BIODIVERSITY LOSS DUE TO THE INCREASE OF MONOCULTURE LAWNS

By

Kalila Scott

FACULTY OF NATUAL RESOURCES MANAGEMENT

LAKEHEAD UNIVERSITY

THUNDER BAY, ONTARIO

May 10th, 2024

Biodiversity Loss Due to the Increase of Monoculture Lawns

by
Kalila Scott

An Undergraduate Thesis Submitted in
Partial Fulfillment of the Requirements for the
Degree of Honours Bachelor of Environmental Management
(or Degree of Honours Bachelor of Science in Forestry)

Faculty of Natural Resources Management
Lakehead University
May 10th 2024

_____ Major Advisor

_____ Second Reader

LIBRARY RIGHTS STATEMENT

In presenting this thesis in partial fulfillment of the requirements for the HBEM degree at Lakehead University in Thunder Bay, I agree that the University will make it freely available for inspection.

This thesis is made available by my authority solely for the purpose of private study and research and may not be copied or reproduced in whole or in part (except as permitted by the Copyright Laws) without my written authority.

Signature: _____

Date: May 10th, 2024

A CAUTION TO THE READER

This HBEM thesis has been through a semi-formal process of review and comment by at least two faculty members. It is made available for loan by the Faculty of Natural Resources Management for the purpose of advancing the practice of professional and scientific forestry.

The reader should be aware that opinions and conclusions expressed in this document are those of the student and do not necessarily reflect the opinions of the thesis supervisor, the faculty or Lakehead University.

ABSTRACT

Lawns have evolved over time, starting as functional spaces in medieval gardens to appearing as the manicured, European-inspired landscapes we know today. The widespread use of monoculture lawns in North America signifies a shift towards a curated environment. These lawns come with consequences for biodiversity due to intensive maintenance like frequent mowing, chemical treatments, and watering. This study explores the history of lawns, the impact of maintenance on biodiversity, and potential sustainable lawn care approaches. This thesis highlights the negative impacts of having monoculture lawns, such as reducing insect populations, disrupting soil quality, and polluting water ecosystems with chemicals. It emphasizes the need for society and municipal regulations to shift towards more eco-friendly lawn management practices. This review stresses the importance of addressing the downsides of monoculture lawns through proactive measures and exploring sustainable alternatives.

TABLE OF CONTENTS

ACKNOWLEDGEMENTS

I would like to express my deepest gratitude to my thesis advisor, Keri Pidgen-Welyki, for their support, invaluable guidance, and continuous encouragement through this research journey. Their expertise, patience, and constructive feedback have been instrumental in shaping this thesis and refining my academic skills. I am also immensely thankful to my second reader Dzhamal Amishev for dedicating their time to reading over my final paper and signing off as my second reader. Thank you to Lakehead for providing me with the resources, facilities, and opportunities necessary for conducting this research. The supportive environment fostered by the department has been crucial in facilitating my academic growth and development. I want to express my deep gratitude to my family for always supporting me with love, encouragement, and belief in my abilities. Their unwavering support has been a pillar of strength and motivation during this journey. Lastly, I am thankful to my friends and colleagues for their encouragement, understanding, and support through all the highs and lows of this academic pursuit. Their friendship and support have truly made this experience memorable.

FIGURES

INTRODUCTION

Urban sprawl is the uncontrolled spread of urban areas due to development and has become a growing issue in modern times (Johnson 2001). Natural systems are rapidly being replaced by cities and farmland to accommodate the human population (Johnson, 2001). Due to this there has been a decline in biodiversity within these areas (Sushinsky et al 2012). Lawns contribute to this loss for various reasons including habitat loss and fragmentation (Robinson 2012). Lawns have evolved over time and are commonly found as monocultures in todays day and age (Robbins and Birkenholtz 2003). They were once seen as a symbol of wealth and privilege but now dominate urban environments, affecting biodiversity and ecosystem health (Sushinsky et al 2012). This thesis looked at the historical roots, ecological impacts and management strategies of lawns while maintaining focus on biodiversity. Despite growing interest in sustainable lawn management, we are still in a transitional stage as a society (Burns 2012; Sushinsky et al 2012). In this stage we are partaking in and feeling the effects of different industrial mindsets while trying to move forward with the knowledge we are obtaining through new studies on sustainability (Burns 2012).

Biodiversity studies show that lawns displace native species and favour invasives that are better adapted to urban settings (Simmons et al 2011; Hayes et al 2023). Within the urban environment it also is common to see a biodiversity decline in adjacent and nearby aquatic ecosystems (Kozlowski and Bondallaz 2012). In particular, high-intensity lawn management has noticeable negative effects on both plant and invertebrate species, which causes disruptions in essential ecological processes such as pollination and seed dispersal (Watson et al 2019). The use of biological indicators can help us assess the impact of lawns on species diversity, ecological

redundancy, and ecosystem services (Parikh et al 2020). Overall, this thesis emphasizes the needs for sustainable lawn management practices that promote biodiversity conservation and restoration in urban environments by understanding the historical trends and ecological implications of monoculture lawns.

OBJECTIVE

The objective of this paper was to demonstrate through the literature how monoculture lawns impact biodiversity by exploring their historical roots, ecological impacts, and sustainable lawn practices.

Commented [DA1]: I guess you mean "how" instead of "now"

HYPOTHESIS

Monoculture lawns have a negative impact on biodiversity by reducing species diversity compared to original landscapes or more ecologically sound lawn management practices.

LITERATURE REVIEW

History and Evolution of Lawns

Human history shaped the world we see today. Understanding it means that we can better comprehend the systems in place and where they came from. This is true for the presence of lawns across North America. We didn't always have the expansive green areas we know today as lawns, the area of our properties that act as a border between our private homes and the outside world. An area to lounge, play games and tend to. In fact, from the 11th-15th century during the medieval period, people of all status took pride in growing their own food(reference). Their medieval gardens contained herbs, vegetables, fruits, flowers and grains (Landsberg 2004; Figure 1).

Figure 1. The Medieval Garden (Landsberg 2004)

By the late 15th century, Renaissance gardens were established in Europe (Turkan and Köksaldı 2021). These gardens featured geometric designs and symmetrical plantings which were popular during this period. They were admired as art pieces (Turkan and Köksaldı 2021; Figure 2).

