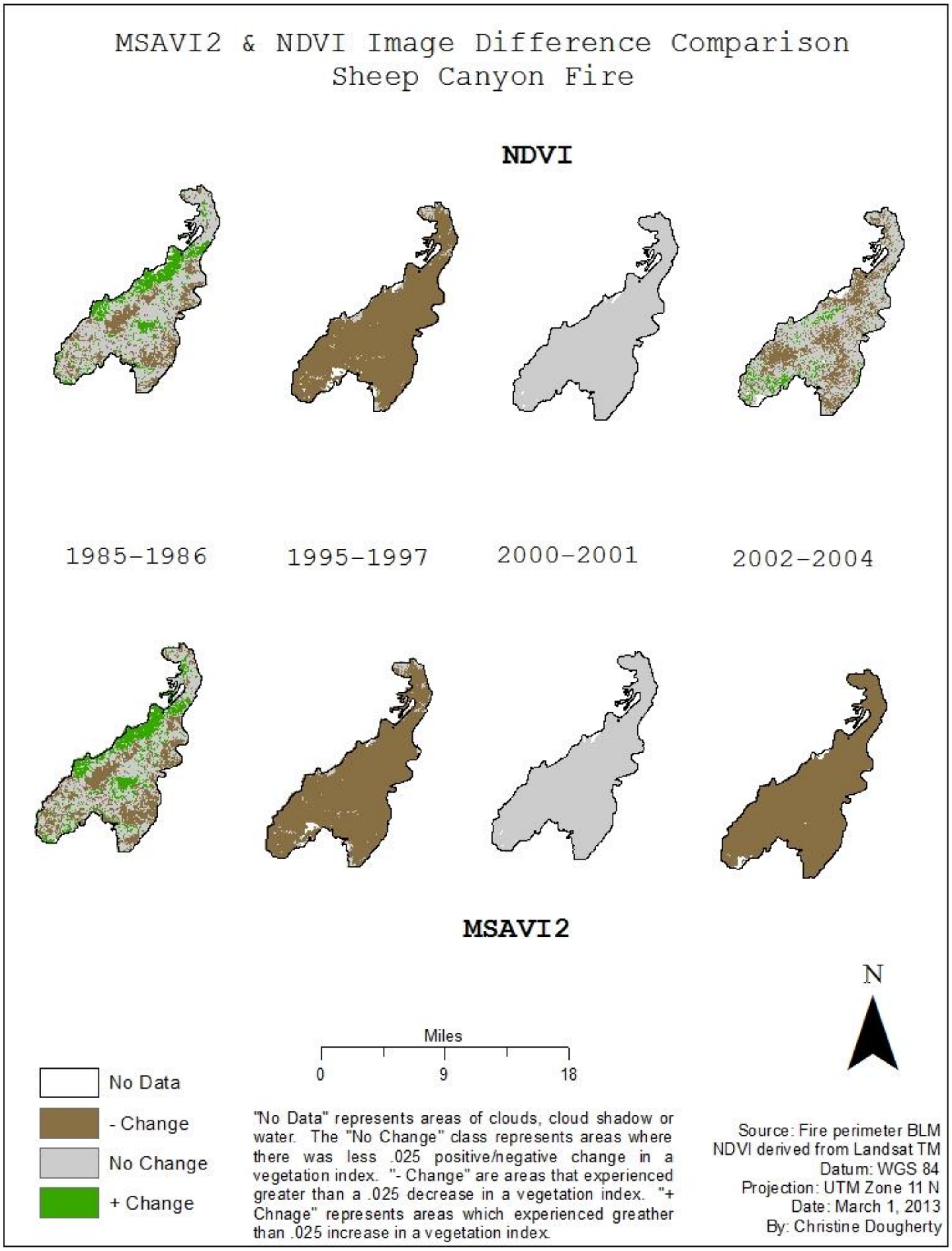

Figure 25 MSAVI2 & NDVI Image Difference Comparison Dixie Fire

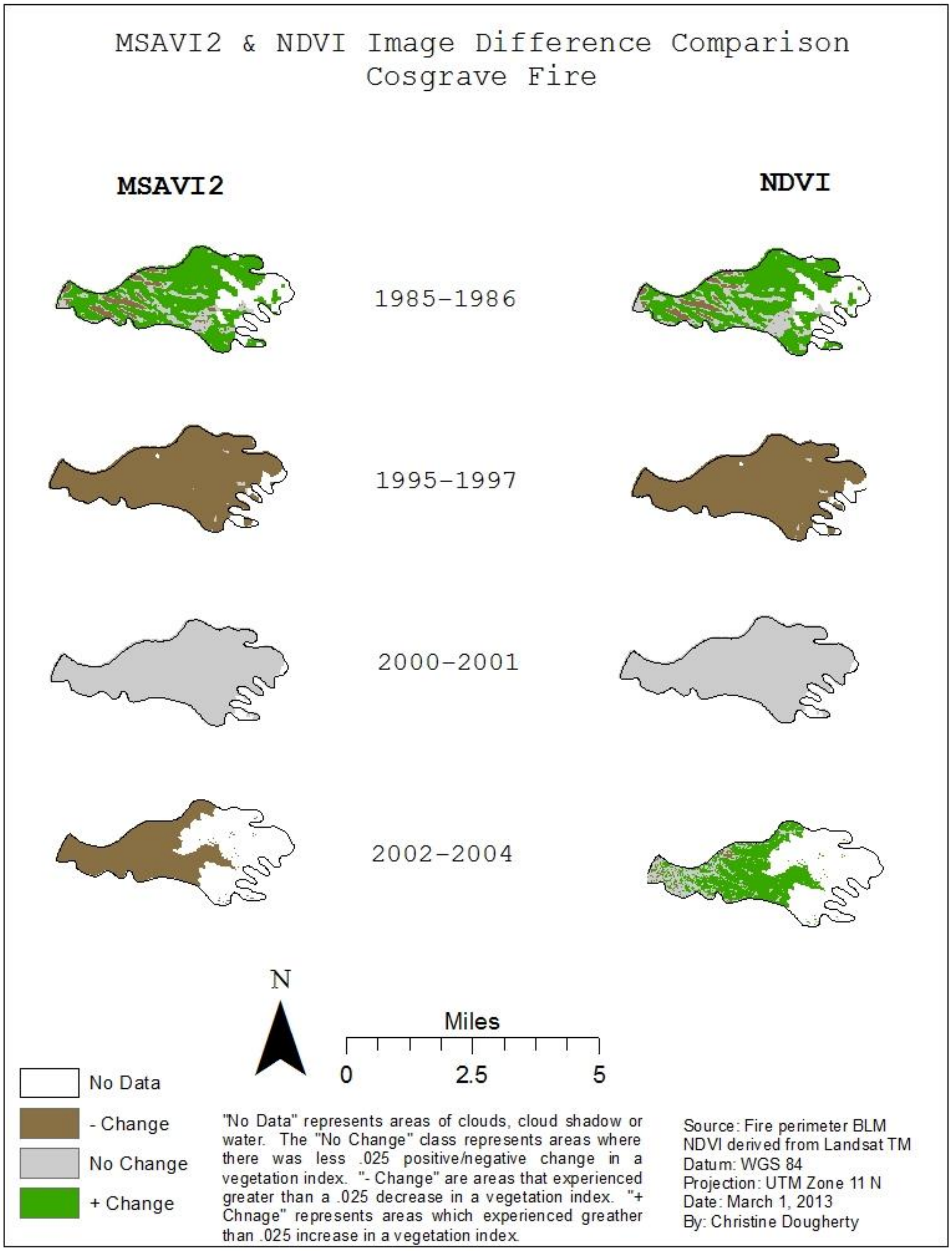

Figure 26 MSAVI2 & NDVI Image Difference Comparison Cosgrave Fire

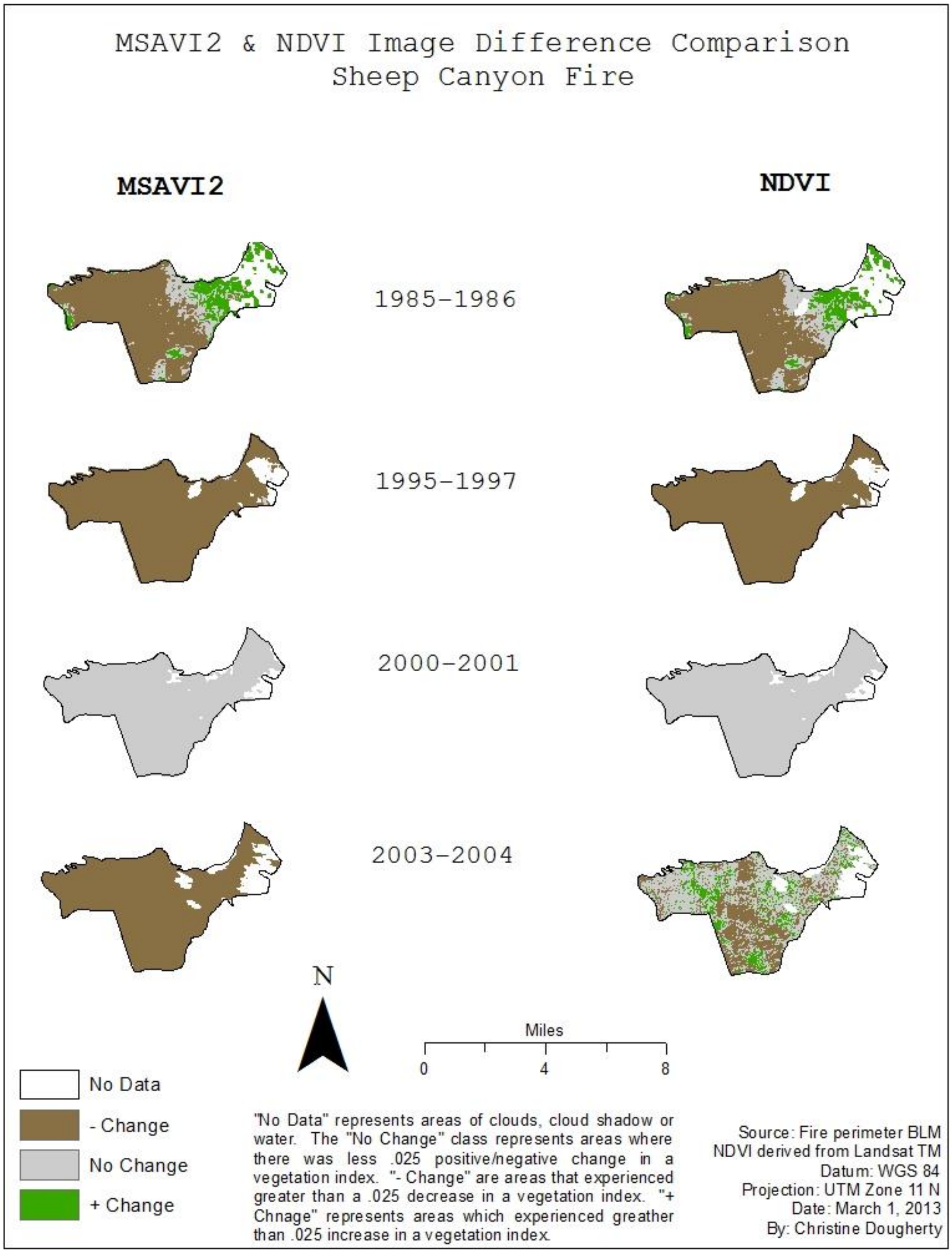

Figure 27 MSAVI2 & NDVI Image Difference Comparison Sheep Canyon Fire

CHAPTER EIGHT: CONCLUSION

This study used Landsat TM data and the MSAVI2 and NDVI vegetation indices to monitor post-fire vegetation recovery of three fire sites in the Winnemucca District. The study used annual and long-term change methods to identify areas which experienced short- and long-term vegetation recovery. The results of this study suggest annual differences in vegetation indices on their own are insufficient to categorize whether this signifies a change in phenology or vegetation type for this region. The study concludes, seasonal intra-annual analysis is necessary as a first step to identifying the different stages of plant phenology before comparison of vegetation change can occur across years. The long-term trend analysis used in this study successfully identified areas experiencing a long-term pattern of vegetation response after fourteen years, but not after twenty. Further studies would be required to confirm whether the long-term trend identified after fourteen years corresponds to a change in vegetation type. The results from the long-term analysis suggest twenty years is too long of a period to monitor a consistent pattern of change for the vegetation in this region.

The final results indicated the data and methods used in this study were not able to sufficiently capture changes in vegetation types. The challenge in analyzing the short-term annual data was trying to differentiate change resulting from phenology and actual vegetation change. Adding statistical analysis helped determine what sites experienced monotonic changes and could potentially provide an indication of persistent change. For this study, due to the limited number of images available for the April-May timeframe only two periods of long-term analysis were tested. Vegetation trends were found after fourteen years, but very few sites experienced this type of trend over a 20-year period. The lack of results after twenty years could be in part due to the nature of vegetation. The trend test accounts for variation between observations, which helps account