EFFECTS OF LAND RECLAMATION ON ORGANIC MATTER DECOMPOSITION AT SMELTER IMPACTED HILL SLOPES

by

Aparna Mukerji

A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science (M.Sc.) in Biology

The Faculty of Graduate Studies,
Laurentian University
Sudbury, Ontario, Canada

THESIS DEFENCE COMMITTEE/COMITÉ DE SOUTENANCE DE THÈSE
Laurentian Université/Université Laurentienne
Faculty of Graduate Studies/Faculté des études supérieures

Title of Thesis Titre de la thèse	EFFECTS OF LAND RECLAMATION ON ORGANIC MATTER DECOMPOSITION AT SMELTER IMPACTED HILL SLOPES	
Name of Candidate Nom du candidat	Mukerji, Aparna	
Degree Diplôme	Master of Science	
Department/Program Département/Programme	Biology	Date of Defence Date de la soutenance July 22, 2020

APPROVED/APPROUVÉ

Thesis Examiners/Examinateurs de thèse:

Dr. John Gunn
(Supervisor/Directeur(trice) de thèse)

Dr. Nathan Basiliko
(Committee member/Membre du comité)

Dr. Graeme Spiers
(Committee member/Membre du comité)

Approved for the Faculty of Graduate Studies
Approuvé pour la Faculté des études supérieures
Dr. David Lesbarrères
Monsieur David Lesbarrères
Dean, Faculty of Graduate Studies
Doyen, Faculté des études supérieures

Dr. Jeffrey Dech
(External Examiner/Examinateur externe)

ACCESSIBILITY CLAUSE AND PERMISSION TO USE

ABSTRACT

Mining, smelting and forest harvest led to severe environmental disturbances across Sudbury region, resulting in extensive forest cover loss, soil erosion and contamination with acids and metals. Regreening efforts began in 1978, by liming, fertilizing and tree planting. However little work has been done to assess the influence of reclamation practices on soil processes and functioning in these industrially damaged landscapes. In particular there is a lack of such information for hillslopes and other challenging sites. In view of this, the present study examined the effects of land reclamation on key ecosystem processes such as litter decomposition and soil respiration (CO_2) and CH_4 and N_2O fluxes and the ecological controls that regulate these processes. The study was conducted along two parallel transects, one within a barren area and the other within a regreened area at a steep hillslope within the Kelly lake watershed, a study site a few kms of the Copper Cliff smelter in Sudbury.

Traditional litter bag decomposition studies are time consuming, expensive, and lack standardization of litter quality. I therefore used a new Tea Bag Index methodology to measure early stage decomposition with two contrasting standardized substrates (Green and Rooibos tea). Tea bag Index parameters were used to quantify the rate at which standardized litter is broken down (decomposition rate index (k)) and to measure the undecomposed residual substrate in the soil (stabilization factor (S)) which has a potential for sequestration. The results revealed that decomposition of Green tea (labile substrate) was twice as fast as Rooibos tea (recalcitrant substrate) in both the reclaimed and barren areas. I found that at reclaimed areas the average Green tea mass loss rates (1.37 ± 0.01 (SE) gm), CO_2 production rates (98.84 ± 5.46 (SE) mg m^{-2} h^{-1}), CH_4 consumption rates (- 0.0104 ± 0.00 (SE) µg m^{-2} h^{-1}) were statistically higher than at barren areas, where the average Green tea mass loss were (1.25 ± 0.01 (SE) gm), CO_2 production rates were (33.79 ± 2.26 (SE) mg m^{-2} h^{-1}) and CH_4 flux rates were (0.0014 ± 0.001 (SE) µg m^{-2} h^{-1}) respectively. Average Rooibos tea mass loss on the other hand showed no significant differences occurred between reclaimed areas (0.69 ± 0.02 (SE) gm) and at barren areas (0.64 ± 0.02 (SE) gm). N_2O flux rates also did not differ significantly between reclaimed (-0.01048 ± 0.0006 (SE) µg m^{-2} h^{-1}) and barren areas and (-0.00073 ± 0.000452 (SE) µg m^{-2} h^{-1}). However, when the combined substrate measure of decomposition rate index (k) was compared, there was no significant differences between the reclaimed area soils (0.012 ± 0.001 (SE) $g \cdot g^{-1} \cdot day^{-1}$) and

the still barren untreated soils (0.013 ± 0.001 (SE) $g \cdot g^{-1} \cdot day^{-1}$). Only the Stabilization factor (S) proved to significantly different with a higher value for the barren soil (0.16 ± 0.009 (SE) $g\ g^{-1}$) than the reclaimed soil (0.09 ± 0.006 (SE) $g\ g^{-1}$) suggesting that the barren areas had slower decomposition resulting in a greater potential for accumulation of undecomposed organic matter in the soil. All soils tested proved to be sources of carbon dioxide. The reclaimed areas appeared to be small sinks for methane and nitrous oxide, whereas at barren areas results were less consistent and the soils appeared as likely to emit or consume methane and nitrous oxide fluxes.

My main finding was that land reclamation enhanced decomposition of labile substrates CO_2 production rates and CH_4 consumption rates but decomposition rate index (k) and soil respiration rates (CO_2) and CH_4, and N_2O fluxes were still very low compared to other less disturbed ecosystems. Stepwise multiple regression analysis revealed that decomposition of Green tea (labile substrate) was most likely influenced by microclimatic factors (i.e. moisture) and that decomposition and soil respiration (CO_2 production rates) decreased with increasing temperature at barren areas. Topography (i.e. elevation(m)) had little or no effect on carbon turnover rates across the study sites. In conclusion, land reclamation influenced key ecosystem processes such as decomposition of labile organic matter and soil respiration, but even after 37 years post-treatment, Sudbury soils in these hillslope sites were shown to be still under severe environmental stress.

Keywords

Mining, land reclamation, carbon, decomposition, soil respiration, Tea bag index

Acknowledgements

I would like to thank my supervisor Dr. John Gunn and my committee members Dr. Nathan Basiliko and Dr. Graeme Spiers for giving me this opportunity, for having faith in me and for supporting me throughout my journey. Thanks to Dr. Beckett, for helping me with my plant identification skills. Thank you to my external examiner, Dr. Jeffrey Dech for his valuable insight.

I am grateful to Aaron Rysdale, Kalpana KC, Lourdes Ortega, Claudia Ash, Emily Smenderovac, Robyn Rumney, Mikkealla Hurley for helping me with my field and lab work.

I would like to thank, Gerusa, Robyn, Katie, I am blessed to have wonderful friends who have stood by me through thick and thin, the friends who've become family. A big thanks to my friend Michelle Kalamandeen for sharing her GIS expertise and for all the wonderful fun times we've spent together.

I am grateful to my friend Richard, for always sharing his wisdom and joy with me, I thoroughly enjoyed our morning conversations.

I would like to extend my gratitude to my colleagues, Adam, James, Natalie, Sara and staff at the Living with the lake Centre.

Last but not the least, I would like to thank my parents for believing in my dreams, my life choices, my decisions and for standing by me for the last five years of living in Canada and more.

Financial support was provided by NSERC, Mine of Knowledge, L-CARE (Landscape Carbon Accumulation through Reductions in Emissions), Fisheries and Oceans Habitat and Restoration Scholarship and The Ontario Graduate Scholarship program.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

BA1/RE1 – Plot

T1 – Subsite

BA – Barren site

RE – Reclaimed site

R_s – Soil respiration

C/N – Carbon/ Nitrogen

CH_4 - Methane

CO_2 – Carbon-dioxide

N_2O – Nitrous-oxide

k – Decomposition rate index

S – Stabilization factor

SOC – Soil organic carbon

TBI – Tea Bag Index

Topography – Elevation gradient (m)

1.0 Introduction

Globally, ecosystems are being altered by the influence of multiple natural and anthropogenic factors (Kirby et al. 2009). Significant exchanges of carbon dioxide, methane and nitrous oxide occur naturally between terrestrial ecosystem and the atmosphere (Richardson et al., 2019). However, since the beginning of industrial revolution excessive concentrations of greenhouse gases have been emitted into the atmosphere due to burning of fossil fuels, industrial emissions, land use change and deforestation (IPCC, 2014). This has resulted in an increase of global temperature at an alarming rate of 0.17 °C/10 years (IPCC, 2001). With increasing concentrations of atmospheric greenhouse gases, in part influenced by ecosystem feedbacks to environmental changes, better understanding of the ability of trees and soils to sequester carbon is of great importance.

Soil respiration (R_s) is the largest source of terrestrial carbon efflux, emitting up to 80 Pg carbon into the atmosphere annually (Raich et al., 2002). R_s comprises combined heterotrophic respiration and autotrophic (root) respiration (Kuzyakov, 2006) and is often used as a biological indicator of soil health in terrestrial ecosystems (Bastida et al., 2008). Some of the main environmental drivers of soil respiration are temperature, moisture, oxygen, nutrient status, soil texture, soil pH, and substrate quality and availability, which is linked to gross and net primary production at different timescales (Luo and Zhou, 2006; Melillo et al., 2002). Previous studies have shown that fluctuations in climatic factors can have a profound impact on key ecosystem processes such as soil respiration (and interrelated organic matter decomposition), resulting in imbalance of ecosystem-level carbon exchange (Boone et al., 1998; Subke et al., 2006; Hartley et al., 2007). Moreover, the potential response of R_s to warming varies diurnally and annually (Davidson and Janssens, 2006). Thus, understanding the effect of environmental controls on soil respiration is crucial to predict climate feedback loops.

Autotrophic respiration contributes from 10% to 90% of total soil respiration, depending on seasonality and primary producer phenology, landscape characteristics and vegetation cover (Hanson et al., 2000). Trees store atmospheric carbon as biomass (aka primary production) as the net result of photosynthesis minus autotrophic respiration (Korner, 2000). Moreover, following senescence or through harvest slash, net primary production in the ecosystem eventually is transformed into aboveground and below ground litters that are mineralized or incorporated in to soil organic matter. In forests the bulk of plant biomass is composed primarily of easy decomposable components such as pectin, protein, starch and hard decomposable components including cellulose, hemicellulose, lignin, which are C-rich and macronutrient poor substrates for soil biota that carry out subsequent decomposition. (Averill, 2011).

Decomposition of organic matter is a biological process mediated through heterotrophic respiration that causes physio-chemical breakdown of complex polymers of dead material into simple organic and inorganic molecules, but also the formation of stable microbial-mediated humus compounds like polyuronic acids in processes that are still poorly understood. Decomposition represents a diverse range of biological, chemical and physical processes, leading to the recycling of nutrients within soils (Didion et al., 2016). Moreover, breakdown and transformation of labile and recalcitrant carbon compounds is an important step in the global terrestrial carbon cycling (Eichorst, 2012). Decomposition rates of leaf litter can vary with differences in nutrients, lignin and secondary metabolites in the litter. Consequently, there can be a wide range of soil organic matter quality in an area, primarily due to different forest vegetation composition (Berg, 2000; Binkley, 1995). Numerous studies have demonstrated that litter decomposition process can be inhibited by plant structural polysaccharides, cellulose, lignin and hemicellulose, which act as a protective barrier to microbial activity, reducing decomposition (Luna-Orea et al., 1996; Ranells and Wagger, 1996; Rosecrance et al., 2000). Furthermore, climatic conditions, soil texture, seasonal variations in moisture or temperature can all influence decomposition and release of nutrients (Jani et al., 2016; Vazquez et al., 2003).

Sequestration of carbon in soils is determined primarily by the balance between carbon input of litter fall, root turnover rates and decomposition by heterotrophic respiration. The residence time of carbon in the soil can vary from a few days to years (von Lützow et al., 2006). Earlier studies have shown that accumulation of soil carbon is vulnerable to environmental factors such as substrate quality, temperature, moisture, pH, nutrient availability (Sariyildiz et.al, 2003; Freeman et al., 2001).

In light of the ecosystem contexts described so far, soils play important roles in the global greenhouse effect and global climate system through the flux of multiple greenhouse gases. Heterotrophic respiration mediated by saprophytic organisms emits carbon dioxide (Basiliko et al., 2009 ; Laiho, 2006). Forest soils are small sources of N_2O and that nitrous oxide can be produced as an intermediate of aerobic autotrophic oxidation of N (nitrification) and when anaerobic reduction of nitrate is involved, can emit, and occasionally consume nitrous oxide (denitrification). Emission or consumption of N_2O flux rates are strongly controlled by soil moisture content (that regulates oxygen availability), nutrient availability, temperature, gas diffusivity and pH (Chapius-Lardy et al., 2007). Further, uplands soils are also typically slight sinks for methane through the activity of high affinity aerobic methane oxidizing bacteria (methanotrophy) that convert methane to carbon-dioxide and water. Methanotrophs are generally mesophilic microorganisms that prefer neutral pH range and soil moisture content, oxygen and nutrient availability are important factors that regulate methane consumption rates (LeMer and Roger 2001).

Land degradation through industrial processes such as mining and smelting can have significant effects on carbon storage and emissions from terrestrial ecosystem. For example, since the late 1800's, extensive logging, mining, smelting activities (ground level fumigations from open roast beds and later from smelters) in Sudbury Ontario released large concentrations of sulfur-dioxide emissions and metal particulates (metals such as Ni, Cu, Fe, Co) in the atmosphere. This led to severe acidification and metal contamination and damage to surrounding vegetation resulting in 80,000 ha of barren and semi-barren areas across the landscape. High wind and soil erosion rates particularly at these barren steep hillslopes further contributed to loss of soil cover (humus and upper mineral layers) and leaching of soil nutrients (SARA group, 2009). In early 1970's, massive reduction and mitigation of atmospheric pollution began. The Copper cliff smelter started operating the 381m tall smokestack to reduce local sulfur deposition and metal contamination and this led to significant improvements in air quality in the Sudbury region (Freedman and Hutchinson 1980). These reductions allowed some degree of ecological recovery and this recovery was further enhanced by restoration efforts, which commenced in 1978 by dispersal of dolomite limestone (Ca and Mg), fertilizing (6 N-24P-24 K) and replanting of native coniferous tree species such as Jack Pine (*Pinus banksiana*) and Red Pine (*Pinus resinosa*)

(Sherman and Beckett, 2003; Winterhalder, (1996, 1985 (a,b)). Since 1978, sulphur-dioxide emissions have reduced to more than 95% and 3,478 ha of land has been limed, fertilized (3,252 ha,) and more than 10, 214,559 trees have been planted in the Sudbury area (City of Greater Sudbury, 2018).

A study of the effects of reclamation on organic matter decomposition in soil at locations like Sudbury can provide important insight on the functioning and sustainability of damaged and reclaimed ecosystems (Bridgham et al., 2013). Traditionally litter bags consisting of mesh bags filled with plant litter were used to measure decomposition rates over a specific period of time (Moore and Basiliko 2006; Winterboum, 1978). Instead in the present study I used a relatively new Tea Bag index method (Keuskamp et al., 2013) to assess litter decomposition using standardized substrate in both reclaimed and untreated barren sites in Sudbury. The Tea Bag Index is unique as it allows researcher s to calculate an early stage decomposition rate index from labile and recalcitrant compounds at a much shorter and a single incubation period (3 months) and allows measurement of the Stabilization factor (S) which accounts for the amount of undecomposed residual labile material, which has a potential for sequestration. In this way TBI can also provide decomposition data that is comparable across different biomes (Cotrufo et al., 2013; Keuskamp et al., 2013).

Soil respiration (CO_2 efflux) and methane and nitrous oxide fluxes were also measured to assess effects of land reclamation with regard to more global concerns of greenhouse gas fluxes from degraded and reclaimed areas (Reichstein and Beer, 2008).

The objectives of this thesis study were to examine the effect of Sudbury's early restoration practices on decomposition and soil carbon efflux rates and interrelated CH_4 and N_2O fluxes using adjacent reclaimed and barren areas, along a steep hillslope in close proximity to the Copper Cliff smelter. The reclaimed area was limed, fertilized, tree planted in 1982 (37 years earlier) while the barren area was left untreated except for benefitting from massive (>95%) reductions in SO_2 and metal particulate emission in recent decades (Spiers, personal communication, 2019). Two main questions were addressed in my study:

(1) How does land reclamation affect organic matter decomposition and CO_2, CH_4 and N_2O fluxes in a smelter impacted landscape, particularly at challenging hillslope sites?

(2) What are the environmental controls (temperature, moisture and topography) of organic matter decomposition, carbon-dioxide and methane and nitrous oxide fluxes?

I predicted that reclaimed area would have higher litter decomposition and soil respiration rates, methane and nitrous oxide fluxes and that carbon turnover rates will increase with higher seasonal temperatures and moisture. Lastly, I predicted that features of the topography of the site will have a significant influence on carbon turnover rates.

2.0 Methodology

The study site:

The study was conducted at a north facing hillslope in the Kelly lake watershed located 3.4 kms from the Copper cliff smelter in Sudbury (Figure 2.1). Ambient temperature in this region varies from average - 15.9 °C in January to 20.3 °C in July, with an average precipitation of 903.3mm and approximately 4 months of snow cover in winter months. (Environment Canada, 2019). Two parallel transects rising approximately 30 m from the lake shore were established along an abrupt edge of reclaimed and still barren areas in the Kelly lake catchment for this study (Figure 2.1, 2.2). The reclaimed forested site was limed, fertilized and tree planted in 1982 while the barren was left un-treated, and like the reclaimed area the barren area was only exposed to regional changes such as the climate and reduced sulphur and metal deposition (>95%) that has occurred in recent decades (Spiers, personal communication, 2019). There was very little soil development across both sites in recent decades. At the reclaimed area, the organic horizon, ranged from 1 to > 10 cm depth, whereas at barren area the organic horizon ranged from 1 to 3 cm soil depth. The depth of mineral horizon ranged from 3 to >10 cm depth at reclaimed area and 2 to >10 cm at barren area. The vegetation community at the reclaimed site was dominated by white birch (*Betula papyrifera*) and jack pine (*Pinus banksiana*), maple (*Acer*), red oak (*Quercus rubra*) and spruce (*Picea*). Barren site had a few small shrubs, grasses and stunted white birch trees (*Betula papyrifera).*

Experimental design:

Elevation or topography (the height above the sea level measured in m) is an important gradient used in ecology to understand the how microclimatic factors (which generally vary with elevation) influence key ecosystem processes (Vincent et al., 2014). In this study, the transect elevation gradient was measured using a hand-held GPS (GNSS I SX Blue GPS with terra4go collector app). Plots were selected at the same elevation level for both reclaimed and barren treatment sites. A total of ten plots were established at 10% rise of the elevation (i.e. approx. a 2.6 m rise) along both barren and reclaimed transects to account for any micro-topographical difference moving up the slope from the lake shore. Plots were labelled and marked by flags at each site. Three replicate subsites were established at each plot, located perpendicular to transect and 50 cm apart.

Soil respiration (CO_2 flux) and CH_4 flux and N_2O flux:

To measure soil respiration R_s (CO_2 flux), methane flux and nitrous oxide flux, three replicate PVC flux collars (n=30) were installed at each plot (50 cm apart), enclosing soil depth of 8 to 10 cm along the two transects in June of 2019 (Figure 2.1, 2.2). The flux collars were carefully placed and left for two weeks to stabilize in the soil before the first measurement (Figure 2.3, 2.4). To measure CO_2, CH_4, N_2O flux a DX-4040 Gasmet portable FTIR multi gas analyzer (Gasmet Technologies) was used (Figure 2.4). Prior to use each day the DX-4040 Gasmet was calibrated and flushed according to manufacturer's calibration protocol. Flux ppm changes in headspace were measured for 5 minutes. I repeated the measurements if readings were unstable. Gases were measured every two weeks from early June to October 2019. To standardize measurements, gas fluxes were always collected in the same order and direction from lowlands to upland area at both treatment sites. DX-4040 Gasmet is susceptible to precipitation events, so measurements were only collected on days without rain or well after any heavy rain events. Soil samples were collected from individual PVC collar (up-to 10cm depth) from each plot at the end of the seasonal study on October 21st, 2019. Organic and mineral layer depth were measured from individual PVC collar. Soils layers were very thin, therefore organic layer and mineral layer from individual soil sample were not separated and we treated as a bulk soil. The soil samples were stored in sealed labelled plastic bags at 4 °C for further analysis of organic carbon. Loss of Ignition was used to determine soil organic carbon content from homogenized sub samples. Thereafter, sub samples were weighed, combusted for 5 hours at 650 °C and reweighted.

Tea Bag Index:

I used the standardized Tea Bag Index protocol developed by Keuskamp et al., (2013), to measure the decomposition process. Commercially available Lipton Green tea [(*Camellia sinensis*) , Katowice Factory, Katowice, Poland (Lipton reference: EAN8722700055525] and Lipton Rooibos tea [(*Aspalathus linearis*) , EAN8722700188438] were used as a standard substrate with initial weight of both tea types ranging from 1.8 g to 2 g. (Duddigan et al., 2020; Keuskamp et al., 2013). Chemical composition of green tea consists of labile carbon with higher cellulose content (C:N ratio (12) and high-water soluble fraction (50%). Whereas, Rooibos tea has recalcitrant, slow decomposing carbon compounds with higher lignin content and a C:N ratio (approximately 43) and consists of half as soluble carbon compounds as Green tea (Cotrufo et al., 2013; Petraglia et al., 2018). The tea bags are fabricated out of a nondegradable non-woven polypropylene bag with mesh size of 0.25mm. The initial weight was measured for each bag before burial at a standard 8cm depth at each site. The labelled tea bags were placed in pairs of Green tea, Rooibos tea and were buried 50 cm uphill from individual PVC collar at each plot (i.e. 3 replicates of each type at each plot; n=30 for each transect).On July 2, tea bags were deployed for an incubation period of approximately 3 months (109 days, (Figure 2.1, 2.2)). Tea bags were extracted from on October 19, brought back the lab and cleaned by a brush to remove soil particles and plant roots. Tea bags were dried in the oven for 48 hours at 70 °C. The tea bags were then emptied and the final dry weight of the tea was then remeasured.

Calculations of Tea Bag Index parameter: Decomposition rate index (k) and Stabilization factor (S):

Decomposition of litter is measured as mass loss of substrate (litter) in time (Weider and Lang, 1982).

$$(1)\ \text{Mass loss} = (M_i - M_f)$$

Where M_i is initial mass measured before burring the tea bags and M_f is the final oven dry mass loss the tea, respectively (Falconer et al., 1933). In addition to litter mass loss, I calculated Tea bag index parameters, stabilization factor (S) and the decomposition rate index (k). Both parameters were calculated using the excel program provided by TBI researchers (available from http://www.teatime4science.org).

The decomposition rate (k) is defined as the change is substrate concentration (mass loss) with incubation time (ds/dt). It can be expressed as a first order reaction or single exponential decay function:

$$(2)\ M_t = M_0\, e^{kt}$$

where M_t is litter mass at time t, M_0 is initial litter mass, and k is the rate constant of mass loss. The single exponential decay model was proposed by Jenny et al., (1949) and further developed by Olson, (1963). The decomposition dynamics occurs in two phases. First, the relatively fast decomposition of labile carbon, followed by slow decomposition of recalcitrant carbon. The double exponential decay model assumes litter decomposition of both labile and recalcitrant fraction. (Weider and Lang, 1982). The double exponential decay model is expressed as:

$$(3)\ X_{t} = ae^{-k_1 t} + (1 - a)^{-k_2 t}$$

In equation 3, X_t represents the fraction remaining of litter (in grams) after an incubation period (*t* in days), *a* is the labile decomposable fraction, (1-a) is the recalcitrant fraction and k_1 and k_2 are decomposition constant for both labile and recalcitrant carbon.

To develop a better understanding of early stage decomposition process in an ecosystem, Keuskamp et al., (2013) used the Double exponential decay model to develop a two-phase decomposition equation, coupling both Green and Rooibos tea incubated and decomposed in the same vicinity (Seelan et al., 2019). TB1 assumes that decomposition constant (k) of recalcitrant carbon in short term incubation experiment is negligible and can only be estimated for long term studies. The two-phase decomposition equation was expressed as:

$$(4)\ X_{t} = ae^{-kt} + (1 - a)$$

In equation 4, X_t represents the fraction remaining of litter (in grams) after an incubation period (*t* in days), k_t is the decomposition rate index (in day^{-1}), and *a* is the labile decomposable fraction, (1-a) is the recalcitrant fraction. Decomposition rate index k, represents rate at which of labile fraction of a plant material is broken-down. (Keuskamp et al., (2013).

Decomposition rate index (k) is calculated by decomposition of rooibos tea and green tea allows estimation for decomposable fraction (a). The decomposition index (k) is estimated as:

$$(5)\ k = -\ln((X_r - (1 - a_r))/a_r)/t$$

Where X_r is the fraction of rooibos tea (mass remaining, calculated from M_i/M_f). a_r is the decomposable fraction of rooibos tea and t is the incubation time expressed in days. (Petragalia et al., 2019; Keuskamp et al., 2013).

