RECOVERY OF PHYSICAL AND BIOLOGICAL SOIL PROPERTIES AND VEGETATION ON RECLAIMED OIL WELL PADS IN WESTERN NORTH DAKOTA

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The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

MASTER OF SCIENCE

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ABSTRACT

Since 2000, the oil industry in North Dakota has grown to become the fifth largest oil producing and the second largest oil production and reserve state in the country. This increase in growth and activity has contributed to large amounts of ecological disturbance and degradation in western North Dakota. Oil companies are required to complete reclamations on disturbed and degraded lands once well pad activity ceases at a site. It is unclear how successful these reclamations are though as studies have found that significant ecological recovery can take multiple decades. This study assessed the recovery of soil properties and vegetation establishment on reclamations varying in age up to 37 years. It was determined that, at least in western North Dakota, soil microbes in reclaimed areas reflect those of undisturbed areas more over time and that time does not appear to have much effect on vegetation presence in reclaimed areas.

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1. INTRODUCTION

In 2020, the industries of mining, quarrying, and extraction of oil and natural gases contributed the greatest amount to North Dakota's gross domestic product, accounting for the largest proportion of human impacts on public and private lands in the state (Statista, 2020). As of August 2021, North Dakota was listed as the fifth largest crude oil producing state in the country with 39,001 drilled oil wells (US EIA, 2021a). Though crude oil was discovered in 1951, the industry did not establish a foothold in the state until the early 2000's. This was due, in large part, to the advent of two new drilling techniques, horizontal drilling and hydraulic fracking (US EIA, 2021a). The application of these two techniques enabled greater exploration of the Bakken Shale formation and aided in the discovery of large crude oil reserves in western North Dakota. The United States Geological Survey estimated that there are up to 11.4 billion barrels of "undiscovered and technically retrievable" crude oil within the Bakken Shale formation, a majority of which is located beneath western North Dakota (US EIA, 2021). Since the early 2000's, North Dakota's oil industry has grown to become the second largest crude oil producing and proven crude oil reserves containing state in the country (US EIA, 2021a).

This increase in oil well activities over the past two decades has led to greater amounts of disturbed lands and regional ecosystems. These disturbances impact ecosystems shortly after the approval of a surface lease agreement by state officials and private landowners as oil companies begin construction of the well pad. This process consists of leveling the well pad site and constructing any needed access roads as well as removing and storing topsoil. The topsoil that is removed and stored is generally no deeper than the top twelve inches of the soil (CSUR, 2021). Referred to as "stockpiling" (Strohmayer et al., 1999), topsoil is stored off site in piles that are closely monitored for potential erosion and other damages, oftentimes being covered by landscape fabric or vegetation as a protective measure for the duration of the surface lease (Strohmayer et al., 1999). The soil disturbances are responsible for some of the longer lasting impacts that oil and natural gas extraction activities have on ecosystems (Janz et al., 2019).

The removal and storage of topsoil is mandatory in the site preparation process as this soil will be re-spread during reclamation following the plugging of the oil well. Returning the topsoil is intended to promote the return of the fertility and quality of the soil back to pre-disturbance levels. Reclamation regulations in North Dakota also require the application of a native grass and plant seed mix over the disturbed areas that were natural rangelands prior to disturbance in order to re-establish native vegetation and ecological functions (ND State Land Dept., 2021). The North Dakota Department of Trust Lands specifies the mixture of native grass seed that is applied during reclamation (Table 1).

Table 1. University and school lands seed mixture specifications**.** North Dakota Department of Trust Lands seeding specification for reclamation projects in North Dakota. Complete details can be found in Appendix C. (ND Dept. of Trust Lands, 2022).

Species	**Lbs. (PLS*/acre)**
Western Wheatgrass (*Pascopyrum smithii)*	8
Slender Wheatgrass (*Elymus trachycaulus)*	5
Green Needlegrass (*Nassella viridula)*	4
Side-Oats Grama (*Bouteloua curtipendula)*	2
Total Grass Seed	19

Though there are no federal mandates for well pad reclamation, the Surface Mining Control and Reclamation Act of 1977 is often used as a model by states to guide reclamation regulations.

Upon completion of the reclamation, the oil company submits a report to the state of North Dakota which notifies the North Dakota Department of Trust Lands' Surface and Minerals Management division that the reclamation has been completed and is ready for state inspection (ND Trust Lands, 2021). The Surface and Minerals Management Department sends a team of surface field staff to inspect the site. In rangeland systems these inspectors are checking that the soil layers and landscape terrain have been restored, the site has been seeded, and that a weed-free seed bed has been established (Sedivec et al., 2015). As long as these items have been addressed, the inspectors sign off on the reclamation and the oil company is released from the surface lease.

Vegetation establishment, especially that of native vegetation, is a crucial aspect of well pad reclamation as vegetation is used as an indicator of recovery and site conditions because it serves as a partial reflection of the soil conditions below (Chambers, 1983). This is due to the important services that vegetation provides to the physical, chemical, and biological properties of the soil. Vegetation aids in topsoil retention, slows the flow rate of overland runoff water, increases infiltration into the soil profile, reduces water loss due to evaporation and provides nutrients via organic matter decomposition and nutrient exchange between the roots and soil (Bradshaw, 2000).

All of these services provided by vegetation lay the foundation for the successful recovery of the soil, primarily the microbial (bacteria and fungi) and the physical (bulk density, water content, etc.) properties. The recovery of the physical soil properties is important for the long-term success of the reclamation and can serve as an indicator for the recovery of the soil microbial community (Dominguez-Haydar et al., 2019). Microbial recovery following a reclamation is important because of the functions that these organisms contribute to the ecosystem. Some examples of this are nitrogen fixation, nutrient cycling, water filtration and storage, the breakdown of organic matter, as well as aiding in the uptake of nutrients and water into roots in return for carbon from plants in the case of mycorrhizal fungi (Ingham, 2021). While these initial surveys do provide information on the beginnings of site recovery, they do not assess soil status nor the recovery of soil properties after well pad activities. Due to soil's importance to the ecosystem, it is not realistic to deem reclamation activities successful without analyzing the recovery of soil properties in the years that follow.

The climate of western North Dakota makes gauging soil conditions below the surface based off of surface level conditions (vegetation and surface soil) difficult. This region of North Dakota is semi-arid, averaging 15 inches of precipitation annually, with widely varying temperatures (average lows ranging between 0^{o} F and 15^{o} F in the winter and average highs ranging between 65^{o} F and 72^{o} F in the summer) throughout the year (Enz et al., 2003). The climate conditions along with the rolling terrain and average wind speeds of 10 to 13 mph (Enz et al., 2003) make crop cultivation difficult, with most landowners opting to utilize their lands as rangeland.

Despite these climatic conditions, there is a diverse mix of native vegetation species found in this region. Much of western North Dakota lies within the "Missouri Slope" ecological region, exhibiting a mixture of western mixed- and short-grass prairies, consisting of roughly twelve grass and fifteen smaller forb species (ND Fish & Game, 2021). Species composition varies throughout the region and depends primarily on site-specific conditions. These varying site conditions could influence species establishment and vegetation composition on reclaimed sites, potentially resulting in different species compositions than those found in the surrounding rangelands (Sedivec et al., 2014). Consequently, while vegetation recovery is an aspect of a successful reclamation, vegetation present in the reclaimed areas may differ from those in the surrounding undisturbed areas.

Understanding how the recovery of soil microbial communities and vegetation establishment are influenced by reclamation activities are important when determining reclamation success. Without knowing if a site continues to exhibit recovery towards undisturbed conditions over time, barring additional disturbances to the area, it is not reasonable to say whether or not a reclamation has been successful. Due to the ever-changing nature of ecosystems and lack of historical records for the conditions of these sites, the success of a reclamation should be determined based on how closely the soil properties and vegetation in the reclaimed areas align with the conditions in the adjacent undisturbed areas.

