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Research Paper

A content analysis of urban forest management plans in Canada: Changes in social-ecological objectives over time

Camilo Ordóñez Barona[a,b,*], Annick St Denis[c], Jackson Jung[a], Corinne G. Bassett[d], Sylvain Delagrange[e], Peter Duinker[f], Tenley Conway[a]

[a] Department of Geography, Geomatics and Environment, University of Toronto at Mississauga, 3359 Mississauga Road, Mississauga, ON L5L 1C6, Canada
[b] Green Municipal Fund (GMF), Federation of Canadian Municipalities, Ottawa, Canada
[c] Département des Sciences biologiques, Université du Québec à Montréal (UQAM), 141 avenue du Président-Kennedy, Montréal, QC H2X 1Y4, Canada
[d] Faculty of Forestry, University of British Columbia (UBC), 2424 Main Mall, Vancouver, BC V6T 1Z4, Canada
[e] Department of Natural Sciences, University of Quebec in Outaouais, Institute of Temperate Forest Sciences, 56 Main Street, Ripon, QC J0V1V0, Canada
[f] School for Resource and Environmental Studies, Dalhousie University, 6100 University Ave, Suite 5024, Halifax, NS B3H 4R2, Canada

HIGHLIGHTS

- We analysed the content of 74 Canadian urban forest management plans.
- Ideas referring to increasing tree abundance dominate.
- Ideas related to increasing tree abundance and climate change increased in 20 years.
- Administration and tree maintenance ideas are more mentioned in smaller cities.
- Increasing urban forest abundance may have management trade offs.

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ABSTRACT

Urban forests are a critical element of urban environmental planning. Greater awareness of the ecosystem services provided by urban forests over the last two decades has led to an increased interest in improving urban forest management. In Canada, the conditions of management are usually articulated by a municipal government in an urban forest management plan (UFMP). This study responds to previous studies on the content of Canadian UFMPs to provide a more comprehensive and updated comparison of UFMPs across Canada. While previous research has examined the content of UFMPs at a moment in time, and often when far fewer plans existed, in this study we consider changes in content over time and the influence of the social-ecological characteristics of municipalities on this content. We combined quantitative and qualitative content analyses, including topic modelling text analysis algorithms and interpretative thematic coding, to extract content, in the form of topics or themes, from 74 UFMPs. We assessed the distribution of these topics and themes by year of publication, and the influence of social-ecological characteristics upon this distribution using standard correlation and means differences analysis procedures. We found that Canadian UFMPs contain a broad number of themes and topics but are dominated by ideas referring to increasing tree abundance. Comparatively less attention is being paid to climate change and community stewardship. Mentions of increasing tree abundance and climate change rose over time. There was also a greater mention of administration, community education, and increasing tree abundance in smaller municipalities. Canadian municipalities may be well positioned to increase the abundance of urban forests given current management conditions. While abundance itself is beneficial, increasing abundance without addressing issues related to biodiversity, vulnerability of urban forests to climate change, and community stewardship, is a management trade-off that could, for example, increase abundance in the short term, but increase vulnerability in the long term. While focused on Canadian cities, this study also provides guidelines for possible cross-country comparisons and reflections on how UFMPs can be powerful management and planning tools for a climate-resilient and sustainable future.

* Corresponding author.
E-mail address: camilo.ordonez@utoronto.ca (C. Ordóñez Barona).

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1. Introduction

Urban forestry is a critical element of urban planning. Around the world, many cities are actively implementing nature-based solutions; the popularity of so-called million tree programs exemplify this (e.g., US, McPherson et al., 2017; China, Yao et al., 2019; Canada, NRCan, 2023). At the same time, there has also been a rise in the development of strategic and operational plans related to urban forests. These plans may be called strategic, master, policy, or action plans, but will henceforth be referred to as urban forest management plans (UFMPs). UFMPs are necessary guides to successful urban forestry programs and often reveal the management conditions of urban forestry.

While definitions of urban forests are diverse, and UFMPs usually include their own definitions, urban forests may be broadly defined as all trees within urban areas (Konijnendijk et al., 2006). We would add to that all the biota associated with trees plus the air, soil, and water elements that support their abiotic environment. Urban forests provide a diverse array of ecosystem services that support urban biodiversity and human communities (Nowak et al., 1996; Nowak, 2006; Roy et al., 2012; Seamans, 2013; Livesley et al., 2016; Paquette et al., 2021). When they are not well managed, urban forests can incur unwarranted high costs (Vogt et al., 2015) or even create lose-lose scenarios where ecosystem services provisioning is low, but disservices are high (Roman et al., 2021).

While urban forestry faces many challenges, at the same time, there are opportunities to increase or optimize the abundance, diversity, and arrangement of trees in cities, thus improving the supply of the ecosystem services that urban forests provide. These challenges and opportunities require strategic and comprehensive management that reflect the trees, the human communities, and the resources required to support sustainable and climate-resilient urban forests (Clark et al., 1997; Ordóñez & Duinker, 2013).

In this context, UFMPs provide a way for municipalities to implement strategic and comprehensive urban forest management (Gibbons & Ryan, 2015). UFMPs articulate a multi-year and multi-functional vision of urban forestry, along with objectives, indicators, and targets (Ordóñez & Duinker, 2013). Visions typically include broad goals, specific management objectives, and desired outcomes for both the urban forest and its contributions to the community. The management objectives address the operational and strategic ecological, environmental, social, political, economic, and spatial–temporal dimensions or urban forestry, reflecting the breadth of urban forest management (Kenney et al., 2011; Steenberg et al., 2019). More practically, UFMPs are a way to: justify existing urban forest programs and budgets; outline requirements for program development to politicians as well as internal and external stakeholders; and engage with the public about urban forest issues.

An examination of municipal plans can provide insights into how natural assets are being managed (e.g., Taylor et al., 2021; Hoover et al., 2021; Grabowski et al., 2022). This has also been the case for UFMPs. However, in the decade since the first comprehensive analysis of Canadian UFMPs (i.e., Ordóñez & Duinker 2013), the number of municipalities that have produced plans has increased more than five-fold. As a result, we identified a need to update previous studies and reflect on the evolution of urban forestry, most specifically the management and planning aspects.

In this study, we analyzed 74 UFMPs to reveal commonalities and trends in urban forestry across Canada. We sought to address three questions: (1) what is the content of UFMPs, in terms of the frequency of mention, representativeness, and structure of management topics or themes?; (2) does the content of plans change over time?; and (3) what social-ecological characteristics of municipalities (e.g., population, income, etc.) associate with this content? Answering these questions can help us develop insights on what is being addressed and what is being ignored in urban forestry, including social-ecological objectives, and how these objectives change over time. These are matters of great interest to researchers and practitioners working in urban forestry, municipal asset management, urban ecology, green infrastructure, or urban planning, among other professions.

2. Conceptual framework

Making plans and implementing them is the basis of management. The plan is central to guiding action. This action depends on, on one hand, robust statements of intent, and, on the other hand, specifications of the actions required to fulfill the statements of intent. Action implementation without a plan is not management, nor is creation of a plan that is not implemented.

These ideas apply across natural resources and ecosystems, such as forests (CSA, 2016), and are equally valid for urban forests (Ordóñez & Duinker, 2013). Until the late 20th and early 21st centuries, few municipalities had management plans for their urban forests, instead relying on the discretion of professionals charged with tree care and managing available budgets (Konijnendijk, 2003).

Canadian municipalities have a history of developing management plans for natural assets, such as parks and forests. These assets could be included in broader municipal plans (e.g., sustainability or environmental plans) or have specific planning documents (i.e., UFMPs). A growing number of municipalities have adopted plans specific for environmental sectors (e.g., stormwater, waste, air quality). Examination of municipal plans provides information about what is being managed, alongside strategic and operational details (Berke & Conroy, 2000; Taylor et al., 2021; Hoover et al., 2021; Grabowski et al., 2022). This supports research based on questions regarding what is and what is not included, and provides insight into intended futures (Boulton et al., 2018; Taylor et al., 2021).

