Urban foresters' perceptions about the role of soil and fungi in urban forest management and climate mitigation

by Nicola Radatus-Smith[1*] and Shashi Kant[1]

ABSTRACT

The benefits of soil and mycorrhizal fungi in mitigating climate impacts through their vital role in carbon sequestration are well recognised in the academic literature but are not well incorporated in current urban forest planning and policies. We conducted a survey to examine urban foresters' perceptions about the incorporation of current scientific understanding of the role of soil and fungi, and stakeholders' engagement in urban forest management. Overall, urban foresters perceive that soil and fungi are important, however, little consideration is given to their incorporation in urban forest management practices and policies. Many stakeholders' engagement is low in urban forest management. Urban foresters perceive that decision makers have little knowledge about the role of soil and fungi which may pose barriers to its integration in planning and policies. The key challenges revealed by the survey include the lack of funding, conflicting priorities, and the lack of mechanisms to transfer scientific knowledge to urban foresters and inter-departmentally. Municipalities should develop policies that enhance knowledge transfer and integration to enhance the efficacy of urban forest's strategies that work to support municipal climate goals. Furthermore, collaboration with diverse stakeholder groups may enhance communication and subsequently increase support for urban forest initiatives.

Keywords: urban forest management, soil, fungi, carbon sequestration, climate change

RÉSUMÉ

Les bénéfices engendrés par les champignons du sol et les mycorhizes au niveau de l'atténuation des changements climatiques grâce au rôle vital qu'ils jouent dans la séquestration du carbone sont bien connus, mais ne sont pas incorporés dans les politiques de changements climatiques et de foresterie urbaine. Nous avons étudié les perceptions des forestiers urbains relativement à l'inclusion des connaissances scientifiques rattachées aux sols et aux champignons dans l'aménagement des forêts urbaines au Canada. Les perceptions des forestiers urbains ont été recueillies au moyen d'un sondage. Somme toute, les forestiers urbains considèrent que les sols et les champignons sont importants dans l'aménagement des forêts urbaines, mais que cependant, il y peu d'intérêt qui leur sont accordés lors de leur aménagement. De plus, les politiciens sont perçus comme ayant peu de connaissances sur les bénéfices tirés du sol et des champignons, et qu'il y a peu d'engagement généralement de la plupart des groupes d'intervenants impliqués en foresterie urbaine. Certains forestiers ont identifié les principaux défis comme étant le manque de financement, des priorités conflictuelles et l'absence de disponibilité et de mécanismes de transfert des connaissances au niveau des forestiers urbains et des départements impliqués. Les municipalités devraient élaborer des directives pour permettre un plus grand échange de connaissances et favoriser l'efficacité des stratégies de foresterie urbaine qui permettraient d'appuyer l'atteinte des objectifs climatiques des municipalités. De plus, la collaboration entre les différents groupes d'intervenants est essentielle pour accroître la communication et par conséquence, appuyer les projets et les initiatives de foresterie urbaine.

Mots clés : aménagement des forêts urbaines, sol, champignons, carbone, séquestration, changements climatiques

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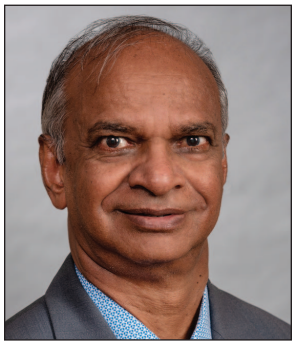

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Introduction

Global rise in population has led to increased urbanization and a subsequent increase in grey infrastructure, which has resulted in an alteration of the global landscape, reduction of natural resources and a destabilization of the affected ecosystems (Teixeira da Silva *et al.* 2018). Urbanization, consequently, impacts the ecosystem services that humans depend on, such as clean air, water, and climate change resiliency (Epelde *et al.* 2022). Urban areas are already facing many climate change challenges, such as flooding and heat waves, increasing the urgency and need for cities to plan how they will mitigate and adapt to these challenges (Cheng *et al.* 2021). The relationship between nature and human wellbeing

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is integrated and therefore, it is important for cities to consider the benefits of incorporating nature when planning their urban spaces (Amini Parsa *et al.* 2020).

There has been an increase in the utilization of nature-based solutions in cities as a means to adapt to and mitigate impacts of climate change by restoring many ecosystem services that benefit the well-being of city residents (Amini Parsa *et al.* 2020). A common nature-based solution adopted in cities is tree planting, which has been used as a strategy for reducing greenhouse gas (GHG) emissions in cities, as well as mitigating the risk of floods, removing air pollutants, and reducing the urban heat island effect (Epelde *et al.* 2022). This global trend is being observed, whereby cities are striving to create and maintain their urban forests to address multiple issues associated with climate change mitigation, including improving the health of urban residents and encouraging positive relationships among people and nature (Buil *et al.* 2021).