Despite the abundance of oil well pads and oil activity, no studies have looked at the recovery of soil and vegetation on reclaimed oil well pads in the short- and mixed-grass prairies of western North Dakota. However, insight into how the soil and vegetation may recover in these areas may be gleaned from studies that have been conducted on other energy infrastructure developments such as oil pipelines and mineral mining.

In China, for example, two separate studies found that there was no significant recovery in microbial activity on reclaimed mines in the first 20 years following reclamation but found significant recovery in microbial activity on reclaimed sites older than 20 years when compared to undisturbed areas (Li et al., 2014 and Li et al., 2018). Despite similar conclusions, the objectives and methods used in these studies were different. Li et al. (2018) assessed microbial activity by analyzing soil enzyme activities and determined the diversity of the microbial community via DNA isolation and pyrosequencing rRNA. Whereas Li et al. (2014) utilized PCR-based 454 pyrosequencing to compare the bacterial community in their study area soils.

In North America, three separate studies similarly found that there was no significant recovery in microbial activity on disturbed sites until 20 years following reclamation when compared to undisturbed areas (Avirmed et al., 2014 and Janz et al., 2019). Avirmed et al. (2014) did so by studying the soil organic matter and conceptually divided it into fractions (active and intermediate) based on decomposition kinetics in soils from the sagebrush steppe area of south-central Wyoming. They also analyzed homogenized soil subsamples for total carbon (C) and nitrogen (N) using a Perking Elmer CHNS/O Elemental Analyzer 2400 Series-2. Janz et al. (2019) determined the total organic carbon via dry combustion for agricultural soils in south-central Alberta. The third study conducted a phospholipid fatty acid (PLFA) analysis in soils from the sagebrush of south-central Wyoming and determined that while there were noted improvements in microbial activity on sites older than 20 years, their data suggested that it took greater than 55 years (the limit of their study) to see significant recovery in microbial activity (Gasch et al., 2016). These studies came to similar conclusions about the recovery of soil microbial communities despite variance in study methodologies and locations. It stands to reason that similar delays in the recovery of soil microbial communities will be reflected in this study despite the differences in methodology and location.

Two studies also looked at vegetation presence and how different vegetation may influence soil recovery following reclamation activities. Gasch et al. (2016) studied how the composition of vegetation in reclaimed areas recovered in comparison to undisturbed areas and found that as time progressed since reclamation, the vegetation more closely resembled that of the adjacent undisturbed rangelands, though still showing differences in species composition at the limit of their study (55 years). Li et al. (2014) looked at determining if establishing certain vegetation species in reclaimed areas influenced soil recovery and found that in establishing vegetation from specific families, *Gramineae* and *Leguminosae*, the recovery of soil conditions and bacterial diversity were promoted, resulting in positive impacts on the recovery of soil microbial communities.

In addition to studying the recovery of soil microbes and vegetation on reclaimed sites, several of these studies included bulk density analyses to determine the level of soil compaction within their study sites (Avirmed et al., 2014, Dominguez-Haydar et al., 2019, Gasch et al., 2015). A bulk density analysis, which is measured in weight of dry soil per unit volume, is commonly utilized in soil recovery studies because it can be used as an explanatory variable for the conditions of other soil properties such as the soil water holding capacity, vegetation establishment, and microbial activity (Dominguez-Haydar et al., 2019).

Soil compaction levels can provide insights into how much water is able to infiltrate into and be stored in the soil as well as the likelihood of vegetation establishment on the site because root growth and health is negatively impacted by high levels of soil compaction (USDA-NRCS, 2022). All of these soil characteristics; soil compaction, soil moisture as well as vegetation establishment directly impact the recovery of the soil microbial community. Microbial recovery is dependent on receiving carbon and other nutrients that plants provide to the soil environment via root systems and decomposition in addition to water and oxygen within the soil (Chen et al., 2007). Thus, understanding the impacts that soil compaction can have on the recovery of a reclamation project is important.

Determining the adequacy of current reclamation practices is critical as the world holds a finite amount of oil and oil wells “dry up” every day. This means that oil production will not be able to continue indefinitely and, eventually, all existing well pads will require reclamation.

Research needs to be conducted now to determine how these ecological systems and processes are responding to reclamation over time to ensure greater reclamation success in the future.

In order to understand the long-term recovery of reclaimed areas on oil well pads, soil samples and vegetation assessments need to be conducted on completed reclamations that vary in time since their completion, unless it is possible to track the recovery of a single reclamation over many years. This study was initiated in the early spring of 2021, meaning that assessing the recovery process of an individual reclamation over the course of many years was not a viable option. In order to account for this, a chronosequence design was utilized. This study assessed the long-term recovery of reclaimed oil well pads by analyzing the current soil and vegetation conditions on multiple sites that differ in years since reclamation in an attempt to draw conclusions about reclamation recovery over time. While tracking the recovery of a single reclamation for many years would provide good information on how a particular site is recovering, it does not look at how reclamations recover across larger areas.

By analyzing the current conditions of multiple reclamations over a larger area this study was able to assess recovery trends for reclamations across the landscape. Each of the study sites consists of its own microclimate and is influenced by different internal and external factors that could impact the recovery process. In an attempt to account for these various influences, multiple samples were collected across each study site's reclaimed and undisturbed areas. Within each site, the mean values for all of the soil properties were calculated separately for the reclaimed and undisturbed soil samples. The reclamation and undisturbed area mean values were compared within each site as well as over time in order to assess the differences in soil properties and to identify any trends in recovery over time. By including reclamations of multiple ages in this study and determining mean values for the soil properties at each site, site specific influences are accounted for and minimized.

In this study, the physical and biological soil properties on reclaimed crude oil well pads ranging from 4 to 37 years since reclamation were compared to that of soil collected from adjacent undisturbed rangelands to assess site recovery. Vegetation was surveyed on the oil well pads as well as in the adjacent rangelands in order to compare bare ground percentages and determine differences in vegetation composition, particularly the presence of seed mix and invasive grass species. The objectives of this study were to (1) determine if soil properties recover as time since reclamation increases; (2) assess how long it takes for the reclaimed soil data to reflect the undisturbed soil data; and (3) determine if reclamation influences the growth and presence of vegetation in comparison to the surrounding undisturbed areas.

Fig. 1. Conceptual model of soil and vegetation values within sites. Conceptual model representing the anticipated results for the differences between reclaimed and undisturbed soil properties within each study site. The differences between these areas were anticipated to be different across the study sites, but this is a general overview of the anticipated results. The larger ends of the shapes below the image represent higher values in that area. The "Soil Type" at the bottom indicates that the soil types (Table 3) were expected to be consistent across the entirety of a site (reclaimed and undisturbed areas).

2. METHODS AND MATERIALS

2.1. Field Site Descriptions

This study was conducted on seven reclaimed crude oil well pads in McKenzie County, North Dakota that represented a chronosequence in time since reclamation (4, 7, 12, 18, 25, 31, and 37 years). The site locations were determined using the North Dakota oil and gas GIS map (ND Oil & Gas, 2022) (Fig. 1). These sites were selected due to their proximity to one another, similarities in climate, ecological conditions, and land management practices as well as their proximity to the Bakken Shale formation. All of these sites were owned by the state of North Dakota and administered by the North Dakota Department of Trust Lands. These lands are considered to be “school/university lands” and are held to common reclamation standards, including the use of a state mandated seed mixture (Table 1), and land management activities.

