2023

Quantitative Change Analysis of Undisturbed Lands in Eastern South Dakota: 2012-2021

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QUANTITATIVE CHANGE ANALYSIS OF UNDISTURBED LANDS IN EASTERN SOUTH DAKOTA: 2012-2021

By

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A Thesis submitted in partial fulfillment of the requirements for the

Master of Science

Major in Biological Science

South Dakota State University

2023

THESIS ACCEPTANCE PAGE

Riley Wollschlager

This thesis is approved as a creditable and independent investigation by a candidate for the master's degree and is acceptable for meeting the thesis requirements for this degree. Acceptance of this does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

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ACKNOWLEDGEMENTS

I would like to thank my major academic advisor, Dr. Alexander "Sandy" Smart. Thank you for your guidance and support in the research and writing stage that improved my Master's research and gave me skills for a future career. I would also like to thank Pete Bauman, who oversaw and managed a large portion of research that made my Master's possible. Thank you for the guidance and support during this project that allowed me to succeed academically and professionally. I appreciate every opportunity you gave me to work on this undisturbed prairie project. Also, a special thank you to Brad Richardson for your countless hours of training and guiding me in both my undergraduate and graduate work. The insight and time you took to teach me the intricacies of this project/software has improved my professional abilities and it does not go unnoticed. I would also like to thank my graduate committee, Dr. Josh Leffler and Dr. Bob Watrel, for taking the time to provide insightful and constructive edits on my thesis.

Next, a big thank you to my parents. Thank you for always supporting me throughout my academic and career endeavors. Thank you for teaching me the value of work ethic in everything you do. I know the values you instilled in me growing up will continue to transfer to my professional career after academics. Thank you for convincing me to pursue my dreams with this degree. I wouldn't have succeeded in this field without your leadership and I'm grateful that you were my first and most important teachers.

Lastly, I would like to thank South Dakota State University for providing me with this opportunity to advance academically and professionally. My time with the Department of Natural Resource Management has been special at SDSU.

This research was made possible through grant funding provided by the National Fish and Wildlife Foundation for a grant entitled “Identifying Undisturbed Grassland Habitat to Inform and Prioritize Conservation Investments (SD) (NFWF ID: 66948). Additional funding was also provided through various partner organizations including: the Natural Resources Conservation Service; South Dakota Department of Game, Fish, and Parks; South Dakota State University College of Agriculture, Food, and Environmental Sciences’ Natural Resources Management Department; South Dakota State University College of Natural Sciences’ Geography and Geospatial Sciences Department; and Northern State University College of Arts and Sciences.

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ABSTRACT

QUANTITATIVE CHANGE ANALYSIS OF UNDISTURBED LANDS IN EASTERN SOUTH DAKOTA: 2012-2021

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The actual rate of loss of undisturbed prairie and woodland in eastern South Dakota is unknown, and the landscape composition of the region continues to change. Undisturbed land is land with no proven prior cropping or other disturbance history. Agriculture, development, recreation, and other land use practices create disturbances resulting in the further conversion of undisturbed prairies and woodlands. Previous work by South Dakota State University (SDSU) quantified the remaining undisturbed land in eastern South Dakota as of 2012 (Bauman et al 2016). Farm Service Agency (FSA) common land unit (CLU) and National Agricultural Imagery Program (NAIP) imagery were the primary data used by SDSU to quantify undisturbed land as of 2012. Analysis was then conducted utilizing South Dakota Natural Resource Conservation Service (NRCS)derived Light Detecting and Ranging (LiDAR) imagery to determine additional areas of disturbance not previously detected with other methods.

The objective of our study was to quantify the rate of conversion of Potentially Undisturbed Land between 2012-2021, using the SDSU Potentially Undisturbed Land results of the 2012 analysis as a baseline. Undisturbed land is defined as not being cultivated or mechanically disrupted (Bauman et al. 2016). Our analysis revisited previously designated polygons where LiDAR indicated a change in land use. Images containing land use change detected by LiDAR were contrasted with National Agricultural Imagery Program (NAIP) imagery to determine if the conversion of the land

was prior or post 2012. Any LiDAR-indicated land conversion prior to 2012 was not included in our analysis. Once we determined the date of conversion for the LiDAR data, we then analyzed the remaining undisturbed land tracts to determine if additional conversion occurred after 2012.

The total land area in these counties is 9,164,826 hectares (22,646,780 acres), of which 1,946,936 hectares (4,810,985 acres) or 21% was considered potentially undisturbed as of 2012. Our analysis concluded that an additional 56,561 hectares (139,766 acres) of previously undisturbed land in eastern South Dakota was converted between 2012 and 2021.

Undisturbed prairies are complex ecosystems with a myriad of above and below ground biotic and abiotic components and are believed to be irrecoverable once they have been converted to other land use. Conversion of undisturbed lands in eastern South Dakota is, therefore, irreversible. For perspective, our data suggests an average rate of conversion of over 1,214 hectares (3,000 acres) per county over this 9-year period, or roughly 134 hectares (333 acres) per county per year.

CHAPTER 1: INTRODUCTION AND LITERATURE REVIEW

Historically, the Great Plains presented a diverse mosaic of lakes, rivers, and undisturbed prairie. These areas had adequate soil health and pollinator species for sustainable ecosystems (Osterman et al. 2021). Great Plains undisturbed prairies historically covered 12 states in the Midwest from the Dakotas to Texas (Cunfer 2005). The advance of European settlement across the United States began in the 1800s (Goring et al. 2015) and set a series of major land conversion events into motion. Cultivation of crops was the leading cause of undisturbed prairie conversion across the Great Plains (Anderson 2011). One of the single most important pieces of legislation responsible for the cultivation of the Great Plains was the introduction of the Homestead Act. This guaranteed people the right to build housing on undisturbed prairie if they were cultivating the land (Anderson 2011). The Homestead Act resulted in the mass conversion of a sustainable ecosystem over a short period of time (Anderson 2011). Originally beginning with hand cultivation or ox and plow, conversion began slowly. However, improved technology quickly increased conversion rates on an already extensively changed landscape (Paarlberg and Paarlberg 2008). By the mid-1900s, much of the tallgrass prairie across the Great Plains became cropland (USDA-NASS Census of Agriculture 1950, 1964). What remained were small, isolated patches of prairie. These areas of undisturbed prairie are what support a diverse array of plants and animals, which is increasingly imperiled.

Locating and protecting these remaining tracts of undisturbed prairie are of utmost importance to an ever-dwindling biodiversity across the Great Plains. The previous SDSU analysis by Bauman et al. (2016) and related reports attempted to identify the remaining undisturbed lands in eastern South Dakota. Our current study is an attempt to identify the 'rate' of conversion over time. Eastern South Dakota is already a widely converted landscape, where most of the land area is represented by cropland. Undisturbed prairie makes up a small percentage of the total land use across eastern South Dakota (Bauman et al. 2016). Therefore, the protection of these undisturbed habitats found within this study should be carefully managed by agencies in the coming decades.

Great Plains History

The Great Plains span ten different States and two Canadian Provinces in North America from east of the Rocky Mountains and west of the deciduous forest boundary along the Missouri River south of Sioux City, IA, and north along the western border of Minnesota (Duncan 1972). These undisturbed prairies took root after the Pleistocene glacial period ended (Walker et al. 2009). During this time, many large land mammals disappeared from the Great Plains (Augustine et al. 2021). With the Pleistocene ending, a climatic shift overtook the area. The compounding factors of fewer large herbivores and more favorable weather patterns changed the landscape composition (Augustine et al. 2021). The warming climate led to the increase in grasses, switching from a more woody environment. During the Holocene era, the vegetation type switched from C_3 (cool season) grasses to C_4 (warm season) (Woodburn 2017). Still today, both types of grasses exist on the landscape. These characteristics could have been changed by fluctuating precipitation during the growing season.

Moving into the Holocene period, the Great Plains once again boasted millions of terrestrial mammals and avian species (Augustine et al. 2021). These animals induced habitat heterogeneity in undisturbed prairie through their daily routine of trampling and grazing (Augustine et al. 2021). There is a positive relationship between species richness and heterogeneity from which the Great Plains thrived (Bar-Massada and Wood 2013). However, grazing interactions of large herbivores in the Holocene and their effects have not been fully addressed (Milchuanas et al. 1988).

Undisturbed prairies during this period were subject to many sources of abiotic stressors, like fire. Large wildfires have always been a part of undisturbed prairie biomes until recent centuries (Higgins 1986). The Great Plains experienced increased burning from 12,000 to 2,000 BP (Marlon et al. 2013). Peak burning took place in the late Holocene, 2,000 to 1,000 BP. Evidence suggests that this may be caused by climatic shifts in North America (Leys et al. 2018). Sediment cores were used to correlate climate change with fire regimes. $\Delta^{13}C$, an isotopic signature, showed that tall-grass prairie varied in its response to climate change but escalating aridity increased burning on the prairie (Clark et al. 2001). During this period of frequent burning, the Great Plains were dominated by C_4 grasses (Clark et al. 2001).

Populations established on the Great Plains in similar fashions around the world, changing the landscape as they went. The earliest accounts of European exploration, in the 1500s, led by Francisco Coronado took place in the southernmost part of the Great Plains (Hart and Hart 1997). At the time of European expansion, some characteristics of the Great Plains had changed. The prairies were dominated by short-grass species and arid "desert-like" conditions were prevalent (Hart and Hart 1997). These conditions were different to previous late Holocene climates, where increased precipitation allowed tall-grass prairies to thrive (Jiang et al. 2013). Precipitation during the growing season was like that of the modern-day Midwest (Mock 2000). Sufficient precipitation and land characteristics (treeless, relatively flat, and well-drained soils) made the Great Plains exemplary for farming and ranching, which led to the opportunity for undisturbed prairie to cropland conversion to occur. Nearly 60% of the Great Plains ecoregion has a moderate risk of being converted, if not already (Olimb and Robinson 2019).

North American undisturbed prairies are some of the most endangered landscapes on the planet (Samson et al. 2010). Unfortunately, very few undisturbed prairies in the U.S. can be defined as pristine. Many become tainted by non-undisturbed plants or woody species encroachment (Stromberg et al. 2007). Conservation of the Great Plains has been underway following the impacts of European settlement. Areas of future conservation should focus on quantifying, retaining, and restoring undisturbed habitats (undisturbed prairie and woodland).

South Dakota Land Composition (Before 2012)

Cropland and Farmland

In 2012, 2.23 million hectares (5.5 million acres) of corn *(Zea mays.)* were planted for grain and silage in South Dakota. Trailing behind corn were 1.90 million hectares (4.7 million acres) and 0.89 million hectares (2.2 million acres) of soybeans (*Glycine max*) and wheat (*Triticum aestivum*), respectively (USDA-NASS Census of Agriculture 2012). Production of other crops adds to the cropland total each year. Oats

(*Avena sativa*), barley (*Hordeum vulgare*), sorghum (*Sorghum bicolor*), sunflowers (*Helianthus annuus*), and potatoes (*Solanum tuberosum*) combined for over 344,199 hectares (850,535 acres) in 2012 (USDA-NASS Census of Agriculture 2012). Farm size has increased across South Dakota in the last 25 years. In 1997, there were around 3,000 farms with 810 or more hectares (2,000 acres) (USDA-NASS Census of Agriculture 2012). In 2012, there were nearly 5,000 farms with 810 hectares (2,000 acres) or more (USDA-NASS Census of Agriculture 2012). During these 15 years, farm size of 810 hectares or more (2,000 acres) grew by nearly 40% (USDA-NASS Census of Agriculture 2012).

This trend of increasing cropland continued until it peaked at 9,376,281 hectares (23,169,296 acres) in 1940 (Table 1.1). After 1940, the cropland acreage and number of farms in South Dakota decreased significantly. This was likely due to the economic effects from the 1930s Dust Bowl, which lasted for nearly a decade (Schubert et al. 2004). The Dust Bowl left many farmers with the inability to grow crops after it was over. Recovering farms showed decreasing cropland area totals between 1950 and 1964. Simultaneously, the post Dust Bowl era saw some of the greatest technological advancements in the farming industry. This agricultural revolution introduced the most efficient gas-powered tractor of its time (Paarlberg and Paarlberg 2008). These gas-powered tractors replaced steam engines and horses. The technological advancements of this era seemed to offset the effects of the Dust Bowl. Increasing cropland totals continued from 1964 to 2002 (USDA-NASS Census of Agriculture 2012).