During the decomposition process, fraction of decomposable labile carbon compounds become recalcitrant (Prescott, 2010). Theoretically and mathematically, the stabilization factor (S) represents the accumulated mass remaining of labile carbon compound in soil after environmental constraints inhibit and restrict the decomposition process. This residual mass in the soil has a potential for immobilization (Seelan et al., 2019; Keuskamp et al., 2013). The stabilization factor (S) equation from (Keuskamp et al., 2013) is calculated by the deviation from the actual decomposable fraction (a) and hydrolysable faction H of labile carbon compounds:

$$(6)\ S = 1 - a_g/H_g$$

In equation (6), S represents the stabilization factor, a_g stands for the decomposable fraction and H_g represents Hydrolysable fraction of the green tea. a_g is calculated by the division of the final weight of green tea and the initial measured weight of green tea. H_g is the sum of non-polar extracts, acid solubles and water solubles of green tea. For the calculation of TBI parameters, I used (hydrolysable fraction H; 0.842 g g-1 for Green tea; 0.552 g g-1 for Rooibos tea), measured by Keuskamp et al., (2013), using sequential carbon fraction technique developed by (Ryan et al., 1990). The Tea Bag Index methodology assumes that the stabilization of labile carbon compound in an ecosystem is independent of the relative composition (hydrolysable fraction), size and litter quality. Therefore, the stabilization factor for both substrates is assumed to be equivalent. The decomposable fraction of rooibos tea (a_r) is calculated from the hydrolysable fraction of rooibos tea (H_r) and the stabilization factor (S) (Keuskamp et al., 2013):

$$(7)\ a_r = H_r\ (1-S)$$

Temperature:

Soil temperature was monitored hourly using Temperature data logger (Elitech Technology, Model: RC 5+ PDF) The data loggers were labelled and deployed on June 19th, 2019. At each plot, a temperature data logger was buried 8cm deep, equal to the depth of the tea bags and a second data logger was placed at the soil surface. Temperature data loggers were placed 25cm uphill from the middle PVC collar at each plot (Figure 2.3). A total of 20 data loggers were installed per treatment site (10 buried at sub soil surface; 10 on soil surface). The data loggers were retrieved on October 19th, brought back to the lab, and the data was extracted on the Elitech software (http://www.elitechus.com).

Moisture:

Volumetric moisture is defined as the volume of water content per unit volume of soil (Fenchel et al., 2012). Volumetric moisture was measured by Field Scout TDR 150 Spectrum probe at 6 to 8cm depth (VWC%). Moisture measurements were not consistent and were influenced by rainfall events. Therefore, moisture reading from the month of august were used for data analysis. Gravimetric moisture is defined as mass of water content per mass of dried soil (Bilskie et al., 2001). It is calculated as:

Equation (1) Water content = (Wet weight of soil – dry weight of soil / dry weight of soil)

Topographic wetness index:

Topographic wetness index is defined as $\ln(a/\tan\beta)$. Where 'a' is the local upslope area per unit length and '$\tan\beta$' is the local slope. TWI was developed by Beven and Kirkby, (1979). TWI is used to understand the effect of topography on hydrological processes (Sorensen et al., 2005). To calculate TWI, 2m resolution Central Ontario Orthophotography Project (COOP) 2016 Digital Elevation Model (DEM) Land Information Ontario (LIO) dataset was derived from: https://geohub.lio.gov.on.ca/datasets/1ce266ee55c44ffca2d457bc5db13b92 (Package B).
The System for Automated Geoscientific Analyses (SAGA) in Quantum GIS (QGIS) was used to calculate the Topographic Wetness Index (TWI), (Figure 2.5).

Figure (2.1) Map of Kelly lake watershed. Plot set up of reclaimed forested and barren treatment site. Plots were set up ≤ 249 m (lowland) to < 275m (upland) in elevation. Reclaimed plots are labelled RE and barren plots are labelled as BA. Reclaimed site was limed, fertilized, tree planted in 1982. Adjacent, barren site was left un-treated except for long-term trends in atmospheric acid and metal deposition.

Figure (2.2) Representative views of the two study sites (A) a general picture of reclaimed (limed, fertilized and tree planted area) looking down towards Kelly lake and (B) a general picture of un treated barren area looking up the slope from the Lake towards some relic birch trees.

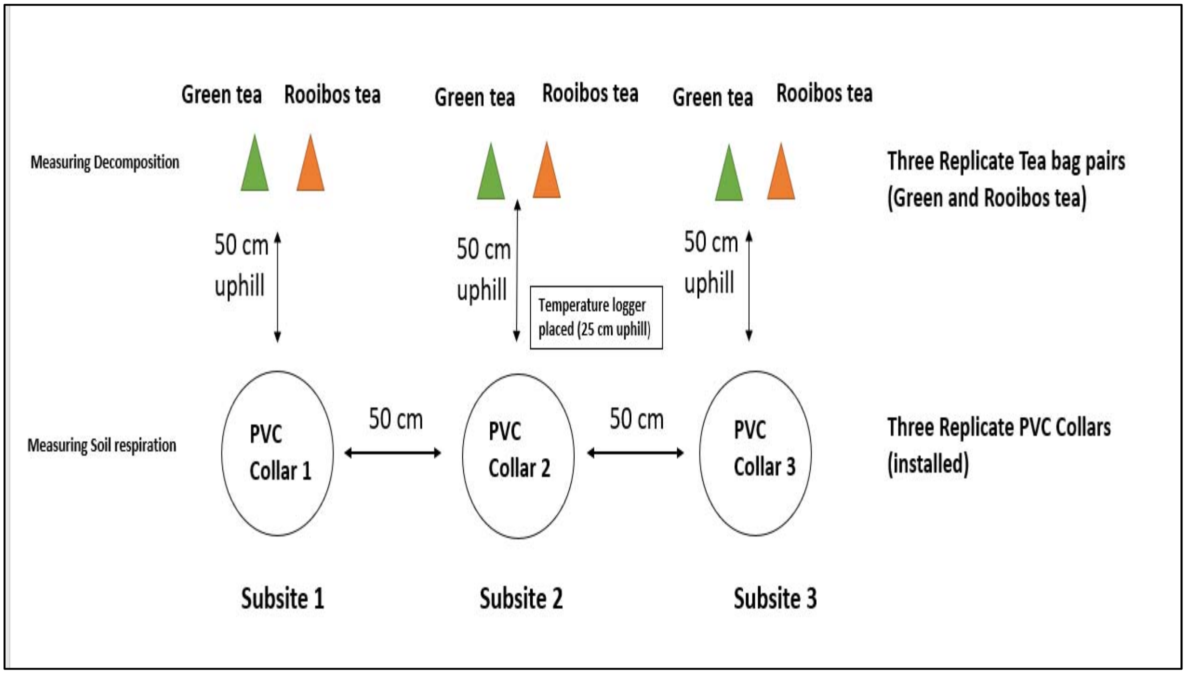

Figure (2.3) Layout of plot design for each treatment site. Three PVC flux collars were installed 50 cm apart at each plot to measure soil respiration and decomposition. Three replicates of Green and Rooibos tea (in pairs) were placed 50cm uphill of individual PVC flux collar, and buried at a depth of 8cm to measure decomposition process by simple Tea Bag Index metric. The temperature data loggers were buried at 8cm soil depth and placed on the surface, 25cm uphill from the middle PVC collar.

Figure (2.4) Photograph of plot RE8 showing collar arrangement and gas flux measurements using DX-4040X Gasmet, portable FTIR multi gas analyzer.

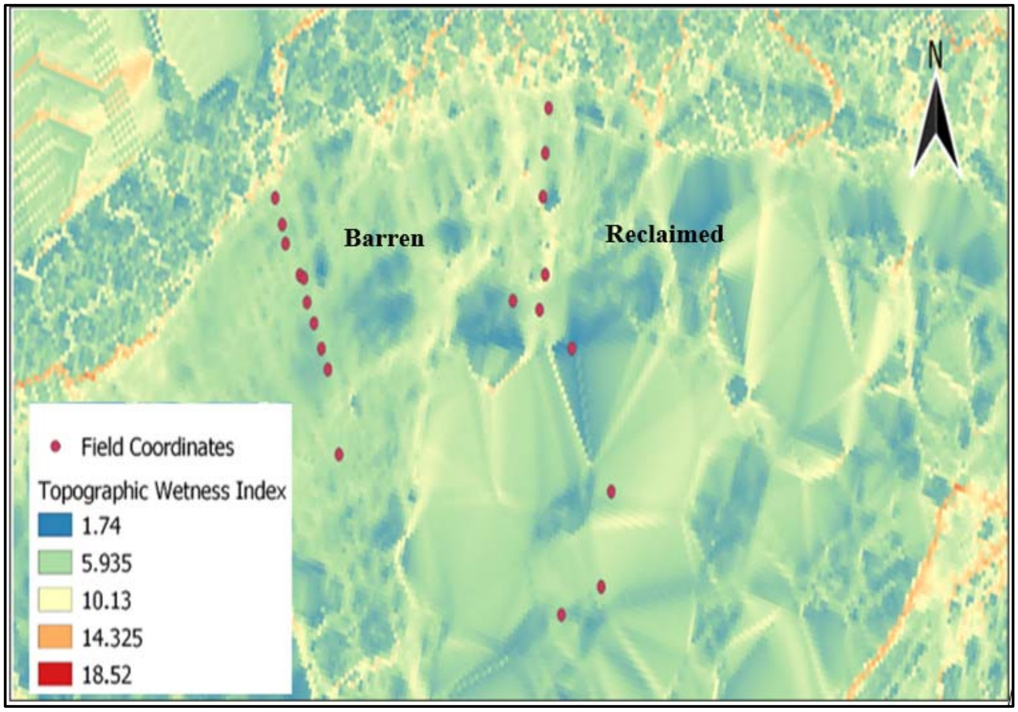

Figure (2.5) Map of Kelly lake watershed, showing distribution of Topographic wetness index of both barren exposed area and reclaimed forested area. TWI was calculated using System for Automated Geoscientific Analyses SAGA.

Statistical analysis:

Two sample-t-test were used to investigate differences of the decomposition of Green tea as well as Rooibos tea between the barren exposed site and reclaimed tree planted site. Tea Bag Index parameters, decomposition rate index (k) was calculated using the double exponential equation and stabilization factor was calculated by the (S) equation developed by Keuskamp et al., (2013). Two sample-t-test was used to compare decomposition rate index (k) between the two study sites. Welsh-t-test was used to assess stabilization factor (S) between the two treatment sites. Linear regression was used to calculate slope (rate of change) in Microsoft excel software and the gas mass concentrations were calculated using the ideal gas law ($n = PV/RT$). Where Pressure was 1 atm, chamber volume was (1.9L), R, the ideal gas constant ($R = 0.082$ l atm/(K·mole) and T was average temperature of the treatment site for that day. Mann-Whitney-U-test (non - parametric test) was used to assess differences of flux rates between treatment sites to address the issue of unequal variances between the replicated flux measurements. The Kruskal-Wallis test (non-parametric) was used to evaluate CO_2, CH_4, N_2O fluxes at different measurement time points between the two treatment sites. A linear model was used to assess the effect of substrate quality (Green and Rooibos tea) and treatment (barren and reclaimed area) on litter mass loss. Welsh-t-test was used to assess differences in environmental controls (SOC, temperature, moisture) across both study sites. Pearson's correlation coefficient was used to explore the relationship between decomposition of both tea types, k, S and environmental variables. When data was non parametric Spearman's correlation coefficient was used to understand the relationship between gas flux rates and environmental controls. Multiple regression models were used to address the issue of individual covariance between measured variables and explore multiple environmental controls of carbon turnover rates. Study sites were analyzed independently to understand the environmental controls of soil respiration and decomposition. Normality assumptions were tested using Shapiro-Wilk test. Data were tested for homogeneity of variances by F test for parametric data and Fligner-Killeen test (non -parametric). Multicollinearity was investigated using Variance inflation factor (VIF) between measured variables. Statistically significant differences were assumed at ($P = 0.05$). All statistical analyses were done using R statistical software (R Core Team, 2018, 3.5.1).

3.0 Results

Effect of land use change on decomposition of standardized substrates:

The decomposition of Green tea (labile substrate) was significantly higher in the reclaimed area than in the barrens ($P < 0.001$), while the Rooibos tea (recalcitrant substrate) exhibited much less and no significant differences in decomposition between treatment sites ($P = 0.09$). Average mass loss of the Green tea was 1.37 ± 0.01 (SE) gm (76.34%) at reclaimed site and 1.25 ± 0.01 (SE) gm (70.7%) at barren site ((range: 59.9% to 83.2%), Table 3.2, Figure 3.1). Average mass loss of Rooibos tea was 0.69 ± 0.02 (SE) gm (35.1%) at reclaimed site and 0.64 ± 0.02 (SE) gm (32.6 %) at barren site, respectively (range: 22.03% to 46.2%, Figure 3.1). The decomposition rate index (k) was approximately 0.01 $g \cdot g^{-1} \cdot d^{-1}$ and not found to be significantly different between reclaimed and barren sites (range: 0.006 d^{-1} to 0.03 d^{-1} ($P = 0.8$)). Average stabilization factor (S) was significantly higher with an average of 0.16 ± 0.009 (SE) $g \cdot g^{-1}$ at barren site compared to 0.09 ± 0.006 (SE) $g \cdot g^{-1}$ at reclaimed site, respectively ((range: 0.04 to 0.2), Table 3.2, Figure 3.2, ($P < 0.001$)).

Effect of land use change on soil respiration (CO_2 flux) CH_4 flux, and N_2O flux:

Averaged across all measurements, CO_2 production rates at the reclaimed site were 98.84 ± 5.46 (SE) mg m^{-2} h^{-1} and were significantly higher than at barren site 33.79 ± 2.26 (SE) mg m^{-2} h^{-1}, respectively ((range: 21.7 mg m^{-2} h^{-1} to 120 mg m^{-2} h^{-1}), Table 3.2, ($P < 0.001$)). CO_2 emitted was highest in the months of July and August across both study sites (Table 3.2, (Figure 3.5)).

CH_4 flux rates and N_2O flux rates were very low across all sites but slightly faster at the reclaimed site. Averaged across all measurements, CH_4 consumption rates at reclaimed site – 0.0104 ± 0.00 (SE) µg m^{-2} h^{-1} were significantly greater than at barren site 0.0014 ± 0.001 (SE) µg m^{-2} h^{-1} , respectively ((range: – 1.10^{-5} µg m^{-2} h^{-1} to 0.02 µg m^{-2} h^{-1}), Table 3.2, ($P = <0.01$)). CH_4 exchange rates at barren site were just as likely to be positive (production) as negative (oxidation rates). In the month of August, CH_4 oxidation rates were significantly greater at the reclaimed site than CH_4 production rates at barren site (Figure 3.5).

Averaged across all measurements, N_2O consumption rates at the reclaimed site -– 0.0104 ± 0.0006 (SE) µg m^{-2} h^{-1} were not significantly different from N_2O flux rates at barren site 0.0007

± 0.0004 (SE) μg m^{-2} h^{-1}, respectively ((range: – 0.0002 μg m^{-2} h^{-1} to -0.004 μg m^{-2} h^{-1}) ,Table 3.2, (P =0.09)). Barren areas were as likely to consume as emit nitrous oxide. Although, in August, N_2O consumption rates were significantly higher at reclaimed site than N_2O production rates at barren site (Figure 3.5). Overall, CO_2, CH_4 and N_2O flux rates generally increased during the months of July and August. (Figure 3.5).

Soil properties and environmental controls:

Soils were significantly cooler and more moist at the reclaimed areas as compared to barren areas. Across the season, average daily soil temperatures differed by about 2 °C, both at the surface level (18.8 °C vs 17 °C) and at the 8 cm depth (17.4 °C vs 15.5 °C). Average daily maximum surface soil temperatures were also more extreme in the barrens (31.9 °C compared to 30.1 °C) compared to the less exposed tree covered reclaimed sites (highest temperatures spanning up to 55 to 61.2 °C, Table 3.1, Figure 3.6, (P <0.001)). Across all sites the months of June, July, and August were consistently warmer months in terms of soil temperatures than September and October (Appendix T7). Volumetric moisture % (7.98% vs 15.4 %) and Gravimetric moisture (g H_2O g $Soil^{-1}$) (0.61 g H_2O g $Soil^{-1}$ vs 1.10 g H_2O g $Soil^{-1}$) were both significantly higher at the reclaimed site than at barren site (Table 3.1). Soil organic matter (%) was also found to be significantly higher at reclaimed sites (25.3%) as compared to barren exposed untreated site (14.4%) (Table 3.1).

Effect of substrate quality:

Mass loss varied significantly with litter quality between the two treatments. Labile substrate of higher Substrate quality decomposed twice as fast in comparison to recalcitrant substrate (lower litter quality). Across all sites, mass lost from Green tea was (73.33%) and Rooibos tea (33.76%). Substrate quality and treatment accounted for 90% and 1.6% variability in decomposition of litter mass loss, respectively (Table 3.3, (P < 0.001)). The overwhelming influence of substrate quality (i.e. green tea vs red tea) in this model may have diminished the apparent lack of treatment effect simply because of the very narrow range of the mass differences by using highly standardized substrates (i.e. a very narrow continuous variable in the model).

Environmental controls of decomposition and CO_2, CH_4, N_2O fluxes:

Across barren site, Green tea mass loss (r = 0.6, P <0.05), Rooibos tea mass loss (r =0.6, P <0.05) and decomposition rate index (k) (r= 0.6, P <0.05) were significantly and negatively correlated with maximum surface temperature. Decomposition rate index (k) was also negatively correlated to sub soil temperature (8cm depth) (r =-0.6, P <0.05). CO_2 efflux was weakly correlated to sub soil temperature (r = -0.5, p =0.09). CH_4 flux was weakly and positively correlated to moisture (r = 0.4, P = 0.1) At the reclaimed site, however, Green tea mass loss was strongly and positively correlated to volumetric moisture (r = 0.7, P <0.01) but negatively correlated to topography (r = 0.9, P <0.01). Rooibos tea mass loss, stabilization factor was not correlated to moisture or temperature. Although, decomposition rate index (k) was weakly correlated with topography (r =0.5, P = 0.1). CH_4 uptake was strongly and negatively correlated to N_2O uptake (r = -0.8, P <0.01). Significant correlations between environmental controls suggested the influence of multiple ecological factors on decomposition and soil respiration. At reclaimed site, moisture was strongly and negatively correlated to topography (r = -0.7, P = 0.01). Across all sites, gravimetric moisture was strongly and positively correlated to soil organic carbon (r = 0.8, P < 0.01, Appendix, (T2, T3, T4, T5)).

Stepwise multiple regression analysis was performed to identify environmental drivers of decomposition and soil respiration (CO_2) and CH_4 and N_2O fluxes. At barren site volumetric moisture, topography, surface temperature were best predictors of Green tea mass loss and together accounting for 20% variability in decomposition of green tea (P = 0.02). Surface temperature, maximum surface temperature were the primary predictors of Rooibos tea mass loss, together explaining 20% of variance (P = 0.01). Moreover, sub soil temperature and surface temperature-controlled decomposition rate index (k), together accounting for 10% variation (P = 0.06). Moisture, surface temperature and topography were the best predictors of stabilization factor (S) with 20% variability explained (P = 0.01). Soil temperature and moisture were the best predictors of CO_2 production, together explaining 20% of variance (P = 0.007). Moisture was the best predictor of CH_4 flux rate and accounting for 10% variation (P = 0.03). Although, at reclaimed site, topography was the primary controller of Green tea mass loss (20% of variance explained, P = 0.01) and a weak predictor of decomposition rate index (k) (10% variance explained, P = 0.06, Appendix (T6)).

Overall, multiple regression models suggest decomposition of Green tea (higher substrate quality), Rooibos tea (lower substrate quality), decomposition rate index (k) and CO_2 production rates showed reduced temperature sensitivity at barren exposed site (Appendix T6). Decomposition of labile, recalcitrant substrate, soil respiration (carbon-dioxide production rates) and decomposition rate index (k) decreased with increasing soil temperature. Moreover, moisture was the predominant control of methane flux at barren site. Contrastingly, at the reclaimed tree planted site, temperature was not the determining environmental control of decomposition and CO_2, CH_4, N_2O fluxes. Interestingly, across all sites, decomposition of labile substrate showed a consistent pattern of increased sensitivity to microclimatic factors. Lastly, topography (elevation) was a poor predictor of decomposition and CO_2 and CH_4, N_2O fluxes across both treatments.

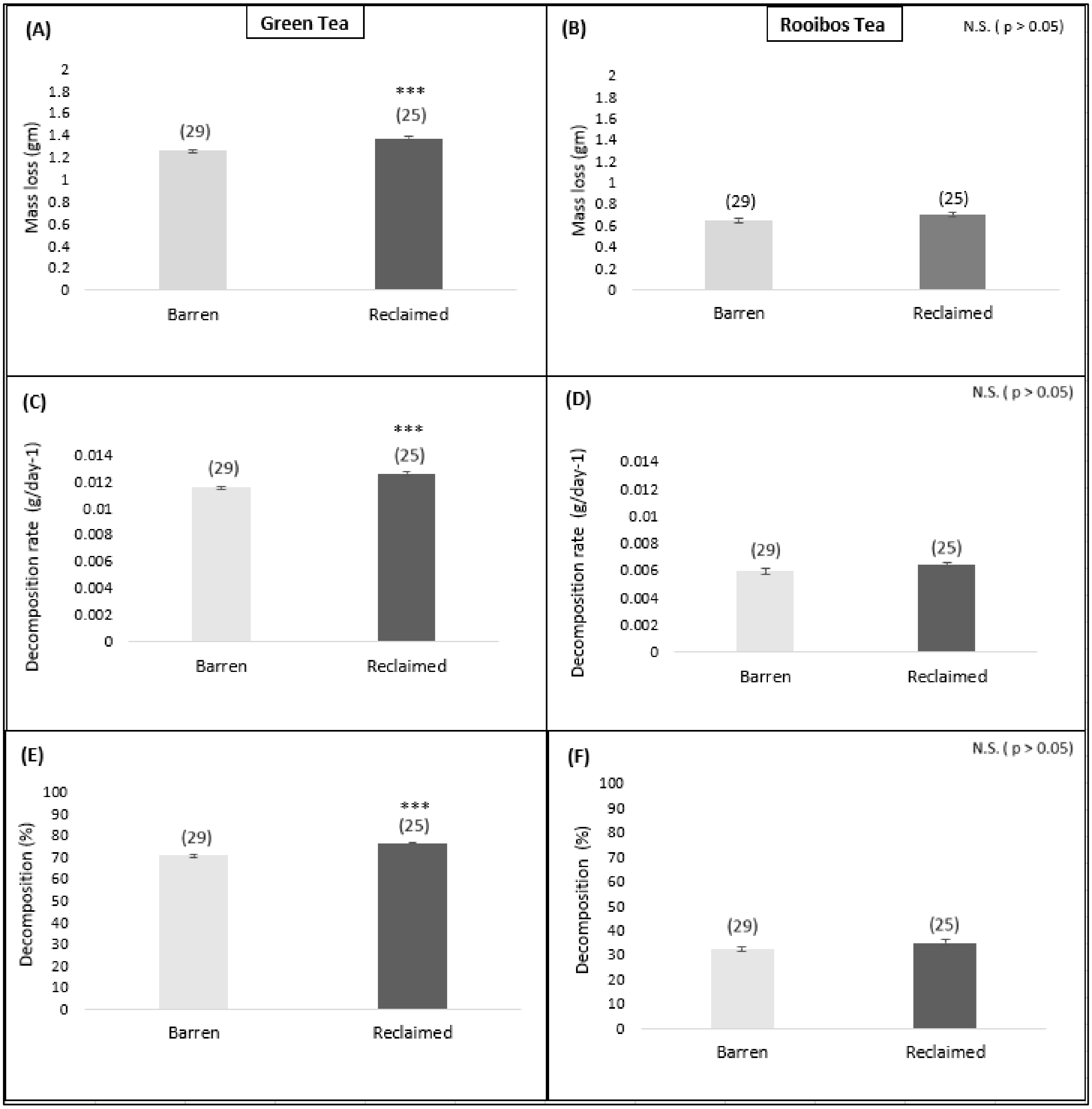

Figure (3.1) Differences of (A) Green tea mass loss (gm), (B) Rooibos tea mass loss (gm), (C) Green tea decomposition rate (g/day^{-1}), (D) Rooibos tea decomposition rate (g/day^{-1}), (E) Green tea decomposition (%), (F) Rooibos tea decomposition (%) detected using t-test in barren exposed site and reclaimed tree planted site. Values are mean and standard error. * $P < 0.05$. **$P < 0.01$. ***$P<0.001$

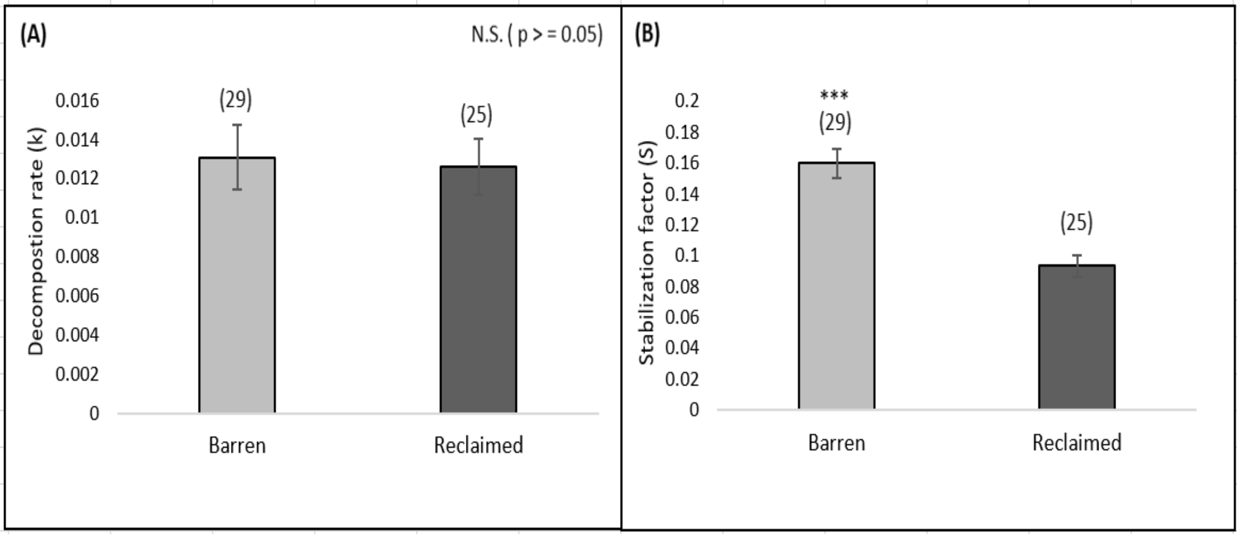

Figure (3.2) Comparison of (A) Decomposition rate index (k) $g \cdot g^{-1} \cdot d^{-1}$, (B) Stabilization factor (S) $g \cdot g^{-1} \cdot day^{-1}$, of barren exposed site (n= 29) and reclaimed tree planted site (n =25). Values are mean and standard error. *$P < 0.05$. ** $P < 0.01$. ***$P<0.001$

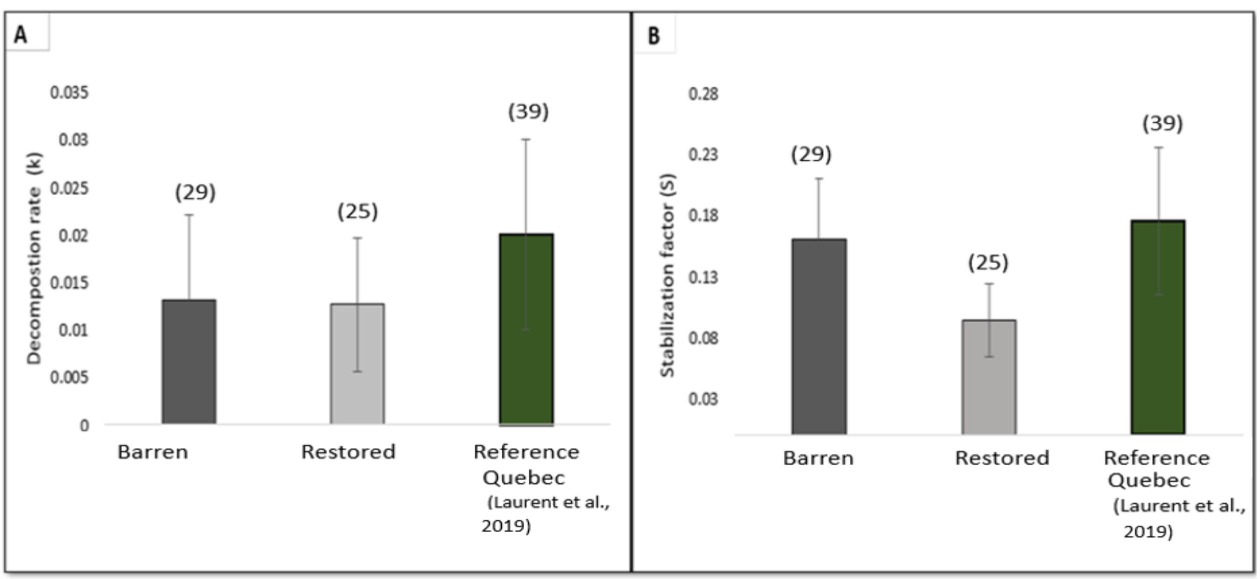

Figure (3.3) Comparison of (A) Decomposition rate index (k) $g \cdot g^{-1} \cdot d^{-1}$, (B) Stabilization factor (S) $g \cdot g^{-1} \cdot day^{-1}$, of barren exposed site (n= 29) and reclaimed tree planted site (n =25) compared to a undisturbed Riparian woodland forest Massawippi, Quebec, Canada (n =39)) (Laurent et al., 2019). Values are mean and standard deviations.

