The Short-term Response of Soil Mesofauna Community Density and Diversity to Dryland Reclamation Practices in Boreal Forest Soils of Northern Alberta.

by

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COMMITTEE APPROVAL

The members of Gregory Hook's Thesis Committee certify that they have read the thesis entitled "The Short-term Response of Soil Mesofauna Community Density and Diversity to Dryland Reclamation Practices in Boreal Forest Soils of Northern Alberta" and recommend that it be accepted as fulfilling the thesis requirements for the Degree of Master of Science in Environment and Management:

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Abstract

Open pit mining practices, including those used in the oil sands region of Northern Alberta, disturb large areas of land and impact different soil ecosystem functions. These disturbances affect soil mesofauna communities, which are crucial to the success of reclamation efforts. Soil invertebrates, respond more rapidly to environmental changes because of their short life cycles, as such may be useful to assess the recovery of reclaimed soil ecosystems over time. Soil mesofauna (mites, collembola, and other small invertebrates) community densities and relative abundance were used to evaluate the early stages of reclamation soil development. Response of soil mesofauna community structure to disturbed soil ecosystems could indicate how below-ground biota in reclaimed soils recover from disturbance over time and help provide a faster, and more accurate assessment of reclamation success.

Table of Contents

List of Figures

List of Tables

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Dedication

To my wife, Sarah Neiman, and my daughter, Hazel Hook, without whom this project may have received more of my undivided attention.

Introduction

Soil ecosystems provide a vast array of services, including climate regulation, water purification, erosion control, decomposition, and nutrient conservation (Birge, Bevans, Allen, Angeler, Baer, & Wall, 2016). Anthropogenic disturbance can impact soil ecosystem function, resilience, productivity, and quality. Soil quality is defined as a soil's capacity to sustain biotic productivity and maintenance of environmental health (Chaves, Lozada, & Gaspar, 2017). Reduction in soil quality can impede a soil's ability to provide ecosystem services (Gardi, Montanarella, Arrouays, Bispo, Lemanceau, Jolivet, Mulder, Rombke, Rutgers, & Menta, 2009). Soil ecosystems integrate biotic and abiotic factors in, on and below the upper soil horizons. Biotic factors include vegetation, microbial life, as well as animals. Abiotic factors include chemical composition and texture of the cover soil and the subsoil. The majority of biological activity in soil occurs in the Leafy, Fibric, and Humic (LFH), and A soil horizons (Gardi et al., 2009). Maintaining soil quality in these horizons following anthropogenic disturbances requires attention to both biotic and abiotic factors in a holistic manner.

Current practices for mining oil sands in Northeastern Alberta results in a great deal of disturbance to the boreal forest ecosystems, from soil removal to the construction of tailings containment ponds and processing facilities, to the eventual reclamation of these disturbed ecosystems. Oil sand is a form of petroleum hydrocarbon ore, also known as bitumen, that was trapped in quartz sand. Oil sand is formed by the decomposition of marine organic matter and subsequent exposure to sufficient pressure and temperature to create oil (Government of Alberta, 1995-2018). One method of oil sands extraction is through physical mining of bitumen from shallower ore formations. Oil sands mining in North-eastern Alberta began in 1978 when Syncrude started their operation North of Fort McMurray (Government of Alberta, 2017). This method utilizes large shovels to remove overburden materials, the layers of material above the ore formations. Overburden material includes large volumes of marine clay shales, deposits that were formed by the oceans that previously engulfed the area. These shales are often extremely sodic and saline but are helpful for constructing structures such as tailings pond dykes. Once the overburden is removed, bitumen is then gathered using those same shovels and transported to an extraction plant.

When oil sand mine operations finish extraction, governmental regulations require that disturbed lands be reclaimed to a naturally productive boreal forest ecosystem (Government of Alberta, 2017-a). The reclamation process includes placing a meter-thick layer of subsoil or suitable overburden material capped with a 20 cm layer of topsoil or peat mineral material over process affected landscapes to re-establish soil function and support naturally recovering ecosystems. Soils are categorized by layers which are composed from the surface of the LFH layer followed by the A, B, and C horizons beneath (Soil Classification Working Group (SCWG), 1998). LFH is composed of organic material in different states of decomposition (SCWG, 1998). The A horizon is composed mainly of mineral material leached from the decomposition of the LFH layer. LFH and the A horizon together form the forest floor coversoil (SCWG, 1998). The B horizon of soil, underneath the A horizon, is considered subsoil (SCWG, 1998). Suitable overburden material used in reclamation as a replacement for subsoil is found in the C horizon and must fall within chemical criteria guidelines found in the regulatory approvals for oil sands mines (SCWG, 1998). The problem with using only soil chemistry data as a means of determining the quality of a soil ecosystem is that it does not integrate abiotic and biotic components or identify a soil's capacity to continuously support ecosystem functions (de Paul Obade & Lal, 2016). Using chemical criteria as the sole measure of soil quality in reclamation sites is insufficient and does not encapsulate the entirety of biogeochemical processes in soil ecosystems (Parisi, Menta, Gardi, Jacomini, & Mozzanica, 2005).

Direct placement is a method of reclamation where soil is taken from an in-situ area prior to mining and immediately placed as reclamation material in another location, rather than indirect methods of placement where reclamation material is sourced from stockpiles (MacKenzie, 2011). Direct placement has a number of advantages: the vegetation seed bank is still intact in the soil, other propagules are still present and viable (i.e. seeds and root fragments), some of the soil animals, fungi and bacteria will have survived, and there is less chance of altering the soil chemistry (MacKenzie, 2011). However, complete recovery of soil ecosystems requires an integrated management approach that uses key soil properties including chemical and physical properties, and biological organisms (Lal, 2011).

Organisms found in soil ecosystems include a wide diversity of flora and fauna. Flora in soils ranges from fungus, and lichens to forbes and grasses and other flowering plants, to woody stemmed plants such as shrubs and trees. Fauna includes animals such as rodents, spiders, worms, and insects. However, this study focuses on soil mesofauna. Mesofauna are soil invertebrates, including Acari (mites), Collembola (springtails), and other mesofauna. Soil mesofauna range in size from 0.1 to 2 mm in width and complete all or a portion of their active life-cycle in the soil horizons. (Dervash, Bhat, Mushtaq, & Singh, 2018). Acari are eight-legged arthropods that can be found abundantly in a wide array of ecosystems (Devarsh, et. al., 2018). In soils, Acari includes three major suborders; Oribatida, Mesostigmata, and Prostigmata (Miller, Battigelli, Beasley, & Drury, 2017). Collembola (springtails) are soft-bodied, wingless arthropods with rudimentary eyes that are found in soil, litter, and on water surfaces (Gullan & Cranston, 2005). The families of Collembola that were found and identified in this study included Entomobryidae, Hypogastruridae, Sminthuridae, Isotomidae, Neelidae, and Onychuiridae. Other mesofauna in this study encapsulated any other invertebrate specimens that were found in the samples including Diptera, Coleoptera, Thysanoptera, Homoptera, Hymenoptera, Formicidae, Lumbricidae, Psocoptera, Arachnida, Enchytraeidae, Symphyla, and Geophilomorpha.

The importance of Mesofauna is in their ability improve soil quality through the acceleration of organic decomposition, whereby saprophagous or detritivorous mesofauna physical breakdown organic detritus in the litter layer (Gullan & Cranston, 2005). Mesofauna enhance soil microbial activity, sequestration of carbon, and reduce propagation of soil-borne diseases and pests (Berch, Battigelli, & Hope, 2007; Miller, et. al., 2017). Population regulation of bacterial and fungal colonies results from Mesofauna feeding and passive transport of spores (Miller et. al., 2017). Regulation of the microbial and fungal colonies enhances decomposition of organic materials and soil formation. Soil mesofauna also represent a large reservoir of biodiversity and are an important component of boreal forest ecosystem food webs, making them a vital component to study when investigating soil quality (Dervash, et. al., 2018). Because mesofauna, such as Acari and Collembola, inhabit the pore spaces created by other organisms found in soil, they are largely restricted in terms of movement and therefore more susceptible to soil ecosystem disturbances, such as those caused by oil sands mining (Dervash, et.al., 2018).

Berch, et. al. (2007) demonstrated that oribatid mites and Collembola could be good indicators of forest soil ecosystem recovery from forestry activities and soil compaction in British Columbian spruce stands. Oribatid mites reach densities of over hundreds of thousands of individuals per metre squared (Santorufo, Van Gestel, Rocco, & Maisto, 2012; Battigelli, 2011, McAdams, Quideau, Swallow, & Lumley, 2018) Oribatids are “k-selected” organisms that develop slowly, with long life spans, and low metabolic rates (Battigelli, 2011). Their life history traits along with their high species diversity in natural sites make them good indicators for the recovery of forest ecosystems (Dervash et. al. 2018). Oribatid mite life history coupled with their limited dispersal ability, reduce their ability to escape from anthropogenic disturbances, which results in significant loss of species (Battigelli, 2011).

Many studies have shown that Collembola are also capable of being used as bioindicators of soil quality (Battigelli, Spence, Langor, & Berch, 2004; Miller et.al., 2017; Roy, Roy, & Baitha, 2018). Collembola are "r-selected" organisms, reproducing more rapidly with higher numbers of offspring, and faster development rates than oribatid mites (Battigelli, 2011). Life-histories of Collembola allow them to respond more rapidly to disturbances than most oribatid mites (Battigelli, 2011). Collembola communities are influenced by a number of environmental factors (i.e. soil texture, moisture content, temperature, and chemistry). A study in Germany found that fungivorous Collembola improved seedling germination in soils by reducing saprophytic fungus populations in grasslands (Mitschunas, Wagner, & Filser, 2008).

The use of mesofauna as bioindicators is not a new approach. Many studies have used them to different extents (Brown, 1997, Nakamura, Proctor, & Catterall, 2003; Majer et. al., 2007; Chaves et. al., 2017; Miller, et. al., 2017; McAdams, et. al., 2018). Mesofauna perform various ecosystem services in the soil which include regulation of fungi colonization, improved microbial activity, decomposition, and nutrient cycling. (Berch, et. al., 2007; Roy, et. al., 2018). Changes in species richness and evenness of both Acari and Collembola were useful indicators of forest recovery after disturbances in boreal forest soils in British Columbia's mountainous regions (Berch, et. al., 2007). A study by Prinz, Moody, Fraser, Van der Vliet, Lemieux, Scroggins, & Siciliano. (2012) found a correlation between soil salinity and invertebrates, indicating that excessive soil salinity disrupts osmoregulation in both Collembola and oribatid mites. The loss of body water in mesofauna disrupted reproduction, growth, and survival (Prinz, et. al., 2012). Research on mesofauna populations during the reclamation of bauxite mines in Western Australia has also been done to assess the potential use of mesofauna as indicators of reclamation efforts (Majer, Brennan, & Moir, 2007). Majer et al. 2007 included 30 years of recovery research and acknowledged the importance of including invertebrates for the regulation and monitoring of reclamation processes. A study conducted by McAdams et. al. (2018) investigated the potential of using oribatid mite recovery as a bioindicator in oil sands mines following reclamation. McAdams et. al. (2018), identified a number of species including *Pilogalumna sp., Ceratoppia quadridentate arctica,* and *Oribatodes mirabilis,* as suitable candidates for use as bioindicators of soil ecosystem recovery in reclaimed sites because they are k-strategist that are greatly impacted by soil disturbances and take longer to recover than other oribatid species.