Potentially Undisturbed Habitat Conversion

Recent Land Conversion Events

Improved technology along with cheap fertilizers (anhydrous ammonia, rock phosphate, potash, and urea) may have led to the recovery of South Dakota farms and resulted in the gradual increase in cropland totals between 1964 and 2002 (Paarlberg and Paarlberg 2008). Also, herbicides like 2,4-D allowed producers to control summertime weeds, lambsquarters (*Chenopodium album*), ragweed (*Ambrosia artemisiifolia*), and water hemp (*Amaranthus tuberculatus*), which increased yields and allowed for more economical farming (Bernards et al. 2012; Robinson et al. 2012). Similarly, new equipment technologies and land modification practices allowed for the farming of less than ideal undisturbed land that was not previously converted (Paarlberg and Paarlberg 2008). Such practices (tiling and rock removal) could have made it more economically feasible for farmers to convert previously inadequate undisturbed prairie and woodland into row crop agriculture. Thus, conversion of undisturbed land continued across an already heavily changed landscape.

Present-Day Land Conversion

Bauman et al. (2016) attempted to quantify eastern South Dakota's remaining undisturbed lands. This report introduced the term 'Potentially Undisturbed' to describe land that had no provable disturbance history, and this is likely undisturbed or virgin sod. Undisturbed or natural habitat is defined as "a complex of natural, primarily undisturbed or indigenous vegetation, not currently subject to cultivation or artificial landscaping, a primary purpose of which is to provide habitat for wildlife, either terrestrial or aquatic (Cornell Law School 2022). Lands that were not categorized as Potentially Undisturbed are considered “disturbed” and had been subject to manipulation or cultivation of vegetation or topsoil in the past.

From 2006 to 2012 grassland decreased by nearly 497,763 hectares (1,230,000 acres) in eastern South Dakota’s National Agricultural Statistics Service (NASS) regions (Reitsma et al. 2014). In NASS regions where grassland area declined, it concomitantly saw increases in competing land use classification such as cropland, non-ag, habitat, and open water areas (Reitsma et al. 2014). Recently improved methods of detection have led to more accurate estimates of undisturbed prairie conversion (Nguyen et al. 2019).

One of the greatest threats to undisturbed prairie is conversion to cropland. Undisturbed prairie is most often converted into row crop agriculture in the form of corn or soybeans (Smith et al. 2008). A survey of farm operators between 2004 and 2014 showed that 40% had converted some undisturbed prairie (Wimberly et al. 2017). The driving force of this type of conversion is economics (Rashford 2011). The market value of grain prices has the potential to sway land use decisions. The higher market value of crops can potentially increase the undisturbed prairie rate to cropland conversion (Nickel 2022; Wright and Wimberly 2013). In 2012, the market value of corn hovered between $6.50 and $8.00. Following $8.00 corn in 2012 was an extended period of decline between 2013 and 2020 (Schwab 2022). Between 2013 and 2020 the highest corn price was in 2014, reaching nearly $5.08 (National Agricultural Statistics Service 2022). However, the average between these years was below $4.50 (National Agricultural

Statistics Service 2022). March of 2021 saw a spike in corn prices once again, reaching $7.32 (National Agricultural Statistics Service 2022). Corn commodity prices have continued to hover above $5.00 since (National Agricultural Statistics Service 2022). Soybean markets showed similar trends. Rashford (2011) models indicated that if market trends continued, undisturbed prairie conversion rates would increase. Now, 11 years later, our data supports that prediction.

Recently, an industrial-specific source of conversion, directly related to row crop agriculture, has arisen. Ethanol refinery developments have widespread impacts on the conversion of undisturbed prairies. Wright et al. (2017) states there is an increase over time in undisturbed prairie to cropland conversion when in proximity to ethanol refineries, and nearly 3.6 million acres of undisturbed prairie were included in conversion near such refineries.

Slowing down conversion due to increased market value and industrialization is important to undisturbed prairie existence. One such system is the integration of crop-livestock systems (ICLS). Integration of crop-livestock systems may decrease the risk of undisturbed prairie to cropland conversion by improving soil health and financial stability on farming operations (Smart et al. 2020). Economic improvement of non-crop agriculture on undisturbed prairie systems will decrease undisturbed prairie to cropland conversion (Kemp and Michalk 2007).

While most undisturbed habitat conversion in this region is due to cropland expansion, there are other factors. Residential and industrial disturbance such as golf courses, schools, building sites, wind turbines, gravel pits, or roads also create the potential for undisturbed prairie disturbance (Bauman et al. 2016). Wind energy has the potential to impact rates of conversion on undisturbed prairies, and demand for this type of energy has grown in recent years. In 2006 energy consumption was 472 quadrillion British thermal unit (Btu) (Saidur 2011). It is estimated that total energy consumption in 2030 will be nearly 678 quadrillion Btu (Saidur 2011). Increased energy demands call for increased infrastructure. Each wind turbine directly impacts the land from 0.4 to 1.2 hectares (Bureau of Land Management 2005).

Impacts of Potentially Undisturbed Habitat Conversion

The Current State of Endangered and Threatened Undisturbed Prairie Species:

Eastern South Dakota is home to many different undisturbed prairie species. Some of these species are facing serious population declines, often due to habitat loss. The Eskimo curlew is a species that used eastern South Dakota undisturbed prairies as a migrating corridor (Faanes and Senner 1991). This was often a place where scientists documented their movement and habitat needs. Currently, South Dakota Game, Fish, and Parks (SDGFP) has Eskimo Curlew listed as 'State Endangered'. Eskimo Curlews are also listed as federally endangered. Another species at risk is the whooping crane. These birds relied on wet prairies across the Great Plains to provide roosting and foraging sites during migration. (Austin et al. 2019; Pearse et al. 2020). The Whooping Crane is state and federally listed as endangered. Some mammal populations in eastern South Dakota are also facing declines due to habitat, primarily undisturbed prairie loss. The swift fox is a undisturbed prairie predator that dens in short and midgrass prairies (Uresk and Sharps 1986), and is state listed as threatened due to multiple forms of anthropogenic encroachment (Hillman and Sharps 1978). Retaining large tracts of undisturbed prairie is a leading strategy for maintaining species populations and diversity. Future management of ducks, undisturbed prairie birds, and mammals all rely on management ability to decrease the fragmentation of undisturbed prairie habitat (Ball et al 1995; Warner 1994; Kamler 2003).

Emerging Land Use Analysis

The introduction of computers, high-resolution cameras, and other technologies has led to many scientific advancements and analysis protocols in land use research. The study and management of natural resources have also improved with increasing technological abilities. Remote sensing is one such advancement often used in recent land use studies. Rangeland ecologists and other environmental scientists are attempting to better understand land use across the globe. In 2017, the World Wildlife Fund released a report quantifying undisturbed prairie loss to cropland. They used USDA National Agricultural Statistics Service Cropland Data Layer and Agriculture and Agri-Food Canada Annual Crop Inventory. This quantified approximate annual grassland change across the Great Plains (World Wildlife Fund 2017). They estimated that 1.05 million hectares (2.6 million acres) were converted in the U.S. from grassland to row crop agriculture between 2018-2019 (World Wildlife Fund 2017). In 2014, a South Dakota Land Use Change report was published (Reitsma et al. 2014). This project grouped land use cover into five categories (croplands, undisturbed prairies, non-ag, habitat, and water) between 2006-2012. They analyzed random imagery observations layered with high-resolution NAIP imagery. Randomly selected observation points were analyzed across the state and labeled based on land use change (Reitsma et al. 2014). They estimated nearly 728,434 hectares (1.8 million acres) of undisturbed prairie loss during the study period. At the same time, they estimated that the cropland increased by 566,559 hectares (1.4 million acres) (Reitsma et al. 2014).

Many of these studies are relying on similar data layers to quantify land use and change throughout their respective areas. Johnston (2014) used the USDA Cropland Data Layer and National Agricultural Statistics Service to quantify land use and its relation to other variables (climate, agronomic practice, and biofuels). Like many other studies, they found that corn and soybeans increased by 27% percent from 2010 to 2012 (Johnston 2014). However, many of these studies fail to quantify undisturbed habitats, specifically. Many studies incorporate revegetated broken land or other grasslands (CRP) in their studies. Our study is unique in that it is specifically attempting to identify rates of conversion of undisturbed prairie habitats.

Other research has transitioned into creating models to detect land use change rather than manually observing with aerial imagery. SLEUTH (Slope, Landuse, Exclusion, Urban, Transportation, Hillshade) is a cellular automata model that categorizes land use over large scales (Chaudhuri and Clarke 2013; Clarke 2008). However, its simplicity in detection characteristics may limit its usefulness when attempting to determine specific undisturbed prairie-to-cropland change (Clarke 2005). Rashford et al. (2011), published a model that aimed to predict the probability of undisturbed prairie conversion based on economics rather than aerial imagery. They found that undisturbed prairie conversion would not only continue but increase if cropland commodity trends were like that of between 2001 and 2006.

The Future of Undisturbed Habitats and the Northern Great Plains

The future of undisturbed lands across North America will become increasingly uncertain over the next 100 years. The northern Great Plains are now a threatened ecosystem due to anthropogenic encroachment (Perkins et al. 2019). Undisturbed prairie conversion will continue across the northern Great Plains if there is a high market value for row crops (Classen 2012). Until recently, the rate of conversion has not been fully addressed. Management strategies must be put into place to slow or stop the conversion of remaining undisturbed habitats. Biodiversity is likely to decrease in correlation with the conversion of undisturbed prairie and woodland (Hanski 2011).

Direct conversion is still the greatest threat to undisturbed prairie; however, indirect effects can take effect on large scales. Undisturbed prairies that remain may be degraded by adjacent crop production (Shaffer et al. 2019). Wind energy farms have the potential to degrade undisturbed prairie habitats further through direct and indirect effects (McNew et al. 2014). A thorough look at criteria that justify a complete undisturbed prairie or undisturbed prairie restoration may be needed. Research on current management strategies could positively affect the outcome of the remaining land. Some management strategies could include new regulations or techniques on fire regimes and grazing. Prescribed fire has been shown to positively affect undisturbed prairie composition and survival (Novak et al. 2021). More precisely, prescribed fire can hinder invasive grasses and woody species' effects on undisturbed prairies (Novak et al. 2021). Ecologists and rangeland managers should aim to convey these messages to producers who may be unaware of such techniques.

Government support and subsidies may diminish the effects of prior management actions on undisturbed habitats. Crop insurance subsidies showed statistically significant positive effects on the amount of cropland acreage (Feng 2013). Similarly, government undisturbed prairie programs such as CRP showed decreased enrollment efforts due to insurance subsidies (Feng 2013). If the trends continue, undisturbed habitats will continue to be converted or depreciated at unsustainable rates. Awareness of undisturbed prairie-to-cropland conversion has gained awareness throughout recent years. The Great Plains are unique in value. They provide much of the land needed for increasing livestock and biofuels (Heitschmidt et al. 2001; Smart et al. 2010). Many of these lands are also at risk of reaching a tipping point in sustainability due to land-use change (Joshi et al. 2019). Natural resource management should focus efforts on protecting and restoring declining resources if they are to remain for future generations.

Research Overview

This study aims to quantify the rate of change in undisturbed habitats in eastern South Dakota. Through this process, we will gain a better understanding of the land use on eastern South Dakota's remaining habitat. Our research intends to build off previous work by SDSU, which quantified undisturbed habitat area as of 2012 (Bauman et al. 2016). Results from this study will allow for more informed decisions on undisturbed prairie and woodland management. It may also illuminate management strategies for several wildlife species and their response to habitat loss or gain. This study may serve as a precursor for future research on undisturbed prairie to cropland change (Murray et al. 2003; Wu 2016).

TABLES

Table 1.1 Historical cropland, pastureland, farms, and land area in South Dakota. (USDA-NASS Census of Agriculture (1920, 1950, 1964, 1997, 2002, 2012, 2017).