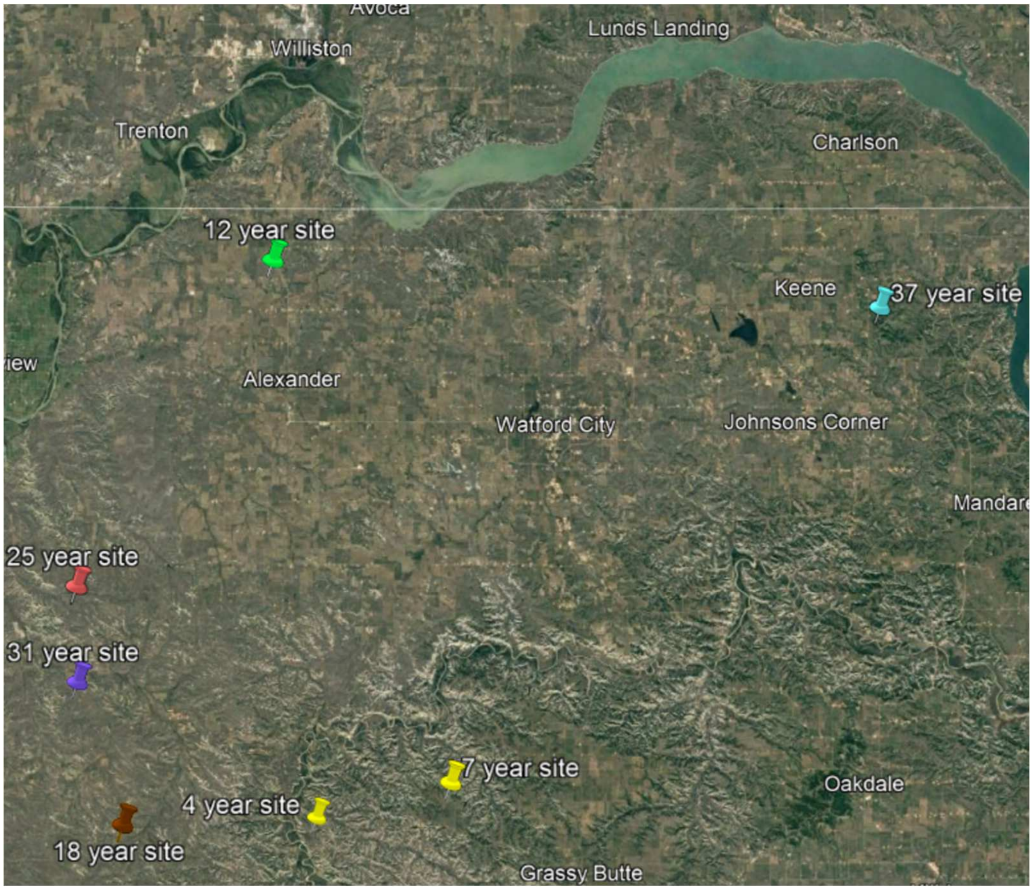

Fig. 2. Map of McKenzie County, ND with study site locations. Map of McKenzie County, ND from Google Earth showing the locations of the seven reclaimed oil well pad study sites ranging in age from 4 to 37 years since reclamation on North Dakota Trust Lands (Google Earth, 2022).

The terrain in this part of the state consists of grasslands and rolling hills as well as canyons with near vertical cliffs along the Little Missouri River. There are varying degrees of slope and geological features which have resulted in differing soil types and profiles throughout the region (Soil Survey Staff, 2022). The variation in terrain and soil types are represented across the reclaimed sites in this study (Table 2).

Table 2. Soil classifications and descriptions for each study site. Soil classifications, slope, and soil type for seven reclaimed crude oil well pads on North Dakota Trust Lands in McKenzie County, North Dakota used for this study (Soil Survey Staff, 2022).

Site	**Soil Classification**	**Slope**	**Soil Type**
4	Rhame-Fleak Complex	9 % to 50%	Sandy Loam
7	Rhame-Chinook	9% to 15%	Fine Sandy Loam
12	Upslope: Niobell-Williams Downslope: Zahl-Cabba-Maschetah Complex	Upslope: 3% to 6% Downslope: 6% to 70%	Upslope: Loam Downslope: Loam/Silt Loam
18	Cherry-Cabba-Brandenburg Complex	9% to 35%	Silt Loam
25	Cherry-Cabba	9% to 45%	Silt Loam
31	Zahl-Williams-Cabba Complex	6% to 9 %	Loam/Clay Loam/Silt Loam
37	Zahl-Cabba-Arikara Complex	9% to 70%	Loam/Silt Loam

2.2. Soil Sampling and Analysis

Field sampling occurred May 16-18, 2022. At each site, soil samples were collected from six locations within each reclaimed area along two transects perpendicular to the slope of the area. For the transect locations, one was located uphill of the oil pump coordinates and the other was located downhill. To determine the locations of the transects and sampling areas, 25 m were measured directly upslope and directly downslope from the oil pump coordinates. From these initial sampling areas, 25 m were then measured and marked in both directions perpendicular to the slope to locate the other sampling points within the study area. A soil sample was collected at each of the locations along the transects from within a 1m^2 area centered on the transect point. The dimensions of each study site were limited to 50 m by 50 m to increase the likelihood that the reclaimed sampling areas would be located within the former well pad boundaries, which have standard dimensions of 100 m by 100 m (CSUR, 2021). Additionally, soil samples were collected along both transects at distances of 75 m from the middle sampling area in both directions as well as an additional 50 m uphill and downhill from the transect sampling points in the surrounding undisturbed areas. The samples taken from the undisturbed areas were used as reference for the reclamation samples (Fig. 2).