for phenological changes across years, but at some point the expectation would be for vegetation to plateau and have only variable phenological change again. If vegetation change occurs rapidly, then this test will not be a good indicator of that change. On the other hand, if vegetation gradually changes over time this could help to identify these changes.

Both the short- and long-term methods used in this study assume changes can be detected at a scale consistent with the imagery (30 meter). In some instances this may not be the case. For example, if the primary species of concern has a similar response to a vegetation index as the surrounding vegetation then the two would not be distinguishable using this method. Additionally, if concern is with a species that is relatively sparse and mixed in with other types of vegetation the 30-meter scale may be too large to detect change.

Modifications to the methods used in this study could help better identify areas of vegetation change. Instead of using any available Landsat imagery from April-May, an approach which incorporates another step to specifically identify the green up/senescence of grasses could be helpful. Another sensor with a more frequent revisit period than

Landsat would be required to conduct this type of analysis. Once the appropriate green up timeframe was determined then the Landsat imagery could be evaluated to determine whether the available imagery would be useful. If Landsat imagery is available at an appropriate timeframe, then it could be compared across years to identify changes in the spatial extent of vegetation. This method though would still not address how to differentiate between different types of grasses.

Another potential method to determine vegetation change would be to use a trend test incorporating more intra-annual images. By incorporating many images from a single year a seasonal trend test could be applied for short or medium-term studies. The process used in this study was not conducive to medium-term changes because the number of images available was too limited, but incorporating more images could allow for medium-term recovery analysis.

