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Effects of Seasonality, Tree Species and Urban Green Space on Deciduous Leaf Litter Decomposition in Lithuania

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Abstract: Understanding ecological processes and environmental change in different urban green spaces is an important challenge to secure human well-being. The variety of urban green spaces provides a platform to generate knowledge on how urban environments affect tree leaf decomposition and quality. We measured the leaf litter decomposition of four dominant native deciduous tree species from five different urban green spaces over three time periods in Kaunas, Lithuania. Using the modified litter bag technique, we calculated the decomposition of 60 leaf litter samples for 4, 8, and 12 months respectively. For each leaf litter sample, we determined total N, total P, and organic C. Results indicated that the decomposition of leaf litter amongst tree species, urban green spaces and seasonality (time) were significantly different. The leaf litter of *Betula pendula* and *Acer platanoides* from street green spaces decomposed fastest during the spring-summer period. *Quercus robur* showed small but significant leaf litter loss differences between the green spaces, with the leaf litter from peri-urban forest decomposing the fastest. A decreased C:N ratio for *Q. robur* leaf litter showed accelerated leaf litter decay. In conclusion, our results show that the ecological processes of leaf litter decomposition, differs between tree species, type of urban green spaces and seasonality and thus must be considered in urban town planning to help maintain urban environments.

Keywords: city trees; deciduous trees; green infrastructure; leaf litter quality; nutrient cycle; parks; peri-urban forest; street trees; urban environmental processes

1. Introduction

Urban environments can influence vegetation richness, species composition and tree health through heat accumulation, building density, the level of traffic, and the degree of drainage and soil waterproofing [1,2]. Trees provide many ecological processes and functions, such as the regulation of microclimates, abating air pollution, decorating urban spaces, creating species habitats, and delivering benefits for human well-being [3–5]. Research on European urban green spaces have shown that they are extremely modified [6,7] and can cause changes in ecological processes. Understanding the effects of local human induced changes to climate, soil, water, and air quality in urban green spaces is challenging. Often, poor site conditions, artificial ecosystems, and a lack of professional tree maintenance creates unhealthy conditions for tree growth in urban areas [8,9]. Abiotic factors such as the use of anti-icing salt during winter, buildings, pavements, and utility trenching negatively affect tree health and longevity [10]. These perceived benefits for human well-being also modify the local environment by influencing tree growth, growing season duration, nutrient accumulation in leaves, and leaf litter decomposition, as well as other key processes [11,12]. Leaf litter decomposition is an important process that can provide an indicator of ecosystem function and health at various levels [13].

Leaf litter decomposition is a key biogeochemical process in both forest ecosystems and urban areas, which enriches the soil and local waterways with nutrients [14,15]. In relation to soil nutrients, Waring and Schlesinger [16] estimate that nutrients released during litter decomposition can provide between 69%–87% of the yearly essential elements required by trees. However, leaf litter decomposition in urban areas may ultimately contribute to the eutrophication of surface water through storm water runoff [14]. Both abiotic factors, such as climate (mainly temperature, soil moisture, and evapotranspiration) and litter quality (in particular nitrogen, lignin, and polyphenol concentrations, C:N and C:P ratios), and biotic factors such as soil organism activity determine leaf litter decomposition [17–20].

Urban green spaces are characterized by different abiotic and biotic factors. These factors may affect the nutrition quality of leaf litter, thus changing the food source for microbial decomposers. For example, Carreiro et al. [21] suggested that decomposer activity in peri-urban forests may be affected by both altered leaf litter quality and altered environments. Decomposition of leaf litter can be predicted by many factors; the C:N, C:P, and N:P ratios are the main recognized factors [22–24]. The decomposition rate is positively correlated with C and N concentrations, and negatively correlated with the C:N ratio of fresh leaf litter [25–28]. According to the hypothesis that C:N ratio is a suitable predictor for decomposition rates [25,29], it seems likely that a lower C:N ratio may lead to an increase in C and N litter mineralization [30]. Thus, the activity of microbial decomposers is often limited by nitrogen (N) availability.

Understanding the effects of environmental conditions and how they affect ecological processes is a crucial step in forming management strategies to cater for the needs of human well-being in urban areas. The aim of this study was to explore leaf litter decomposition of four deciduous tree species collected from five different urban green spaces. We hypothesized that leaf litter decomposition, as an ecological process, would be different based on i) tree species, ii) type of urban green space, iii) seasonality (e.g., time and duration) and iv) leaf litter nutrients.