Urban forests are defined as all trees within a city, and the process of urban forestry often focuses only on the management of trees (Ordonez and Duinker 2014). Urban forest decision-making can be defined as "the process of what, why, and how decisions are made in relation to urban forests, including how trees are planted, protected, maintained, or removed" (Ordonez *et al.* 2020). Consequently, it is predominantly trees, the visible vegetation above ground, that is considered in the management and planning of urban green spaces (Sieghardt *et al.* 2005). There is a major gap within such practices as they rarely consider the integral ecosystem's biotic and abiotic components such as soil and the associated microorganisms, which provide nutrients to the vegetation while also playing a role in the sequestration of carbon (Schittko *et al.* 2022).

There is growing academic literature on the role of arbuscular mycorrhizal fungi (AMF) in sequestering carbon within the soil as well as supporting overall health of trees which would support their effectivity in producing benefits for climate change adaptation and mitigation (Stevenson *et al.* 2020). Their essential function in supporting trees has sparked the use of AMF as a key indicator to measure forest health (Buil *et al.* 2021). In an urban context, which fosters a harsh environment, there are imposing challenges on the abundance and effectivity of AMF in producing such benefits (Kumar and Hundal 2016). Urban soils often contain less nutrients, are polluted with anthropogenic chemicals, and compacted which cumulatively reduce the levels of AMF fungi and subsequently reduce the health and resilience of urban trees (Kumar and Hundal 2016). Despite the lower abundance of AMF in city soils, there is evidence that AMF inoculation can be leveraged to increase plant biomass in contaminated soils (Balacco *et al.* 2022). Though these findings have added to the current understanding and knowledge in an academic capacity, it is unclear whether this information is known and being considered by stakeholders involved in urban forest planning and policy.

As mentioned, urban forestry tends to focus on the management of trees, putting management efforts towards tree selection to enhance and expand the ecosystem services in an urban environment (Amini Parsa *et al.* 2020). The above-mentioned services provided by soil and its associated microorganisms are underrepresented in climate goals of cities, as carbon sequestration by cities accounts mainly for the direct capture by trees (Nowak *et al.* 2013). However, soil, more generally, is increasingly being recognized as important by policy makers (Teixeira da Silva *et al.* 2018). Sieghardt *et al.* (2005) highlights that, with an increase in soil science, there has been a change in public awareness and opinion around the importance of soil health. Teixeira da Silva *et al.* (2018) conducted an analysis of soil science incorporated in urban planning in large cities around the globe. It was found that soil is addressed as providing important ecosystem functions within city plans (Teixeira da Silva *et al.* 2018). Despite positive trends, there remains a lack of incorporation of the scientific knowledge on soil and mycorrhizal fungi in urban forest planning and policy (Teixeira da Silva *et al.* 2018). This presents an opportunity to study stakeholders involved in urban forestry decision making and the reasons behind this gap.

In Canada, federal and provincial governments are promoting nature-based solutions to climate change though plantation programs, such as Canada's 2 Billion Trees Program (Government of Canada 2022) and the 50 Million Tree Program in Ontario (Forests Ontario 2022). The recent initiative of the Green Municipal Fund—Growing Canada's Communities Canopies (GCCC)—is designed "with an eye to future climate conditions and the maintenance of diverse urban canopies" (Green Municipal Fund 2024). Given these priorities and directions of various governments/agencies in Canada, an understanding of the gap between the scientific knowledge about the role of soil and fungi in carbon sequestration and its incorporation in urban forestry planning and policies becomes critical.

In a recent municipal-level study in Canada, Cheng *et al.* (2021) explored the relationship between climate change and urban forest policies in 20 of the largest cities. The study found that 10 cities mentioned the mitigative benefits of urban forests, where six specifically mentioned carbon storage in their climate policies (Cheng *et al.* 2021). As a first step to our study, we expanded on the work of Cheng *et al.* (2021) and reviewed urban forest management plans (UFMP) across Canada for the incorporation of knowledge specific to soil and fungi. This was done to better understand the current landscape in terms of whether UFMP are incorporating knowledge on carbon sequestration and storage in soil. Various plans were selected and analyzed from medium to large cities across Canada that had urban forest management plans/strategies available. This included Calgary, Edmonton, Guelph, Halifax, Hamilton, London, Mississauga, Ottawa, Regina, Saskatoon, Toronto, and Vancouver. Overall, when Canadian cities do discuss soil in their UFMP, it is described as an essential component for tree growth and health. However, this was not accompanied by information on actions related to the management of soil health, which aligns with the findings of Teixeira da Silva *et al.* (2018). Furthermore, plans only discussed trees as having a primary role in carbon sequestration, whereby only the Saskatoon and Vancouver plans recognized the role of soil in carbon storage. No plan mentioned fungi or microorganisms in relation to benefits or management. These findings are also aligned with the findings from Teixeira da Silva *et al.* (2018). Following this investigation, it may be concluded that Canadian UFMPs are not including information relating to the important role of soil and fungi in carbon sequestration, missing an opportunity

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where an UFMP can be used to enhance climate strategies. As cities are enhancing and attempting to address climate change in their urban forest management plans, it's important to understand what knowledge is being considered when creating these plans and the governance of such plans (Ordóñez *et al.* 2020).

