Maintaining age diversity in urban forests through continuous tree planting: The potential of the Miyawaki method for urban forestry in Edmonton, AB.

by

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Abstract

Edmonton's urban forest provides ecosystem benefits such as mitigating urban heat island effects and enhancing the air quality, particularly through trees with substantial and dense canopies. The City of Edmonton is currently engaged in an ambitious urban forestry program to plant two million trees by 2030 to achieve a 20% canopy cover by 2071. However, planting such a large quantity within a short period risks creating an imbalanced age and size class distribution. Such imbalances may diminish ecosystem services and resilience, with implied lack of age class structure of urban forests potentially increasing vulnerability to extreme weather events, such as droughts. To maintain a balanced age class and enhance resilience, a consistent annual tree planting rate is recommended. The Miyawaki method, known for creating dense, self-sustaining forests that require only three years of maintenance, offers an alternative strategy to create urban forests. Already proven globally, this method ensures a continuous supply of young trees to offset older ones and sustain consistent canopy cover and ecosystem services. This research project attempts to make the case for adopting a steady planting approach using the Miyawaki method as a more effective long-term strategy compared to the ambitious short-term initiatives to enhance Edmonton's urban forest ecosystems.

1. Introduction

Urban forests encompass all city trees and serve as nature-based solutions to climate change by sequestering carbon, and reducing urban heat island effects through cooling, whilst providing ecosystem services at multiple scales as outlined in Figure 1 (from Hallet et al., 2023).

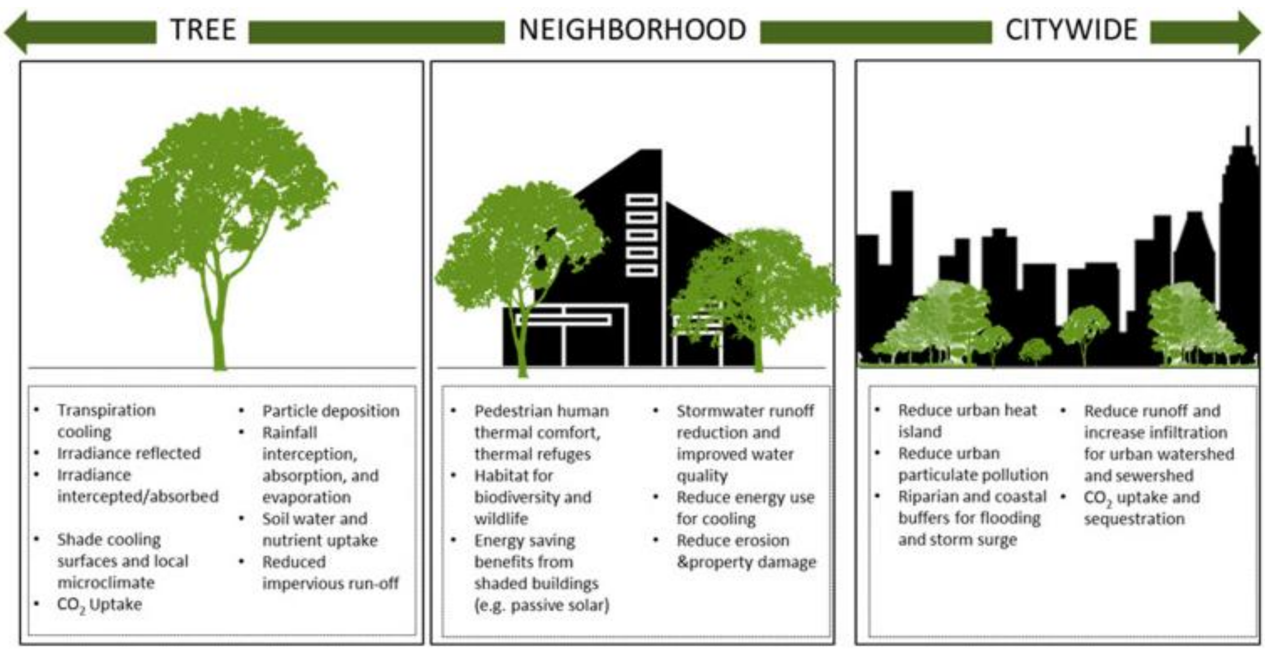

Figure 1: Urban forest ecosystem services at multiple scales.

Note: The figure outlines potential ecosystem services provided by urban trees at multiple scales. From “Climate change and urban forests,” by R. A. Hallet, M. R. Piana, M. L. Johnson, & L. A. Brandt, *In Future Forests: Mitigation and Adaptation to Climate Change* (p. 245), 2023, Elsevier. Copyright 2024 by Elsevier Inc.

However, inadequate city management practices, such as planting rates, lead to the formation of mature, even-aged classes that are susceptible to drought (see Socha et al., 2023). Furthermore, a decrease in ecosystem services occurs when there is an insufficient number of young trees to replace those that are dying (see Mänttäri et al., 2023; Vangi et al., 2024 Preprint).

The importance of canopy cover lies in its ability to cool urban areas through shading, mitigating urban heat islands. A study conducted in the upper Midwest USA revealed that canopy cover influences air temperature across various scales (Ziter et al., 2019). Raising canopy cover from 0% to 100% over a 10-meter radius results in a 0.7 ºC decrease in daytime temperature, while larger scales show more significant decreases: 1.3 ºC within a 30-meter radius and 1.5 ºC within a 60 to 90-meter radius (Ziter et al., 2019). A considerable reduction in temperature was observed in areas with a canopy cover of 40% or greater (Ziter et al., 2019). This effect has also been thoroughly reviewed by Hallet et al. (2023). This ecosystem service becomes valuable amidst the rise in extreme weather events and heightened air pollution levels (Ordóñez & Duinker, 2014). Trees directly mitigate air pollution as they absorb gaseous pollutants through their leaf stomata or intercept particulate matter on their surfaces (Nowak, 2018), there is more surface area for dry deposition on larger leaves allowing for more pollutant uptake (Walters & Sinnett, 2021). It is estimated that 16,520 tonnes of pollutants were removed by the urban forests of fifteen Canadian cities in 2010, as seen in Table 1 (based on data from Nowak et al., 2018). Dense canopies further mitigate ground-level pollution by impeding upper air pollutants from reaching ground-level airspace, thereby enhancing air quality beneath the canopy (Nowak, 2018). Consequently, the proliferation of trees with dense canopies amplifies the amount of ecosystem services within urban forests, prompting cities to prioritize the expansion of canopy cover.