2. Materials and Methods

2.1. Site Description

The study was carried out during 2013–2014 in Kaunas (54°53′50″ N, 23°53′ 10″ E), the second largest city in Lithuania with a population of 302,000 inhabitants and a territory of 158 km². The average annual precipitation is 600 mm. The average temperature in January is −5.2°C, and in July +16.9 °C. The soil type of the sampled peri-urban forest consisted of both *Luvisols* and *Podzols*, and the soil profile of the urban green spaces was *Anthrosols*.

The design of this research focused on two aspects. Firstly, five different types of green spaces: 1) large urban parks >1 ha (LP); 2) small urban parks <1 ha (SP); 3) broad street greenery (minimum four lanes of traffic) (BSG); 4) narrow street greenery (maximum two lanes of traffic) (NSG); and 5) peri-urban forests (PUF). Secondly, we selected four common native deciduous tree species that were >60 (±5) years of age: Norway maple (*Acer platanoides* L.), silver birch (*Betula pendula* Roth), small-leaved lime (*Tilia cordata* Mill.), and common oak (*Quercus robur* L.). Using a stratified sampling method, we selected 60 locations throughout the study area (12 sampling location for each type of green space). The number of sampling locations was limited to 60, due to the availability of the five types of green spaces within Kaunas (Figure 1).

Figure 1. Locations of the deciduous leaf litter collection and urban green spaces in Kaunas, Lithuania. Note: PUF = Peri-urban forest, LP = Large park, SP = Small park, BSG = Broad street greenery, and NSG = Narrow street greenery.

2.2. Leaf Litter Decomposition

We used the modified litter bag technique to study leaf litter decomposition [31,32]. At the end of autumn in 2013, we collected leaf litter samples for each of the four tree species (*T. cordata*, *A. platanoides*, *B. pendula*, and *Q. robur*) from the five green space types. Fallen leaf litter was collected off the ground within 2 meters of the tree trunk. Following leaf litter collection, we dried all leaf litter samples at 30 °C and prepared 180 (60 × 3 repeats) fiber mesh (bag size 20 × 20 cm, mesh size was 1.4 mm) bags with 5 grams of leaf litter. Subsequently, we placed each leaf litter bag side by side on the ground, in a controlled peri-urban forest environment with the same environmental conditions on December 1st, 2013. The soil type of the control site was *Luvissols*. After 4 months (April 1st, 2014), 8 months (August 1st, 2014), and 12 months (December 1st, 2014) we collected 60 of the 180 leaf litter bags, respectively. Directly following each collection of the leaf litter bags, we analyzed and calculated their decomposition by measuring the loss in mass of each bag (i.e., 3 time periods). In total, we collected 180 samples (four tree species × five green spaces × three sampling times × three replicates = 180).

2.3. Leaf Litter Quality

Leaf litter chemical analyses were performed at the Agrochemical Research Laboratory of Lithuanian Research Centre for Agriculture and Forestry. For each leaf litter sample (N=180), we determined: total N (EU directive 72/199/EEC); total P (EU directive 71/393/EEC); organic C – by dry combustion at 900 °C with a CNS analyzer (ISO 10694: 1995).

2.4. Statistical Data Analysis

After determining that the data did not have a normal distribution, a non-parametric test was used to analysis the data [33]. As standard ANOVA is robust against departures from normality [34],

we began the statistical analysis by firstly applying a two-factor ANOVA (urban green spaces, five levels, and tree species, four levels). We did this to test if the loss in litter mass amongst the various urban green spaces is dependent upon the tree species. Secondly, having found significant interactions, we then analyzed the data by each tree species separately using a non-parametric Kruskal–Wallis ANOVA test [35] to identify significant differences between the five different green spaces and the four deciduous tree species. Data analyses were performed using Statsoft Statistica 10.0 and Microsoft Excel.

3. Results

3.1. Leaf Litter Decomposition of Four Tree Species in Time

The total mean leaf litter loss in mass for each tree species, without differentiation of green spaces, showed large differences over 4, 8, and 12 months (Figure 2). Firstly, over these three periods, results showed that *Q. robur* leaf litter decomposed the slowest. In contrast, the highest leaf litter decomposition was recorded by *A. platanoides* over 4 months and *B. pendula* over 8 and 12 months, respectively. Secondly, the eight-month period showed the largest losses of leaf litter mass out of the three time periods for all four tree species. Thirdly, results showed that the total mean loss of leaf litter mass over 12 months (from December 2013 to December 2014) was significantly different between species.