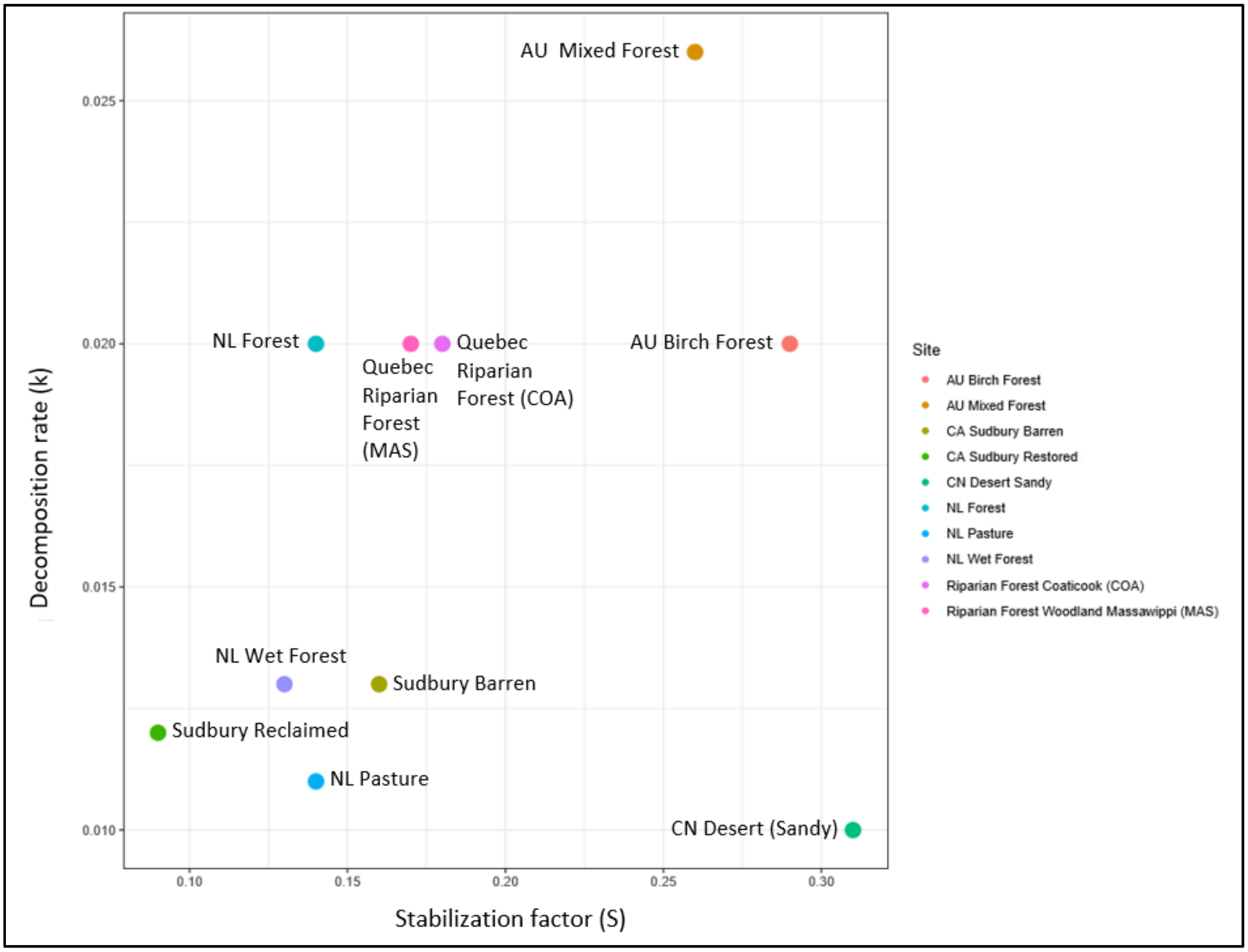

Figure (3.4) The mean decomposition rate index (k) and stabilization factor (S) for barren and reclaimed site compared to data obtained from Keuskamp et al., (2013) and Laurent et al., (2020). Labels indicate different ecosystems (Natural undisturbed forest and a Desert). AU Birch forest (Austria, n =10), CA, Sudbury Barren site (Canada, Sudbury , n = 29), CA, Sudbury Reclaimed site (Canada, Sudbury , n = 26), CN Desert sandy soil (China, n= 5), NL (Netherlands, n =4), NL, Riparian Forest (Quebec, St. Lawrence river watershed, n = 39).

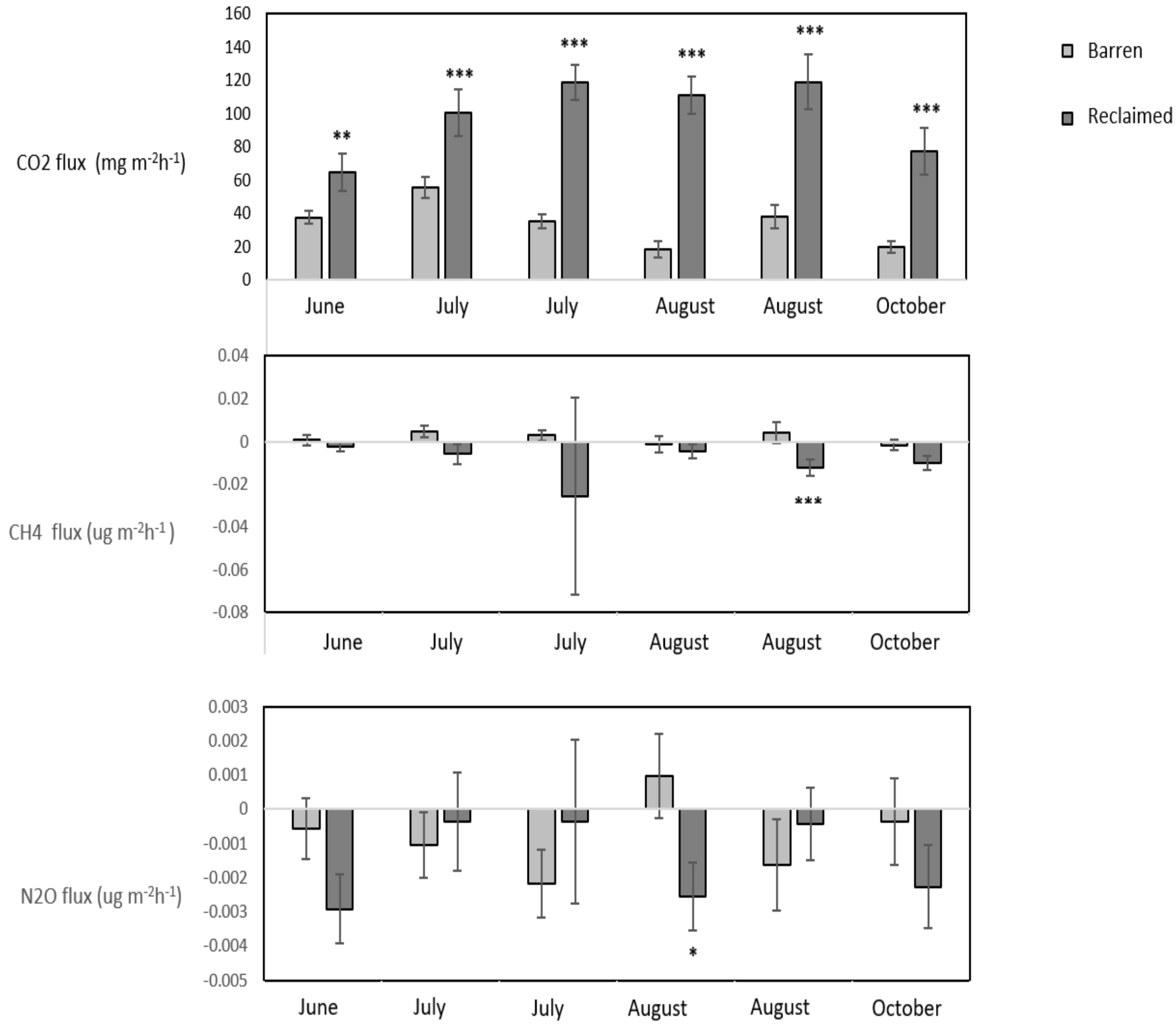

Figure (3.5) Soil respiration (CO_2 flux (mg m^{-2} h^{-1})), CH_4 flux (µg m^{-2} h^{-1}), N_2O flux (µg m^{-2} h^{-1})) across all sites (barren exposed site and reclaimed tree planted site) and gas flux measurements (n = 6). Values are means and standard errors and positive values indicate effluxes and negative values represent consumption rates. Significant differences are shown by *P < 0.05. ** P < 0.01. ***<P 0.001

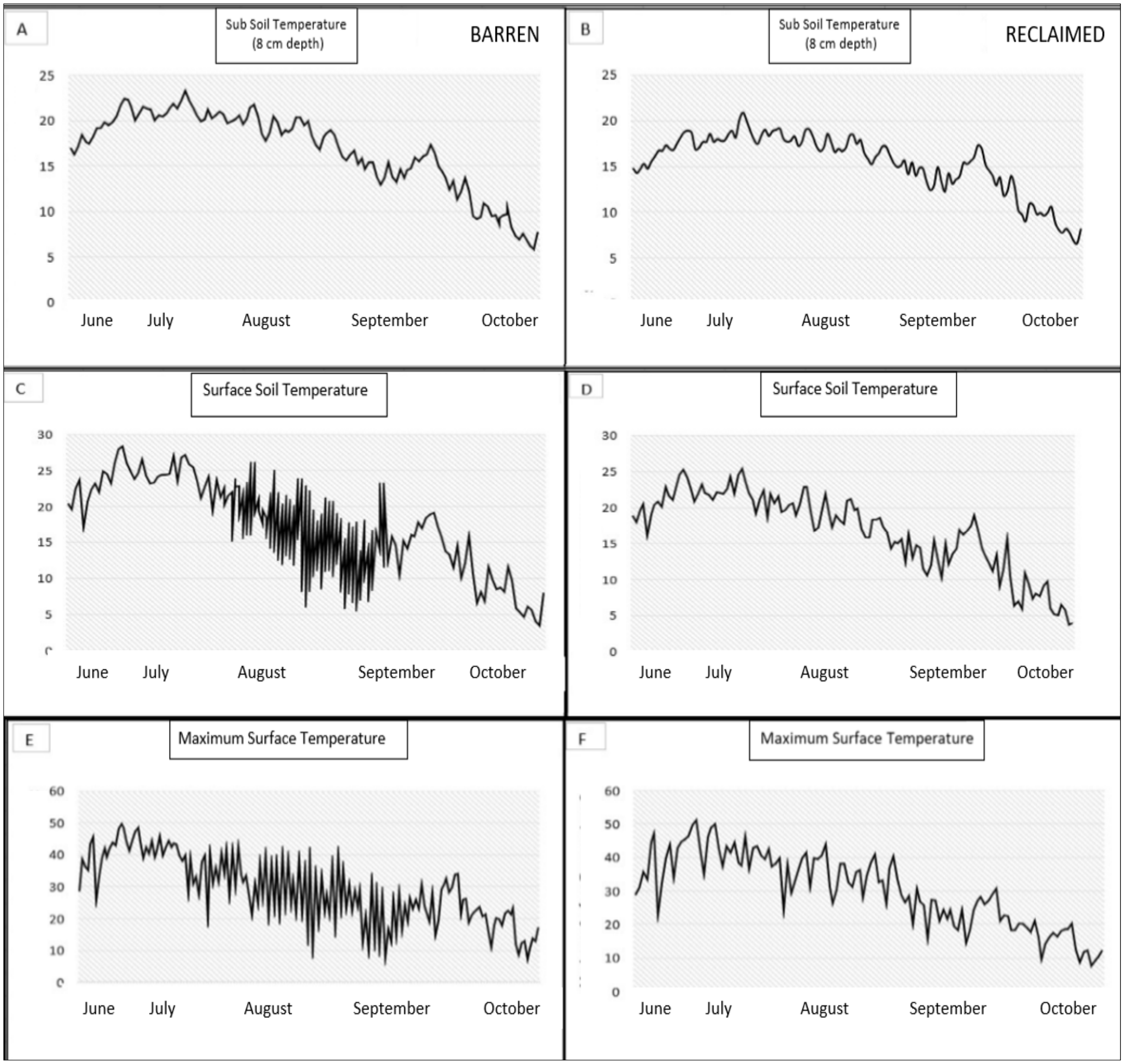

Figure (3.6) Patterns of mean daily, sub soil temperature °C (8cm depth), surface soil temperature °C and maximum surface temperature °C in barren and reclaimed treatment sites.

Table (3.1) *Summary of mean (SE) values of soil properties SOC (%), Gravimetric moisture ($g\ H_2O\ g\ Soil^{-1}$), Volumetric moisture %, Sub soil temperature °C, Surface temperature °C, Maximum Surface temperature °C at barren and reclaimed areas.*

Treatment site	SOC	Gravimetric Moisture	Volumetric Moisture	Soil temperature	Surface temperature	Maximum surface temperature
Site/P	**<0.01**	**<0.01**	**0.01**	**<0.001**	**<0.001**	**<0.001**
Barren	14.47(1.67)	0.61 (0.08)	7.98(0.94)	17.41 0.13)	18.6(0.19)	31.9 (0.35)
Reclaimed	25.33(3.31)	1.10 (0.13)	15.4 (1.36)	15.52 (0.11)	16.99(0.16)	30.1 (0.35)

Significant relationships of soil properties between treatments are in bold (P <0.05).
*P < 0.05. ** P < 0.01. ***<P 0.001

Table (3.2) *Summary statistics for differences detected by a t-test between the barren and reclaimed areas. Mass loss of Green tea (gm), Mass loss of Rooibos tea (gm), Green tea mass loss %, Rooibos tea mass loss %, Decomposition rate of Green tea ($g\ day^{-1}$), Decomposition rate of Rooibos tea ($g\ day^{-1}$),Decomposition rate index (k) ($g \cdot g^{-1} \cdot day^{-1}$), Stabilization factor (S) – TBI ($g\ g^{-1}$), CO_2 ($mg\ m^{-2}\ h^{-1}$)flux , CH_4 ($\mu g\ m^{-2}\ h^{-1}$) flux and N_2O ($\mu g\ m^{-2}\ h^{-1}$) flux . Positive values indicate gas efflux rates and negative values represent consumption rates.*

Variables	Barren site Mean (SE)	Reclaimed site Mean (SE)	P value
Green tea mass loss	1.25 (0.01)	1.37 (0.01)	**<0.001**
Rooibos tea mass loss	0.64 (0.02)	0.69 (0.02)	0.09
Green tea mass loss %	70.72(0.79)	76.34 (0.57)	**<0.001**
Rooibos tea mass loss %	32.60 (1.003)	35.10 (1.04)	0.08
Decomposition rate Green tea	0.01 (0.001)	0.012 (0.0001)	**<0.001**
Decomposition rate Rooibos tea	0.005 (0.0001)	0.006 (0.0001)	0.09
Stabilization factor (S)	0.16 (0.009)	0.09 (0.006)	**<0.001**
Decomposition index (k)	0.013 (0.001)	0.012 (0.001)	0.8
CO_2 efflux rates	33.79 (2.26)	98.84 (5.46)	**<0.001**
CH_4 flux rates	0.0014 (0.001)	- 0.0104 (0.00)	**<0.01**
N_2O flux rates	-0.00073(0.000452)	-0.01048(0.000608)	0.09

Significant differences (P < 0.05) are in bold. *P < 0.05. ** P < 0.01. ***<P 0.001

Table (3.3)	*Linear Model to assess the effect of substrate quality (Green and Rooibos tea) and Land reclamation on substrate mass loss across Sudbury's landscape (barren and reclaimed areas)*						
	Coefficient	**Standard error**	**t value**	**F value**	**% Variation**	**R^2**	**P value**
Substrate Quality	-0.6	0.1	-33.6	577.3	90	0.9	**<0.001**
Treatment	0.08	0.1	4.5		1.6		
	Significant differences (P < 0.05) are in bold. *P < 0.05. ** P < 0.01. ***<P 0.001						

4.0 Discussion:

Soils sustain above ground and below ground life, by providing key ecosystem services such as supporting soil biodiversity, driving mineral cycling processes and nurturing plant growth. The findings from my study were consistent with results of previous studies (Narendrula, 2017; Nkongolo et al., 2016; Goupil et al., 2014), that suggest that reclamation efforts by liming, fertilization and tree planting does increase soil health, but recovery of soil biota and soil functioning is still very slow across Sudbury's landscape.

Effect of land reclamation on standardized substrate decomposition:

I found evidence that liming and tree planting measurably influenced carbon turnover rates. Decomposition of labile substrate was higher at limed and tree planted areas. Soil amendment slightly increased decomposition of recalcitrant substrate, although mass loss rates did not differ significantly between treatments. This supports past studies that suggest that decomposition is impacted at barren areas, primarily due to low pH, metal toxicity inhibiting microbial growth, nutrient limitation, and the effect of climatic constraints (Nkongolo et al., 2016; Gratton et al., 2002). Moreover, our results are consistent with a previous litter bag studies (Freedman et al., 1980; Hutchinson et al., 1996; Johnson et al., 2004), that confirmed retarded litter decomposition in heavily contaminated barren soils, compared to dense forested areas, across Sudbury's landscape.

Fungi and invertebrate communities are primary decomposers of recalcitrant carbon compounds in the soil (Lavelle et al., 1997; Trojanowski et al., 1984). A recent study Duddigan et al., (2020) investigating Tea bag index, indicated that nitrogen availability in soils, affects decomposition of Rooibos tea (C: N = 42.8). Furthermore, studies by Narendrula-Kotha et al., (2017, a, b,c) conducted at the same site as my current study, reported very low fungi to bacteria ratios, associated with high levels of Cu in the soil. In addition, the authors showed that microbial biomass and enzymatic activities were significantly lower in eroded barren areas than at limed, tree planted areas, again suggesting that metal toxicity and nutrient limitation in soil were constraining recovery and development of oligotrophic and invertebrate communities (Fierer et al., 2007; Lavelle et al., 1997). These characteristics of degraded sites appear to affect breakdown of recalcitrant compounds across all sites.

Effect of land reclamation on Tea Bag Index parameters:

In the present study, early stage decomposition rate index (k) did not improve with the original Sudbury soil reclamation treatment (at least not 37 years later) with no significant difference between treatment areas. If my results were to be compared to the study by Laurent et al., (2019), the decomposition rate index (k) measured at a natural boreal riparian woodland were twice as great as those at reclaimed areas in Sudbury (Figure 3.3). Comparing the decomposition rates obtained from the present study to those from studies across the globe (Laurent et al., 2019; Keuskamp et al., 2013) showed our values are among the lowest range of decomposition rates observed in the various studied ecosystems (Figure 3.4). This suggest that heterotrophic communities in Sudbury soil, whether reclaimed or barren, are under still under severe environmental stress and that natural recovery of decomposition process is limited. It thus appears that rebuilding of the soil structure and fertility through continued monitoring and restoration efforts in needed to enhance nutrient availability, reduce toxicity and restore soil biota across Sudbury's landscape.

Stabilization factor (S) or the amount of residual material or accumulated carbon was higher at barren areas than reclaimed but still lower at both treatment sites compared to a natural riparian watershed in Quebec (Laurent et al., 2019). Stabilization factor (S) represents the inhibitory effect of environmental constraints on decomposition, resulting in accumulation of residual mass in the soil with a potential for stabilization (Keuskamp et al., 2013; Duddingan et al., 2020). Our results support studies (Elumeeva et al., 2018; MacDonald et al., 2018; Keuskamp et al., 2013), that suggest retarded decomposition due to low microbial activity, microclimatic constraints and nutrient limitation could be contribution to the measured Stabilization factor (S).

The present study is a first attempt at assessing the impact of land reclamation by investigating carbon turnover rates using a simple Tea Bag Index metric in a smelter impacted landscape. Based on the findings, it is evident that Tea Bag Index is an effective tool for assessing recovery of heterotrophic activity in metal contaminated soils. Although, careful interpretation is required before firm conclusions are drawn.

Effect of land reclamation on soil respiration (CO_2 flux) and CH_4 flux and N_2O flux:
Soil respiration represents combined biological activity of rhizosphere and heterotrophic respiration (Goupil et al., 2014). This activity depends on litter input by above ground biomass and photosynthates by roots (Kibblewhite et al., 2008). The results from my study are consistent with previous literature (Narendrula, 2017; Goupil et al., 2014) that suggest that liming and tree planting enhances CO_2 production rates in Sudbury. We found at reclaimed area that CO_2 emission rates were 2.9 times greater than those at barrens. This difference is presumably due to higher pH, autotrophic root respiration and heterotrophic activity and low metal toxicity at reclaimed areas (Narendrula, 2017). However, my findings still showed that CO_2 production rates at reclaimed areas were still 2.4 times lower than those at a Canadian plantation forest (Basiliko et al., 2009) suggesting that microbial activity and root respiration is still very reduced in our reclaimed sites.

In the present study, methane and nitrous oxide flux rates were also very low across all sites. One possible explanation for this could be rapid immobilization of the small amounts of available nutrients by microbes and plants (Nkongolo et al., 2017, 2016). The slightly higher CH_4 consumption rates I detected at reclaimed site can be attributed to methanotrophic activity throughout the season (Schnell et al., 1994). Methanotrophs are aerobic microorganisms that are found at the interface of organic horizon and mineral horizon (Adamsen and king, 1993) and their growth is limited by substrate availability (methane, methanol, methylated amines, formate and formamide) and affected by oxygen availability, moisture, temperature, pH of the soil (Billings et al., 2000; Benstead et al., 1997; King et al., 1992). Previous studies have reported that methane uptake rates decline with increasing moisture and decreasing methane and oxygen diffusivity in well drained forest soils (Bowden et al., 1998; Castro et al., 1994). The seasonal variation of methane uptake rates that I detected does suggest methanotrophs are active in barren areas. However, the methane production rates may enhance if soil pores remained saturated for prolonged periods of time, although this seems unlikely given the nature of the site and the low moisture contents measured at the barrens (Kallistova et al., 2017; Thauer et al., 2008; Yavitt et al. 1995). Interestingly Peichle et al. (2010) also occasionally observed net soil-level CH4 emissions in a dry pine forest. When compared to the study by Basiliko et al., (2009), my reclaimed soils had approximately, $3*10^3$ times lower methane consumption rates than those at a Canadian plantation forest.