Along with biological components of soil, abiotic aspects also need to be considered during reclamation. Soil textures are one important aspect of the soil ecosystem and need to be considered when assessing reclamation success. Soil texture influences stored water content as well as water infiltration rates through soil, which impacts soil organisms (Zartman, 2006). Soil moisture content can, in certain conditions, be more closely linked to the soil mesofauna community structure than vegetation or other soil properties (Sylvain & Wall, 2011). The texture of soil influences the distribution of solutes and water through the soil profile (Li, Chang, & Salifu, 2014). Soil water supply is linked strongly to ecosystem growth and development, and as such, soil texture affects soil quality and productivity (Stepien, Samborski, Godowski, Dobers, Chormanski, & Szatylowicz, 2015).

Soil quality guidelines for oil sands operations require that soil used for reclamation meet standards set in place by the Alberta Energy Regulator (AER) approval process (Alberta Energy Regulator, 2016). These soil standards investigate three primary sources of concern around soil quality and include sodium adsorption ratio (SAR), electrical conductivity (EC), and soil acidity (pH). The use of these chemical criteria stems from the impact of materials such as overburden which have high sodicity and salinity and can be detrimental to soil ecosystem function due to upward migration saline water into reclaimed soils (Strilesky, Humphreys, & Carey, 2017). Texture of soils being used in reclamation is also tested to ensure that mixing of coarse-textured soils (CTS) and fine-textured soils (FTS) is minimized, as these soils support very different forest ecosystems (Mackenzie, 2011).

The research being conducted in this study will consider how soil mesofauna communities recover in the short-term from direct placement employed by oil sands mines and investigate how they interact with soil chemical quality. It will also establish a baseline to assess soil ecosystem recovery by looking at the recovery of mesofauna communities associated with reclamation practices relative to undisturbed and milder disturbances of boreal forest soils. Understanding the recovery trajectories of mesofauna communities to pre-disturbance levels may assist in creating a recovery index to assess the success or failure of recovery following disturbance.

Methods

This study used a quantitative analysis of data from field samples that were collected to evaluate patterns in soil ecosystem community structure (O'Leary, 2014). Changes in the structure and density of soil mesofauna communities may indicate how reclamation practices affect forest recovery patterns in soil ecosystems (Battigelli, et. al., 2004). Soil texture and chemical information and mesofauna data were collected from field samples and analyzed to investigate the potential of integrating biological properties with selected physical and chemical properties. Soil disturbances used in this study are representative of disturbance types that oil sands developments create. Density and distribution of soil invertebrate populations in soils with specific textural composition were analyzed among soil disturbance types. Quantitative analyses are appropriate for this study as it concerns a multivariate system, with sampling conducted to create a baseline of boreal forest soil recovery on reclamation sites (Eberhardt, 1991). Collection of soil mesofauna from the field, followed by identification and enumeration of specimens collected provided quantitative data for this study.

The study was conducted in North-eastern Alberta, in the Boreal forest ecosystem (See Figure 1). This area has a mean annual rainfall of 316mm, with mean monthly temperatures of 17.1°C in July and -17.4°C in January, and an average of 97 frost-free days per year (Environment Canada, 2018). Figure 1 indicates the general location of the study site within Alberta as well as detailed sample site locations at the study site.

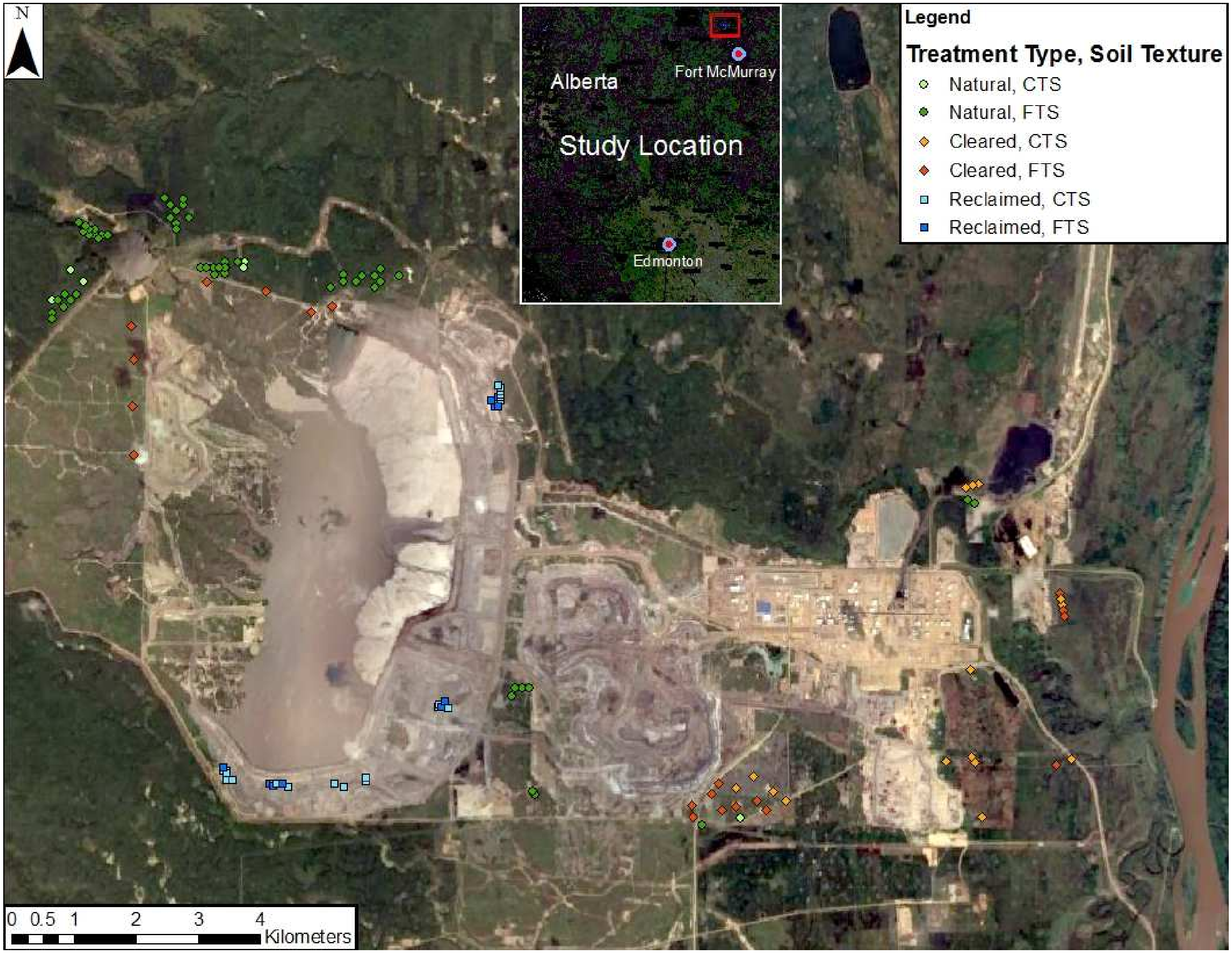

Figure 1. Map of Study Sample Locations by Treatment and Texture. (Image: Google Earth, 2019).

Sample sites were located on an oil sands mine lease in North-eastern Alberta in the regional municipality of Wood Buffalo within a 12 km radius of the mine site where the study took place. Sample sites were selected to represent three different situations: i) undisturbed natural sites (N) to be used as a reference site, ii) moderately disturbed cleared sites (C), and iii) reclaimed sites (R). Natural sites were chosen from areas that were in proximity to the other sample locations on site. Both cleared sites and reclaimed sites experienced anthropogenic disturbance of the soils at different levels. Cleared sites were selected due to the moderate amount of disturbance caused by the machinery salvaging and mulching trees and shrubs. This level of disturbance is mainly affecting surface soils, with some compaction and soils movement. The cleared sites were chosen from areas where clearing had taken place within the last five year around the site that were labeled as d-ecosites. Reclaimed sites were chosen based on their age since soil placement. Soils at these locations had been completed disturbed during the process of salvaging soil and placing them at the reclaimed sites. Locations where samples were taken on the site and the disturbance (or treatment) type and soil texture at each location can be seen in Figure 1. The Reclaimed sites were limited to the areas that were reclaimed within the 2017/2018 reclamation season at the sites. The decision to include only the first year of reclamation was done in order to ensure that the reclaimed sites represented baseline mesofauna assemblages and densities at the beginning of their progression. Mesofauna assemblages expected in these reclaimed sites were anticipated to consist solely of organisms that were present during the salvage of in-situ material. There would have been little chance for immigration of new mesofauna for a number of reasons; the recency of the salvage and placement of soils reduces the chances of new mesofauna moving in, and their restricted ability to disperse coupled with the distance of the reclaimed sites from sources of immigrating mesofauna.

Natural sites were randomly selected from areas classified as “d-ecosites” using the Alberta Vegetation Inventory (Alberta Sustainable Resource Development (ASRD), 2005). This is the dominant ecosite targeted for reclamation on oil sands site where this research project was located. D-ecosites are characterized by low-bush cranberry, a mesic moisture regime, with a medium nutrient regime (Beckingham & Archibald, 1996). Natural sites were randomly selected in areas in proximity to the study site that had not experienced any visible physical impacts from the mining process.

Cleared sites, designated as d-ecosites included both fine and coarse-textured soils prior to clearing of trees and shrubs, were mulched by a forestry company between 2012 and 2017 to create more easily accessible areas or fire breaks. The reason for including such a range of cleared sites was the fact that there were so few areas with consistent disturbance timeframes, areas have been selectively cleared on the sites based on project requirements. Cleared sites experienced a moderate amount of soil disturbance, from removal of vegetation and heavy equipment traffic. Sample locations were a random selection of sites that had experienced clearing.