Several recent studies have explored how emerging environmental and sustiainability concepts have been included in municipal planning documents, particularly in North America. For example, Lam & Conway (2018) and Thompson et al. (2019) explored how ecosystem services, a concept developed in the late 20th century (Costanza et al., 1997), have been incorporated into municipal plans related to parks, greenspace, and urban forests. Such research found that most strategic attention is given to cultural services and more operational attention is given to regulating services. Other studies have examined the adoption of the concept of green infrastructure in both comprehensive (e.g., sustianability plans) and sector-specific plans (e.g., stormwater plans) in both Canada (Conway et al., 2020) in and the US (Grabowski et al., 2022).

The needs of urban societies and the ways they have managed their trees have shifted significantly over time. Many local governments have been responsible for forests and trees. Canada was one of the first implementers of the concept of urban forestry in the 1970s (Jorgensen, 1970). Nevertheless, at that time, urban forestry primarily focused on the aesthetic contributions of trees to the city environment and the management of tree risk (Kenney & Idziak, 2000). As the research on quantifying the ecosystem services provided by urban trees advanced, such as air pollution regulation and microclimate control (Nowak et al., 1996), and as the concept of ecosystem services became more popular (Costanza et al., 1997; MEA, 2005), urban forestry discourse adopted ecosystem services as the dominant framing (Nowak, 2006; Roy et al., 2012; Seamans, 2013; Livesley et al., 2016). However, despite renewed interest in urban forestry since the 2000s, many cities in North America, including US (Kovacs et al., 2010) and Canada (Gaudon & Smith, 2020), were dealing with the loss of urban trees associated with the invasive pest emerald ash borer (*Agrilus planipennis*). Indeed, while many municipalities were losing significant portions of their tree canopies, they were also considering how to increase tree canopy and planning for this enhancement.

Given the increased interest in urban forestry, many researchers have analysed the content of UFMPs to help understand management directions and conditions in urban forestry. For example, Ordóñez & Duinker (2013) completed a content analysis of 14 English-language

UFMPs from across Canada – the number of UFMPs that were available at that time. They documented the breadth of management subject matter included in the plans, but also found that the plans focused on tree maintenance aspects with scant coverage and lack of specificity (i.e., clear link between objectives, indicators, and targets) of other management themes related to nature conservation, community engagement, and climate change, to name a few. Since then, several studies have examined specific aspects of Canadian UFMPs. Almas & Conway (2016) found that strategies regarding native tree species planting and representation in Southern Ontario municipalities were vague. Kowalski & Conway (2019) concluded that subject matter related to food trees received only limited attention. Finally, Cheng et al. (2021) found limited coherence and overlap between the content of UFMPs and climate-change policies in ten Canadian cities.

Beyond Canada, Gibbons & Ryan (2015) analysed UFMPs across towns and cities in Washington State (US) and found that plans were dominated by content related to tree maintenance and tree establishment and that many plans did not go into detail about tree monitoring and plan implementation. In Australia, Phelan et al. (2018) examined the UFMPs for 18 local government authorities and found that there was little coherence between local plans and state-level strategies about urban vegetation. More recently, Grant et al. (2022) explored how environmental justice issues were included in 107 UFMPs from the most populous cities in the US.

Today, as new management issues emerge in urban forestry, there is a need to update our understanding of how to plan for them. For instance, research about ecosystem services provision, demand, and supply in urban forestry has increased exponentially (Escobedo et al., 2019). There is also a greater understanding of the threats facing urban forests, including dealing with multiple environmental stressors that make it difficult to grow trees in cities (Jim, 2013); harmonizing the relationship between trees and the urban built infrastructures, such as powerlines (Lecigne et al., 2018; Perrette et al., 2021); the effects on trees by urban (re-) development (Nitoslawski et al., 2017; Steenberg et al., 2019; Nowak & Greenfield, 2020), particularly tree loss on private urban lands (Clark et al., 2020); ecological threats, such as new and invasive vegetation, and new pests and diseases (Kovacs et al., 2010; Gaudon & Smith, 2020; Paquette et al., 2021); biodiversity homogenization and loss of habitat provision (Aronson et al., 2017); constrained municipal budgets (Kenney & Idziak, 2000; Hauer et al., 2011); numerous stakeholders who may have competing goals (Conway & Vander Vecht, 2015); and uncertainties associated with the changing climate (Khan & Conway, 2020).

It is unclear whether this new knowledge and areas of research have influenced more recent UFMPs compared to older UFMPs in terms of patterns of content. Ultimately, much of the recent research on UFMPs has been done with specific topics of interest as guiding lenses (e.g., native species; food provision; climate change; environmental justice; see references above), rather than comprehensively across all possible management objectives and outcomes, as undertaken previously by Ordóñez & Duinker (2013) and then later by Gibbons & Ryan (2015). Also, most studies have provided a snapshot of content at a moment in time, rather than comparing content over time.

Furthermore, there may be social-ecological characteristics of municipalities that associate with content patterns. For example, Grant et al. (2022) assessed how population size and racial diversity drove a higher mention of environmental justice themes across plans in US cities. Overall, operational capacities, including budget, expertise, and professional capacity, are major drivers in the development of municipal plans and their content (see Hoover et al., 2021; Grabowski et al., 2022). So, population is not the only factor defining municipal resources. However, objective information or data on budgets, expertise, and professional capacity may be difficult to obtain or may be proprietary. One way to account for the factor of operational capacity is to examine the influence of the type of municipality. This is a way of differentiating, for example, between municipalities at the core of a larger metropolitan region, and other types of municipalities, such as high- or low-density suburban or peri-urban municipalities, and municipalities not within a metropolitan region, among other possible types (e.g., Statistics Canada, 2022). Type of municipality can be influential because it determines financial resources, social context, and, in some cases, extent or amount of natural assets. As such, one could hypothesize that some subject matter in urban forestry may be mentioned more in UFMPs released by municipalities at the core of a larger metropolitan region (i.e., in Canada, urban core within a census metropolitan area, or CMA; see Methods section for details), which in Canada usually means cities with greater financial resources and, possibly, also a smaller amount of natural assets. This has not been considered before in UFMP research.

Other social-ecological characteristics that may associate with content include ecozones, resource abundance, economic conditions, and cultural characteristics of communities. Ecozones in Canada (AAFC, 2013) define the ecological backdrop in which municipalities are located (see Methods for details). Municipalities with more abundant urban forests (e.g., larger current canopy cover or more abundant natural forest areas) may articulate management in different ways than municipalities with less abundant urban forests (e.g., smaller current canopy cover or with most of its trees within streetscapes). The average level of income of households within the municipality may define the availability of resources or demands expressed. Finally, cultural differences, which, at the broadest national level in Canada, means the difference between French- and English-speaking communities, may influence beliefs about the role of local government and expectations related to urban trees. However, few, if any, studies have analysed the influence of such a wide range of social-ecological factors upon UFMP content patterns.

3. Methods

The work was carried out under the *Trees and their social-ecological effects - Arbres et leurs effets socio-écologiques* (TreeSEE-ArbES) collaborative research partnership, 2021–2023. The research partnership included researchers from various academic backgrounds (i.e., urban ecology, urban planning, forestry, environmental sciences, environmental geography) working in various Canadian universities, various municipal government partners, and non-governmental organizations involved in urban forestry action and education, some of which are co-authors of this article. Researchers and professional partners working in partner municipalities co-designed the study and interpreted the results.

3.1. Study areas and data sources

We conducted a search for UFMPs following existing protocols first established by Ordóñez & Duinker (2013) and subsequently replicated by Almas & Conway (2016), Kowalski & Conway (2019), and Cheng et al. (2021). From January to May 2022 we systematically searched the websites of the 100 most populous Canadian municipalities for UFMPs, followed by a purposeful search using the Google search engine for other municipalities, later complemented by a search in the municipality's website. We did not make inquiries with Canadian municipal staff to access documents; we only included documents that were publicly available online as of the cut-off date (details in Supplement 1). We assessed each document's inclusion based on the eligibility criteria from Ordóñez & Duinker (2013) and Grant et al. (2022). We identified 74 municipalities that had UFMPs, including municipalities in eight of the 10 Canadian provinces, but none from the three Canadian territories. Most documents were in English (n = 61), with the remainder in French (n = 23). Also, most of the documents were from municipalities in large metropolitan regions (i.e., census metropolitan areas, or CMAs, such as the Greater Toronto Area; Statistics Canada, 2022), but there were also plans from smaller towns and urban centres outside CMAs (details in Supplement 1) (Fig. 1).