Figure 2. Renaissance gardens of the Villandry (Renaissance gardens of Villandry 2018)

By the early 17th century, the Renaissance period had come to an end and a new modern era began (Gaudio 2020). Lawns as we know them today, featuring short mown grass, came about in the 18th century, originating in France and England through the English Landscaping Movement (Brown and Williamson 2016). Lancelot "Capability" Brown was a famous English landscaping artist renowned for his interpretation of what a lawn should look like (Brown and Williamson 2016; Figure 3). He was a large influence on today's monoculture lawns as he was obsessed with smoothing out the wildness of nature and having a controlled green space (Bormann F.H et al 2001).

Figure 3. Lawn design by famous English landscaper Lancelot "Capability" Brown (Lancelot "capability" brown, n.d.)

Commented [KP2]: Does this have a name?

Commented [KP3]: Put reference here instead

It was around this same time that Britain was colonizing America and so their ideas about nature and landscaping were brought over as well (Bormann et al 2001; Brown and Williamson 2016). Thomas Jefferson was one of the first to replicate the European lawn and so, wealthy U.S landowners quickly followed suit (Bormann et al 2001; Robbins 2008). Until the mid-nineteenth century it was only common for the rich to have maintained lawns while everybody else stuck with their "messy" yards filled with vegetables, herbs and weeds. This is because lawns require time, energy and money to maintain (Bormann et al 2001; Robbins 2008; Watson et al 2019). They were seen as a privilege to have and so, as technology advanced so did the opportunity for more Americans to be able to upkeep their lawn. With the perception of wealth and status in mind, many Americans jumped at the opportunity to have a green, cleared out space. By the mid-twentieth century lawns were an integral part of the lives of all Americans (Bormann et al 2001; Robbins 2008).

Figure 4. Typical North American Lawn (Fisher 2018)

Commented [KP4]: Be consistent in your reference style use (last name, date)

Commented [KS5R4]: I always use last name and date but for some of the few non-scientific sources I used for random or specific points that were harder to find scientific sources for, there didn't seem to be an author. Are these unusable then?

In 1962 Rachel Carson published her famous book Silent Spring. This book got the ball rolling on environmental awareness as she brought up many issues relating to the use of the chemicals being used to aid in humanities control over nature (Carson 2022). Now, there is more information about lawns and how to minimize one's environmental impact when managing one (Pooya et al 2013; Ignatieva et al 2015, 2020; Paudel and States 2023). The idea of planting more native species to increase species diversity and reduce water usage are in the minds of more people today than in previous decades (Pooya et al 2013; Survis and Root 2017; Toro and Ribbons 2020).

Commented [DA6]: Did you mean "today THAN in previous decades"?

Figure 5. Modern approach to more sustainable lawns (Cubie 2022)

However, change takes time and the effects that monoculture lawns have had on biodiversity over these many years of human development continue to be studied. When it comes to spreading information and implementing actions based on research, there is often a lag (Bandura 2009). When researchers identify issues such as the negative effects of monoculture lawns on

biodiversity, it takes time for that knowledge to reach a wider audience, including policymakers, landscapers, and homeowners (Larson et al 2015). Even after awareness spreads, it takes time for individuals and organizations to act and implement changes and this delay in action is evident in various environmental policy cases (Larson et al 2015; Karlsson and Gilek 2020). Despite existing knowledge of the negative impacts of monoculture lawns on biodiversity, there is always more to discover. A wide range of knowledge is essential for creating successful solutions to reduce any harmful effects and encourage landscaping practices that support biodiversity (Ignatieva et al 2020). The aesthetic and functionality of lawns have fluctuated over the years as people follow the current trends of their time (Bormann et al 2001). Trends can, however, be influenced by current research and awareness (Ferguson and Bargh 2004). The evolution of lawns varies in various parts of the world however this literature review, research on North American biodiversity will be the focus.

Biodiversity Impacts of Lawn Maintenance

Three main practices go into maintaining a monoculture lawn: mowing, chemical usage, and watering (Robbins 2008; Ignatieva et al 2015). All three practices have some sort of impact on biodiversity and should be replaced or redesigned with sustainable alternatives in mind (Ignatieva et al 2015; Paudel and States 2023).

Insects are important biodiversity indicators due to their abundance and diversity, ecological roles and influence on agriculture, human health, and natural resources (Geoffrey and Scudder 2017). Insects make up more than 50% of the species composition on the planet, at over one million insect species overall (Purvis and Hector 2000; figure 6). They are very sensitive to their surrounding environment, making them incredible bioindicators for any environmental and anthropogenic changes (Parikh et al 2020). In ecology, insects have many valuable ecological

functions such as pollinating flowering plants, essential for reproduction and food production, (Kevan and Baker 1983; Geoffrey and Scudder 2017). They act as decomposers, decaying organic matter into readily available nutrients boosting various other organisms' growth (Yang and Gratton 2014). They also serve as a food source for many other species (Humbert et al 2021). So how do lawns contribute to negative impacts on insect biodiversity?

Mowing is a common lawn maintenance practice known to have detrimental effects on insect populations by limiting their food sources and shelter (Humbert et al 2021; Proske et al 2022). This leads to declines in insect populations which then has a cascading trophic effect on all other species relying on insects for their food source or other ecological functions (Yang and Gratton 2014; Smith et al. 2015; Geoffrey and Scudder 2017). Insects help manage pest species, aid in nutrient cycling, pollination, and seed dispersal and are overall an integral to maintaining healthy, resilient and thriving ecosystems (Prather et al. 2012; Geoffrey and Scudder 2017; Klink et al. 2019; Humbert et al. 2021). When insects are threatened other species such as birds, mammals and plants are impacted as well (Geoffrey and Scudder 2017).