Reclaimed sites were established during the winter of 2017 over an overburden structure composed mainly of marine shales and placement consisted of 1.0 meter of suitable overburden with approximately 0.2 m of forest floor soil of both fine and coarse-textured. Reclaimed sites were all constructed to produce d-ecosites as the final ecosite phase, once reclamation is certified. At each reclaimed site, one sample was taken from each of three cardinal directions

(North, East, and West) to create a robust representation of variability within the reclamation soils being tested (United States Environmental Protection Agency (USEPA) 2002). Sample sites were selected at random from pre-established sampling points created by the operator. Reclaimed sites had high levels of soil disturbance and compaction (MacKenzie, 2011). Soils used for reclamation were harvested from one location by excavator and placed at reclamation locations using haul trucks. Soils were spread across reclamation sites using D9 and D10 Caterpillar bulldozers. During the reclamation program at the site, which ran from November 2017 to April 2018, two types of reclamation material, fine-textured soil, and coarse-textured soil were placed based on lab texture analysis from samples taken at each site.

Sampling Protocol

For mesofauna abundance and variety, soil texture, and chemical data samples were collected from each sample sites identified in Figure 1 in October to November of 2016, in June of 2017, and July of 2018. Mesofauna soil samples were collected as cores measuring 4.5 cm in diameter, and roughly 10 cm in depth, using a custom-made tube extractor. A depth of 10cm was chosen because it represented the average depth of soil seen at the sample locations and having a consistent depth ensured that similar representation of mesofauna densities were retrieved. Soil core samples were placed in labeled plastic bags and sent to the University of Alberta in coolers with blue ice for mesofauna extraction within 48 hours of collecting. Grab samples of approximately 1.0 kg of soil were also collected in Ziploc bags from the same locations and sent to a lab in Edmonton for physical and chemical analyses. These samples were composite samples that represented the soil conditions at each location where three mesofauna samples were taken.

Arthropod Extraction and Identification

Arthropod extraction was started within 48 hours of collection in the Soil Plant Relationship lab at the University of Alberta. Soil mesofauna were extracted from each soil core using a modified Merchant-Crossley extractor (Norton, 1986). This behavioural extraction method used 7W incandescent light bulbs suspended over each sample inside a PVC pipe to heat and dry the soil core. This forced any mobile invertebrates to move to the bottom of the holder to escape the heat and desiccation (Miller et. al., 2017). Light intensity was gradually increased over 7 days to allow for movement of mesofauna through the soil column. Specimens were collected in containers filled within glycol to kill and preserve the specimens. For identification and sorting, samples were rinsed with water through 56 µm sieve to remove the glycol (Miller et. al., 2017). Sieve contents were then back washed into a watch glass for classification and counting under a dissecting microscope (Miller et. al., 2017). Acari were identified to suborders of Oribatida, Mesostigmata, and Prostigmata. Collembola were identified to family level as either Entomobryidae, Hypogastruridae, Isotomidae, Neelidae, Onychiuridae, or Sminthuridae. Acari and Collembola life strategy (i.e. r vs k strategists) provides a rapid and informative picture of community structure (Paz-Ferreiro & Fu, 2016). All other mesofauna found were classified to class, order, or family depending on their type (Miller, et. al., 2017). Classification at this level allows for less experienced persons to identify mesofauna correctly with minimal training, while still presenting some results to compare among treatment types.

Correct taxonomic identification of organisms present in soil samples is crucial to the validity of the research results. To reduce the risk of misidentification of invertebrate specimens and maintain consistency, Dr. Jeff Battigelli from the University of Alberta ran a workshop for the team to identify mesofauna. The numbers of individuals per taxon were recorded for each sample.

Soil Chemical and Physical Analyses

Soil parameters measured and evaluated from the grab samples collected from each site location included soil texture, pH, sodium adsorption ratio (SAR), and electrical conductivity (EC). ALS Labs in Edmonton performed the chemical and physical analyses of the soil samples. SAR, EC, and pH, which are based on provincial governmental approval criteria for reclamation, establish soil baseline conditions under which soil biota currently survive in the soil matrix (Canadian Council of Ministers of the Environment (CCME), 1999; Lal, 2011). These three soil parameters were used to evaluate changes to forest floor chemistry based on disturbance, within the context of soil texture. Soils were categorized using the soil texture classes triangle from the Canadian System of Soils Classification (SCWG, 1998). Sandy Loam, Loamy Sand, Sand were categorized as coarse textured soils (CTS) and all other soil textures were considered fine textured soils (FTS) (SCWG, 1998). Samples were grouped by soil texture due to the different properties of coarse textured soils compared to fine textured soils. Mesofauna communities are significantly impacted by soil moisture regimes and one aspect that soil texture influences is water retention (Sylvain & Wall, 2011; Dervash, et. al., 2018). Examination of SAR and EC in this study coincide with the abundance of marine overburden used for construction of landforms throughout oil sands operations. Ensuring that salinization caused by overburden materials does not impede soil ecosystem functioning is important for reclamation practices.

Data Analyses

Data collected in this study were analyzed using appropriate statistical methods based on previous studies of the mesofauna groups (Krebs, 1999; Battigelli et. al., 2004; Miller, et. al., 2017). Density (number of individuals per sample) and relative abundance ((number of individuals per taxon/total individuals collected in the sample) × 100) of mesofauna were used in analyses. Density values are presented as the number of individuals/m^2 and relative abundances are presented as a percent of the total individuals/sample. All values are reported as mean ± standard error, unless stated otherwise (Battigelli, et. al., 2004).

Data were transformed to meet assumptions of normality before analyses; density data were log transformed (log10 (X + 1), where X = actual count of individuals for a taxon) and relative abundance data were arcsine transformed (arcsin $\sqrt{(p)}$, where p = relative abundance of the taxon). Variances were treated as equal in the analyses (Battigelli, et. al., 2004).

Data were analyzed using JMP 14 statistical software. Mesofauna groups were analyzed using a one-way ANOVA (treatment types). The hypothesis considered for the ANOVA test was that there was no difference in density or relative abundance of soil mesofauna among different treatment types. A Tukey's Studentized range test was used to determine where significant differences, if present, were among treatment types. The intent of the analyses was to establish a baseline data set of soil mesofauna communities among treatment types at these locations to determine if it is possible to construct a biologically-relevant trajectory of soil quality recovery in reclaimed areas. It may be possible to use these data and results to inform future research projects that seek to understand reclamation best practices and ecosystem recovery.

The chemical data collected in this study were compared among the treatment types, to determine if there were any significant changes in soil chemistry based on disturbances. An

ANOVA test using JMP 14 was used to test the hypothesis that there was no significant difference in soil chemistry criteria among disturbance types. The intent of this analysis was to determine if the changes in soil chemistry could potentially be related to the treatment type and by extension be a possible explanation of any changes found in mesofauna communities.

Soil chemical criteria were also analyzed with specific mesofauna groups identified in this study in order to identify any potential correlations between mesofauna and soil chemistry criteria. Regression analyses were performed in Excel to compare the response of densities of mesofauna numbers to SAR, EC, and pH in the different soil textures. These parameters were chosen due to regulatory requirements set in place by the AER (AER, 2016). R-squared values indicate how the data followed the regression line, with 1.00 score indicating all the variability in the data was captured by the model. The F-value along with the probability of F indicate the strength and significance of the relationships in the regression analyses.

Results

Mean densities of total mesofauna in soils on the study site differed significantly among the treatment types, with similar declines in densities from natural and cleared sites to reclaimed sites. The decline in densities from natural and cleared sites to reclaimed sites was similar in both CTS and FTS (See Figure 2).

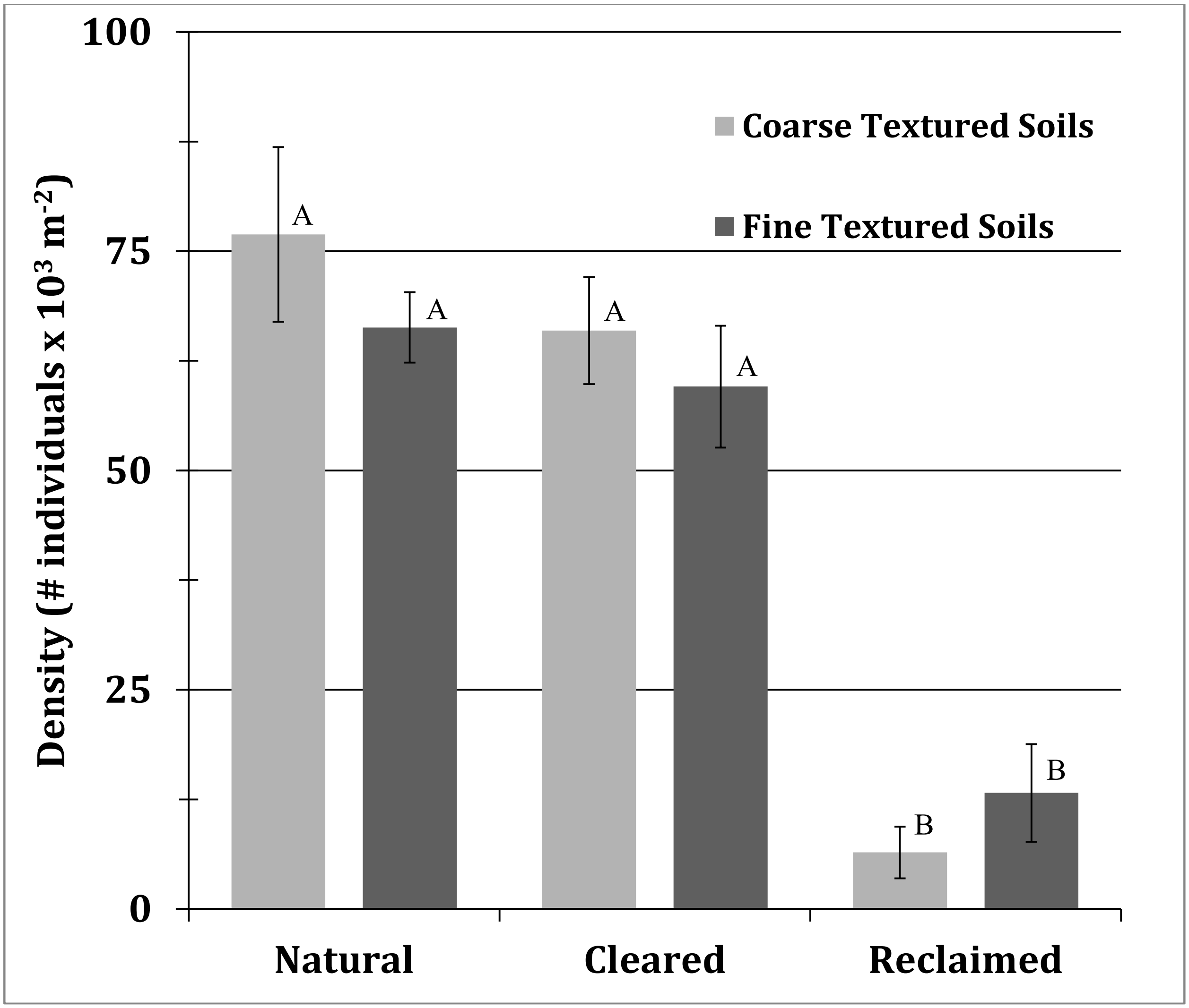

Figure 2. Total Mean Densities of Mesofauna Amoung Treatment Types grouped by CTS and FTS. (Different upper-case letters represent significant difference ($P \leq 0.05$ within soil texture only) (Tukey test)).

