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RESEARCH ARTICLE

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Ecological and economic benefits of low-intensity urban lawn management

Christopher J. Watson | Léonie Carignan-Guillemette | Caroline Turcotte | Vincent Maire | Raphaël Proulx

Centre de Recherche sur les Interactions Bassins Versant – Écosystèmes Aquatiques, Université du Québec à Trois-Rivières, Trois-Rivières, Québec, Canada

Correspondence
Christopher J. Watson
Email: chris.watson@uqtr.ca

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Abstract

1. Intensive management of urban lawns is globally widespread, predominantly for aesthetic reasons. However, a growing body of knowledge demonstrates negative ecological and environmental effects of this practice.
2. We present a meta-analysis of North American and European studies from 2004 to 2019, which incorporates three previously unpublished datasets from eastern Canada, to investigate how mowing intensity impacts the ecology of urban lawns.
3. The meta-analysis provides aggregated evidence that invertebrate and plant diversity is lower in urban lawns under increased mowing intensity. This decline is independent of the level of contrast between mowing 'treatment' and 'control' (e.g. height or frequency of mowing), which differed considerably between studies. Intensive mowing also increases the occurrence of pest species (e.g. herbivorous beetle larvae and allergenic plants), though studies in this group were limited to northern environments. Changes in ecosystem-level variables (soil temperature, soil moisture deficit and carbon deficit) were less evident and suggest changes in abiotic processes may take longer to become apparent.
4. An economic case study of the mowing costs in Trois-Rivières, Canada, suggests that cost savings of 36% may be possible with a modest reduction of mowing frequency.
5. *Synthesis and Applications*. Increasing urban biodiversity and reducing greenhouse gas emissions are strong motivators for reducing lawn management intensity. We also suggest that the benefits of reducing pest species while saving lawn management costs may provide additional social and economic incentives for decision makers to review urban greenspace management practices.

KEYWORDS
biodiversity, lawn, lawn management, meta-analysis, mowing, pests, urban ecology, weeds

1 | INTRODUCTION

The currently accepted aesthetic of a manicured and uniform urban lawn is at odds with the environmental services that urban greenspaces provide (Shwartz, Turbé, Julliard, Simon, & Prévot, 2014; Smith & Fellowes, 2015). Intensively managed lawns have been demonstrated to reduce plant and insect diversity of an urban system: frequent low mowing reduces vegetation structure and composition by favouring low-growing annual plants or grasses, and reduces floral resources for pollinators by removing taller flowering structures

(Forbes, Cooper, & Kendle, 1997; Lerman, Contosta, Milam, & Bang, 2018). This produces a cascade effect within the community that lowers ecosystem resilience and provides opportunities for colonization by unwanted pest species (Busey, 2003). Intensively managed lawns also require considerable public funds (e.g. maintenance costs, see Hedblom, Lindberg, Vogel, Wissman, & Ahrné, 2017), contribute to greenhouse gas loadings (Gu, Crane, Hornberger, & Carrico, 2015), and are often reliant on environmentally detrimental fertilizers and pesticides (Haith, 2010; Stoate et al., 2001). Alternative options such as grass-free lawns or a 'benign neglect' approach (Smith, Broyles, Larzleer, & Fellowes, 2015; Venn & Kotze, 2014) have been promoted to address these issues. However, limited social acceptance has ensured that intensively managed lawns remain a global preference (Nassauer, Wang, & Dayrell, 2009).

Currently there is not a large body of work that investigates the effects of urban lawn mowing regime on ecological factors, although publications in this field are growing (e.g. Chollet, Brabant, Tessier, & Jung, 2018; Lerman et al., 2018; Norton et al., 2019). Most studies examine effects of mowing on one factor (e.g. bee abundance), over a 1- or 2-year period. However, drawing general conclusions over short time frames can be difficult due to within-year variation of abiotic and biotic factors (Koricheva & Gurevitch, 2014). It is evident from the growing literature that mowing impacts a range of ecological facets concurrently, and this cumulative effect has not yet been quantified. Meta-analysis is a useful approach to aggregate results from studies conducted over many years and geographical areas to explore beyond the scale of individual studies.

This research aims to investigate the effects of mowing intensity on urban ecological variables without incorporating other management practices (e.g. fertilizers or pesticide application). We refer to 'mowing intensity' as either low mowing height or high mowing frequency. Our objectives were to evaluate the effect of mowing intensity on a range of ecological and environmental variables in urban lawns. In this context, 'urban lawns' comprise a range of land uses dominated by lawn within urban areas, including residential yards, parks, road boundaries (verges, roundabouts, etc.) and public rights-of-way. Our approach was to conduct a meta-analysis of published research, supplemented with data holdings within the research group, to quantify the impact of increased mowing intensity on representative ecological domains. We include an economic case study to estimate potential cost savings of adopting low- versus high-intensity management.