In terms of governance, urban forest decision makers are essential determinants of the success of tree planting agendas (Ordóñez *et al.* 2020). There is a range of stakeholders that participate in the decisions made regarding urban forests, however municipal managers play a central role (Ordóñez *et al.* 2020). In Canada, this management role is often assigned to urban foresters. Urban foresters are responsible for the creation and council of the urban forest management plans; therefore, they work closely within municipalities and often with decision makers. For the purpose of this study, we will use the term decision makers to refer to municipal employees that have decision making power over policy, sometimes also referred to as policy makers and includes political leaders. Where relevant, we use political leaders distinctly and decision makers includes both policy makers and political leaders. Urban foresters are uniquely positioned to have first-hand insights into decision making processes and information incorporated into UFM plans. As mentioned, the municipal policies indicate a lack of knowledge incorporation on the benefits of soil and fungi. However, to glean more insight into the decision making and management processes beyond what is published, it is essential that urban foresters are consulted. Their intimate work with such a subject presents an opportunity to better understand what their level of knowledge is on the recent and growing academic literature as it relates to the benefits of soil and fungi in climate mitigation. Furthermore, their perceptions can provide useful insight on its degree of importance to successful management of urban forests and the feasibility of incorporating such knowledge into policy and practice.

This paper aims to understand the relationship between scientific knowledge on soil and mycorrhizal fungi in climate mitigation and the policy and management decisions being made in Canada surrounding urban forest management. The main objectives of this study, therefore, are to understand and analyze urban foresters' perceptions in regard to the scientific knowledge on soil and fungi and the level of its incorporation in urban forest management plans, and to identify the challenges and opportunities to enhance the incorporation of the scientific knowledge. We address five research questions: (i) What is the level of knowledge of urban foresters on the role of soil and mycorrhizal fungi in carbon sequestration and what are their perceptions on its incorporation in urban forest planning? (ii) What are the perceptions of urban foresters on the level of importance of the role of soil in urban forest planning and management and its incorporation in urban forest planning? (iii) What are the perceptions of urban foresters on the level of importance of the role of fungi in urban forest planning and management and its incorporation in urban forest planning? (iv) What are the perceptions of urban foresters on the level of engagement of different stakeholder groups in urban forest management planning? And (v) What are the challenges and opportunities for integrating scientific knowledge on soil and mycorrhizal fungi within municipal decision making in Canada?

Methods

Data collection

A survey method was used to collect data and was similar to the survey of DeRoeck (2004). The survey was designed to ask urban foresters questions that address the five research questions. All questions and the abbreviations used for each question are given in Table 1. The survey was organized into three main sections: (i) academic background and work experience, (ii) urban foresters' knowledge and perception about the importance of scientific knowledge and its incorporation in urban forest management plans, and (iii) urban foresters' perceptions about the knowledge of other stakeholders and their involvement in urban forest management plans. The first section contained three questions that were asked to determine whether cofounding variables were present that would impact the survey responses. The second section included nine questions that address the first, second, and third research questions. The third section contained eight questions that address the fourth and fifth research questions.

All questions, except questions 1–3, 12, and 20, which were open-ended questions, were asked using a Likert scale of 1–5, where 1 means none and 5 means high agreement. This allowed for quantitative values to be collected and used for data analysis.

The survey was distributed to urban foresters across Canada through the CANUFNET listserv on January 14th, 2023, and closed on May 12th, 2023. The listserv allowed for a broader range of urban foresters to access and participate in the survey, collecting a sufficient sample size to conduct data analysis.

Data analysis

Statistical analysis was conducted on the survey responses using the Jamovi software. For the questions from the first section of survey, only geographic location could be analyzed. Survey responses from question two were used to group survey responses by geographic location whereby the survey responses from sections two and three were grouped by geographic location and compared using t-test analysis. In addition, for the questions from sections two and three, the statistical significances of the differences between mean values of the responses of questions within the same section were tested using t-test. Correlation analysis was conducted within each group to compare correlations between responses to all questions within each group.

In addition, the survey included a few open-ended questions to get a general idea. The answers to these questions, notably questions 12 and 20, were used in the discussion.

Results

The survey received 87 responses. However, 20 were removed due to incomplete answers, duplicate responses, or non-Canadian respondents. Therefore, the sample size for analysis was 67.