Fine Textured Soils (FTS)

Total mesofauna densities in FTS were reduced fivefold in reclaimed sites compared to natural sites ($F= 79.7506$, $p<0.0001$) (See Table 1 and Figure 2). Densities in cleared sites did not differ significantly from natural sites.

Total Acari densities differed significantly among the treatments, with densities nearly 4 times higher in natural and cleared sites than in reclaimed sites ($F=68.9286$, $p<0.0001$). Oribatida ($F=61.543$, $p<0.0001$) and Prostigmata ($F=35.6238$, $p<0.0001$) mean densities in natural and cleared sites were also significantly greater than densities in reclaimed sites. Oribatid and prostigmatid mite densities had the same pattern as total Acari densities among treatments. Mean densities of Mesostigmata ($F=61.9248$, $p<0.0001$) differed significantly among all three treatments with values highest in natural sites (4,878/m^2), followed by cleared sites (3,109/m^2), and lowest values in reclaimed sites (178/m^2) (See Table 1).

Mean density of total Collembola ($F=61.2047$, p<0/0001) also differed significantly among treatments with densities in natural and cleared sites (8,942/m^2 and 5,868/m^2 respectively) 20 to 30 times higher than in reclaimed sites (314/m^2). Within Collembola, there were some striking differences between families and their densities among the treatment sites. Hypogastruridae ($F=8.8857$, $p=0.0003$) and Onychiuridae ($F=10.8975$, $p<0.0001$) had lower densities in reclaimed sites compared to natural and cleared sites. Sminthuridae ($F=7.0683$, $p=0.0014$) had a mean density in natural sites more than 10 times higher than mean densities in cleared or reclaimed sites. Isotomidae ($F=2.0579$, $p<0.0001$) had a mean density in natural sites nearly five times higher than the mean density in cleared sites. Isotomidae also had a mean density in cleared sites that was ten times higher than the mean density in reclaimed sites.

However, densities of both Entomobryidae and Neelidae did not differ significantly among treatment types. (See Table 1).

Densities of other mesofauna ($F=10.8975$, $p<0.0001$) in natural sites differed significantly from cleared and reclaimed sites. Mean density of other mesofauna in natural sites was 1,769/m^2 and 1,467/m^2 in cleared sites while only 516/m^2 in reclaimed sites (See Table 1).

Table 1. *Summary of Mean Densities (# Individuals/m^2 ± SE) Among Treatment Types Within Fine Textured Soils (FTS).*

		Natural			Cleared			Reclaimed		
Acari		55,587	±6,260	A	52,467	±6,260	A	12,396	±5,019	B
	Oribatida	40,963	±3,058	A	30,460	±5,296	A	8,443	±4,246	B
	Prostigmata	9,746	±1,353	A	18,898	±2,344	A	3,773	±1,879	B
	Mesostigmata	4,879	±403	A	3,109	±697	B	180	±559	C
Collembola		8,942	±1,032	A	5,868	±1,787	A	314	±1,433	B
	Entomobryidae	163	±56	A	140	±97	A	0		A
	Hypogastruridae	2,317	±829	A	3,039	±1,435	A	45	±1,151	B
	Isotomidae	5,170	±549	A	1,397	±951	B	112	±762	C
	Neelidae	12	±9		0			0		
	Onychiuridae	955	±223	A	1,292	±386	A	135	±309	B
	Sminthuridae	326	±63	A	0		B	22	±87	B
Other mesofauna		1,770	±259	A	1,467	±492	B	516	±360	B
Total mesofauna		66,299	±4,014	A	59,558	±6,953	A	13,226	±5,575	B

*Means ± (SE) followed by different upper-case letter (by row only) are significantly different ($P \leq 0.05$) (Tukey test)

Relative abundance of total Acari did not differ significantly among the treatment types. However, within Acari, both prostigmatid ($F=4.8975$, $p=0.0094$) and mesostigmatid ($F=24.5159$, $p<0.0001$) mites had relative abundances that changed significantly with treatment type. Prostigmatid mites were nearly twice as abundant in reclaimed sites than in natural sites. While mesostgmatid mites dropped from 7% in natural sites to 2% in reclaimed sites. Relative abundance of oribatid mites did not differ significantly among natural, cleared, or reclaimed sites (59, 51, and 48% respectively) (See Table 2).

Relative abundance of Collembola ($F=16.7587$, $p<0.0001$) was significantly higher in natural and cleared sites than in reclaimed sites. Collembola in reclaimed sites (6%) was about half of the abundance Collembola found in natural sites (13%). Within Collembola, only Hypogastruridae ($F= 5.2694$, $p= 0.0067$) and Isotomidae ($F= 32.3383$, $p< 0.0001$) experienced any significant changes in their relative abundances. Hypogastruridae declined in their relative abundance from 3% in natural sites and 5% in cleared sites to 1% in reclaimed sites. Relative abundance of Isotomidae was four times lower in cleared (2%) and reclaimed (2%) sites than in natural sites (8%). Mean relative abundances of Entomobryidae, Sminthuridae, Onychiuridae, and Neelidae did not differ significantly among any of the treatments (See Table 2).

Despite a relative abundance of 3% in both natural and cleared sites and 9% in reclaimed sites (See Table 2). There was no significant difference between the treatment types for other mesofauna due to the low abundances of other mesofauna coupled with the higher variability seen in the standard error.

Table 2. *Comparison of Mean Relative Abundances (% of Total Fauna ± SE) Among Treatment Types Within Fine Textured Soils (FTS).*

	Natural			Cleared			Reclaimed		
Acari	83.77%	±2.04%	A	87.93%	±3.52%	A	85.02%	±2.83%	A
Oribatida	59.41%	±3.13%	A	51.07%	±5.42%	A	48.70%	±4.34%	A
Prostigmata	17.24%	±2.71%	B	30.86%	±4.70%	AB	33.89%	±3.77%	A
Mesostigmata	7.13%	±0.69%	A	6.01%	±1.19%	A	2.44%	±0.96%	B
Collembola	13.30%	±1.40%	A	9.45%	±2.42%	A	5.53%	±1.94%	B
Entomobryidae	0.26%	±0.11%		0.38%	±0.20%		0%		
Hypogastruridae	3.16%	±0.98%	A	5.15%	±1.69%	A	1.02%	±1.36%	B
Isotomidae	7.78%	±0.81%	A	1.60%	±1.41%	B	1.96%	±1.13%	B
Neelidae	0.01%	±0.01%		0%			0%		
Onychiuridae	1.53%	±0.53%	A	2.27%	±0.92%	A	2.04%	±0.74%	A
Sminthuridae	0.56%	±0.24%	A	0.05%	±0.42%	A	0.51%	±0.34%	A
Other Mesofauna	2.93%	±1.60%	A	2.62%	±2.78%	A	9.45%	±2.23%	A

*Mean relative abundances ± (SE) followed by different upper-case letter (by row only) differed significantly among treatment sites ($P \leq 0.05$) (Tukey test)

Mesofauna categories without an upper-case letter associated with them were not subjected to an ANOVA test, as the abundances of the mesofauna were too low.

Coarse Textured Soils (CTS)

Total mesofauna densities (F= 54.7869, p<0.0001) in natural (77,000/m^2) and cleared (66,000/m^2) sites were significantly higher by about ten times than in reclaimed (6,000/m^2) sites (See Table 3 and Figure 2).

In CTS, mean density of Acari (F= 54.5864, p< 0.0001) in reclaimed sites (5,687/m^2) was over ten times lower than mean densities found in both natural (67,592/m^2) and cleared sites (57,846/m^2). Oribatid mites (F= 52.124, p<0.0001) followed a similar trend with a significantly lower mean density in reclaimed sites (3,190/m^2) than in natural (51,663/m^2) or cleared sites (36,468/m^2). However, mean densities of Prostigmatid mites (F= 10.6365, p< 0.0001) in cleared sites (18,037/m^2) were twice that of natural sites (9,221/m^2) and nine times higher than reclaimed sites (2,357/m^2). Mesostigmatid mite (F= 13.6561, p<0.0001) mean densities in cleared sites (3,340/m^2) were significantly lower than natural sites (6,707/m^2) and significantly higher than density values in reclaimed sites (139/m^2) (See Table 3).

Mean densities of Collembola (F= 36.094, p<0.0001) differed significantly among all three site types. Natural (8,500/m^2) sites were 40% higher than cleared (6,000/m^2) sites, while cleared sites were more than ten times higher than reclaimed (500/m^2) sites. There was no significant difference in Entomobryidae (F= 2.8121, p= 0.0655) mean density among the different site types in the study. Mean density of Hypogastruridae (F= 16.9541, p<0.0001) in natural (1,300/m^2) sites were three times higher than in cleared (400/m^2) sites and over seven times higher than in reclaimed (60/m^2) sites. Densities of Sminthuridae (F= 20.3, p<0.0001) in natural (210/m^2) sites were 200 times higher than mean densities in cleared (0/m^2) and reclaimed (0/m^2) sites. Isotomidae (F= 31.5812, p< 0.0001) had a higher mean density in natural (4,297/m^2)

sites than in cleared (2,712/m^2) sites, and mean density in reclaimed (138/m^2) sites were significantly lower than in cleared sites. Neelidae ($F= 5.1095$, $p= 0.008$) had a significantly higher mean density in cleared (79/m^2) sites compared to natural and reclaimed sites, which were both at 0 individuals per m^2. Onychiuridae ($F= 9.4568$, $p= 0.0002$) densities in natural (2,410/m^2) and cleared (2,751/m^2) sites were similar to each other, and significantly higher than densities in reclaimed (296/m^2) sites (See Table 3).

Mean densities of other mesofauna ($F= 14.5333$, $p< 0.0001$) in natural sites did not differ significantly from either cleared or reclaimed sites. However, mean densities in cleared sites were ten times higher in cleared sites than in reclaimed sites (See Table 3).