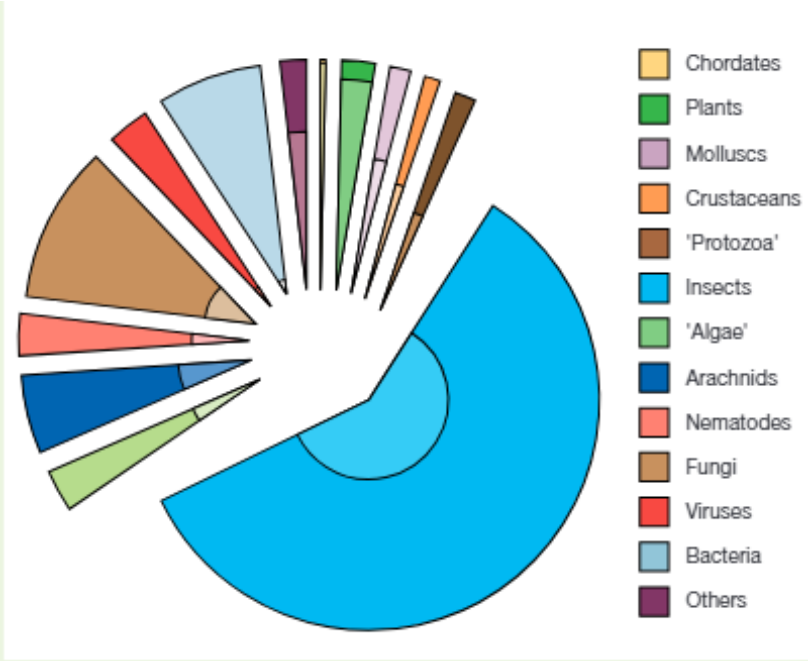

Figure 6. Species Composition on the Planet (Purvis and Hector 2000)

Understanding the relationship between insects, plants and soil microbial communities is important because they have an interconnected relationship with one another (Heinen et al 2018). Where one thrives or struggles the others usually follow through their reciprocal interactions. This means where one is impacted by a disturbance, such as lawn mowing, the others are likely to be impacted as well (Heinen et al 2018). This disturbance may further the collapse of ecosystem functions in an already disturbed, homogenous environment (MacDougall et al 2013).

There is a lot that insects do in the soil ecosystem. Beetles, ants and termites help in breaking down organic material, which includes old plant parts or remains of dead animals, into tiny particles during their feeding and decomposition processes (Ulyshen 2014). This accelerates organic matter decomposition and releases elements such as nitrogen, phosphorus and potassium

into the soil that can then be taken up by plants, enhancing their growth as well as productivity levels (Harmon et al 1999; Ulyshen 2014). Some insects, such as ants, beetles, bees and wasps both mature and larvae, burrow underground creating tunnels that help air, water and nutrients to move around while also allowing soil structure becomes stronger and more porous, which leads to easier water penetration and better drainage (McColloch and Hayes 1922). This allows for plant roots to go down deeper into the soil better and get more nutrients out of it (Harmon et al 1999). Organic materials coming from dead plants, animals or excrement that come from burrow insects through their holes makes the soils richer because they provide nutrients that increase soil fertility (McColloch and Hayes 1922; Ulyshen 2014).

Without insects our crops would not grow, and many other taxonomic groups would struggle to reproduce and survive due to insects' relationships to plant and soil microbial communities (Yang and Gratton 2014, Figure 7). Soil-dwelling insects like predatory beetles, hoverflies and spiders' prey on harmful pest insects that destroy crops or harm plants, furthering their beneficial relationship with each other (Arnold et al 2021). Research shows that insects also have a mutually beneficial relationship with rhizobia bacteria (Nitrogen fixing bacteria) as well as their symbiotic legume plants (Kempel et al 2009). Rhizobia fixes atmospheric nitrogen into a useable form for plants, indirectly benefiting insect herbivores by improving nutritional quality of the plant (Kempel et al 2009). Essentially, plants provide food and shelter for insects, which then help maintain nutrients and soil structure within the soil, which than helps soil microorganisms thrive (Figure 7). These microorganisms then help with nitrogen fixation for plants . These are just some reasons to why the interconnectedness of microbial, insect and plant communities are important to soil ecosystem health and why it is imperative that attempts are made, and measures are put in place towards the conservation and improvement of this relationship.

Commented [KP7]: Both mature and larvae may do this

Commented [KP8]: This is oversimplified. There is a lot to be said about what has been alluded to in this sentence. This requires more depth and explanation

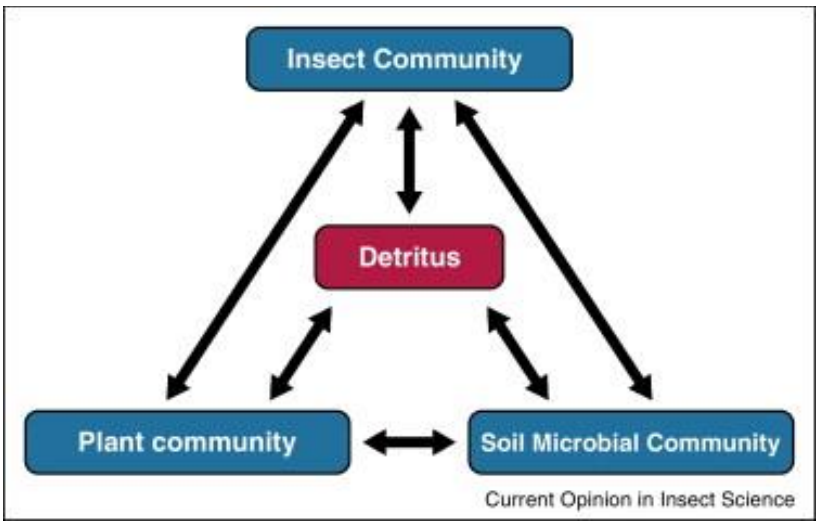

Figure 7. Reciprocal interactions between soil, plant and insect communities (Yang and Gratton 2014)

Species richness, abundance and genetic diversity are all good indicators of biodiversity (Biggs et al 2007). They can be measured using different diversity indices, such as the Shannon-Weiner Species Diversity index and the Simpson's diversity index (Biggs et al 2007; Tasser et al 2008). The Shannon-Weiner index considers both species richness and evenness allowing for less abundant species to still be accounted for (Nolan and Callahan 2005). The Simpson's diversity index is more concerned with dominance, variations in abundance and intuitive interpretation (He and Hu 2005). These two indices are commonly used together for species diversity measurements to provide a more accurate output of data (Fedor and Zvaríková 2019). Other diversity indices include the Fisher Alpha Index, Berger and Parker Dominance Index, Brillouin Index, and the McIntosh U Index (Fedor and Zvaríková 2019).