Year	Land Area in Farms (hectares)	Cropland Total (hectares)	Pastureland Total (hectares)	Number of Farms
1880	N/A	324,100	746,005	13,645
1910	20,151,530	6,405,043	3,968,566	77,644
1920	20,151,530	7,364,974	6,434,929	74,637
1925	20,151,530	9,141,547	5,583,497	79,537
1940	19,822,731	9,376,280	N/A	72,454
1950	19,822,731	8,021,553	9,272,621	66,452
1964	19,781,809	7,570,553	10,292,061	49,703
1982	19,671,432	7,623,766	9,466,786	37,148
1997	17,863,588	7,974,813	9,325,639	33,191
2002	17,719,191	8,225,926	9,936,670	31,736
2007	17,678,705	7,730,490	9,898,019	31,169
2012	17,505,517	7,748,645	9,310,742	31,989
2017	17,507,587	8,021,667	9,178,088	29,968

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CHAPTER 2: DETERMINING THE CONVERSION RATES OF UNDISTURBED PRAIRIE IN EASTERN SOUTH DAKOTA

ABSTRACT

Conversion of undisturbed lands across eastern South Dakota continues at an unknown rate. This conversion poses a threat to all undisturbed habitats that remain. Undisturbed lands cannot be fully recovered once they have been converted to other uses. The objective of this study was to assess the rate of change on undisturbed prairie in eastern South Dakota between 2012 and 2021. We hypothesize that there will be undisturbed habitat conversion due to agriculture and other anthropogenic causes. The first step in our process was to re-visit an existing dataset developed by SDSU Extension that utilized Level II Light Detecting and Ranging (LiDAR) data provided by the South Dakota Natural Resources Conservation Service. SDSU Extension used LiDAR imagery layered with the Farm Service Agency (FSA) common land unit (CLU) and National Agricultural Imagery Program (NAIP) imagery to quantify Potentially Undisturbed Land. Polygon images with LiDAR-indicated disturbance that occurred after 2012 were removed from the base 2012 Potentially Undisturbed Lands layer and were ‘counted’ as new land conversion for our evaluation. Our second step was to evaluate all remaining Potentially Undisturbed Land for conversion within eastern South Dakota that wasn’t held in the LiDAR database. This remaining conversion was assessed using the original undisturbed land database from Bauman et al. (2016). We analyzed this undisturbed land database using NAIP imagery (2012, 2014, 2016, 2018, and 2021) to detect land conversion between 2012 and 2021. In step one, we found LiDAR indicated conversion after 2012 in all 44 counties of eastern South Dakota in at least one year between 2012-2021. In total, 14,558 hectares (35,976 acres) of previously undisturbed prairie and

woodland met definitive conversion characteristics based on post-2012 LiDAR data. This decreased the total estimated amount of undisturbed land remaining in eastern South Dakota as of 2021. In step two, we found other previously undisturbed land conversion that totaled 42,002 hectares (103,790 acres). We determined that undisturbed habitats continue to be converted due to agriculture and other anthropogenic disturbances.

INTRODUCTION

The conversion of grasslands throughout the Northern Great Plains and South Dakota has been a topic of concern in recent years. Recent research has made it clear that conversion is still happening at an alarming rate (Wright and Wimberly 2013; Reitsma et al 2014). These papers quantified the conversion rate of all grasslands throughout the Northern Great Plains. It is important to note that previous analysis were not able to distinguish the disturbance history or type of grasslands, and therefore potentially included grasslands which may be undisturbed, but also could be hay land or CRP. Inclusion of hay land or CRP would not be an accurate rate of change in truly undisturbed habitat that remained.

Our analysis utilized existing data from eastern South Dakota to assess the rate of change in previously undisturbed habitats. Bauman et al. (2016) developed unique methods to discern undisturbed grasslands and woodlands that has potentially never been converted. This previous work provided us the ability to create a method for quantifying the rate of change in this habitat.

From 2014 to 2021, an undisturbed land inventory project was conducted to quantify ‘potentially’ undisturbed prairie in eastern South Dakota (see Bauman et al.

2016). Geographic Information Systems (GIS) and aerial imagery were used to view surface characteristics when determining land use status. This process used Farm Service Agency's (FSA) Common Land Unit (CLU) to produce a refined detection layer. They used CLU data land classification codes to determine land that had been previously cropped. This approach ultimately determined historical land use as of 2012 and included technicians manually searching for 'clues' on the landscape that could indicate previous land disturbance. Such clues could be sets of linear tracks or lines, viewed with LiDAR, on the surface. This could indicate prior row crop plantings and would be investigated until a designation was assigned. Lands that were determined to have prior cropping history or other disturbance were removed from the remaining acreage. The remainder of the land would be categorized as 'potentially' undisturbed grassland or woodland. These remote sensing methods quantified the remaining undisturbed habitats that remained in eastern South Dakota as of 2012. We applied this refined database to our research to capture the conversion of all undisturbed grassland and woodland.

In our first step we aim to represent the remaining undisturbed habitat more accurately within eastern South Dakota, using LiDAR based data. LiDAR used in the SDSU analysis was acquired and processed between 2016 and 2020. Thus, for accuracy, it was necessary for us to evaluate whether the land disturbances indicated in the LiDAR data occurred before or after 2012 (Figure 2.4). LiDAR is a laser technology that uses radar to observe atmospheric and land characteristics (Collis 1970). One of LiDAR's best functions is to determine land use or structure on Earth's surface. LiDAR can be used to detect minute elevation differences on Earth's surface (Tarolli 2014) (Figure 2.5). Terrestrial LiDAR can detect hillslopes, rivers, tectonic plates, and anthropogenic signatures on topography (Tarolli 2014). This made it a credible and useful tool for detecting land use change (e.g., cropland, housing development, renewable energy) and allowed researchers to collect data from satellite imagery in hard-to-reach areas. LiDAR land use classifications have been used from megacities to small homesteads (Bujan et al. 2012; Zhang et al. 2017). Recently, LiDAR has been used to improve the accuracy of agricultural land use change throughout the Midwest (Mesas 2012). Results showed a 40% increase in accuracy when combining LiDAR with traditional aerial imagery to determine land use (Mesas 2012). We used a LiDAR-refined database produced by SDSU Extension to determine the amount of remaining undisturbed habitat in eastern South Dakota.

In step two we aim to quantify the rate of change (e.g., cropland conversion) in Potentially Undisturbed Land between 2012 and 2021. After using LiDAR to assess conversion rates hidden by revegetation (i.e.., LiDAR data analysis) we used remote sensing methods and previous datasets to quantify remaining undisturbed prairies in eastern South Dakota. Remote sensing has become a useful tool for land managers to determine and predict future land use all over the world (Liping et al. 2018; Ozcan et al. 2008). There are many ways of using remote sensing and GIS to detect change on the earth's surface, including post-classification comparisons (Alqurahsi and Kumar 2013). Post-classification comparisons determine land use or other characteristics in the same area but in different time periods.

NAIP imagery is a type of remote sensing data and is useful in determining land use and land cover classifications (Prasai et al. 2021). We used NAIP imagery in similar ways to determine land use with GIS software and potentially undisturbed habitat data.

Research has found that remote sensing methods are successful and accurate at identifying land use change, especially when linked to specific sources such as agriculture practices like cultivating or plowing (Kastens and Legates 2002; Rogan and Chen 2004; Green et al. 1994). Previous researchers didn't use or have access to the datasets and technology we did. Therefore, our research more accurately represented the conversion rates of truly undisturbed grassland prairie and woodland.

MATERIALS AND METHODS

Study Area and Methods

Our study was conducted in 44 Counties located east of the Missouri River where land was dominated by a mixture of cropland and pasture. The landscape of eastern South Dakota was impacted by glaciation 11,000 BP (Kehew and Lord 1986), providing highly fertile soils for crop production. Historically, the landscape was covered with tallgrass prairie in the furthest eastern portion of South Dakota and mixed-grass prairie everywhere else (Woodburn 2017).

step 1: LiDAR Data Analysis

From 2016 to 2021, SDSU Extension utilized Level II LiDAR data provided by the South Dakota Natural Resources Conservation Service to assess undisturbed lands for additional categorization of lands where initial analysis showed signs of potential prior conversion but where definitive proof was lacking (Bauman et al. 2016). Research staff refined LiDAR processing steps first developed in Canada (Lark et al. 2015). By adjusting the LiDAR imagery with a variety of filters, staff were able to clearly identify historic land disturbance (unpublished methodology). SDSU Extension used LiDAR imagery layered with the Farm Service Agency (FSA) common land unit (CLU) and National Agricultural Imagery Program (NAIP) imagery to quantify Potentially Undisturbed Land as of 2012. However, since NRCS LiDAR data was collected and analyzed from 2016 to 2020, it was impossible to determine if LiDAR indicated land disturbance occurred prior to or after 2012. Results from this undisturbed land inventory project were the baseline for this quantitative change analysis of undisturbed lands in eastern South Dakota from 2012-2021 project.

Bauman et al. (2016) created a database that contained a list of LiDAR detected disturbance from the baseline project. We used this database as a baseline to search for evidence of conversion after 2012. We created shapefiles in ArcMap 10.5 for the counties we were analyzing. Layered over the top of these shapefiles was the NAIP imagery for the county of analysis in the years 2012, 2018, and 2021. Turning on and off this imagery layer for each year would allow us to put a timestamp on the conversion seen. When conversion was found we labeled the polygon with the year nearest that conversion happened. This analysis used multiple map scales (e.g., 1:8000, 1:3000, etc.) to accurately assess the current land use. A full list of disturbance categories and associated examples can be found in (Table 2.2).

Analysis of the LiDAR data was conducted in two separate efforts from September 2021 to December 2021. In succession, from January 2022 to May 2022, the analysis was conducted in the same counties and quantified the total converted acreage from 2018-2021. The sum of these two efforts provided the total converted acreage of ‘disturbed’ land based on LiDAR analysis methods between 2012-2021.

step 2: Review of Potentially Undisturbed Land

In May 2021, we assembled an aerial imagery layering system into ArcMap 10.5.. Two distinct layers made up our mapping system to be analyzed. SDSU Extension created the base layer that quantified Potentially Undisturbed Lands in eastern South Dakota as of 2012. Layered over this was NAIP imagery with corresponding years of analysis: 2012, 2014, 2016, 2018, and 2021. This imagery was downloaded from the NRCS Geospatial Data Gateway. We selected the “N+hn” aerial imagery because it allowed us to analyze undisturbed habitat conversion with little color or shade interference. 2020 NAIP imagery was incomplete and did not provide the necessary images to analyze the entirety of eastern South Dakota. Thus, we dropped it from our imagery analysis layer and replaced it with the year 2021. NAIP images are unique in that they construct mosaics of the land during peak agriculture growing seasons. This allows remote sensing to accurately identify new and existing cropping during the “leaf on” stage when it is most distinguishable. We used this imagery to portray land use on a bi-annual basis.

We analyzed each square mile section throughout eastern South Dakota’s 44 counties. When analyzing these data, we observed land use and potential change temporally. We examined land use change in two separate efforts. The first being from May 2021-January 2022, where we analyzed change between 2012-2018. From February 2022- May 2022 we analyzed change between 2018-2021. Any new conversion polygon found between 2012 and 2021 was removed from the Potentially Undisturbed Land

(PUDL) layer, created during the undisturbed land inventory project by SDSU Extension (2012).

Counties with substantial amounts of woodland polygons occasionally experienced natural vegetation composition changes over time. Polygons that were labeled woodland and demonstrated change into undisturbed prairie between 2012 and 2021 were relabeled to represent the current land type more accurately. Therefore, if tree coverage dropped below 50% of the total polygon acreage, then the polygon was relabeled to “undisturbed grassland” (Figure 2.15). Similarly, if undisturbed prairie polygons showed a 50% change into “woodland” they were labeled to their most current vegetation type. However, the vegetation switch from undisturbed grassland to woodland was rare.

During this project analysis, we labeled and quantified individual wind turbines throughout the entire study area (Figure 2.9). Wind turbines have been increasing across eastern South Dakota and the Prairie Coteau. If the wind turbine was held within the PUDL layer its concrete base and access road were removed (Figure 2.11). These structural bases and access roads met our conversion criteria. Often, there were new wind turbines outside of the PUDL layer we analyzed. We would label these wind turbines with the nearest year they were seen, with NAIP imagery. We calculated the sum of all wind turbines between 2012-2018 and 2018-2021. This gave us a new standing total of wind turbines across eastern South Dakota as of 2021. Less often, there were wind turbines present in 2012 but were since removed in 2014, 2016, 2018, or 2021. These wind turbine points were removed from the PUDL layer or data. An attribute table was created to track the removal of wind turbines across the study area.