Figure 2. The combined mean proportion of leaf litter loss (mass) through decomposition for four native deciduous tree species in the urban green spaces of Kaunas, Lithuania. The first four-month period represents December to April, the eight-month period represent December to August, and the 12-month period commenced in December and finished at the end of November. The error bars represent standard error. N = 15; 5 green spaces × 3 replicates).

3.2. Influence of Different Urban Green Spaces on Tree Species Leaf Litter Decomposition

The initial two-factor ANOVA on urban green spaces (5 levels) and tree species (4 levels) show that, overall, there was a significant difference for both 8 months ($P < 0.0001$) and 12 months ($P < 0.0001$), respectively (Figure 3). However, over 4 months there was no overall significance ($P < 0.054$).

The subsequent non-parametric Kruskal–Wallis ANOVA test showed the following results for each tree species.

Figure 3. The mean proportion of leaf litter remaining (mass) from the 2-factor ANOVA, for four native deciduous tree species in five different types of urban green spaces in Kaunas, Lithuania. The first four-month period represents December 1st to April 1st, the eight-month period represent December 1st to August 1st, and 12 months starts in December 1st, 2013 and ends December 1st, 2014. The error bars represent 95% confidence intervals.

A. platanoides

Leaf litter decomposition of *A. platanoides* showed that over 4, 8, and 12 months the total amount of leaf litter loss was greatest in narrow and broad street greeneries, whereas the lowest loss leaf litter mass was recorded in large urban parks and in peri-urban forests (after 8 and 12 months) (Table 1). *A. platanoides* leaf litter from the broad street greeneries and narrow street greeneries recorded losses of 26% and 24% more, respectively, compared to peri-urban forest (60%) over 12 months. The Kruskal–Wallis test showed a significant difference between leaf litter decomposition of *A. platanoides* in the different green spaces for all three time periods; 4 months $H(4, N=45) = 14.2$ $P = 0.0066$, 8 months $H(4, N=45) = 36.6$ $P < 0.0001$, and 12 months $H(4, N=45) = 38.1$ $P < 0.0001$. The leaf litter decomposition rate of *A. platanoides* peaked during the eight-month period, ranging between 10.2 (peri-urban forest) to 13.8 (narrow street greenery) mg per day (Figure 4).

Table 1. The mean leaf litter mass lost in grams for the four native deciduous trees species by the type of urban green space recorded over three time periods (4 months, 8 months, and 12 months). The ($\pm$) represent standard error, $N=3$ for the means.

Urban Green Spaces	Exposure (Months)	<i>Acer Platanoides</i>	<i>Betula Pendula</i>	<i>Tilia Cordata</i>	<i>Quercus Robur</i>
Peri-urban forests	4	0.55 (± 0.07)	0.31 (± 0.13)	0.44 (± 0.11)	0.23 (± 0.09)
	8	2.45 (± 0.08)	2.71 (± 0.03)	1.70 (± 0.07)	1.00 (± 0.05)
	12	3.01 (± 0.02)	4.13 (± 0.04)	2.98 (± 0.03)	1.70 (± 0.11)
Large urban parks	4	0.17 (± 0.05)	0.37 (± 0.14)	0.18 (± 0.07)	0.04 (± 0.02)
	8	2.51 (± 0.06)	2.08 (± 0.13)	1.04 (± 0.10)	0.72 (± 0.04)
	12	2.97 (± 0.03)	3.56 (± 0.07)	2.86 (± 0.04)	1.06 (± 0.08)
Small urban parks	4	0.46 (± 0.11)	0.41 (± 0.05)	0.29 (± 0.12)	0.06 (± 0.02)
	8	2.82 (± 0.07)	2.27 (± 0.08)	1.39 (± 0.04)	0.77 (± 0.08)
	12	3.21 (± 0.04)	3.75 (± 0.03)	2.66 (± 0.05)	1.11 (± 0.07)
Broad street greeneries	4	0.62 (± 0.09)	0.61 (± 0.06)	0.38 (± 0.08)	0.07 (± 0.02)
	8	3.17 (± 0.02)	3.64 (± 0.06)	1.72 (± 0.10)	0.80 (± 0.04)
	12	4.30 (± 0.03)	4.48 (± 0.02)	2.96 (± 0.03)	1.10 (± 0.03)
Narrow street greeneries	4	0.56 (± 0.06)	0.63 (± 0.04)	0.33 (± 0.06)	0.06 (± 0.01)
	8	3.33 (± 0.03)	3.94 (± 0.04)	1.59 (± 0.12)	0.79 (± 0.10)
	12	4.18 (± 0.02)	4.63 (± 0.02)	2.66 (± 0.06)	1.22 (± 0.06)