To help address some of the issues encountered in this study, additional types of imagery could be incorporated to identify vegetation change. The focus of this study was on the 1985 fire season and since then more advanced sensors have been developed which help provide information on vegetation change. The sensors available now have more spectral bands which help to distinguish vegetation in the mid-infrared areas which is useful for distinguishing semi-arid vegetation. While they could not be applied to previous studies, they will be helpful in future vegetation analyses.

The vegetation indices used in this study provided a general indication of how an area's vegetation responded on an annual basis, but distinguishing changes in vegetation classes versus phenological differences posed a number of challenges. The environmental conditions and vegetation types found in Winnemucca make it difficult to monitor vegetation using traditional methods. The methods used in this study were not able to positively discern areas of vegetation change, but modifying the techniques could identify these areas in future studies.

APPENDIX

I. Downloaded Images

Year	Month	Day	Landsatscene	Landsat Scene Identifier	Day
1985	April	5	42032	LT50420321985095XXX02	95
1986	May	26	42032	LT50420321986146XXX03	146
1987	April	27	42032	LT50420321987117XXX03	117
1987	May	13	42032	LT50420321987133XXX02	133
1988	April	29	42032	LT50420321988120XXX03	120
1988	May	15	42032	LT50420321988136XXX08	136
1989	April	16	42032	LT50420321989106XXX02	106
1989	May	2	42032	LT50420321989122XXX02	122
1989	May	26	42032	LT40420321989146XXX02	146
1990	April	3	42032	LT50420321990093XXX02	93
1990	May	21	42032	LT50420321990141XXX03	141
1992	April	8	42032	LT50420321992099AAA02	99
1992	May	10	42032	LT50420321992131XXX02	131
1992	May	26	42032	LT50420321992147XXX02	147
1993	April	27	42032	LT50420321993117XXX02	117
1993	May	15	42032	LT50420321993133XXX02	133
1994	April	14	42032	LT50420321994104XXX03	104
1995	May	15	42032	LT50420321995139XXX02	139
1997	April	6	42032	LT50420321997096XXX02	96
1997	May	8	42032	LT50420321997128AAA02	128
1999	April	12	42032	LT50420321999102AAA01	102
1999	May	30	42032	LT50420321999150AAA01	150
2000	April	30	42032	LT50420322000121XXX02	121
2001	April	17	42032	LT50420322001107XXX02	107
2001	May	3	42032	LT50420322001123XXX02	123
2002	May	6	42032	LT50420322002126LGS01	126
2004	April	9	42032	LT50420322004100PAC02	100
2004	April	25	42032	LT50420322004116PAC02	116
2005	April	12	42032	LT50420322005102PAC01	102
2005	May	14	42032	LT50420322005134PAC01	134
2005	May	30	42032	LT50420322005150PAC01	150
				Median Julian Day 122	