2 | MATERIALS AND METHODS

2.1 | Data compilation

Our objective in identifying suitable studies for the meta-analysis was to select experimental lawn management studies within an urban setting. Studies were deemed suitable if they used mowing intensity (either height or frequency) as an experimental factor, coupled with an ecologically relevant response variable. We searched the Scopus database on 8 February, 2019 with the following combinations of keywords: "(lawn OR turf) AND mowing AND (urban OR city)". We filtered the resultant publications for eligibility according to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta Analyses) flow diagram outlined in Figure 1 (Moher, Liberati, Tetzlaff, & Altman, 2009).

Generally, studies were ineligible when: full-text of the article was not available even after contacting the authors; mowing was incidental to the study and not an experimental factor; response variables were not ecologically relevant; confounding factors (e.g. fertilization) could not be isolated; a non-urban context was used; or simulated data were presented. Details of selected studies are presented as Table 1.

2.2 | Data extraction and processing

We extracted the mean and statistical variation (standard deviation or standard error) for each response variable in control and treatment groups. Reported data were used when available. Otherwise, data were extracted from published figures using the Web Plot Digitizer tool (Rohatgi, 2017), which is reliable for extracting data from published sources (Drevon, Fursa, & Malcolm, 2017). Where summary data on median, and interquartile range was presented, mean and standard deviation was estimated (Wan, Wang, Liu, & Tong, 2014). Variables with multi-temporal data (e.g. soil moisture) were summarised using the mean and pooled standard deviation to provide an aggregated value per site per year. Where seasonal trends were evident in raw multi-temporal data (e.g. soil temperature), data was detrended using a polynomial function and analysis applied to the residuals. In addition to published data, we used 13 datasets from three previously unpublished studies within the authors' research group. The methods associated with these studies are presented as Appendix S1 in Supporting Information.

2.3 | Effect size and analyses

To minimize heterogeneity resulting from the range of study variables, we grouped each dataset into one of four ecological functions: *Invertebrate Communities*, *Plant Communities*, *Pest Species* and *Abiotic Processes*. For each variable, we used control (i.e. low management intensity) and treatment (i.e. high management intensity) statistics to calculate Hedges' g as the measure of effect size. Hedges' g is the calculated and bias-corrected standardized mean difference; the difference between the treatment and control effect size, divided by the pooled standard deviation (Hedges, 1981).

For the meta-analysis, we ran multilevel random-effect models fitted using a restricted maximum likelihood estimator (REML). Multilevel models account for non-independence of multiple variables within one study, which is common in the biological literature (Nakagawa & Santos, 2012), while the REML provides a balance between unbiasedness and efficiency (Viechtbauer, 2005). We