The response to the geographical location question was based on either current work location (if working), CURWORK, or the previous last work location, PREWORK, if retired. Out of 67 respondents, 26 (about 39%) were from Ontario, 20 (about 30%) from BC, and the remaining 21 (about 31%) from all other remaining provinces and territories. The details of the number of respondents from different regions are given in Table 2.

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Table 1. List of survey questions and abbreviations

	Questions	Abbreviation
Section A: Questions related to Academic Background and Work Experience		
Q1	Academic Background	ACEBAGR
Q2	Where are you currently working (include the province)?	CURWORK
Q3	Where have you worked in the past 10 years?	PREWORK
Section B: Questions Related to Urban Foresters Scientific Knowledge and Perceptions about Its Importance and Incorporation in Urban Forest Management Plans		
Q4	What is your level of awareness of the scientific knowledge related to the role of soil and fungi in carbon sequestration/climate change mitigation?	AWSCIK
Q5	What is the level of incorporation of this scientific knowledge related to the role of soil and fungi in carbon sequestration in urban forest plans in Canada?	INCKNOW
Q6	Generally, based on your scientific knowledge, how important is soil to the management of urban forests?	IMPSOIL
Q7	To what extent is soil knowledge considered in short-term urban forest planning?	SOISHTM
Q8	To what extent is soil knowledge considered in long-term urban forest planning?	SOILOTM
Q9	Generally, based on your scientific knowledge, how important are fungi in urban forest management?	IMPFNGI
Q10	To what extent is fungi knowledge considered in short-term urban forest planning?	FGISHTM
Q11	To what extent is fungi knowledge considered in long-term urban forest planning?	FGILOTM
Q12	Which inputs have been used by the cities you've worked with to manage soils in urban forests? (if applicable)	MNGINPT
Section C: Questions Related to the Knowledge of Other Stakeholders and their Involvement in Urban Forest Management Plans		
Q13	In your view, what is the level of scientific knowledge of decision makers/political leaders related to the role of soil and fungi in carbon sequestration?	SCKNPOL
Q14	How important is it to involve decision makers when discussing scientific knowledge related to the role soil and fungi in carbon sequestration?	IMINDCM
Q15	What is the current level of engagement of political leaders in urban forest planning?	LVPOENG
Q16	What is the current level of engagement of scientists in urban forest planning?	LVSCENG
Q17	What is the current level of engagement of urban foresters in climate change planning?	LVUFENG
Q18	What do you think about the degree of engagement between scientists and decision makers when it comes to urban forest planning?	DGENGSD
Q19A	From your experience to what extent is there diverse stakeholder engagement in urban forest planning? Soil scientists	ENGSOSC
Q19B	From your experience to what extent is there diverse stakeholder engagement in urban forest planning? Communities	ENGCOMM
Q19C	From your experience to what extent is there diverse stakeholder engagement in urban forestry planning? Indigenous people	ENGINDP
Q19D	From your experience to what extent is there diverse stakeholder engagement in urban forest planning? NGOs	ENGNGOS
Q20	What do you believe to be barriers for policy makers in using scientific knowledge of soil and fungi related to carbon sequestration to inform policies related to urban forest planning within Canada?	BARSCKN

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Therefore, we divided respondents in three groups—from Ontario, BC, and other provinces. The mean values were compared for each (except for open-ended) question between each of these three groups using t-test, which revealed no significant differences between the groups. Similarly, the respondents were divided in three educational groups—College education, Bachelor's degree, and Other, which included PhD and Master's degree. There was no statistically significant difference in the mean values of responses to quantitative questions between these three educational groups. Hence, we concluded that there are no differences in the responses of urban foresters due to their geographical locations or education.

Next, we present the results in two sub-sections. The first is focused on urban foresters' knowledge and perception about the importance of scientific knowledge and its incorporation in urban forest management plans. These results are based on the responses in Section 2 of the survey and address Research Questions 1, 2, and 3. The second subsection is focused on urban foresters' perceptions about the knowledge of other stakeholders and their involvement in urban forest management plans. These results address Research Questions 4 and 5 using responses from Section 3 of the survey.

Table 2. Geographical Distribution of Survey Respondents

Province/Territory	Number of Respondents
Alberta	6
British Columbia	20
Manitoba	2
Nova Scotia	2
Ontario	26
Quebec	7
Saskatchewan	3
Yukon	1

Table 3. Mean values of the level of scientific knowledge, importance of soil, and importance of fungi and their incorporation in urban forest management plans

Measure	Mean Value
AWSCIK	3,12
IMPSOIL	4.50
IMPFNGI	4.06
INCKNOW	1.98
SOISHTM	2.69
SOILOTM	2.57
FGISHTM	2.06
FGILOTM	2.09

Table 4. Correlation matrix with *p*-value (brackets) for questions relating scientific knowledge and its importance and incorporation in urban forest management plans