BIBLIOGRAPHY

"About LTDL." *Land Treatment Digital Library*. USGS, Web. 29 Mar. 2014. <https://ltdl.wr.usgs.gov/about.aspx>.

"About Terra." *NASA: TERRA (EOS AM-1) The EOS Flagship*. Web. 27 Feb. 2014. <http://terra.nasa.gov/about/>.

"About the BLM." *Bureau for Land Management*. Department of Interior, Web. 20 Feb. 2014. <http://www.blm.gov/wo/st/en/info/About_BLM.html>.

Baugh, W. M., and D. P. Groeneveld. "Broadband Vegetation Index Performance Evaluated for a Low-cover Environment." *International Journal of Remote Sensing* 27.21 (2006): 4715-4730.

Boyte, Stephen. "Cheatgrass Dieoff in the Great Basin- Quantifying Spatial Extents and Potential Causal Mechanisms." Mapping interannual cheatgrass production and dieoff in the Great Basin using remote sensing data and ecological models. USFS RMRS Shrub Sciences Lab. <http://www.youtube.com/watch?v=ZxcCJcDGXXQ> 15 Mar. 2012. Lecture.

Bradley, Bethany A., and John F. Mustard. "Identifying Land Cover Variability Distinct From Land Cover Change: Cheatgrass in the Great Basin." *Remote Sensing of Environment* 94.2 (2005): 204-213.

Brooks, Matthew, and Michael Lusk. *Fire Management and Invasive Species: A Handbook.* Arlington, VA: U.S. Fish and Wildlife Service, 2008. Print.

"Burned Area Emergency Stabilization and Rehabilitation Handbook." *Bureau for Land Management*. 12 Feb. 2007. Web. 27 May 2013. <www.blm.gov/pgdata/etc/medialib/blm/wo/Information_Resources_Management/policy/blm_handbook.Par.52739.File.dat/h1742-1.pdf>.

Campbell, James B., and Randolph H. Wynne. *Introduction to remote sensing*. 5th ed. New York: Guilford Press, 2011. Print.

"Central Basin and Range REA Map." *BLM - The Bureau of Land Management*. Web. 15 Sept. 2013.

<http://www.blm.gov/wo/st/en/prog/more/Landscape_Approach/reas/cbasinrange/cbrmap.html>.

Cocke, Allison E., Peter Z. Fule and Joseph E. Crouse. "Comparison Of Burn Severity Assessments Using Differenced Normalized Burn Ratio And Ground Data." *International Journal of Wildland Fire* 14.2 (2005): 189. *Google Scholar*. Web. 25 May 2013.

Cohen, Warren B., Zhiqiang Yang, and Robert Kennedy. "Detecting Trends In Forest Disturbance And Recovery Using Yearly Landsat Time Series: 2. TimeSync â€" Tools for Calibration and Validation." *Remote Sensing of Environment* 114.12 (2010): 2911-2924. Print.

"Components of MODIS." *MODIS Website*. N.p., n.d. Web. 20 Oct. 2013. <http://modis.gsfc.nasa.gov/about/specifications.php>.

Diaz-Delgado, R., F. Lloret, and X. Pons. "Influence of Fire Severity on Plant Regeneration By Means Of Remote Sensing Imagery." *International Journal of Remote Sensing* 24.8 (2003): 1751-1763. Print.

Eidenshink, Jeff, Brian Schwind, Ken Brewer, Zhi-Liang Zhu, Brad Quayle, and Stephen Howard. "A Project for Monitoring Trends in Burn Severity." *Fire Ecology* 3.1 (2007): 3-21. *Monitoring Trends in Burn Severity Documents & References*. Web. 1 July 2013.

Eiswerth, M, K Krauter, S Swanson, and M Zielinski. "Post-fire Seeding On Wyoming Big Sagebrush Ecological Sites: Regression Analyses of Seeded Nonnative and Native Species Densities." *Journal of Environmental Management* 90.2 (2009): 1320-1325. Print. Provides useful information specific to Winnemucca

Elmore, Andrew J., John F. Mustard, Sara J. Manning, and David B. Lobell. "Quantifying Vegetation Change in Semiarid Environments: Precision and Accuracy of Spectral Mixture Analysis and the Normalized Difference Vegetation Index." *Remote Sensing of Environment* 73 (2000): 87-102. *Brown University*. Web. 6 June 2013.

Epting, Justin, and David Verbyla. "Landscape-level Interactions of Prefire Vegetation, Burn Severity, And Postfire Vegetation Over A 16-year Period in Interior Alaska." *Canadian Journal of Forest Research* 35.6 (2005): 1367-1377. *Google Scholar*. Web. 6 July 2013.