Table 3. *Comparison of Mean Densities (# Individuals/m² ± SE) Among Treatment Types Within Coarse Textured Soils (CTS).*

		Natural			Cleared			Reclaimed		
Acari		67,592	±8,995	A	57,846	±5,508	A	5,687	±2,672	B
	Oribatida	51,663	±7,013	A	36,468	±4,294	A	3,190	±2,083	B
	Prostigmata	9,222	±4,316	B	18,038	±2,643	A	2,358	±1,282	B
	Mesostigmata	6,707	±986	B	3,340	±604	A	139	±293	B
Collembola		8,488	±2,075	A	6,013	±1,271	B	518	±616	C
	Entomobryidae	314	±93	A	39	±57	A	28	±27	A
	Hypogastruridae	1,258	±238	A	432	±146	B	55	±71	B
	Isotomidae	4,297	±984	A	2,712	±602	B	139	±292	C
	Neelidae	0		AB	79	±22	A	0		B
	Onychiuridae	2,410	±1,236	A	2,751	±757	A	296	±367	B
	Sminthuridae	210	±32	A	0		B	0		B
Other Mesofauna		838	±624	AB	2,083	±382	A	231	±185	B
Total mesofauna		76,918	±9,963	A	65,941	±6,101	A	6,436	±2,959	B

*Means ± (SE) followed by different upper-case letter (by row only) are significantly different ($P \leq 0.05$) (Tukey test)

The relative abundance of total Acari ($F= 1.7457$, $p= 0.1806$) in CTS did not differ significantly among treatment types. Proportions of oribatid mites ($F= 5.1648$, $p= 0.0076$) were significantly higher, by roughly 20%, in cleared sites compared to reclaimed sites. Natural sites did not differ significantly from either reclaimed or cleared sites. Prostigmatid mites ($F= 0.7447$, $p= 0.4779$) had no significant difference in relative abundances among treatment types. While mesostigmatid mites ($F= 4.342$, $p= 0.0159$) differed significantly in their relative abundances, the Tukey Studentized test could not distinguish where the difference lay among the sites (See Table 4).

Relative abundance of total Collembola ($F= 0.7064$, $p= 0.4962$) in CTS did not differ significantly among treatment types. Entomobryidae ($F= 0.4327$, $p= 0.6501$), Hypogastruridae ($F= 0.8753$, $p= 0.4204$), and Onychiuridae ($F= 0.1748$, $p=0.8399$) did not differ significantly among treatment types. While relative abundance of Isotomidae ($F= 3.1176$, $p= 0.0492$) differed significantly among treatments, the Tukey test was not able to determine where the differences were. Neelidae ($F= 5.1095$, $p= 0.008$) had a relative abundance in cleared sites that was significantly higher than in reclaimed sites, but the relative abundance of Neelidae in natural sites did not differ significantly from either cleared or reclaimed sites (See Table 4).

Proportions of other mesofauna ($F= 0.0957$, $p= 0.9089$) in the CTS, did not differ significantly among the three treatments (See Table 4). Relative abundances of other mesofauna were all below 10% with high standard error values.

Table 4. *Comparison of Mean Relative Abundances (% of Total Fauna ± SE) Among Treatment Types Within Coarse Textured Soils (CTS).*

		Natural			Cleared			Reclaimed		
Acari		87.19%	±12.07%	A	90.65%	±7.39%	A	80.74%	±3.58%	A
	Oribatida	67.22%	±12.62%	AB	54.45%	±7.73%	A	36.32%	±3.75%	B
	Prostigmata	11.61%	±13.22%	A	30.71%	±8.10%	A	40.80%	±3.93%	A
	Mesostigmata	8.35%	±4.83%	A	5.49%	±2.96%	A	3.62%	±1.44%	A
Collembola		11.84%	±6.27%	A	6.93%	±3.84%	A	11.98%	±1.86%	A
	Entomobryidae	0.42%	±0.42%	A	0.27%	±0.26%	A	0.21%	±0.13%	A
	Hypogastruridae	1.70%	±3.17%	A	0.63%	±1.94%	A	2.13%	±0.94%	A
	Isotomidae	5.98%	±3.32%	A	3.12%	±2.03%	A	3.07%	±0.99%	A
	Neelidae	0%			0.16%	±0.05%		0%		
	Onychiuridae	3.51%	±4.73%	A	2.75%	±2.89%	A	6.58%	±1.40%	A
	Sminthuridae	0.23%	±0.04%		0%			0%		
Other Arthropods		0.97%	±5.89%	A	2.42%	±3.61%	A	7.28%	±1.75%	A

*Mean relative abundances ± (SE) followed by different upper-case letter (by row only) differed significantly ($P \leq 0.05$) (Tukey test)

Mesofauna categories without an upper-case letter associated with them were not subjected to an ANOVA test as the abundances of the mesofauna were too low.

Chemistry

Analysis of chemical data for both FTS and CTS revealed significant differences in SAR, pH, and EC among treatments, except for SAR in CTS. For all three variables, natural soil values were significantly lower than values in reclaimed soils (See Table 5). Cleared site values were between natural and reclaimed site values except for pH in CTS where pH values for cleared and reclaimed sites were both higher (6.5 and 6.2, respectively) than natural sites (5.08). None of the sites demonstrated any increases in soil salinity or sodicity outside the ranges seen the natural reference sites, indicating that migration of saline water from the overburden structures had not affected the soils sampled in the study.

Table 5. *Comparison of Mean Sodium Adsorption Ratio (SAR), pH, and Electrical Conductivity (EC) (dS/m^{-1}) Values in Natural, Cleared, and Reclaimed Treatment Types Grouped by Coarse Textured Soil (CTS) and Fine Textured Soil (FTS).*

Soil Texture	FTS								CTS							
Treatment Type	Natural		Cleared		Reclaimed				Natural		Cleared		Reclaimed			
SAR	0.59	±1.13	0.77	±0.78	1.69	±1.15	***		0.31	±0.10	0.67	±1.02	0.76	±0.37		
pH	5.50	±0.61	5.27	±0.58	7.06	±0.09	***		5.08	±0.38	6.59	±0.39	6.28	±0.54	***	
EC (dS/m^{-1})	0.41	±0.04	0.41	±0.06	0.95	±0.14	***		0.43	±0.02	0.55	±0.04	1.12	±0.97	*	

* Indicates level of significance of $p < 0.05$
*** Indicates level of significance of $p < 0.0001$

The regression analyses completed on the mesofauna density against chemistry data revealed some significant results, but R^2 values were too low to indicate strong relationships among the variables (See Tables 6 and 7). With the taxonomic analysis done at a coarse level of specificity, there was not enough information available to correlate chemistry data to mesofauna that were collected. Coarse level of identification was used due to limited time and money to learn or pay for identification to be completed. Species-level determinations might allow for a more rigorous analysis of chemistry because certain species of soil mesofauna have variable tolerance to soil chemistry.

Regression analyses of soil mesofauna group density against soil chemistry parameters in the coarse textured soils presented a few significant correlations between changing chemistry and mesofauna densities (See Table 6.) Notably, SAR had a moderately significant ($p < 0.05$) correlation to Other Mesofauna, but with an R^2 value of less than 0.05. There was also a weak correlation ($p < 0.10$) between Acari ($F = 2.94$) and SAR with an R^2 value of 0.03. EC only indicated moderate correlations ($p < 0.05$) with Acari ($F = 5.75$) and Oribatida ($F = 5.02$), with R^2 values of 0.06 and 0.05 respectively. Significant correlation ($p<0.005$) were noticed between pH and Acari ($F = 23.40$) and Collembola ($F = 10.48$) numbers, although the R^2 values were both below 0.25. Both Hypogastruridae ($F = 4.75$) and Sminthuridae ($F = 7.54$) had moderately significant correlations to pH, but again both R^2 values were less than 0.08. The weak R^2 values indicated that the correlations found did not strongly follow the regression trends, in other words, only a small portion (<25%) of the data follow the trends.

Table 6. *Summary of Regression Analyses Results of Mesofauna Density Against Selected Soil Chemistry Data in Coarse Textured Soils.*

	SAR			EC (dS/m)			pH		
	F (df=1,88)		R^2 Value	F (df=1,88)		R^2 Value	F (df=1,88)		R^2 Value
Acari	2.94	*	0.03	5.75	**	0.06	29.40	***	0.25
Oribatida	2.58		0.03	5.02	**	0.05	0.50		0.01
Mesostigmata	1.06		0.01	2.15		0.03	0.20		0
Prostigmata	1.31		0.02	2.51		0.02	0.47		0.01
Collembola	0.03		0	1.07		0.01	10.48	***	0.11
Entomobryidae	0.80		0.01	1.90		0.02	2.15		0.02
Hypogastruridae	0.97		0.01	2.64		0.03	4.75	**	0.05
Isotomidae	0.07		0	1.13		0.01	0.51		0.01
Neelidae	0.23		0	0.42		0.01	1.76		0.02
Onychiuridae	0.46		0.01	0.21		0	0.01		0
Sminthuridae	1.41		0.02	0.96		0.01	7.54	**	0.08
Other Mesofauna	4.53	**	0.05	1.63		0.02	0.31		0

* Indicates level of significance of $p < 0.1$
** Indicates level of significance of $p < 0.05$
*** Indicates level of significance of $p < 0.005$

Table 7. *Summary of Regression Analyses Results of Mesofauna Density Against Selected Soil Chemistry Data in Fine Textured Soils*.

	SAR			EC (dS/m)			pH		
	F (df=1,95)		R^2 Value	F (df=1,95)		R^2 Value	F (df=1,95)		R^2 Value
Acari	2.22		0.02	14.24	***	0.13	23.40	***	0.20
Oribatida	2.08		0.02	12.91	***	0.12	17.76	***	0.16
Mesostigmata	5.35	**	0.05	28.63	***	0.23	33.84	***	0.26
Prostigmata	0.06		0	0.75		0.01	4.06	**	0.04
Collembola	3.51	*	0.04	11.78	***	0.11	14.41	***	0.13
Entomobryidae	0.01		0	2.75		0.03	3.58	*	0.04
Hypogastruridae	0.36		0	1.84		0.02	3.47	*	0.04
Isotomidae	5.06	**	0.05	16.13	***	0.15	12.64	***	0.12
Neelidae	0.06		0	1.06		0.01	1.47		0.02
Onychiuridae	0.26		0	0.06		0	0.70		0.01
Sminthuridae	2.53		0.03	2.21		0.02	3.47	*	0.04
Other Mesofauna	8.27	***	0.08	3.69	*	0.04	1.21		0.01

* Indicates level of significance of $p < 0.1$
** Indicates level of significance of $p < 0.05$
*** Indicates level of significance of $p < 0.005$

Discussion

In FTS, densities of mesofauna ranged from 13,226 individuals/m^2 in reclaimed sites to 66,299 individuals/m^2 in natural sites. Densities of soil mesofauna in the CTS ranged from a low of 6,435 individuals/m^2 in reclaimed sites to a high of 76,918 individuals/m^2 in natural sites. Densities in both FTS and CTS natural sites were roughly similar to densities reported in other studies with mesofauna densities ranging from 50,000 to 100,000 individuals/m^2 in undisturbed boreal forest soils in the Fort McMurray region (Lindo and Visser, 2004; Battigelli, 2011; McAdams et. al., 2018). Overall, a short-term decline in mean densities of soil mesofauna on reclaimed sites was expected due to the significant impact of soil movement on soil ecosystem (Battigelli, et al. 2004), but there is more that can be extrapolated from the data collected.