Globally natural forest soils are small sources of nitrous oxide (IPCC, 2001). N_2O flux can be emitted during aerobic nitrification and facultative anaerobic denitrification (Bremner, 1997; Poth, 1986). However past literature suggest that soils can also consume N_2O during processes such as denitrification (anerobic), heterotrophic nitrification (aerobic denitrification) and nitrifier denitrification (ammonia oxidation) (Rosenkranz et al. 2006; Chapius-Lardy and others 2007; Philatie et al., 2007; Wrage et al., 2001; Conrad 1996; Robertson et al., 1989). A study by Kydyer and Cho (1983) showed that nitrification is mostly confined to aerobic zone of the soil whereas denitrification occurs in deeper, anerobic, waterlogged areas and that the conditions favoring these processes are primarily driven by soil moisture content (oxygen availability), soil temperature, soil pH and soil C/N ratios which directly influence microbial activity and growth (Philatie et al., 2007). Additionally, N_2O emission usually occur in well aerated forest soils with low soil C/N ratios (high nutrient availability) and that increasing temperatures may increase nitrous oxide production rates in soils (Klemedtsson et al., 2005). In contrast net N_2O consumption may arise in dry or wet conditions in soils with usually higher C/N ratios (Frasier et al., 2010; Chapius-Lardy and others 2007; Rosenkranz et al., 2006). Most researchers suggest aerobic denitrification is responsible for N_2O uptake rates observed in dry soils due to relatively high oxygen availability (Bateman et al., 2005; Chapius-Lardy and others 2007). Generally, bacteria are known to be responsible for nitrous oxide consumption, however recent studies have shown that fungi are also capable of N_2O uptake (Shoun et al., 1992). Previous studies have reported that boreal forest, temperate mixed forest and Mediterranean pine forest were weak sinks for nitrous oxide due to nitrogen limitation in soils (Frasier et al., 2010; Philatie et al., 2007; Rosenkranz et al. 2006). Interestingly, measurements at barren area showed soils consumed nitrous oxide throughout the season with the only exception of N_2O production rates in August, demonstrating that seasonal changes influence microbial activity. In the present study nitrous oxide uptake rates were again markedly lower (5 times) than those measured at maritime and sub-boreal plantation forests by Basiliko et al., (2009). suggesting both areas are affected by nutrient limitation in the soil, low moisture content and low microbial biomass (Klemedtsson et al., 2005; Price et al., 2004, Khalil et al., 2002).

Substrate quality, a primary driver of decomposition:

My results were consistent with those of Cornwell et al., (2008), who suggested that litter quality (substrate quality) had a major influence on decomposition. I was able to show that Green tea (labile substrate) representative of higher litter quality decomposed twice as fast as the Rooibos tea (recalcitrant substrate of lower litter quality) a finding in agreement with previous studies using these TBI standardized substrates (Houben et. al., 2018; Petraglia and others 2019). The difference in decomposition, is likely due differences in the physical and chemical composition of the two teas. For example, Green tea leaves are more fragile, more vulnerable to breakdown and leaching, compared to the coarse needle like Rooibos tea (Liu, et al., 2005; Keuskamp et. al., 2013). A large number of microbes can metabolize the labile carbon compounds, in comparison to a narrow range of microorganisms that can break down the recalcitrant carbon compounds (McGuire et. al., 2019). Keuskamp et al., (2013) reported that Green tea (labile substrate) consists of low C/N ratio and higher water-soluble fraction, while Rooibos tea (recalcitrant substrate) presents a higher C/N and C/P ratio, as well as lower water-soluble fraction and nutrient concentrations. The study by Heim et al., (2004) showed substrates with higher C/N ratios indeed had slower decomposition. Moreover, Djukic et al., (2018) was able to use a comparative approach by Tea Bag Index method to show that litter quality is the predominant environmental control on decomposition process across various ecosystems. My linear regression model supported this finding by showing substrate quality explained 90% of variation in mass loss rates while treatment (land reclamation) only accounted for only an addition 1.6% of the variation in mass loss rates.

Influence of microclimatic factors:

In accordance with previous literature, (Fanin et al., 2019; Petraglia et al., 2018; Liu et al., 2005) I found that decomposition of Green tea was more sensitive to microclimatic factors than Rooibos tea, across all sites. This is likely due it's the physical and molecular complexity. As labile substrate (Green tea) are easily decomposable due to its fragility and chemical composition of lower C/N ratio and high hydrolysable fraction as compared to recalcitrant carbon. Moreover, it is probable, that leaching of soluble compounds resulted in higher labile substrate mass loss (Fanin et al., 2019; Keuskamp et al., 2013). For example, a recent study by Fanin et al., (2019) revealed that climatic factors (moisture, temperature) were the primary controllers of Green tea decomposition, whereas edaphic factors (tree species richness, soil texture) primarily determined, Rooibos tea decomposition.

Soils in the reclaimed areas (with a dense tree cover) were significantly cooler and moister than soils in the barren areas. I found that decomposition of both labile (Green tea) , recalcitrant substrates (Rooibos tea) and CO_2 production rates declined with increasing temperatures at the barren areas a finding consistent with other research findings that have shown that sustained warming, desiccation stress and limited quality or quantity of substrates (Cable et al., 2011; Gershenson et al., 2009; Chen et al., 2005; Schimel et al; 1994) resulted in reduced microbial activity, denaturation of microbial enzymes or shift in microbial community composition (Liu et al., 2018; Cable et al., 2011; Balsar and Wixon, 2009; Pietikåinen et al., 2005; Luo et al., 2001; Saleska et. al; 1999; Rustard et al., 1998; Zogg et al., 1997; Peterjohn et al., 1994). Previous studies have suggested that the optimal temperatures for microbial activity in boreal soils are between 25 to 30 °C (Cable et al., 2011; Pietikåinen et al., 2005; Petterson et al., 2003, Bååth et al., 2001). In my study I found daily maximum temperatures were high in both the reclaimed and the barren area soils observed across the season. The average daily maximum surface temperature ranged from 31.9 °C at barrens and 30.1 °C at reclaimed areas (with highest temperatures spanning up to 55 to 61.2 °C). Daily maximum surface temperatures were greater than the suggested optimal of 30 °C for 68 days in barren areas and 65 days in reclaimed areas. These differences in temperature between barren and reclaimed area soils may appear small, but Allison et al., (2008) reported that sustained artificial warming of even 0.5 C significantly decreased microbial abundance and soil respiration rates in a natural boreal forest. However, in my study measured temperature did not prove to have a significant influence on decomposition and soil respiration for my reclaimed sites. This suggests that substrate availability, moisture, and perhaps root respiration are more likely the dominant factors affecting carbon turnover rates. Li et al., (2017) also concluded that soil temperature sensitivity is primarily controlled and masked by availability of labile substrate.

Moisture is known to be a primary controller of methane fluxes in soils (Born et al., 1990) and I found a positive correlation between methane fluxes (consumption and production rates) and moisture at barren areas. Although, reclaimed areas had significantly higher moisture levels than barren areas, yet no statistically significant relationship was found between moisture and methane uptake at these forested areas within the scope of my study. A study by Striegl et al.,(1992) showed a positive relationship between soil moisture content and CH_4 consumption rates in desert soils. However, many other studies have shown methane consumption rates tend to increase with declining moisture and are strongly regulated by CH_4 and oxygen diffusivity in forest soils (Billings et al., 2000; Benstead et al., 1997; Conrad et al., 1996; Castro et al. 1995; Koschorreck and Conrad 1993; King et al., 1992). Additionally, a study by Bender and Conrad (1995) showed that CH_4 consumption rates are controlled by nitrogen availability, pH, soil texture and soil aggregate size in addition to moisture.

Influence of topography:

I went into this study expecting that landscape topography might have a significant effect on decomposition and CO_2, N_2O and CH_4 fluxes because of literature evidence of the role of topography on climatic factors, edaphic factors, plant community composition (Gerdol et al., 2016). However, topography proved to be a poor predictor of decomposition rates, soil respiration and carbon sequestration across the scale of topography I included in the design. My sites were situated on a rocky steep slope covering only a small range of elevation (30 m) and a seasonal mean sub soil temperature differences of only 1 °C to 2 °C. Recent study by Preston et al., (2020) conducted in Sudbury, reported that soil organic carbon was influenced by topography, presumably through enhanced erosion on steeper slopes, while Becker et al., (2018) investigated decomposition by TBI method over a board elevation gradient in natural montane ecosystems showed that decomposition rate index (k) and stabilization factor (S) were strongly affected by climatic factors. My transects were by contrast not extensive enough to be able to detect such variability.

Conclusion:

My study demonstrated that the Sudbury's land reclamation techniques of liming, fertilization and tree planting does influence key ecosystem processes of litter decomposition and soil respiration. I found that land reclamation increased decomposition of labile substrate, CO_2 production rates and CH_4 consumption rates of soil. However, even 37 years after the reclamation treatment and massive associated improvements in air quality (95% reductions in Sulphur and metal deposition), the decomposition of recalcitrant substrates is extremely slow with no significant difference between forested and barren sites. Moreover, decomposition rate index (k) and soil respiration (CO_2) and CH_4 and N_2O fluxes were also very low relative to other less disturbed ecosystems. My findings suggest that both the treated and untreated soils are nutrient limited and heterotrophic communities are still highly stressed. I found that substrate quality was the key factor influencing decomposition. At barren areas decomposition of labile, recalcitrant organic substrates and CO_2 flux rates from soils decreased with increasing temperatures at these exposed sites. This suggests that barren areas were substrate limited, presumably due to negligible fresh litter input and that microbial communities are stressed by the dry and warm conditions. In contrast at the reclaimed area, temperature was not correlated to carbon turnover rates, suggesting that the primary factors affecting decomposition and soil respiration were of substrate availability and moisture as well as root respiration associated with the reestablished plant communities. Lastly, topography had little or no effect on carbon turnover rates across both study sites. The important take home message is that even 37 years after the reclamation treatment, Sudbury soils are still under severe environmental stress and that evidence of natural recovery of healthy soil functioning is promising but meagre.

Future Studies:

Land reclamation is critical for maintaining ecosystem services, increase recolonization of biodiversity and mitigate climate change. Therefore, it is important to understand the recovery trajectory of disturbed landscapes and further invest in rebuilding of soil fertility and key ecosystem processes such as organic matter decomposition and soil respiration (Cooke et al., 2002; Harris et al., 2006).My results show that the standardized Tea bag index methodology is a useful method to assess recovery of early stage decomposition process in metal contaminated soils. Previous studies have shown tea bags incubated in soil are decomposed by microbes as well as invertebrates (Keuskamp et al., 2013, Lavelle et al., 1997). To primarily measure microbial decomposition, I suggest protecting the tea bags from predation by invertebrates by using termite exclusion method, recently developed by Teo et al., (2020). Moreover, to, better understand long term decomposition dynamics I suggest future studies to use native litter (coniferous and deciduous litter) from Sudbury to understand decomposition rates of both labile and recalcitrant fraction using the double exponential model developed by Bunnel and Tait (1974). I would also recommend measuring and comparing decomposition rates from reclaimed forest in Sudbury to a control site (a natural undisturbed boreal forest with podzol sandy soils in close proximity to Sudbury and within Great lakes St. Lawrence forest region).

Soil respiration can vary widely both temporally and spatially (Brooks and Farquhar et al., 1985) and that future studies to be directed towards examining greenhouse gas fluxes from soil by partitioning root respiration and heterotrophic respiration measurements to understand the role of heterotrophs and root exudates on plant growth, nutrient cycling and carbon stocks. I would also suggest, measuring decomposition rates and gas flux rates from varied soil horizons and across different seasons. I would suggest measuring additional parameters such as pH of the soil and litter, nutrient analysis (soil and litter (C/N, C/P, N/P ratios) and soil inorganic nitrogen, total nitrogen), microbial biomass, root biomass, bioavailable metals, vegetation species richness, bulk density of soil. The effect of climate warming on changes on vegetation and carbon stocks in metal impacted landscapes will of course be important studies to conduct. Lastly, I recommend continued monitoring of carbon turnover rates every 5 years as well as using the present study site as a chronosequence site due to its unique site characteristics.

REFERENCES

Adamsen, A. P. S., & King, G. M. (1993). Methane consumption in temperate and subarctic forest soils: rates, vertical zonation, and responses to water and nitrogen. *Appl. Environ. Microbiol.*, *59*(2), 485-490.

Akala, V. A., & Lal, R. (2000). Potential of mine land reclamation for soil organic carbon sequestration in Ohio. *Land Degradation & Development*, *11*(3), 289-297.

Allison, S. D., & Treseder, K. K. (2008). Warmng and drying suppress microbial activity and carbon cycling in boreal forest soils. *Global change biology*, *14*(12), 2898-2909.

Amiro, B. D., & Courtin, G. M. (1981). Patterns of vegetation in the vicinity of an industrially disturbed ecosystem, Sudbury, Ontario. *Canadian Journal of Botany*, *59*(9), 1623–1639. https://doi.org/10.1139/b81-221

Averill, C., & Finzi, A. (2011). Increasing plant use of organic nitrogen with elevation is reflected in nitrogen uptake rates and ecosystem δ15N. *Ecology*, *92*(4), 883–891. https://doi.org/10.1890/10-0746.1

Bååth, E. (2001). Estimation of fungal growth rates in soil using 14C-acetate incorporation into ergosterol. *Soil Biology and Biochemistry*, *33*(14), 2011-2018.

Balser, T. C., & Wixon, D. L. (2009). Investigating biological control over soil carbon temperature sensitivity. *Global Change Biology*, *15*(12), 2935-2949.

Bardgett, R. D., Freeman, C., & Ostle, N. J. (2008). Microbial contributions to climate change through carbon cycle feedbacks. *The ISME Journal*, *2*(8), 805–814. https://doi.org/10.1038/ismej.2008.58

Basiliko, N., Khan, A., Prescott, C. E., Roy, R., & Grayston, S. J. (2009). Soil greenhouse gas and nutrient dynamics in fertilized western Canadian plantation forests. *Canadian journal of forest research*, *39*(6), 1220-1235.

Bastida, F., Zsolnay, A., Hernández, T., & García, C. (2008). Past, present and future of soil quality indices: A biological perspective. *Geoderma*, *147*(3–4), 159–171. https://doi.org/10.1016/j.geoderma.2008.08.007

Bateman, E. J., & Baggs, E. M. (2005). Contributions of nitrification and denitrification to N 2 O emissions from soils at different water-filled pore space. *Biology and fertility of soils*, *41*(6), 379-388.

Becker, J. N., & Kuzyakov, Y. (2018). Teatime on Mount Kilimanjaro: Assessing climate and land-use effects on litter decomposition and stabilization using the Tea Bag Index. *Land Degradation & Development*, *29*(8), 2321–2329. https://doi.org/10.1002/ldr.2982

Beedlow, P. A., Tingey, D. T., Phillips, D. L., Hogsett, W. E., & Olszyk, D. M. (2004). Rising atmospheric CO2 and carbon sequestration in forests. *Frontiers in Ecology and the Environment*, *2*(6), 315-322.

Benstead, J., & King, G. M. (1997). Response of methanotrophic activity in forest soil to methane availability. *FEMS Microbiology Ecology*, *23*(4), 333-340.

Berg, B. (2000). Litter decomposition and organic matter turnover in northern forest soils. *Forest Ecology and Management*, *133*(1–2), 13–22. https://doi.org/10.1016/s0378-1127(99)00294-7

Berg, B., Berg, M. P., Bottner, P., Box, E., Breymeyer, A., De Anta, R. C., & Madeira, M. (1993). Litter mass loss rates in pine forests of Europe and Eastern United States: some relationships with climate and litter quality. *Biogeochemistry*, *20*(3), 127-159.

Billings, S. A., Richter, D. D., & Yarie, J. (2000). Sensitivity of soil methane fluxes to reduced precipitation in boreal forest soils. *Soil Biology and Biochemistry*, *32*(10), 1431-1441.

Bilskie, J., & Scientific, C. (2001). Soil water status: content and potential. *Campbell Scientific, Inc. App. Note: 2S-1 http://s. campbellsci. com/documents/ca/technical-papers/soilh20c. pdf (2 de Abril de 2014)*.

Binkley, D. (1995). The Influence ofTree Species on Forest Soils: Processes and Patterns. In *Proceedings of the trees and soil workshop* (Vol. 7, p. 994).

Boone, R. D., Nadelhoffer, K. J., Canary, J. D., & Kaye, J. P. (1998). Roots exert a strong influence on the temperature sensitivity of soil respiration. *Nature*, *396*(6711), 570–572. https://doi.org/10.1038/25119

Born, M., DÖrr, H., & Levin, I. (1990). Methane consumption in aerated soils of the temperate zone. *Tellus B*, *42*(1), 2-8.

Bowden, R. D., Newkirk, K. M., & Rullo, G. M. (1998). Carbon dioxide and methane fluxes by a forest soil under laboratory-controlled moisture and temperature conditions. *Soil Biology and Biochemistry*, *30*(12), 1591-1597.

Bowman, J. P., Sly, L. I., Nichols, P. D., & Hayward, A. C. (1993). Revised taxonomy of the methanotrophs: description of Methylobacter gen. nov., emendation of Methylococcus, validation of Methylosinus and Methylocystis species, and a proposal that the family Methylococcaceae includes only the group I methanotrophs. *International Journal of Systematic and Evolutionary Microbiology*, *43*(4), 735-753.

Bremner, J. M. (1997). Sources of nitrous oxide in soils. *Nutrient cycling in Agroecosystems*, *49*(1-3), 7-16.

Bridgham, S. D., Cadillo-Quiroz, H., Keller, J. K., & Zhuang, Q. (2013). Methane emissions from wetlands: biogeochemical, microbial, and modeling perspectives from local to global scales. *Global Change Biology*, *19*(5), 1325–1346. https://doi.org/10.1111/gcb.12131

Brooks, A., & Farquhar, G. D. (1985). Effect of temperature on the CO 2/O 2 specificity of ribulose-1, 5-bisphosphate carboxylase/oxygenase and the rate of respiration in the light. *Planta*, *165*(3), 397-406.

Bunnell, F. L., & Tait, D. E. N. (1974). Mathematical simulation models of decomposition processes. *Soil organisms and decomposition in tundra*, 207-225.

Bunnell, F. L., & Tait, D. E. N. (1974). Mathematical simulation models of decomposition processes. *Soil organisms and decomposition in tundra*, 207-225.

Cable, J. M., Ogle, K., Lucas, R. W., Huxman, T. E., Loik, M. E., Smith, S. D., ... & Charlet, T. N. (2011). The temperature responses of soil respiration in deserts: a seven desert synthesis. *Biogeochemistry*, *103*(1-3), 71-90.

Carey, J. C., Tang, J., Templer, P. H., Kroeger, K. D., Crowther, T. W., Burton, A. J., ... & Jiang, L. (2016). Temperature response of soil respiration largely unaltered with experimental warming. *Proceedings of the National Academy of Sciences*, *113*(48), 13797-13802.

Castro MS, Steudler PA, Melillo JM, Aber JD, Bowden RD (1995) Factors controlling atmospheric methane consumption by temperate forest soils. Glob Biogeochem Cycles 9:1–10

Castro, M. S., Melillo, J. M., Steudler, P. A., & Chapman, J. W. (1994). Soil moisture as a predictor of methane uptake by temperate forest soils. *Canadian Journal of Forest Research*, *24*(9), 1805-1810.

Chen H, Tian HQ (2005) Does a general temperature-dependent Q_{10} model of soil respiration exist at biome and global scale? J Integr Plant Biol 47:1288–1302

City of Greater Sudbury. (2018). Regreening Program: 2018 Annual Report. Retrieved from https://www.greatersudbury.ca/live/environment-and-sustainability1/regreening-program/

City of Greater Sudbury. (2019). Sudbury Regreening (App). Retrieved May 9, 2019, from https://sudbury.maps.arcgis.com/apps/webappviewer/index.html?id=73fcef8187864784a3a6aad98eb9c1ba

Cobo, J. G., Barrios, E., Kass, D. C. L., & Thomas, R. J. (2002). Decomposition and nutrient release by green manures in a tropical hillside agroecosystem. *Plant and soil*, *240*(2), 331-342.

Conrad, R. (1996). Soil microorganisms as controllers of atmospheric trace gases (H2, CO, CH4, OCS, N2O, and NO). *Microbiol. Mol. Biol. Rev.*, *60*(4), 609-640.

Conrad, R. 1996. Soil microorganisms as controllers of atmospheric trace gases (H2, CO, CH4, OCS, N2O, and NO). Microbiol. Rev., 60(4), 609–640

Cooke, J. A., & Johnson, M. S. (2002). Ecological restoration of land with particular reference to the mining of metals and industrial minerals: A review of theory and practice. *Environmental Reviews*, *10*(1), 41-71.

Cooke, J. A., & Johnson, M. S. (2002). Ecological restoration of land with particular reference to the mining of metals and industrial minerals: A review of theory and practice. *Environmental Reviews*, *10*(1), 41-71.

Cornwell, W. K., Cornelissen, J. H., Amatangelo, K., Dorrepaal, E., Eviner, V. T., Godoy, O., ... & Quested, H. M. (2008). Plant species traits are the predominant control on litter decomposition rates within biomes worldwide. *Ecology letters*, *11*(10), 1065-1071.

Cotrufo, M. F., Wallenstein, M. D., Boot, C. M., Denef, K., & Paul, E. (2013). The Microbial Efficiency-Matrix Stabilization (MEMS) framework integrates plant litter decomposition with soil organic matter stabilization: do labile plant inputs form stable soil organic matter? *Global Change Biology*, *19*(4), 988–995. https://doi.org/10.1111/gcb.12113

Courtin, G. M. (1994). The last 150 years: a history of environmental degradation in Sudbury. *Science of The Total Environment*, *148*(2–3), 99–102. https://doi.org/10.1016/0048-9697(94)90388-3

Dauer, J. M., Chorover, J., Chadwick, O. A., Oleksyn, J., Tjoelker, M. G., Hobbie, S. E., … Eissenstat, D. M. (2007). Controls over leaf and litter calcium concentrations among temperate trees. *Biogeochemistry*, *86*(2), 175–187. https://doi.org/10.1007/s10533-007-9153-8

Davidson, E. A. (2012). Representative concentration pathways and mitigation scenarios for nitrous oxide. *Environmental Research Letters*, *7*(2), 024005.

Davidson, E. A., & Janssens, I. A. (2006). Temperature sensitivity of soil carbon decomposition and feedbacks to climate change. *Nature*, *440*(7081), 165-173.

de Blécourt, M., Brumme, R., Xu, J., Corre, M. D., & Veldkamp, E. (2013). Soil Carbon Stocks Decrease following Conversion of Secondary Forests to Rubber (Hevea brasiliensis) Plantations. *PLoS ONE*, *8*(7), e69357. https://doi.org/10.1371/journal.pone.0069357

De Catanzaro, J. B., & Beauchamp, E. G. (1985). The effect of some carbon substrates on denitrification rates and carbon utilization in soil. *Biology and Fertility of Soils*, *1*(4), 183-187.

De Deyn, G. B., Cornelissen, J. H. C., & Bardgett, R. D. (2008). Plant functional traits and soil carbon sequestration in contrasting biomes. *Ecology Letters*, *11*(5), 516–531. https://doi.org/10.1111/j.1461-0248.2008.01164.x

Didion, M., Repo, A., Liski, J., Forsius, M., Bierbaumer, M., & Djukic, I. (2016). Towards Harmonizing Leaf Litter Decomposition Studies Using Standard Tea Bags—A Field Study and Model Application. *Forests*, *7*(12), 167. https://doi.org/10.3390/f7080167

Dixon, R. K., Solomon, A. M., Brown, S., Houghton, R. A., Trexier, M. C., & Wisniewski, J. (1994). Carbon Pools and Flux of Global Forest Ecosystems. *Science*, *263*(5144), 185–190. https://doi.org/10.1126/science.263.5144.185

Djukic, I., Kepfer-Rojas, S., Schmidt, I. K., Larsen, K. S., Beier, C., Berg, B., ... & Humber, A. (2018). Early stage litter decomposition across biomes. *Science of the total environment*, *628*, 1369-1394.

Dlugokencky, E. J., Nisbet, E. G., Fisher, R., & Lowry, D. (2011). Global atmospheric methane: budget, changes and dangers. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, *369*(1943), 2058-2072.

Duddigan, S., Shaw, L. J., Alexander, P. D., & Collins, C. D. (2020). Chemical Underpinning of the Tea Bag Index: An Examination of the Decomposition of Tea Leaves. *Applied and Environmental Soil Science*, *2020*, 1–8. https://doi.org/10.1155/2020/6085180

Eichorst, S. A., & Kuske, C. R. (2012). Identification of Cellulose-Responsive Bacterial and Fungal Communities in Geographically and Edaphically Different Soils by Using Stable Isotope Probing. *Applied and Environmental Microbiology*, *78*(7), 2316–2327. https://doi.org/10.1128/aem.07313-11

Environnent Canada, 2019. http://climate.weather.gc.ca/climate_normals/results_e.html?stnID=4132andprov=andlang=eanddCode=1anddispBack=1andStationName=sudburyandSearchType=Containsandprovince= ALLandprovBut=andmonth1=0andmonth2=12.

Falconer, J. G., Wright, J. W., & Beall, H. W. (1933). The decomposition of certain types of forest litter under field conditions. *American Journal of Botany*, 196-203.

Fanin, N., Bezaud, S., Sarneel, J. M., Cecchini, S., Nicolas, M., & Augusto, L. (2019). Relative Importance of Climate, Soil and Plant Functional Traits During the Early Decomposition Stage of Standardized Litter. *Ecosystems*, 1-15.