Table 1: Estimated pollution removal by the urban forests of fifteen Canadian cities:

Pollutant:	Removal in 2010 (tonnes):
CO	112
NO_2	2434
O_3	12,370
SO_2	939
$PM_{2.5}$	665

Note. The table created outlines the estimated pollution removal by the urban forests of fifteen Canadian cities in 2010. The data for 2010 is from “Air pollution removal by urban forests in Canada and its effect on air quality and human health” by D. J. Nowak, S. Hirabayashi, M. Doyle, M. McGovern, & J. Pasher, *Urban Forestry & Urban Greening* (p. 43), 2018, Elsevier. Copyright 2024 by Elsevier B.V.

To sustain long-term canopy cooling in residential areas, urban trees require a balanced age-class structure. If all trees are planted simultaneously, this ecosystem service lasts only about three decades, as net primary production (NPP) is highest in the early to middle ages of 16-50 years before declining (Vangi et al., 2024 Preprint), necessitating simultaneous replacement of neighbourhood trees. Strategically placing trees to increase canopy cover mitigates urban heat island effects, while ensuring adequate space as emphasized by Ziter et al. (2019). This spatial arrangement facilitates continuous planting rates to maintain consistent canopy cover through timely plantings to maintain mature trees for optimal ecosystem service delivery (Walters & Sinnett, 2021).

According to Pretzsch et al. (2023), mature trees play a significant role in providing ecosystem services like temperature mitigation through cooling. Age classes ranging from 1-60 years old offer cooling benefits ranging from 1,346 kWh $ha^{-1}yr^{-1}$ to 30,126 kWh $ha^{-1}yr^{-1}$. The peak occurs in age classes 61-90 years old, providing cooling benefits from 29,433 kWh $ha^{-1}yr^{-1}$ to 35,556 kWh $ha^{-1}yr^{-1}$, before declining to 12,858 kWh $ha^{-1}yr^{-1}$ in age classes 91-100 years old. Managing forest age diversity balances benefits and disadvantages across all age classes (Vangi et al., 2024 Preprint). Moreover, larger healthy trees sequester more carbon, remove more air pollution, and provide more shade than smaller healthy trees (Walters & Sinnett, 2021). Planting 10,000 large stock trees annually, considering a 0.5% mortality rate, results in storing 17,528.9 more tonnes of carbon and sequestering 13,144.4 more tonnes compared to small stock trees (Walters & Sinnett, 2021), with benefits scaling up with increased tree planting. However, small stock trees can be advantageous due to their space efficiency.

Edmonton’s urban forest reduces surface urban heat islands by offering shade and cooler temperatures in the summer and warmth in the winter, countering heat island effects exacerbated by albedo warming and weak evapotranspiration year-round (Welegedara et al., 2023). Edmonton’s urban forests improve air quality by directly removing pollutants such as ozone, carbon monoxide, nitrogen dioxide, sulfur dioxide, and particulate matter as summarized in Table 2 (based on data from Nowak et al., 2018). Therefore, it is important to maintain urban forests so they can continue to provide cities with consistent ecosystem services and withstand potential threats.

Table 2*:* Estimated pollution removal by Edmonton's urban forest:

Pollutant:	Removal in 2009: (tonnes)	Removal in 2010: (tonnes)
CO	6.07	1.30
NO_2	73.93	56.00
O_3	254.25	218.40
SO_2	13.22	10.30
$PM_{2.5}$	N/A	18.60
PM_{10}	181.84	N/A
Total:	531.31	304.60

Note. The table created outlines the estimated pollution removal by Edmonton's urban forest in 2009 and 2010. The data for 2009 is from *Urban Forest Management Plan* (p. 15), by The City of Edmonton, 2012, (https://www.edmonton.ca/public-files/assets/document?path=PDF/Urban_Forest_Management_Plan.pdf). The data for 2010 is from "Air pollution removal by urban forests in Canada and its effect on air quality and human health" by D. J. Nowak, S. Hirabayashi, M. Doyle, M. McGovern, & J. Pasher, *Urban Forestry & Urban Greening* (p. 43), 2018, Elsevier. Copyright 2024 by Elsevier B.V.

Increasing development and drought pose threats to Edmonton's urban forest. There has been a 15% decrease in vegetation over the last 21 years, "The removal of mature vegetation during development, particularly trees, significantly contributed to the increased UHI effect in these developed areas." (Welegedara et al., 2023, p. 7). Li & Bou-Zeid (2013) highlight cities' heightened vulnerability to heat waves due to UHI, which can increase daytime temperatures by 5 ºC to 10 ºC. Drought conditions and secondary pests have led to the death of approximately 30,000 trees in a decade, a significant increase from previous estimates of 600-900 (Government of Canada, 2016). Moreover, it is anticipated that the number of trees impacted will rise because "extreme drought conditions are likely to become more common in Alberta along with the GMT warming" (Eum et al., 2023, p. 1). Edmonton's vulnerability is attributed to its location shielded by major mountain ranges, resulting in reduced precipitation and increased variability, which, coupled with low spring runoff due to diminished cold-season precipitation, can induce droughts (Bonsal et al., 2011).

To achieve the 20% canopy cover goal set out in Edmonton's Urban Forest Management Plan, the city plans to plant two million trees by 2030 (City of Edmonton, 2023). This thesis aims to evaluate the current strategy's efficacy in maintaining long-term ecosystem services and canopy cover while exploring alternative approaches to enhance urban forest resilience. The research contributes to adaptive strategies for urban forests, important for mitigating climate change impacts and addressing disrupted disturbance regimes in Alberta. Understanding urban forests assists Edmonton to improve urban planning and enhance ecosystem services. Comprehensive literature and case study reviews constitute the methodological approach of this study.