Acari in both FTS and CTS were the most abundant taxa of soil mesofauna, with mean relative abundances over 80% on natural sites, similar to what has been found in many other studies (Battigelli, 2011; McAdams et. al., 2018; Santorufo, 2012). Higher abundances of Acari might be related to their tolerance for a wider range of soil moisture contents (Miller et. al., 2017). Studies have indicated a loss of mite abundance and an increase in Collembola abundance following anthropogenic disturbances, which were attributed to both soil conditions and the life strategies that each taxon exhibits (Miller et. al., 2017, Behan-Pelletier, 2003). Some mites are disturbance specialists, such as members of the suborder Prostigmata, and capable of recovering in densities rapidly following disturbances to the soils (Battigelli, 2011). Oribatida generally have a low tolerance to disturbance due to their life history as k-strategists, with long life spans, low metabolism, and low fecundity (Behan-Pelletier & Newton, 1999). The young age of reclamation sites in this study could explain the low relative abundance of Oribatid mites found in all the treatments. The limited time to recover from anthropogenic disturbance in this study may explain the lack of significant change among the abundances of oribatid mites.

Collembola were the second most abundant group of mesofauna found in the soil ecosystems of the northern boreal forest soils in this study similar to densities recorded in earlier studies (Battigelli et al, 2004; Battigelli, 2011). Previous studies have suggested a potential for their use as soil quality bioindicators (Parisi et. al., 2005; Miller et. al., 2017). Collembola have diverse, species-specific feeding patterns and species respond quickly to changes in nutrient availability and disturbances (Battigelli, 2011; Tsiafouli, Thebault, Sgardelis, DeRuiter, Van Der Putten, Birkenhofer, Hemerik, De Vries, Bardgett, Brady, Bjornlund, Jorgensen, Christensen, D'Hertefeld, Hotes, Gerahol, Frouz, Liiri, Mortimer, Setala, Tzanopoulos, Uteseny, Pizl, Stary, Wolters, & Hedlund, 2015). However, this would require more specific taxonomic identification of collected specimens than was carried out in this study. Due to budget and time constraints, this study was only able to identify Collembola to the family level. However, further taxonomic effort could help elucidate specific responses of collembolan species to varying soil conditions, as Collembola includes a great diversity of species, which are tolerant of a wide range of soil properties and conditions (McIntyre, Rango, Fagan, & Faeth, 2001; Santorufo et al., 2012).

The similarity in changes in mesofauna densities and relative abundances between different soil textures can be attributed to the disturbance of soils caused by oil sand mines. Disturbances to forest soil ecosystems can change soil moisture regimes, chemistry, organic matter composition, and compaction (Lindo & Visser, 2004). Due to the substantial disruption to soil ecosystems caused by mining oil sands, reclaimed soils will have significantly reduced soil mesofauna communities. During removal of soils from one location and their placement in another location as part of the reclamation process, soils undergo a great deal of disturbance.

Disturbance of soil greatly impacts the survivability of soil mesofauna, through physical injury to individual mesofauna, or alteration of the ecosystem to an extent that it is no longer suitable for mesofauna survival, via changes in moisture regimes, chemistry, and other soil fauna. Reclamation of below ground systems requires information on the structure and function of the biota populations before and after disturbance, in addition to documenting various abiotic factors of the soils. Soil texture can also be a significant determinant of mesofauna communities, as they require adequate pore space to survive (Miller et. al., 2017). Pore space influences soil moisture retention, food availability in the form of bacteria and fungi for mesofauna, and abundance of predators (Dervash, et. al., 2018).

Fine Textured Soil

Significant loss of density indicates that numbers of mesofauna in reclaimed sites have been heavily impacted by anthropogenic disturbance, but relative abundance remaining stable indicates that community structure has been retained to a certain degree in-spite of the disturbance. Recovery of populations of oribatid mites has previously been observed in many different soil ecosystems including oil sands (Majer, et. al., 2007; McAdams et. al., 2018). The different mesofauna groups (Acari, Collembola, and other) all responded with a similar decline in mean densities following disturbances from salvage and placement of soil during the reclamation process. Lower densities for all these groups in the short time frame of the study agrees with the hypothesis that mesofauna populations within reclaimed sites in the oil sands mines have been significantly affected. Disturbances caused by physically removing soils from in situ locations and placing them at reclamation sites reverts soil ecosystems to a primary succession state, where complex interactions usually found older growth forest soils have not yet developed. Recovery patterns of mesofauna communities to pre-disturbance densities in the long term will be important to monitor in order to ensure the development of locally common boreal forests.

Acari were the more dominant group found in the FTS of “d-ecosites” sampled in this study. They accounted for more than 80% of the total mesofauna in all three treatment types, which indicates that mites maintained high relative abundance despite reclamations effects on soils. This high abundance of mites over the other mesofauna, including Collembola, has been observed in findings from other studies (Miller et. al. 2017, Coleman, Crossley, & Hendrix, 2004). Among Acari, oribatid mites had the highest densities in reclaimed sites, which corresponds with a number of studies indicating the dominance of oribatid mites in undisturbed soil ecosystem (Blair, Todd, & Callaham, 2000; Santorufo, et. al., 2012; Miller, et. al. 2017). Prostigmatid mites had higher densities in cleared sites, with higher relative abundances, which has been observed in previous studies involving fire impacts on soils ecosystem (Blair, et. al., 2000). Lower densities of prostigmatid mites in the reclaimed sites are likely due to the recent completion of the reclamation on site, as many of the mesofauna populations will not have had a chance to recover towards pre-disturbance densities. Relative abundance of prostigmatid mites was significantly higher in reclaimed sites, which could indicate that their populations were not as heavily impacted during the movement of soil or that their populations were able to recover more rapidly compared to the other mesofauna groups. Prostigmatid mites include a number of species, some of which are r-strategists and others that are k-strategists (McAdams et. al., 2018). Mesostigmatid mites had densities that corresponded with the disturbance level, with a steady decline in densities from undisturbed natural sites to moderately disturbed cleared sites, followed by a further decline in density in completely disturbed reclaimed sites. These density patterns could correspond to the level of disturbance experienced or to the time that the areas have had to recover since the disturbance was created.

Hypogastruridae and Isotomidae were the dominant families of Collembola found in the FTSs, followed closely by Onychiuridae. Higher mean densities of Isotomidae and Onychiuridae in some soil ecosystems have been documented in the literature around agricultural soil, although, an abundance of Hypogastruridae was not observed (Miller, et. al., 2017). Of all the families of Collembola identified in this study, only Entomobryidae and Neelidae did not experience a significant decline in mean densities among treatment sites, possibly due to the low densities and high variability of these families found in this study. McAdams et. al. (2018) indicated that rarer mesofauna, such as neelids and entomobryids, can serve as more informative bioindicators in soil ecosystems recovering from disturbance. Mesofauna that are less abundant are more susceptible to disturbances and can take longer to recover to pre-disturbance densities. Recovery of mesofauna with low densities could indicate ecosystem recovery, as their numbers begin to increase in undisturbed forest soils. There are a variety of factors that can influence Collembola communities, including soil moisture content, bulk density, salinity, sodicity, and pH, all of which can be impacted by soil disturbances (Blair, et. al., 2000; Tsiafouli, at. al., 2015; Enriquez, Tejedo, Benayas, Albertos, & Lucianez, 2017; Miller, et. al., 2017). Collembola are susceptible to disturbance of soil ecosystems, which is likely the cause of the significant decline in their density and relative abundance in this study. While Collembola with r-strategy life histories should be expected to have higher densities in disturbed sites, this was not the case for reclaimed sites. Lower densities in reclaimed sites could be attributed to the age of the reclamation sites, having only been in place for a few months. Without a sufficient period of time following the disturbance event, mesofauna populations have not had time to recover their numbers, resulting in the low observed numbers.

Coarse Textured Soil

Similar to relative abundances of Acari in FTS, 80% of the mesofauna found in CTS were also Acari. Relative abundance of Collembola in CTS soils did not experience a similar decline in relative abundance as seen in FTS, despite the insignificant decline in density from cleared to reclaimed sites. Other mesofauna found in the study also experienced a similar decline in reclaimed sites compared to natural and cleared sites. The general pattern found in this study was that reclaimed sites had lower mean densities than cleared sites, and cleared sites had lower mean densities than natural sites.

Oribatid mites were the dominant Acari in both natural and cleared sites followed by prostigmatid mites, and then mesostigmatid mites. All three groups experienced a significant decline in density between cleared sites and reclaimed sites. This follows a similar pattern observed in a number of studies following disturbances to soil ecosystems (Battigelli et. al., 2004; Lindo & Visser, 2004; Miller et. al., 2017). Prostigmatid mite relative abundance was higher in cleared and reclaimed sites compared to natural sites, which is common for soil disturbances (Blair et. al., 2000). There are numerous mite groups that are disturbance specialists, such as astigmatid mites or species from the families of Brachychthoniidae, Tectocepheidae, and Oppiidae, and capable of recovering rapidly following disturbances, which could be attributed to the maintenance of stable community structure (Battigelli, 2004). Assessing Oribatida at a species level might provide more information on recovery of disturbed ecosystems, as oribatids are a more sensitive group of arthropods to disturbance (Behan-Pelletier and Newton, 1999; Dervash, et. al., 2018).

Collembola densities were decimated from thousands of individuals per square meter to mere hundreds in reclaimed sites. The dramatic reduction in densities may be a result of a sensitivity Collembola have to habitat changes that may include lack of food or changes to moisture regimes. Loss of density could also be related to the severity of the disturbance to the soil and the lack of time elapsed between the placement of reclamation material and when the sites were sampled. Without sufficient time between the movement of the soils and sampling for mesofauna, populations may not have had a chance for their life strategy of high fecundity to significantly increase their population densities. This trend was seen in the more abundant families of Collembola (Hypogastruridae, Isotomidae, and Onychiuridae), found in the CTS. A decline in Collembola populations corresponds to a number of studies that found that Collembola were sensitive to disturbances (Tsiafouli, et. al., 2015; Miller, et. al., 2017; Roy et. al., 2018). Collembola, being r-strategists in terms of life history, have been found to recover rapidly following disturbance of soil ecosystems, yet this was not observed in this study possibly due to the severity of the disturbance and the lack of time between disturbance and sampling of reclaimed sites (Miller et. al. 2017). However, Isotomidae and Onychiuridae both displayed rapid recovery of population densities when comparing reclaimed to cleared sites.