3.2. Datasets

To meet the assumptions about the data inherent to the analytical approaches, we created two datasets. The first (i.e., "long" dataset, n = 74) included all UFMP documents we could find for Canadian municipalities. The second (i.e., "short" dataset, n = 63) included only documents with shared characteristics that made direct content comparisons among them appropriate. These characteristics include the element of management (i.e., all trees in the municipality) and jurisdiction (i.e., municipal not regional or other type of jurisdiction) (details in Supplement 1). We used the long dataset for exploration of a comprehensive range of topics covered by UFMPs, and we used the shorter dataset for extracting a comparative range of themes covered by UFMPs.

3.3. Data analysis

To address the first research question, we conducted a qualitative interpretation analysis, relying on thematic coding, applied to the "short" dataset of UFMPs (n = 63), and a quantitative text analysis, relying on topic modelling, applied to the "long" dataset of UFMPs (n = 74).

3.3.1. Thematic coding

Based on procedures developed by Ordóñez & Duinker (2013), Gibbons & Ryan (2015), Kowalski & Conway (2019), Cheng et al. (2021), and Grant et al. (2022), all of which relied on qualitative interpretative content analysis (Krippendorff, 2018), we used a combined deductive and inductive thematic coding technique (Terry et al., 2017) with the goal of discerning how an idea was being treated within the text and coding this idea based on the original wording as much as possible. This was applied to the "short" data dataset so we could have consistent characteristics of UFMPs when comparing frequency of themes (see above; see also Supplement 1). We used QSR NVivo v.12 (https://www.qsrinternational.com/nvivo) text queries to initially

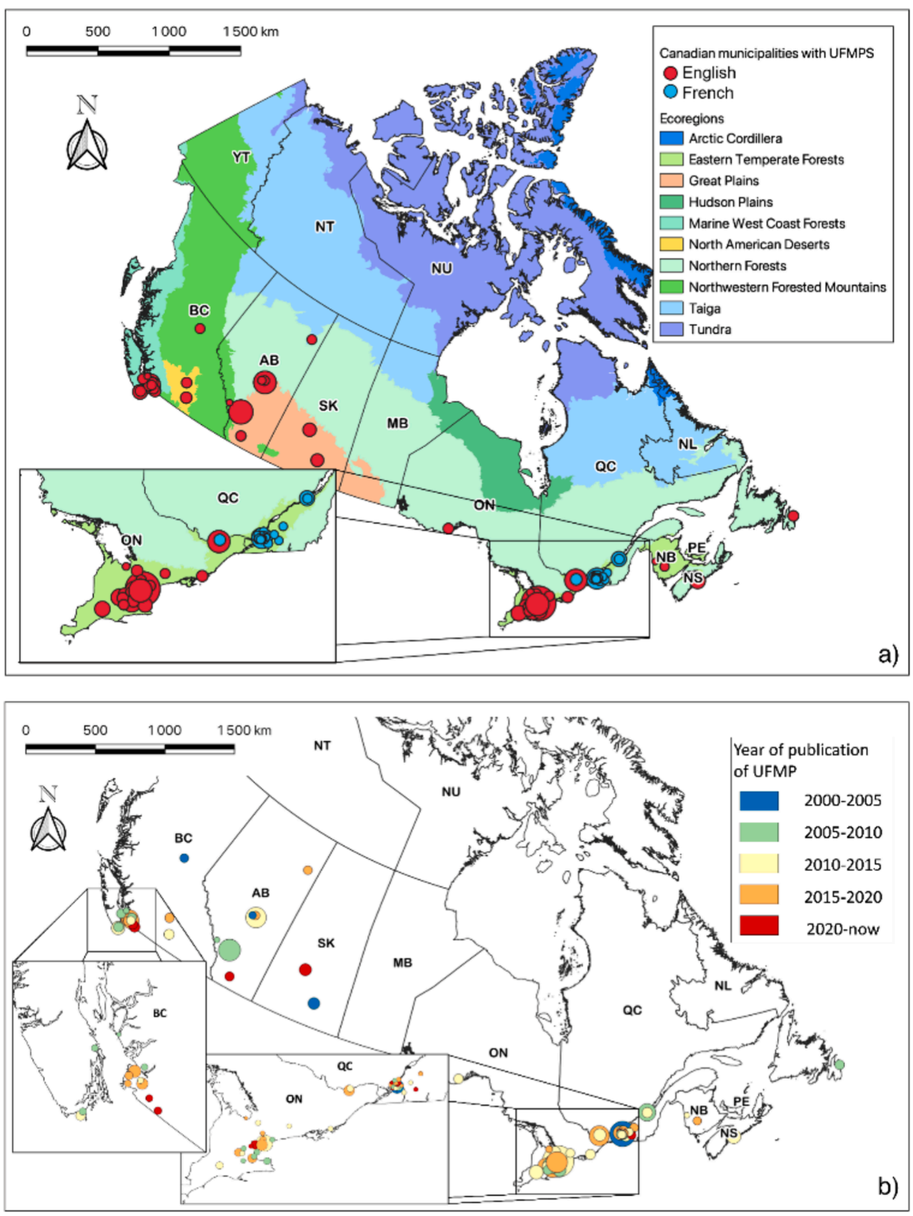

Fig. 1. Distribution and characteristics of Canadian municipalities with urban forest management plans (UFMPs) identified in this study. a) Location of municipalities within their ecozone, and publication language of the UFMP. b) Year of publication of UFMP in five-year intervals. Size of circles in both panels refers to municipal population.

conduct searches of concepts and terms included in the content framework developed by Ordóñez & Duinker (2013; Table 1 in publication; "theme", "criteria", and "indicator" columns). Ideas were then coded by interpreting how the idea was treated by reading the broader context (i.e., paragraph and/or adjacent sentences).

Whenever an idea did not fit the existing terminology in the content framework by Ordóñez & Duinker (2013), new codes were generated. We did not code based on the mere mention of an idea, but rather how it was being substantially explained/discussed. We also applied constant comparison principles (Krippendorff, 2018), meaning all codes were simultaneously compared across the dataset to achieve coding comparability. This process made coding more efficient, combining both deductive (i.e., using existing ideas from Ordóñez & Duinker, 2013) and inductive (i.e., grounding the coding on the data) interpretative techniques. We later structured the codes by building thematic hierarchies, with themes at higher level of abstraction and subthemes at lower level of abstraction.

Two co-authors were involved directly in the coding analysis, in English and French, under the supervision of the lead author. The coding was done in the original language and then codes were translated into English. Inter-coder reliability and validity was achieved by using common procedures for multiple coders, including first coding together one document and identifying divergences; generating a codebook with comparable terminology for coding (in English and in French); and holding frequent discussions to ensure consistent application of the codebook (Hemmler et al., 2022). Coding density (i.e., the % of a document that was coded) was used as a reliability metric for coding consistency (details in Supplement 2).

The data generated from this analysis were termed "themes", or ideas at the highest level of abstraction extracted from the plans through thematic coding. These data represented frequency of mention of themes across UFMPs. To make the data comparable across plans, frequency of mention was normalized by dividing the number of mentions by the word count of the document (i.e., mentions per 1,000 words of text) as done by Grant et al. (2022). This way we accounted for a document's length and the presence of figures and numbers.