2. Problem Identification

The city of Edmonton has approximately 12.8 million trees in inventory as seen in Figure 2 (from City of Edmonton, 2012), with only approximately 385,000 boulevard and open space publicly owned trees (City of Edmonton, 2023), and an annual tree mortality of 3000-3200 trees (City of Edmonton, 2021). At present, Edmonton's forest canopy cover stands at 10.5% according to (City of Edmonton, 2012) potentially reaching up to 13% with alternative assessment methods by Rutherford (2023). Notably, 24% of tree removals in the last two years were from trees planted within the previous six years (City of Edmonton, 2021), indicating a low establishment rate where not all planted trees reach maturity.

To achieve the 20% urban forest canopy target by 2071, Edmonton aims to plant two million net new urban trees by 2030, alongside existing and new initiatives for canopy growth and maintenance on public and private lands (City of Edmonton, 2023). However, this approach may not be optimal for Edmonton's climate, as it could lead to an even-aged urban forest, making it more vulnerable to declining ecosystem services (see Mänttäri et al., 2023; Vangi et al., 2024 Preprint) and increased drought mortality (see Socha et al., 2023).

Land Use	% Tree Canopy	Estimated Number of Trees
Ag/Urban Residential	7.60	3,475,220
Commercial	5.00	142,787
Industrial	8.40	693,328
Direct/Other (roadways)	1.30	26,550
Park and Natural areas	14.80	1,008,891
Residential	15.50	7,155,637
Institutional	8.40	305,778
CITY TOTAL	10.30	12,808,191

Figure 2: Tree Canopy Cover in Edmonton, AB.

Note. This figure outlines Edmonton's complete tree canopy by land use, percent cover, and estimated number of trees in 2012. From *Urban Forest Management Plan* (p. 13), by The City of Edmonton, 2012, (https://www.edmonton.ca/public-files/assets/document?path=PDF/Urban_Forest_Management_Plan.pdf).

Current strategies to increase canopy cover include replacing trees lost to drought, infrastructure and construction projects, conducting annual health assessments on half of the publicly owned trees, and implementing pruning, treatment, removal, and replacement based on these evaluations. Additionally, between 5,000-7,000 trees are planted in new developments (City of Edmonton, 2012). The Root for Trees program, Edmonton's volunteer tree planting initiative, planted 34,167 trees and shrubs in 2023 and a total of 323,484 since 2013 (City of Edmonton, n.d.-c).

Sole reliance on tree planting is insufficient to attain canopy cover goals and provide ecosystem services as not all trees reach maturity (Sousa-Silva et al., 2023). In Melbourne, new tree plantings aimed at preventing net loss did not contribute to canopy coverage targets due to tree removals. Over nine years, public parks in Melbourne experienced a 6.2% canopy cover loss offset by a 5.3% gain, resulting in less than 1% decline overall, slowing canopy cover growth mainly due to development (Croeser et al., 2020). The slow increase in canopy cover in Edmonton can be attributed to elevated tree removal rates of trees planted within the past six years (City of Edmonton, 2021), a 15% decline in vegetation cover from 1999-2020 (Welegedara et al., 2023) and the incomplete replacement of trees lost during the late 90's and early 2000's drought (City of Edmonton, n.d.-a). Canopy cover is also lost when it is removed due to safety concerns, or diseases and pests (Sousa-Silva et al., 2023), as observed in Edmonton, where the City prunes elms and other disease-prone trees every four years to prevent potential infestations (City of Edmonton, n.d.-b).

Planting two million trees to increase canopy cover is advantageous for an expected useful life of 59 years (City of Edmonton, 2021). However, these seedlings would dominate the urban forest, resulting in an even-aged forest structure that diminishes ecosystem services as mature trees age. As per Vangi et al. (2024 Preprint), ecological benefits increase with age. In Finland, under future climate conditions of RCP 2.6, a Scots pine forest peaks in productivity between ages 28 and 56, with a low NPP of approximately 120 g C m^{-2} $year^{-1}$ when young, stabilizing around 420 g C m^{-2} $year^{-1}$, before declining to 230-250 g C m^{-2} $year^{-1}$ as it ages (Vangi et al., 2024 Preprint). Scots pine comprise 3% of Edmonton's street trees (City of Edmonton, 2012) as illustrated in Figure 3. If there is a lack of mature trees to offer maximum ecosystem services, there will be a decline in these services.

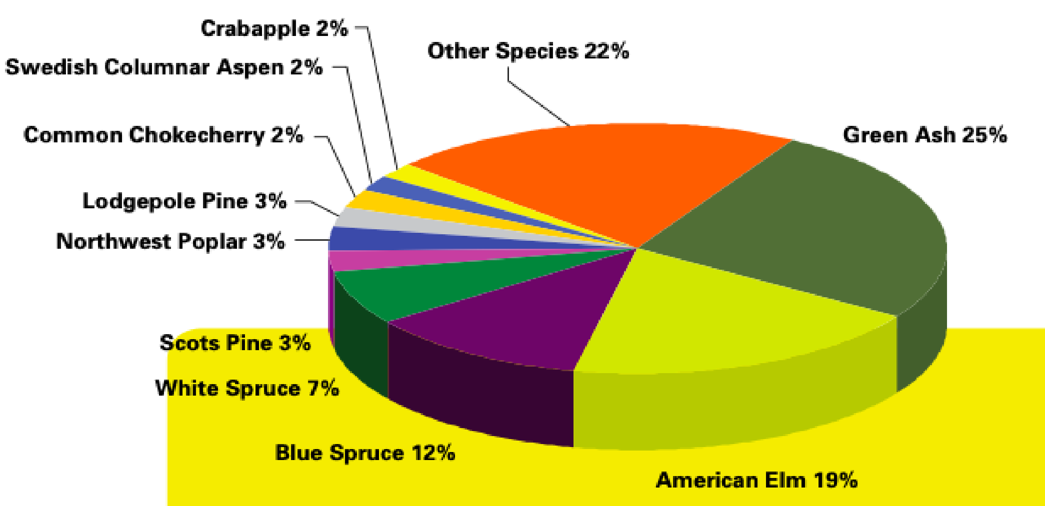

Figure 3: Composition of Top 10 Edmonton Street Trees.