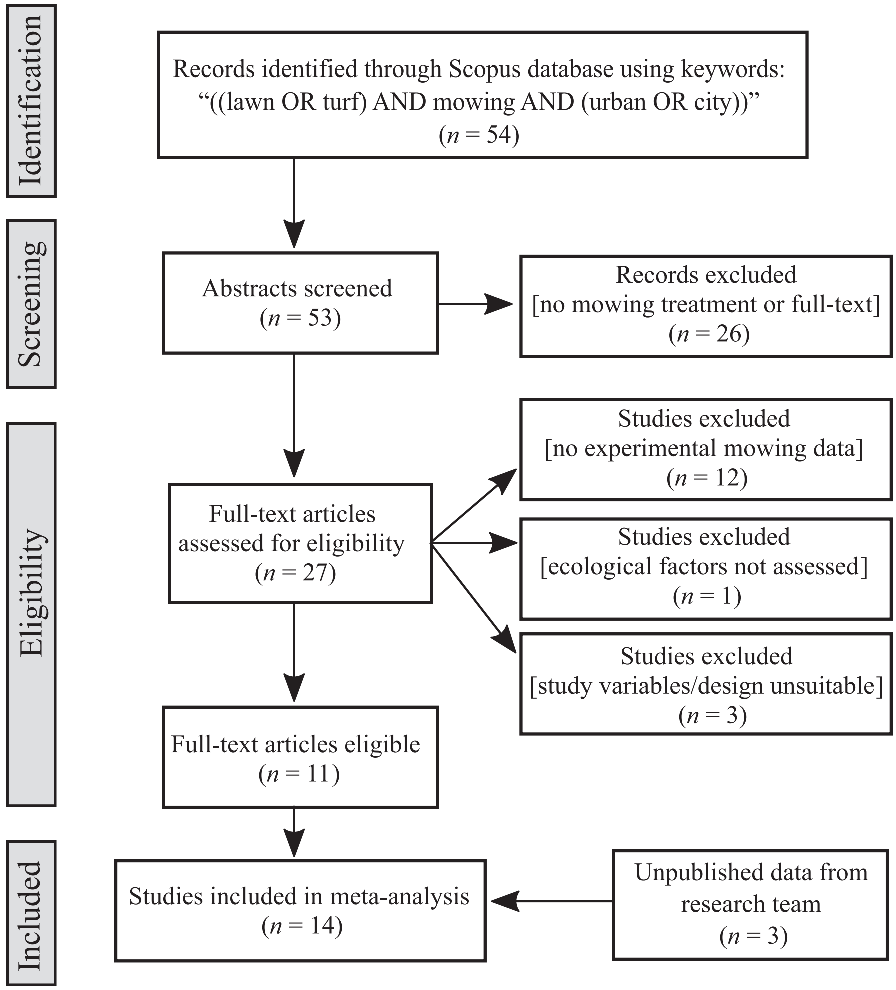

FIGURE 1 PRISMA flow diagram showing the process for selecting and filtering eligible studies for meta-analysis inclusion

assessed the proportion of variation due to heterogeneity across studies with Higgins' I^2, a commonly-used index that can be interpreted as a percentage of the total variability in effect sizes due to true differences between the studies (Del Re, 2015; Wallace et al., 2017). Hedges' *g* calculations and all other components of the meta-analyses were conducted using the METAFOR package (Viechtbauer, 2010) in R version 3.5.0 (R Core Team, 2018).

2.4 | Moderator variables

For studies with more than two levels of mowing intensity, we used the most and least intense levels for our analysis. The method of measurement varied between studies and included mowing frequency, mowing at fixed heights, as well as qualitative descriptions (e.g. 'intensive'). Intensive mowing treatments were typically between weekly and monthly frequencies, whereas controls ranged from mowing every 3 weeks to being unmanaged for 10 years (Table 1). To account for this variability between studies, we tested if mowing gradient influenced the effect size. We assigned each study a semi-quantitative categorical variable to represent the difference between the treatment and control management. We hypothesized that a large gradient in mowing intensity between treatment and control would lead to a greater effect size. We tested this by adding mowing gradient as a moderator variable in the analysis of *Invertebrate Communities* (n = 17), as other groups had too few experiments to produce meaningful results. We used three levels of mowing gradient (Small, Moderate or Large) which represented a balance between resolution and representation. We evaluated the fit of the moderator variable model using the Akaike information criterion, corrected for small samples (AIC_c; detailed within Burnham & Anderson, 2004), relative to the model with no moderator.

2.5 | Assessing bias

Estimates of publication bias in meta-analyses often include formal assessment using the Egger's test for significance of asymmetry (Egger, Smith, Schneider, & Minder, 1997). In this study, our grouped classes do not provide sufficient samples for formal assessment. Instead, we assessed the likelihood of publication bias by investigating the focus of journals from which the studies were drawn. Our a priori assumption was that bias was more likely if the journals had a conservation focus, and that any bias would be towards ecologically negative results of intensive lawn management. Of the 11 published studies used, two are in journals with a conservation focus (*Biological*

TABLE 1 Details of eligible studies for inclusion in the meta-analysis. Studies are grouped by author/date and include study year; response variable(s) measured; number of observations; details of control/treatment; location information; and lawn type

Author(s) and publication date	Study year	Response variables	Variable group	Number observations		Mowing control	Mowing treatment		Location	Lawn types
				Control	Treatment		Measure	Magnitude		
Helden and Leather (2004)	2002	Species Richness (Hemiptera) Abundance (Hemiptera)	Invertebrates	4	5	0–1/year	Frequency	1/week	Bracknell, UK 51° 23' 00.00'' 0° 43' 00.00''	Roundabouts Road verges
Venn and Kotze (2014)	2003	Species Abundance (Carabidae) Species Richness (Carabidae)	Invertebrates	20	25	Unmanaged (10 years)	Qualitative	Intensive	Helsinki, Finland 60° 10' 00.00'' 24° 57' 00.00''	Public parks
Allaire et al. (2008)	2006	CO_2 Flux	Abiotic Processes	10	9	1–3/year	Frequency	1/week	Quebec City, QC, Canada 46° 48' 00.00'' 71° 23' 00.00''	Unspecified
Lilly et al. (2015)	2007/2008	Carbon Biomass	Abiotic Processes	18	18	10 cm	Height	5 cm	College Park, MD, USA 39° 00' 30.36'' 76° 56' 28.69''	Private facility
Wastian, Unterweger, and Betz (2016)	2010	Species Richness (Bees) Abundance (Bees) Shannon Diversity (Bees)	Invertebrates	5	5	2/year	Frequency	12/year	Tübingen, Germany 48° 31' 17.89'' 9° 03' 27.52''	Public lawns
Smith et al. (2015)	2011	Insect Richness Insect Family Richness Shannon Diversity	Invertebrates	4	4	1/month	Mixed	2 cm	Reading, UK 51° 26' 11.60'' 0° 56' 27.60''	Private lawn
Smith and Fellowes (2015)	2011/2012	Floral Abundance Floral Visibility	Plants	8	8	1/month	Mixed	2 cm	Reading, UK 51° 26' 11.60'' 0° 56' 27.60''	Private lawn
Unterweger et al. (2017)	2012	Species Richness (Hemiptera) Abundance (Hemiptera)	Invertebrates	8	8	2/year	Frequency	8/year	Tübingen, Germany 48° 31' 17.89'' 9° 03' 27.52''	Public lawns and meadows
Lerman et al. (2018)	2013/2014	Floral Richness Floral Abundance Species Richness (Bees) Abundance (Bees)	Plants Invertebrates	8 8	8 8	1/3 weeks	Frequency	1/week	Springfield, MA, USA 46° 06' 05.34'' 72° 35' 23.32''	Private yards
Lerman and Contosta (2019)	2013/2014	Soil Temperature Soil Moisture CO_2 Flux	Abiotic Processes	8	8	1/3 weeks	Frequency	1/week	Springfield, MA, USA 46° 06' 05.34'' 72° 35' 23.32''	Private yards
Turcotte	2016	Insect Diversity Abundance (Scarab Larvae) Soil Temperature Subsoil Temperature	Invertebrates Pest Species Abiotic Processes	10 10 8	10 10 8	0–3/year	Frequency	1/week	Trois-Rivières, QC, Canada 46° 20' 42.54'' 72° 32' 51.72''	Road verges