Escuin, S., R. Navarro, and P. Fernandez. "Fire Severity Assessment By Using NBR (Normalized Burn Ratio) And NDVI (Normalized Difference Vegetation Index) Derived From LANDSAT TM/ETM Images." *International Journal of Remote*

Sensing 29.4 (2008): 1053-1073. *Taylor & Francis*. Web. 28 May 2013.

"Fire Science Brief." *Fire Science*. Web. 30 Oct. 2013. <http://www.firescience.gov/projects/briefs/08-2-1-11_FSBrief147.pdf>.

"Frequently Asked Questions about the Landsat Missions." *Landsat Missions*. USGS, 30 May 2013. Web. 20 Aug. 2013. <http://landsat.usgs.gov/band_designations_landsat_satellites.php>.

Gilabert, M.A., J. Gonzalez-Piqueras, F.J. Garcia-Haro, and J. Melia. "A Generalized Soil-Adjusted Vegetation Index." *Remote Sensing of Environment* 82 (2002): n. pag. *Center for Air Pollution Impact & Trend Analysis - Washington University in St. Louis*. Web. 30 June 2013.

"Growth Habits Codes and Definitions | USDA PLANTS." *Welcome to the PLANTS Database | USDA PLANTS*. Web. 27 May 2013. <http://plants.usda.gov/growth_habits_def.html>.

Han, Guifeng, Yongchuan Yang, and Shuiyu Yan. "Vegetation Activity Trend and Its Relationship with Climate Change in the Three Gorges Area, China." *Advances in Meteorology* 2013 (2013): 1-11. *Hindawi Publishing Company*. Web. 7 Apr. 2014.

Heddinghaus, T.R. and P. Sabol, 1991: A review of the Palmer Drought Severity Index and where do we go from here? Proceedings, 7th Conf. on Appl. Climatol., 10-13 Sept. 1991, Boston: American Meteorological Society, 242-246.

Helsel, Dennis R., and Robert M. Hirsch. "Trend Analysis." Statistical Methods in Water Resources Techniques of Water Resource Investigations. USGS, 2002. 323-355. Web. 10 Jan. 2014. <http://pubs.usgs.gov/twri/twri4a3/pdf/chapter12.pdf>.

Huang, Chengquan, Samuel N. Goward, Karen Schleeweis, Nancy Thomas, Jeffrey G. Masek, and Zhiliang Zhu. "Dynamics Of National Forests Assessed Using The Landsat Record: Case Studies In Eastern United States." *Remote Sensing of Environment* 113.7 (2009): 1430-1442. *http://www.sciencedirect.com*. Web. 3 Aug. 2013.

Huang, Shengli, Christopher Potter, Robert L. Crabtree, Stacey Hager, and Peggy Gross. "Fusing Optical and Radar Data to Estimate Sagebrush, Herbaceous, and Bare Ground Cover in Yellowstone." *Remote Sensing of Environment* 114.2 (2010): 251-264. Print.

Huete, A.R., R.D. Jackson, and D.F. Post. "Spectral Response of a Plant Canopy with Different Soil Backgrounds." *Remote Sensing of Environment* 17.1 (1985): 37-53.

Sciene Direct. Web. 7 July 2013.

Hunter, Molly E., Philip N. Omi, Erik J. Martinson, and Geneva W. Chong. "Establishment of non-native plant species after wildfires: effects of fuel treatments, abiotic and biotic factors, and post-fire grass seeding treatments." *International Journal of Wildland Fire* 15.2 (2006): 271. Print.

Ji, Lei, and Albert J. Peters. "Assessing Vegetation Response to Drought in the Northern Great Plains Using Vegetation and Drought Indices." *Remote Sensing of Environment* 87.1 (2003): 85-98. *Google Scholar*. Web. 28 July 2013.

Kapur, J.N., PK. Sahoo, and A.K.C. Wong. "A new method for gray-level picture thresholding using the entropy of the histogram." *Computer Vision, Graphics, and Image Processing* 29.3 (1985): 273-285. *ScienceDirect*. Web. 14 Jan. 2014.

Kennedy, Robert E., Zhiqiang Yang, and Warren B. Cohen. "Detecting Trends in Forest Disturbance and Recovery Using Yearly Landsat Time Series: 1. LandTrendr Temporal Segmentation Algorithms." *Remote Sensing of Environment* 114.12 (2010): 2897-2910. Print.

Kittler, J., and J. Illingworth. "Minimum Error Thresholding." *Pattern Recognition* 19.1 (1986): 41-47. *ScienceDirect*. Web. 10 Jan. 2014.

Knapp, Paul. "Cheatgrass (Bromus tectorum L.) Dominance in the Great Basin Desert: History, Persistence, and Influences to Human Activities." *Global Environmental Change* 6 (1996): 37-52. *University of North Carolina - Greensboro*. Web. 20 Aug. 2013.

Kushla, J. D., and W. J. Ripple. "Assessing Wildfire Effects with Landsat Thematic Mapper Data." *International Journal of Remote Sensing* 19.13 (1998): 2493-2507. *Taylor & Francis*. Web. 6 July 2013.

"LANDFIRE Homepage." *LANDFIRE Homepage*. Web. 30 May 2013. <http://www.landfire.gov/>.

"Landsat Thematic Mapper 4 and 5 (TM4 and TM5) - Landscape Toolbox Wiki." *Landscape Toolbox Wiki - Landscape Toolbox Wiki*. Web. 20 Oct. 2013. <http://wiki.landscapetoolbox.org/doku.php/remote_sensor_types:landsat_tm_5>.