Note. This image was created to represent the species distribution of Edmonton's street trees. From *Urban Forest Management Plan* (p. 12), by The City of Edmonton, 2012, (https://www.edmonton.ca/public-files/assets/document?path=PDF/Urban_Forest_Management_Plan.pdf).

Moreover, in Turku, Finland, the urban forest comprises 38,438 primarily maturing or mature trees, with fewer young trees planted several decades ago (Mänttäri et al., 2023). While the urban forest currently maximizes ecosystem services, the city anticipates a decline in services like air pollution removal over the next 50 years due to current planting rates of 500 trees annually. As trees diminish, their numbers are expected to decrease by 7.8% to 35,456, with pollution removal decreasing by 8.4% from 8.97 tons/year to 8.22 tons/year. Initially, maturing trees will offset tree cover loss, resulting in increased carbon storage from 12,336 tons to 15,492 tons and carbon sequestration from 284 tons/year to 317 tons/year. However, over time, "as older trees die, the insufficient number of maturing trees leads to a gradual decline in both carbon storage and sequestration." (Mänttäri et al., 2023, p. 10), reflecting inadequate planting rates to replace the number of dying trees.

Rapidly planting two million trees poses challenges for Edmonton as the urban forest matures, making mature trees increasingly vulnerable to drought-induced mortality. Research shows that older and taller trees face mortality rates of up to 50% at productive sites during drought conditions (Socha et al., 2023). This concern is exacerbated by projections indicating an escalation in global mean temperature and drought conditions in Alberta (Eum et al., 2023).

During the drought period from 2015 to 2019, an even-aged Scots pine forest in Poland encountered significant mortality among mature stands the following year (Socha et al., 2023). Mortality rates rose from 30% to 50% for mature trees on more productive sites and were exacerbated by a climatic water balance (CWB) of -120 or lower from May to August, which is attributed to the heightened water demand for mature and productive trees (Socha et al., 2023). Moreover, rising temperatures led to decreased CWB despite consistent precipitation levels, increasing drought susceptibility among mature trees on productive sites, potentially resulting in canopy mortality (Socha et al., 2023). This highlights the potential negative impacts of Edmonton's current strategy in light of projected climate changes.

In addition, quickly planting two million trees will strain city maintenance operations, including pruning and watering, as outlined in Table 3 (based on data from City of Edmonton, 2021). With lower establishment rates of new plantings in Edmonton (City of Edmonton, 2021), high volumes of new plantings strain tree replacement and maintenance resources without significantly advancing canopy cover goals. Even with the successful establishment of seedlings, aging trees increase maintenance costs (Mänttäri et al., 2023), risking high mortality without proper care (Walters & Sinnett, 2021). Gradual planting allows for manageable resource allocation and maintenance procedures.

Table 3*:* Current maintenance practices scheduled by the City of Edmonton:

Area or type of tree:	Maintenance practices employed in the corresponding area:
Maintained trees	● Watering new trees for 3-5 years after planting depending on species type ● Pruning every 3-7 years depending on species ● Destaking trees and removing rodent protection 3 years after planting
Naturalization areas (these practices are only employed until trees mature, then they are treated as naturally wooded areas)	● Water for 3 years ● Annual weed control after mowing and planting stops ● Clearance pruning along trails, curbs, property lines
Naturally wooded areas	● Vegetation clearing every 5 years ● Clearance pruning along edges

Note. This table lists maintenance practices employed by the City of Edmonton and excludes annual and risk mitigation assessments; the analysis pertains to scheduled maintenance practices. The data is from *Urban Forest Asset Management Plan* (p. 9-10), by The City of Edmonton, 2021, (https://www.edmonton.ca/sites/default/files /public-files/assets/PDF/Urban-Forest-Asset-Management-Plan.pdf).

Maintenance and stewardship are of increasing importance to ensure the survival and health of trees (Roman et al., 2015). Despite Root for Trees, Edmonton's volunteer tree planting initiative (City of Edmonton, n.d.-c), implementing stewardship programs for tree maintenance can alleviate maintenance burdens on the city of Edmonton. Palo Alto and Philadelphia utilized stewardship for successful urban tree maintenance, achieving a 95.4% to 99.4% annual survival rate six years post-planting (Roman et al., 2015). Furthermore, the mortality rate is threefold lower in trees with active stewardship (Walters & Sinnett, 2021).

Planting rates and timing influence canopy cover and ecosystem services, including carbon storage and sequestration (Walters & Sinnett, 2021). A study in Bristol, UK aimed to achieve a 37.2% canopy cover in 27 years, starting from 11.9% with 618,000 trees and an annual planting rate of 10,000 trees. Initial large stock tree planting within 10 years is projected to maximize canopy cover growth in the shortest period, store 11,145.3 tons more carbon, sequester 14,725.1 tons more carbon, and increase leaf area by 698.5 ha while requiring fewer trees (Table 4).

Table 4: Comparison of 10 and 27-year planting rates in Bristol, UK in 2045:

	Canopy Cover (%)	Total Number of Trees (#)	Leaf Area (ha)	Stored Carbon (tons)	Sequestered Carbon (tons)
10 years	37.3	787,282	25,500	457,964	384,941
27 years	37.9	927,384	24,802	446,819	370,216

Note. This Table compares planting trees in 10 years or 27 years in Bristol, UK to achieve a 37.2% canopy cover by 2045, employing a 0.5% mortality rate. The data is from "Achieving tree canopy cover targets: A case study of Bristol, UK" by M. Walters, & D. Sinnett, *Urban Forestry & Urban Greening* (p. 4), 2021, Elsevier. Copyright 2024 by Elsevier B.V

However, implementing continuous planting over 27 years resulted in a slightly larger canopy cover increase of 0.66%. While the 10-year approach initially showed an 8.3% higher canopy cover by 2036, the 27-year continuous planting method eventually surpassed it by 2045, proving advantageous in the long term. Despite taking longer to achieve the desired canopy cover, the 27-year approach offers greater age-class diversity in the urban forest, ensuring a stable population and manageable tree replacement strategies in the future (Walters & Sinnett, 2021). Rather employing a consistent planting rate is more advantageous for Edmonton to increase age class diversity and reduce drought-induced mortality while maintaining constant ecosystem services like mitigating urban heat islands and removing air pollution. To address urbanization and environmental shifts, maintaining a distribution of both young and mature trees is optimal (Mänttäri et al., 2023).