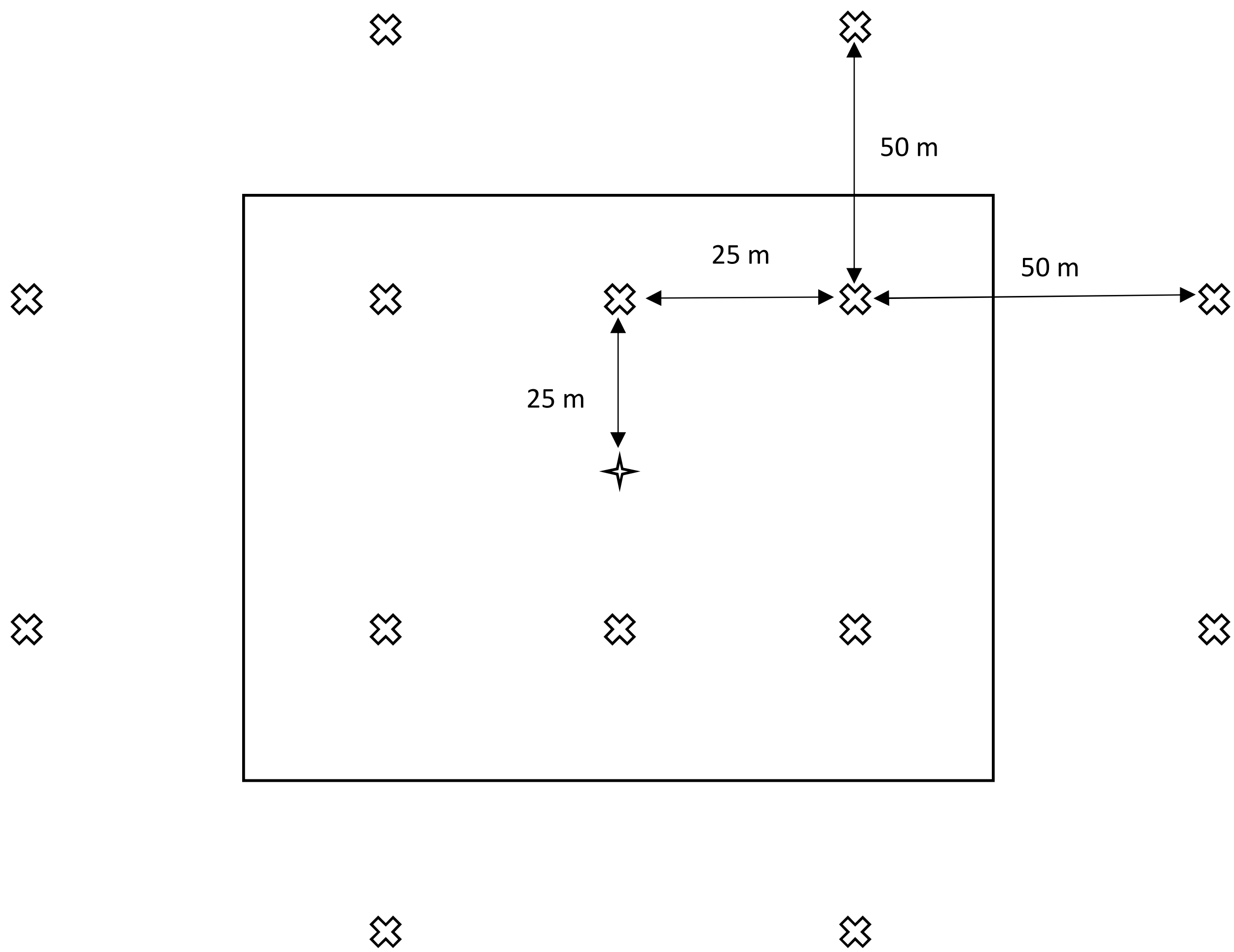

Fig. 3. Sampling design for each study area. Sampling design at each study site- top of the diagram is uphill, bottom of diagram is downhill. The box represents the former well pad site, the x's indicate each of the sampling locations, and the star marks the oil well pump coordinates (from which the sampling area locations were determined).

Soil samples were collected from the top 14 cm using a trench shovel at each of the six 1 m^2 sampling locations within the reclamation areas as well as from the eight undisturbed sampling areas. Each sample was placed in a separate quart sized zip lock bag, filled to between ½ and ¾ its total volume. A second soil sample was collected from each of the sampling areas using a hammer core, which was kept separate from the other soil samples, to determine bulk density. All soil samples were then stored in coolers with ice packs for transport and then refrigerated once in the lab until they were processed. In the lab, the weight of the soil samples and bulk density cores were determined. Once weighed, approximately half of the soil from the sample bags was removed and air dried for 48 to 72 hours while the other half remained in the refrigerator.

2.2.1. Soil Analysis

The soil subsamples were prepared via the same method prior to conducting analyses to determine pH (acidity), electrical conductivity (salinity), and permanganate oxidizable carbon (active carbon). Each of the air-dried soil samples were individually ground and shaken through a 2mm sieve. Soil pH was determined using the methods described by Thomas et al. (1996), electrical conductivity (EC) was determined using the methods described by Rhoades (1996), and permanganate oxidizable carbon (POXC) was analyzed using the methods described by Weil et al. (2003).

Gravimetric water content (GWC, soil moisture) was determined using subsamples collected directly from refrigerated soils. Each subsample was weighed prior to being dried in an oven at 105^{o} C for 24 to 48 hours and then analyzed using the methods described by Gardner et al. (1986). Microbial biomass carbon (MBC, microbial activity) was assessed using subsamples collected from the refrigerated soils and analyzed utilizing a combination of the methods described by Beck et al. (1997), Joergensen et al. (1996), and Vance et al. (1987).

MBC and POXC are indicators of two different types of carbon contained in the soil. MBC is a measure of carbon contained in the living organic matter of the soil, i.e., it is a measure of the soil microbial community (e.g., bacteria and fungi) and utilizes the fraction of carbon produced by the living soil organisms (Thangavel et al., 2019). POXC refers to the carbon contained in the soil that is coming from actively decaying organic matter (e.g., decaying litter, dead microorganisms, etc.) and is available as a food source for the microbial community (Soil Health Nexus, 2022). POXC is also used as an indicator of soil fertility because it provides a measure of the size, or at least potential size, of the microbial community which, in turn, influences soil fertility.

2.2.2. Bulk Density

Bulk density (BD), which is a measure of soil compaction, was determined by calculating the dried soil mass of the soil cores using the GWC values for each soil sample and then dividing this dry soil weight by the volume of the hammer corer cylinder, as described by Blake et al. (1986).

Each one of the soil properties measured in this study that are referred to above play an important role the condition of the soil within a site, as well as the overall ecosystem, and can have an impact on the recovery processes of both the soil environment and vegetation establishment (Table 3).

Table 3. Soil properties, analysis methods, and ecological significance**.** Soil properties included in this study and descriptions of their ecological significance relative to reclamation.

Soil property	**Analysis method**	**Ecological Significance**
BD	Blake et al. (1986)	BD is the measurement of soil compaction. Soil compaction can be used as an indicator for how much space is available in the soil. The higher the BD value, the greater the soil compaction. Greater soil compaction limits the amount of water that can infiltrate and be stored in the soil (as well as air) and hinders root growth and establishment. Greater soil compaction can also hinder the microbial community by limiting the amount of oxygen and water they receive as well as the amount of carbon (and other nutrients) that comes from the breakdown/decay of vegetation and other organic matter, all things that microbes require for life. (USDA-NRCS, 2022).
GWC	Gardner et al. (1986)	GWC is a measure of how much water is stored in the soil at any given time. It is directly influenced by soil compaction (BD) and serves as an indicator for the amount of water that is within the soil that could be used by vegetation and microbes.
EC	Rhoades (1996)	EC is a measure of the salinity of the soil. All living things have a range of tolerance within which they are able to survive. This is important in reclamation recovery assessments because high salinity levels limit the amount and types of vegetation species that are able to grow in the soil and can restrict the populations and activity of the microbial community.
pH	Thomas et al. (1996)	pH is a measure of soil acidity. This soil property is primarily influenced by the presence of vegetation and more specifically the breakdown/decay of organic matter (e.g., vegetation) which contributes H^+ (hydrogen) to the soil environment and increases the acidity. Soils that are too alkaline or too acidic may limit the presence of some plant species and microbes.
MBC	Beck et al. (1997), Joergensen et al. (1996), Vance et al. (1987)	MBC is a measure of the carbon that is within living microbial cells within the soil. This property serves as an indicator of the size of the microbial community, which influences the fertility of the soil.
POXC	Weil et al. (2003)	POXC is a measure of the active carbon within the soil. This property is determined from assessing the amount of carbon within the soil that comes from the easily degradable fraction of organic matter (e.g., vegetation) and serves as an indicator for the potential size of the microbial community as this is their primary food source. It is also used as an indicator for soil fertility as microbial community size and activity plays a major role in soil fertility levels (higher POXC is correlated with greater soil fertility).

2.3. Vegetation Surveys and Analysis

Prior to collecting soil samples, a picture was taken of each of the 14 sampling locations within each study site (Fig. 2) from shoulder height (approximately 1.5 m) using a Canon PowerShot SX620 Digital Camera w/25x Optical Zoom, a method similar to the one used by Gasch et al. (2016). The images were then used to assess the ground cover percentages and cover types for each study site using the "SamplePoint" software (Booth, 2006). To do this, each image was uploaded into the "SamplePoint" software where the ground cover percentages were determined by analyzing 100 different points within each 1 m^2 sampling area image. The cover type data was combined into one set of data for each study site in order to determine the ground cover type and percentages across the entirety of each reclaimed area and then were compared to that of the undisturbed area.

Vegetation samples were collected June 13-14, 2022, at each study site from both the reclaimed and surrounding undisturbed areas. This was done by walking the reclaimed areas in a serpentine pattern across the site and by walking the undisturbed areas in outwardly expanding circles around the reclaimed areas. Vegetation was collected based on appearance (attempted to collected as many different looking vegetation samples as possible), pressed in a textbook, and stored in separate bags until assessment. Vegetation was identified (Sedivec et al., 2011 and Stevens, 1950) when possible or otherwise classified as either a grass, forb, or shrub. The types and the number of species present on the reclamation sites were then compared with those present in the undisturbed areas for each respective study site.

2.4. Statistical Analysis

Soil data were analyzed using R statistical software version 4.2.1 and RStudio (R Core Team, 2022). In order to evaluate if any of the soil properties differed between reclaimed and undisturbed areas within individual sites, soil property values (BD, GWC, EC, pH, MBC, and POXC) were compared using Mann-Whitney U tests to account for the unpaired data between the reclaimed and undisturbed areas. For each study site there were six values from the reclaimed area being tested against eight values from the undisturbed area. The results of the Mann-Whitney U tests are representative of the difference between the soil properties of the reclaimed and undisturbed areas within each study site.