Undisturbed land was defined as not being mechanically manipulated in the past. These areas (undisturbed) were not subject to 'iron in the ground' practices (Bauman et al. 2016). Potential error during this initial analysis might include tracts of land within undisturbed areas that may have previously experienced manipulations to the ground but lacked definitive visual evidence and therefore did not meet the methodology criteria to be labeled as 'disturbed' and removed from the PUDL layer. The review of Potentially Undisturbed Land using NAIP was a complementary effort to the LiDAR data analysis. Using similar but separate methods we were able to quantify a new 'potentially' undisturbed land total in eastern South Dakota. The sum of acres converted in both methodologies were deducted from the original undisturbed land inventory (see Bauman et al. 2016).

It's important to recognize the inherent error bias that may come from this type of analysis. Miniscule as they might be there is some potential for subjectivity and scale issues within ArcGIS programs, which is why we cannot apply standard statical analysis to the project results. Bauman et al. (2016) created the original polygons in a 1:8000 scale. This scale allowed technicians to view an entire square mile section 258 hectares (640 acres) of land on one computer map frame.. However, for our project greater map scales up to 1:1000 were used periodically when assessing minute disturbances. Most often we used small scales when attempting to remove field creep areas. When we were unable to see conversion after highlighting a polygon in 1:1000 scale it was deemed too subjective to add to the total converted area. During this project, scaling down can create an inaccuracy in border from the scale that the original polygon was drawn at (1:8000). Some very minimal conversion could have been type one error due to the inconsistencies of scale being used during analysis.

RESULTS

step 1: LiDAR Data Analysis

The analysis of the LiDAR database resulted in added conversion across eastern South Dakota. Eastern South Dakota has 9,164,826 hectares (22,646,779 acres) of terrestrial land in eastern South Dakota. Of these, a total of 166,388 hectares (411,155 acres) (1.8%) (Table 2.1) were analyzed during this stage of the project, including nearly 29,000 individual polygons. The mean patch size, or average size of each polygon, was 4.9 hectares (12.1 acres) (Table 2.1). The project analysis was separated into two timeline categories, 2012-2018 and 2018-2021. We found that LiDAR-indicated land conversion that occurred between 2012 and 2018 equated to 10,908 hectares (26,955 acres) (Figure 2.2). The years between 2012 and 2018 made up 75% of the total area of conversion indicated by LiDAR data. From 2018-2021, an additional 3,650 hectares (9,021 acres) of LiDAR indicated land disturbance was found (approximately 25%) (Figure 2.2). In total, we identified 14,558 hectares (35,976 acres) of LiDAR indicated land conversion that occurred between 2012 and 2021. This area was then removed from the PUDL layer as of 2021.

Between 2012 and 2021 nearly 14,558 hectares (35,976 acres) of undisturbed land were categorized as newly converted, which is 8.7% of the total area analyzed during the

LiDAR analysis. Some counties saw between 20-35% of their analyzed area converted in these years. The converted area amount was not consistent throughout the study sites. Northeast and southeast South Dakota displayed some of the lowest conversion rates, as a high degree of historic conversion to cropland had already occurred in these rich row crop areas in the past. The northwestern section of our study area, which had more remaining undisturbed grass cover available for conversion, displayed the highest new conversion rates (Figure 2.2). Eight of the nine counties in the top percentile of conversion were found in this Missouri Coteau region, a part of the Northwestern Glaciated Plains (Figure 2.1). These eight counties (McPherson, Edmunds, Faulk, Potter, Sully, Hyde, Hand, and Hughes) saw the conversion of 8,629 hectares (21,323 acres) between 2012-2021. In other words, less than 20% of the counties contributed to more than 58% of the total conversion indicated by LiDAR across eastern South Dakota. In total, LiDAR indicated conversion of undisturbed grassland between 2012 and 2021 only decreased the total remaining undisturbed land area by about 0.63%. Most land conversions detected in the LiDAR analysis were due to agriculture expansion. No new wind turbines were detected within any LiDAR analysis polygons. It is important to note that most conversion that isn’t revegetated can be readily found using NAIP imagery.

step 2: Review of Potentially Undisturbed Land

The analysis of the Potentially Undisturbed Land layer from 2012 resulted in newly found conversion up until 2021. We found 9,164,826 hectares (22,646,779 acres) make up the entirety of terrestrial land in eastern South Dakota. Of these, a total of 1,992,589 hectares (4,923,797 acres) (21%) were analyzed during the review of Potentially Undisturbed Land stage of this project (Table 2.3). Of the area analyzed we detected conversion of nearly 42,002 hectares (103,790 acres) across eastern South Dakota. The mean area analyzed in the 44 counties was 45,285 hectares (111,904 acres) (Table 2.3). Making up this area was 146,000 separate polygons. The mean PUDL polygon count in each county was over 3,000.

The project analysis was separated into two timeline categories, 2012-2018 and 2018-2021, respectively. From 2012-2018, 27,656 hectares (68,340 acres) met definitive conversion characteristics when analyzed with NAIP imagery. This area makes up 66% of the total area converted within the study. From 2018-2021, 14,345 hectares (35,449 acres) met definitive conversion characteristics. This area makes up the remaining 34% of the area converted within the study site.

Acreage removal was not consistent throughout the study area and similar results were found during the LiDAR Analysis. The Northeast, East, and Southeast displayed lower conversion rates, in general, than the Northcentral and Central parts of the study area. Four counties in eastern South Dakota (Brown, Spink, Beadle, and Hand) had 9,791 hectares (24,195 acres) converted over the study period years. It is reasonable to note that these counties, with the most area converted, represent four of the largest counties in eastern South Dakota.

Similar results were found when analyzing the percent decrease in PUDL during the review of Potentially Undisturbed Lands using NAIP imagery (Figure 2.8). Most conversion found during the review of Potentially Undisturbed Land was due to agriculture expansion of row crops (Figure 2.12). We addressed ‘field creep’ as a primary source of additive conversion (Figure 2.14). Field creep is the successional expansion, annually, of an already existing crop field further into potentially undisturbed ground. Generally, the expansion is a few “rows” every year or two throughout the study period.

Combined Rate of Change:

The two separate methodologies were combined to demonstrate the full extent of undisturbed grassland conversion. Between 2012 and 2021, 56,156 hectares (139,766 acres) (Figures 2.16 and 2.18) were converted from undisturbed grassland to other land use types (e.g., cropland, housing developments, etc.) (Figure 2.7 and 2.13). Some counties (McPherson, Hand, Brown, and Hyde) counties saw over 2,832 hectares (7,000 acres) of undisturbed grassland conversion between 2012 and 2021. The remaining undisturbed prairie area as of 2012 made up 21.7% of the total land base in eastern South Dakota. The remaining undisturbed prairie area in 2021 represents just 21.2% of the total land base, which makes it less convincing that our current undisturbed land conservation strategies have been adequate over the last decade (Table 2.5)

DISCUSSION

We found that eastern South Dakota continued to see undisturbed grassland conversion in recent years (2012-2021). Increasing commodity prices and anthropogenic disturbance are contributing to the conversion of these grasslands (Claassen 2012). Although the cropland area has decreased since 2002, the conversion of undisturbed prairie remains. This raises concerns for the future sustainability of undisturbed habitats across the Great Plains.

Other research has been published quantifying grassland to cropland conversion and land use change (Joshi et al. 2019; Reitsma et al. 2014; Wright and Wimberly 2013). Their tools for measuring conversion in grasslands couldn't and didn't discern undisturbed (native) grasslands from disturbed ones. Therefore, some of the disturbed land that they labeled as new conversion or cropland may have taken place on revegetated areas. These revegetated areas could have been historically converted and revegetated to a grass or grass-like cover. So, by the nature of their methods they would have no way to determine if this conversion was historic or within their research timeline. Our research used more refined methods to detect truly new conversion on undisturbed habitats since 2012. Our research would therefore eliminate any inflation of conversion results and only result in the loss of specifically undisturbed habitat.

Step one of our study quantified the rate of change in undisturbed habitats between the years 2012 and 2021 using existing LiDAR data. One of the biggest differences in methodology from other research is this project's use of LiDAR, as a refinement tool, to increase accuracy and completeness when determining land use. LiDAR can detect elevation changes on earth's surface that would not be readily seen with other aerial imagery methods. The results from this study are crucial for land managers in understanding current undisturbed habitat change in eastern South Dakota, as cropland-to-undisturbed prairie change may affect every aspect of natural resource management (range, wildlife, fish) directly or indirectly (With et al. 2008).

Step two of our study was the review of Potentially Undisturbed Land, like the LiDAR analysis, had varying amounts of acre removal throughout the eastern half of the state (Figure 2.3). However, each county had at least one polygon that showed newly converted area. This supports ours and others hypothesis that conversion is taking place across eastern South Dakota due to anthropogenic encroachment (Claassen 2012). Other research supports our claim that conversion is still taking place across the Great Plains (Cunfer 2005, Polsky 2004).

Although we found undisturbed habitat conversion in each part of our study area, it was not uniform in distribution. Most of the conversion during our analysis took place in the northwestern and midwestern portions of eastern South Dakota. According to NRCS, these areas are labeled based on ecoregion level as the Northwestern and Northern Glaciated Plains (Figures 2.1 and 2.17). Other research has confirmed our results that land use change can be reasonably predictive based on specific ecoregions. Ecoregion boundaries can promote or impede certain land use changes (Gallant et al. 2004). Land use change is dependent on several variables, such as smaller patches of ground with similar topography and soil characteristics (Gallant et al. 2004). A related study using GIS and other remote sensing techniques found similar results. When analyzing undisturbed prairie to cropland conversion or deforestation, patches of high conversion were found in specific ecoregions that may be more conducive for farming or ranching as well (Hailemariam et al. 2016). These ecoregion-specific changes are generally related to the net monetary gain that may be achieved when converting undisturbed lands into cropland. The Northwestern and Northern Glaciated Plains showed higher levels of land use change in areas where marginal cropland was economically greater (Auch et al. 2011). This agrees with other research that land use change may be dependent on commodity prices in each region (Rashford et al. 2011).

We found most of our converted acres, nearly 60%, in the Northwestern and Northern Glaciated Plains (Figure 2.2). We also found evidence that the percent of Potentially Undisturbed Land decreased at higher rates in these ecoregions (Figure 2.6). NRCS-derived major land resource areas (MLRA) look at the composition of specific ecoregion vegetation and soil. They also determine slope grade and susceptibility to erosion. Some land use changes may be contributed based on weather variability in the ecoregion as well (Auch et al. 2011). These characteristics are key to understanding an ecoregion's susceptibility to be converted for residential or agricultural uses. The vegetation composition of several MLRAs located in the Northwestern Glaciated Plain is 85-90% grasses or grass-like plants, 7% forbs, and 3% shrubs (USDA: NRCS Major Land Resource Areas 2006). While ecoregions in the north and southeast have 75-80% grasses or grass-like plants, 10% forbs, and 8% shrubs (USDA: NRCS Major Land Resource Areas 2006). This may indicate once again that the trend we see in Northwestern Glaciated Plains conversion is due to its conduciveness to farming and availability of marginal undisturbed prairie (Hailemariam et al. 2016; Gallant et al. 2004). We may also reasonably assume that this intensely converted ecoregion is more financially beneficial to current producers than other areas with undisturbed prairie and woodland.

Renewable energy resources have begun to scatter the landscape in the last few decades. Renewable energy comes in many forms: wind power, solar power, bioenergy (organic matter burned as a fuel) and hydroelectric. During this research we created a data layer that located and quantified new wind turbine expansion across eastern South Dakota post 2012 (Figures 2.9 and 2.10). Specifically, wind turbines can have negative impacts on upland avian species: passerines and ground nesting birds (Leddy et al. 1999). Similarly, passerines and ground nesting birds tend to avoid areas of nesting habitat that are within 80 meters of wind turbines (Leddy et al. 1999). Therefore, renewable energy can have direct effects on upland game and passerine undisturbed prairie habitats. Access roads and concrete bases are classic sources of conversion and were removed from the PUDL layer. Most wind turbine expansion in our study area was on already converted cropland. However, there were occurrences where new wind turbines were built on or adjacent to potentially undisturbed prairie. Future research into the effects of these newly developed wind turbines across eastern South Dakota should be conducted.