(Continues)

TABLE 1 (Continued)

Author(s) and publication date	Study year	Response variables	Variable group	Number observations		Mowing control	Mowing treatment		Location	Lawn types
				Control	Treatment		Measure	Magnitude		
Chollet et al. (2018)	2016	Species Richness (Plants) Shannon Diversity (Plants) Functional Richness (Plants) Phylogenetic Diversity (Plants)	Plants	35	40	1/year	Frequency	15–20/year	Rennes, France 48° 06' 00.00'' 1° 40' 00.00''	Unspecified
Carignan-Guillemette	2017	Occurrence (Earthworms) Occurrence (Scarab Larvae) Occurrence (Elaterid Larvae) Soil Temperature	Invertebrates Pest Species Abiotic Processes	28 28 9	28 28 9	1/year	Frequency	1/week	Trois-Rivières, QC, Canada 46° 20' 42.54'' 72° 32' 51.72''	Road verges
Carignan-Guillemette	2018	Occurrence (Earthworms) Occurrence (Scarab Larvae) Occurrence (Elaterid Larvae) Occurrence (Plant Allergen) Occurrence (Lawn Weed)	Invertebrates Pest Species Pest Species (Plants)	20 28 4	20 28 4	1/year	Frequency	1/week	Trois-Rivières, QC, Canada 46° 20' 42.54'' 72° 32' 51.72''	Road verges

Conservation; *Biodiversity Conservation*), four in journals dedicated to urban forestry and planning (*Urban Forestry & Urban Greening*, *Landscape and Urban Planning*), and three in dedicated entomology journals (*Journal of Hymenoptera Research*, *Heteropteron*, and the *European Journal of Entomology*). The remaining two studies are published in the *Canadian Journal of Soil Science* and *Basic and Applied Ecology*. Three studies were conducted in the city of Trois-Rivières by the same group of authors, but in different environmental contexts. Since no other studies considered pest species explicitly, results from the latter have a limited potential of generalization. We propose that in the absence of formal investigation, the balance of journal types suggests little motivation for publication bias. In addition, the unpublished data have no publication bias and show a mixture of positive and negative effects for different variables.

Time-lag bias has been known to impact ecological meta-analyses where studies occur over long periods of time and differences in methods may impact trends in effect size (Nakagawa & Santos, 2012). In this meta-analysis, 85% of studies were conducted between 2014 and 2019 and no time lag bias is expected due to this short interval.

3 | RESULTS

The results of the meta-analysis show clear effects of mowing intensity, with the ecological groups responding in different direction and magnitude. Figure 2 illustrates the effect size for individual variables and the pooled effect size within each group. Effect size is presented as Hedge's g, with the sign of g corresponding to the effect direction with increased mowing intensity. *Plant Communities* ($g = -0.38$, $z = -3.59$, $p < .001$) and *Invertebrate Communities* ($g = -1.05$, $z = -2.12$, $p < .05$) showed significant negative effect sizes with increased mowing intensity, whereas *Pest Species* had a positive response ($g = 0.93$, $z = 1.77$, $p = .08$). *Abiotic Processes* was slightly positive (i.e. ecosystem-level pressures increase with increased mowing intensity) but the confidence around the effect size largely overlapped zero ($g = 0.44$, $z = 1.15$, $p = .25$). Although the grouped effect sizes do not appear large relative to some individual effects, *Invertebrate Communities* and *Pest Species* show a large effect size (>0.8), according to Cohen's 'rule of thumb', and *Plant Communities* and *Abiotic Processes* have an effect size between small (0.2) and medium (0.4) (Cohen, 1988; Sawilowsky, 2009).