Feger, K. H. (2010). Book Review: K. Lorenz, R. Lal: Carbon Sequestration in Forest Ecosystems. *Journal of Plant Nutrition and Soil Science*, *173*(2), 315–316. https://doi.org/10.1002/jpln.201090008

Fenchel, T., Blackburn, H., King, G. M., & Blackburn, T. H. (2012). *Bacterial biogeochemistry: the ecophysiology of mineral cycling*. Academic press.

Fierer N, Allen AS, Schimel JP et al (2003) Controls on microbial CO_2 production: a comparison of surface and subsurface soil horizons. Glob Change Biol 9:1322–1332

Flanagan, P. W., Viereck, L. A., & Dyrness, C. T. (1986). *Forest ecosystems in the Alaskan taiga: a synthesis of structure and function* (p. 230). K. Van Cleve, & F. S. Chapin III (Eds.). New York: Springer-Verlag.

Frasier, R., Ullah, S., & Moore, T. R. (2010). Nitrous oxide consumption potentials of well drained forest soils in southern Quebec, Canada. *Geomicrobiology Journal*, *27*(1), 53-60.

Freedman, B., & Hutchinson, T. C. (1980). Effects of smelter pollutants on forest leaf litter decomposition near a nickel–copper smelter at Sudbury, Ontario. *Canadian Journal of Botany*, *58*(15), 1722-1736.

Freedman, B., & Hutchinson, T. C. (1980a). Effects of smelter pollutants on forest leaf litter decomposition near a nickel–copper smelter at Sudbury, Ontario. *Canadian Journal of Botany*, *58*(15), 1722–1736. https://doi.org/10.1139/b80-200

Freedman, B., & Hutchinson, T. C. (1980b). Pollutant inputs from the atmosphere and accumulations in soils and vegetation near a nickel–copper smelter at Sudbury, Ontario, Canada. *Canadian Journal of Botany*, *58*(1), 108–132. https://doi.org/10.1139/b80-014

Freeman, C., Ostle, N., & Kang, H. (2001). An enzymic "latch" on a global carbon store. *Nature*, *409*(6817), 149–149. https://doi.org/10.1038/35051650

Gardner, W. C., Broersma, K., Naeth, A., Chanasyk, D., & Jobson, A. L. (2010). Influence of biosolids and fertilizer amendments on physical, chemical and microbiological properties of copper mine tailings. *Canadian journal of soil science*, *90*(4), 571-583.

Gerdol R, Marchesini R, Iacumin P. 2016. Bedrock geology interacts with altitude in affecting leaf growth and foliar nutrient status of mountain vascular plants. Journal of Plant Ecology 10:839–50.

Gershenson A, Bader NE, Cheng WX (2009) Effects of substrate availability on the temperature sensitivity of soil organic matter decomposition. Glob Change Biol 15:176–183

Gibert, O., de Pablo, J., Cortina, J. L., & Ayora, C. (2005). Municipal compost-based mixture for acid mine drainage bioremediation: Metal retention mechanisms. *Applied Geochemistry*, *20*(9), 1648-1657.

Gilbert, O. L., & Anderson, P. (1998). *Habitat creation and repair*. Oxford University Press on Demand.

Gillabel, J., CEBRIAN□LOPEZ, B. E. A. T. R. I. Z., Six, J., & Merckx, R. (2010). Experimental evidence for the attenuating effect of SOM protection on temperature sensitivity of SOM decomposition. *Global Change Biology*, *16*(10), 2789-2798.

Golley, F. B. (1999). Considering theoretical and practical needs of ecology. *Ecological Engineering*, *12*(3-4), 181-187.

Goupil K, Nkongolo K (2014) Assessing soil respiration as an indicator of soil microbial activity in reclaimed metal contaminated lands. Am J Environ Sci 10: 403-411.

Gratton, W. S., Nkongolo, K. K., & Spiers, G. A. (2000). Heavy metal accumulation in soil and jack pine (Pinus banksiana) needles in Sudbury, Ontario, Canada. *Bulletin of environmental contamination and toxicology*, *64*(4), 550-557.

Gundale, M. J., Nilsson, M., Bansal, S., & Jäderlund, A. (2012). The interactive effects of temperature and light on biological nitrogen fixation in boreal forests. *New Phytologist*, *194*(2), 453-463.

Gunn, J., Keller, W., Negusanti, J., Potvin, R., Beckett, P., & Winterhalder, K. (1995). Ecosystem recovery after emission reductions: Sudbury, Canada. *Water, Air, and Soil Pollution*, *85*(3), 1783-1788.

Hackney, C. T., & De La Cruz, A. A. (1980). In Situ Decomposition of Roots and Rhizomes of Two Tidal Marsh Plants. *Ecology*, *61*(2), 226–231. https://doi.org/10.2307/1935178

Harris, J. A., Hobbs, R. J., Higgs, E., & Aronson, J. (2006). Ecological restoration and global climate change. *Restoration Ecology*, *14*(2), 170-176.

Hartley, I. P., Heinemeyer, A., Evans, S. P., & Ineson, P. (2007). The effect of soil warming on bulk soil vs. rhizosphere respiration. *Global Change Biology*, *13*(12), 2654–2667. https://doi.org/10.1111/j.1365-2486.2007.01454.x

Heim, A., & Frey, B. (2004). Early stage litter decomposition rates for Swiss forests. *Biogeochemistry*, *70*(3), 299-313.

HoÈgberg, P., Nordgren, A., Buchmann, N., Taylor, A. F., Ekblad, A., HoÈgberg, M. N., ... & Read, D. J. (2001). Large-scale forest girdling shows that current photosynthesis drives soil respiration. *Nature*, *411*(6839), 789-792.

Högberg, P., Näsholm, T., Franklin, O., & Högberg, M. N. (2017). Tamm Review: On the nature of the nitrogen limitation to plant growth in Fennoscandian boreal forests. *Forest Ecology and Management*, *403*, 161-185.

Houben, D., Faucon, M. P., & Mercadal, A. M. (2018). Response of Organic Matter Decomposition to No-Tillage Adoption Evaluated by the Tea Bag Technique. *Soil Systems*, *2*(3), 42.

Houghton, J. T., Ding, Y. D. J. G., Griggs, D. J., Noguer, M., van der Linden, P. J., Dai, X., ... & Johnson, C. A. (2001). *Climate change 2001: the scientific basis*. The Press Syndicate of the University of Cambridge.

Hutchinson, T. C., & Symington, M. S. (1997). Persistence of metal stress in a forested ecosystem near Sudbury, 66 years after closure of the O'Donnell roast bed. *Journal of Geochemical Exploration*, *58*(2-3), 323-330.

IPCC, T. (2007). Climate change 2007: synthesis report. *Contribution of working groups I, II and III to the fourth assessment report of the intergovernmental panel on climate change*, 95-212.

Jandl, R., Lindner, M., Vesterdal, L., Bauwens, B., Baritz, R., Hagedorn, F., ... & Byrne, K. A. (2007). How strongly can forest management influence soil carbon sequestration?. *Geoderma*, *137*(3-4), 253-268.

Jani, A. D., Grossman, J., Smyth, T. J., & Hu, S. (2015). Winter legume cover-crop root decomposition and N release dynamics under disking and roller-crimping termination approaches. *Renewable Agriculture and Food Systems*, *31*(3), 214–229. https://doi.org/10.1017/s1742170515000113

Jastrow, J. D., Amonette, J. E., & Bailey, V. L. (2006). Mechanisms controlling soil carbon turnover and their potential application for enhancing carbon sequestration. *Climatic Change*, *80*(1–2), 5–23. https://doi.org/10.1007/s10584-006-9178-3

Jenkinson, D. S., Adams, D. E., & Wild, A. (1991). Model estimates of CO2 emissions from soil in response to global warming. *Nature*, *351*(6324), 304–306. https://doi.org/10.1038/351304a0

Jenny, H., Gessel, S. P., & Bingham, F. T. (1949). Comparative study of decomposition rates of organic matter in temperate and tropical regions. *Soil science*, *68*(6), 419-432.

Johnson, D. W. (1992). Effects of forest management on soil carbon storage. Water, Air, & Soil Pollution, 1–2, 83–120

Johnson, D., & Hale, B. (2004). White birch (Betula papyrifera Marshall) foliar litter decomposition in relation to trace metal atmospheric inputs at metal-contaminated and uncontaminated sites near Sudbury, Ontario and Rouyn-Noranda, Quebec, Canada. *Environmental Pollution*, *127*(1), 65-72.

Kallistova, A. Y., Merkel, A. Y., Tarnovetskii, I. Y., & Pimenov, N. V. (2017). Methane formation and oxidation by prokaryotes. *Microbiology*, *86*(6), 671-691.

Keuskamp, J. A., Dingemans, B. J. J., Lehtinen, T., Sarneel, J. M., & Hefting, M. M. (2013). Tea Bag Index: a novel approach to collect uniform decomposition data across ecosystems. *Methods in Ecology and Evolution*, *4*(11), 1070–1075. https://doi.org/10.1111/2041-210x.12097

Khalil, M. I., Rosenani, A. B., Van Cleemput, O., Fauziah, C. I., & Shamshuddin, J. (2002). Nitrous oxide emissions from an Ultisol of the humid tropics under maize–groundnut rotation. *Journal of Environmental Quality*, *31*(4), 1071-1078.

Khdyer, I. I., & Cho, C. M. (1983). Nitrification and Denitrification of Nitrogen Fertilizers in a Soil Column 1. *Soil Science Society of America Journal*, *47*(6), 1134-1139.

Kibblewhite MG, Ritz K, Swift MJ (2008) Soil health in agricultural systems. Philos Trans R Soc Lond B Biol Sci 363: 685-701.

King, G. M. (1992). Ecological aspects of methane oxidation, a key determinant of global methane dynamics. In *Advances in microbial ecology* (pp. 431-468). Springer, Boston, MA.

King, G. M., & Adamsen, A. P. S. (1992). Effects of temperature on methane consumption in a forest soil and in pure cultures of the methanotroph Methylomonas rubra. *Appl. Environ. Microbiol.*, *58*(9), 2758-2763.

Kirby, R. R. et al. 2009. Synergistic effects of climate and fishing in a marine ecosystem. – Ecosystems 12: 548 – 561.

Klemedtsson L, von Arnold K, Weslien P et al (2005) Soil CN ratio as a scalar parameter to predict nitrous oxide emissions. Global Change Biol 11:1142–1147

Klemedtsson, L., Von Arnold, K., Weslien, P., & Gundersen, P. (2005). Soil C/N ratio as a scalar parameter to predict nitrous oxide emissions. *Global Change Biology*, *11*(7), 1142-1147.

Knorr, M., Frey, S. D., & Curtis, P. S. (2005). Nitrogen additions and litter decomposition: a meta-analysis. *Ecology*, *86*(12), 3252–3257. https://doi.org/10.1890/05-0150

Knorr, W., Prentice, I. C., House, J. I., & Holland, E. A. (2005). Long-term sensitivity of soil carbon turnover to warming. *Nature*, *433*(7023), 298–301. https://doi.org/10.1038/nature03226

Korner, C. (2000). Biosphere Responses to CO_2Enrichment. *Ecological Applications*, *10*(6), 1590. https://doi.org/10.2307/2641226

Koschorreck M, Conrad R (1993) Oxidation of atmospheric methane in soil: measurements in the field, in soil cores, and in soil samples. Glob Biogeochem Cycles 7:109–121

Kurz, W. A., Shaw, C. H., Boisvenue, C., Stinson, G., Metsaranta, J., Leckie, D., … Neilson, E. T. (2013). Carbon in Canada's boreal forest — A synthesis. *Environmental Reviews*, *21*(4), 260–292. https://doi.org/10.1139/er-2013-0041

Kutsch, W. L. (2007). Soil Respiration and the Environment. By Y. Luo and X. Zhuo. Burlington, MA, and San Diego, CA, USA: Academic Press (2006), pp. 320, £39.99. ISBN-10: 0-12-088782-7. *Experimental Agriculture*, *43*(3), 402–403. https://doi.org/10.1017/s0014479707005078

Kuzyakov, Y, Friedel, J. ., & Stahr, K. (2000). Review of mechanisms and quantification of priming effects. *Soil Biology and Biochemistry*, *32*(11–12), 1485–1498. https://doi.org/10.1016/s0038-0717(00)00084-5

Kuzyakov, Y. (2002). Separating microbial respiration of exudates from root respiration in non-sterile soils: a comparison of four methods. *Soil Biology and Biochemistry*, *34*(11), 1621–1631. https://doi.org/10.1016/s0038-0717(02)00146-3

Kuzyakov, Y., & Cheng, W. (2001). Photosynthesis controls of rhizosphere respiration and organic matter decomposition. *Soil Biology and Biochemistry*, *33*(14), 1915-1925.

Kuzyakov, Yakov, & Larionova, A. A. (2005). Root and rhizomicrobial respiration: A review of approaches to estimate respiration by autotrophic and heterotrophic organisms in soil. *Journal of Plant Nutrition and Soil Science*, *168*(4), 503–520. https://doi.org/10.1002/jpln.200421703

Laganière, J., Paré, D., Bergeron, Y., Chen, H. Y. H., Brassard, B. W., & Cavard, X. (2013). Stability of Soil Carbon Stocks Varies with Forest Composition in the Canadian Boreal Biome. *Ecosystems*, *16*(5), 852–865. https://doi.org/10.1007/s10021-013-9658-z

Laiho, R. (2006). Decomposition in peatlands: Reconciling seemingly contrasting results on the impacts of lowered water levels. *Soil Biology and Biochemistry*, *38*(8), 2011–2024. https://doi.org/10.1016/j.soilbio.2006.02.017

Landsberg, J. J., & Waring, R. H. (1997). A generalised model of forest productivity using simplified concepts of radiation-use efficiency, carbon balance and partitioning. *Forest Ecology and Management*, *95*(3), 209–228. https://doi.org/10.1016/s0378-1127(97)00026-1

Lavelle, P., Bignell, D., Lepage, M., Wolters, V., Roger, P., Ineson, P., Heal, O.W. & Dhillion, S. (1997) Soil function in a changing world: the role of invertebrate ecosystem engineers. European Journal of Soil Biology, 33, 159-193.

Lavelle, P., Bignell, D., Lepage, M., Wolters, V., Roger, P., Ineson, P., Heal, O.W. & Dhillion, S. (1997) Soil function in a changing world: the role of invertebrate ecosystem engineers. European Journal of Soil Biology, 33, 159-193.

Lessard, R., Rochette, P., Topp, E., Pattey, E., Desjardins, R. L., & Beaumont, G. (1994). Methane and carbon dioxide fluxes from poorly drained adjacent cultivated and forest sites. *Canadian journal of soil science*, *74*(2), 139-146.

Li, Q., Tian, Y., Zhang, X., Xu, X., Wang, H., & Kuzyakov, Y. (2017). Labile carbon and nitrogen additions affect soil organic matter decomposition more strongly than temperature. *Applied Soil Ecology*, *114*, 152-160.

Liu, P., Huang, J., Han, X., Sun, O. J., & Zhou, Z. (2006). Differential responses of litter decomposition to increased soil nutrients and water between two contrasting grassland plant species of Inner Mongolia, China. *Applied Soil Ecology*, *34*(2-3), 266-275.

Liu, Y., He, N., Wen, X., Xu, L., Sun, X., Yu, G., ... & Schipper, L. A. (2018). The optimum temperature of soil microbial respiration: Patterns and controls. *Soil Biology and Biochemistry*, *121*, 35-42.

Luna-Orea, P., Wagger, M. G., & Gumpertz, M. L. (1907). Decomposition and Nutrient Release Dynamics of Two Tropical Legume Cover Crops. *Agronomy Journal*, *88*(5), 758–764. https://doi.org/10.2134/agronj1996.00021962008800050013x

Luo, Y., & Zhou, X. (2006). Processes of CO2 production in soil. *Soil respiration and the environment. Academic Press, Elsevier, San Diego, CA*, 35-59.

Luo, Y., Wan, S., Hui, D., & Wallace, L. L. (2001). Acclimatization of soil respiration to warming in a tall grass prairie. *Nature*, *413*(6856), 622-625.

Lutzow, M. v., Kogel-Knabner, I., Ekschmitt, K., Matzner, E., Guggenberger, G., Marschner, B., & Flessa, H. (2006). Stabilization of organic matter in temperate soils: mechanisms and their relevance under different soil conditions - a review. *European Journal of Soil Science*, *57*(4), 426–445. https://doi.org/10.1111/j.1365-2389.2006.00809.x

MacDonald, E., Brummell, M. E., Bieniada, A., Elliott, J., Engering, A., Gauthier, T. L., ... & Strack, M. (2018). Using the Tea Bag Index to characterize decomposition rates in restored peatlands. *Boreal Environment Research*, *23*(221-235).

MacDonald, E., Brummell, M. E., Bieniada, A., Elliott, J., Engering, A., Gauthier, T. L., ... & Strack, M. (2018). Using the Tea Bag Index to characterize decomposition rates in restored peatlands. *Boreal Environment Research*, *23*(221-235).

Magnani, F., Mencuccini, M., Borghetti, M., Berbigier, P., Berninger, F., Delzon, S., … Grace, J. (2007). The human footprint in the carbon cycle of temperate and boreal forests. *Nature*, *447*(7146), 849–851. https://doi.org/10.1038/nature05847

Maxwell, C. D. (1991). Floristic changes in soil algae and cyanobacteria in reclaimed metal-contaminated land at Sudbury, Canada. *Water, Air, and Soil Pollution*, *60*(3-4), 381-393.

McGuire, K. L., & Treseder, K. K. (2010). Microbial communities and their relevance for ecosystem models: decomposition as a case study. *Soil Biology and Biochemistry*, *42*(4), 529-535.

Melillo JM, Steudler PA, Aber JD, Newkirk K, Lux H, Bowles FP, Catricala C, Magill A, Ahrens T, Morrisseau S (2002) Soil warming and carbon-cycle feedbacks to the climate system. Science 298:2173–2176.

Merilä, P., Malmivaara-Lämsä, M., Spetz, P., Stark, S., Vierikko, K., Derome, J., & Fritze, H. (2010). Soil organic matter quality as a link between microbial community structure and vegetation composition along a successional gradient in a boreal forest. *Applied Soil Ecology*, *46*(2), 259-267.

Metz, B., Davidson, O., Swart, R., & Pan, J. (Eds.). (2001). *Climate change 2001: mitigation: contribution of Working Group III to the third assessment report of the Intergovernmental Panel on Climate Change* (Vol. 3). Cambridge University Press.

Monteith, D. T., Stoddard, J. L., Evans, C. D., de Wit, H. A., Forsius, M., Høgåsen, T., … Vesely, J. (2007). Dissolved organic carbon trends resulting from changes in atmospheric deposition chemistry. *Nature*, *450*(7169), 537–540. https://doi.org/10.1038/nature06316

Murungu, F. S., Chiduza, C., Muchaonyerwa, P., & Mnkeni, P. N. S. (2010). Decomposition, nitrogen and phosphorus mineralization from winter-grown cover crop residues and suitability for a smallholder farming system in South Africa. *Nutrient Cycling in Agroecosystems*, *89*(1), 115–123. https://doi.org/10.1007/s10705-010-9381-5

Narendrula, R. (2017). *Biochemical and molecular characterization of microbial communities from a metal contaminated and reclaimed region* (Doctoral dissertation, Laurentian University of Sudbury)

Narendrula-Kotha, R., & Nkongolo, K. K. (2017). Bacterial and fungal community structure and diversity in a mining region under long-term metal exposure revealed by metagenomics sequencing. *Ecological Genetics and Genomics*, *2*, 13-24.

Narendrula-Kotha, R., & Nkongolo, K. K. (2017). Changes in enzymatic activities in metal contaminated and reclaimed lands in Northern Ontario (Canada). *Ecotoxicology and environmental safety*, *140*, 241-248.

Narendrula-Kotha, R., & Nkongolo, K. K. (2017). Microbial response to soil liming of damaged ecosystems revealed by pyrosequencing and phospholipid fatty acid analyses. *PloS one*, *12*(1).

Nkongolo, K. K., Michael, P., Theriault, G., Narendrula, R., Castilloux, P., Kalubi, K. N., ... & Spiers, G. (2016). Assessing biological impacts of land reclamation in a mining region in canada: Effects of dolomitic lime applications on forest ecosystems and microbial phospholipid fatty acid signatures. *Water, Air, & Soil Pollution*, *227*(4), 104.

Olson, J. S. (1963). Energy storage and the balance of producers and decomposers in ecological systems. *Ecology*, *44*(2), 322-331.

Pachauri, R. K., Allen, M. R., Barros, V. R., Broome, J., Cramer, W., Christ, R., ... & Dubash, N. K. (2014). *Climate change 2014: synthesis report. Contribution of Working Groups I, II and III to the fifth assessment report of the Intergovernmental Panel on Climate Change* (p. 151). IPCC

Pang, X., Zhu, B., Lü, X., & Cheng, W. (2015). Labile substrate availability controls temperature sensitivity of organic carbon decomposition at different soil depths. *Biogeochemistry*, *126*(1-2), 85-98.

Peichl, M., Arain, M. A., Ullah, S., & Moore, T. R. (2010). Carbon dioxide, methane, and nitrous oxide exchanges in an age□sequence of temperate pine forests. *Global Change Biology*, *16*(8), 2198-2212.

Peterjohn, W. T., Melillo, J. M., Steudler, P. A., Newkirk, K. M., Bowles, F. P., & Aber, J. D. (1994). Responses of trace gas fluxes and N availability to experimentally elevated soil temperatures. *Ecological applications*, *4*(3), 617-625.

Pettersson, M., & Bååth, E. (2003). Temperature-dependent changes in the soil bacterial community in limed and unlimed soil. *FEMS Microbiology ecology*, *45*(1), 13-21.

Pietikäinen, J., Pettersson, M., & Bååth, E. (2005). Comparison of temperature effects on soil respiration and bacterial and fungal growth rates. *FEMS microbiology ecology*, *52*(1), 49-58.

Pihlatie, M., Pumpanen, J., Rinne, J., Ilvesniemi, H., Simojoki, A., Hari, P., & Vesala, T. (2007). Gas concentration driven fluxes of nitrous oxide and carbon dioxide in boreal forest soil. *Tellus B: Chemical and Physical Meteorology*, *59*(3), 458-469.

Pihlatie, M., Pumpanen, J., Rinne, J., Ilvesniemi, H., Simojoki, A., Hari, P., & Vesala, T. (2007). Gas concentration driven fluxes of nitrous oxide and carbon dioxide in boreal forest soil. *Tellus B: Chemical and Physical Meteorology*, *59*(3), 458-469.

Post, W. M., Emanuel, W. R., Zinke, P. J., & Stangenberger, A. G. (1982). Soil carbon pools and world life zones. *Nature*, *298*(5870), 156–159. https://doi.org/10.1038/298156a0

Poth, M. (1986). Dinitrogen production from nitrite by a Nitrosomonas isolate. *Appl. Environ. Microbiol.*, *52*(4), 957-959.

Preston, C. M., Trofymow, J. A. (Tony), & Working Group, the C. I. D. E. (2000). Variability in litter quality and its relationship to litter decay in Canadian forests. *Canadian Journal of Botany*, *78*(10), 1269–1287. https://doi.org/10.1139/cjb-78-10-1269

Preston, M. D., Brummell, M. E., Smenderovac, E., Rantala-Sykes, B., Rumney, R. H., Sherman, G., ... & Hebert, M. (2020). Tree restoration and ecosystem carbon storage in an acid and metal impacted landscape: Chronosequence and resampling approaches. *Forest Ecology and Management*, *463*, 118012.

Price, S. J., Sherlock, R. R., Kelliher, F. M., McSeveny, T. M., Tate, K. R., & Condron, L. M. (2004). Pristine New Zealand forest soil is a strong methane sink. *Global Change Biology*, *10*(1), 16-26.

Puckett, K. J., Niebeor, E., Flora, W. P., & Richardson, D. H. S. (1973). sulphur dioxide: its effect on photo-synthetic 14c fixation in lichens and suggested mechanisms of phytotoxicity. *New Phytologist*, *72*(1), 141–154. https://doi.org/10.1111/j.1469-8137.1973.tb02019.x

Raghoebarsing, A. A., Pol, A., Van de Pas-Schoonen, K. T., Smolders, A. J., Ettwig, K. F., Rijpstra, W. I. C., ... & Strous, M. (2006). A microbial consortium couples anaerobic methane oxidation to denitrification. *Nature*, *440*(7086), 918-921.

Raich, J. W., Potter, C. S., & Bhagawati, D. (2002). Interannual variability in global soil respiration, 1980-94. *Global Change Biology*, *8*(8), 800–812. https://doi.org/10.1046/j.1365-2486.2002.00511.x

Ranells, N. N., & Wagger, M. G. (1907). Nitrogen Release from Grass and Legume Cover Crop Monocultures and Bicultures. *Agronomy Journal*, *88*(5), 777–882. https://doi.org/10.2134/agronj1996.00021962008800050015x

Rayfield, B., Anand, M., & Laurence, S. (2005). Assessing Simple Versus Complex Restoration Strategies for Industrially Disturbed Forests. *Restoration Ecology*, *13*(4), 639–650. https://doi.org/10.1111/j.1526-100x.2005.00082.x

Reichstein, M., & Beer, C. (2008). Soil respiration across scales: The importance of a model–data integration framework for data interpretation. *Journal of Plant Nutrition and Soil Science*, *171*(3), 344–354. https://doi.org/10.1002/jpln.200700075

Rezanezhad F., Price J.S., Quinton W.L., Lennartz B., Milojevic T. & Van Cappellen P. 2016. Structure of peat soils and implications for water storage, flow and solute transport: A review update for geochemists. Chemical Geology 429: 75–84.