Commented [DA9]: Spelling I found was Weiner (instead of Wiener):
https://bio.libretexts.org/Workbench/General_Ecology_Ecology/Chapter_22%3A_Biodiversity/22.5%3A_Measuring_Biodiveristy
https://www.ableweb.org/biologylabs/wp-content/uploads/volumes/vol-27/22_Nolan.pdf

Intensely mowed lawns reduce biodiversity by reducing species richness, abundance, and genetic diversity of insects (Bonari et al 2017; Unterweger et al 2017; Lerman et al 2018; Sehrt et al 2020; Toro and Ribbons 2020; Wintergerst et al 2021; Proske et al 2022; Figures 8-13). When it comes to species richness, vegetative structures like tall grasses and wildflowers provide a diverse habitat for different kinds of insects to thrive when they are not mowed down, contributing to a richer ecosystem (Unterweger et al 2017; Sehrt et al 2020; Toro and Ribbons 2020; Figure 8-10).

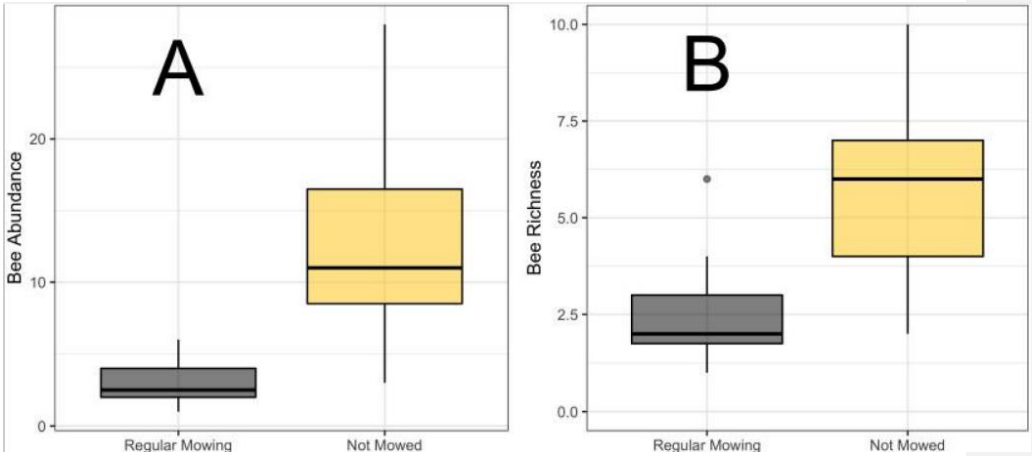

Figure 8. Bee richness and abundance in mowed vs unmowed lawns (Toro and Ribbons 2020).

Reduced mowing also allows for a wider range of plant species to take root, that would otherwise not have the chance to due to disturbance from mowing (Chollet et al 2018; Sehrt et al 2020; Figure 9).

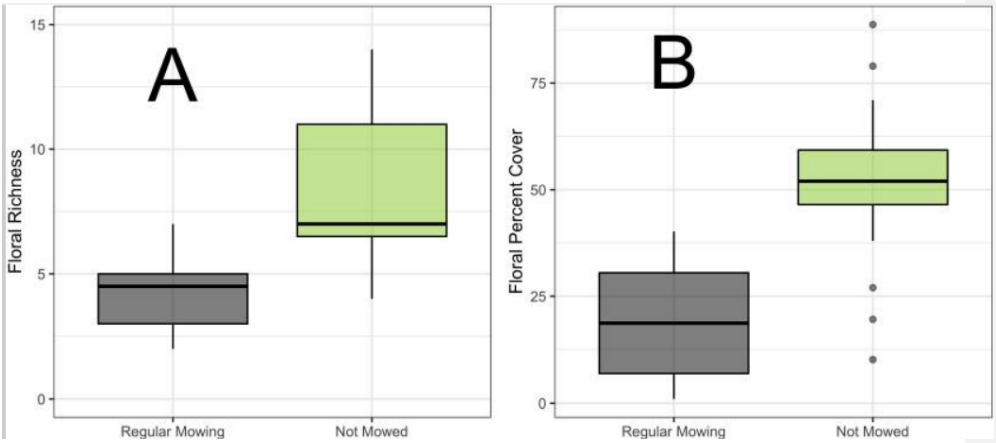

Figure 9. Plant richness and floral percent cover in mowed vs unmowed lawns (Toro and Ribbons 2020).

This further increases species richness by providing more resources and habitats for different kinds of organisms that would usually not be able to thrive under a disturbed and homogenized lawn setting (Sehrt et al 2020; Proske et al 2022). Undisturbed meadow environments show significantly higher rates of both individual insects and number of different species when compared to intensely mowed lawns (Unterweger et al 2017; Figure 10).

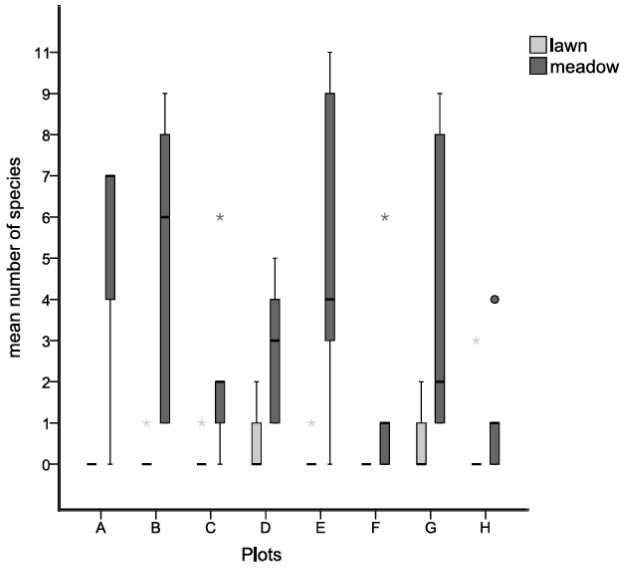

Figure 3: Comparison of the total number of species between intensely and extensively mowed areas (for an explanation of abbreviations, see Fig. 1). Black bars: extensively mowed meadow. Grey bars: intensely mowed lawn. WILCOXON-Test, n=6, A: p = 0.039; B: p = 0.027; C: p = 0.039; D: p = 0.042; E: p = 0.042; F: p = 0.102; G: p = 0.042; H: p = 0.336. (A, B, C, D, E and G = significant). * extreme values and ° outliers are all included in the statistical tests.