	AWSCIKN	INCKNOW	IMPSOIL	SOISHTM	SOILOTM	IMPFNGI	FGISHTM	FGILOTM
AWSCIKN	–							
INCKNOW	**0.364 (0.003)**	–						
IMPSOIL	**0.397 (<.001)**	0.229 (0.069)	–					
SOISHTM	-0.007 (0.956)	0.139 (0.273)	0.090 (0.470)	–				
SOILOTM	0.070 (0.575)	0.243 (0.053)	0.098 (0.430)	**0.696 (<.001)**	–			
IMPFNGI	0.143 (0.251)	0.171 (0.177)	**0.486 (<.001)**	-0.087 (0.484)	-0.010 (0.936)	–		
FGISHTM	0.007 (0.957)	**0.462 (<.001)**	0.062 (0.618)	**0.442 (<.001)**	**0.630 (<.001)**	0.020 (0.873)	–	
FGILOTM	0.067 (0.592)	**0.430 (<.001)**	0.134 (0.280)	**0.361 (0.003)**	**0.672 (<.001)**	0.137 (0.270)	**0.830 (<.001)**	–

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Urban foresters' level of scientific knowledge and perceptions about the importance of scientific knowledge and its incorporation in Urban Forest Management Plans

The mean values of responses related to the level of scientific knowledge, importance of soil, and importance of fungi and their incorporation in urban forest management plans are given in Table 3. The responding urban foresters, on average, rated their level of scientific knowledge (AWSCIKN) to be moderate (3.12), the importance of fungi (IMPFNGI) to be very important (4.06), and the importance of soil (IMPSOIL) as extremely important (4.50) with regards to the management of urban forests, and these three means are significantly ($p < 0.001$) different from each other. However, they perceive that the incorporation of scientific knowledge related to soil and fungi with respect to carbon sequestration in urban forest management plans is low (INCKNOW = 1.98) which is significantly lower ($p < 0.001$) than the average scientific knowledge of urban foresters (AWSCIKN) and the importance of soil (IMPSOIL) and fungi (IMPFNGI). Similarly, they show that the consideration of this knowledge for fungi, in both short-term (FGISHTM = 2.06) and long-term (FGILOTM = 2.09) urban forest management plans, is low, and moderate for soil (SOISHTM = 2.69 and SOILOTM = 2.57). There are no significant differences ($p > 0.05$) between the mean values of knowledge considerations of soil or fungi for short-term and long-term plans. However, the means of knowledge consideration of soil for both short-term and long-term plans are significantly higher ($p < 0.001$) than the respective mean value for fungi.

The correlations and their statistical significances in Table 4 illustrate some interesting relationships. First, urban foresters' scientific knowledge related to the role of soil and fungi in carbon sequestration (AWSCIKN) has significant correlations with its incorporation in urban forest management plans (INCKNOW) ($p < 0.05$) and the importance of soil (IMPSOIL) ($p < 0.001$) but is not significant with the importance of fungi (IMPFNGI) ($p = 0.251$). However, the importance of soil and the importance of fungi have significant ($p < 0.001$) correlations. Second, the incorporation of scientific knowledge (INCKNOW) is significantly correlated with the consideration of fungi in the short-term ($p < 0.001$) and the long-term ($p < 0.001$) urban forest management

plans but not with the consideration of soil in either short- or long-term plans. However, for both soil and fungi, the consideration in short-term plans is significantly ($p < 0.001$) correlated with the consideration in long-term plans, and the consideration of soil, in both short- and long-term plans, is significantly (either $p < 0.001$ or $p < 0.005$) correlated with the consideration of fungi.

Perceptions of urban foresters about the knowledge of other stakeholders and their involvement in Urban Forest Management Plans

On average, respondents indicated that the level of scientific knowledge of political leaders on the role of soil and fungi in carbon sequestration is low (SCKNPOL = 1.56) but perceived that their involvement in discussions related to scientific knowledge related to the role soil and fungi in carbon sequestration is very important (IMINDCM = 3.81) while the average degree of engagement between political leaders and scientists in urban forest management planning is moderate (DGENGSD = 2.57). The comparison of mean values indicated that the importance of political leaders' involvement in scientific discussions (IMINDCM) is significantly higher ($p < 0.001$) than their actual involvement (DGENGSD) which is significantly higher ($p < 0.001$) than the level of their scientific knowledge (SCKNPOL). In addition, the involvement of decision makers (DGENGSD) and their level of scientific knowledge (SCKNPOL) have significantly ($p < 0.001$) positive correlations.

In urban forestry planning, the current level of average engagement of most stakeholder groups is moderate (3) – political engagement LVPOENG = 2.82, scientist engagement LVSCENG = 3.16, community members ENGCOMM = 3.23, and NGOs ENGNGOS = 2.94 respectively, except for groups of soil scientists ENGSOSC = 2.23 and indigenous peoples ENGINDM = 2.37 respectively, it is low.