With trends in crop commodity prices, government subsidies, and climate the conversion of undisturbed habitats will continue at current rates, if not increase (Rashford et al. 2011; Feng et al. 2013; Polsky 2004). Land managers should target these government approved subsidies and aim to take a more conservation friendly approach. Crop commodity prices are difficult to mitigate in their ability to manipulate cropland and undisturbed prairie numbers; however, there is potential for reducing conversion based on commodity prices. Before 1996, producers were prevented from expanding corn, soybeans, and other crops and received farm program payments instead (Claassen 2012). This management strategy, or one similar, could be used in the future to protect undisturbed land from its most detrimental forces. The newly developing biofuel technology in the late 2000s also led to large amounts of undisturbed prairie conversion. Currently, cropland expansion may be outpacing governmental policies that aim to restrict conversion (Lark et al. 2015). However, modifying Sodsaver and other bills may decelerate cropland expansion before it’s too late (Lark et al. 2015).

If current trends in the rate of conversion of undisturbed habitats continue, land managers may struggle to maintain and produce sustainable habitats for wildlife, fish, and humans alike. Many eastern South Dakota counties have already approached a tipping point in sustainability due to land use change (Joshi et al. 2019). Our Analysis of land use in eastern South Dakota resulted in the finding of 56,156 hectares (139,766 acres) of undisturbed land conversion between 2012-2021. Most often this conversion was due to cropland expansion; however, housing developments and renewable energy attributed to conversion as well. Any added conversion to an already susceptible ecosystem will produce negative outcomes in biodiversity across the Northern Great Plains (Warner 1994; Ribic 2009; Nichols 1995). Results from this research solidify the need for undisturbed habitat protection. Dwindling amounts of truly unbroken habitat remain and they will likely face future conversion pressure.

Some error may exist throughout our research when attempting to identify small parcels of conversion, termed as 'field creep'. Field creep is the small scale expansion of cultivated cropland into undisturbed land. Often, this expansion is seen continuing in sequential years. In some cases, this error took place when Bauman et al. 2016 originally mapped at 1:8000 scale and the field edges at ground level were slightly inaccurate. So, sometimes we labeled it as truly field expansion or field creep. Other times it was interpreted as field expansion and was not and therefore resulted in a false positive. This type one error could have only inflated our numbers; however, this was likely minimal.

Even though error exists with subjectivity and scaling issues it does not exist in the LiDAR data analysis. LiDAR conversion can't be refuted, and it happened where the technology detected it. Likewise, our areas (Northwestern and Northern Glaciated Plains) and patterns of new conversion fit well with other research in the Missouri Coteau region. Ultimately, even though some error exists it may not be as important to the big picture of conversion as we think. LiDAR backs up our results, proving exact locations of new conversion throughout the study area. It is likely that the type one error of conversion is negligible when determining the percent land base of undisturbed land remaining in eastern South Dakota.

Future Research

This project was built off the previous Potentially Undisturbed Land layer made by SDSU Extension. By quantifying the undisturbed land in this previous land inventory project, we were able to calculate a rate of change using similar methodologies and GIS software. Through this methodology a new Potentially Undisturbed Land layer (PUDL) was systematically updated based on new NAIP imagery years: 2014, 2016, 2018, 2021 (Table 2.5). Currently, this PUDL layer reflects the most updated land use throughout eastern South Dakota. Thus, establishing a new baseline PUDL layer for similar future research. A recommendation should be made to research the rate of conversion in future years to determine a more accurate rate on undisturbed lands and whether it is increasing or decreasing. Future projects may look to use LiDAR to assess new conversion across the state, instead of NAIP imagery. The irrefutable nature of LiDAR along with machine learning capabilities of this type of data may accelerate future land use research. Unfortunately, the temporal aspect of this research cannot precisely predict conversion until it has already happened. However, we can reasonably assume the rate of conversion will continue to exist at levels found in this project.

Understanding the current rate of change of Potentially Undisturbed Land in eastern South Dakota may lead to legislation to merit its protection. From this research, policy makers will have the ability to make more informed decisions on land use. The protection of a natural resource usually begins with evidence of continued depletion due to a specific cause. This research provides evidence of native habitat depletion due to specific anthropogenic actions (e.g., cultivated cropland).

TABLES

Table 2.1 LiDAR analysis statistics. Total areas (LiDAR data hectares Analyzed), total polygons (Polygons), overall polygon size (Polygon Size (hectares)), total area converted (Hectares converted in LiDAR Analysis), and percent of hectares that were converted in correlation with total county hectares reviewed during LiDAR analysis (Percent of hectares converted in LiDAR data analysis).

County	LiDAR data hectares Analyzed	Polygons	Polygon Size (hectares)	Hectares converted in LiDAR Analysis	Percent of hectares converted in LiDAR data analysis
Aurora	5,141	1,199	4.29	365	7.12
Beadle	4,928	1,022	4.82	324	6.58
Bon Homme	1,050	498	2.10	113	10.82
Brookings	1,652	482	3.44	60	3.66
Brown	2,808	439	6.39	373	13.31
Brule	2,371	381	6.23	196	8.29
Buffalo	1,096	186	5.91	166	15.21
Campbell	1,515	597	2.55	121	8.02
Charles Mix	3,396	1,034	3.28	319	9.40
Clark	4,955	973	5.10	640	12.92
Clay	411	188	2.19	19	4.71
Codington	2,223	598	3.72	223	10.04
Davison	506	147	3.44	74	14.78
Day	4,319	857	5.06	107	2.48
Deuel	4,866	736	6.60	262	5.40
Douglas	761	374	2.02	64	8.51
Edmunds	7,342	1,139	6.43	786	10.71
Faulk	12,735	1,138	11.21	626	4.92
Grant	2,829	669	4.25	106	3.75
Hamlin	654	257	2.55	21	3.34
Hand	10,655	608	17.52	1,135	10.65
Hanson	105	38	2.75	18	17.95
Hughes	2,494	500	4.98	848	34.02
Hutchinson	312	105	2.99	39	12.57
Hyde	15,878	1,636	9.71	1,134	7.15
Jerauld	3,586	674	5.30	261	7.29
Kingsbury	5,618	1,023	5.50	278	4.95
Lake	1,058	460	2.31	73	6.91

Lincoln	12	7	1.86	0.19	1.44
Marshall	6,996	803	8.70	211	3.03
McCook	1,065	390	2.71	49	4.65
McPherson	20,956	2,655	7.89	2,174	10.38
Miner	2,387	692	3.44	125	5.24
Minnehaha	1,041	378	2.75	142	13.64
Moody	2,712	788	3.44	263	9.72
Potter	4,261	664	6.43	577	13.56
Roberts	8,492	1,512	5.63	299	3.53
Sanborn	440	85	5.18	6.8	1.56
Spink	1,233	311	3.97	70	5.68
Sully	4,905	552	8.90	1,343	27.40
Turner	905	242	3.72	169	18.73
Union	196	94	2.10	25	13.18
Walworth	4,594	1,076	4.29	261	5.68
Yankton	910	469	1.94	71	7.82
Average:	3,781	651	4.90	330	9.30
Total:	166,388	2,8676	215.62	14,559	

Table 2.2 Disturbance categories with land use type examples often scene during the review of Potentially Undisturbed Land and LiDAR data analysis.

Disturbance Category	
Agricultural Disturbance or Cultivation	cultivated cropland former cropland that is now flooded food plots tree plantings drainage ditches or tiling farm sites: feedlots, windbreaks, animal enclosures Acute animal feeding operations
Residential Conversion	Municipal housing developments adjacent building sites and rural homesteads golf courses driveways racetracks sporting infrastructure: fields, grandstands, etc.

	other private or municipal buildings: schools, churches, cemeteries
Industrial Disturbance	
	Roads: highway, parking lots railways digging operations: mining, gravel, and sand pits renewable energy: wind turbines, access roads, solar Industrial buildings: power plants

Table 2.3 Review of Potentially Undisturbed Land statistics. Total hectares per county that were analyzed during the project (Total Hectares Analyzed), Total polygons within each county that were analyzed (Polygons Analyzed), Total hectares that were converted from 'potentially' undisturbed lands (PUDL) per county (Hectares converted (2012-2021), and the percentage of the total hectares that were converted during this step (Percent of Analyzed hectares converted).

County	Total Hectares Analyzed	Polygons Analyzed	Hectares converted (2012-2021)	Percent of Analyzed Hectares converted
Aurora	50623	2259	1006	1.99
Beadle	70484	4285	2325	3.30
Bon Homme	26201	3017	357	1.36
Brookings	29478	3921	843	2.86
Brown	59414	4651	2700	4.54
Brule	69284	3433	1622	2.34
Buffalo	75239	1765	357	0.47
Campbell	70559	2963	502	0.71
Charles Mix	76706	5975	872	1.14
Clark	41779	5867	1374	3.29
Clay	6675	1411	124	1.86
Codington	29759	3746	1042	3.50
Davison	16654	1334	573	3.44
Day	43984	8699	1289	2.93
Deuel	39762	4430	588	1.48

Douglas	17669	1687	684	3.87
Edmunds	72779	4169	1811	2.49
Faulk	70054	3688	1555	2.22
Grant	40535	3635	750	1.85
Hamlin	13935	2284	565	4.06
Hand	126684	3641	2625	2.07
Hanson	16490	1407	552	3.34
Hughes	65288	2298	783	1.20
Hutchinson	30161	3272	883	2.93
Hyde	96464	2139	1771	1.84
Jerauld	48715	2157	1015	2.08
Kingsbury	25808	4151	873	3.38
Lake	12642	2628	338	2.67
Lincoln	11021	2303	287	2.61
Marshall	57173	5418	663	1.16
McCook	17234	2242	392	2.27
McPherson	112429	3201	1199	1.07
Miner	25864	2263	615	2.38
Minnehaha	22751	4496	1444	6.35
Moody	14929	3435	552	3.70
Potter	63967	2268	499	0.78
Roberts	68614	7090	912	1.33
Sanborn	38373	2405	953	2.48
Spink	54900	3794	2142	3.90
Sully	51182	1820	930	1.82
Turner	13573	2355	431	3.18
Union	8443	1651	348	4.12
Walworth	64000	2531	294	0.46
Yankton	24310	3678	563	2.32
Total:	**1992590**	**145862**	42002	
Average:	**45286**	**3315**	955	**2.48**

Table 2.4 Eastern South Dakota wind turbines in each county in given years of detection. The increase in wind turbines from the start of the project until 2021 is highlighted in green.

County	Beginning Wind Turbines (2012)	Beginning Wind Turbines (2018)	Ending Wind Turbines (2021)	Increase in Wind Turbines 2012-2021
Aurora	53	53	62	9
Beadle	1	1	1	0
Bon Homme	0	8	42	42
Brookings	150	139	178	28
Brown	1	1	1	0
Brule	50	59	59	9
Buffalo	0	0	0	0
Campbell	0	55	55	55
Charles Mix	0	20	40	40
Clark	0	11	81	81
Clay	0	0	0	0
Codington	0	0	137	137
Davison	0	0	0	0
Day	67	68	68	1
Deuel	24	24	218	194
Douglas	0	0	0	0
Edmunds	0	0	0	0
Faulk	0	0	0	0
Grant	0	0	60	60
Hamlin	0	0	0	0
Hand	10	10	10	0
Hanson	0	0	0	0
Hughes	0	0	0	0
Hutchinson	0	2	21	21
Hyde	27	27	91	64
Jerauld	89	89	89	0
Kingsbury	0	0	0	0
Lake	0	0	0	0
Lincoln	0	0	0	0
Marshall	0	0	0	0
McCook	0	0	0	0
McPherson	59	59	59	0
Miner	0	0	0	0
Minnehaha	0	0	0	0
Moody	0	0	0	0
Potter	0	0	0	0
Roberts	0	0	15	15
Sanborn	0	0	0	0
Spink	0	0	0	0
Sully	0	0	0	0

Turner	0	0	0	0
Union	0	0	0	0
Walworth	0	0	0	0
Yankton	0	0	0	0
Total:	531	**626**	**1287**	**756**
Average:	12.06	14.22	29.25	**17.18**

Table 2.5 Change in Potentially Undisturbed Lands in individual counties of eastern South Dakota between 2012 and 2021.