R software (R Core Team, 2022) was also used to conduct regression analyses between the age of the reclamation site (years since reclamation) and the mean values of the response variables (each of the soil properties) collected from the reclaimed and undisturbed areas. The goal of these analyses was to determine how the mean soil property observations related to time since reclamation. This relationship is estimated with the resulting best fit lines and R-squared values which represent how closely the observations vary from the best fit line as well as p-values which determine the statistical significance (α=.05) of the results of the regression analyses. For each property, the best fit line and its equation should allow for the prediction of future soil property values for each site, assuming that the observed trends do not change over time, as well as provide insight into how the reclaimed and undisturbed soil property values compare over time.

3. RESULTS

3.1. Soil Properties

The purpose of the soil sampling and analyses that were conducted in this study were chosen to aid in determining if soil properties recover as time since reclamation increases as well as to assess how long it takes for the reclaimed soil data to reflect the undisturbed soil data. The Mann-Whitney U tests that were conducted to compare soil property data between reclaimed and undisturbed soils resulted in few statistically significant differences (α=0.05) (Table 3). There were statistically significant differences in at least one value for BD within the 12- and 31-year-old sites, GWC within the 12-year-old site, pH within the 4-year-old site, MBC within the 4- and 25-year-old sites, and POXC within the 4-year-old site.

Table 4. Mann-Whitney U test data**.** Statistics (soil property mean values and p-values) for Mann-Whitney U Tests comparing soil properties of reclaimed ® and adjacent undisturbed (U) soil at seven sites. *Bold font denotes that at least one value is statistically significantly different between the reclaimed and undisturbed data(α=0.05).

Mann-Whitney U Tests																		
Years Since Reclamation	Bulk Density			Gravimetric Water Content			Electrical Conductivity			pH			Microbial Biomass Carbon			Permanganate Oxidizable Carbon		
	g/cm^3			g/g			µS/cm			- log[H+]			mg/kg			mg/kg		
	Mean Values			Mean Values			Mean Values			Mean Values			Mean Values			Mean Values		
	R	U	P	R	U	P	R	U	P	R	U	P	R	U	P	R	U	P
4	1.52	1.37	0.08	0.12	0.16	0.26	164.4	171.7	0.57	8.09	7.44	**0.004**	100	307	**0.001**	386	700	**0.01**
7	1.37	1.24	0.12	0.15	0.18	0.19	188.8	197.2	0.95	8.01	7.73	0.16	317	397	0.41	470	750	0.08
12	1.43	1.27	**0.01**	0.2	0.27	**0.04**	307	312.5	1	7.96	7.89	0.65	264	545	0.08	553	793	0.13
18	1.29	1.25	0.39	0.26	0.27	0.61	387.6	304.5	0.14	8.02	7.75	0.23	328	473	0.07	751	738	0.95
25	1.3	1.24	0.75	0.25	0.26	0.7	419	342.2	0.07	7.91	7.85	0.17	327	600	**0.04**	689	692	0.95
31	1.34	1.26	**0.03**	0.23	0.22	0.84	318.4	273.9	0.08	8.05	7.82	0.37	732	670	0.95	585	760	0.18
37	1.16	1.19	0.79	0.38	0.31	0.17	427	357.1	0.43	7.54	7.54	0.93	1088	626	0.07	903	732	0.18

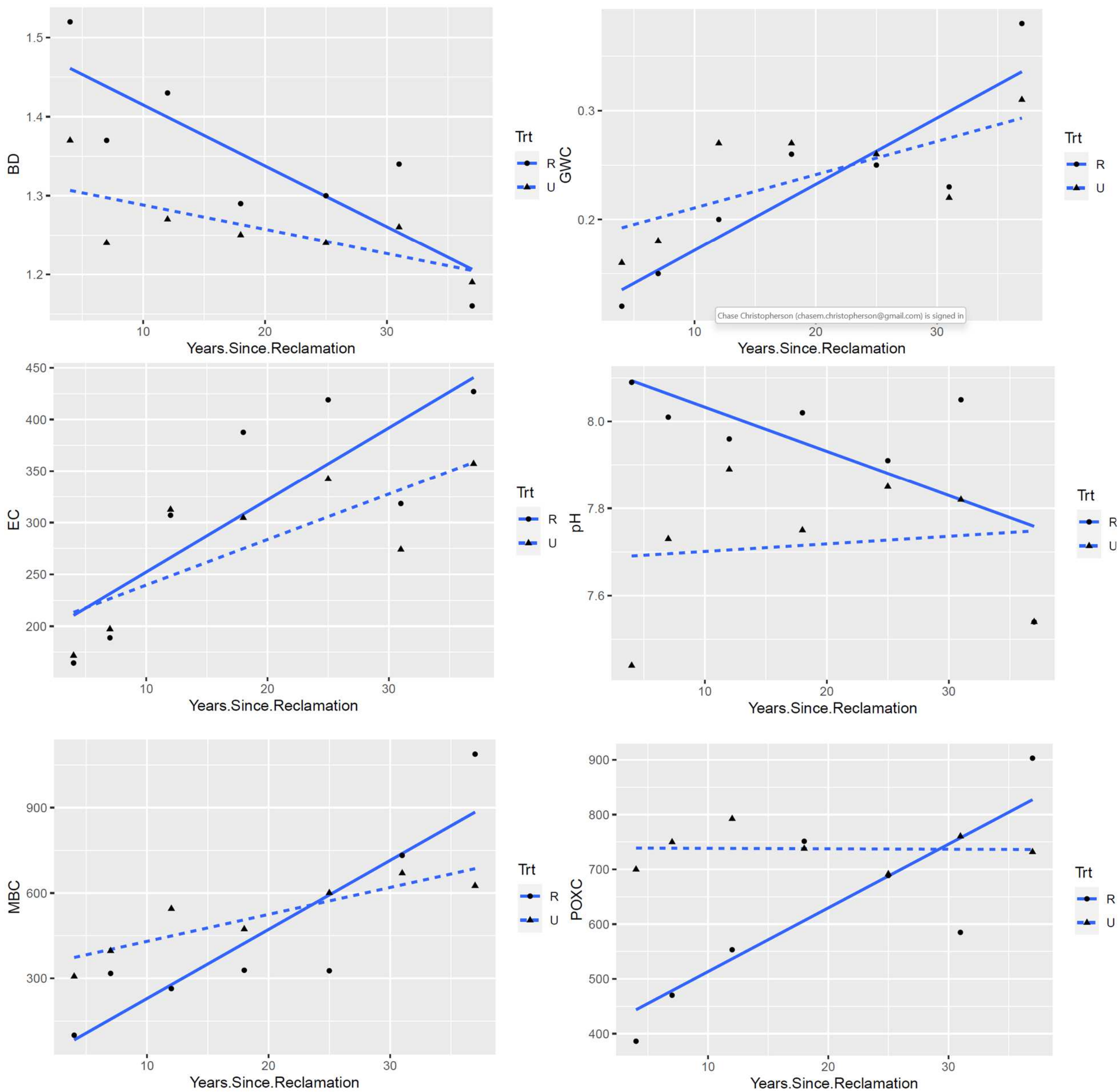

Fig. 4. Regressions for mean soil property data. Mean soil property values of the reclaimed and undisturbed areas from each study site (n=6 for the reclaimed soil data and n=8 for the undisturbed soil data) along with the best fit lines for each soil property, the dashed best fit line and triangles represent the undisturbed soil data, and the solid best fit line and dots represent the reclaimed soil data. The R-squared values, best fit line equations, and p-values for each of these graphs are in Table 5.