3.1 | Heterogeneity

Three ecological groups (*Invertebrate Communities*, *Pest Species* and *Abiotic Processes*) showed high total heterogeneity and between-study variance, which reflect data derived from statistical populations with different true effect sizes. Higgins' I^2 for these groups were correspondingly high ($I^2 = 84.18$ for *Invertebrate Communities*, $I^2 = 80.28$ for *Pest Species*, and $I^2 = 71.17$ for *Abiotic Processes*). Conversely, the *Plant Communities* group showed extremely low

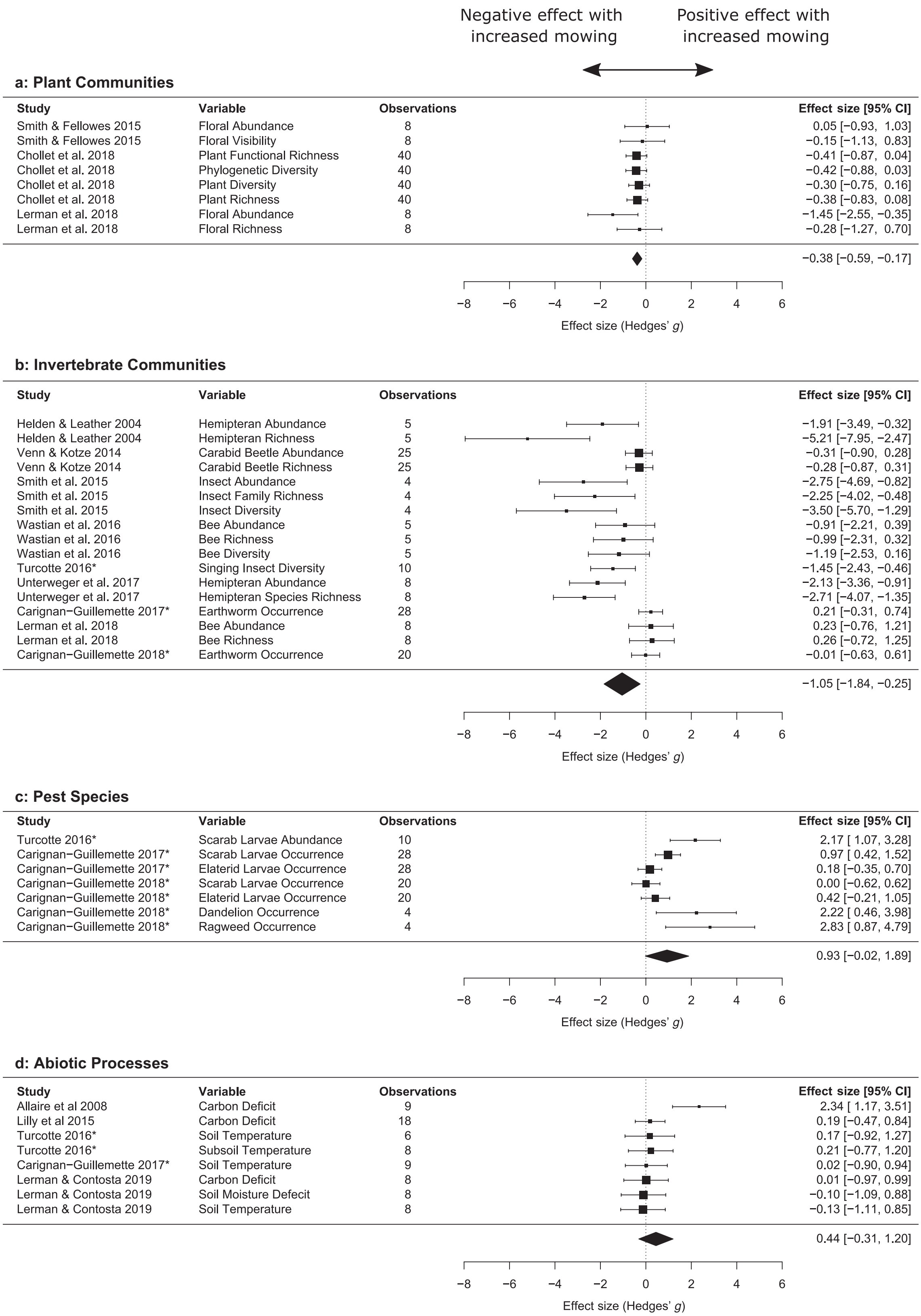

FIGURE 2 Individual and summary effect sizes (Hedges' *g*) resulting from increased mowing intensity, for four groups: a: Plant Communities, b: Invertebrate Communities, c: Pest Species, d: Abiotic Processes. The sign of the effect reflects the positive or negative impact of increased mowing. The size of each square (mean g) is proportional to the weighting within each group. Error bars around the mean are ±95% confidence interval (CI). The * symbol indicates unpublished datasets

heterogeneity and variance ($I^2 = 0$), suggesting that the pooled estimate of effect size is converging rapidly with the addition of new experimental data.