County	Total County Hectares	Total PUDL hectares (2012)	Total PUDL hectares (2018)	Total PUDL hectares (2021)	Percent Change in PUDL (2012-2021)
Aurora	184,400	50,623	50,000	49,512	-2.19
Beadle	327,351	70,485	68,992	68,019	-3.5
Bon Homme	150,470	26,201	25,957	25,815	-1.47
Brookings	208,423	29,478	28,887	28,609	-2.95
Brown	448,046	59,414	57,454	56,612	-4.72
Brule	219,064	69,285	68,069	67,624	-2.4
Buffalo	126,143	75,239	75,068	74,871	-0.49
Campbell	199,646	70,559	70,179	70,045	-0.73
Charles Mix	297,667	76,706	76,126	75,794	-1.19
Clark	250,515	41,770	40,747	40,024	-4.18
Clay	107,910	6,675	6,606	6,541	-2.01
Codington	185,665	29,759	28,973	28,671	-3.66
Davison	113,047	16,654	16,258	16,073	-3.49
Day	282,476	43,984	42,991	42,667	-2.99
Deuel	164,914	39,763	39,393	39,134	-1.58
Douglas	112,356	17,669	17,233	16,977	-3.92
Edmunds	297,912	72,780	71,871	70,863	-2.63
Faulk	260,264	70,054	69,273	68,415	-2.34
Grant	178,159	40,536	39,989	39,746	-1.95
Hamlin	139,289	13,935	13,518	13,353	-4.18
Hand	372,712	126,684	124,949	123,638	-2.4
Hanson	112,764	16,490	16,139	15,938	-3.34
Hughes	207,142	65,288	64,939	64,393	-1.37
Hutchinson	210,805	30,161	29,525	29,273	-2.94

Hyde	224,272	96,464	95,702	94,431	-2.11
Jerauld	137,841	48,715	48,129	47,655	-2.18
Kingsbury	223,589	25,808	25,055	24,897	-3.53
Lake	148,901	12,642	12,380	12,283	-2.84
Lincoln	149,859	11,021	10,828	10,734	-2.61
Marshall	229,259	57,173	56,750	56,425	-1.31
McCook	149,425	17,234	17,007	16,826	-2.37
McPherson	298,088	112,429	111,587	110,576	-1.65
Miner	148,069	25,864	25,376	25,183	-2.64
Minnehaha	210,738	22,752	21,744	21,250	-6.6
Moody	134,970	14,929	14,569	14,326	-4.04
Potter	232,535	63,967	63,672	63,281	-1.07
Roberts	294,002	68,615	67,882	67,601	-1.48
Sanborn	147,584	38,373	37,707	37,414	-2.5
Spink	390,811	54,900	53,432	52,756	-3.91
Sully	277,053	51,183	50,740	50,077	-2.16
Turner	159,878	13,573	13,330	13,109	-3.42
Union	120,985	8,444	8,229	8,081	-4.3
Walworth	192,626	64,000	63,810	63,694	-0.48
Yankton	137,201	24,310	23,867	23,733	-2.37
Total:	9,164,834	**1,992,590**	**1,964,933**	**1,946,937**	
Average:	208,291	45,286	44,658	44,249	**-2.64**

FIGURES

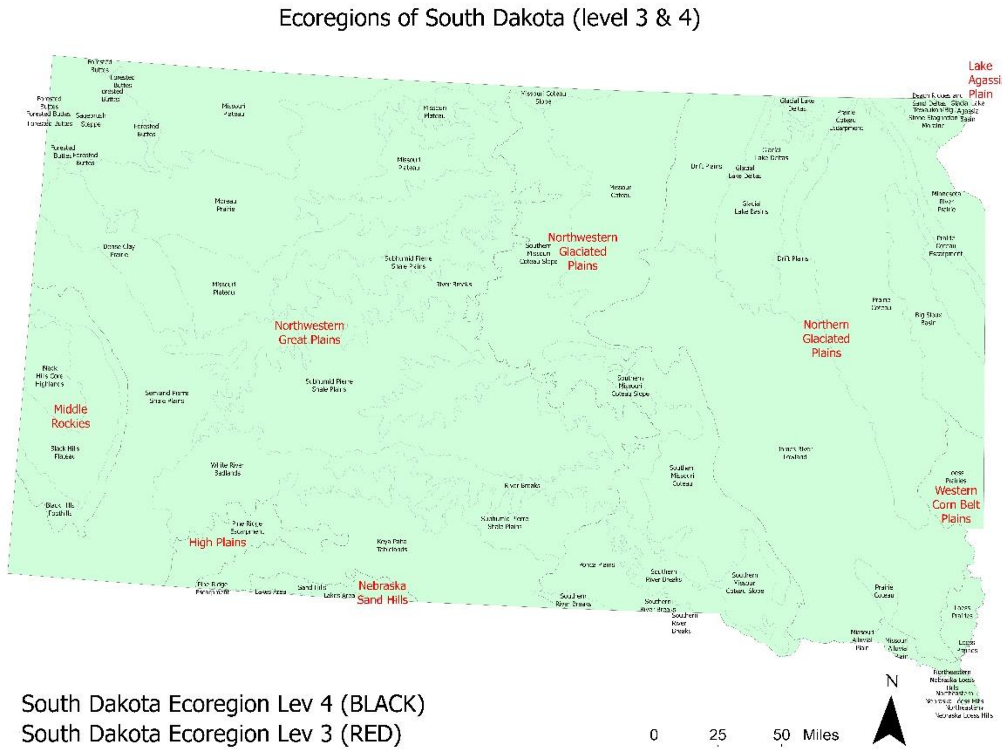

Figure 2.1 Individual ecoregions within the state of South Dakota. Level 3 ecoregions are highlighted with red text and a darker outline. Level 4 ecoregions are highlighted with black text and lighter outlines.

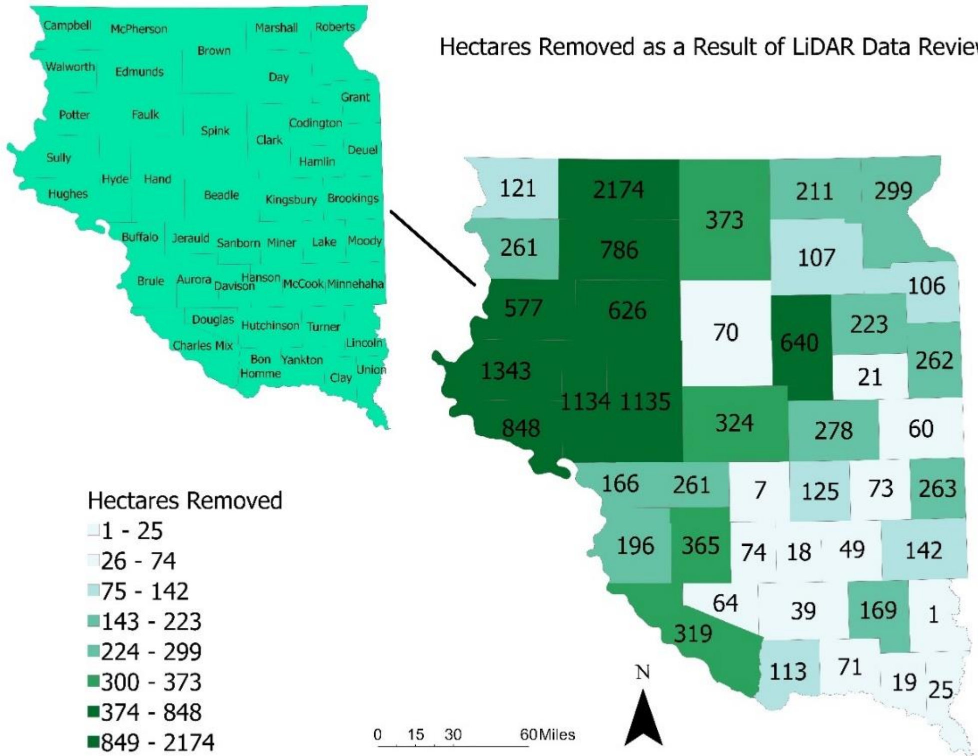

Figure 2.2 Map of the study area with corresponding hectares that were converted during the LiDAR analysis.

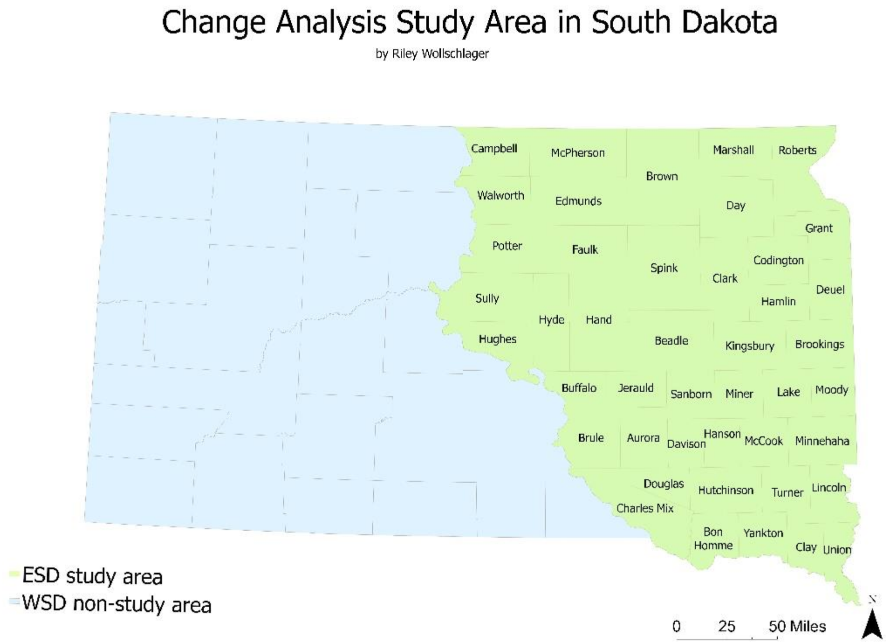

Figure 2.3 Project study area. Highlighted in green and labeled is the study area for *Quantitative Change Analysis of Undisturbed Lands in eastern South Dakota: 2012-2021*

Figure 2.4 Example of LiDAR detected disturbance data we reviewed. We found additive disturbance post 2012 using NAIP imagery and the SDSU LiDAR dataset. This type of conversion was included in our total land use change 2012-2021.

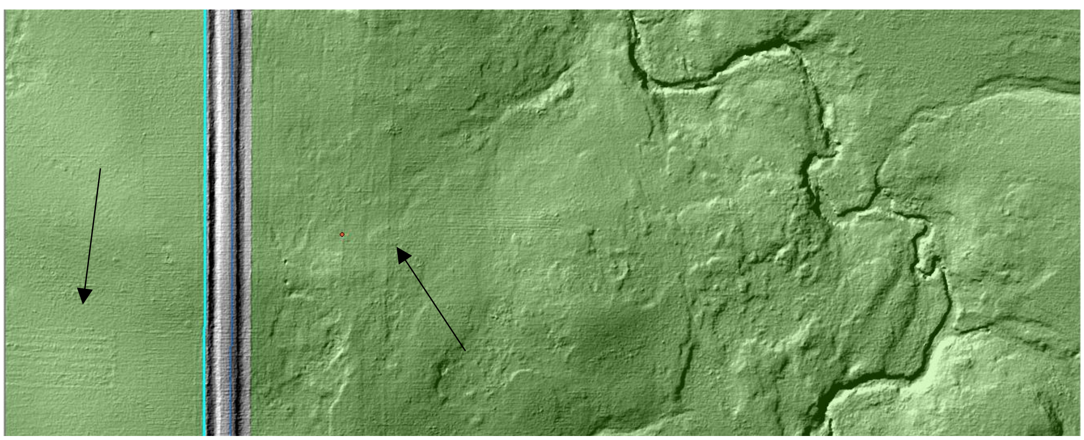

Figure 2.5 Example of LiDAR technology with indications of LiDAR detected disturbance (parallel lines) found by technicians from previous SDSU projects.