Figure 4. The mean daily decomposition rate of four different deciduous leaf litter types from five urban greens spaces over 4, 8, and 12 months, respectively, in Kaunas, Lithuania.

B. pendula

Results of *B. pendula* leaf litter decomposition showed that over 4, 8, and 12 months, decomposition of leaf litter loss was greatest in narrow street greeneries and broad street greeneries (Table 1). After 4 months, the lowest loss of *B. pendula* leaf litter mass was recorded in the peri-urban park; however, after 8 months and 12 months, large parks recorded the lowest loss of leaf litter mass (Table 1). The Kruskal–Wallis test showed a significant difference between leaf litter decomposition of *B. pendula* in the different green spaces for both the eight-month ($H(4, N = 45) = 39.9, P < 0.0001$) and twelve-month ($H(4, N = 45) = 40.4, P < 0.0001$) periods. There was no significant difference between decomposition of leaf litter in the urban green spaces for the first four months ($H(4, N = 45) = 5.8, P = 0.2149$). The leaf litter decomposition rate of *B. pendula* peaked during the eight-month period, ranging between 8.4 (large parks) to 16.7 (narrow street greenery) mg per day (Figure 4).

T. cordata

Results of *T. cordata* litter decomposition showed that over 4, 8, and 12 months the total amount of leaf litter loss was greatest in peri-urban forests followed by broad street greeneries. After 4 and 8 months, the lowest loss leaf litter mass was recorded in large urban parks, and after 12 months in small urban parks (Table 1). After 12 months, *T. cordata* lost between 52%–60% of litter mass for all green space types. These results showed the least variation between the different green spaces (Figure 3). The Kruskal–Wallis test showed a significant difference between leaf litter decomposition of *T. cordata* in the different green spaces for both the eight-month ($H(4, N = 45) = 20.9, P = 0.003$) and twelve-month ($H(4, N = 45) = 23.9, P < 0.0001$) periods. There was no significant difference between decomposition of leaf litter in the urban green spaces for the first four-month period ($H(4, N = 45) = 7.7, P = 0.1042$). The leaf litter decomposition rate of *T. cordata* peaked during the twelve-month period, ranging between 7.3 (small parks) to 9.8 (large parks) mg per day (Figure 4).

Q. robur

Results of *Q. robur* leaf litter decomposition showed that over 4, 8, and 12 months the total amount of leaf litter loss was greatest in peri-urban forests. The leaf litter decomposition of the other green space types was similar, with only a 0.08% difference. (Table 1). After 12 months, leaf litter mass lost

in peri-urban forest significantly differed from all other urban green spaces. The Kruskal–Wallis test showed a significant difference between leaf litter decomposition of *Q. robur* in the different green spaces for both the eight-month ($H(4, N = 45) = 9.7, P = 0.0463$) and twelve-month ($H(4, N = 45) = 19.7, P = 0.0006$) periods. There was no significant difference between the decomposition of leaf litter in the different urban green spaces for the first four-month period ($H(4, N = 45) = 4.9, p = 0.2958$). The leaf litter decomposition rate of *Q. robur* peaked relatively slowly compared to the other species during all periods, peaking over the twelve-month period with a range of 2.9 (large parks) to 4.7 (peri-urban forests) mg per day (Figure 4).

3.3. Leaf Litter C:N, C:P, and N:P Ratios

B. pendula leaf litter recorded the highest C:N ratios from broad street greeneries (59.2 g g^{-1}) and from large urban parks (58 g g^{-1}). The lowest C:N ratios were recorded in the peri-urban forests (42 g g^{-1}). These differences were significant. In contrast, the leaf litter of *T. cordata* from all greeneries showed the lowest C:N ratio ($30\text{--}35.2 \text{ g g}^{-1}$) (Table 2).