The other mesofauna did not change significantly in relative abundance; however, mean density was significantly higher in cleared sites compared to natural sites. There may be species within this group able to provide some indication of ecosystem function. For example, nematode species have been found to tolerate wide varieties of soil conditions, and have been linked to low Collembola populations, through competition or predation (Santorufo et. al., 2012). Further investigation into responses of nematodes may indicate recovery soil ecosystem function, but the techniques for mesofauna extraction were not designed for targeted sampling of nematodes. With the high diversity and low occurrences of some other soil mesofauna groups, it is difficult to conclude from the data in the present study if these groups would be adequate measures of soil ecosystem recovery. A more selective study with an inquiry into these specific groups may give better indications of population dynamics. For setting a baseline of these groups, the information gathered lends to a level of current densities within reclaimed sites and densities to target for determining a trajectory of recovery.

Chemistry

Studies have linked abundance and density of mesofauna taxa with various chemical and physical characteristics of soils, some linking changes in specific species population, such as *Oppia nittens,* with toxicity in soils (Santorufo et. al., 2012; Princz, Behan-Pelletier, Scroggins, & Siciliano, 2012). Salinity can alter mesofauna communities in soils treated with manure (Miller, et. al., 2017). There have also been positive correlations between mesofauna density and soil EC, as well as pH (Prinz, et. al. 2012, Miller et. al. 2017). Increases in SAR, pH, and EC in the FTSs (see Table 5) could be linked to changes seen in mesofauna communities. Due to the lack of samples for SAR, pH, and EC that had measurements outside the range seen in natural reference sites, and the guidelines imposed by the AER, it is impossible to make any firm conclusions regarding the effects of these chemical criteria on soil mesofauna in this study. Further field sampling and analysis of these parameters would be required in order to solidify any links between soil mesofauna and soil quality criteria. A longer-term study monitoring movement of saline or sodic water from overburden structures would give more indication of potential limitations around reclaiming overburden structures. While regression analyses were completed in this study, no significant correlations between mesofauna density and any of the chemical parameters were observed. The lack of correlation is possibly due to an insufficient number of chemistry data points that fall outside typical forest ecosystem. All of the sample locations from disturbed sites had SAR's, EC's, and pH's that were similar to those of natural sites. Another potential difficulty with chemical testing parameters and the connection to mesofauna could be that the samples are bulk grab samples of material which get mixed during the sampling and analysis processes. Mixing of samples leads to an average of chemical criteria for the entirety of the sample because mesofauna are such small organisms and sometimes inhabit small ranges in depth, average chemical data may not represent what mesofauna experience in undisturbed soils (Gullan & Cranston, 2005).

Lessons Learned and Future Research

There are a number of lines of inquiry that require more attention such as; climatic factors (weather events during the sampling, month that sampling was completed, year), more consistency in the timing and conditions of sample collection would have created more robust data. With more manpower and budget, there could have been more attention to sample timing that was not covered in this study. Further investigation into details such as soil moisture content and chemistry along with fungus and bacterial populations and potentially vegetation would create a more holistic representation of mesofauna communities.

The sampling of sites was timed so that only one year of reclamation was sampled and the year that these locations were sampled and the year the cleared and natural sites were sampled could have resulted in some differences in the observed mesofauna in the samples collected. There was also a lack of consistency in the seasonality of the sampling completed, ensuring that the samples were all collected at similar times of the year with similar weather patterns would help reduce any potential discrepancies in mesofauna present in the soils due to environmental factors. Ensuring that samples were collected from all three treatment types at in the same years and continuing to sample around the same time of the year would reduce the potential discrepancies due to environmental factors influencing mesofauna densities and abundances.

Vegetation communities were not assessed as part of this research because there is significant overlap in vegetation species and community structure across varying soil textures within the Boreal forest (Beckingham and Archibald, 1996). Studies, such as the one done by Work, Shorthouse, Spence, Volney, & Langor, (2004), have demonstrated a lack of correlation between epigeaic (surface dwelling) arthropods and mixed wood boreal forest stand cover. Additionally, vegetation growth and mesofauna communities are strongly tied to water supply, which is affected by climate, topography, soil texture, nutrient supply, and groundwater (Stepien et. al., 2015). Although, McAdams, et. al. (2018) found that there was a connection to aspen cover and oribatid mite recovery in boreal forests of northern Alberta, her study focused on species level identification rather than the broader communities. Studying these connections would require more rigorous inquiry in the form of more sites, samples, and parameters, such as moisture, vegetation, ages and types of disturbance, and climate, included in the study, as well as further statistical analysis.

Conclusion

Soil is a key component of global environmental sustainability issues like climate change, global water, energy, and food security, and biodiversity (Adhikari & Hartemink, 2016).

Anthropogenic activities around the world have significantly impacted terrestrial ecosystems and their ability to sustain those ecosystem services upon which we rely. The oil sand mines in northern Alberta boreal forests are such an anthropological development, and the forest soil ecosystems that are affected require a holistic method of assessing soil quality and recovery to help in deciding which management techniques are viable (Ludwig, Wilmes, & Schrader, 2018). Recovery and re-colonization of reclaimed soil by mesofauna will require an understanding of which organisms are present prior to disturbance and how soil conditions influence mesofauna community development. Mesofauna have species specific responses to biotic and abiotic properties of soil, therefore more attention to species is required (Widenfalk, Leinaas, Bengtsson, & Birkemoe, 2018). Both Collembola and oribatid mites, such as *Folsomia candida, Pilogalumna sp., Ceratoppia quadridentate arctica, Oribatodes mirabilis, Oppia nittens*, have been identified as potential candidates for a more rapid and accurate assessment of soil quality conditions (Princz, et. al., 2010; Miller, et. al, 2017; McAdams, et. al., 2018).

This study found that assemblages of mesofauna found in natural reference sites were similar to the mesofauna assemblages following disturbance. Maintenance of the community structure in reclaimed sites is important as they represent similar ecosystem relationships found in natural sites. It also indicates that there was likely no immigration of mesofauna from other sources, and that ecosystem function recovery will have to rely on these assemblages of mesofauna recovering naturally over time.

The lack of correlation found between chemical parameters of the soil to mesofauna present indicates that there may be other more important criteria for determining recovery of the soil ecosystems in reclaimed sites on oil sands leases.

Soil mesofauna are an integral part of soil ecosystems around the world, through decomposition of organic material, consumption of fungi, and linkage to higher trophic levels. (Dervash et. al. 2018). Understanding community structure and composition of soil mesofauna will enhance insight into soil ecosystems functioning that current vegetation and chemical analyses may not provide. Further study is required to assess the impact of long-term anthropogenic activities in these soil ecosystems in order to develop a faster way to identify successful recovery in these disturbed environments.

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Appendix A: Sample location points and related texture and treatment information.

Table A-1

Summary of Sample Sites and Attributes Associated with Each Sites (Sample ID Number, Year, Latitude, Longitude, Texture, and Treatment).

Sample ID	Sample Year	Latitude	Longitude	Soil Texture	Treatment
16-1-28	2016	57.31227	-111.796	CTS	Cleared
16-1-38	2016	57.32978	-111.733	CTS	Cleared
16-21	2016	57.31050	-111.782	CTS	Cleared
16-2-16	2016	57.30796	-111.807	CTS	Cleared
16-2-28	2016	57.31227	-111.796	CTS	Cleared
16-23	2016	57.31181	-111.786	CTS	Cleared
16-2-38	2016	57.32978	-111.733	CTS	Cleared
16-27	2016	57.31407	-111.791	CTS	Cleared
16-29	2016	57.30791	-111.794	CTS	Natural
16-31	2016	57.31644	-111.740	CTS	Cleared
16-32	2016	57.31721	-111.733	CTS	Cleared
16-33	2016	57.31635	-111.732	CTS	Cleared
16-34	2016	57.30846	-111.730	CTS	Cleared
16-37	2016	57.31706	-111.706	CTS	Cleared
16-42	2016	57.33933	-111.709	CTS	Cleared
16-43	2016	57.34015	-111.709	CTS	Cleared
16-46	2016	57.35660	-111.732	CTS	Cleared
16-49	2016	57.35642	-111.733	CTS	Cleared
16-50	2016	57.35611	-111.735	CTS	Cleared
16-1	2016	57.38436	-111.939	FTS	Cleared
16-10	2016	57.35933	-111.958	FTS	Cleared
16-11	2016	57.32515	-111.856	FTS	Natural
16-1-17	2016	57.30968	-111.807	FTS	Cleared
16-12	2016	57.32632	-111.853	FTS	Natural
16-13	2016	57.32629	-111.855	FTS	Natural
16-14	2016	57.32629	-111.851	FTS	Natural
16-1-41	2016	57.32629	-111.851	FTS	Natural
16-15	2016	57.31093	-111.849	FTS	Natural
16-16	2016	57.30796	-111.807	CTS	Cleared
16-18	2016	57.31147	-111.850	FTS	Natural
16-19	2016	57.31299	-111.800	FTS	Cleared