Table 5. Regression analysis data**.** Regression analysis results (r-squared, best fit line equation, and p-values) for soil property data (n=6 and n=8) from the reclaimed and undisturbed areas, respectfully, of each study site when compared to time since reclamation. P-values indicate the likelihood that the regression analysis results occurred by chance.

	Regression Analysis						
		Bulk Density	Gravimetric Water Content	Electrical Conductivity	pH	Microbial Biomass Carbon	Permanganate Oxidizable Carbon
		g/cm^3	g/g	µS/cm	-log[H+]	mg/kg	mg/kg
Best Fit Line Equation	R	y = 1.5 - 0.0077x	y = 0.11 + 0.006x	y = 180 + 7x	y = 8.1 - 0.01x	y = -14 + 24x	y=40 + 12x
	U	y = 1.3 – 0.0031x	y = 0.18 + 0.0031x	y = 180 + 4.4x	y = 7.7 + 0.0017x	y = 340 + 9.5x	y= 740 - 0.08x
R-squared	R	0.71	0.7	0.67	0.46	0.79	0.67
	U	0.49	0.49	0.59	0.017	0.80	0.0008
P-value	R	0.003	0.002	<0.001	0.03	0.006	<0.001
	U	0.003	0.002	<0.001	0.03	<0.001	<0.001

Regression analyses indicated that as time since reclamation increased, soil properties change. Values of some properties in reclaimed soils decreased over time (BD and pH), while other properties increased over time (EC, GWC, MBC, POXC). The regression analyses also show that the condition of the soil properties in the undisturbed areas are also variable across sites (ages). The graphs represent the relationships between soil property values and time since reclamation (Fig. 3) and show the best fit line for each soil property data set. These best fit lines provide a mathematical trend line for the soil property data across the seven sites, changing in time since reclamation up to 37 years. As time since reclamation increased, the reclaimed soil property values converge on the undisturbed soil property values. This is represented in all of the regression analyses apart from the one for EC, which has the reclaimed and undisturbed values diverging as time increased.

3.2. Vegetation Surveys

3.2.1. Vegetation Cover

Vegetation cover and sampling was utilized in this study in order to determine if reclamation influences the growth and presence of vegetation in comparison to the surrounding undisturbed areas. Using the “SamplePoint” software, it was determined that the most prevalent cover types across the seven sites, regardless of time since reclamation, were grass species and litter consisting primarily of dead grass. Though bare soil accounted for 14% of the reclaimed area on the 4-year-old site, 19% of the reclaimed area on the 18-year-old site, and 21% of the reclaimed area on the 25-year-old site, it did not account for more than 9% in any of the other reclaimed or undisturbed areas. Some sort of vegetation, including litter layer, was found to cover the majority of the ground for both the reclaimed and undisturbed areas across all sites with small amounts of bare soil, apart from the exceptions listed previously. The complete data for ground cover percentages are in Appendix B.

3.2.2. Vegetation Species Presence

Across all sites the undisturbed areas had a greater number of species present when compared to the species found within the reclaimed areas. Both the reclaimed and undisturbed areas consisted primarily of grass and forb species with limited amounts of small woody shrubs and trees.

Many native vegetation species were found across all sites, both in the reclaimed and undisturbed areas, though there were invasive and weed species present as well. Dandelions (*Taraxacum officinale*) were found across all sites in both the reclaimed and undisturbed areas, which, despite being naturalized to the region, are considered a weed species. One species of note, the common yarrow (*Achillea millefolium*), is a plant that is native to North Dakota and was found in abundance in both the reclaimed and undisturbed areas of the 7-, 18-, 25-, and 37-year-old sites but was absent across the 4- and 31-year-old sites as well as the undisturbed area of the 12-year-old site. This species, while native to the area, is commonly found growing in dry, degraded, and disturbed soils and is considered a weed in some situations (Wildflower Center, 2022).

Grasses were the primary vegetation found in both the reclaimed and undisturbed areas across all study sites. At least one species of invasive grass was found in both the reclaimed and undisturbed areas in addition to native grasses across all sites. The invasive grasses with the greatest presence across all sites were Kentucky bluegrass (*Poa Pratensis*), crested wheatgrass (*Agropyron Cristatum*), and smooth brome (*Bromus Inermis*). Of the grass species that are required by the state of North Dakota to be planted across reclaimed oil well pads on North Dakota Department of Trust Lands "school/university" lands in this region (Table 1), all but side-oats grama (*Bouteloua Curtipendula*) were found to be present to some extent either within the reclaimed areas, undisturbed areas, or both.

4. DISCUSSION

The purpose of this study was to determine if the soil properties and vegetation on reclaimed oil well pad sites recover to reflect that of adjacent undisturbed areas as time since reclamation increases. The reclamations conducted on the oil well pads in this study had clear impacts on the recovery of soil properties and vegetation establishment. Based on the significance level used in this study (α=0.05), few significant differences were found between reclaimed and undisturbed soil properties in as little as four years following the reclamation. The exceptions to this being that the pH, MBC, and POXC data were found to be significantly different between the reclaimed and undisturbed areas of the 4-year-old site, though this was not found in older sites, suggesting that the soil conditions in the reclaimed areas reflect those of the undisturbed areas. However, if p-values between 0.06 and 0.1 are considered to be somewhat significant then eight more differences in soil property values would be considered significantly different (Table 4). This means that while these soil properties with p-values between 0.06 and 0.1 are not considered significantly different at the α=0.05 level, they do not indicate that the reclaimed areas have recovered to the point of reflecting undisturbed soil conditions. The history of disturbance and the age of the reclamation did not appear to have an impact on the vegetation present or bare ground percentages in comparison to the undisturbed areas.

In contrast to other studies that have been conducted on vegetation composition and ground coverages (Gasch et al., 2016) the bare ground percentages as well as weed and invasive species presence were not greater on younger sites than that found on the older sites (Sylvain et al., 2019). This finding also extends to the lack of differences in vegetation presence and bare ground percentages between the reclaimed and surrounding undisturbed areas. Instead, a mix of both native and non-native grass species as well as native forb and shrub species were found across both the reclaimed and undisturbed areas (Gasch et al., 2015, Sylvain et al., 2019). It is worth mentioning that, observationally, the undisturbed areas did appear to have a greater number of species present than the reclaimed areas. This is strictly observational data though as species identification was inconclusive and not a primary aspect of this study.

The soil property data followed anticipated trends based on previous studies (Li et al., 2018, Janz et al., 2019, Gasch et al., 2015, Avirmed et al., 2014). It was determined that the BD values were higher in the younger reclaimed areas, which could be attributed to more recent compression caused by the use of heavy equipment during well pad activities, but then decreased over time (Fig. 3). This decrease in bulk density as time since reclamation increases could be the result of vegetation presence (primarily root growth which creates space in the soil), an increase in water infiltration and retention, a result of burrowing insects and animals, the soil types (sandy/silty loams, and clay loams), or a combination of these, and other, factors (USDA-NRCS, 2022).

GWC values did not align with previous studies (Gasch et al., 2015) as we found that these values were lower in younger reclamation areas and increased over time. GWC is a measure of the weight (amount) of water that is found in the soil at any given time (Bilskie, 2001). The water holding capacity is determined by the porosity of the soil environment (the greater the porosity, the greater the space available for water or air), which is inversely related to BD (Mobilian et al., 2022). This trend in GWC over time could be the result of different soil textures and particle sizes across the study sites. Based on the soil types (Table 2), the soil in the older study sites appear to have smaller soil particles, which also increases the water holding capacity of the soil.

A possible reason for GWC appearing to increase could be that BD decreases across the reclaimed areas. This could be due to the porosity within the soil increasing as BD values decrease, which means that there is greater water infiltration into the soil as well as increased space available to hold water within the soil. The establishment of vegetation could also be aiding in the increase in soil water content because vegetation presence decreases water loss due to evaporation (Rodrigues et al., 2021) as well as contributes to water infiltration and storage in spaces made by root growth and subsequent decay (Logsdon, 2013). The lack of significant differences found between reclaimed and undisturbed data aligns with a similar study that looked at the GWC of reclaimed sites at different soil depths where the GWC of reclaimed soils was found to reflect that of undisturbed soils (Qi et al., 2020).