Table 2. Mean ratios of carbon to nitrogen (C:N (g g^{-1})), carbon to phosphorus (C:P (g g^{-1})), and nitrogen to phosphorus (N:P (g g^{-1})), recorded in the leaf litter of four native deciduous tree species from five different urban green spaces (PUF = peri-urban forest, LP = large urban park, SP = small urban park, BSG = broad street greenery, and NSG = narrow street greenery) in Kaunas, Lithuania. The ($\pm$) represent standard error, $N = 3$ for the means.

Tree Species	PUF	LP	SP	BSG	NSG
C:N (g g^{-1})					
<i>Acer platanoides</i>	45.2 ± 1.8	43.8 ± 0.4	43.0 ± 0.3	40.4 ± 1.7	39.2 ± 0.2
<i>Betula pendula</i>	42.0 ± 3.7	58.0 ± 0.1	41.3 ± 3.8	59.2 ± 1.9	53.0 ± 0.4
<i>Tilia cordata</i>	32.0 ± 0.4	35.2 ± 0.3	30.8 ± 0.2	31.0 ± 0.2	30.0 ± 2.6
<i>Quercus robur</i>	40.5 ± 1.9	39.4 ± 0.1	40.3 ± 0.9	36.3 ± 0.8	38.5 ± 0.8
C:P (g g^{-1})					
<i>Acer platanoides</i>	809 ± 64	498 ± 3	426 ± 8	537 ± 33	487 ± 26
<i>Betula pendula</i>	632 ± 29	240 ± 11	256 ± 18	244 ± 12	342 ± 9
<i>Tilia cordata</i>	550 ± 14	480 ± 12	401 ± 20	484 ± 9	590 ± 66
<i>Quercus robur</i>	777 ± 17	583 ± 17	329 ± 20	525 ± 22	872 ± 10
N:P (g g^{-1})					
<i>Acer platanoides</i>	17.9 ± 1.1	11.4 ± 0.3	9.9 ± 0.2	13.3 ± 0.5	12.4 ± 1.0
<i>Betula pendula</i>	15.4 ± 2.1	4.1 ± 0.03	6.5 ± 1.8	4.1 ± 0.1	6.5 ± 0.4
<i>Tilia cordata</i>	17.2 ± 0.5	13.7 ± 0.3	13 ± 1.0	15.5 ± 0.3	19.6 ± 0.9
<i>Quercus robur</i>	19.2 ± 0.6	14.8 ± 0.7	8.1 ± 0.6	14.4 ± 0.5	22.7 ± 0.4

Q. robur leaf litter from narrow street greeneries and large parks (583 g g^{-1}) and *A. platanoides* from peri-urban forest (809 g g^{-1}), recorded the highest C:P ratio. In contrast, *B. pendula* leaf litter recorded the lowest C:P ratio from the large urban parks (240 g g^{-1}) (Table 2). The leaf litter of *A. platanoides* showed the largest C:P ratio difference (383 g g^{-1} , $P=0.010$) between peri-urban forests and small urban parks.

Q. robur leaf litter generally showed the highest N:P ratios as following: peri-urban forests (19.9 g g^{-1}), narrow street greeneries (22.7 g g^{-1}), and large urban parks (14.8 g g^{-1}). The leaf litter of *B. pendula* from all greeneries showed the lowest N:P ratio, ranging between $4.1\text{--}15.4 \text{ g g}^{-1}$.

4. Discussion

4.1. Leaf Litter Decomposition in Time and Space

Overall, our study shows that there is large variation in the decomposition of leaf litter between urban green spaces, tree species, and in time (seasonal). This supports Jacob et al. [36], in that there are differences between the three diversity levels regarding leaf litter decomposition from individual tree

species. Firstly, results show that leaf litter decomposition is influenced by tree species, with *B. pendula* showing the highest rate of decay, followed by *A. platanoides*, *T. cordata*, and *Q. robur*. We found that the decomposition of leaf litter by seasonality and time (4, 8, and 12 months) was significantly different. The smallest losses in mass occurred during the first four-month interval (the winter period), with *Q. robur* only losing 1.8% and *A. platanoides* losing the most with 9.4%. This may be attributed to atmospheric and soil temperatures as they were largely sub-zero during winter, thus restricting the activity of microorganisms.