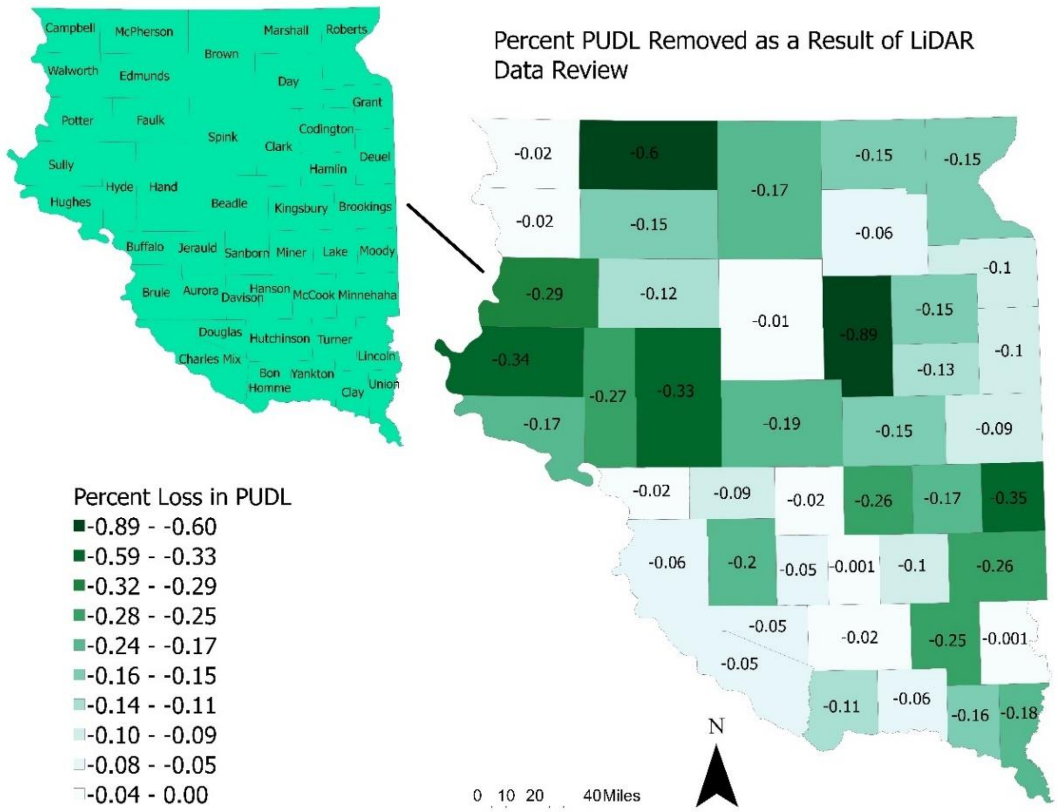

Figure 2.6 Map showing the percent of Potentially Undisturbed Land converted during LiDAR analysis.

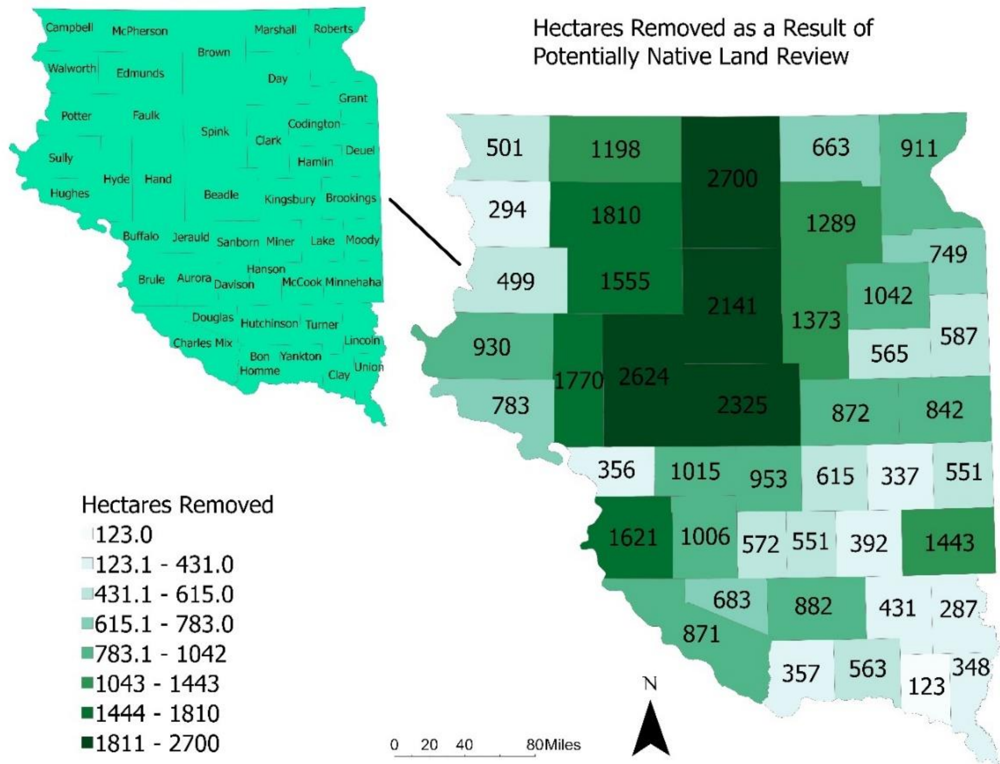

Figure 2.7 Map of the study area with corresponding hectares that were converted during the review of Potentially Undisturbed Land using NAIP imagery.

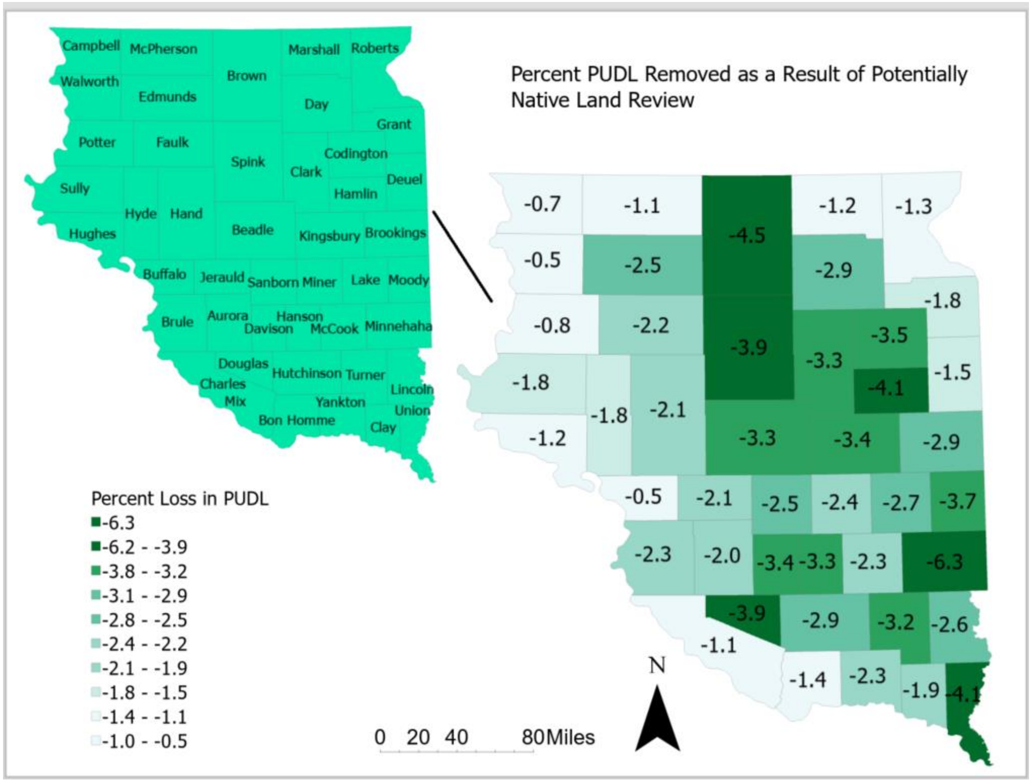

Figure 2.8 Map showing the percentage of Potentially Undisturbed Land that was converted using NAIP imagery.

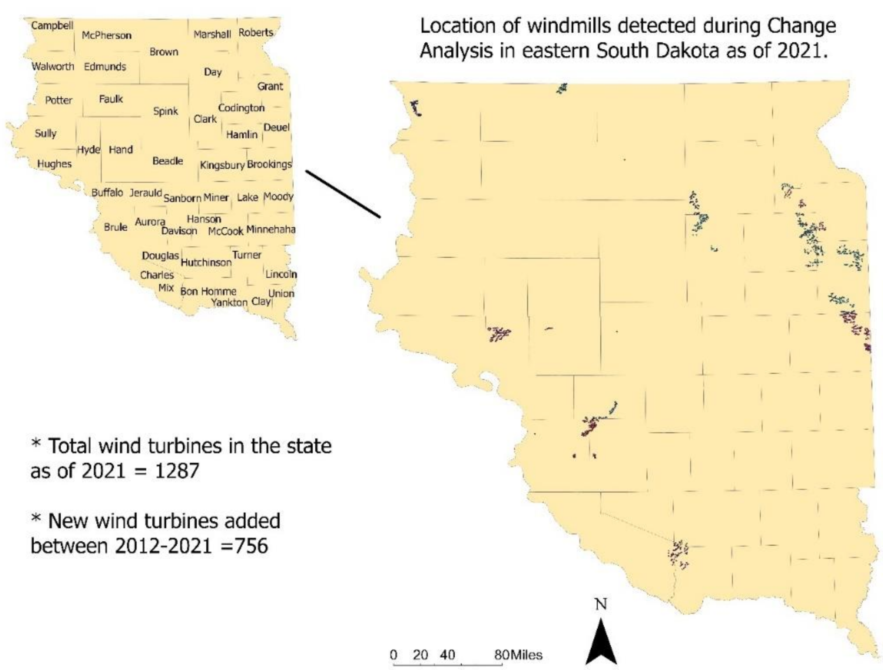

Figure 2.9 Map of easern South Dakota counties and corresponding wind turbine locations that were detected using NAIP imagery during the review of Potentially Undisturbed Land.

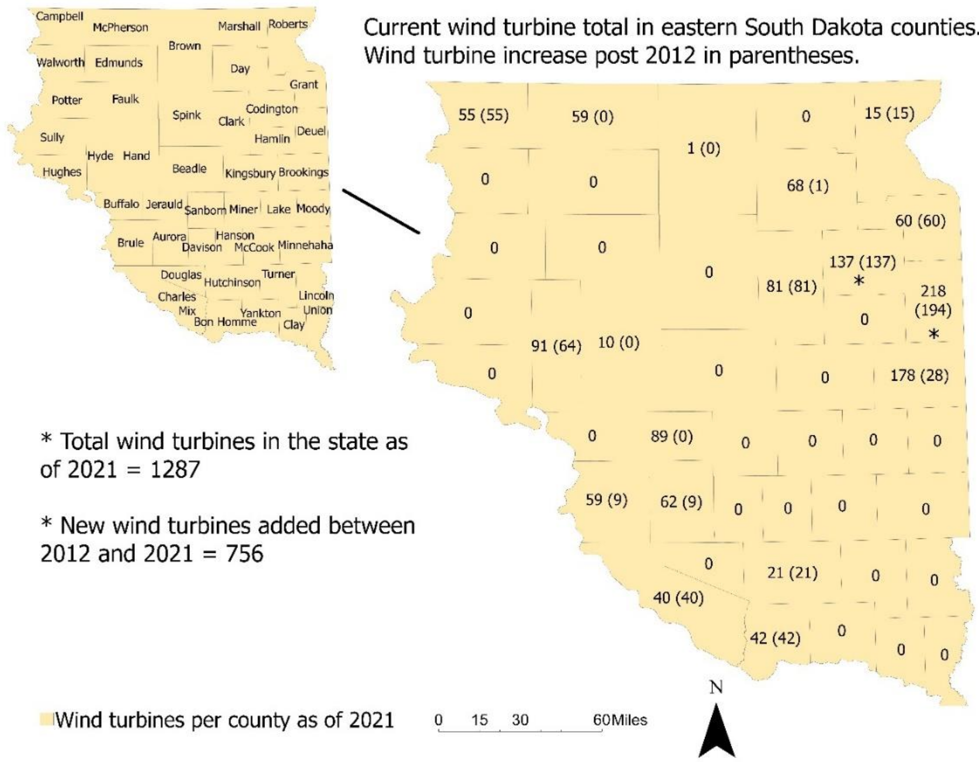

Figure 2.10 Map of eastern South Dakota counties and correpsonding wind turbine totals. In parenthensees are wind turbines detected during the review of Potentially Undisturbed Land and represent turbines built post 2012.