Discussion

Degree of scientific knowledge, its importance and inclusion in practice

Urban foresters reported having moderate knowledge of the role of soil and fungi in carbon sequestration, AWSCIKN = 3.12. As such, it may be assumed that they have moderate knowledge of the importance of fungi and soil in climate change adaptation. Still, there is a consensus among urban foresters that soil and fungi are important to the management of urban forests more generally, IMPSOIL = 4.50 and IMPFNGI = 4.06, respectively. However, there is a perceived lacking in actual implementation/incorporation of soil and fungi management practices in the short- and long-term, SOISHTM = 2.69 and SOILOTM = 2.57 and FGISHTM = 2.06 and FGILOTM = 2.09, respectively. This is indicative of a gap in which the importance is not accurately translated into the planning and implementation of effective urban forest management practices. Further, fungi were reported as having slightly lower levels of consideration of their importance and incorporation in both the short- and long-term management of urban forests compared to soil. These results agree with the recent nature of academic literature on soil science which has influenced a growing awareness by the public and decision makers to the importance of soil health (Teixeira da Silva *et al.* 2018). For fungi, however, the depth of literature is still being developed on their benefits, which would contribute to a lesser degree of knowledge and application of these practices in municipal urban forest management.

We emphasize that the number of responses from several provinces, including Quebec (seven responses), except for Ontario and British Columbia, were low. This low response may have resulted in an incomplete picture. For example, Quebec seems to embrace the use of mycorrhizae more than other parts of Canada. The use of mycorrhizae appears in numerous manuals, user guides and other materials connected with the planting of trees in urban forests of the province. Similar observations may be there from other provinces with a low response rate.

Current challenges to the degree of scientific knowledge and its inclusion in practice

There are various factors that could be contributing to a lack of implementation of practices that focus on the benefits of soil and fungi, despite urban foresters' knowledge of its importance. As a final question in the survey, urban foresters were asked to comment on what they believed to be the barriers for policy makers in using scientific knowledge of soil and fungi related to carbon sequestration to inform policies related to urban forest planning within Canada. Their responses to the question are used in the following discussion.

One of the main challenges is that foresters are constrained within the political system. Their knowledge and expertise can only go as far as the municipal structure allows. Unless there are policies in place that require decision makers to engage with scientific information, there remains tension and resistance that dictates how urban forests are planned and managed. A key element of this challenge is the governmental priorities that work against the enhancement of urban forest management (Anonymous 2023). Currently, communities are facing many challenges, such as housing, infrastructure, health, and inflation, which compete with values for environmental protection (Anonymous 2023). The most relevant competitor to enhancing urban forest management is development pressure, which is resulting in urban forest management no longer being in the forefront of planning discussions - "Another hurdle to navigate in approving development. Development pays the bills" (Anonymous 2023). A study by Ordóñez *et al.* (2020) of municipal urban forest managers across Australia, stated urban densification and expansion as a challenge to implementing their planting strategies. The issue of increasing growth and development in cities has resulted in tension between environmental protection and development. In addition, the federal and provincial governments of Canada have their respective tree plantation programs but provide limited resources for scientific research, technology transfer, and policy development pertaining to urban forest planning and management.

Policy barriers

As mentioned, there is considerable incentive to increase development, as it results in financial gain to developers and political parties they are affiliated with. Any form of environmental law in place has been seen as a nuisance and a higher cost to developers, delaying them from moving forward with their projects. This challenge is notably prevalent in Ontario, as the current political party in 2023 is overshadowing

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municipal efforts to protect natural resources and has removed measures that ensure consideration for environmental benefits. The Planning Act is the main form of legislation in Ontario that gives the power to approve development above any other law that would require environmental protection (Planning Act 1990). In recent years, the Planning Act has been modified to reduce the importance of mechanisms that protect the environment and preserve the environmental services they provide (Bill 229 2020). Further, this reduces the authority of conservation officers (Bill 229 2020). These changes are in conjunction with an increase push in development led by the Progressive Conservative Party following the provincial election in Ontario in 2016. This has resulted in a massive barrier to municipalities, as provincial laws are driving negative impacts through policy barriers on urban forest management and environmental protection.

Funding constraints

As a consequence of resources being prioritized on development and other municipal functions, there is a lack of funding allocated to urban forestry departments, limiting opportunities for municipalities to engage with scientific knowledge, utilize it when making decisions, and subsequently in the implementation and management of urban forests. Urban foresters responded, "lack of funding for scientists and management or to prioritize keeping up with trends causing a reactive over proactive approach, tension between trust of scientists and political will to engage with them" (Anonymous 2023). Due to funding constraints, municipalities may not have respective positions in their department for researching topics like soil and fungi. Therefore, the lack of funding inhibits urban foresters' ability to put efforts towards enhancing their knowledge and subsequently utilise it in decision making (Ordonez and Duinker 2014). The lack of funding also creates constraints within the implementation of practices once research and knowledge are gleaned. Effective management practices require resources which municipalities will not allocate money towards if it is not seen as a priority. Therefore, municipalities cannot invest in the management tools needed to enhance the health of soil and fungi.