Richardson, A. D., Hollinger, D. Y., Shoemaker, J. K., Hughes, H., Savage, K., & Davidson, E. A. (2019). Six years of ecosystem-atmosphere greenhouse gas fluxes measured in a sub-boreal forest. *Scientific data*, *6*(1), 1-15.

Robertson, L. A., Cornelisse, R., De Vos, P., Hadioetomo, R., & Kuenen, J. G. (1989). Aerobic denitrification in various heterotrophic nitrifiers. *Antonie van Leeuwenhoek*, *56*(4), 289-299.

Romero-Olivares, A. L., Allison, S. D., & Treseder, K. K. (2017). Soil microbes and their response to experimental warming over time: a meta-analysis of field studies. *Soil Biology and Biochemistry*, *107*, 32-40.

Rosecrance, R. C., McCarty, G. W., Shelton, D. R., & Teasdale, J. R. (2000). Denitrification and N mineralization from hairy vetch (Vicia villosa Roth) and rye (Secale cereale L.) cover crop monocultures and bicultures. *Plant and Soil*, *227*(1-2), 283-290.

Rosén, K., & Lindberg, T. (1980). Biological nitrogen fixation in coniferous forest watershed areas in Central Sweden. *Ecography*, *3*(3), 137-140.

Rosenkranz, P., Brüggemann, N., Papen, H., Xu, Z., Seufert, G., & Butterbach-Bahl, K. (2006). N 2 O, NO and CH 4 exchange, and microbial N turnover over a Mediterranean pine forest soil.

Rumney, R. (2019). *Effects of restoration on carbon storage in smelter impacted industrial barrens* (Doctoral dissertation, Laurentian University of Sudbury).

Rustad, L. E., & Fernandez, I. J. (1998). Experimental soil warming effects on CO2 and CH4 flux from a low elevation spruce–fir forest soil in Maine, USA. *Global Change Biology*, *4*(6), 597-605.

Saint-Laurent, D., & Arsenault-Boucher, L. (2020). Soil properties and rate of organic matter decomposition in riparian woodlands using the TBI protocol. *Geoderma*, *358*, 113976.

Saleska, S. R., Harte, J., & Torn, M. S. (1999). The effect of experimental ecosystem warming on CO2 fluxes in a montane meadow. *Global Change Biology*, *5*(2), 125-141.

Santibáñez, C., Verdugo, C., & Ginocchio, R. (2008). Phytostabilization of copper mine tailings with biosolids: implications for metal uptake and productivity of Lolium perenne. *Science of the Total Environment*, *395*(1), 1-10.

SARA Group. 2009. Sudbury soils study volume III: ecological risk assessment. hhttp://www.sudburysoilsstudy.com/EN/ indexE.htmi

Sariyildiz, T. (2003a). Interactions between litter quality, decomposition and soil fertility: a laboratory study. *Soil Biology and Biochemistry*, *35*(3), 391–399. https://doi.org/10.1016/s0038-0717(02)00290-0

Sariyildiz, T. (2003b). Interactions between litter quality, decomposition and soil fertility: a laboratory study. *Soil Biology and Biochemistry*, *35*(3), 391–399. https://doi.org/10.1016/s0038-0717(02)00290-0

Scheffer, R. A., & Aerts, R. (2000). Root decomposition and soil nutrient and carbon cycling in two temperate fen ecosystems. *Oikos*, *91*(3), 541–549. https://doi.org/10.1034/j.1600-0706.2000.910316.x

Schimel, D. S., Braswell, B. H., Holland, E. A., McKeown, R., Ojima, D. S., Painter, T. H., … Townsend, A. R. (1994). Climatic, edaphic, and biotic controls over storage and turnover of carbon in soils. *Global Biogeochemical Cycles*, *8*(3), 279–293. https://doi.org/10.1029/94gb00993

Schnell, Sylvia, and Gary M. King. "Mechanistic analysis of ammonium inhibition of atmospheric methane consumption in forest soils." *Appl. Environ. Microbiol.* 60.10 (1994): 3514-3521.

Seelen, L. M. S., Flaim, G., Keuskamp, J., Teurlincx, S., Arias Font, R., Tolunay, D., … de Senerpont Domis, L. N. (2019). An affordable and reliable assessment of aquatic decomposition: Tailoring the Tea Bag Index to surface waters. *Water Research*, *151*, 31–43. https://doi.org/10.1016/j.watres.2018.11.081

Seibert, J., Stendahl, J., & Sørensen, R. (2007). Topographical influences on soil properties in boreal forests. *Geoderma*, *141*(1-2), 139-148.

Sherman, G. G., & Beckett, P. J. (2003). Carbon sequestration patterns in the replanted areas of the Sudbury barrens. *Forest Research Information Paper. Ontario For. Res. Inst., Ontario, Canada*.

Sherman, G. G., & Beckett, P. J. (2003). Carbon sequestration patterns in the replanted areas of the Sudbury barrens. *Forest Research Information Paper. Ontario For. Res. Inst., Ontario, Canada*.

Shoun, H., Kim, D. H., Uchiyama, H., & Sugiyama, J. (1992). Denitrification by fungi. *FEMS Microbiology Letters*, *94*(3), 277-281.

Sievers, T., & Cook, R. L. (2018). Aboveground and Root Decomposition of Cereal Rye and Hairy Vetch Cover Crops. *Soil Science Society of America Journal*, *82*(1), 147–155. https://doi.org/10.2136/sssaj2017.05.0139

Sitch, S., Cox, P. M., Collins, W. J., & Huntingford, C. (2007). Indirect radiative forcing of climate change through ozone effects on the land-carbon sink. *Nature*, *448*(7155), 791–794. https://doi.org/10.1038/nature06059

Smith, P., Martino, D., Cai, Z., Gwary, D., Janzen, H., Kumar, P., ... & Scholes, B. (2008). Greenhouse gas mitigation in agriculture. *Philosophical transactions of the royal Society B: Biological Sciences*, *363*(1492), 789-813.

Sörensen, R., Zinko, U., & Seibert, J. (2006). On the calculation of the topographic wetness index: evaluation of different methods based on field observations.

Steudler, P. A., Bowden, R. D., Melillo, J. M., & Aber, J. D. (1989). Influence of nitrogen fertilization on methane uptake in temperate forest soils. *Nature*, *341*(6240), 314-316.

Stocker, T. F., Qin, D., Plattner, G. K., Tignor, M., Allen, S. K., Boschung, J., ... & Midgley, P. M. (2013). Climate change 2013: The physical science basis. *Contribution of working group I to the fifth assessment report of the intergovernmental panel on climate change*, *1535*.

Subke, J.-A., Inglima, I.,& Francesca Cotrufo, m. (2006). Trends and methodological impacts in soil CO2 efflux partitioning: A metaanalytical review. *Global Change Biology*, *12*(6), 921–943. https://doi.org/10.1111/j.1365-2486.2006.01117.x

Tang, J., Baldocchi, D. D., & Xu, L. (2005). Tree photosynthesis modulates soil respiration on a diurnal time scale. *Global Change Biology*, *11*(8), 1298-1304.

Tarnocai, C., Canadell, J. G., Schuur, E. A. G., Kuhry, P., Mazhitova, G., & Zimov, S. (2009). Soil organic carbon pools in the northern circumpolar permafrost region. *Global Biogeochemical Cycles*, *23*(2), n/a-n/a. https://doi.org/10.1029/2008gb003327

Teo, A., Kristensen, N. P., Keuskamp, J. A., Evans, T. A., Foo, M., & Chisholm, R. A. (2020). Validation and Extension of the Tea Bag Index to Collect Decomposition Data from Termite-rich Ecosystems. *Pedobiologia*, 150639.

Teo, A., Kristensen, N. P., Keuskamp, J. A., Evans, T. A., Foo, M., & Chisholm, R. A. (2020). Validation and Extension of the Tea Bag Index to Collect Decomposition Data from Termite-rich Ecosystems. *Pedobiologia*, 150639.

Thauer, R. K., Kaster, A. K., Seedorf, H., Buckel, W., & Hedderich, R. (2008). Methanogenic archaea: ecologically relevant differences in energy conservation. *Nature Reviews Microbiology*, *6*(8), 579-591.

Trojanowski, J., Haider, K., & Hüttermann, A. (1984). Decomposition of 14 C-labelled lignin, holocellulose and lignocellulose by mycorrhizal fungi. *Archives of Microbiology*, *139*(2-3), 202-206.

Urbanska, K. M., Webb, N. R., & Edwards, P. J. (Eds.). (1997). *Restoration ecology and sustainable development*. Cambridge University Press.

Vazquez, A., Flammini, A., Maritan, A., & Vespignani, A. (2003). Global protein function prediction from protein-protein interaction networks. *Nature Biotechnology*, *21*(6), 697–700. https://doi.org/10.1038/nbt825

Venegas, A., Rigol, A., & Vidal, M. (2015). Viability of organic wastes and biochars as amendments for the remediation of heavy metal-contaminated soils. *Chemosphere*, *119*, 190-198.

Vesterdal, L., Clarke, N., Sigurdsson, B. D., & Gundersen, P. (2013). Do tree species influence soil carbon stocks in temperate and boreal forests? Forest Ecology and Management, 309, 4–18. https://doi.org/10.1016/j.foreco.2013.01.017

Vesterdal, L., Schmidt, I. K., Callesen, I., Nilsson, L. O., & Gundersen, P. (2008). Carbon and nitrogen in forest floor and mineral soil under six common European tree species. *Forest Ecology and Management*, *255*(1), 35-48.

Vincent, A. G., Sundqvist, M. K., Wardle, D. A., & Giesler, R. (2014). Bioavailable soil phosphorus decreases with increasing elevation in a subarctic tundra landscape. *PLoS One*, *9*(3), e92942.

Wang, K.-Y., S. Kellomäki, T.S. Zha, and H. Peltola. 2004. Component carbon fluxes and their contribution to ecosystem carbon exchange in a pine forest: An assessment based on eddy covariance measurements and an integrated model. Tree Physiol. 24:19–34.

Watson, W. Y., & Richardson, D. H. (1972). Appreciating the potential of a devasted land. *The*

Forestry Chronicle, *48*(6), 312–315. https://doi.org/10.5558/tfc48312-6

Wider, R. K., & Lang, G. E. (1982). A critique of the analytical methods used in examining decomposition data obtained from litter bags. *Ecology*, *63*(6), 1636-1642.

Winterbourn, M. J. (1978). An evaluation of the mesh bag method for studying leaf colonization by stream invertebrates. *SIL Proceedings, 1922-2010*, *20*(3), 1557–1561. https://doi.org/10.1080/03680770.1977.11896729

Winterhalder, K. (1985). The use of manual surface seeding, liming and fertilization in the reclamation of acid, metal-contaminated land in the sudbury, ontario mining and smelting region of canada. *Journal American Society of Mining and Reclamation*, *1985*(1), 196–204. https://doi.org/10.21000/jasmr85010196

Winterhalder, K. (1996a). Environmental degradation and rehabilitation of the landscape around Sudbury, a major mining and smelting area. *Environmental Reviews*, *4*(3), 185–224. https://doi.org/10.1139/a96-011

Winterhalder, K. (1996b). Environmental degradation and rehabilitation of the landscape around Sudbury, a major mining and smelting area. *Environmental Reviews*, *4*(3), 185–224. https://doi.org/10.1139/a96-011

Wrage, N., Velthof, G. L., Van Beusichem, M. L., & Oenema, O. (2001). Role of nitrifier denitrification in the production of nitrous oxide. *Soil biology and Biochemistry*, *33*(12-13), 1723-1732.

Yavitt, J. B., Fahey, T. J., & Simmons, J. A. (1995). Methane and carbon dioxide dynamics in a northern hardwood ecosystem. *Soil Science Society of America Journal*, *59*(3), 796-804.

Young, T. P. (2000). Restoration ecology and conservation biology. *Biological Conservation*, *92*(1), 73–83. https://doi.org/10.1016/s0006-3207(99)

Zogg, G. P., Zak, D. R., Ringelberg, D. B., White, D. C., MacDonald, N. W., & Pregitzer, K. S. (1997). Compositional and functional shifts in microbial communities due to soil warming. *Soil Science Society of America Journal*, *61*(2), 475-481.

APPENDIX

SUPPLEMENTARY TABLES AND FIGURES

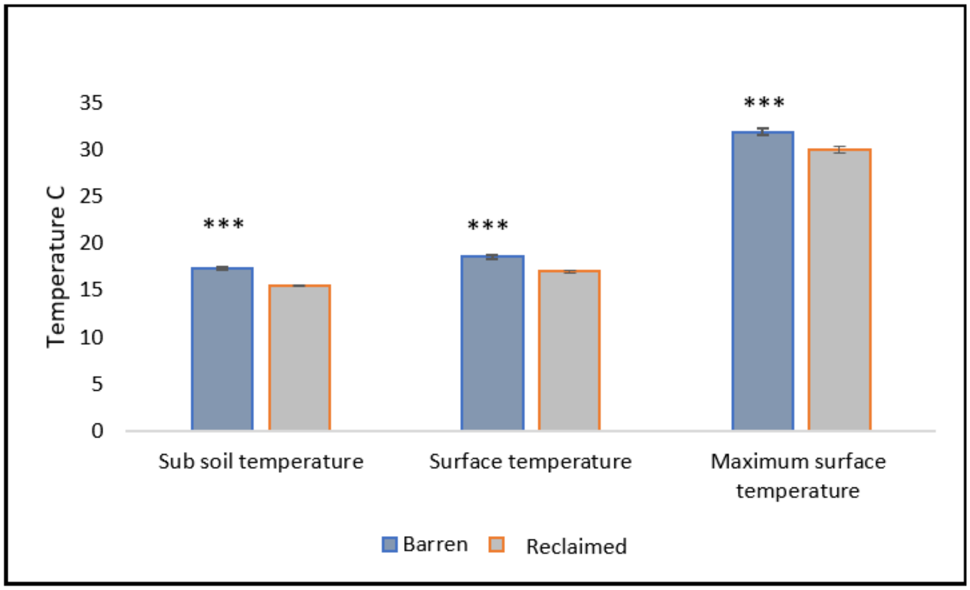

Figure (1) Differences of soil temperature °C at 8 cm depth, surface soil temperature °C and maximum surface temperature °C detected by t-test between barren exposed site (n =10) and reclaimed tree planted site (n =10). Values are mean and standard error. * P < 0.05. ** P < 0.01. ***P<0.001

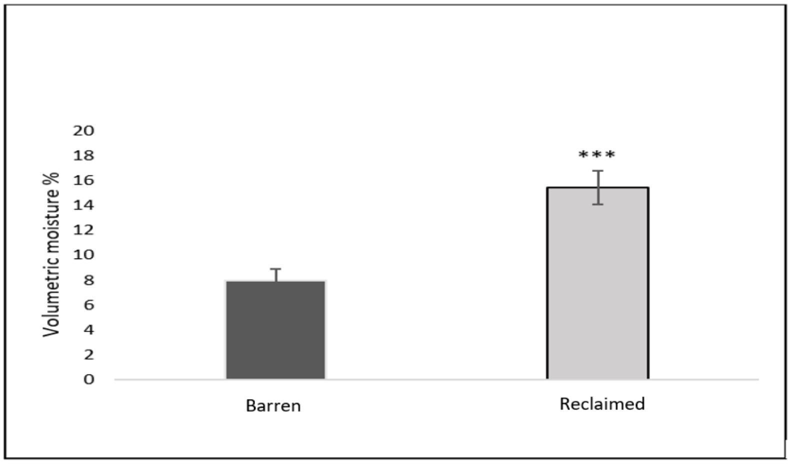

Figure (2) Difference of volumetric moisture (%) detected by t test between barren site (n = 30) and reclaimed tree planted site (n= 30). Values are mean and standard error. * P < 0:05. *** P < 0.01

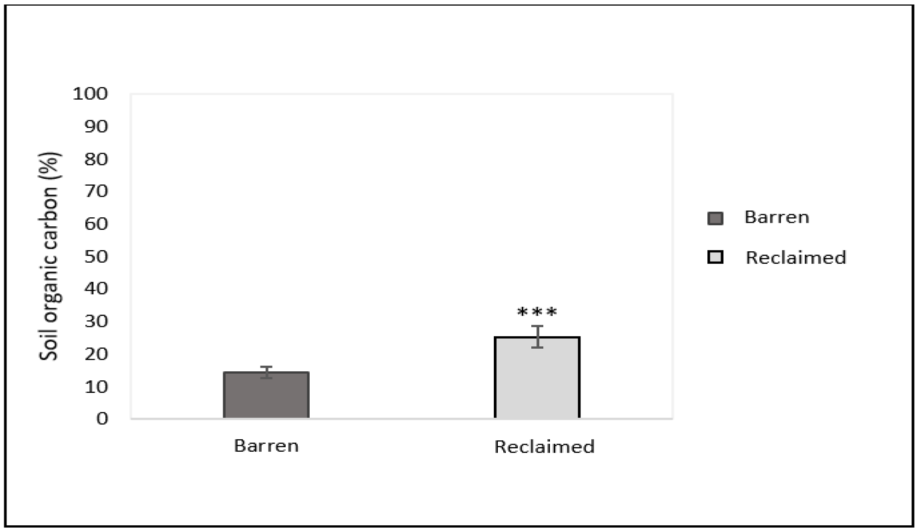

Figure (3) Difference of soil organic carbon (%) detected by t test between barren exposed site (n=30) and reclaimed tree planted site (n=30). Values are mean and standard error. *P < 0:05. *** P < 0.01.

Table (A1) Summary of mean (SE) values of CO_2 efflux (mg m^{-2} h^{-1}), CH_4 flux (µg m^{-2} h^{-1}), N_2O flux (µg m^{-2} h^{-1}) at measurement days at barren and reclaimed treatment site.(n=30) each day. Positive values indicate gas efflux rates and negative values represent consumption rates.

Treatment (Site)	Date	CO2	CH4	N2O
Barren	19 June 2019	37.332 (3.887)	0.001 (0.003)	-0.001 (0.001)
Barren	11 July 2019	55.449 (6.433)	0.005 (0.003)	-0.001 (0.001)
Barren	24 July 2019	35.427 (4.185)	0.003 (0.002)	-0.002 (0.001)
Barren	7 August 2019	18.190 (4.938)	-0.001 (0.004)	0.001 (0.001)
Barren	21 August 2019	37.922 (7.121)	0.004 (0.005)	-0.002 (0.001)
Barren	2 October 2019	19.549 (3.600)	-0.002 (0.002)	0.000 (0.001)
Reclaimed	20 June 2019	64.737 (11.127)	-0.002 (0.002)	-0.003 (0.001)
Reclaimed	10 July 2019	100.358 (13.955)	-0.006 (0.005)	0.000 (0.001)
Reclaimed	25 July 2019	118.737 (10.614)	-0.026 (0.00)	0.000 (0.002)
Reclaimed	9 August 2019	111.090 (11.446)	-0.005 (0.003)	-0.003 (0.001)
Reclaimed	22 August 2019	118.837 (16.503)	-0.012 (0.004)	0.000 (0.001)
Reclaimed	9 October 2019	77.342 (13.982)	-0.010 (0.003)	-0.002 (0.001)

Table (A2) Pearson correlation coefficients of Tea Bag Index parameters and soil properties across Reclaimed area in Sudbury. Mass loss of Green tea (gm), Mass loss of Green tea (gm), Rooibos tea mass loss %, Decomposition rate index (k) ($g \cdot g^{-1} \cdot day^{-1}$), stabilization factor (S)($g\ g^{-1}$), Topography (m) Volumetric moisture %, Soil temperature °C , Surface temperature °C , Maximum Surface temperature °C .Gravimetric moisture ($g\ H_2O\ g\ Soil^{-1}$), SOC (%).Significant relationships ($P < 0.05$) are bold. * $P < 0.05$. ** $P < 0.01$. *** $P < 0.001$

	Green tea mass loss	Rooibos tea mass loss	Decomposition rate (k)	Stabilization factor (S)	Microtopography	Volumetric moisture	Sub soil temperature	Surface temperature	Maximum surface temperature	SOC	Gravimetric moisture
Green tea mass loss	1	-0.48	-0.54	-0.37	**-0.94*** **	**0.72** **	0.4	0.51	0.22	**-0.63***	-0.24
Rooibos tea mass loss		1	**0.93*** **	0.16	0.42	-0.26	-0.1	-0.07	0.02	0.41	0.47
Decomposition rate (k)			1	0.4	0.5	-0.38	-0.08	-0.16	0.03	0.23	0.23
Stabilization factor (S)				1	0.33	-0.48	-0.24	-0.08	0.07	-0.09	-0.32
Microtopography					1	**-0.76** **	-0.34	-0.57	-0.33	0.47	0.06
Volumetric moisture						1	0.63	0.54	0.37	-0.29	0.03
Sub soil temperature							1	0.41	0.44	-0.36	-0.23
Surface temperature								1	**0.68***	0.07	0.39
Maximum surface temperature									1	0.24	0.36
SOC										1	**0.84*** **
Gravimetric moisture											1

Table (A3) Spearman correlation coefficients of Soil respiration and soil properties across Reclaimed area in Sudbury. CO_2 ($mg\ m^{-2}\ h^{-1}$), CH_4 ($\mu g\ m^{-2}\ h^{-1}$), N_2O ($\mu g\ m^{-2}\ h^{-1}$), Topography (m) Volumetric moisture %, Soil temperature °C , Surface temperature °C, Maximum Surface temperature °C , Gravimetric moisture ($g\ H_2O\ g\ Soil^{-1}$), SOC (%). Significant relationships ($P < 0.05$) are bold. * $P < 0.05$. ** $P < 0.01$. *** $P < 0.001$

	CO_2	CH_4	N_2O	Microtopography	Volumetric Moisture	Sub soil temperature	Surface temperature	Maximum Surface temperature	SOC	Gravimetric moisture
CO_2	1	-0.16	0.09	0.57	-0.51	0.07	0.037	0.07	0.36	0.24
CH_4		1	**-0.81*** **	0.34	0.152	0.06	-0.06	-0.15	0.40	0.26
N_2O			1	-0.15	-0.36	-0.44	-0.08	-0.14	-0.35	-0.16
Microtopography				1	**-0.76***	-0.34	-0.56	-0.33	0.47	0.057
Volumetric Moisture					1	0.63	0.53	0.37	-0.29	0.03
Sub soil temperature						1	0.41	0.44	-0.35	-0.23
Surface temperature							1	0.67	0.06	0.38
Maximum Surface temperature								1	0.24	0.36
SOC									1	**0.84*** **
Gravimetric moisture										1

Table (A4) Pearson correlation coefficients of Tea Bag Index parameters and soil properties across Barren area in Sudbury. Mass loss of Green tea (gm), Mass loss of Green tea (gm), Rooibos tea mass loss %,, Decomposition rate index (k) ($g \cdot g^{-1} \cdot day^{-1}$), stabilization factor (S) ($g\ g^{-1}$), Topography (m) Volumetric moisture %, Soil temperature °C , Surface temperature °C , Maximum Surface temperature °C .Gravimetric moisture ($g\ H_2O\ g\ Soil^{-1}$), SOC (%). Significant relationships ($P < 0.05$) are bold. * $P < 0.05$. ** $P < 0.01$. *** $P < 0.001$

	Green tea mass loss	Rooibos tea mass loss	Decomposition rate (k)	Stabilization factor (S)	Microtopography	Volumetric moisture	Sub soil temperature	Surface temperature	Maximum surface temperature	SOC	Gravimetric moisture
Green tea mass loss	1	**0.65***	0.3	**-0.86*****	0.17	0.53	0	-0.06	**-0.67***	-0.5	-0.34
Rooibos tea mass loss		1	0.74	**-0.61***	0.02	0.01	-0.21	0.28	**-0.66***	**-0.77*****	**-0.77*****
Decomposition rate (k)			1	-0.28	0.18	-0.19	**-0.61***	0.25	**-0.64***	-0.49	-0.43
Stabilization factor (S)				1	0.27	-0.31	0.21	-0.25	0.43	0.47	0.29
Microtopography					1	0.48	0.2	-0.42	-0.52	0.02	-0.04
Volumetric moisture						1	0.59	-0.24	-0.29	-0.22	-0.06
Sub soil temperature							1	-0.27	0.13	-0.11	-0.16
Surface temperature								1	0.28	0.1	0.03
Maximum surface temperature									1	0.61	0.53
SOC										1	**0.91*****
Gravimetric moisture											1

Table (A5) Spearman correlation coefficients of Soil respiration and soil properties across Barren area in Sudbury. CO_2 ($mg\ m^{-2}\ h^{-1}$), CH_4 ($\mu g\ m^{-2}\ h^{-1}$), N_2O ($\mu g\ m^{-2}\ h^{-1}$), Topography (m) Volumetric moisture %, Soil temperature °C , Surface temperature °C , Maximum Surface temperature °C , Gravimetric moisture (g H2O g $Soil^{-1}$), SOC (%). Significant relationships ($P < 0.05$) are bold. * $P < 0.05$. ** $P < 0.01$. *** $P < 0.001$

	CO_2	CH_4	N_2O	Microtopography	Volumetric Moisture	Sub soil temperature	Surface temperature	Maximum surface temperature	SOC	Gravimetric moisture
CO_2	1.00	0.26	0.00	-0.29	-0.02	-0.56	0.51	-0.20	-0.14	0.13
CH_4		1.00	0.29	-0.08	0.45	0.25	0.20	0.03	-0.14	0.00
N_2O			1.00	-0.11	0.51	0.36	0.19	0.21	-0.39	-0.36
Microtopography				1.00	0.48	0.20	-0.42	-0.52	0.02	-0.04
Volumetric Moisture					1.00	0.59	-0.24	-0.29	-0.22	-0.06
Sub soil temperature						1.00	-0.27	0.13	-0.11	-0.16
Surface temperature							1.00	0.28	0.10	0.03
Maximum Surface temperature								1.00	0.61	0.53
SOC									1.00	**0.90*****
Gravimetric moisture										1.00

Table (A6) Stepwise backward multiple regression analysis of individual land use treatment site (Barren and Reclaimed). Mass loss of Green tea (gm), Mass loss of Green tea (gm), Rooibos tea mass loss %,Decomposition rate index (k) ($g \cdot g^{-1} \cdot day^{-1}$), stabilization factor (S) ($g\ g^{-1}$), CO_2 ($mg\ m^{-2}\ h^{-1}$), CH_4 ($\mu g\ m^{-2}\ h^{-1}$), N_2O ($\mu g\ m^{-2}\ h^{-1}$), Topography (m) Volumetric moisture %, Sub soil temperature °C , Surface temperature °C , Maximum Surface temperature °C .Gravimetric moisture (g H_2O g $Soil^{-1}$), SOC (%).Significant relationships ($P < 0.05$) are bold. * $P < 0.05$. ** $P < 0.01$. *** $P < 0.001$

Treatment	Dependent	Factors	Coefficient	% variance	Factor (p value)	F statistic	R^2	Model (p value)
Barren	**Green tea mass loss**	Moisture %	0.005	11.5	0.08	**3.59**	0.2	**0.02**
		Microtopography	-0.002	0.28	0.1			
		Surface temperature	-0.01	18.32	0.01			
	Rooibos tea mass loss	Surface temperature	0.03	4.3	0.07	4.80	0.2	**0.01**
		Maximum surface temperature	-0.01	22.7	<0.01			
	Decomposition rate (k)	Sub Soil temperature	-0.002	10.2	0.08	3.05	0.1	0.06
		Surface temperature	-0.0008	8.7	0.1			
	Stabilization factor (s)	Moisture %	-0.003	5.6	0.1	4.25	0.2	**0.01**
		Microtopography	0.003	10.2	0.05			
		Surface temperature	0.007	17.87	0.01			
	CO2	Sub Soil temperature	-8.96	20.9	<0.01	5.98	0.2	**0.007**
		Moisture	0.98	9.7	0.06			
	CH4	Moisture	0.0004	14.37	0.03	4.70	0.1	**0.03**
Restored	**Green tea mass loss**	Microtopography	- 0.004	9.16	0.01	2.32	0.2	**0.01**
	Decomposition rate (k)	Microtopography	0.0003	14	0.06	3.85	0.1	0.06

Table (A7) Descriptive summary of monthly Sub soil temperature °C , Surface temperature °C , Maximum Surface temperature °C .