3.2 | Influence of moderators

Contrary to our expectations, the addition of a three-level moderator variable to describe the level of contrast between mowing treatment and control showed no improvement ($AIC_c = 50.09$) over the model with no moderators ($AIC_c = 49.54$). This suggests that any improvement in fit resulting from the moderators are offset by the added complexity of the model (Burnham & Anderson, 2004).

4 | DISCUSSION

4.1 | Ecological impact

Increased intensity of lawn management shows consistent and distinct negative impacts to different facets of urban ecology. Of particular note was invertebrate and plant diversity, which were significantly negative, and pest species, which were favoured by increased lawn management. The corollary of this result is that a reduction in lawn mowing intensity could prevent losses in invertebrate diversity and plant function, while at the same time limiting pest species. Individual studies may be impacted by local climate or geographical effects (Koricheva & Gurevitch, 2014); and when results between years diverge (e.g. Dobbs & Potter, 2014), interpretation can be complex. Conversely, our meta-analysis provides aggregated evidence across geographic regions and taxonomic groups. The collated data used in this study showed high heterogeneity, even when subset to ecologically relevant groups. This is expected given the different variables, objectives and treatment types in the selected studies. Despite this heterogeneity, a clear effect size was evident for two of the four groups, providing strong evidence for cumulative negative impacts of mowing intensity on plant and insect diversity. This contributes to our growing understanding of urban ecology, a field that is recognised as being under-represented in the ecological literature (Martin, Blossey, & Ellis, 2012).

Plant Communities, which included diversity and floral output, showed a consistent negative response despite diverse variables within this group. Although most individual studies gave non-significant effect sizes, the group effect was significantly negative. This result is not surprising: regular mowing removes tall reproductive structures such as flowering stems (Lerman et al., 2018) and favours low-growing, annual or biennial species (Forbes et al., 1997). Consequently, the structural complexity, floral diversity, litter dynamics, and soil enrichment will be reduced. The bottom-up effect of plants on herbivores in an ecosystem is well understood (Hunter & Price, 1992), and floral diversity impacts the diversity of pollinators (Ghazoul, 2006), hence we would expect a trophic cascade from plant diversity to the diversity of other organisms.

Invertebrate Communities was the most studied of the groups (17 datasets within 8 studies) and showed a significant negative effect of increased mowing intensity. The loss of insect diversity in managed environments is commonly reported in the literature (Smith & Fellowes, 2015; Unterweger, Rieger, & Betz, 2017) and we expected that a meta-analysis of urban lawns would reflect these findings. The advantages that a high insect diversity provides in terms of pollination, biocontrol, decomposition of organic matter and general trophic regulation has been long-held (Baldock et al., 2015; Isaacs, Tuell, Fiedler, Gardiner, & Landis, 2009); hence it is reasonable to assume that a decrease in invertebrate diversity would result in a negative ecological impact.

Pest Species was the least studied group of variables, with seven datasets from three studies in eastern Canada. Six of seven variables showed an increase in pest abundance with increased mowing intensity, though the overall effect was moderate. In turfgrass production, a lower mowing height is known to increase abundance of a variety of pest insects and weeds through decreasing lawn rooting capacity and providing opportunities for colonization (Busey, 2003; Dobbs & Potter, 2014). These and other studies were not included in our meta-analysis due to their agricultural/commercial context or inclusion of other factors (e.g. fertilizers). However, results from the turfgrass production field provides supporting evidence that pests are favoured by higher intensity mowing in urban lawns.

Among the pest species included in our analysis, common ragweed *Ambrosia artemisiifolia* has particular importance as one of the most allergenic species in North America and Europe (Dullinger, Kleinbauer, Peterseil, Smolik, & Essl, 2009). The cost of ragweed-based allergies has been estimated at CAD $155 million per year in Québec (2005 data; Ngom & Gosselin, 2014), and €133 million per year in Austria and Bavaria (Richter et al., 2013). Associated health and cost impacts is expected to increase as temperatures and atmospheric CO_2 concentration rise, drought events become more likely, and the ragweed flowering season lengthens (Ziska et al., 2003, 2011). Ruderal species such as ragweed that have more rapid reproduction than other species (Grime, 1977; Munoz, Violle, & Cheptou, 2016) are able to colonize disturbances resulting from intense mowing. Reduction of lawn mowing intensity may thus represent one cost-effective measure in reducing ragweed spread, decreasing the local pollen load, and reducing public health costs.