3. Alternative urban forestry strategies

Instead of aiming to plant two million trees by 2030, the City of Edmonton could adopt a sustained planting strategy, as demonstrated in Bristol, UK (Walters & Sinnett, 2021), utilizing the Miyawaki method. Preserving age diversity within the urban forest mitigates anticipated challenges, including decreased ecosystem services and challenges in maintenance and drought-related mortality as the forest ages uniformly.

The Miyawaki method, pioneered by Akira Miyawaki in Japan, offers an innovative approach to rapidly establishing small native forests on valuable sites (Miyawaki & Golley, 1993). In contrast to prior assumptions that native forests require 300 years to develop, these forests can grow to 20 meters in height within 23 years and achieve self-management within three years of initial planting (Miyawaki, 1998). By leveraging native species and natural processes this method accelerates ecosystem development, yielding mature ecosystems in significantly shorter timeframes, quasi-natural forests were seen in 15-20 years in Japan, and 40-50 years in Southeast Asia (Miyawaki, 1999). As of 1998, over 600 sites across Japan, Malaysia, Melaka, Kuala Lumpur, Southeast Asia, Brazil, and Chile have successfully adopted this method, showcasing its global applicability (Miyawaki, 1998).

This method of forest restoration utilizes knowledge about the potential vegetation, germination, and growth techniques of specific species found in mature ecosystems, alongside site preparation and planting methods (Miyawaki & Golley, 1993). It starts by analyzing natural vegetation patterns, species relationships, and site conditions, focusing on canopy trees (Miyawaki & Golley, 1993). Seeds are then collected, and germinated for one to two years, and when two to three leaves have sprouted they are planted in pots until they are 30-50 centimeters high (Miyawaki, 1999) to ensure strong root systems for survival and soil stabilization benefits (Miyawaki & Golley, 1993). Before planting, the site necessitates surface plowing to loosen the soil (Miyawaki & Golley, 1993). Seedlings are then planted without adhering to a natural pattern, followed by the application of straw mulch around them to maintain soil moisture, protect against cold, inhibit weed growth, and prevent erosion (Miyawaki, 2004). Maintenance involves weed removal for the initial two to three years until the trees are 2-3 meters high and the crown keeps sunlight from penetrating, allowing only a few weeds to grow which the forest will manage itself through natural selection (Miyawaki 1999). Figure 4 is a flow chart outlining the Miyawaki method's restoration and creation of native forests (from Miyawaki, 1999).

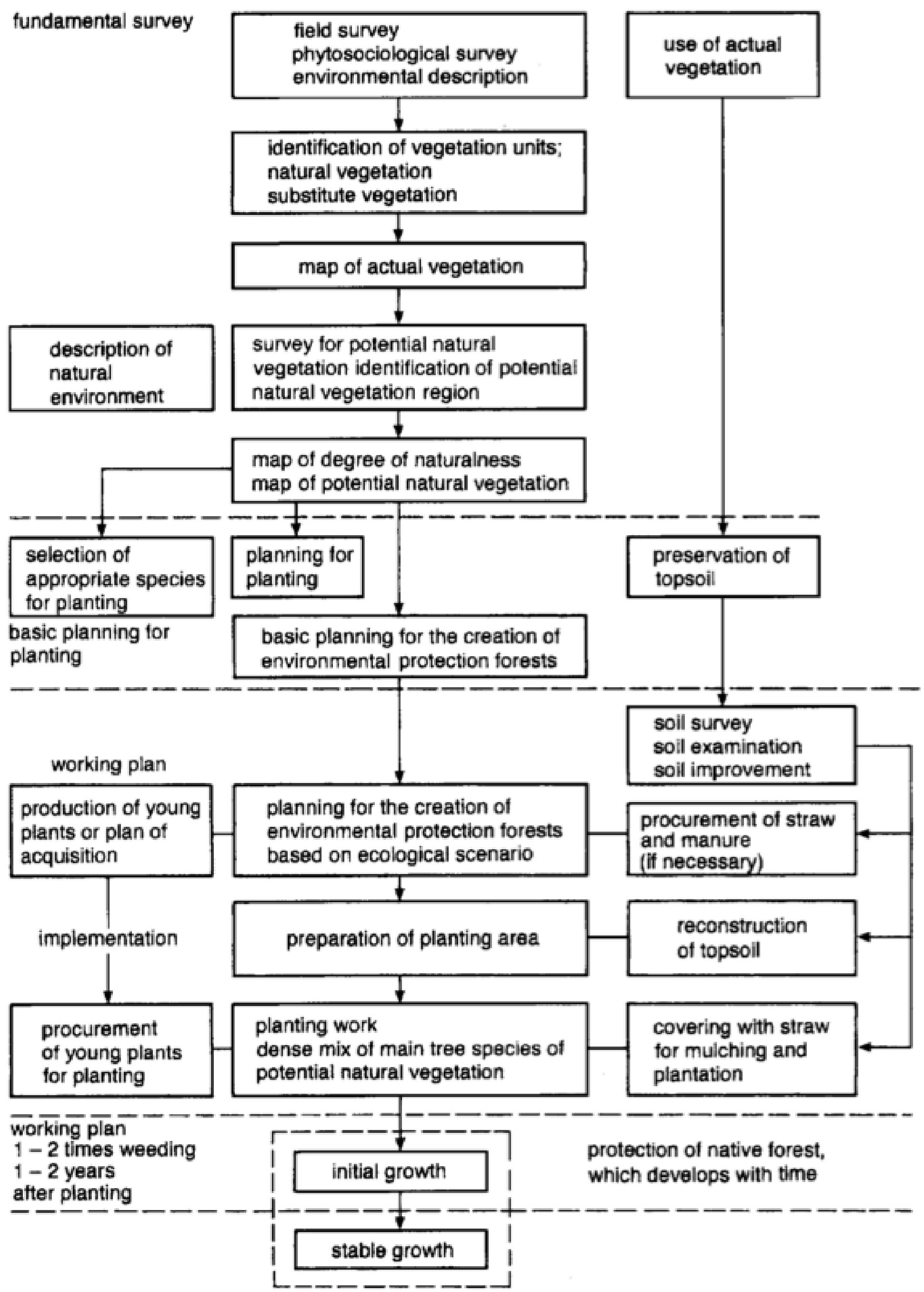

Figure 4: Miyawaki method flow chart for the restoration and creation of native forests:
Note. This flow chart was created to outline the restoration and creation of native forests using the Miyawaki method. From "Creative Ecology: Restoration of Native Forests by Native Trees" by A. Miyawaki, *Plant Biotechnology* (p. 17), 1999.