3.3.2. Topic modelling

We used text analysis algorithms from topic modelling (TM), specifically the Latent Dirichlet Allocation (LDA) algorithm, which is a probabilistic, Bayesian-based procedure (Blei et al., 2003) that automatically uncovers the hidden semantic structures from text-based data (Blei, 2012). LDA interprets the mixture of words that show up consistently in documents as a topic, interprets a document as a mixture of topics, and operationalizes topics as bundles of correlating and co-occurring terms. We used all the available data (i.e., "long" data dataset, or n = 74 plans; details in Supplement 1). Documents were uploaded as PDF files into R v. 4.2.1 (R Core Team, 2022). Using the original PDF file format of the document meant that the data did not have any initial text deletions, so it included all tables, headers, footers, and appendices of the original documents. Considering the dataset was large, this is considering an adequate approach as per Blei (2012). We then used the *topicmodels* package (v. 0.2–14) in R to, first, pre-process the text following standard TM procedures, such as converting to lower case, removing numbers, stop words, white space, and symbols, as per Blei (2012). Second, we post-processed the text after obtaining initial TM results, including removing generic terms such as: the name of municipalities or companies (i.e., third-party companies that wrote the plans, the name of which was repeatedly included as a header or footer in some documents); "trees"; "forests"; and "urban"; among others. Third, we identified the LDA extraction method iteratively, using the same seed to reproduce results, and settled on the Gibbs method, which seemed more sensitive to the data, in contrast to the VEM (variational expectation–maximization) method, which extracted topics by document and not across documents, as was desired. Fourth, we identified the number of topics iteratively, running between 4 and 16 topics, and settled for eight topics as interpretable. Finally, since each document is assigned a probability of falling in a topic ("gamma" value), and each term is assigned a probability of falling in a topic ("beta" value), we exported these data to illustrate the results of the analysis.

The data generated from this analysis were termed "topics", or bundles of co-occurring terms expressing an abstract idea extracted from plans through topic modelling. The data represented gamma and beta values, as explained above. The code for the topic modelling analysis is open source and publicly available at https://github.com/cordezbar/CanadianUFMPs.

3.3.3. Statistical analyses

The remaining research questions were answered by conducting statistical analyses of the data generated from the thematic coding (i.e.,

Table 1
Themes and subthemes extracted via thematic coding from Canadian urban forest management plans (UFMPs) (n = 63).

Theme number	Name of theme	Theme code in Fig. 2	Description and subthemes
1	Administration, legislation, and policy	admin&law	Administration, legislation and policy issues, including staff and employee training, tree regulations and incentives, budgets, municipal documentation, and coordination
2	Canopy cover	canopycover	Canopy cover issues, including measuring canopy cover and calculating its effects
3	Climate change	climatechange	Climate change issues related to urban heat mitigation, carbon sequestration, and urban forest adaptation and vulnerability
4	Economic analysis	economicanalysis	Issues related to economic valuation analysis, benefits and ecosystem services analysis
5	Community Education	communityeducation	Community education issues such as awareness and education programs communication with the community, and community celebrations and competitions
6	Tree heritage	treeheritage	Issues related to historic and heritage trees, including listing and protection
7	Community stewardship	communitystewardship	Community engagement, inclusion, stewardship issues such as community tree-planting and volunteering programs
8	Invasives	invasives	Includes invasive trees and/or vegetation that may challenge the planting or thriving of trees, and invasive pests and diseases, as well as infestation assessments and restoration initiatives
9	Natural Hazards	naturalhazards	Natural hazards and natural disasters issues related to managing and responding to drought, fire, ice, storms, and windthrow
10	Nature and biodiversity	nature&biodiverse	Naturalness, biodiversity, and conservation issues such as connectivity, protection of natural areas, increasing naturalization in plantings, wildlife habitat, and species at risk
11	Tree diversity	treediversity	Tree diversity issues, including increasing diversity overall, and specific diversity subthemes related to age class, structural, type (e.g., coniferous and non-coniferous species), native tree species, and functional diversity
12	Tree establishment and enhancement	treeestablish&enhance	Issues related to tree abundance, including tree establishment and enhancement of tree numbers, tree sizes, tree quality, tree growing conditions, and tree planting programs
13	Tree maintenance	treemaintenance	Tree maintenance issues including hazard trees, pest and diseases affecting trees, pruning, removal and replacement, non-hazard related tree damage, and tree inventories

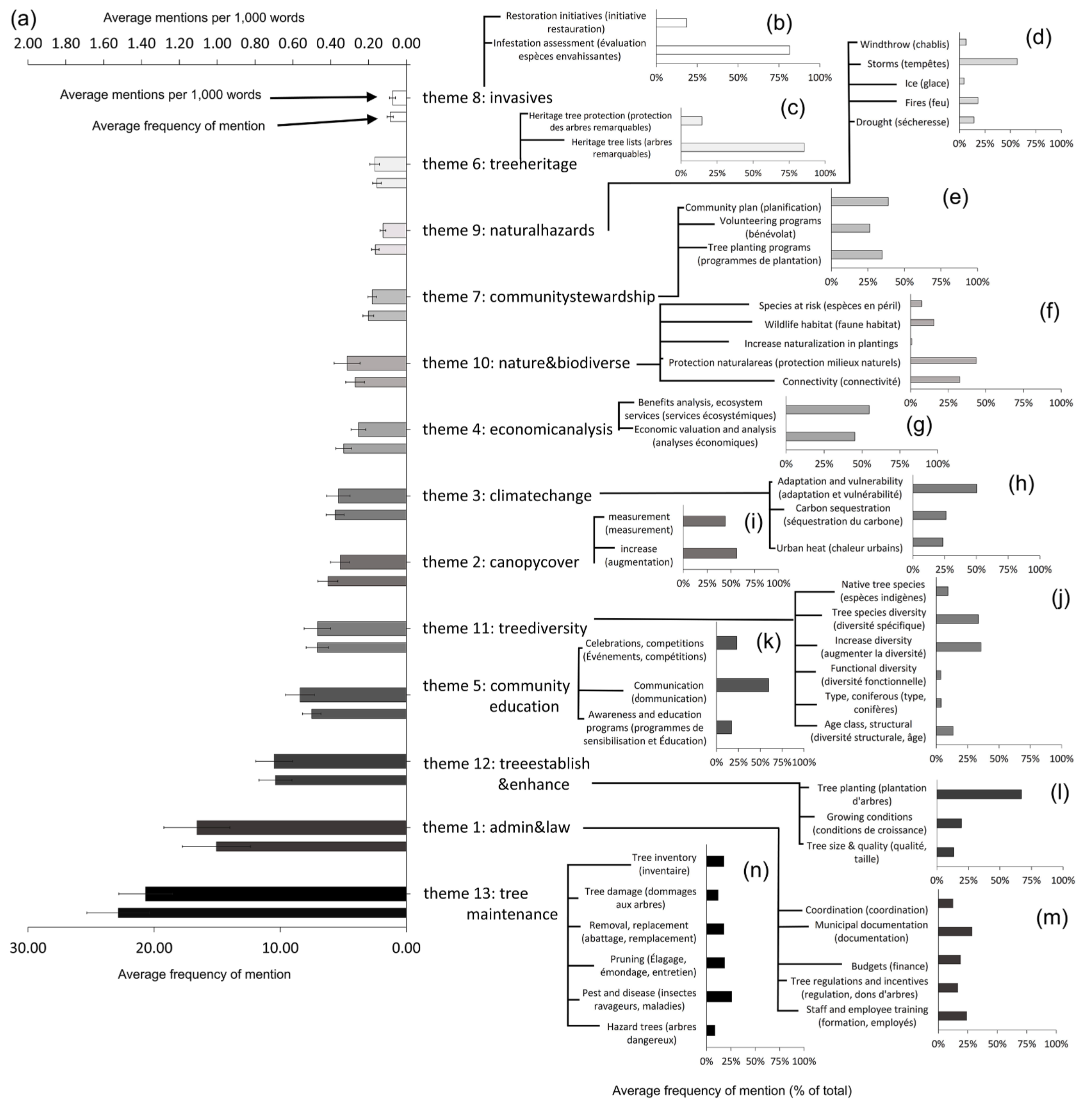

Fig. 2. Results of thematic coding of Canadian urban forest management plans (UFMPs) (n = 63). (a) Average mentions of themes across all plans, using two metrics: frequency of mention (top axis) and mentions per 1,000 words (bottom axis). Error bars indicate standard error. (b-n) Percent of total mentions for corresponding subthemes. For interpretation, see also Table 1. Theme mentions across the UFMPs are provided as complementary results in Supplement 3 (Supplementary Fig. 2).

themes) and topic modelling (i.e., topics).

To assess patterns of content over time, we followed and expanded the analytical procedures developed by Grant et al. (2022). We used a correlation test using Spearman's rank correlation (rho) to determine the association between theme mentions per 1,000 words and year of publication of the UFMP.