Treatment	Month	Subsoil Temperature	Surface temperature	Maximum Surface Temperature
Barren	June	19.58(0.30)	22.76(0.28)	38.22(0.61)
Barren	July	21.04(0.08)	24.33(0.15)	41.71(0.39)
Barren	August	19.08(0.10)	19.73(0.22)	34.15(0.49)
Barren	September	14.65(0.12)	14.87(0.18)	24.98(0.41)
Barren	October	9.12(0.24)	8.26(0.23)	14.84(0.44)
Reclaimed	June	17.78(0.38)	20.98(0.29)	37.01(0.85)
Reclaimed	July	18.40(0.09)	22.21(0.12)	40.97(0.54)
Reclaimed	August	17.21(0.08)	18.75(0.13)	34.01(0.48)
Reclaimed	September	14.33(0.09)	13.91(0.14)	22.75(0.33)
Reclaimed	October	9.16(0.17)	8.06(0.21)	13.39(0.29)

Table (A8) Descriptive summary of plot characteristics of the two study sites (barren site and reclaimed forested site). Elevation is measured in meters (above sea level). Soil temperature was measured by Elitech temperature data loggers at the soil surface and at 8cm depth. Maximum surface temperatures were calculated manually from individual surface data logger. Volumetric moisture was measured as (%Volumetric water content).

Treatment	Site	Elevation(m)	Latitude	Longitude	Soil Temperature °C	Surface Temperature °C	Maximum Surface Temperature °C	Volumetric Moisture (%VWC)
Barren	BA1	249.874	46.446518	-81.05633987	17.32877395	19.26442252	52.9	2.76
Barren	BA2	252.696	46.44645	-81.05626283	18.48291115	19.26442252	52.9	12.8
Barren	BA3	255.473	46.446399	-81.0562189	17.24066488	18.63582942	49.8	5.76
Barren	BA4	258.236	46.446326	-81.05608608	16.52498321	18.45433177	55.2	6.56
Barren	BA5	261.063	46.446257	-81.05600703	17.35795836	20.66676449	55.6	3.96

Barren	BA6	263.723	46.446206	-81.05593619	15.49425789	20.14887257	45.3	7.53
Barren	BA7	266.658	46.446142	-81.05585689	16.41373405	18.05564137	51.4	3.7
Barren	BA8	269.436	46.446089	-81.05578946	17.4906313	17.81997985	45.6	7.26
Barren	BA9	272.355	46.445859	-81.05561916	17.87981867	18.48969107	49	16.33
Barren	BA10	275.037	46.445685	-81.05551473	19.13418482	18.17552048	49.4	13.06
Reclaimed	RE1	249.876	46.447122	-81.05458195	15.26212223	18.29130289	60.4	23.8
Reclaimed	RE2	252.71	46.446988	-81.05455355	15.86574882	17.34253028	61.2	16.1
Reclaimed	RE3	255.365	46.446859	-81.05452042	15.5916051	16.40533915	52.2	15.66
Reclaimed	RE4	258.867	46.446637	-81.05441879	17.20634654	17.46736064	60	27.7
Reclaimed	RE5	261.195	46.446521	-81.05460921	15.7481867	16.82283412	38.6	15.76
Reclaimed	RE6	263.804	46.446529	-81.05441783	15.46276024	16.04452653	52.2	18.9
Reclaimed	RE7	266.634	46.446458	-81.05415451	14.34627267	15.75799194	37.2	10.73
Reclaimed	RE8	269.319	46.446096	-81.05372612	15.30735393	16.37871921	52.1	11.83
Reclaimed	RE9	272.318	46.445809	-81.0536881	14.64100067	16.93623237	56	7.6
Reclaimed	RE10	275.118	46.445678	-81.0539272	15.69183742	16.68710544	53.5	5.66

Table (A9) Summary of soil characteristics from individual PVC collar (subsite) at each plot from Barren and Restored forested study site. Organic layer and Mineral layer depth were measured up-to 10cm depth from soil within individual collar.

Treatment Site	Subsite	Total Collar soil depth (cm)	Organic layer depth (cm)	Mineral layer depth (cm)
Barren	BA1T1	10	0	10
Barren	BA1T2	6	0	6

Barren	BA1T3	3	0	3
Barren	BA2T1	8	8	0
Barren	BA2T2	10	0	10
Barren	BA2T3	10	0	10
Barren	BA3T1	10	0	10
Barren	BA3T2	10	0	10
Barren	BA3T3	10	0	10
Barren	BA4T1	6	1	5
Barren	BA4T2	10	7	3
Barren	BA4T3	7	0	7
Barren	BA5T1	4	0	4
Barren	BA5T2	6	0	6
Barren	BA5T3	7	0	7
Barren	BA6T1	10	2	8
Barren	BA6T2	10	3	7
Barren	BA6T3	10	0	10
Barren	BA7T1	10	0	10
Barren	BA7T2	10	0	10
Barren	BA7T3	9	1	8
Barren	BA8T1	5	0	5
Barren	BA8T2			
Barren	BA8T3	10	3	7
Barren	BA9T1	10	0	10
Barren	BA9T2	5	0	5
Barren	BA9T3	10	0	10
Barren	BA10T1	10	0	10
Barren	BA10T2	10	0	10
Barren	BA10T3	10	0	10
Reclaimed	RE1T1	10	0.5	9.5
Reclaimed	RE1T2	N/A	N/A	N/A
Reclaimed	RE1T3	10	3	7
Reclaimed	RE2T1	10	5	5
Reclaimed	RE2T2	10	7	3
Reclaimed	RE2T3	10	5	5
Reclaimed	RE3T1	5	2	3
Reclaimed	RE3T2	10	3	7
Reclaimed	RE3T3	10	5	5
Reclaimed	RE4T1	7	0	7
Reclaimed	RE4T2	10	2	8
Reclaimed	RE4T3	10	1	9
Reclaimed	RE5T1	8	1	7
Reclaimed	RE5T2	10	1	9
Reclaimed	RE5T3	10	3	7

Reclaimed	RE6T1	10	8	2
Reclaimed	RE6T2	8	6	2
Reclaimed	RE6T3	10	10	0
Reclaimed	RE7T1	10	1	9
Reclaimed	RE7T2	10	2	8
Reclaimed	RE7T3	10	1	9
Reclaimed	RE8T1	10	0.5	9.5
Reclaimed	RE8T2	10	0.5	9.5
Reclaimed	RE8T3	10	5	5
Reclaimed	RE9T1	6	0	6
Reclaimed	RE9T2	10	2	8
Reclaimed	RE9T3	10	2	8
Reclaimed	RE10T1	8	3	5
Reclaimed	RE10T2	7	7	0
Reclaimed	RE10T3	10	6	4

Table (A10) Treatment and Mass loss of Green tea (gm), Rooibos tea mass loss %, Decomposition rate index (k) ($g \cdot g^{-1} \cdot day^{-1}$), stabilization factor (S) ($g\ g^{-1}$) at (un- treated un-limed) and Reclaimed (limed, fertilized and tree planted).

Location	Treatment	Plot	Subsite	Green tea mass loss	Rooibos tea mass loss	Stabilization factor (S)	Decomposition rate index (k)
Sudbury	Barren	BA1	BA1T1	1.366	0.658	0.099	0.0099
Sudbury	Barren	BA1	BA1T2	1.213	0.667	0.192	0.0130

Sudbury	Barren	BA1	BA1T3	1.222	0.744	0.166	0.0151
Sudbury	Barren	BA2	BA2T1	1.268	0.678	0.125	0.0106
Sudbury	Barren	BA2	BA2T2	1.291	0.622	0.133	0.0101
Sudbury	Barren	BA2	BA2T3	1.254	0.689	0.136	0.0118
Sudbury	Barren	BA3	BA3T1	1.141	0.669	0.196	0.0124
Sudbury	Barren	BA3	BA3T2	1.34	0.702	0.128	0.0121
Sudbury	Barren	BA3	BA3T3	1.278	0.58	0.109	0.0084
Sudbury	Barren	BA4	BA4T1	1.192	0.437	0.183	0.0061
Sudbury	Barren	BA4	BA4T2	1.209	0.522	0.164	0.0077
Sudbury	Barren	BA4	BA4T3	1.237	0.52	0.178	0.0075
Sudbury	Barren	BA5	BA5T1	1.305	0.71	0.122	0.0119
Sudbury	Barren	BA5	BA5T2	1.131	0.592	0.199	0.0102
Sudbury	Barren	BA5	BA5T3	1.131	0.59	0.249	0.0114
Sudbury	Barren	BA6	BA6T1	1.328	0.694	0.094	0.0114
Sudbury	Barren	BA6	BA6T2	1.356	1.01	0.098	0.0532
Sudbury	Barren	BA6	BA6T3	1.266	0.572	0.147	0.0084
Sudbury	Barren	BA7	BA7T1	1.174	0.793	0.231	0.0321
Sudbury	Barren	BA7	BA7T2	1.264	0.531	0.135	0.0079
Sudbury	Barren	BA7	BA7T3	1.13	0.614	0.26	0.0134
Sudbury	Barren	BA8	BA8T1	1.336	0.59	0.141	0.0090
Sudbury	Barren	BA8	BA8T3	1.283	0.813	0.16	0.0197
Sudbury	Barren	BA9	BA9T1	1.282	0.698	0.142	0.0128
Sudbury	Barren	BA9	BA9T2	1.445	0.667	0.085	0.0101
Sudbury	Barren	BA9	BA9T3	1.348	0.683	0.136	0.0120
Sudbury	Barren	BA10	BA10T1	1.21	0.619	0.197	0.0106
Sudbury	Barren	BA10	BA10T2	1.33	0.555	0.149	0.0087
Sudbury	Barren	BA10	BA10T3	1.117	0.59	0.288	0.0126
Sudbury	Reclaimed	RE1	RE1T1	1.377	0.703	0.087	0.0110
Sudbury	Reclaimed	RE1	RE1T2	1.396	0.739	0.099	0.0129
Sudbury	Reclaimed	RE1	RE1T3	1.466	0.75	0.057	0.0117
Sudbury	Reclaimed	RE2	RE2T1	1.464	0.639	0.122	0.0106
Sudbury	Reclaimed	RE2	RE2T2	1.353	0.585	0.111	0.0085
Sudbury	Reclaimed	RE2	RE2T3	1.495	0.673	0.054	0.0094
Sudbury	Reclaimed	RE3	RE3T1	1.322	0.622	0.116	0.0096
Sudbury	Reclaimed	RE3	RE3T2	1.442	0.616	0.101	0.0085
Sudbury	Reclaimed	RE3	RE3T3	1.383	0.638	0.088	0.0095
Sudbury	Reclaimed	RE4	RE4T1	1.443	0.665	0.084	0.0104
Sudbury	Reclaimed	RE4	RE4T3	1.35	0.593	0.096	0.0084
Sudbury	Reclaimed	RE5	RE5T2	1.391	0.732	0.086	0.0116
Sudbury	Reclaimed	RE6	RE6T1	1.369	0.688	0.069	0.0106
Sudbury	Reclaimed	RE6	RE6T2	1.384	0.773	0.05	0.0120

Sudbury	Reclaimed	RE6	RE6T3	1.333	0.77	0.081	0.0121
Sudbury	Reclaimed	RE7	RE7T1	1.51	0.678	0.011	0.0092
Sudbury	Reclaimed	RE7	RE7T2	1.371	0.608	0.11	0.0087
Sudbury	Reclaimed	RE7	RE7T3	1.217	0.521	0.157	0.0080
Sudbury	Reclaimed	RE8	RE8T2	1.355	0.966	0.1	0.0363
Sudbury	Reclaimed	RE8	RE8T3	1.316	0.871	0.131	0.0234
Sudbury	Reclaimed	RE9	RE9T1	1.297	0.666	0.124	0.0109
Sudbury	Reclaimed	RE9	RE9T2	1.238	0.686	0.15	0.0125
Sudbury	Reclaimed	RE9	RE9T3	1.414	0.725	0.072	0.0112
Sudbury	Reclaimed	RE10	RE10T1	1.262	0.944	0.133	0.0311
Sudbury	Reclaimed	RE10	RE10T3	1.369	0.609	0.045	0.0078

Table (A11) Averaged across the season, measurements of CO_2 (mg m^{-2} h^{-1}), CH_4 (μg m^{-2} h^{-1}), N_2O (μg m^{-2} h^{-1}) at both Barren and Reclaimed site. Positive values indicate gas efflux rates and negative values represent consumption rates.

Location	Treatment	Plot	Subsite	Date	CO2	CH4	N2O
Sudbury	Barren	BA1	BA1T1	6/19/2019	41.58755	0.008069	0.002858
Sudbury	Barren	BA1	BA1T2	6/19/2019	54.23296	0.004775	-0.00379
Sudbury	Barren	BA1	BA1T3	6/19/2019	28.35919	0.013263	0.004669
Sudbury	Barren	BA2	BA2T1	6/19/2019	27.00046	0.014812	-0.00409
Sudbury	Barren	BA2	BA2T2	6/19/2019	22.56646	-0.01331	0.000275
Sudbury	Barren	BA2	BA2T3	6/19/2019	43.14543	-0.01269	-0.00089
Sudbury	Barren	BA3	BA3T1	6/19/2019	29.14925	-0.01178	0.002485
Sudbury	Barren	BA3	BA3T2	6/19/2019	18.2783	-0.00853	-0.00302
Sudbury	Barren	BA3	BA3T3	6/19/2019	27.60661	-0.0003	0.001808
Sudbury	Barren	BA4	BA4T1	6/19/2019	44.61053	0.012354	0.001089
Sudbury	Barren	BA4	BA4T2	6/19/2019	52.47535	0.002011	-0.00476
Sudbury	Barren	BA4	BA4T3	6/19/2019	47.10294	-0.0045	-0.00198
Sudbury	Barren	BA5	BA5T1	6/19/2019	55.62306	0.010897	0.005693
Sudbury	Barren	BA5	BA5T2	6/19/2019	53.9834	-0.0055	0.001048
Sudbury	Barren	BA5	BA5T3	6/19/2019	67.62174	-0.00999	-0.00434
Sudbury	Barren	BA6	BA6T1	6/19/2019	72.7591	-0.01951	0.003846
Sudbury	Barren	BA6	BA6T2	6/19/2019	68.63762	0.005448	-0.00016
Sudbury	Barren	BA7	BA7T1	6/19/2019	-2.01096	0.016256	0.000564
Sudbury	Barren	BA7	BA7T2	6/19/2019	0.884883	-0.00762	-0.00306
Sudbury	Barren	BA7	BA7T3	6/19/2019	2.825153	-0.02359	0.002132
Sudbury	Barren	BA8	BA8T1	6/19/2019	32.18178	-0.00905	-0.00535
Sudbury	Barren	BA8	BA8T2	6/19/2019	0	0.002808	0.008027
Sudbury	Barren	BA8	BA8T3	6/19/2019	40.12043	-0.01243	-0.0087
Sudbury	Barren	BA9	BA9T1	6/19/2019	53.59731	0.041979	-0.01355
Sudbury	Barren	BA9	BA9T2	6/19/2019	66.14095	0.011185	0.004578
Sudbury	Barren	BA9	BA9T3	6/19/2019	26.58999	0.008391	0.001181
Sudbury	Barren	BA10	BA10T1	6/19/2019	30.87564	0.013772	-0.00847
Sudbury	Barren	BA10	BA10T2	6/19/2019	30.87564	0.00572	0.00303
Sudbury	Barren	BA10	BA10T3	6/19/2019	45.81891	-0.01209	0.002028
Sudbury	Barren	BA1	BA1T1	7/10/2019	54.35534	0.002409	-0.00799
Sudbury	Barren	BA1	BA1T2	7/10/2019	37.26195	0.006083	-0.00357
Sudbury	Barren	BA1	BA1T3	7/10/2019	23.28699	-0.00643	0.002924
Sudbury	Barren	BA2	BA2T1	7/10/2019	37.498	0.005241	0.003949
Sudbury	Barren	BA2	BA2T2	7/10/2019	12.35103	0.008445	0.002183
Sudbury	Barren	BA2	BA2T3	7/10/2019	39.30678	0.019021	0.001072
Sudbury	Barren	BA3	BA3T1	7/10/2019	22.25481	-0.00426	-0.00522
Sudbury	Barren	BA3	BA3T2	7/10/2019	11.90915	0.016859	-0.00492
Sudbury	Barren	BA3	BA3T3	7/10/2019	25.50381	-0.00175	-0.00695

Sudbury	Barren	BA4	BA4T1	7/10/2019	25.68883	-0.01755	0.004778
Sudbury	Barren	BA4	BA4T2	7/10/2019	29.49372	-0.01428	0.002549
Sudbury	Barren	BA4	BA4T3	7/10/2019	41.13545	-0.00318	0.001406
Sudbury	Barren	BA5	BA5T1	7/10/2019	0	0.014469	-0.0024
Sudbury	Barren	BA5	BA5T2	7/10/2019	25.37527	-0.00387	0.009496
Sudbury	Barren	BA5	BA5T3	7/10/2019	38.67513	-0.01421	-0.00095
Sudbury	Barren	BA6	BA6T1	7/10/2019	75.31733	0.027738	0.00071
Sudbury	Barren	BA6	BA6T2	7/10/2019	82.63881	-0.02346	-7.9E-05
Sudbury	Barren	BA6	BA6T3	7/10/2019	60.03426	0.019977	-0.00742
Sudbury	Barren	BA6	BA6T1	7/11/2019	105.632	0.010706	-0.00027
Sudbury	Barren	BA6	BA6T2	7/11/2019	141.7815	0.030182	-0.00215
Sudbury	Barren	BA6	BA6T3	7/11/2019	82.96747	0.008287	-0.00304
Sudbury	Barren	BA7	BA7T1	7/11/2019	106.8525	-0.01784	0.004983
Sudbury	Barren	BA7	BA7T2	7/11/2019	80.0272	-0.00604	-0.00473
Sudbury	Barren	BA7	BA7T3	7/11/2019	89.42122	0.001533	-0.0024
Sudbury	Barren	BA8	BA8T1	7/11/2019	68.03405	0.016484	-0.00343
Sudbury	Barren	BA8	BA8T2	7/11/2019	108.0952	0.030209	-0.01447
Sudbury	Barren	BA8	BA8T3	7/11/2019	25.80485	0.005685	0.002095
Sudbury	Barren	BA9	BA9T1	7/11/2019	97.16275	0.009262	-0.00414
Sudbury	Barren	BA9	BA9T2	7/11/2019	97.01005	0.00937	0.007987
Sudbury	Barren	BA9	BA9T3	7/11/2019	20.78976	0.013181	0.006294
Sudbury	Barren	BA10	BA10T1	7/11/2019	53.25768	0.004717	-0.00861
Sudbury	Barren	BA1	BA1T1	7/24/2019	61.50113	0.0096	-0.00533
Sudbury	Barren	BA1	BA1T2	7/24/2019	49.61528	-0.00426	-0.0027
Sudbury	Barren	BA1	BA1T3	7/24/2019	30.08292	0.015418	-0.01159
Sudbury	Barren	BA2	BA2T1	7/24/2019	35.02199	-0.00807	-0.0002
Sudbury	Barren	BA2	BA2T2	7/24/2019	20.45556	0.013182	-0.00237
Sudbury	Barren	BA2	BA2T3	7/24/2019	56.78788	0.030227	-0.00569
Sudbury	Barren	BA3	BA3T1	7/24/2019	25.5697	0.018039	0.002698
Sudbury	Barren	BA3	BA3T2	7/24/2019	0	0.006946	-0.00565
Sudbury	Barren	BA3	BA3T3	7/24/2019	27.05832	-0.01759	0.000494
Sudbury	Barren	BA5	BA5T1	7/24/2019	34.61422	-0.0094	-0.00179
Sudbury	Barren	BA5	BA5T2	7/24/2019	14.79397	0.011201	-0.00111
Sudbury	Barren	BA5	BA5T3	7/24/2019	52.79289	0.004042	-0.00016
Sudbury	Barren	BA6	BA6T1	7/24/2019	81.13086	0.014936	-0.00446
Sudbury	Barren	BA6	BA6T2	7/24/2019	77.93251	-0.01402	0.000716
Sudbury	Barren	BA6	BA6T3	7/24/2019	44.08668	0.002228	-0.00838
Sudbury	Barren	BA7	BA7T1	7/24/2019	60.25763	0.013185	0.006104
Sudbury	Barren	BA7	BA7T2	7/24/2019	10.56035	-0.00982	-0.00249
Sudbury	Barren	BA7	BA7T3	7/24/2019	16.36932	-0.00209	0.001326
Sudbury	Barren	BA8	BA8T1	7/24/2019	19.3211	-0.01331	0.00539
Sudbury	Barren	BA8	BA8T2	7/24/2019	25.86496	-0.00707	-0.00238
Sudbury	Barren	BA8	BA8T1	7/24/2019	11.89244	-0.00138	0.003117

Sudbury	Barren	BA4	BA4T1	7/24/2019	38.53672	0.01062	-0.00749
Sudbury	Barren	BA4	BA4T2	7/24/2019	36.64298	-0.00162	-0.00282
Sudbury	Barren	BA4	BA4T3	7/24/2019	62.4398	-0.00138	-0.00832
Sudbury	Barren	BA9	BA9T1	7/24/2019	56.30599	0.024783	-0.01648
Sudbury	Barren	BA9	BA9T2	7/24/2019	20.9253	-0.02655	0.011236
Sudbury	Barren	BA9	BA9T3	7/24/2019	12.40207	0.021507	-0.00393
Sudbury	Barren	BA10	BA10T1	7/24/2019	69.99214	0.005742	-0.00017
Sudbury	Barren	BA10	BA10T2	7/24/2019	9.862943	0.013421	-0.00371
Sudbury	Barren	BA10	BA10T3	7/24/2019	0	-0.01026	0.001225
Sudbury	Barren	BA1	BA1T1	8/7/2019	79.64879	-0.00259	-0.00641
Sudbury	Barren	BA1	BA1T2	8/7/2019	72.02587	0.003773	0.008096
Sudbury	Barren	BA1	BA1T3	8/7/2019	50.41855	0.023644	0.002907
Sudbury	Barren	BA2	BA2T1	8/7/2019	52.35423	0.015803	-0.00177
Sudbury	Barren	BA2	BA2T2	8/7/2019	32.4272	-0.00605	-0.00066
Sudbury	Barren	BA2	BA2T3	8/7/2019	78.78841	-0.04207	0.011312
Sudbury	Barren	BA3	BA3T1	8/7/2019	40.10994	0.014268	-0.00047
Sudbury	Barren	BA3	BA3T2	8/7/2019	30.54704	-0.02846	-0.00907
Sudbury	Barren	BA3	BA3T3	8/7/2019	35.52409	0.015631	0.005992
Sudbury	Barren	BA4	BA4T1	8/7/2019	39.0841	0.046633	-0.01015
Sudbury	Barren	BA4	BA4T2	8/7/2019	41.31858	-0.01095	-0.00935
Sudbury	Barren	BA4	BA4T3	8/7/2019	0	-0.00013	-0.0028
Sudbury	Barren	BA5	BA5T1	8/7/2019	2.34488	-0.01172	0.000151
Sudbury	Barren	BA5	BA5T2	8/7/2019	-2.46025	0.019314	-0.00541
Sudbury	Barren	BA5	BA5T3	8/7/2019	-0.37631	-0.00057	-0.00222
Sudbury	Barren	BA6	BA6T1	8/7/2019	-0.61225	0.008782	0.010623
Sudbury	Barren	BA6	BA6T2	8/7/2019	-1.03886	0.001014	0.002113
Sudbury	Barren	BA6	BA6T3	8/7/2019	-1.07883	-0.03976	0.02158
Sudbury	Barren	BA7	BA7T1	8/7/2019	-1.44625	0.013775	0.004737
Sudbury	Barren	BA7	BA7T2	8/7/2019	0.468619	-0.01642	0.00188
Sudbury	Barren	BA7	BA7T3	8/7/2019	2.227354	-0.00374	0.005803
Sudbury	Barren	BA8	BA8T1	8/7/2019	-1.08359	-0.02598	-0.00339
Sudbury	Barren	BA8	BA8T2	8/7/2019	0.649066	-0.03191	0.003044
Sudbury	Barren	BA8	BA8T3	8/7/2019	-0.29986	-0.01809	-0.00056
Sudbury	Barren	BA9	BA9T1	8/7/2019	-1.20105	0.013195	0.004528
Sudbury	Barren	BA9	BA9T2	8/7/2019	0.115197	0.026969	-1.8E-05
Sudbury	Barren	BA9	BA9T3	8/7/2019	-0.63663	-0.0066	0.000255
Sudbury	Barren	BA10	BA10T1	8/7/2019	-0.12107	0.017995	0.004172
Sudbury	Barren	BA10	BA10T2	8/7/2019	-2.00668	-0.01211	-0.00564
Sudbury	Barren	BA10	BA10T3	8/7/2019	0.009186	0.000427	-0.0005
Sudbury	Barren	BA6	BA6T1	8/21/2019	103.8755	-0.01466	-0.0062
Sudbury	Barren	BA6	BA6T2	8/21/2019	68.1541	-0.00169	-0.01267
Sudbury	Barren	BA6	BA6T3	8/21/2019	53.77528	0.004161	-0.00039
Sudbury	Barren	BA7	BA7T1	8/21/2019	53.38252	-0.01305	-0.0072