Figure 10. Species richness in lawn vs meadow environments (Unterweger et al 2017)

Intensely mowed lawns reduce biodiversity by reducing species abundance (Braschler et al 2009; Smith et al 2015; Lerman et al 2018; Wintergerst et al 2021; Proske et al 2022; Figure 8). Not only do diverse habitats harbour more kinds of species, but they can also support more individuals of various species due to an increase of useable habitat and resources (Lerman et al 2018). When a lawn is intensively mowed it takes away the habitat and resources that insect populations need to thrive (Smith et al 2015; Unterweger et al 2017; Lerman et al 2018; Wintergerst et al 2021; Proske et al 2022). Species found in abundance in meadow environments are typically found in low abundance in a lawn environment, supporting the fact that lawns are a heavily disturbed habitat (Unterweger et al 2017).

Number of individuals are important; however, it is the diversity of species and abundance of individuals within each species that are important for overall biodiversity and the functionality of ecosystems (Unterweger et al 2017). Monocultures support species that are adapted to a homogenous habitat (Lerman et al 2018, Wintergerst et al 2021). Non-winged, pest, and ground species all exhibit the opposite effects and have a negative response when reduced mowing regimes are adopted (Proske et al 2022; Figure 9). This could be due to them preferring homogenous habitats as well as increase of various predator species being able to control their numbers more effectively (Wintergerst et al 2021).

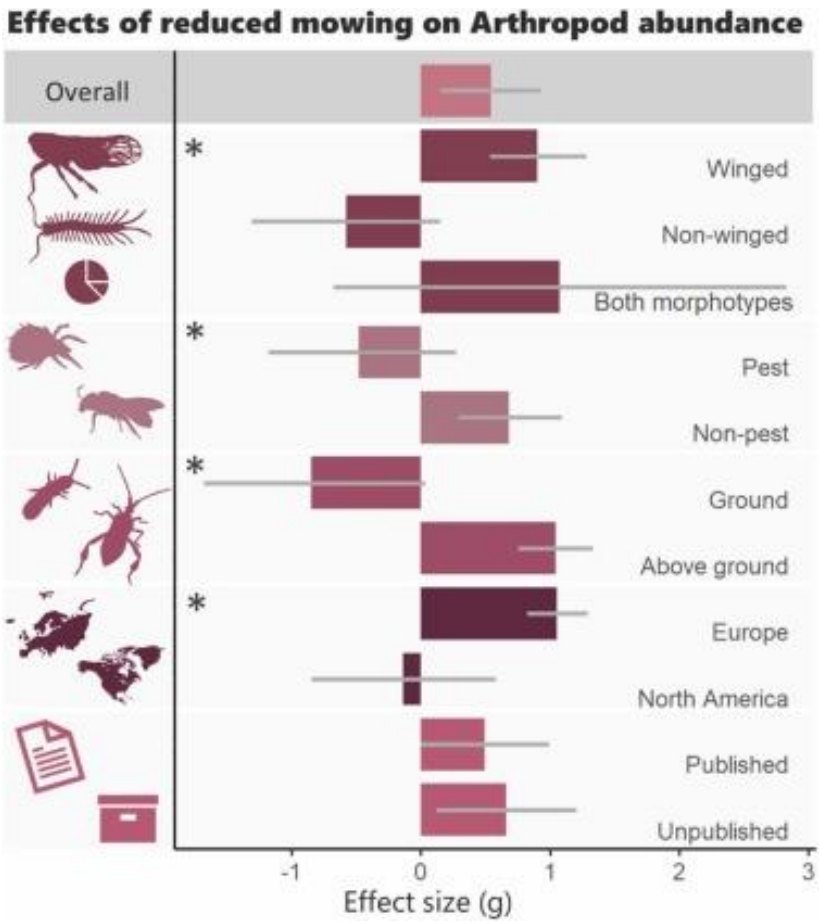

Figure 11. Effects of reduced mowing on arthropod abundance. Effect size measures the strength of the relationship between two variables in a population. Zero means no change, positive numbers indicate an increase in abundance and negative numbers indicate a decrease in abundance.(Proske et al 2022)

Commented [KP10]: Please use the caption to explain the graph further - what is effect size (g); explain how zero means no change, and the positive number means an increase in abundance etc.

The effect of mowing varies between taxonomic groups. This is thought to be due to reasons such as adaptability, resistance to disturbed habitats and ability to thrive or avoid disturbance through flight (Unterweger et al 2017; Wintergerst et al 2021; Figure 10).

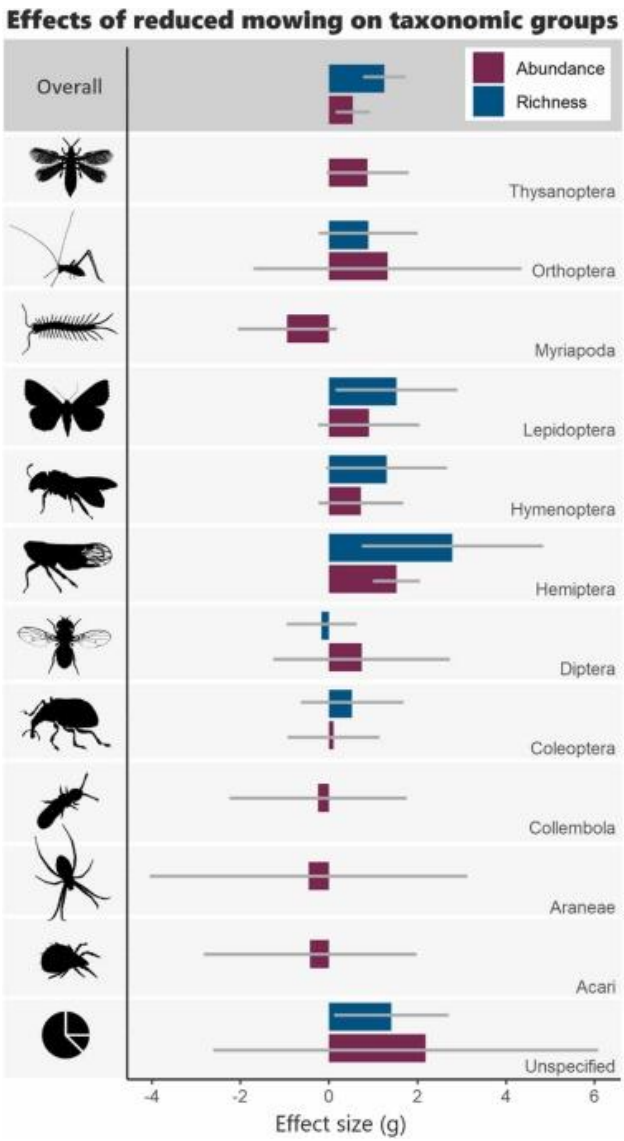

Figure 12. Effects of reduced mowing on taxonomic groups (Proske et al 2022)