Other pest species used in the meta-analysis have an aesthetic and economic impact. Scarab larvae, known as 'white grubs', are lawn pests in eastern North America (Potter, 1998). These larvae feed on grass roots and cause widespread lawn death. Significant effort has been directed into controlling white grubs, including pesticides, biological control and management practices (Grewal, Power, Grewal, Suggars, & Haupricht, 2004). Dandelion *Taraxicum officinale* and wireworm (Elateridae larvae) are likewise considered nuisance species in lawns. These and similar pest species present costs to private and public land managers through control methods or turf replacement.

Our results suggest that frequent mowing, predominantly conducted for aesthetic reasons, may create other aesthetic problems by facilitating increased weed and pest invasions. This finding is somewhat counter-intuitive as mowing is often promoted to control weeds in agricultural systems. Agricultural mowing for weed control is often targeted to maximize removal of plant resources or flowering structures (Wilson & Clark, 2001) and is typically used in crops or managed pastures which are intrinsically disturbed systems. Conversely, resistance of turf grasses to weed invasions relies on minimizing disturbance (Radosevich, Holt, & Ghersa, 1997). Intensive mowing provides has thus been identified as an important contributor to weed invasions in turfgrass production (Busey, 2003) and planted urban meadows (Norton et al., 2019). Although some studies report an inconsistent effect of mowing height (Abu-Dieyeh & Watson, 2005), instances of low mowing height reducing lawn weeds are rare. Despite the influence of mowing intensity on weed invasion potential, individual species responses will ultimately depend on the interaction between species characteristics, management regimes and ecological, climatic and edaphic factors. Urban lawn managers should consider reduction of mowing intensity as part of their pest and weed control strategies.

Pest fauna have a real or perceived increased risk in unmown areas, in particular ticks, rodents, and stinging insects. Maintaining short lawns is often promoted to reduce the risk of a tick encounter (e.g. Stafford, 2007), yet research shows stronger predictors of tick abundance than vegetation type (e.g. tick host density; Dobson, Taylor, & Randolph, 2011). Moreover, the abundance of host-seeking tick larvae and nymphs in vegetation has been reported as near zero in hayfields and grasslands in comparison to shrublands or woodlands (Ostfeld, Cepeda, Hazler, & Miller, 1995). The abundance of certain rodents has been linked to unmown vegetation in some circumstances (Slade & Crain, 2006), though other rodent species showed no such affiliation. In fact, surprisingly little research links vegetation height with rodent activity (Jacob, 2008). An increased likelihood of pest fauna should not be assumed in unmown habitats, and possible impacts should be considered on a case-by-case basis.

The *Abiotic Processes* group represents variables that can negatively affect ecosystem balance, such as soil moisture deficit, increased soil temperature, and carbon loss. While we observed a trend of mowing intensity increasing these variables, only one dataset (Allaire, Dufour-L'Arrivée, Lafond, Lalancette, & Brodeur, 2008) showed a large effect size; consequently the confidence interval for the group effect size overlapped zero (i.e. no effect). It is likely that increases in *Abiotic Processes* would feedback to other ecological groups; that is, a higher soil moisture deficit would restrict lawn root growth, providing more opportunities for pest colonization, leading to lower plant diversity, resulting in lower insect diversity, and so on. While biotic variables often respond quickly to management changes, broader ecosystem functions demonstrate slower rates of change (Proulx et al., 2010) and longer-term observations may be required to detect meaningful trends. We expected that higher mowing intensity would result in higher growing season soil temperature and lower soil moisture levels; however results were more varied than expected. Various plausible explanations exist for this observation: for example, soil moisture may increase with lawn height, thus increasing the heat capacity of the topsoil and buffering night temperatures. In addition, temperature data analysed over several months may obscure discrete trends, particularly in warmer and drier months when shorter vegetation is likely to result in higher soil temperatures.

We predicted that a larger contrast between control and treatment mowing would correlate with a larger effect size. However, the mowing gradient did not have a significant effect on the model. This unexpected finding suggests that even a small reduction in mowing intensity may yield positive ecological effects. Further controlled studies of mowing treatments on individual factors may elucidate these trends more clearly.

This meta-analysis included 40 variables from 14 data sources. Both statistically and practically, a dataset of this size has limitations to analysis and interpretation. Firstly, the data are limited to temperate biomes of Europe and North America, indicating a research gap and opportunities for future research. Additionally, subsetting the study variables to smaller, ecologically relevant groups, increases the chance for one study or variable to dominate the meta-analysis. While a multilevel model takes this into consideration, caution should be applied when interpreting results of small sample size.