Figure 2.11 Example of renewable energy (wind turbine) encroachment into Potentially Undisturbed Land.

Figure 2.12 Example of cropland conversion within our study site and Potentially Undisturbed Land layer.

Figure 2.13 Example of housing development within our study site and Potentially Undisturbed Land layer.

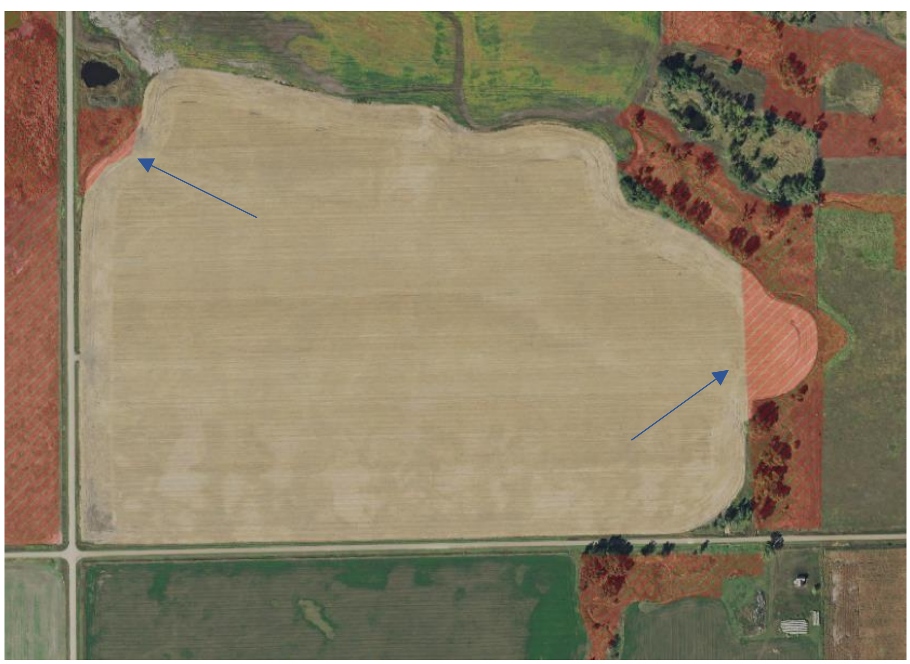

Figure 2.14 Example of field creep within our study site. Red hashed layer represents the Potentially Undisturbed Land (PUDL) layer in 2012. Overlayed is the National Agricultural Imagery Program (NAIP) image from 2021. Conversion of native prairie is located by blue arrows.

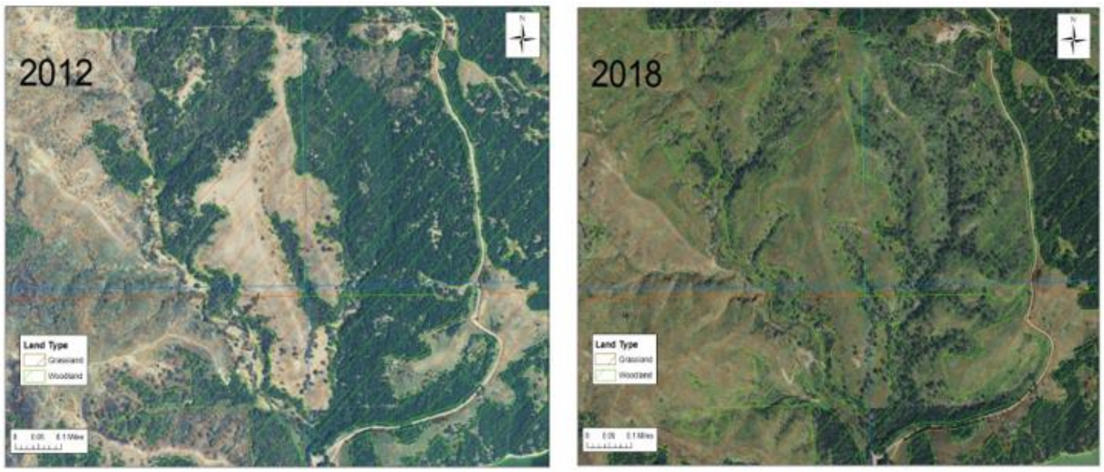

Figure 2.15 Example of vegetation composition change (woodland to grassland) within our study site.

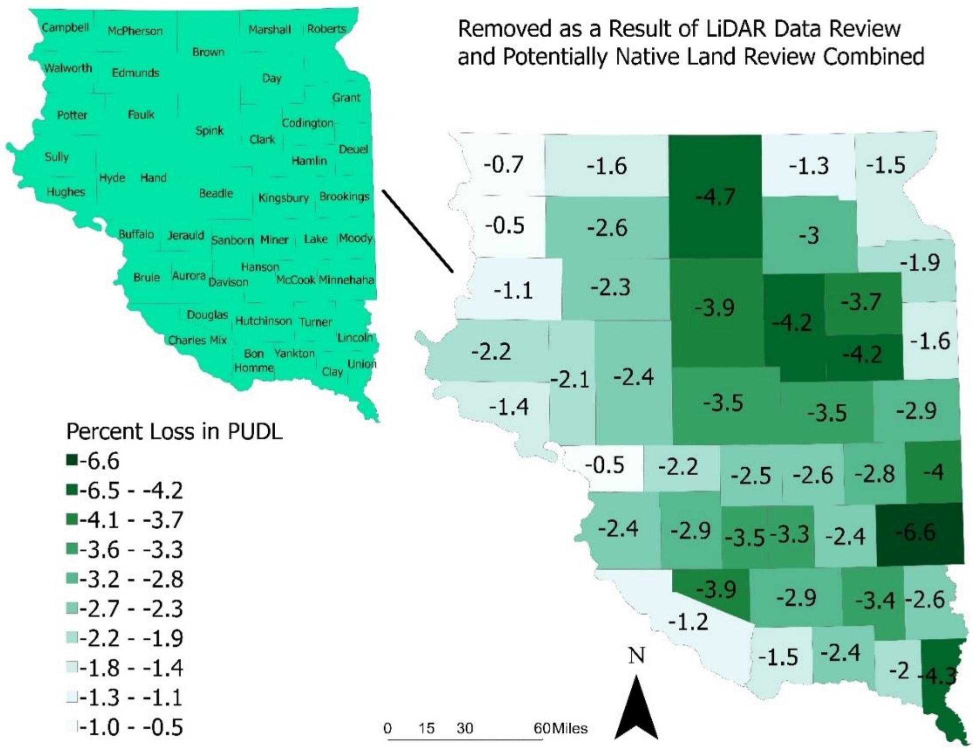

Figure 2.16 Map of the study area with the percent of Potentially Undisturbed Land that were converted based on the review of potentially native land and LiDAR-based data.

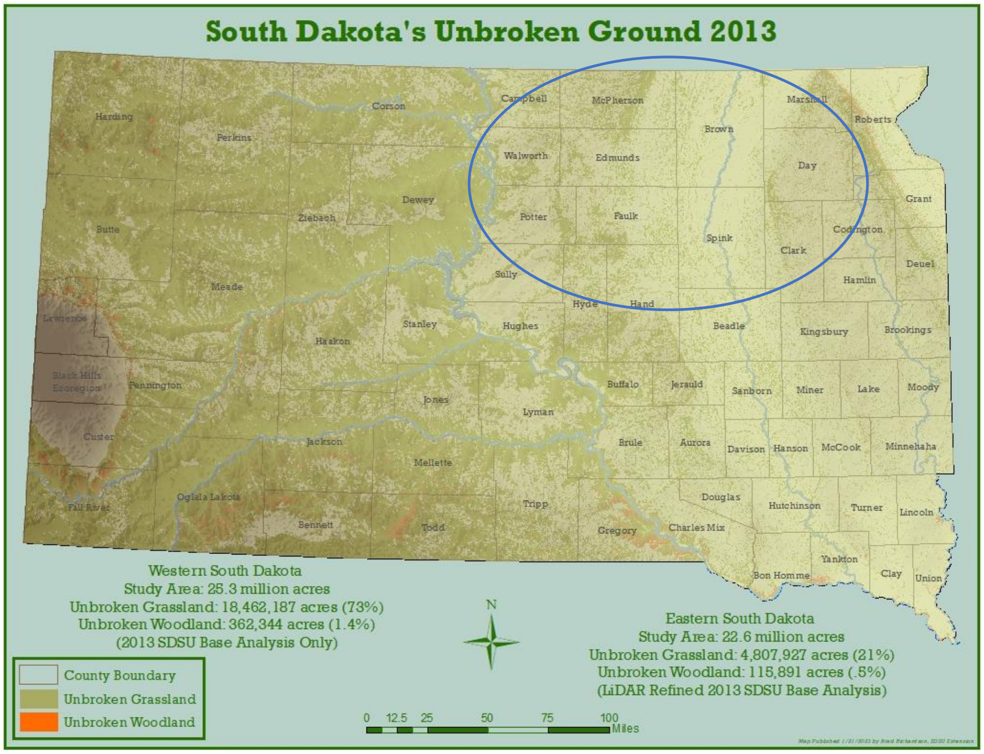

Figure 2.17 Map of eastern South Dakota that shows the undisturbed (native) habitat remaining. Areas with higher densities of undisturbed grassland are shaded a light green. Areas where we found the highest rates of conversion are circled in blue.

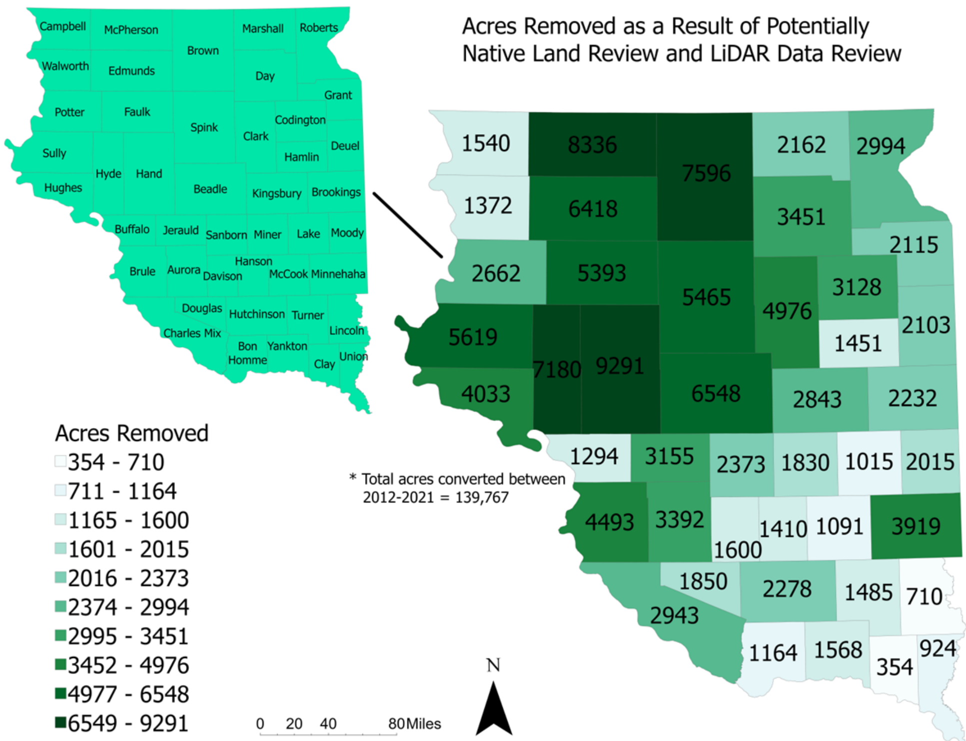

Figure 2.18 Map of the study area and corresponding acres that were converted during the analysis of step one (LiDAR data review) and step two (review of Potentially Undisturbed Land).

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