Initially employed for the restoration of Japan's broad-leaf forests (Miyawaki & Golley, 1993), the Miyawaki method has been recently adopted by Canada to enhance ecosystem services such as air pollution removal, urban heat island mitigation, and biodiversity conservation, while expanding green spaces and canopy cover (*National Mini-Forest Pilot*, 2023). The Miyawaki method provides productive forests in a short time, maintaining age-class diversity with minimal maintenance, alleviating maintenance strains, and increasing ecosystem services such as canopy cover, and cooling effects.

Table 5: Summary of Miyawaki Forests Planted in Belgium

	Barvaux	Axis Parc	Bois de Fa	ITH	Willemeau	Ormeignies
Age (years)	5.1	3.6	5.7	3.6	4.3	6.6
Overall health	Very good	Very good	Very good	Very good	Very good	Very good
Foliage density (%)	50-80	50-80	50-80	<50	<50	50-80
Average height of 15 tallest trees (m)	5.46	4.61	8.3	5.27	3.56	5.48
Increase in planted surface to total surface (m^2)	10	0	0	10	6	15
Temperature inside the forest (ºC)	19	18	21	16	23	24
Temperature outside the forest (ºC)	26.0-45.0	23.0-37.0	31.0-56.0	24.0-38.0	35.0-46.0	26.0-40.0

Note. The temperatures outside exhibit a range because different surfaces outside the forest have different temperatures. The data is from "Report on studying Miyawaki forests in Belgium", by N. de Brabandère & D. Malengreau, 2023, (https://urban-forests.com/wp-content/uploads/2020/05/Report-on-studying-Miyawaki-forests-in-Belgium-060923.pdf).

In Belgium, Miyawaki forests were observed in 2023 and their development was analyzed across six sites: Barvaux, Axis Parc, Bois de Fa, ITH, Willemeau, and Ormeignies. These forests expanded outwardly from the initial planting area (de Brabandère & Malengreau, 2023), and the steady growth rate of young trees through natural selection (Miyawaki, 1993) ensures constant ecosystem services such as shade and cooling benefits (de Brabandère & Malengreau, 2023) as seen in Table 5 (based on data from de Brabandère & Malengreau, 2023). Miyawaki forests reduce temperatures using their foliage density (de Brabandère & Malengreau,

2023) providing a solution for the elevated surface urban heat islands observed in Edmonton's regions with limited canopy cover (Welegedara et al., 2023).

By implementing the Miyawaki method, Edmonton can attain consistent ecosystem services through the sustained growth of young trees (Miyawaki, 1993), as evidenced by the expansion of total surface area compared to the planted surface at various sites in Belgium, including Barvaux, ITH, Willemeau, and Ormeignies (de Brabandère & Malengreau, 2023) as illustrated in Table 5.

The Miyawaki method surpasses previous approaches in arid, drought-prone regions, boasting higher density and accelerated growth (Schirone et al., 2011). Edmonton's January precipitation from 1999 to 2023 averaged 393.62 mm, but in January 2024, it dropped to 38.3 mm (*Total precipitation - Annual data for Edmonton*, n.d.). Given its success in drier climates, implementing the Miyawaki method is advantageous amid projections of exacerbated drought conditions in Alberta due to global warming (Eum et al., 2023).

Sardinia, Italy's annual precipitation stands at 93.44 mm (*Sardinia, Italy Climate*, n.d.), considerably drier than climates where the Miyawaki method has been applied previously, such as Japan with 1,830 mm (Klein, 2024). Its climate features arid summers, cold winters, and thin soils vulnerable to desertification (Schirone et al., 2011). In 1997, two sites were chosen to assess the Miyawaki method's efficacy in arid climates. Site A and B detailed in Table 6 (based on data from Schirone et al., 2011), employed different planting techniques. Site A utilized strip planting with non-working strips interspersed between each planted strip. Maintenance involved brush clearing, tillage, and experimenting with both green material and straw mulch. Conversely, site B employed working strips across the entire plot, with sawdust mulch applied to alternate strips (Schirone et al., 2011).

Site B experienced several reforestation failures primarily due to stagnant water accumulation (Schirone et al., 2011). After a decade, the Miyawaki forests were compared with two 15-year-old stands: R15, planted north of site A, and G15, reforested using the Gradoni method east of site B. Results revealed that the Miyawaki method yielded three to five times greater density at sites A and B compared to R15 and G15, as detailed in Table 7 (based on data from Schirone et al., 2011). Although height differences were insignificant across all sites, the Miyawaki forests, being five years younger, displayed a faster growth rate. Remarkably, these forests required no post-planting maintenance and continued to evolve independently (Schirone et al., 2011), consistent with findings in Japan (Miyawaki, 1999). Hence, Miyawaki forests persist as dense, rapidly growing ecosystems in arid conditions.

Table 6: Site A and B Mortality Rates in Italy.

	Site A	Site B
Seedlings planted (#/ha):	8,600	21,000
Mortality year 1 (%):	15.84	10.24
Mortality year 2 (%):	22.98	35.25
Mortality year 12 (%):	61.00	84.29
Species that survived (#):	20.00	9.00

Note. The data for Site A and B are from "Effectiveness of the Miyawaki method in Mediterranean forest restoration programs", by B. Schirone, A. Salis, & F. Vessella, *Landscape and Ecological Engineering*, 2011, Springer Nature. Copyright 2024 by Springer Nature.