We also compared average theme mentions per 1,000 words between two time periods: documents published before 2011 and after 2011. By "before 2011" we mean documents published between 2000 (i.e., earliest publication year for a document) and 2011 (i.e., the latest period covered by documents analysed by Ordóñez & Duinker, 2013), or the first phase or decade of UFMP adoption in Canada. The later period includes the documents published within the second decade of our analysis timeframe (i.e., "after 2011") when UFMP adoption was more widespread. To make this distinction of time periods self-explanatory in the reporting, we labelled these two time periods as "2000 to 2011" and "2012 to 2022" (details in Supplement 1). To compare average theme mentions across these two categories, we first undertook standard normality testing of the distribution of the themes data (i.e., Shapiro-Wilk and Kolmogorov-Smirnov tests; Rosner, 2015) and then conducted non-parametric means differences analysis using the Mann-Whitney-Wilcoxon rank sum test at and above the 99 % confidence levels.

To assess influence of social-ecological characteristics upon patterns of content we first used the Spearman's rank correlation (rho) test to determine the association between theme mentions per 1,000 words and population, median household income (source Statistics Canada;), and current canopy cover (as reported in the plans; details in Supplement 1). Second, since the population data were skewed, ranging from the City of Toronto, with 2.9 million, and many municipalities with less than 100,000 people, and following Grant et al. (2022), we compared average theme mentions between two population categories: municipalities with less than 100,000 people, and municipalities with more than 100,000 people (details in Supplement 1). Third, we compared average theme mentions per 1,000 words between the binary categorical variables of: language of communities, including English and French (same as the language of the document); Mixedwood plain ecozone (representing 63.5 % of all the UFMPs, with French and English communities evenly represented within that ecozone; details in Supplement 1) and other ecozones collapsed together (i.e., non-Mixedwood plain). Since all French documents were in the Mixedwood plain ecozone, we also conducted the analysis by ecozone only with the English documents. This procedure was also applied to type of municipality. Initially we

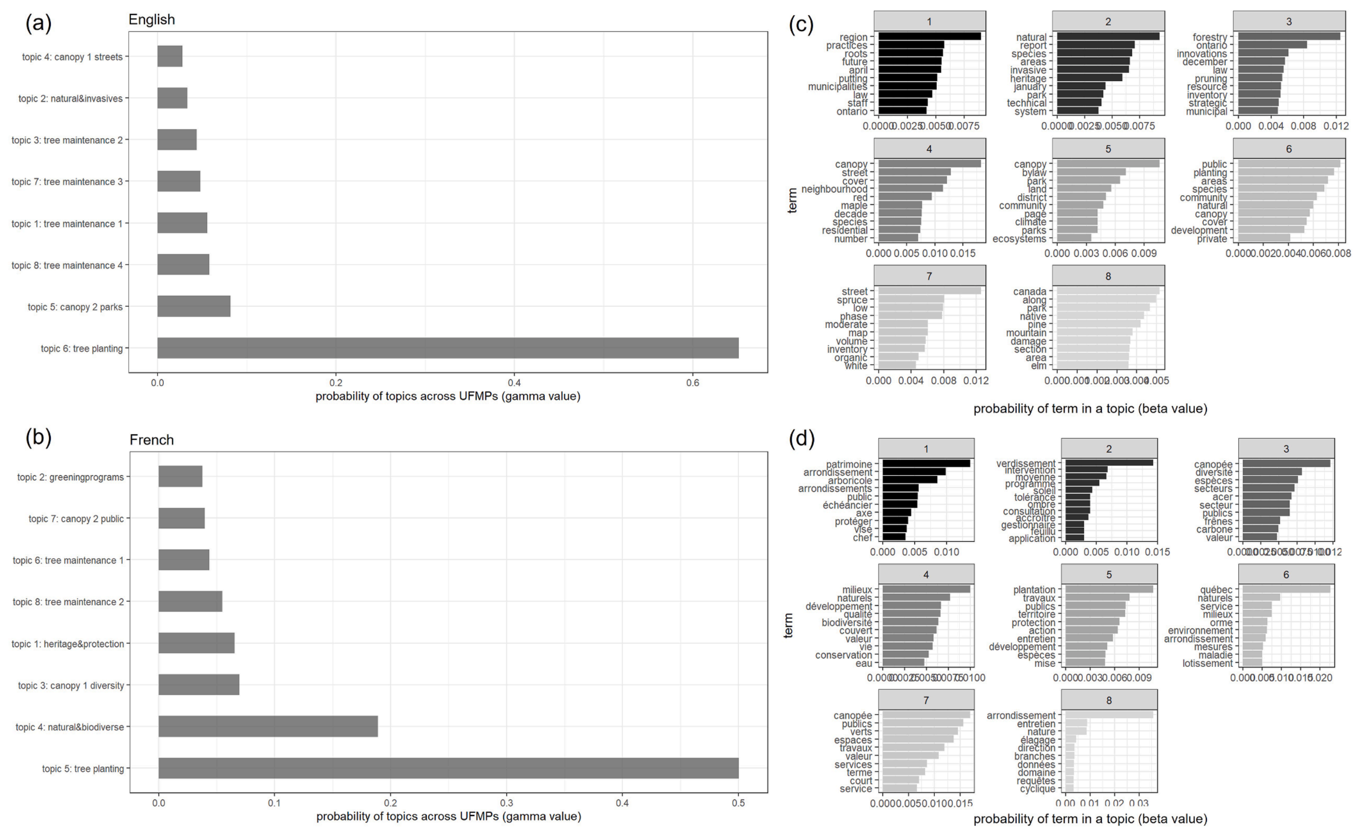

Fig. 3. Results of topic modelling showing topics and associated co-occurring terms across Canadian urban forest management plans (UFMPs) (n = 74). (a-b) Average probability of a UFMP to fall into a topic across all UFMPs ("gamma" value) in English (a) and French (b). (c-d) Probability of co-occurring terms to fall into individual topics in English (c) and French (d). For interpretation, see also Table 2. Topic proportions across the UFMPs are provided as complementary results in Supplement 3 (Supplementary Fig. 3).

classified all municipalities in the database according to the Statistics Canada (2022) classification, which included four types: urban core within a CMA, high density suburb, low density suburb, and urban area outside of a CMA (details in Supplement 1). Due to the high proportion of urban core municipalities (40.5 %) we collapsed these categories into two: urban core and non-urban core (see also Supplement 4). We followed the same procedures detailed above, including standard normality testing and non-parametric means differences analysis.

Given our quantitative analytical approach, we deemed the results for differences by language unreliable, since French documents were on average shorter than English documents, and English documents usually contained more background information. Therefore, there was a strong relationship between coding density and the length of UFMPs (i.e., word count). This is explained in more detail in Supplement 2.

4. Results

4.1. Themes

The thematic coding analysis resulted in 13 themes (Table 1; Fig. 2). The top three most frequently mentioned themes were: (1) Tree maintenance (theme 13); (2) Administration, legislation, and policy (theme 1); and (3) Tree establishment and enhancement (theme 12) (see Table 1 for definitions). The standardization of the data into average mentions per 1,000 words did not change the patterns in the original frequency of mention. Fig. 2 shows average mentions of subthemes across all plans. For example, about 75 % of the mentions of the highly mentioned theme 12, Tree establishment and enhancement, were coded as "tree planting" (in French, "plantation d'arbres") (Fig. 2, panel "i"). Another example was theme 9, Natural hazards, which was not mentioned that much and mostly included mentions of storms but not fire (Fig. 2, panel "d"). Theme 7 on Community stewardship also had very few mentions.

4.2. Topics

The topic modelling analysis resulted in eight topics, each comprised of many co-occurring terms (Fig. 3, Table 2). We used the top ten terms in each topic to interpret their meaning and assign a name to the topics (Table 2). The most common topic, in terms of the probability of a document to contain the topic, was Tree planting, with matching results in both English and French (Topic 6 in English; Topic 5 in French; Fig. 3, Table 2). These results parallel those from the thematic coding, given the high mention of theme 12, Tree establishment and enhancement (Fig. 2). In terms of the diversity of topics, many of the topics were related to tree maintenance (Topics 1, 3, 7, and 8 in English; Topics 6 and 8 in French; Table 2) and canopy cover (Topics 4 and 5 in English; Topics 3 and 7 in French, Table 2). These results also parallel those from the thematic coding, given the high mention of themes 13, Tree maintenance, and theme 12, Tree establishment and enhancement. Finally, the topic related to Naturalness was matched in both English and French (Topic 2 in English; Topic 4 in French; Table 2), but it was more common in French than in English documents (Fig. 3).