In comparison, leaf litter decomposition over 8 months was more intensive for all tree species. This may be caused by changes in climatic condition from winter-spring to spring-summer in the second four-month interval in which microorganism activity increased. The highest losses in mass were recorded during the four- to eight-month interval for all species except *T. cordata*. Leaf litter of *Q. robur* lost 16.3% of mass; this is nine times more compared to the first four-month period. Leaf litter of *B. pendula* had the biggest reduction in mass of 58.6%; this was six times more, compared to the four-month period. Therefore, our results support the notion that the spring-summer period is an important period for nutrient discharge back into the local environments or as run-off into the local river systems [14]. Moreover, the spring-summer period is important for trees to obtain ample nutrients to stimulate growth and flowering. Indeed, this study shows leaf litter decomposition is an important nutrient source that enriches the soil during the spring period.

After 12 months, leaf litter decomposition slowed for all species except *T. cordata*. In total, *B. pendula* and *A. platanoides* lost the most mass; 82% and 70%, respectively. *B. pendula* only lost 1.4 times more compared to the mass loss for 8 months. The high decomposition of *B. pendula* leaf litter obtained in this study was consistent with the findings of Cotrufo et al. [37] but much higher than results found in other European cities. Unlike any of the other species, *T. cordata* leaf litter decomposition showed increased decomposition through all urban green spaces. The increased levels of leaf litter decomposition can provide additional and continuous nutrient enrichment to the soil if combined with other species. However, *Q. robur* only lost 24.7% of its leaf litter mass, in comparison this was only 1.5 times more than its loss after 8 months and well below the leaf litter decomposition of the other three species (Figure 2). Our results suggest that, for the leaf litter of *Q. robur*, 12 months does not provide enough time for its leaf litter to decompose, thus its contribution to providing nutrients back into the soil or as run-off over this time span is minimal in urban green spaces.

4.2. Leaf Litter Decomposition in Different Urban Green Spaces

The leaf litter of *B. pendula* and *A. platanoides* from street green spaces showed the highest losses in leaf litter overall. *Q. robur* leaf litter decomposition showed small but significant differences between the urban green spaces, and the decomposition of *T. cordata* leaf litter showed no significance between the types of green spaces. Our findings are consistent with the results of Dorendorf et al. [38] that leaf litter decomposition for peri-urban forest is slower compared to the other urban green spaces for *A. platanoides* and *B. pendula* but not for *Q. robur* and *T. cordata*. The rate of leaf litter decomposition has been shown to be an indicator of leaf quality, with faster increased rates of decomposition indicating poorer quality (i.e., less nutrients) [39]. In addition, previous research has shown that different leaf litter decomposition rates are due to environmental variability. For instance, leaf litter decomposition can be more rapid in urban areas because of higher temperatures, greater nutrient availability (e.g., soil fertilization), and an increased abundance of earthworms, as well as different soil substrate and pH [40–43]. However, Rawlik et al. [44] found that higher soil temperature may lead to reduced moisture and slower leaf litter decomposition.

Q. robur leaf litter decay was the slowest over 12 months, with only 22%–26% of its leaf litter mass lost within the five different urban green spaces. This is consistent with the notion that *Q. robur* leaf litter is of a lower quality and therefore decomposes relatively slowly [45–47]. Our results showed that *Q. robur* leaf litter from peri-urban forests decayed 12% faster over 12 months compared to leaf litter from the other urban green spaces. The results of other studies with red oak (*Quercus rubra*)

decomposition suggest that litter from the urban forests decayed 25% slower than leaf litter of rural areas [21]. Previous studies on introduced *Q. robur* leaf litter decomposition in Kaunas's urban parks have not shown significant differences between different environmental conditions [48]. Our results show that *Q. robur* litter decomposition from four of the five different types of green spaces were not significantly different. This is similar to the results of Straigytė et al. [49] for leaf litter decomposition of *Q. robur* in small urban parks after 12 months. In contrast, this study found a 19% increase in leaf litter loss for *A. platanoides* over 12 months compared to the 2009 results [49]. This suggests that *A. platanoides* is sensitive to environmental change, but further studies would be needed to confirm the environmental changes within Kaunas.

4.3. Leaf Litter C:N, C:P and N:P Ratio

Litter decomposition is controlled by factors such as climate, litter quality, and soil decomposing organisms [17,24]. In our experiment, we used a controlled environment to limit the variation of climate and soil on the decomposition of the leaf litter samples. Thus, there was only a difference in leaf litter species, collection location, type of green space, and leaf litter quality. High levels of nutrients, especially N, lead to faster decomposition [50]. However, results from boreal forest show that decomposition intensity is negatively correlated to the C:N ratio of leaf litter [51]. We found that rising N concentrations in *Q. robur* leaf litter increased the rate of leaf litter decomposition compared to the study of Janusauskaite and Straigytė [27].