It is important to note, however, that abundance does not equal diversity (Duelli and Martin 2003). This can be seen more in a study looking at urbanization and spider diversity in the Phoenix area. It was found that lawns and agricultural fields harboured the lowest species diversity in comparison to urban desert parks, urban desert remnants, industrial and xeric yards (Shochat et al 2004). They did however have some of the highest species' abundances (Shochat et al 2004). This is because the homogenous nature of these land covers provides ideal habitat for specific and few species (Shochat et al 2004; Lerman et al 2018, Wintergerst et al 2021). This allows them to thrive without any competition and increase in numbers. A high abundance of a limited number of species, however, is not a biodiverse environment (Gotelli and Colwell 2001; Shochat et al 2004; Dornelas 2011).

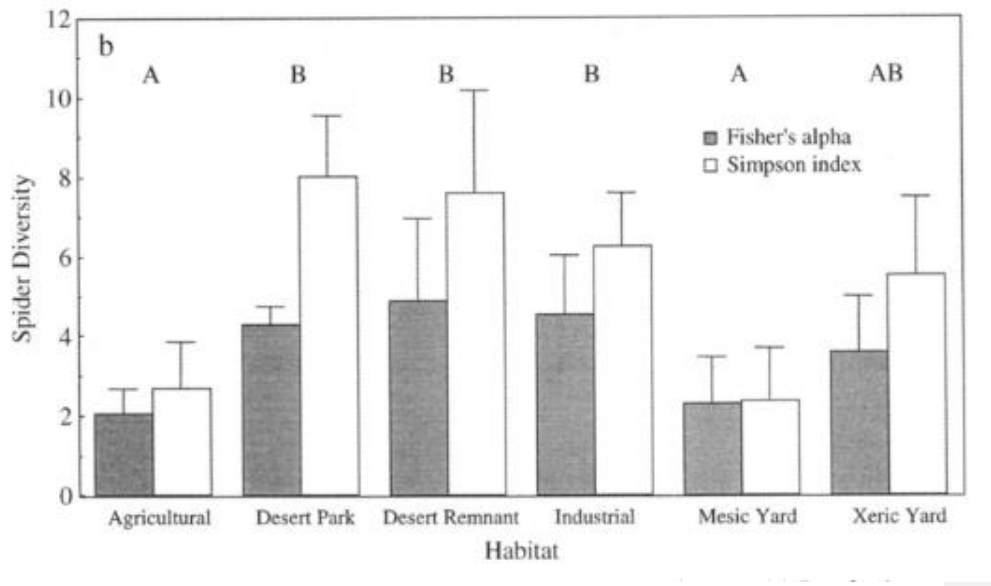

Figure 13. Spider diversity in different environments (Shochat,et al 2004)

Confusion between abundance and richness can cause misinterpretations in biodiversity assessments. Monoculture land covers may provide adequate habitat and resources for very specific species, however, they become unusable for many other species (Hostetler and McIntyre 2004). Species that thrive in these monocultures then become abundant because they have no more competition which may also explain how pest species could potentially increase in a homogenous environment (Hostetler and McIntyre 2004; Wintergerst et al 2021).

With cities replacing natural areas, lawns can play an important role in landscape connectivity and can act as corridors or stepping stones within city environments if maintained properly (Bertoncini et al 2012; Ignatieva et al 2015). Homogenous landscapes lead to reduced genetic diversity within fragments due to limited habitat variation, restricted gene flow and edge effects (Vandergast et al 2006; Johnson and Munshi-South 2017). However, if everyone had a lawn with an ecological purpose, they could serve as natural reserves protecting lost genetic variation (Bertoncini, 2012). Urban development causes habitat loss and fragmentation (Irwin and Bockstael 2007; Fenoglio et al 2021). Homogenous and fragmented landscapes like the lawn lead to reduced genetic heterogeneity which can impact the resiliency of different insect species (Vandergast et al 2006; Vandergast et al 2009; Fenoglio et al 2021). This ultimately leads to their population decline, reducing biodiversity within the city. (Vandergast et al 2006; Vandergast et al 2009; Fenoglio et al 2021).

Commented [KP11]: Why?

Chemicals such as herbicides, pesticides, and fertilizers have been used for over 50 years to maintain lawns (Joyce 1998). They are the second main lawn maintenance practice that will be discussed in this paper due to their impacts on biodiversity. Ever since Rachel Carsons' book Silent Spring came out in 1962 there has been more of an awareness of chemicals and their impacts (Carson 2022). However, we are still absorbing and dealing with those facts to this day.

Commented [KP12]: Redundant.

Awareness is a slow-moving force and even slower are the actions that come with it. Although the world is attempting to move forward more sustainably every day, the sale, use and lack of awareness around these chemical practices are still prevalent (Joyce 1998: Robbins et al 2001). Up to 80 million pounds (36-37 million kilograms) of pesticide ingredients are used on lawns every year in the United States (Meftaul et al 2020). A huge driver of this is that the strong demand for an aesthetic lawn is still prevalent (Held and Potter 2011). Meftaul et al 2020). Different chemicals such as insecticides, fungicides and herbicides indirectly impact pollinator species and predator parasitoids (Figure 14).

Commented [DA13]: Convert to metric units or at least provide equivalent in parentheses.