4.3. Themes and topics over time

We found statistically significant correlations between the year of publication of the UFMP and the themes (in terms of mentions per 1,000 words) of Canopy cover, Climate change, and Tree establishment and enhancement. We also found statistically significant higher mentions in UFMPs that were published in the later decade, meaning between 2012 and 2022, for the themes of Community education and Tree establishment and enhancement. While one topic showed a significant increase over time (Topic 3 Canopy1diversity, related to issues of tree diversity; see Table 2), this was limited to the smaller set of French plans (Fig. 4). Complementary results using 5-year jumps are included in Supplement 3 (Supplementary Figs. 4 and 5).

4.4. Themes and social-ecological characteristics

We found statistically significant correlations between the percentage of current canopy cover in the municipalities and the theme of Invasives. We also found statistically significant higher mentions of the themes of Administration, legislation, and policy, Community education, and Tree maintenance in UFMPs that came from municipalities with a population lower than 100,000 people, and higher mentions of the themes of Administration, legislation, and policy and Tree establishment and enhancement in UFMPs that came from municipalities not at the core of CMAs (i.e., within a CMA but not at the core, and outside a CMA) (Fig. 5). We found no associations between theme mentions and median household income or Canadian ecozones. While some topics showed associations and average proportions (Topic 2 for French plans, greening programs, issues related to tree planting; Topic 2 for English plans, nature & invasives, issues related to invasive vegetation and heritage trees; see Table 2), these results were limited to a smaller set of plans (see for example panel b) in Fig. 5). Generally, results related to topics are less reliable because the data have many outliers.

5. Discussion

The results from our analysis demonstrate that Canadian UFMPs contain diverse content, in terms of the number of themes and topics. However, this content is dominated by ideas referring to increasing tree abundance. Less attention is being paid to other management issues. In this discussion, we interpret the reasons for the patterns and associations found, the answers to our three research questions, and draw implications from these results.

5.1. Content, content over time, and social-ecological associations

The dominance of tree abundance themes and topics, including, for example, ideas related to tree establishment, tree enhancement, and/or tree planting, is in some ways not surprising. A decade ago, Ordóñez & Duinker (2013) obtained similar results, suggesting no change in the way these ideas have dominated urban forestry in Canada. Besides corroborating previous observations, this study also demonstrates that these ideas have also become more dominant over time. This possibly reflects how Canadian municipalities may have become more ambitious in efforts to increase urban forest abundance (e.g., NRCan, 2023), in line with cities elsewhere (Gibbons & Ryan, 2015; McPherson et al., 2017; Phelan et al., 2018; Yao et al., 2019).

The emphasis on increasing tree abundance has a few potential motivations. First, there has been a large loss of urban trees in the US and Canada due to pests and diseases (Kovacs et al., 2010). In Canada, the emerald ash borer (*Agrilus planipennis*) outbreaks, which occurred several decades after the onset of Dutch elm disease (commonly caused by *ascomycete Ophiostoma* fungi), and the fear of losing trees through novel insect pests and diseases such as Asian long-horned beetle (*Anoplophora glabripennis*), augmented these concerns (Gaudon & Smith, 2020). Second, the narrow set of tree species that can possibly be planted has always been a challenge in northern climates (Paquette et al., 2021). While we can successfully plant hundreds of tree species in Canadian cities, the palette typically relied on in Canadian urban forestry is smaller compared to cities elsewhere (Almas & Conway, 2016), thus augmenting susceptibility to biotic and abiotic threats. Third, the increasing lack of available space for planting trees in both public and private urban lands due to urban (re-)development (Jim, 2013; Nitoslawski et al., 2017; Steenberg et al., 2019), including densification, is a key challenge. Thus, the strategic focus on increasing tree abundance responds to these on-going challenges.

Ideas related to canopy cover, climate change, and community education were also more frequently mentioned over time. The high mention of canopy cover is not surprising because it is intrinsically tied with tree abundance and is a key management target in Canada (Kenney et al., 2011; Steenberg et al., 2019). Canopy cover is also a proxy for tree leaf area index, which is used to estimate many ecosystem services, such as air pollution and temperature regulation, among others (Nowak, 2006; Roy et al., 2012; Seamans, 2013; Escobedo et al., 2019). Ecosystem services are a dominant framing in urban forestry as well as municipal natural asset management (references above and Thompson et al., 2019; Hoover et al., 2021; Roman et al., 2021; Grabowski et al., 2022). Moreover, the accessibility, affordability, and reliability of canopy cover assessments has accelerated exponentially due to new remote sensing techniques (Kimball et al., 2014).

Climate change is a pressing threat to urban forests (Khan & Conway, 2020) and it is a globally common concern, so its increased mention is not surprising either. However, much of the content of these plans in relation to climate change responds to using urban forests to reduce heat islands, capture and store carbon, or, in other words, as a nature-based solution to climate change (Cheng et al., 2021), in contrast to adapting urban forests to climate change.

Community issues are key for successful UFMP implementation (Conway & Vander Vecht, 2015). While more frequently mentioned over time, the management theme of community education in this study was simply conceptualized as raising awareness about urban trees, as

Table 2
Topics extracted via topic modelling from Canadian urban forest management plans (UFMPs) (n = 74).

Language	Topic number	Name of topic in Fig. 3	Interpretation based on co-occurring terms
English	1	tree maintenance 1	Tree maintenance issues related to regional laws and standards
	2	natural & invasives	Naturalness issues related to invasive species and heritage trees
	3	tree maintenance 2	Tree maintenance issues related to Ontario forestry
	4	canopy 1 streets	Canopy cover issues related to streets and tree species
	5	canopy 2 parks	Canopy cover issues related to tree bylaws and parks
	6	tree planting	Tree planting issues related to public areas and canopy cover increase
	7	tree maintenance 3	Tree maintenance issues related to tree inventories
	8	tree maintenance 4	Tree maintenance issues related to native tree species and tree damages
French	1	heritage & protection	Issues related to heritage tree protection
	2	Greening programs	Strategic issues related to programming greening programs
	3	canopy 1 diversity	Canopy cover issues related to species diversity
	4	nature & biodiverse	Naturalness issues related to biodiversity and conservation
	5	tree planting	Tree planting issues related to public areas and tree species
	6	tree maintenance 1	Tree maintenance issues related to regional planning and diseases affecting trees
	7	canopy 2 public	Canopy cover issues related to the provision of services
	8	tree maintenance 2	Tree maintenance issues related to tree pruning