Lentile, Leigh B., Zachary A. Holden, Alistair M. S. Smith, Michael J. Falkowski, Andrew T. Hudak, Penelope Morgan, Sarah A. Lewis, Paul E. Gessler, and Nate C. Benson. "Remote Sensing Techniques to Assess Active Fire Characteristics and Post-fire Effects." *International Journal of Wildland Fire* 15.3 (2006): 319. *University of Nebraska - Digital Commons*. Web. 25 May 2013.

Lhermitte, S., J. Verbesselt, W.W. Verstraeten, S. Veraverbeke, and P. Coppin. "Assessing Intra-annual Vegetation Regrowth After Fire Using the Pixel Based Regeneration Index." *ISPRS Journal of Photogrammetry and Remote Sensing* 66 geo (2011): 17-27. *Science Direct*. Web. 25 May 2013.

Lopez-Garcia, M. and Caselles, V., Mapping burns and natural reforestation using Thematic Mapper data. Geocarto International, 6, 1991pp. 31–37.

"Mapping Burn Severity for Burned Area Emergency Response (BAER) and Monitoring Trends in Burn Severity (MTBS)." *MTBS*. Web. 20 Sept. 2014. <http://www.mtbs.gov/bear_mtbs.html>.

Matsushita, Bunkei, Wei Yang, Jin Chen, Yuyichi Onda, and Guoyu Qiu. "Sensitivity Of The Enhanced Vegetation Index (EVI) And Normalized Difference Vegetation Index (NDVI) To Topographic Effects: A Case Study In High-density Cypress Forest." *Sensors* 7.11 (2007): 2636-2651. *Google Scholar*. Web. 25 Aug. 2013.

"MODIS Website." *NASA*. Web. 27 Feb. 2014. <http://modis.gsfc.nasa.gov/about/>.

Morgan, Jessica L., Sarah E. Gergel, and Nicholas C. Coops. "Aerial Photography: A Rapidly Evolving Tool for Ecological Management." *BioScience* 60.1 (2010): 47-59. *ProQuest*. Web. 19 Oct. 2013.

"MTBS Individual Fire-Level Geospatial Data." MTBS. USGS, USFS, RSAC, MTBS, 9 Apr. 2014. <http://www.mtbs.gov/dataquery/>

Muldavin, Esteban H., Paul Neville, and Glenn Harper. "Indices Of Grassland Biodiversity In The Chihuahuan Desert Ecoregion Derived From Remote Sensing." *Conservation Biology* 15.4 (2001): 844-855. *Google Scholar*. Web. 6 June 2013.

Mullins, D.W. and J. Cihlar. "Monitoring Rangeland Using Landsat MSS Data." Geoscience and Remote Sensing Symposium - 12th Canadian Symposium on Remote Sensing. IEEE. Ottawa, Ontario. 13 July 1989. Lecture.

Munyati, C., and D. Makgale. "Multitemporal Landsat TM Imagery Analysis For Mapping And Quantifying Degraded Rangeland In The Bahurutshe Communal Grazing Lands, South Africa." *International Journal of Remote Sensing* 30.14 (2009): 3649-3668. *Taylor & Francis*. Web. 3 Sept. 2013.

"Nevada BLM Geospatial Data." *BLM - Nevada*. Web. 20 Feb. 2014. <http://www.blm.gov/pgdata/etc/medialib/blm/nv/gis/metadata.Par.34343.File.dat/nv_firehistory1910_2007_metadata.pdf>.

Otsu, Noboyuki. "A Threshold Selection Method from Gray-Level Histograms." *IEEE Transactions on Systems, Man, and Cybernetics* 9.1 (1979): 62-66. *Google Scholar*. Web. 14 Jan. 2014.

Palmer, Wayne C. "Meteorological Drought (Report No. 45)." *NOAA Temperature, Precipitation and Drought*. Web. 20 Feb. 2014. <http://www.ncdc.noaa.gov/temp-and-precip/drought/docs/palmer.pdf.>.

Patil, Rohit, Xin Miao, Jill Heaton, and Richard Tracy. "Detection and Classification of Plant Species through SpecTIR Airborne Hyperspectral Imagery in Clark County, Nevada." ASPRS 2006 Annual Conference. ASPRS. Reno, Nevada. 1 May 2006.

Paudel, Keshav Prasad, and Peter Andersen. "Assessing Rangeland Degradation Using Multi Temporal Satellite Images And Grazing Pressure Surface Model In Upper Mustang, Trans Himalaya, Nepal." *Remote Sensing of Environment* 114.8 (2010): 1845-1855. *Sciene Direct*. Web. 7 July 2013.

Perry, Jr., Charles, and Lyle Lautenschlager. "Functional Equivalence of Spectral Vegetation Indices." *Remote Sensing of Environment* 14.1-3 (1984): 169-182. *Sciene Direct*. Web. 23 June 2013.

Peters, A. J., and M. D. Eve. "Satellite Monitoring Of Desert Plant Community Response to Moisture Availability." *Environmental Monitoring and Assessment* 37.1-3 (1995): 273-287. *Science Direct*. Web. 20 Sept. 2013.

Peters, A.J., M.D. Eve, E.H. Holt, and W.G. Whitford. "Analysis of Desert Plant Community Growth Patterns with High Temporal Resolution Satellite Spectra." *Journal of Applied Ecology* 34 (1997): 418-432. *Academic Search Complete*. Web. 20 Sept. 2013.