Sample ID	Sample Year	Latitude	Longitude	Soil Texture	Treatment
16-2	2016	57.38554	-111.937	FTS	Natural
16-20	2016	57.30684	-111.804	FTS	Natural
16-22	2016	57.30912	-111.787	FTS	Cleared
16-24	2016	57.31050	-111.790	FTS	Cleared
16-2-41	2016	57.31050	-111.790	FTS	Cleared
16-25	2016	57.31145	-111.802	FTS	Cleared
16-26	2016	57.30955	-111.796	FTS	Cleared
16-3	2016	57.38653	-111.933	FTS	Natural
16-30	2016	57.30915	-111.799	FTS	Cleared
16-36	2016	57.31621	-111.710	FTS	Cleared
16-4	2016	57.38020	-111.911	FTS	Cleared
16-44	2016	57.33850	-111.709	FTS	Cleared
16-45	2016	57.33766	-111.708	FTS	Cleared
16-47	2016	57.35421	-111.735	FTS	Natural
16-48	2016	57.35384	-111.733	FTS	Natural
16-5	2016	57.37796	-111.959	FTS	Cleared
16-6	2016	57.38323	-111.923	FTS	Cleared
16-7	2016	57.38113	-111.905	FTS	Cleared
16-8	2016	57.37307	-111.958	FTS	Cleared
16-9	2016	57.36642	-111.958	FTS	Cleared
17-40	2017	57.38565	-111.902	FTS	Natural
17-1	2017	57.38741	-111.929	CTS	Natural
17-30	2017	57.38590	-111.975	CTS	Natural
17-31	2017	57.38411	-111.972	CTS	Natural
17-36	2017	57.38140	-111.980	CTS	Natural
17-5	2017	57.38651	-111.929	CTS	Natural
17-10	2017	57.38650	-111.935	FTS	Natural
17-11	2017	57.39546	-111.949	FTS	Natural
17-12	2017	57.39547	-111.945	FTS	Natural
17-13	2017	57.39457	-111.947	FTS	Natural
17-14	2017	57.39637	-111.945	FTS	Natural
17-15	2017	57.39367	-111.949	FTS	Natural
17-16	2017	57.39277	-111.947	FTS	Natural
17-17	2017	57.39636	-111.950	FTS	Natural
17-18	2017	57.39368	-111.944	FTS	Natural
17-19	2017	57.39187	-111.947	FTS	Nautral
17-2	2017	57.38741	-111.934	FTS	Natural

Sample ID	Sample Year	Latitude	Longitude	Soil Texture	Treatment
17-20	2017	57.39094	-111.967	FTS	Natural
17-21	2017	57.39094	-111.969	FTS	Natural
17-22	2017	57.39094	-111.970	FTS	Natural
17-23	2017	57.39095	-111.965	FTS	Natural
17-24	2017	57.39175	-111.969	FTS	Natural
17-25	2017	57.39175	-111.970	FTS	Natural
17-26	2017	57.39144	-111.972	FTS	Natural
17-27	2017	57.39222	-111.971	FTS	Natural
17-28	2017	57.39276	-111.973	FTS	Natural
17-29	2017	57.39035	-111.968	FTS	Natural
17-3	2017	57.38650	-111.937	FTS	Natural
17-32	2017	57.38231	-111.973	FTS	Natural
17-33	2017	57.38231	-111.977	FTS	Natural
17-34	2017	57.38141	-111.975	FTS	Natural
17-35	2017	57.38051	-111.977	FTS	Natural
17-37	2017	57.37961	-111.980	FTS	Natural
17-38	2017	57.37871	-111.980	FTS	Natural
17-39	2017	57.38141	-111.978	FTS	Natural
17-4	2017	57.38650	-111.940	FTS	Natural
17-41	2017	57.38475	-111.902	FTS	Natural
17-42	2017	57.38476	-111.899	FTS	Natural
17-43	2017	57.38387	-111.894	FTS	Natural
17-44	2017	57.38477	-111.892	FTS	Natural
17-45	2017	57.38656	-111.892	FTS	Natural
17-46	2017	57.38385	-111.905	FTS	Natural
17-47	2017	57.38566	-111.897	FTS	Natural
17-48	2017	57.38566	-111.894	FTS	Natural
17-49	2017	57.38567	-111.887	FTS	Natural
17-6	2017	57.38561	-111.934	FTS	Natural
17-7	2017	57.38651	-111.934	FTS	Natural
17-8	2017	57.38741	-111.930	FTS	Natural
17-9	2017	57.38650	-111.939	FTS	Natural
18-E-1	2018	57.31394	-111.933	CTS	Reclaimed
18-E-11	2018	57.36835	-111.860	CTS	Reclaimed
18-E-12	2018	57.36880	-111.860	CTS	Reclaimed
18-E-13	2018	57.36925	-111.860	CTS	Reclaimed
18-E-14	2018	57.36969	-111.860	CTS	Reclaimed

Sample ID	Sample Year	Latitude	Longitude	Soil Texture	Treatment
18-E-19	2018	57.31172	-111.915	CTS	Reclaimed
18-E-2	2018	57.31394	-111.932	CTS	Reclaimed
18-E-20	2018	57.31174	-111.900	CTS	Reclaimed
18-E-22	2018	57.31216	-111.918	CTS	Reclaimed
18-E-24	2018	57.31218	-111.903	CTS	Reclaimed
18-E-25	2018	57.31259	-111.932	CTS	Reclaimed
18-E-26	2018	57.31260	-111.930	CTS	Reclaimed
18-E-28	2018	57.31264	-111.894	CTS	Reclaimed
18-E-32	2018	57.31309	-111.894	CTS	Reclaimed
18-E-33	2018	57.31349	-111.932	CTS	Reclaimed
18-E-4	2018	57.31216	-111.919	CTS	Reclaimed
18-E-46	2018	57.32344	-111.873	CTS	Reclaimed
18-E-5	2018	57.32344	-111.875	CTS	Reclaimed
18-E-50	2018	57.37014	-111.861	CTS	Reclaimed
18-E-6	2018	57.32389	-111.875	CTS	Reclaimed
18-E-8	2018	57.36790	-111.861	CTS	Reclaimed
18-E-9	2018	57.36790	-111.860	CTS	Reclaimed
18-N-1	2018	57.31394	-111.933	CTS	Reclaimed
18-N-11	2018	57.36835	-111.860	CTS	Reclaimed
18-N-12	2018	57.36880	-111.860	CTS	Reclaimed
18-N-13	2018	57.36925	-111.860	CTS	Reclaimed
18-N-14	2018	57.36969	-111.860	CTS	Reclaimed
18-N-19	2018	57.31172	-111.915	CTS	Reclaimed
18-N-2	2018	57.31394	-111.932	CTS	Reclaimed
18-N-20	2018	57.31174	-111.900	CTS	Reclaimed
18-N-22	2018	57.31216	-111.918	CTS	Reclaimed
18-N-24	2018	57.31218	-111.903	CTS	Reclaimed
18-N-25	2018	57.31259	-111.932	CTS	Reclaimed
18-N-26	2018	57.31260	-111.930	CTS	Reclaimed
18-N-28	2018	57.31264	-111.894	CTS	Reclaimed
18-N-3	2018	57.31216	-111.920	FTS	Reclaimed
18-N-32	2018	57.31309	-111.894	CTS	Reclaimed
18-N-33	2018	57.31349	-111.932	CTS	Reclaimed
18-N-4	2018	57.31216	-111.919	CTS	Reclaimed
18-N-5	2018	57.32344	-111.875	CTS	Reclaimed
18-N-6	2018	57.32389	-111.875	CTS	Reclaimed
18-N-8	2018	57.36790	-111.861	CTS	Reclaimed

Sample ID	Sample Year	Latitude	Longitude	Soil Texture	Treatment
18-N-9	2018	57.36790	-111.860	CTS	Reclaimed
18-W-1	2018	57.31394	-111.933	CTS	Reclaimed
18-W-11	2018	57.36835	-111.860	CTS	Reclaimed
18-W-12	2018	57.36880	-111.860	CTS	Reclaimed
18-W-13	2018	57.36925	-111.860	CTS	Reclaimed
18-W-14	2018	57.36969	-111.860	CTS	Reclaimed
18-W-18	2018	57.31171	-111.919	FTS	Reclaimed
18-W-19	2018	57.31172	-111.915	CTS	Reclaimed
18-W-2	2018	57.31394	-111.932	CTS	Reclaimed
18-W-20	2018	57.31174	-111.900	CTS	Reclaimed
18-W-22	2018	57.31216	-111.918	CTS	Reclaimed
18-W-23	2018	57.31217	-111.917	FTS	Reclaimed
18-W-24	2018	57.31218	-111.903	CTS	Reclaimed
18-W-25	2018	57.31259	-111.932	CTS	Reclaimed
18-W-26	2018	57.31260	-111.930	CTS	Reclaimed
18-W-28	2018	57.31264	-111.894	CTS	Reclaimed
18-W-3	2018	57.31216	-111.920	FTS	Reclaimed
18-W-32	2018	57.31309	-111.894	CTS	Reclaimed
18-W-33	2018	57.31349	-111.932	CTS	Reclaimed
18-W-4	2018	57.31216	-111.919	CTS	Reclaimed
18-W-47	2018	57.32434	-111.874	CTS	Reclaimed
18-W-5	2018	57.32344	-111.875	CTS	Reclaimed
18-W-50	2018	57.37014	-111.861	CTS	Reclaimed
18-W-6	2018	57.32389	-111.875	CTS	Reclaimed
18-W-8	2018	57.36790	-111.861	CTS	Reclaimed
18-W-9	2018	57.36790	-111.860	CTS	Reclaimed
18-E-10	2018	57.36835	-111.861	FTS	Reclaimed
18-E-18	2018	57.31171	-111.919	FTS	Reclaimed
18-E-23	2018	57.31217	-111.917	FTS	Reclaimed
18-E-3	2018	57.31216	-111.920	FTS	Reclaimed
18-E-37	2018	57.31439	-111.933	FTS	Reclaimed
18-E-45	2018	57.32344	-111.875	FTS	Reclaimed
18-E-47	2018	57.32434	-111.874	FTS	Reclaimed
18-E-48	2018	57.36700	-111.861	FTS	Reclaimed
18-E-49	2018	57.36790	-111.862	FTS	Reclaimed
18-E-7	2018	57.36700	-111.861	FTS	Reclaimed
18-N-10	2018	57.36835	-111.861	FTS	Reclaimed

Sample ID	Sample Year	Latitude	Longitude	Soil Texture	Treatment
18-N-18	2018	57.31171	-111.919	FTS	Reclaimed
18-N-23	2018	57.31217	-111.917	FTS	Reclaimed
18-N-37	2018	57.31439	-111.933	FTS	Reclaimed
18-N-45	2018	57.32344	-111.875	FTS	Reclaimed
18-N-46	2018	57.32344	-111.873	FTS	Reclaimed
18-N-47	2018	57.32434	-111.874	FTS	Reclaimed
18-N-48	2018	57.36700	-111.861	FTS	Reclaimed
18-N-49	2018	57.36790	-111.862	FTS	Reclaimed
18-N-50	2018	57.37014	-111.861	CTS	Reclaimed
18-N-7	2018	57.36700	-111.861	FTS	Reclaimed
18-W-10	2018	57.36835	-111.861	FTS	Reclaimed
18-W-37	2018	57.31439	-111.933	FTS	Reclaimed
18-W-45	2018	57.32344	-111.875	FTS	Reclaimed
18-W-46	2018	57.32344	-111.873	FTS	Reclaimed
18-W-48	2018	57.36700	-111.861	FTS	Reclaimed
18-W-49	2018	57.36790	-111.862	FTS	Reclaimed
18-W-7	2018	57.36700	-111.861	FTS	Reclaimed