Sudbury	Barren	BA7	BA7T2	8/21/2019	18.56299	0.015178	0.002879
Sudbury	Barren	BA7	BA7T3	8/21/2019	12.18244	0.012807	0.000952
Sudbury	Barren	BA8	BA8T2	8/21/2019	26.3415	-0.00321	-0.00452
Sudbury	Barren	BA8	BA8T3	8/21/2019	10.56747	0.019396	-0.00643
Sudbury	Barren	BA9	BA9T1	8/21/2019	47.89919	0.050237	0.000421
Sudbury	Barren	BA9	BA9T2	8/21/2019	42.72147	-0.00134	0.004101
Sudbury	Barren	BA9	BA9T3	8/21/2019	32.87917	-0.00372	0.002797
Sudbury	Barren	BA10	BA10T1	8/21/2019	36.35369	0.024078	-0.00101
Sudbury	Barren	BA10	BA10T2	8/21/2019	6.060823	-0.00513	0.00376
Sudbury	Barren	BA10	BA10T3	8/21/2019	18.15384	-0.0252	0.00047
Sudbury	Barren	BA1	BA1T1	2/10/2019	24.97399	0.007546	0.004421
Sudbury	Barren	BA1	BA1T2	2/10/2019	30.88608	-0.01054	-0.00035
Sudbury	Barren	BA1	BA1T3	2/10/2019	0	0.012092	-0.0058
Sudbury	Barren	BA2	BA2T1	2/10/2019	0	-0.00688	0.020312
Sudbury	Barren	BA2	BA2T2	2/10/2019	100.9307	-0.00203	0.001083
Sudbury	Barren	BA2	BA2T3	2/10/2019	-4.68099	-0.00221	-0.0006
Sudbury	Barren	BA3	BA3T1	2/10/2019	4.239724	0.001271	0.002168
Sudbury	Barren	BA3	BA3T2	2/10/2019	12.46648	0.010846	0.005481
Sudbury	Barren	BA3	BA3T3	2/10/2019	18.56417	0.020471	0.001471
Sudbury	Barren	BA4	BA4T1	2/10/2019	19.15597	-0.01256	0.00329
Sudbury	Barren	BA4	BA4T2	2/10/2019	44.77636	0.00602	0.002408
Sudbury	Barren	BA4	BA4T3	2/10/2019	15.47711	-0.01167	0.003383
Sudbury	Barren	BA5	BA5T1	2/10/2019	6.033502	0.016122	0.008404
Sudbury	Barren	BA5	BA5T2	2/10/2019	18.52719	-0.00194	-0.00395
Sudbury	Barren	BA5	BA5T3	2/10/2019	28.19536	-0.00707	-0.00999
Sudbury	Barren	BA6	BA6T1	2/10/2019	30.60832	0.008871	-0.01498
Sudbury	Barren	BA6	BA6T2	2/10/2019	24.65332	0.023073	-0.0037
Sudbury	Barren	BA6	BA6T3	2/10/2019	30.31483	-0.0293	-0.0002
Sudbury	Barren	BA7	BA7T1	2/10/2019	17.25318	-0.03316	-0.00805
Sudbury	Barren	BA7	BA7T2	2/10/2019	12.99917	-0.006	-0.01128
Sudbury	Barren	BA7	BA7T3	2/10/2019	3.452981	-0.00584	0.002953
Sudbury	Barren	BA8	BA8T1	2/10/2019	17.54836	0.012973	-0.00419
Sudbury	Barren	BA8	BA8T2	2/10/2019	21.50541	-0.01437	-0.00621
Sudbury	Barren	BA8	BA8T3	2/10/2019	17.6755	0.003714	0.002178
Sudbury	Barren	BA9	BA9T1	2/10/2019	28.66603	-0.01755	0.006523
Sudbury	Barren	BA9	BA9T2	2/10/2019	-0.73386	3.92E-05	-0.00223
Sudbury	Barren	BA9	BA9T3	2/10/2019	16.50718	-0.00392	0.001206
Sudbury	Barren	BA10	BA10T1	2/10/2019	9.374338	-0.00619	-0.00256
Sudbury	Barren	BA10	BA10T2	2/10/2019	17.53925	-0.00012	-0.00192
Sudbury	Reclaimed	RE1	RE1T1	6/20/2019	28.43189	0.009115	0.000582
Sudbury	Reclaimed	RE1	RE1T2	6/20/2019	32.38949	0.013607	0.00203
Sudbury	Reclaimed	RE1	RE1T3	6/20/2019	233.4779	-0.02026	-0.00234
Sudbury	Reclaimed	RE2	RE2T1	6/20/2019	87.18375	-0.00652	-0.01119

Sudbury	Reclaimed	RE2	RE2T2	6/20/2019	56.37068	0.021695	-0.00541
Sudbury	Reclaimed	RE2	RE2T3	6/20/2019	61.6878	0.015678	-0.00972
Sudbury	Reclaimed	RE3	RE3T1	6/20/2019	36.53408	-0.0117	-0.01324
Sudbury	Reclaimed	RE3	RE3T2	6/20/2019	36.80235	-0.00745	0.002241
Sudbury	Reclaimed	RE3	RE3T3	6/20/2019	19.87986	-0.00715	-0.00272
Sudbury	Reclaimed	RE4	RE4T1	6/20/2019	0	0.003726	-0.00109
Sudbury	Reclaimed	RE4	RE4T2	6/20/2019	0	-0.00949	-0.0095
Sudbury	Reclaimed	RE4	RE4T3	6/20/2019	280.4813	-0.01779	-0.00422
Sudbury	Reclaimed	RE5	RE5T1	6/20/2019	68.26932	0.005419	-0.00923
Sudbury	Reclaimed	RE5	RE5T2	6/20/2019	91.06995	-0.00551	-0.00128
Sudbury	Reclaimed	RE5	RE5T3	6/20/2019	65.12328	0.007632	0.001472
Sudbury	Reclaimed	RE6	RE6T1	6/20/2019	79.09947	-0.0047	0.000979
Sudbury	Reclaimed	RE6	RE6T2	6/20/2019	64.86321	-0.00542	0.001814
Sudbury	Reclaimed	RE6	RE6T3	6/20/2019	57.53313	-0.00671	-0.01111
Sudbury	Reclaimed	RE7	RE7T1	6/20/2019	49.62494	-0.0016	-0.00082
Sudbury	Reclaimed	RE7	RE7T2	6/20/2019	41.57229	0.008594	-0.00495
Sudbury	Reclaimed	RE8	RE8T1	6/20/2019	66.35079	-0.01729	0.002096
Sudbury	Reclaimed	RE8	RE8T2	6/20/2019	80.84322	-0.01637	0.001343
Sudbury	Reclaimed	RE8	RE8T3	6/20/2019	0	0.009395	0.003364
Sudbury	Reclaimed	RE7	RE7T3	6/20/2019	57.69601	-0.02001	-0.00193
Sudbury	Reclaimed	RE9	RE9T1	6/20/2019	22.50895	-0.00568	-0.01213
Sudbury	Reclaimed	RE9	RE9T2	6/20/2019	73.67309	0.015339	0.003718
Sudbury	Reclaimed	RE10	RE10T1	6/20/2019	47.3942	-0.00562	0.001792
Sudbury	Reclaimed	RE10	RE10T2	6/20/2019	102.0601	-0.00162	0.002915
Sudbury	Reclaimed	RE10	RE10T3	6/20/2019	36.44476	-0.00636	-0.008
Sudbury	Reclaimed	RE1	RE1T3	7/11/2019	55.90825	0.027956	-0.00477
Sudbury	Reclaimed	RE1	RE1T2	7/11/2019	81.19624	-0.0049	0.003305
Sudbury	Reclaimed	RE1	RE1T1	7/11/2019	100.3554	0.000224	0.007611
Sudbury	Reclaimed	RE2	RE2T1	7/11/2019	173.3811	-0.02587	0.0109
Sudbury	Reclaimed	RE2	RE2T2	7/11/2019	27.0644	-0.05738	0.005061
Sudbury	Reclaimed	RE2	RE2T3	7/11/2019	0	-0.00603	-0.00505
Sudbury	Reclaimed	RE3	RE3T3	7/11/2019	101.7681	-0.04388	-0.01829
Sudbury	Reclaimed	RE3	RE3T2	7/11/2019	90.76579	0.023056	0.004748
Sudbury	Reclaimed	RE3	RE3T1	7/11/2019	48.25996	-0.01758	0.002189
Sudbury	Reclaimed	RE4	RE4T1	7/11/2019	84.09671	0.021784	-0.00243
Sudbury	Reclaimed	RE4	RE4T2	7/11/2019	52.05558	-0.0055	-0.00286
Sudbury	Reclaimed	RE4	RE4T3	7/11/2019	74.73967	0.010072	-0.01076
Sudbury	Reclaimed	RE5	RE5T1	7/11/2019	176.726	-0.00054	-0.00557
Sudbury	Reclaimed	RE5	RE5T2	7/11/2019	334.3758	-0.01653	-0.00284
Sudbury	Reclaimed	RE5	RE5T3	7/11/2019	93.53636	0.00476	-0.0032
Sudbury	Reclaimed	RE6	RE6T1	7/11/2019	150.4541	0.022619	-0.00612
Sudbury	Reclaimed	RE6	RE6T2	7/11/2019	79.01844	0.00709	-0.00137
Sudbury	Reclaimed	RE6	RE6T3	7/11/2019	85.11694	-0.02647	0.000314

Sudbury	Reclaimed	RE7	RE7T1	7/11/2019	115.4612	-0.01762	0.010155
Sudbury	Reclaimed	RE7	RE7T2	7/11/2019	86.78532	-0.03151	0.005724
Sudbury	Reclaimed	RE7	RE7T3	7/11/2019	84.58192	0.01169	-0.00183
Sudbury	Reclaimed	RE8	RE8T1	7/11/2019	57.34656	0.010096	0.007264
Sudbury	Reclaimed	RE8	RE8T2	7/11/2019	155.2387	-0.0212	-0.00063
Sudbury	Reclaimed	RE9	RE9T1	7/15/2019	29.56017	-0.0007	-0.00791
Sudbury	Reclaimed	RE9	RE9T2	7/15/2019	100.905	0.011169	-0.00299
Sudbury	Reclaimed	RE9	RE9T3	7/15/2019	141.5435	-0.00716	0.002638
Sudbury	Reclaimed	RE1	RE1T1	7/25/2019	61.69351	0	-0.00508
Sudbury	Reclaimed	RE1	RE1T2	7/25/2019	225.8843	0.006313	0.000585
Sudbury	Reclaimed	RE1	RE1T3	7/25/2019	58.96823	-0.0251	-0.00353
Sudbury	Reclaimed	RE2	RE2T1	7/25/2019	214.157	-1.43872	0.066348
Sudbury	Reclaimed	RE2	RE2T2	7/25/2019	88.78766	0.013893	-0.00501
Sudbury	Reclaimed	RE2	RE2T3	7/25/2019	112.2355	-0.03074	0.004076
Sudbury	Reclaimed	RE3	RE3T1	7/25/2019	122.4465	-0.00819	-0.00871
Sudbury	Reclaimed	RE3	RE3T2	7/25/2019	84.32484	-0.00413	0.001494
Sudbury	Reclaimed	RE3	RE3T3	7/25/2019	41.86645	-0.03315	0.004099
Sudbury	Reclaimed	RE4	RE4T1	7/25/2019	73.83148	0.106858	-0.01432
Sudbury	Reclaimed	RE4	RE4T2	7/25/2019	62.4557	0.065095	-0.00045
Sudbury	Reclaimed	RE4	RE4T3	7/25/2019	100.2536	0.207415	-0.01904
Sudbury	Reclaimed	RE5	RE5T1	7/25/2019	115.7146	-0.01017	0.00194
Sudbury	Reclaimed	RE5	RE5T2	7/25/2019	189.6628	0.012279	0.001362
Sudbury	Reclaimed	RE5	RE5T3	7/25/2019	98.64332	-0.02038	-0.00961
Sudbury	Reclaimed	RE6	RE6T1	7/25/2019	178.7844	0.020962	-0.00884
Sudbury	Reclaimed	RE6	RE6T2	7/25/2019	111.1476	0.026893	-0.00827
Sudbury	Reclaimed	RE6	RE6T3	7/25/2019	112.3552	0.003889	0.006812
Sudbury	Reclaimed	RE7	RE7T1	7/25/2019	114.2009	-0.00133	0.007403
Sudbury	Reclaimed	RE7	RE7T2	7/25/2019	0	-0.02508	-0.00752
Sudbury	Reclaimed	RE7	RE7T3	7/25/2019	0	0.000026	-4.6E-06
Sudbury	Reclaimed	RE8	RE8T1	7/25/2019	159.5491	0.054567	-2.5E-06
Sudbury	Reclaimed	RE8	RE8T2	7/25/2019	175.819	0.048411	0.001152
Sudbury	Reclaimed	RE8	RE8T3	7/25/2019	169.0814	0.04356	0.01533
Sudbury	Reclaimed	RE9	RE9T1	7/25/2019	60.59995	0.068879	0.003172
Sudbury	Reclaimed	RE9	RE9T2	7/25/2019	178.6846	0.049101	-0.00037
Sudbury	Reclaimed	RE9	RE9T3	7/25/2019	175.9195	0.011916	-0.00184
Sudbury	Reclaimed	RE10	RE10T1	7/25/2019	191.2172	0.015211	-0.01117
Sudbury	Reclaimed	RE10	RE10T2	7/25/2019	197.4111	0.002595	-0.00459
Sudbury	Reclaimed	RE10	RE10T3	7/25/2019	170.6221	0.01472	-0.00935
Sudbury	Reclaimed	RE1	RE1T1	8/9/2019	50.60491	-0.00379	-0.00095
Sudbury	Reclaimed	RE1	RE1T2	8/9/2019	58.52322	0.008329	-0.00019
Sudbury	Reclaimed	RE1	RE1T3	8/9/2019	74.53665	0.031154	-0.00261
Sudbury	Reclaimed	RE2	RE2T1	8/9/2019	199.4047	0.001457	-0.01117
Sudbury	Reclaimed	RE2	RE2T2	8/9/2019	143.7415	-0.00456	0.002652

Sudbury	Reclaimed	RE2	RE2T3	8/9/2019	98.85551	-0.02234	0.00225
Sudbury	Reclaimed	RE3	RE3T1	8/9/2019	87.8244	-0.01843	-0.00571
Sudbury	Reclaimed	RE3	RE3T2	8/9/2019	69.74832	0.007189	0.003355
Sudbury	Reclaimed	RE3	RE3T3	8/9/2019	45.65918	0.011957	0.005661
Sudbury	Reclaimed	RE4	RE4T1	8/9/2019	58.2407	0.017806	-0.01908
Sudbury	Reclaimed	RE4	RE4T2	8/9/2019	46.8458	0.012324	-0.00558
Sudbury	Reclaimed	RE4	RE4T3	8/9/2019	88.03654	0.007591	0.006247
Sudbury	Reclaimed	RE5	RE5T1	8/9/2019	100.3742	-0.06871	-0.00151
Sudbury	Reclaimed	RE5	RE5T2	8/9/2019	200.4515	0.010924	-0.00369
Sudbury	Reclaimed	RE5	RE5T3	8/9/2019	26.19216	-0.00258	-0.00529
Sudbury	Reclaimed	RE6	RE6T1	8/9/2019	173.9081	0.003504	-0.00903
Sudbury	Reclaimed	RE6	RE6T2	8/9/2019	53.85676	0.001352	-0.00531
Sudbury	Reclaimed	RE6	RE6T3	8/9/2019	106.7307	0.001851	-0.00452
Sudbury	Reclaimed	RE7	RE7T1	8/9/2019	103.4549	-0.00251	0.000408
Sudbury	Reclaimed	RE7	RE7T2	8/9/2019	96.47308	-0.00782	-0.00427
Sudbury	Reclaimed	RE7	RE7T3	8/9/2019	101.9102	-0.01388	-0.00603
Sudbury	Reclaimed	RE8	RE8T1	8/9/2019	146.8421	-0.02155	-0.00509
Sudbury	Reclaimed	RE8	RE8T2	8/9/2019	148.4939	-0.04134	0.003427
Sudbury	Reclaimed	RE8	RE8T3	8/9/2019	154.2158	-0.02374	-0.00485
Sudbury	Reclaimed	RE9	RE9T3	8/9/2019	225.5821	-0.01581	-0.00448
Sudbury	Reclaimed	RE9	RE9T2	8/9/2019	125.0986	-0.00827	0.002513
Sudbury	Reclaimed	RE9	RE9T1	8/9/2019	0	0.004369	-0.00559
Sudbury	Reclaimed	RE10	RE10T1	8/12/2019	150.8233	-0.01863	-0.0017
Sudbury	Reclaimed	RE10	RE10T2	8/12/2019	273.576	0.014662	0.007924
Sudbury	Reclaimed	RE10	RE10T3	8/12/2019	187.4074	0.006267	-0.00332
Sudbury	Reclaimed	RE1	RE1T1	8/22/2019	46.374	-0.00753	-0.00359
Sudbury	Reclaimed	RE1	RE1T2	8/22/2019	134.7296	-0.01129	-0.00473
Sudbury	Reclaimed	RE1	RE1T3	8/22/2019	50.78087	-0.03098	0.001131
Sudbury	Reclaimed	RE2	RE2T1	8/22/2019	233.9631	-0.0163	0.001349
Sudbury	Reclaimed	RE2	RE2T2	8/22/2019	38.3186	-0.01425	-0.00268
Sudbury	Reclaimed	RE2	RE2T3	8/22/2019	139.9229	-0.02279	0.002071
Sudbury	Reclaimed	RE3	RE3T1	8/22/2019	92.62006	-0.00385	-0.00192
Sudbury	Reclaimed	RE3	RE3T2	8/22/2019	57.58768	0.009608	-0.00408
Sudbury	Reclaimed	RE3	RE3T3	8/22/2019	20.52678	-0.02996	-0.00058
Sudbury	Reclaimed	RE4	RE4T1	8/22/2019	78.43866	-0.0062	0.003706
Sudbury	Reclaimed	RE4	RE4T2	8/22/2019	2.864739	0.012028	0.006774
Sudbury	Reclaimed	RE4	RE4T3	8/22/2019	373.8251	-0.02204	0.009801
Sudbury	Reclaimed	RE5	RE5T1	8/22/2019	83.54662	-0.0113	-0.00518
Sudbury	Reclaimed	RE5	RE5T2	8/22/2019	203.4631	0.020103	0.003528
Sudbury	Reclaimed	RE5	RE5T3	8/22/2019	32.02371	-0.01685	-0.00094
Sudbury	Reclaimed	RE6	RE6T1	8/22/2019	124.0161	-0.00724	0.000834
Sudbury	Reclaimed	RE6	RE6T2	8/22/2019	57.51085	0.025816	-0.00937
Sudbury	Reclaimed	RE6	RE6T3	8/22/2019	79.52505	-0.03572	0.001855

Sudbury	Reclaimed	RE7	RE7T1	8/22/2019	67.61665	-0.02552	0.007516
Sudbury	Reclaimed	RE7	RE7T2	8/22/2019	83.62943	-0.0327	0.015606
Sudbury	Reclaimed	RE7	RE7T3	8/22/2019	71.95319	0.00801	-0.00155
Sudbury	Reclaimed	RE8	RE8T1	8/22/2019	144.52	-0.04721	-0.0104
Sudbury	Reclaimed	RE8	RE8T2	8/22/2019	85.89035	-0.01369	-0.00479
Sudbury	Reclaimed	RE8	RE8T3	8/22/2019	108.0664	-0.04836	-0.00083
Sudbury	Reclaimed	RE9	RE9T1	8/22/2019	46.143	-0.00925	-0.00677
Sudbury	Reclaimed	RE9	RE9T2	8/22/2019	177.6589	0.029609	-0.00113
Sudbury	Reclaimed	RE9	RE9T3	8/22/2019	206.9442	0.021685	-0.00751
Sudbury	Reclaimed	RE10	RE10T1	8/22/2019	100.8194	-0.03273	-0.00568
Sudbury	Reclaimed	RE10	RE10T2	8/22/2019	214.3641	-0.03063	0.0016
Sudbury	Reclaimed	RE10	RE10T3	8/22/2019	335.0025	-0.01283	-0.00046
Sudbury	Reclaimed	RE1	RE1T1	10/9/2019	32.09212	-0.029	0.002136
Sudbury	Reclaimed	RE1	RE1T2	10/9/2019	38.82445	0.0024	-0.00834
Sudbury	Reclaimed	RE1	RE1T3	10/9/2019	64.75428	-0.0047	-8.9E-05
Sudbury	Reclaimed	RE2	RE2T1	10/9/2019	313.5539	-0.00967	-0.00564
Sudbury	Reclaimed	RE2	RE2T2	10/9/2019	-60.7659	0.0035	-0.00558
Sudbury	Reclaimed	RE2	RE2T3	10/9/2019	88.48896	-0.00159	0.001019
Sudbury	Reclaimed	RE3	RE3T1	10/9/2019	0	-0.02337	-0.00955
Sudbury	Reclaimed	RE3	RE3T2	10/9/2019	17.01345	-0.01878	0.003799
Sudbury	Reclaimed	RE3	RE3T3	10/9/2019	39.04146	0.02142	0.002529
Sudbury	Reclaimed	RE4	RE4T1	10/9/2019	28.3151	-0.00021	-0.00797
Sudbury	Reclaimed	RE4	RE4T2	10/9/2019	29.61349	0.004949	-0.00248
Sudbury	Reclaimed	RE4	RE4T3	10/9/2019	70.78449	0.028483	-0.01388
Sudbury	Reclaimed	RE5	RE5T1	10/9/2019	46.21596	0.002044	-0.00638
Sudbury	Reclaimed	RE5	RE5T2	10/9/2019	192.1975	-0.01745	0.007758
Sudbury	Reclaimed	RE5	RE5T3	10/9/2019	37.40771	-0.01934	0.004089
Sudbury	Reclaimed	RE6	RE6T1	10/9/2019	120.5976	-0.03256	0.003099
Sudbury	Reclaimed	RE6	RE6T2	10/9/2019	36.42739	-0.0294	-0.00883
Sudbury	Reclaimed	RE6	RE6T3	10/9/2019	62.4212	-0.01392	0.002648
Sudbury	Reclaimed	RE7	RE7T1	10/9/2019	40.43259	0.00276	-0.00522
Sudbury	Reclaimed	RE7	RE7T2	10/9/2019	23.70754	-0.0236	-0.00847
Sudbury	Reclaimed	RE7	RE7T3	10/9/2019	65.14811	-0.00228	0.004192
Sudbury	Reclaimed	RE8	RE8T1	10/9/2019	102.84	-0.03333	-0.0061
Sudbury	Reclaimed	RE8	RE8T2	10/9/2019	125.1517	0.011012	-0.0047
Sudbury	Reclaimed	RE8	RE8T3	10/9/2019	167.5073	-0.0458	-0.00329
Sudbury	Reclaimed	RE9	RE9T1	10/9/2019	1.089713	-0.00193	7.52E-05
Sudbury	Reclaimed	RE9	RE9T2	10/9/2019	241.0985	-0.00594	0.005445
Sudbury	Reclaimed	RE9	RE9T3	10/9/2019	121.9672	-0.03067	-0.01724
Sudbury	Reclaimed	RE10	RE10T1	10/9/2019	44.04699	-0.04138	-0.00226
Sudbury	Reclaimed	RE10	RE10T2	10/9/2019	146.9562	0.004402	0.014149
Sudbury	Reclaimed	RE10	RE10T3	10/9/2019	83.34251	0.000245	-0.00295