Despite not finding significant differences in EC between the reclaimed and undisturbed areas, it was determined through regression analysis that the EC across the seven study sites increased as time since reclamation increased, a trend similarly exhibited by the EC values from the undisturbed areas. The regression analysis suggested that EC is lower in younger reclaimed areas and that it increased in a dependent matter as time since reclamation increased, contrary to the findings of Gasch et al. (2016). Possible explanations for these observed trends could be soil conditions from lower in the soil profile rising towards the surface as time since reclamation increases, soil mixing during stockpiling and respreading, site specific soil profiles, the terrain and location of the sites (sun exposure, hillside, uphill or downhill, etc.), influences from the surrounding areas or a combination of these and other influences.

The regression analyses that were produced for the recovery of pH, MBC, and POXC align with what was anticipated based on previous findings (Li et al., 2018, Janz et al., 2019, Gasch et al., 2015, Avirmed et al., 2014, Qi et al., 2020). Reclaimed soils were found to have higher pH values than the undisturbed areas across all study sites, similar to Gasch et al. (2015) apart from the 37-year-old site. However, this information coupled with the regression analysis suggests that as reclamations increase in age the soil becomes more acidic. It should be noted that the soils in these areas are alkaline in nature (Lopez-Bucio et al., 2000 and Soil Survey Staff, 2022) and that while the soils are increasing in acidity over time, the soils are still alkaline with pH values remaining above 7.

It stands to reason that the trends found in POXC data will be similar to the trends found for MBC (Zhang et al., 2021). The increase in the POXC and MBC observations over time occurred as the pH decreased. The reason that these three sets of data show changes with time since reclamation and have similar data trends is that they are influence by the presence of vegetation and litter layers (Li et al., 2014). Active decay of vegetation contributes carbon, as well as other nutrients, to the soil which increases the POXC content within the soil. This increase in POXC translates to more active carbon in the soil and results in greater levels of microbial activity, increasing the MBC content (Breker, 2022). Similarly, the decay of organic matter within the soil environment contributes H^+ to the soil and causes the pH to decrease, making the soil more acidic (Zhang, 2017). It would follow that a litter layer will develop with the establishment of vegetation on these reclaimed sites, continuing to contribute organic matter to the soil which produces the exhibited trends in data for pH, POXC, and MBC over time.

Though the significant differences appear to cease after 4 years based on the significance level for this study (α=0.05), this does not mean that these soil properties reflect one another nor that the soils on the reclaimed areas are sufficiently recovered. In looking at the regression analyses, the soil property values from the reclaimed areas continue to trend towards the values from the undisturbed areas as time increases across the study sites. This means that the reclaimed soils continue to recover as time increases despite the Mann Whitney U tests suggesting that significant differences cease after 4 years. These findings coincide with the findings from previous studies that suggest that soil properties continue to recover over time and that soil microbial recovery is delayed in comparison to other soil properties (Avirmed et al., 2014, Janz et al., 2019, Li et al., 2018, Li et al., 2014). These previous studies indicated significant recovery did not occur until 20 years or more following reclamation and this study suggests that significant differences (indications of significant recovery) in the microbial communities cease between 4- and 7-years following reclamation. It is important to note that the regression analyses for the pH, MBC and POXC data from the undisturbed areas show that these properties change over time as well. The change in values for the undisturbed data could be contributing to the cessation of significant differences for these soil properties after 4 years as the undisturbed soil properties appear to either trend towards the reclaimed data or have shallower data slopes than the reclaimed data, resulting in lesser differences between the values.

It is important to mention that while each of these sites is located in McKenzie County, ND, they are not in the exact same geographic location. This means that they are all subject to different external influences that could play a role in the progress of each site's recovery. These sites have their own microclimate where the soil types, vegetation communities, precipitation levels, wildlife and insect communities, current land use, the site's position on the landscape (hillside, valley, prairie, etc.), and the surrounding areas vary to some degree and have influences on the conditions and recovery of these sites that are not accounted for in this study.

5. CONCLUSION

Overall, it was determined that there were not many statistically significant differences between the soil properties from the reclaimed and undisturbed areas based on the significance level chosen for this study ($\alpha=0.05$). The pH, MBC, and POXC values were found to be significantly different between the reclaimed and undisturbed areas within the 4-year-old site with MBC and POXC having somewhat significant ($\alpha=0.06$-0.1) differences across some older sites (Table 4). Finding that EC is increasing over time was unanticipated and the exact reason for this is unknown. However, a possibility for this trend could be that the EC values are the results of soil conditions further down in the soil profile than 14 cm (which were assessed in this study) that rise up through the soil over time. Bare ground percentages were found to not be heavily influenced by age of reclamation (Appendix B) and is most likely influenced to a greater extent by the terrain, vegetation, climate, and soil of the site.

From this study it appears that the reclamation activities conducted in this region of North Dakota are successful in beginning the recovery process on these disturbed areas. Establishing vegetation serves as a primer for soil recovery by aiding in erosion reduction, decreasing compaction through root growth, decreasing evaporation (increasing soil moisture content), and contributing vital nutrients to the soil. The lack of distinction in the vegetation communities between the reclaimed and undisturbed areas across all study sites suggests that the applied seed mix has been successful in establishing grasses on these reclaimed sites. Invasive and weed species were found across all sites and are not an inherent issue for a successful reclamation as they provide the same benefits to the soil environment as native species, though they should be monitored as time goes on to ensure they are not hindering native vegetation establishment.

The level of recovery of the soil properties and the lack of significant, as well as somewhat significant, differences between the reclaimed and undisturbed areas across these study sites align with the results of previous studies, though the recovery process appears to be occurring faster in this region with reclaimed soils reflecting undisturbed soils within the limits of this study, 37 years. This could be a result of successful vegetation establishment on reclaimed sites, contributing to the physical, chemical, and biological aspects of the soil early in the recovery process. It is important to note that this study looked to determine how soil properties on reclaimed oil well pads recovered over time in comparison to the undisturbed areas adjacent to the reclaimed areas. This means that while the results of this study show that reclaimed soil properties begin to reflect those of the undisturbed soils, this does not mean that the reclaimed soils are reflecting "ideal" conditions nor that these areas are reflecting historical conditions. The results and conclusions drawn from this study refer strictly to the recovery of reclaimed soils in comparison to the surrounding undisturbed areas.

In addition to early and continued vegetation establishment, proper soil stockpiling and re-spreading should continue to be a point of emphasis for oil well pad reclamation in this region. While these results suggest that the initial reclamation surveying methods utilized by the North Dakota Trust Land Department are sufficient for establishing baseline site conditions for successful recovery, long-term monitoring of these sites could provide insights into any lingering impacts of oil well pad activities, such as yearly soil assessments. While these soil assessments could be as thorough as a land manager would like, it is not realistic to have the time or resources to conduct in depth soil analyses every year. An example of a soil analysis that could be conducted yearly is electrical conductivity testing which could provide beneficial insight into the recovery of the soils and the lasting impacts of oil well pad activity.

Brine spills are a common occurrence in active oil well pad areas and can have long lasting impacts on local ecosystems, such as hindering vegetation and microbial recovery. "Brine" refers to a saltwater biproduct of oil extraction that has extremely high salt concentrations. Despite the efforts that oil companies put into spill prevention, brine spills still occur both above and below ground. When this happens, oil companies are required to clean up the spill and remediate the affected areas. Despite cleanup efforts, it is possible that the impacts of the brine spill are greater than what is anticipated by the oil company. Conducting EC analyses on these reclaimed areas as well as the surrounding rangelands on a regular basis could help detect changes in the soil salinity that could potentially be a delayed result of previous brine spills and allow for proactive management. There are many other soil monitoring methods that could be utilized for regular site assessment, but this is an easy and cost-effective method to monitor the recovery of these sites. Long-term monitoring could provide insight into current reclamation activities and site recovery, leading to better reclamation and land management methods to further the recovery and future productivity of these disturbed lands.