Table 7: Plant density of Miyawaki forests in Sardinia, Italy compared to previous reforestation methods.

	Site A	Site B	R15	G15
Plant Density (plants/ha)	1040	800	242	175

Note. The data is from "Effectiveness of the Miyawaki method in Mediterranean forest restoration programs", by B. Schirone, A. Salis, & F. Vessella, *Landscape and Ecological Engineering*, 2011, Springer Nature. Copyright 2024 by Springer Nature.

The Miyawaki method alleviates maintenance burdens placed on cities by establishing self-sufficient forests capable of natural regeneration (Miyawaki, 1998). Maintenance varies across sites; for instance, the Barvaux forest in Belgium received only two watering post-planting yet endured a severe drought in 2018 and a flood in 2021, remaining in excellent condition with no adverse effects observed in 2023 (de Brabandère & Malengreau, 2023). Conversely, plot 203 in Southeast Asia initially required increased maintenance due to persistent grass weeds, but three years after planting, no further maintenance was necessary and the forest thrived, reaching heights of 6-10 meters (Miyawaki, 1999).

Planting Miyawaki forests entails a significant upfront investment (Miyawaki & Golley, 1993) due to the cultivation of seedlings and initial maintenance operations such as weeding, required for the first three years (Miyawaki, 1999; Miyawaki, 2004). However, once planted and maintained, ongoing costs are minimal or nonexistent (Miyawaki & Golley, 1993). Implementing a phased planting approach for these forests can help manage resource demands for cities like Edmonton. Moreover, leveraging stewardship efforts to gather, pot, and plant seedlings (Miyawaki, 2004) presents a cost-effective solution while fostering community engagement. An advantage to the Miyawaki method is its adaptability to various climates, soils, and geological conditions to meet specific objectives in different regions (Miyawaki & Golley, 1993), demonstrated in Japan (Miyawaki, 1999), Italy (Schirone et al., 2011), Southeast Asia (Miyawaki, 1999) and Belgium (de Brabandère & Malengreau, 2023).

For Edmonton, selecting native tree species resilient to drought, possessing large canopies to mitigate urban heat island effects, and exhibiting strong carbon storage and air pollution reduction capabilities would be advantageous. While not common in Edmonton, Japan has utilized forests to shield industrial facilities (Miyawaki & Golley, 1993). A technique that could be adopted to enhance green spaces and canopy cover while protecting roads and houses from noise and air pollution, given Edmonton’s dispersed industrial presence and rapid urbanization projections, expected to reach 1.5 million in 20 years, or an average annual increase of 23,000 people (City of Edmonton, 2021).

The adoption of the Miyawaki method by the City of Edmonton is recommended over the plan to plant two million trees by 2030 due to its successful implementation in drought-prone environments (see Schirone et al., 2011). This method offers essential ecosystem services like urban cooling (see de Brabandère & Malengreau, 2023) and sustains itself without ongoing human intervention after an initial three-year period. Moreover, it facilitates the steady growth of young trees through natural selection (Miyawaki, 1993), ensuring consistent provision of ecosystem services.

4. Discussion

The study findings propose that adopting a continuous planting approach using the Miyawaki method can address the long-term challenges associated with planting two million trees by 2030 in Edmonton. With Edmonton's planting strategy, the urban forest will transition to a more even-aged forest, although ecosystem productivity will be higher as the trees mature simultaneously, it is likely to result in a decline in net primary production or ecosystem services as urban trees grow old simultaneously (see Mänttäri et al., 2023; Vangi et al.,2024 Preprint). The discrepancy in ecosystem services such as carbon storage and sequestration will be a result of insufficient planting rates, as there are not enough maturing trees to combat the loss of dying trees and replace their role in providing these services. In the context of long-term urban forest management, the strategy of planting two million trees to enhance canopy cover appears shortsighted.

As the urban forest matures collectively, the risk of drought-induced mortality in mature productive trees escalates (see Socha et al., 2023). Moreover, considering the projected rise in both severity and frequency of droughts in Alberta (see Eum et al., 2023), this approach may lead to widespread mortality within the urban forest, decreasing canopy cover. Additionally, the quick planting approach may strain city maintenance resources, leading to increased mortality rates without sufficient care (Walters & Sinnett, 2021) and higher costs (Mänttäri et al., 2023) in the long term. Over the past two years, 24% of the trees removed in Edmonton had been planted within the previous six years (City of Edmonton, 2021). In contrast, cities like Palo Alto and Philadelphia achieved 95% or higher survival rates for urban trees six years post-planting, credited to effective stewardship practices (see Roman et al., 2015). Given Edmonton's lower establishment rates, the endeavor to plant two million trees would strain city resources for watering and maintenance, with limited progress towards canopy cover objectives, proving this strategy may not be the most effective.

The Miyawaki method addresses all potential threats anticipated for Edmonton's urban forest. Its continuous growth of young trees (Miyawaki, 1993) fosters natural regeneration without human intervention (de Brabandère & Malengreau, 2023), ensuring age diversity. This diversity ensures an adequate supply of maturing trees to replace ecosystem services lost due to drought-induced mortality and old age, ensuring continual provision of ecosystem services. Moreover, Miyawaki forests facilitate manageable resource allocation and maintenance, achieving self-sufficiency within three years post-planting (see de Brabandère & Malengreau, 2023; Miyawaki, 1998; Miyawaki, 1999). This gradual planting approach allows Edmonton to allocate resources effectively with assurance that the forests will become self-sustaining in three years, while still delivering vital ecosystem services like urban cooling (see de Brabandère & Malengreau, 2023).