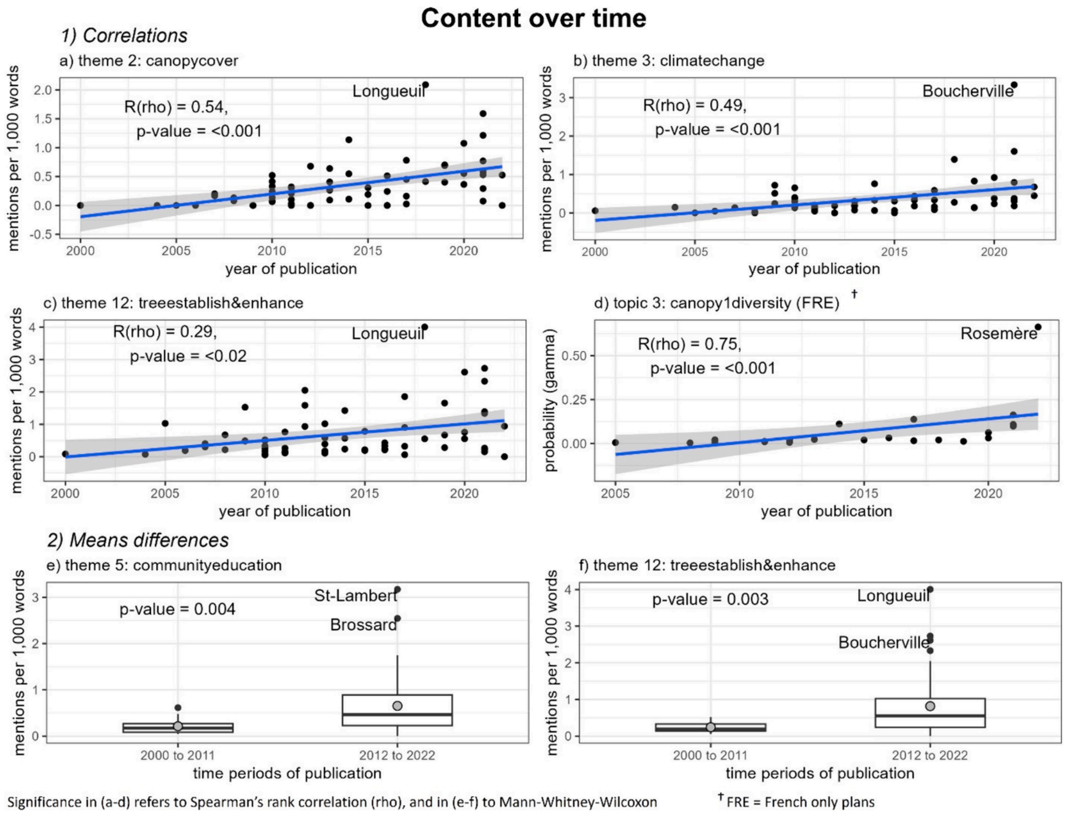

Fig. 4. Selected statistically significant results for changes of content (themes and topics; see Tables 1 and 2 for interpretation) over time based on year of publication of Canadian urban forest management plans (UFMPs) (for themes, n = 63; for topics, n = 74, split by language of UFMP). 1) Scatter plots between content and year of publication. Only statistically significant associations are included (a-d). The plots show linear trend lines with 95 % confidence intervals, and the value of the Spearman (rho) correlation test and its p-value. Since panel d) refers to topics, the y-axis is specified as "gamma" value, or the probability of a document falling in a topic. 2) Boxplots indicating average content by the two time periods of publication (details in *Methods, Data Analysis*). Only statistically significant differences are included (e-f). The plots show the result of the Mann-Whitney-Wilcoxon test and its p-value. Note the variable y-axis: this is to accommodate variable mentions and facilitate interpretation. Datapoints outside the range are labeled with the municipality's name.

per the content of the plans. Community stewardship was coded separately. Given much discussion in the academic literature about community stewardship (e.g., Buijs et al., 2019; Clark et al., 2020), as well as environmental justice in urban forestry (e.g., Grant et al., 2022), it is surprising that more attention is not given to these management issues in UFMPs.

We also found a positive association between ideas related to invasive plant and tree species and the percent canopy cover of a municipality. This may reflect the fact that municipalities with a higher percent canopy cover may also have a larger area of natural forests or woodlands in their urban forest. While concerns about invasive pests and diseases are very species-dependent (Kovacs et al., 2010; Gaudon & Smith, 2020; Paquette et al., 2021), the management of invasive plant and tree species is a bigger concern in natural forests and woodlands than in street tree management.

The higher mentioning of administration and policy, community education, and tree maintenance in smaller municipalities, and the higher mentioning of administration and policy and tree establishment and enhancement in those outside the urban core of CMAs, may reflect the fact that small municipalities often lack resources for urban forestry (Kenney & Idziak, 2000), and/or sometimes manage more trees and larger forested areas. As a result, smaller municipalities and municipalities outside of core metropolitan regions are still addressing more conventional urban forestry issues such as maintenance (Vogt et al., 2015), municipal budgeting (Hauer et al., 2011), and internal coordination (Conway & Vander Vecht, 2015), whereas larger municipalities may already have addressed these issues prior to developing a UFMP. Additionally, such municipalities may require more community engagement, as well as low-cost interventions, to help achieve their urban forest targets with fewer resources.

5.2. *Implications*

The future image of urban forestry established by UFMPs is influenced by a complex combination of local issues, including how urban forests are conceptualized; the policy setting; ownership regimes; the resources available; political will; community relations; development pressures; among many others. We recognize that UFMPs are still relatively new in the toolbox of municipal planning, so their efficacy is still difficult to assess. Also, the notion of comparable urban forestry has underlying political, social, and geographical assumptions. For example, Canada is a liberal economy and a democratic government, with a Western legal framework. The Canadian experience with urban forestry can only be compared to a similar context. Finally, the content of UFMPs may be discipline dependent. For instance, foresters and natural asset managers are usually the types of professionals that develop these plans, while planners and other types of professionals develop more strategic, vision-oriented, plans or policies. Ultimately, no standard definition exists regarding the difference between a UFMP or an action, strategy, policy, or plan, among other similar terms. Recently, many cities have developed tree planting strategies, either as a stand-alone plan or as a derivative subplan of UFMPs (Eisenman et al., 2024). While ideally such plans should be already a part of the ecosystem management and planning process that guides UFMPs, others may see these plans as the only strategy needed to harness the benefits of vegetation in urban areas. This adds another layer of variability and overlap between the types of

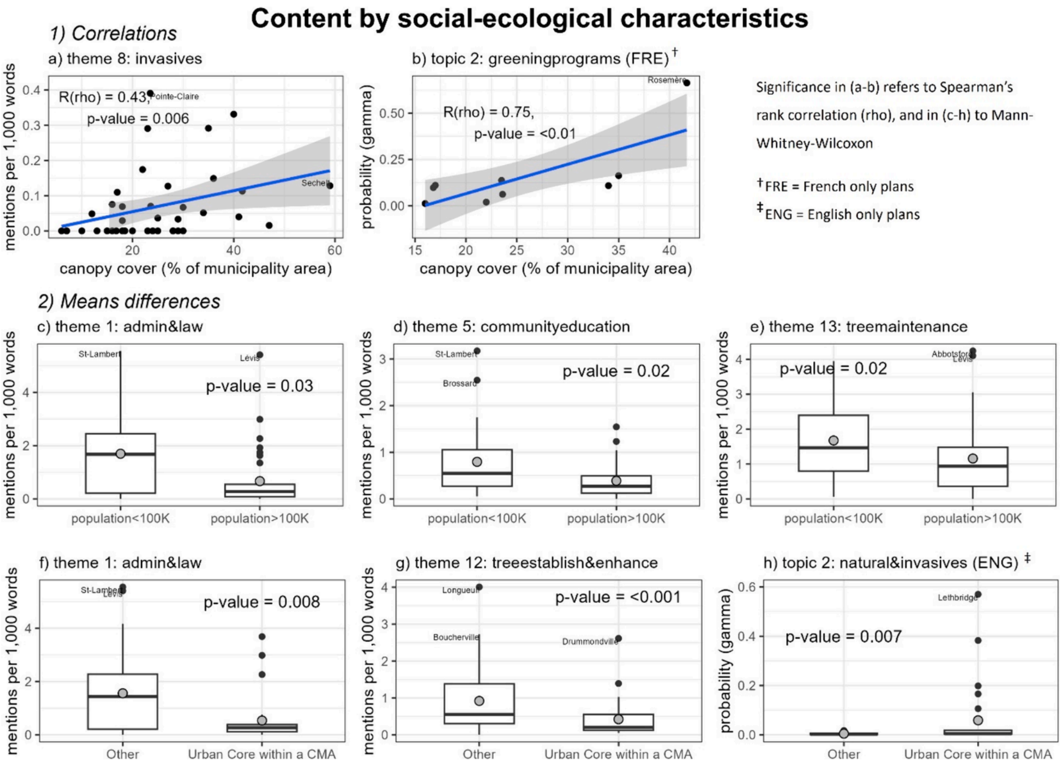

Fig. 5. Selected statistically significant results for the analyses on changes of content (themes and topics; see Tables 1-2 for interpretation) by social-ecological characteristics of Canadian urban forest management plans (UFMPs) (themes, n = 63; topics, n = 74, by language). 1) Scatter plots between content and current canopy cover as % of municipality area. The plots show linear trend lines with 95 % confidence intervals, and the value of the Spearman (rho) correlation test and its p-value. 2) Boxplots indicating average content of UFMPs with a population of or less than 100,000 (population < 100 K) and higher than 100,000 (population > 100 K); and municipalities classified as urban cores within a CMA and other types of municipalities (details in *Methods,*). The plots show the result of the Mann-Whitney-Wilcoxon test and its p-value. Since panels b) and h) refer to topics, the y-axis is specified as "gamma" value, or the probability of a document falling in a topic. Only statistically significant results are included. Note the variable y-axis: this is to accommodate variable mentions and facilitate interpretation. Datapoints outside the range are labeled with the municipality's name.

available municipal documents.