Access to knowledge

Another challenge that was addressed was in transferring knowledge on the benefits of soil and fungi to urban forest management and a "lack of knowledge and mechanism to facilitate knowledge transfer with scientists not having the opportunity or outlet to share this information (lack of training of staff and consultants on the basics of fungi and soil)" (Anonymous 2023). Much of the research comes from universities, there is no mechanism in place that allows for innovative research to be shared with decision makers to inform their practices (Anonymous 2023). This, then, leaves the burden on the municipalities which, as mentioned, are often under-resourced and do not have the capacity to conduct research and be proactive in their management. The research found that, the role of both soil and fungi to climate change adaptation is left out where knowledge incorporation, INCKNOW = 1.98. This may be a consequence to both the lack of resources and the lack of mechanisms in place to allow for new research and information to be easily accessed by municipalities. As with the knowledge on fungi and soil health, the lack of knowledge incorporation in UFMP could be attributed to the recent nature of this research, where the benefits to an urban context are less well known or established in current literature. Therefore, there should be ways in which information can be more effectively transferred and where research is geared towards policy applications.

Tensions between science and politics

Another challenge is that there are barriers present that impact the success of scientific knowledge being accepted by politicians. The current political structures require a degree of certainty, needing a direct cause and effect in order to implement (Guldin 2003). This poses challenges when scientific knowledge is uncertain in nature and can change and develop over time. Within the literature on the role of soil and mycorrhizal fungi in carbon sequestration, the effectiveness is dependent on the specific location and environmental factors (Buil *et al.* 2021). Topics such as climate change and soil are broad and have complex interactions which makes it challenging to find ways to incorporate that into current practices within municipalities. Therefore, decision makers may be resistant to adopt management when there is no certainty that the results will lead to their desired outcome. Further, the nature of political systems is to have fragmented ownership that lacks coordination and cross collaboration (Ordonez and Duinker 2014). Urban foresters shared that there is a "resistance to learning" and "lack of care" (Anonymous 2023). The consequence of this is a lack of wanting to learn due to a belief that it's not their responsibility, creating tensions between science and policy. This tension is furthered by politicians lacking the foundation for distilling scientific information (Ordonez and Duinker 2014). This study revealed that politicians are believed to have a little scientific knowledge on the role of soil and fungi in carbon sequestration, SCKNPOL = 1.56. Guldin (2003) argues that the information is available, but politicians do not know how to use it, as it lacks a direct political application. Therefore, the lack of knowledge creates tension as there is no shared understanding and often a lack of support to the policies trying to be implemented. Interestingly, Ordonez *at al.* (2020) found that coordination of stakeholders had a lager impact than larger budgets on their successful policy decisions.

Stakeholder engagement and opportunities

There is a trend in which there is increased incorporation of SDGs into municipal plans, which encourage considering natural resources in the urban context (Teixeira da Silva *et al.* 2018). Moreover, politicians are under pressure to redesign their cities in a way that is allowing them to achieve net zero targets. However, our research found that political leaders have little awareness of the scientific knowledge, SCKNPOL = 1.56, which warrants attention that there needs to be greater incorporation of scientists and political decision makers in order to create plans that consider how systems work together rather than separately. We also found that soil scientists have low engagement ENGSOSC = 2.21. Urban foresters believe that there should be greater engagement between decision makers and scientists, IMINDCM = 3.81, which is a positive indication that there can be growth in this area in the future. Both groups need strategies and resources that would

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help support their ability to work towards greater engagement and overall holistic management. Another intersection emerges as urban foresters self-report as having high engagement with municipal climate change planning (Anonymous 2023). The study by Ordonez *at al.* (2020) found that strengthening the coordination of departments within the municipality is an effective approach for governments to implement their urban forest strategies. There is an opportunity where the information on fungi and soil can be leveraged when creating climate action plans as well as considering the interlinkages between urban forest health and climate change mitigation and adaptation.

For these reasons, there needs to be communication where information is presented in a way that is easy to understand and highlights the value of fungi and soil, framed in a way that connects with political values. Teixeira da Silva *et al.* (2018) recognized a need to develop a strategy for integrating ecosystem services of soil into management plans to develop monitoring and mitigation activities that have relevance to climate strategies, and thus relevant to new political agendas. There needs to be ways in which the information can be provided in a digestible format and in a way that is tailored to the group they are speaking with so that there is greater acceptance and adoption of effective strategies. As explored in this paper, there are benefits of soil and fungi in carbon sequestration, which is of interest to many organizations, as stakeholders are under pressure to disclose their emissions and find innovative ways to promote the removal of carbon from the atmosphere. Therefore, it could lead to greater acceptance and adoption of practices when parties are aligned on the mutual benefits of such management practices. Guldin (2003) found that forestry researchers that were able to engage in the policy arena and in communication and focused on innovation and adaptive management to influence forest policy decisions in their study area. Adopting these strategies requires a willingness from scientists to distil the data and frame the ecosystem services of soil into broad concepts that are applicable to an urban setting (Teixeira da Silva *et al.* 2018).