4.2 | Economic impact

The economic costs of lawn management are not commonly reported but may represent significant public expenditure. We used the city of Trois-Rivières, Québec, Canada as a case study to assess the economic component of lawn maintenance. The Ville de Trois-Rivières provided mowing contractor costs to estimate the cost per hectare of mowing activities. This value incorporated workers' salaries,

TABLE 2 Comparison of the current, and low-intensity scenarios for area and costs of mowing in urban areas managed by the Ville de Trois-Rivières

		Current scenario			Low-intensity scenario		
Mowing regime	Area (ha)	Mowing frequency (average)	Total mown area (ha)	Cost ($CAD)	Mowing frequency (average)	Total mown area (ha)	Cost ($CAD)
High use	273	15 per year	4,095	$791,755	10 per year	2,730	$527,837
Low use	118	3 per year	354	$68,445	1 per year	118	$22,815
Total	391		4,449	$860,200		2,848	$550,652

equipment operation and fuel, and did not include pesticides or fertilizers. Our analysis did not include any indirect economic benefits from improved ecosystem services (e.g. increased pollination).

The cost of mowing in this jurisdiction is based on total area of lawn, with two types of mowing regime. Areas with high public use (e.g. public parks, verges) were mown frequently to a height of between 7 and 15 cm (approximately 15 times per year). Areas with lower public use (e.g. vacant areas) were mown less frequently, approximately three times per year. Precise frequency of mowing varies depending on growth rate, microclimate and social demand, but average estimated values are presented. Sports fields that require short, regular mowing were not included in the analysis.

In 2018, CAD $860,200 (approximately USD $640,000) was allocated to mowing activities over 391 ha of urban lawns. Table 2 presents the frequency, area and costs of mowing for both the current scenario and a hypothetical low-intensity scenario. The current scenario represents a total mown area of 4,449 ha/year with a resultant mowing cost of CAD $193/ha. (approximately USD $143/ha). Under a hypothetical low-intensity scenario, low use lawn would be cut once per year, and high use lawn reduced from 15 to 10 mowing events per year.

Although mowing costs per hectare under the current scenario are substantially lower than reported in other jurisdictions (USD $3,200/ha in Sweden; Hedblom et al., 2017), our analysis suggests a reduction of approximately 36% (CAD $310,000; USD $231,000) from reducing mowing frequency from 15 times per year to 10 times per year in high use areas, and from three times per year to once per year in low use areas. Under a low-intensity scenario that reduces the abundance of pest species, costs for herbicide application and replacing damaged lawns would also be less. Despite these potential savings, the willingness of public land managers to implement low-intensity lawn management will likely depend on local factors such as social acceptance, requirements of lawn users and public safety considerations (e.g. traffic visibility).

A low-intensity management regime would reduce greenhouse gas emissions as a function of reduced mowing area. However, the impact of mowing regimes on other facets of the carbon budget remains uncertain. Urban lawns are expected to be carbon sinks under typical management (Zirkle, Lal, & Augustin, 2011), but this magnitude will be relative to a variety of interacting management factors including retention of clippings, irrigation, fertilization, and pesticide use as well as climate, species composition and soil characteristics (Law & Patton, 2017; Lilly, Jenkins, & Carroll, 2015; Poeplau, Marstorp, Thored, & Kätterer, 2016; Selhorst & Lal, 2013). Further research is needed to disentangle the effects of mowing from management and environmental factors.

5 | CONCLUSIONS

Overall, this meta-analysis demonstrates clear negative ecological effects with increased mowing intensity. In addition to known advantages such as carbon emission reductions, we propose that a reduction in mowing intensity in urban lawns is likely to promote urban invertebrate and plant diversity, and associated ecosystem services. Further, we suggest that important flora and fauna pest species are likely to be favoured by intensive mowing, and that reduction of mowing frequency may be a cost-effective method to assist in their control. Although the potential ecological benefits are clear, reducing operational and public health costs may provide a greater incentive for decision makers to adopt lower-intensity lawn management.

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AUTHORS' CONTRIBUTIONS

R.P. and V.M. conceived and managed the study. L.C.-G. and C.J.W. contributed equally to the manuscript, including data compilation, analysis and writing. L.C.-G. and C.T. conducted fieldwork and analysis of individual study components.

DATA AVAILABILITY STATEMENT

Data available via Scholars Portal Dataverse: https://doi.org/10.5683/SP2/RRJTEN (Watson, Carignan-Guillemette, Turcotte, Maire, & Proulx, 2019).

ORCID

Christopher J. Watson https://orcid.org/0000-0003-3320-431X
Vincent Maire https://orcid.org/0000-0002-3245-2568
Raphaël Proulx https://orcid.org/0000-0002-9188-9225

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SUPPORTING INFORMATION

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