Pilliod, D.S., and J.L. Welty. "Land Treatments Digital Library Search." *Land Treatments Digital Library Home page*. USGS, Web. 1 Dec. 2013. <https://ltdl.wr.usgs.gov/>.

"Plants Profile for Bromus tectorum (Cheatgrass)." *Plants Profile for Bromus tectorum (Cheatgrass)*. USDA, n.d. Web. 1 Apr. 2014. <http://plants.usda.gov/core/profile?symbol=BRTE#>.

Pleniou, Magdalini , and Nikos Koutsias. "Sensitivity of Spectral Reflectance Values to Different Burn and Vegetation Ratios: A Multi-Scale Approach Applied in a Fire Affected Area." *ISPRS Journal of Photogrammetry and Remote Sensing* 79 (2013): 199-210. *Science Direct*. Web. 25 May 2013.

"Product Guide: Landsat Climate Data Record Surface Reflectance." *Landsat Missions*. USGS, Web. 30 Sept. 2013. <landsat.usgs.gov/documents/cdr_sr_product_guide.pdf>.

"Publications Gap Analysis." *National Gap Analysis Program*. USGS, Web. 12 Feb. 2014. <http://gapanalysis.usgs.gov/publications/>.

Purevdorj, Ts., R. Tateishi, T. Ishiyama, and Y. Honda. "Relationships between Percent Vegetation Cover and Vegetation Indices." *International Journal of Remote Sensing* 19.18 (1998): 3519-3535. *Taylor & Francis*. Web. 28 July 2013.

Qi, J, A Chehbouni, a Huete, Y Kerr, and S Sorooshian. "A Modified Soil Adjusted Vegetation Index." *Remote Sensing of Environment* 48.2 (1994): 119-126. *Science Direct*. Web. 17 June 2013.

Quarmby, N. A., M. Milnes, T. L. Hindle, and N. Silleos. "The Use of Multi-temporal NDVI Measurements from AVHRR Data for Crop Yield Estimation and Prediction." *International Journal of Remote Sensing* 14.2 (1993): 199-210. Print.

"RSAC - Remote Sensing Applications Center FAQ." *Remote Sensing Applications Center - USDA Forest Service*. Web. 30 Mar. 2014. <http://www.fs.fed.us/eng/rsac/baer/barc.html>.

"Remote Sensing Phenology." *Remote Sensing Phenology*. USGS, Web. 25 Sept. 2013. <http://phenology.cr.usgs.gov/overview.php>.

Richards, Rebecca T., Jeanne C. Chambers, and Christopher Ross. "Use of Native Plants on Federal Lands: Policy & Practice." *Journal of Range Managment* 51.6 (1998): n. pag. *Arizona State*. Web. 30 Oct. 2013.

Richardson, Arthur J., and C. L. Weigend. “Distinguishing vegetation from soil background information." *Photogrammetric Engineering and Remote Sensing* 43.12 (1977): 1541-52. Print.

Roberts, D.A., M.O. Smith, and J.B. Adams. "Green Vegetation, Nonphotosynthetic Vegetation, and Soils in AVIRIS Data." *Remote Sensing of Environment* 44.2-3 (1993): 255-269. *Science Direct*. Web. 20 Aug. 2013.

Rouse, J.W., R.H.Haas, J.A.Schell, and D.W.Deering, 1973: Monitoring Vegetation Systems in the Great Plains with ERTS, Third ERTS Symposium, NASA SP-351 I: 309-317.

Satterwhite, Melvin B., and J. Ponder Henley. "Spectral characteristics of selected soils and vegetation in Northern Nevada and their discrimination using band ratio techniques." Remote Sensing of Environment 23.2 (1987): 155-175. Defense Technical Information Center. Web. 14 Jan. 2014.

Schmidt, Heike, and Arnon Karnieli. "Remote Sensing of the Seasonal Variability of Vegetation in a Semi-arid Environment." *Journal of Arid Environments* 45.1 (2000): 43-59. *Ben Gurion University*. Web. 30 June 2013.

Sesnie, Steven, Brett Dickson, Steven Rosenstock, and Jill Rundall. "A comparison of Landsat TM and MODIS vegetation indices for estimating forage phenology in desert bighorn sheep (Ovis canadensis nelsoni) habitat in the Sonoran Desert, USA." *International Journal of Remote Sensing* Online (2011): *Google Scholar*. Web. 20 Oct. 2013.

"Siberian Wheatgrass." *Plant Fact Sheet*. USDA, Web. 30 Mar. 2014. <http://plants.usda.gov/factsheet/pdf/fs_agfr.pdf>.

Smits, P. C., S. G. Dellepiane, and R. A. Schowengerdt. "Quality assessment of image classification algorithms for land-cover mapping: A review and a proposal for a cost-based approach." *International Journal of Remote Sensing* 20.8 (1999): 1461-1486. *http://www.sciencedirect.com*. Web. 14 Oct. 2013.

Snay, Richard A., and Tom Soler. "Reference Systems: Part 3: WGS 84 and ITRS." *Professional Survey* March (2000): *Professional Surveyor*. Web. 20 Feb. 2014.

Sonnenschein, Ruth, Tobias Kummerle, Thomas Udelhoven, Marion Stellmes, and Patrick Hostert. "Differences in Landsat-based trend analyses in drylands due to the choice of vegetation estimate." *Remote Sensing of Environment* 115 (2011): 1408-1420. *Science Direct*. Web. 7 July 2013.