Rapid decomposition of *B. pendula* and *A. platanoides* leaf litter from street greeneries indicates in this study that these species may be the most appropriate to deliver important nutrients back into the soil. The loss of C and N via leaf litter removal in urban green spaces can create nutrient limitations for some vegetation due to diminished opportunities to recycle nutrients [52]. In addition, artificial ground surfaces within urban areas around green spaces can create barriers for soil enrichment (e.g., street greeneries) [53]. Thus, the entry of nutrients back into the soil profiles of green spaces is very crucial and a critical component for optimal tree growth.

Research on leaf litter from woodlands in the Netherlands found that leaf litter concentrations of C and P were significantly correlated with the rate of litter decomposition [54]. We found that the C:P ratio also differed between tree species and some green spaces. The biggest C:P ratio variation (543 g g⁻¹) was recorded for *Q. robur* leaf litter between urban forests and small parks. The differences between large parks and broad street greeneries were not significant. Our study shows that the variation between the decomposition rates of leaf litter from different types of green spaces may be because leaf quality is affected by urban environments. However, the decomposition of leaf litter can be negatively influenced by the foliar uptake of atmospheric pollutants, and indirectly through alterations in local climate and changes in soil fertility caused by pollutant loads and altered nutrient cycling regimes. For instance, Varnagirytė-Kabašinskienė et al. [55] found that the leaf litter of both *Q. robur* and *T. cordata* had large nutrient fluxes. This may explain the slow decomposition of the *Q. robur* and *T. cordata* leaf litter found in our research. However, results on leaf litter decomposition can be difficult to interpret directly due to two main causes. Firstly, the differences in leaf decomposition between different urban green spaces may vary, and under normal conditions green spaces contain mixed plant communities and thus mixed litter types. Secondly, soil characteristics (such as soil communities, pH, and soil quality) in combination with litter quality may cause different trends in the leaf litter decomposition of different green spaces. Indeed, Straigytė et al. [41] found a negative correlation between leaf litter decomposition in peri-urban forests and acidic soils with a low N:P ratio.

4.4. Planning of Urban Green Space

Currently, the Kaunas city municipality uses *T. cordata* in their replacement program for street greeneries. Our study supports the inclusion of *A. platanoides*, *B. pendula*, and *Q. robur* in their replacement program. However, as a study shows, understanding the decomposition of leaf litter can help city planners select the most suitable tree species and maintenance programs (for example, leaf

litter collection and soil fertilization) for each urban green space. The slow decomposition of *Q. robur* and *T. cordata* can be appropriate in areas with high artificial surfaces where nutrients cannot penetrate back into the soil profile or nutrient run-off should be prevented. Whereas the rapid decomposition of *B. pendula* and *A. platanoides* leaf litter indicates that these species are best suited for growing in urban green spaces where a rapid replenishment of soil nutrients are needed. Thus, the results of our study on leaf litter decomposition from different urban green spaces may provide city planners in Lithuania, with similar species and environmental conditions, knowledge on how urban environments affect leaf litter decomposition.

Although this study focused on only four commonly found deciduous tree species, we advocate the use of all native trees currently found in the green spaces of Kaunas as this would help maintain both natural ecological processes and the current levels of biodiversity that are both important for delivering benefits to human well-being.

In conclusion, our research results show that leaf litter decomposition, as an environmental process, was significantly different between seasonality (time duration of 8 and 12 months), tree species, leaf litter nutrient release, and the types of green spaces. Firstly, the highest level of leaf litter decomposition was recorded during the spring season (between 4–8 months). Secondly, there were large difference between the leaf litter decomposition of the four deciduous tree species (*B. pendula*, the fastest, and *Q. robur*, the slowest). Thirdly, we found significant differences in C:N, C:P, and N:P ratios between leaf litter decomposition and nutrient level for the five different types of green urban spaces. *Q. robur* showed accelerated leaf litter decay when the C:N ratio decreased. This study highlights the complexity of urban environments and that more research on the processes of leaf litter decomposition using multiple species or mixed species, and with different environmental characteristic across various cities, are needed to further understand the processes and mechanisms of litter decomposition and nutrient dynamics in urban environments.

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