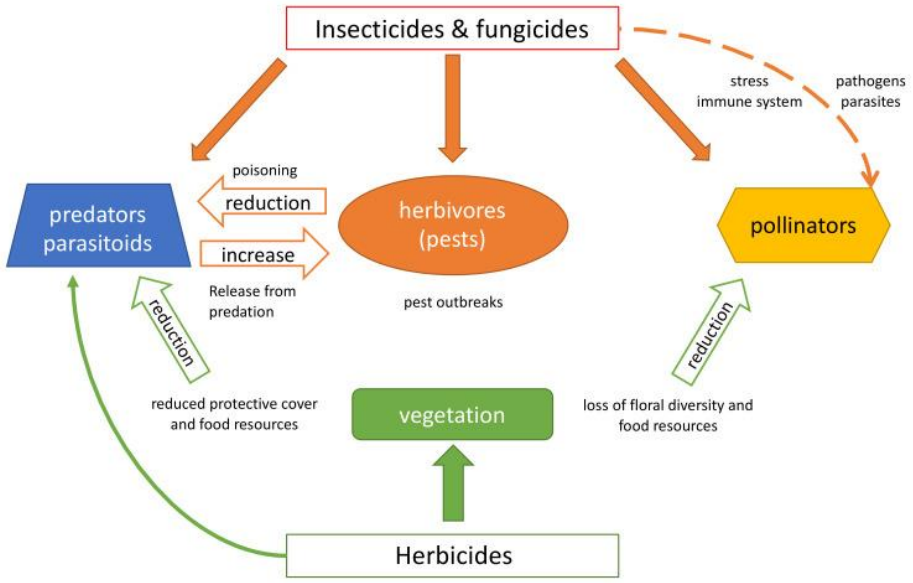

Figure 14. Effects of pesticides on terrestrial arthropods (Sánchez-Bayo 2021)

For example, herbicides contribute to the loss of floral diversity and food resources ultimately reducing pollinator numbers even though pollinators were not the direct target (Sánchez-Bayo 2021;). Pollinators are also indirectly impacted by insecticides and fungicides by stressing their

immune systems (Robbins 2008; Toro and Ribbons 2020; Sánchez-Bayo 2021;). Herbicides also reduce protective cover and food resources for predator species that usually help control pest populations and insecticides and fungicides reduce predatory arthropods which can also contribute to the increase of pest species (Sánchez-Bayo 2021;).

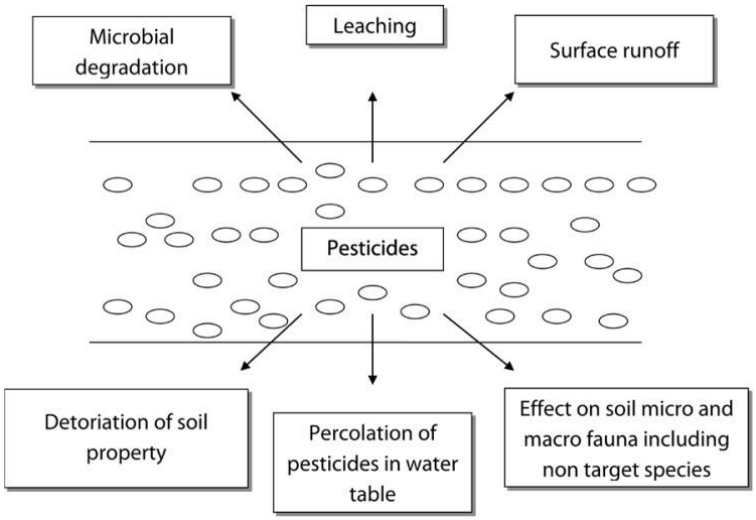

Figure 15. Pesticide effects on soil health (Miglani and Bisht 2019)

The intricate effects of chemical usage and their impacts on ecosystems can be complex. This complexity is what makes it hard to predict the full impacts that a lawn management practice, such as chemical use, can have on an ecosystem (reference). As discussed, insects serve as important ecological players and indicators for biodiversity so the quality of the soil and plants they rely on for food and shelter are also crucial to ecosystem health. Healthy soil allows growth for plants that provide ecological benefits to other species (Heinen et al 2018). Chemicals can cause a decline in beneficial soil microorganisms, which then negatively impacts all other species relying on the soil for ecosystem services such as plants and insects (McColloch and

Hayes 1922; Harmon et al 1999; Kempel et al 2009; Ulyshen 2014; Heinen et al 2018; Miglani and Bisht 2019; Arnold et al 2021; Figure 16).

Overall, lawn care involving chemical usage leads to a decrease in biodiversity by disrupting ecosystems, contaminating soil, reducing habitat availability for beneficial soil microbes and insects, harming pollinator populations and promoting invasive species (Joyce 1998; Hernke and Podein 2011; Aronson et al 2017; Miglani and Bisht 2019; Sánchez-Bayo 2021).

Soil is not the only environmental element experiencing contamination due to lawn care practices. Watering is the third main lawn maintenance practice that this paper will discuss. Water usage in lawn care is closely linked to adverse affects on biodiversity due to the runoff that moves harmful chemicals into surrounding aquatic systems (Robbins et al 2001; Conners and Black 2004; Overmyer et al 2005; Weston et al 2005). These systems can include ponds, streams and rivers running through urban areas. Whether through direct watering or rainfall, the water cycle plays a significant role in moving lawn chemicals to surrounding bodies of water where they degrade water quality and cause harm to aquatic organism's systems (Robbins et al 2001; Conners and Black 2004; Overmyer et al 2005; Weston et al 2005).

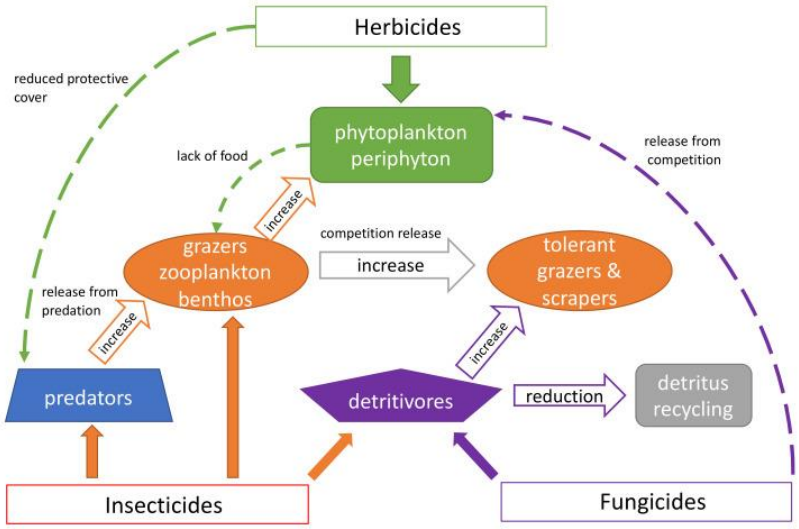

Figure 16. Effects of pesticides on aquatic species (Sánchez-Bayo 2021)