Tedrow, Linda, and Keith Weber. "NDVI Changes over a Calendar Year in the Rangel ands of Southeast Idaho." *Final Report: Assessing Post - Fire Recovery of Sagebrush - Steppe Rangelands in Southeastern Idaho*. Idaho State University, Web. 15 July 2013. <http://giscenter.isu.edu/research/Techpg/nasa_postfire/pdf/Ch9.pdf>.

Tsai, Wen-Hsiang. "Moment-preserving thresholding: a new approach." *Computer Vision, Graphics, and Image Processing* 29.3 (1985): 377-393. *ScienceDirect*. Web. 14 Jan. 2014.

Veraverbeke, S., I. Gitas, T. Katagis, A. Polychronaki, B. Somers, and R. Goossens. "Assessing Post-Fire Vegetation Recovery Using Red-Near Infrared Vegetation Indices: Accounting for Background and Vegetation Variability." *ISPRS Journal of Photogrammetry and Remote Sensing* 68 (2012a): 28-39. *Science Direct*. Web. 25 May 2013.

Veraverbeke, S., S. Hook, and G. Gulley. "An Alternative Spectral Index for Rapid Fire Severity Assessments." *Remote Sensing of Environment* 123 (2012b): 72-80. *ScienceDirect*. Web. 28 July 2013.

Veraverbeke, Sander, Stefan Lhermitte, Willem W. Verstraeten, and R. Goossens. "Evaluation of pre/post-fire differenced spectral indices for assessing burn severity in a Mediterranean environment with Landsat Thematic Mapper." *International Journal of Remote Sensing* 32.12 (2011): 3521-3537. *Google Scholar*. Web. 25 May 2013.

Vogelmann, James E., George Xian, Collin Homer, and Brian Tolk. "Monitoring gradual ecosystem change using Landsat time series analyses: Case studies in selected forest and rangeland ecosystems." *Remote Sensing of Environment* 122 (2012): 92-105. *University of Nebraska - Lincoln*. Web. 9 Sept. 2013.

Weiss, Jeremy L., David Gutzler, Julia E. Allred Coonrod, and Clifford N. Dahm. "Long-term Vegetation Monitoring With NDVI in a Diverse Semi-arid Setting, Central New Mexico, USA." *Journal of Arid Environments* 58.2 (2004): 249-272. *Science Direct*. Web. 20 Aug. 2013.

"What is RAVG?" *U.S. Forest Service Post-Fire Vegetation Conditions* -. U.S. Department of Agriculture, Web. 21 Dec. 2013. <http://www.fs.fed.us/postfirevegcondition/whatis.shtml>.

"Winnemucca District Drought Response Plan." *Winnemucca District Office*. Web. 15 Sept. 2013. <https://www.blm.gov/epl-front-office/projects/nepa/35505/43321/46372/FEA_Drought_MGT_Plan.pdf>.

"Winnemucca District Office." *BLM - The Bureau of Land Management*. Web. 30 May 2013. <http://www.blm.gov/nv/st/en/fo/wfo.html>.

"Winnemucca District Proposed RMP/ Final EIS." *Winnemucca District Office*. Web. 15 Sept. 2013. <http://www.blm.gov/pgdata/etc/medialib/blm/nv/field_offices/winnemucca_field_office/rmp/rmp_files.Par.85959.File.dat/Chapter_1_-_Introduction.pdf>.

"Winnemucca Fire and Aviation." *BLM - The Bureau of Land Management*. Web. 30 May 2013. <http://www.blm.gov/nv/st/en/fo/wfo/blm_programs/Fire_and_Aviation.html>.

Yang, Jian, Peter J. Weisberg, and Nathan A. Bristow. "Landsat remote sensing approaches for monitoring long-term tree cover dynamics in semi-arid woodlands: Comparison of vegetation indices and spectral mixture analysis." *Remote Sensing* *of Environment* 119 (2012): 62-71. *Science Direct*. Web. 7 July 2013.

Young, James A., and Raymond A. Evans. "Population Dynamics after Wildfires in Sagebrush Grasslands." *Journal of Range Management* 31.4 (1978): 283-289. *JSTOR*. Web. 20 Aug. 2013.

Zhu, Zhiliang, Carl Key, Donald Ohlen, and Nate Benson. "Evaluate Sensitivities of Burn-Severity Mapping Algorithms for Different Ecosystems and Fire Histories in the United States." *Final Report to the Joint Fire Science Program* Final Report to the Joint Fire Science Program (2006): *FireScience*. Web. 6 July 2013.

Zhu, Zhe, and Curtis E. Woodcock. "Object-based cloud and cloud shadow detection in Landsat imagery." *Remote Sensing of Environment* 118 (2012): 83-94. *fmask*. Web. 10 Mar. 2014.

Zielinski, Michael J."Poster: Controlling Erosion on Lands Administered by the Bureau of Land Management, Winnemucca District, Nevada." Symposium on Ecology, Management, and Restoration oflntermountain Annual Rangelands, http://www.fs.fed.us/rm/pubs_int/int_gtr313/int_gtr313_143_146.pdf, Boise, ID. 18 May 1992. Lecture.

BIOGRAPHY

Christine Dougherty received her Bachelor of Arts from George Washington University in 2007. After graduating, she studied at Queen's University – Belfast where she received a Master of Arts in Comparative Ethnic Conflict in 2008. During her time in Belfast, Christine worked at the non-profit organizations the Institute for Conflict Research and the Housing Rights Service. Upon returning to D.C., Christine joined Macfadden and Associates to work for the United States Agency for International Development in support of the Office of Civilian-Military Cooperation and the Power Africa Initiative.