In addition, it would be beneficial to apply the same strategy to different stakeholder groups. As found in this study, there is currently low (2) to moderate (3) engagement in UFM planning from stakeholder groups such as community members, Indigenous peoples, and NGOs, ENGCOMM = 3.22 ENGINDP = 2.37, ENGNGOS = 2.94, respectively. Gaining support of these groups is important when driving change. This is because political will is highly influenced by public pressure. Therefore, community support might allow for more resources to be allocated towards UFM. Interestingly, Ordonez *at al.* (2020) found that coordination of stakeholders had a greater impact than larger budgets on their successful policy decisions. Communication to these stakeholder groups can be achieved through awareness campaigns that focus on the benefits of soil and fungi. Informing the community of initiatives can also mitigate resistance and misinformation (Stevenson *et al.* 2020). Further, involving the stakeholders can strengthen trust and build capacity, which can encourage community involvement in management strategies and can ease the cost burden on municipal budgets. It is also important to develop these relationships, as they can provide valuable input and perspectives on ways in which management strategies can be improved. By analyzing urban forest policies, Cheng *et al.* (2021) provided examples of the ways that municipalities are currently enhancing stakeholder collaboration such as implementing community-based tree planting/care programs and forming stakeholder working groups.

Despite the benefits of increasing communication and engagement, there remains a resistance to allocating resources and time to developing communication strategies and engagement mechanisms to transfer this information to the respective parties. These initiatives take time and effort which is a constraint within municipalities. However, investing time now may result in more efficient practices that can occur once these groups are integrating and aligning their information and vision (Cheng *et al.* 2021). The science-policy gap is complex, however, the need to reduce this gap is essential for effective planning and management to take place (Guldin 2003).

The use of management strategies that target fungi and soil processes is occurring in some cities throughout Canada. Urban foresters highlighted that such strategies are being used, including biochar, organic matter (mulching), and fungal inoculants (Anonymous 2023). However, the above challenges impede the success of these initiatives. The resources are available to enhance the climate benefits of their green spaces and should become common practice with cities. This means that there needs to be a commitment to consider this within long-term management, rather than only in the first few years. It takes leadership and policy to be developed that considers how improving the health of soil and fungi in urban forest management can be integrated within the larger goals and values of municipalities. Municipalities should take into consideration their long-term goals and make investments into these strategies. Policies should be developed that set standards for best practices when talking about sustainability (Teixeira da Silva *et al.* 2018). Such policies should also focus on mechanisms for information transfer among various stakeholders to ensure information transfer and joint knowledge creation. "The benefits of soil health and strong fungal networks are important, but without policy, management strategies cannot be developed that would result in enhancing ecosystem health" (Teixeira da Silva *et al.* 2018).

Conclusion

This study addressed five research questions on the level of scientific knowledge of urban foresters on the role of soil and fungi in carbon sequestration, their perceptions about the importance of incorporating this scientific knowledge and the level of engagement of multiple stakeholders in urban forest management plans, and the challenges and opportunities for incorporating scientific information on soil and fungi in urban forest planning decisions.

Canadian urban foresters believe both soil and fungi are important in the management of urban forests, however, there is little consideration of them in the actual management of urban forests. Further, politicians are believed to have little knowledge of the benefits of soil and fungi, and overall, there is low engagement of stakeholder groups in urban forest management planning. The main challenges are municipal structures that contribute to compartmentalized work environments, a lack of resources to be allocated to research and

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knowledge transfer and competing priorities such as increased development pressure that side-line efforts to improve urban forest management. These challenges have created tensions and a lack of political will to put effort towards engaging with scientific information. To achieve effective management that enhances climate goals, the focus should be on tailored communication that aligns the values of politicians and scientists to create unity rather than division. Future research should focus on developing frameworks for municipalities to tangibly incorporate scientific knowledge and engagement of stakeholders into decision-making processes. As climate change threats will continue to impact our communities, municipalities will require strategies that focus on sustainable environments, societies, and governance. A key to achieving this will be to invest in strategies that focus on systems thinking and ways in which they can engage all departments to effectively tackle these challenges. This research contributes to the broader understanding of municipal structures and the challenges and opportunities for them to work towards achieving sustainability.

Finally, the study is based on urban foresters' perceptions which may be challenged for its scientific foundations, but it has a great managerial and policy value. Future studies should extend this research by including the perceptions of all categories of stakeholders and increasing the sample size.

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