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APPENDIX A. T-TESTS AND REGRESSION ANALYSIS DATA

Table A1. Reclaimed and undisturbed area soil property means. Soil property means for soil collected from the reclaimed (R) (n=6) and undisturbed (U) (n=8) areas for the seven study sites on North Dakota Trust Lands in McKenzie County, North Dakota.

	Soil Property Means												
Years Since Reclamation	Bulk Density		Gravimetric Water Content		Electrical Conductivity		pH		Microbial Biomass Carbon		Permanganate Oxidizable Carbon	
	g/cm^3		g/g		µS/cm		-log[H+]		mg/kg		mg/kg	
	Mean		Mean		Mean		Mean		Mean		Mean	
	R	U	R	U	R	U	R	U	R	U	R	U
4	1.52	1.37	0.12	0.16	164.4	171.7	8.09	7.44	100	307	386	700
7	1.37	1.24	0.15	0.18	188.8	197.2	8.01	7.73	317	397	470	750
12	1.43	1.27	0.2	0.27	307	312.5	7.96	7.89	264	545	553	793
18	1.29	1.25	0.26	0.27	387.6	304.5	8.02	7.75	328	473	751	738
25	1.3	1.24	0.25	0.26	419	342.2	7.91	7.85	327	600	689	692
31	1.34	1.26	0.23	0.22	318.4	273.9	8.05	7.82	732	670	585	760
37	1.16	1.19	0.38	0.31	427	357.1	7.54	7.54	1088	626	903	732

Table A2. Soil property mean differences between reclaimed and undisturbed areas. Difference in means between data collected from the reclaimed area (n=6) and data collected from the undisturbed surrounding rangeland (n=8). * Denotes that the mean difference between reclaimed and undisturbed values for the soil property were statistically significantly related as time since reclamation increased (α=0.05).

Soil Property Mean Differences						
Site	Bulk Density*	Gravimetric Water Content	Electrical Conductivity*	pH*	Microbial Biomass Carbon	Permanganate Oxidizable Carbon
	g/cm^3	g/g	µS/cm	-log[H+]	mg/kg	mg/kg
4	0.15	-0.04	-7.2	0.65	-207	-311
7	0.13	-0.03	-8.4	0.28	-79	-280
12	0.16	-0.07	-5.5	0.07	-281	-239
18	0.04	-0.01	83.1	0.28	-145	13
25	0.06	-0.01	76.8	0.06	-274	-3
31	0.08	0.01	44.4	0.23	63	-175
37	-0.03	0.07	69.9	-0.00	463	171

Table A3. T- and p-values for mean difference data. T- and p-values for each soil property's mean difference across all study sites. *Denotes that there is statistical significance in the change in mean differences in regard to time since reclamation.

Regional T-test Results						
	Bulk Density	Gravimetric Water Content	Electrical Conductivity	pH	Microbial Biomass Carbon	Permanganate Oxidizable Carbon
	g/cm^3	g/g	µS/cm	-log[H+]	mg/kg	mg/kg
T-value	-3.28	0.69	-2.27	-2.70	0.66	1.72
P-value	0.01*	0.51	0.04*	0.02*	0.52	0.11

APPENDIX B. GROUND COVER PERCENTAGES

Table B1. Ground cover percentages by site and area. Ground cover percentages for entire sampling area of both reclaimed and undisturbed sites by cover type.

4							
Reclaimed							
Grass	Litter	Soil	Shrub	Forb	Rock	Invasive	Unknown
58%	23%	14%	3%	0%	1%	0.2%	0.8%
Undisturbed							
Grass	Litter	Soil	Shrub	Forb	Rock	Invasive	Unknown
61%	21%	6%	9%	0%	0%	1%	2%
7							
Reclaimed							
Grass	Litter	Soil	Shrub	Forb	Rock	Invasive	Unknown
28%	36%	7%	13%	4%	0%	10%	2%
Undisturbed							
Grass	Litter	Soil	Shrub	Forb	Rock	Invasive	Unknown
59%	27%	3%	3%	0%	0.1%	7%	0.9%
12							
Reclaimed							
Grass	Litter	Soil	Shrub	Forb	Rock	Invasive	Unknown
73%	22%	2%	2%	0%	0.2%	0.8%	0%
Undisturbed							
Grass	Litter	Soil	Shrub	Forb	Rock	Invasive	Unknown
57%	25%	9%	8%	0%	1%	0%	0%
18							
Reclaimed							
Grass	Litter	Soil	Shrub	Forb	Rock	Invasive	Unknown
34%	28%	19%	8%	1.5%	1.5%	8%	0%
Undisturbed							

Grass	Litter	Soil	Shrub	Forb	Rock	Invasive	Unknown
39%	24%	5%	20%	0.5%	6%	5%	0.5%
25							
Reclaimed							
Grass	Litter	Soil	Shrub	Forb	Rock	Invasive	Unknown
47%	24%	21%	0.8%	0.8%	5%	1%	0.4%
Undisturbed							
Grass	Litter	Soil	Shrub	Forb	Rock	Invasive	Unknown
55%	38%	2%	5%	0.1%	0%	0%	0%
31							
Reclaimed							
Grass	Litter	Soil	Shrub	Forb	Rock	Invasive	Unknown
41%	39%	7%	1%	0%	1%	10%	1%
Undisturbed							
Grass	Litter	Soil	Shrub	Forb	Rock	Invasive	Unknown
48%	40%	7%	2.6%	0%	0.2%	2%	0.2%
37							
Reclaimed							
Grass	Litter	Soil	Shrub	Forb	Rock	Invasive	Unknown
56%	29%	3%	11%	0.7%	0%	0%	0.3%
Undisturbed							
Grass	Litter	Soil	Shrub	Forb	Rock	Invasive	Unknown
67%	20%	3%	10%	0.2%	0%	0%	0%

APPENDIX C. ND DEPT. OF TRUST LANDS NATIVE GRASS SEEDING SPECIFICATIONS FOR UNIVERSITY & SCHOOL LANDS

Exhibit "C"

NORTH DAKOTA
BOARD OF UNIVERSITY & SCHOOL LANDS
ND Department of Trust Lands

Native Grass Seeding Specifications

Species	lbs. PLS*/acre
Western wheatgrass	8
Slender wheatgrass	5
Green needlegrass	4
Side-oats grama	2
	19

*PLS - Pure Live Seed (based on 50 PLS/sq. feet)

1. The seed bed should be firmly packed (footprints left in the soil should be less than 1/2 inch deep).
2. An early spring seeding (before May 24th) is preferred. A dormant fall seeding (after October 20th) is acceptable.
3. A cover crop of oats at 10 lbs. PLS/acre must be seeded on the disturbed area.
4. A drill designed specifically for native grass seeding will give the best seeding results. The seed should be planted at a depth of 1/2 to 1 inch. Precaution must be taken not to plant the seed too deeply in the soil or poor germination will result.
5. On areas where equipment cannot be used, broadcast seed and rake or drag to cover seed. Where seed is broadcast, double the seeding rate.
6. Use only North Dakota certified seed.

CAUTION: Be sure to clean out the drill before seeding to avoid any contamination with smooth brome grass or crested wheatgrass that may remain in the drill from previous use on private land. These are invasive grasses in native prairie and are not allowed on school trust lands. Contamination with or use of crested wheatgrass or smooth brome will result in the applicant being required to spray out the grass and reseed with the above native grass seed mixture. Sweet clover and alfalfa are also not allowed – only the above native grass seed mixture may be used for revegetation on school trust land.

JHS

Fig. C1. Native grass seeding specifications for university and school lands. Document provided by the North Dakota Department of Trust Lands outlining the reseeding requirements and mandates for reclamations on school/university lands (ND Dept. Trust Lands, 2022).