Nonetheless, UFMPs can still provide an empirical basis on urban forestry trends and futures. While there is certainly a dominance of the idea of increasing tree abundance in the future, many UFMPs do not systematically link urban forest growth management objectives with desired environmental and social conditions. For instance, which conditions do municipalities hope to improve and by how much by increasing canopy cover from 15 % to 20 %, or by planting 100,000 trees over ten years? Explicit links between desired conditions and management objectives within UFMPs would make it possible to evaluate the efficacy and efficiency of UFMPs over the long term. In doing so, these exercises must include baseline data, changes over time, and comparisons of municipalities with similar conditions to semi-experimentally assess differences. One of the expectations of these types of investigations is to inspire municipalities to find links between urban forest development and desired social-ecological conditions.

Second, the paradigm that more abundance – such as increased in canopy cover or number of trees– will result in more desired services/value (i.e., a so-called "supply–demand" paradigm) will carry municipalities only so far unless other critical issues are addressed. Increased abundance is obviously beneficial in itself, because it can result in an increased provision of ecosystem services in the short term. However, a focus on abundance without consideration of other management issues may cause undesirable trade-offs in the long term. For example, extensive investment in increasing abundance, may limit capacity to maintain and manage a larger number of trees; increasing abundance without considering impoverished biodiversity could lead to more homogenization and diversity loss; increasing abundance without reducing vulnerability to climate change could lead to increased vulnerability; and increasing abundance without focus on community engagement could decreased community buy-in and stewardship.

Climate change vulnerability and community stewardship are excellent examples of trade-offs. For instance, while many Canadian UFMPs make the connection between more trees and improved local climate conditions, they usually do not assess which elements of the urban forest will thrive or decline due to climate change or identify the necessary adaptive responses. Moreover, while many UFMPs recognize the importance of community education, many do not explicitly articulate management objectives related to citizen-led activities and/or co-management agreements, among other possible community stewardship objectives and actions.

While this observation about trade-offs in urban forestry is not new (e.g., Roman et al., 2021), in this study we provide an empirical basis for it and identify the specific trade-offs. One of the expectations of these types of investigations is to inspire municipalities to increase abundance while also paying attention to the management objectives that can sustain this urban forest enhancement in the long term.

5.3. Limitations and strengths

The UFMPs in this study varied in terms of, for example, their definitions of urban forests (i.e., which trees are included; trees alone or trees plus other ecosystem elements); length (i.e., word count; for instance, French were shorter in general than English documents); and jurisdiction (i.e., type of municipalities). These differences created challenges to extracting, interpreting, classifying, and comparing UFMP content.

There were advantages to using two datasets and two analytical approaches. While it is not standard to subset data or combine analytical techniques, in our case this helped complement the analysis and corroborate results. Despite the different datasets and analytical techniques, the results generated similar patterns of content, such as the dominance of ideas referring to increasing tree abundance, reinforcing their importance. This may have been due to the inherent and parallel assumptions of both the mathematical modelling of the text and the interpretation of the text, despite the differences in available data. In contrast to latent semantic analysis (i.e., Leximancer®), which generates word associations across the data (see Boulton et al., 2018), topic modelling generates structured bundles of co-occurring terms and assumes that documents are made up of a mixture of topics, which is also an inherent assumption in thematic coding.

Nonetheless, there were also divergences between datasets and analytical approaches. Perhaps because of the larger dataset, or because of the inherent characteristics of the mathematical modelling of the text, topic modelling was not able to reveal content related to administrative, climate change, or community stewardship ideas, content that was revealed through the interpretation of the text using a smaller dataset. All in all, the text modelling extracted a smaller diversity of ideas than the interpretation of the text. We offer that, when documents consist of similar words, and similar combinations of words, it may be harder to unlock their semantic structure via mathematical modelling regardless of the amount of data. This only reinforces the importance of complementing the analysis with the interpretation of the text. Also, many of the ideas that were not revealed by modelling referred to abstract concepts that could be described in many ways and, subsequently, with many different co-occurring terms, making them easier to identify through interpretation than through modelling.

Overall, the results of this study should be taken in the context of the data and methods used. We recognize that applying quantitative analytical approaches to qualitatively generated data invites assumptions of data distributions which may not fit the data. This is why we interpreted the statistically significant results with some level of caution. Nonetheless, we wanted to go beyond a descriptive, one-moment-in-time analysis, so a quantitative analytical approach fit with our research questions and research goals. We also recognize that we extracted content by interpreting the broadest possible expression of an idea. A more in-depth analysis may be able to reveal more complexity.

Given the multi-level and multi-unit government, and multi-functional, nature of urban forestry, there may be documentation other than UFMPs that could contain information about urban forests and their futures. In some places, urban trees may be embedded in regional, provincial/state, or national policies, or even in policies of other units in local government (e.g., climate change; stormwater; parks; biodiversity). This makes research examining the management of urban forests that much more challenging, and points to the need to not only examine UFMPs, but also to evaluate other documents and to speak directly to those in charge of implementing UFMPs about their implementation. Ultimately, while UFMPs can reveal information about intention, it does not include enough information about what happens after plan adoption. Complementary studies are needed to understand how UFMPs are being implemented.

6. Conclusion

By combining analytical techniques to examine UFMPs, this study demonstrated consistency between methods and content across Canadian UFMPs. A UFMP is the culmination of a notable effort by a municipality to articulate a vision for the future of its urban forest. Canadian municipalities have worked hard to cover a wide range of management subject matter in their UFMPs, thus revealing how urban forestry is not just about trees but includes environmental conditions, planning, sustainability, development, and human communities, among other issues. While these results mean that there have not been big shifts in UFMP content over time, future research studies could focus on shifts across different versions of a UFMP within one municipality, as municipalities begin to update their UFMPs.

How cities prioritize management concerns, how they conceptualize natural resources, and the size and characteristics of their communities, are some of the most significant factors that determine strategic urban forestry. Canadian urban forestry is mostly concerned with increasing tree abundance, but we also note that even the most ambitious plans to increase tree abundance may still be challenged by limited biodiversity, climate change vulnerability, and lack of community stewardship. This means that while Canadian municipalities are positioning themselves to either access new funding or increase their budgets to plant more trees, and perhaps to maintain them according to the status quo, they may not be well positioned to address biodiveristy issues, climate change threats, and to engage their communities in an improved stewardship of urban forests. Urban foresters, urban planners, environmental managers, and other professionals working in municipalities who may be developing, updating, or implementing UFMPs, can look to numerous existing plans so they can expand the breadth of content needed to manage their urban forests. However, they should also be mindful of balancing traditional management content, like tree planting and tree maintenance, with issues that have been under-emphasized but are critical to climate-resilient and equitable urban forests, like biodiversity, climate change vulnerability, and community stewardship.

CRediT authorship contribution statement

Camilo Ordóñez Barona: Writing – review & editing, Writing – original draft, Visualization, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Annick St Denis:** Writing – review & editing, Resources, Methodology, Formal analysis, Data curation, Conceptualization. **Jackson Jung:** Writing – review & editing, Resources, Methodology, Formal analysis, Data curation, Conceptualization. **Corinne G. Bassett:** Writing – review & editing, Methodology, Formal analysis, Data curation. **Sylvain Delagrange:** Writing – review & editing, Methodology, Formal analysis, Data curation. **Peter Duinker:** Writing – review & editing, Supervision, Resources, Methodology, Data curation, Conceptualization. **Tenley Conway:** Writing – review & editing, Supervision, Methodology, Funding acquisition, Data curation, Conceptualization.

Declaration of competing interest

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Data availability

Data are public and fully available for use. Enough details about data sourecs and data analyses procedures are included in the article.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.landurbplan.2024.105154.

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