Research indicates that urban areas face challenges in augmenting canopy cover due to rapid urbanization (see Croeser et al., 2020), and "cities with a growing population are more likely to face canopy reduction" (Ock et al., 2024, p. 13). This challenge is compounded by space constraints in cities, limiting the expansion of canopy cover (Pataki et al., 2021). For instance, in Portland, OR changes in spatial structure decreased canopy cover from 30.7% in 2015 to 29.8% in 2020, notably in residential areas, as cities undergo development (Ock et al., 2024). Space constraints are exacerbated by competing demands, such as the need for affordable housing (Pataki et al., 2021). Similarly, in Melbourne, park canopy cover decreased by 1% over nine years mainly attributed to development activities, particularly major private developments necessitating vehicle access during construction (Croeser et al., 2020). Portland's experience highlights how the removal of existing trees due to building footprint expansion and tree removal on private lands decreases urban tree canopy more than development and residential zone changes (Ock et al., 2024). Socioeconomic factors, including race, also play a role, with neighbourhoods populated by non-white families and low-income households experiencing a reduction in canopy cover (Ock et al., 2024). Furthermore, spatial constraints pose challenges for ecosystem services such as stormwater regulation, as demonstrated by less water infiltrating into the soils in Southern Merri-bek due to a high level of impervious surface (Ren et al., 2023). The 15% decline in vegetation cover observed in Edmonton over the previous 21 years (Welegedara et al., 2023) underscores the importance of strategic urban planning to avoid planting trees in areas allocated for future development. Additionally, pollution mitigation efforts through tree planting are hindered by limited space and the increasing volume of pollutants in cities (Pataki et al., 2021). While current practices involve mass tree planting initiatives (see Walters & Sinnett, 2021), there is growing recognition of the importance of maintenance and stewardship in ensuring urban tree survival (see Roman et al., 2015).

Rapidly growing trees are often considered more susceptible to disasters and have shorter lifespans compared to slower-growing counterparts, which are perceived as more stable and durable (Black et al., 2008). Research conducted in Merri-bek, Melbourne from 2009 to 2020 revealed that smaller trees exhibited faster growth rates, resulting in a substantial increase in relative canopy cover, while larger trees achieved greater absolute canopy expansion (Ren et al., 2023). Smaller trees demonstrated relative canopy mean growth rates of 100% to 140%, whereas larger trees exhibited mean growth rates of 30% to 41% (Ren et al., 2023). Protecting and maintaining larger trees is imperative for overall canopy expansion, the relationship was found to be independent of urban form or species.

Future research should explore the strategic use of smaller, faster-growing trees to quickly establish canopy cover, while larger, slower-growing trees mature, thereby ensuring a variable age structure in the urban forest. However, in Brazil, the introduction of fast-growing intermediate species led to challenges due to inadequate vegetation surveys, resulting in the higher mortality of indigenous species and slower growth of Miyawaki forests, reaching only 8-10 meters in a decade, significantly slower than expected (Miyawaki, 2004). While Canada currently has only five pilot sites (*National Mini-Forest Pilot*, 2023), the promising outcomes of Miyawaki forests worldwide offer optimism for their success in Canadian contexts.

Furthermore, future research can advance these findings by delving into a species-specific analysis to identify native species exhibiting heightened drought tolerance while offering extensive and dense canopies to align with Edmonton's canopy coverage objectives and mitigate urban heat island effects. By pinpointing and cultivating drought-resistant species, Edmonton's urban forest stands to increase its survival against anticipated drought occurrences (see Eum et al., 2023). This study in agreement with Vangi et al. (2024 Preprint), emphasizes the significance of age-class diversity when building resilient and stable urban forests. Although Edmonton's urban forest is maturing with an average age of 16 years old (City of Edmonton, 2021), sustaining this mature age class demands continuous planting rates and the application of the Miyawaki method. Prioritizing an uneven-aged urban forest obviates the need to wait approximately 16-50 years for optimal net primary production, as indicated by Vangi et al. (2024 Preprint). This research contributes to existing literature by outlining the influence of age class distribution on urban forests, an area that remains relatively unexplored.

These findings hold significance as they advocate for a more informed and effective management strategy for urban forests, which can be applied to climates akin to that of Edmonton. By gaining a deeper understanding of urban forests, they can be manipulated to enhance the provision of ecosystem services, including mitigating urban heat island effects. This research contributes to the development of adaptive strategies for urban forests, important for mitigating the impacts of climate change such as the escalating severity and frequency of droughts in Alberta (Eum et al., 2023). By proposing enhanced management techniques, the urban forest stands to promote consistent ecosystem services like carbon sequestration, carbon storage, improve air quality, and regulate temperature.

The perspective from this study hopes to contribute considetion of the importance of accounting for age-class diversity when cities embark on ambitious planting initiatives, as such endeavors may yield unintended consequences.

5. Conclusion

The city of Edmonton's plan to boost canopy cover by planting two million trees by 2030 represents an ambitious project with good intentions, and it highlights the value that is placed by municipal decision makers on enhancing the urban environment. However, ambitious projects can have unintended consequences, and the current policy could have repercussions due to the creation of an even-aged urban forest. This approach poses challenges such as diminished ecosystem services, heightened vulnerability of an eventually large population of old trees to large-scale, drought-induced mortality events, and down the reoad very likely increase strain on city resources for maintenance and urban tree renewal.

The Miyawaki method offers an alternative solution by rapidly establishing dense, self-sustaining forests. These Miyawaki forests continue to thrive without ongoing maintenance, fostering constant ecosystem benefits like urban temperature regulation by generating young trees through natural selection. Experience elsewhere suggest that this method could offer an alternative efficacious urban forestry approach for Edmonton to adopt. This research highlights the potential drawbacks of ambitious planting initiatives aimed at increasing canopy cover in the short term, advocating instead for managing age-class diversity within urban forests to ensure consistent benefits while mitigating threats and creating stable and sustainable urban foresty management requirements.

This research is confined to assessing the potential challenges associated with Edmonton's initiative to plant two million trees by 2030 aimed at increasing canopy cover. It explores threats such as reduced ecosystem services, drought-induced mortality, and resource limitations. Although the Urban Forest Management Plan suggests strategies for enhancing urban forest resilience, these are not addressed in this study. Furthermore, this study does not delve into the specifics of tree species or suitable planting sites in Edmonton, as these aspects fall outside the scope of this research. Nonetheless, the findings may have relevance for similar urban centers facing comparable climate conditions and challenges as investigated in this paper.

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