Insecticides negatively impact aquatic arthropods and can reduce predator populations such as dragonfly nymphs, which then indirectly cause tadpole species to increase and can cause trophic cascades and impact water quality (Overmyer et al 2005; Sánchez-Bayo 2021; Figure 17). Fungicides are toxic to aquatic organisms, increase phytoplankton abundance due to reduced predation from susceptible species and disrupt saprophytic function in aquatic ecosystems impacting nutrient cycling (Zubrod et al 2019; Sánchez-Bayo 2021; . Herbicides decrease the abundance of grazing invertebrates by reducing phytoplankton or periphyton, affecting food webs, and reduce macrophyte biomass which then limits the available shelter for predatory insects (Sánchez-Bayo 2021;). Essentially, these run-off chemicals harm aquatic systems by interfering with their natural balance and function (Robbins 2001; Conners and Black 2004; Overmyer et al 2005; Weston et al 2005; Zubrod et al 2019; Carson 2022).

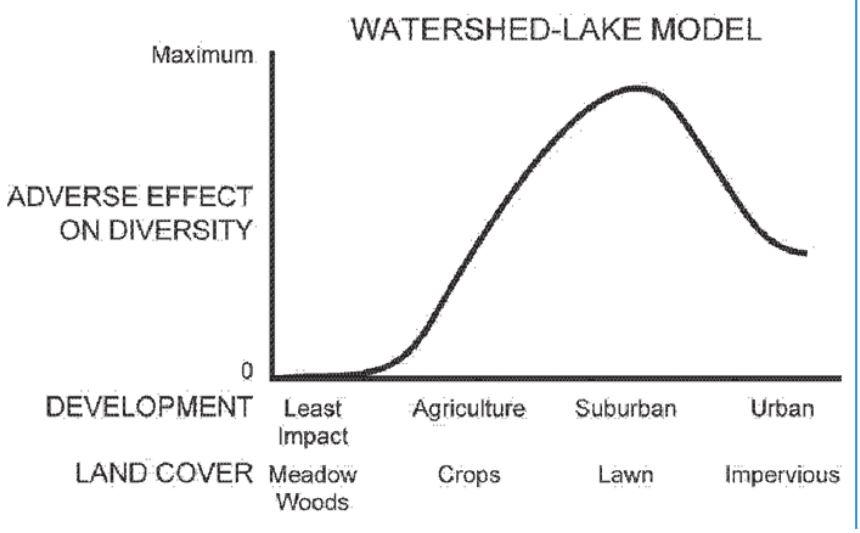

Figure 17. Correlation between watershed cover and productivity of the ponds (Dodson 2009)

When looking at the correlation between watershed cover and the productivity of the ponds, one study found that land cover was seen to be a better predictor of pond biodiversity than primary productivity (Dodson 2009; Figure 18).

Lawn land cover had the greatest adverse effects on surrounding bodies of water in comparison to meadow woods, crops and impervious surfaces (Dodson 2009; Figure 18). Indicator species used in this study were zooplankton, submerged macrophytes, mollusks, spring and summer amphibians as well as fish. Intensively managed lawns were strongly correlated with low diversity or with the absence of at least five of the taxonomic groups as can be seen in the figures above (Dodson 2009). Diversity was measured by species richness as well as species abundance and whether groups were present or absent. Water quality measures were also considered. For

Commented [KP14]: Try to get a screen clipping instead. This is too blurry.

lawn and agriculture land covers chemical levels were much higher, resulting in the reduction of aquatic diversity (Dodson 2009; Figure 19). Amphibians and reptiles living in cities and suburbs encounter many different harmful substances, a main one being lawn chemicals, which harm their health and make it harder for them to survive ultimately leading to their decline in biodiversity (Rouse et al 1999; Relyea 2005; Croteau et al 2008; Dodson 2009; Sánchez-Bayo 2021).

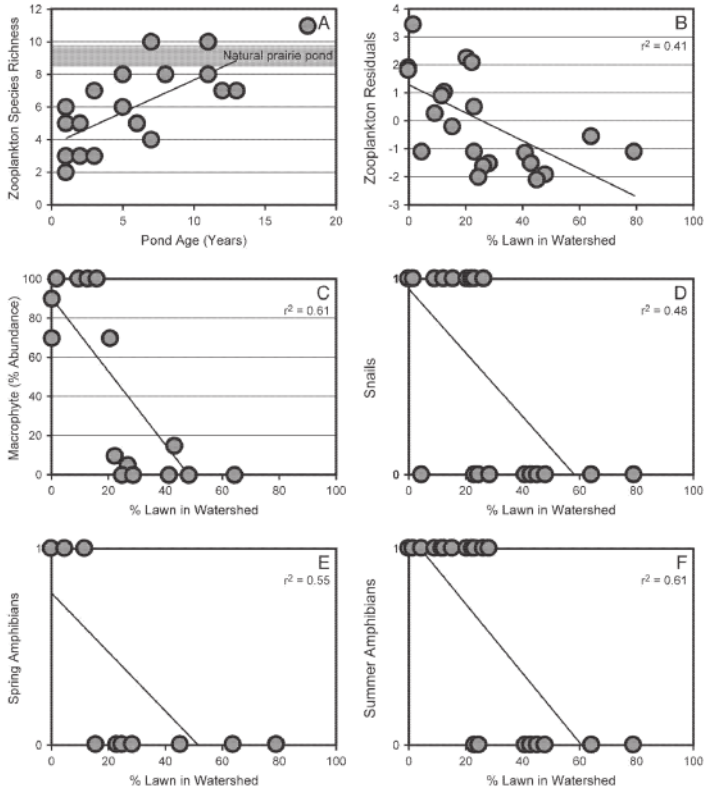

Figure 18. Pond indicator species for biodiversity (Dodson 2009)

The interconnectedness of air, soil, and water means that any action affecting one will inevitably impact the others, mirroring the intricate relationship among insects, plants, and soil microbes. When chemicals are applied to lawns they may get washed away into surrounding bodies of water (Rouse et al 1999; Relyea 2005; Croteau et al 2008; Dodson 2009; Sánchez-Bayo 2021). From there they may evaporate into the air contributing to air pollution and then rain back down on our landscapes. It is a toxic cycle that impacts biodiversity along the way.

Commented [DA15]: These three sentences could be lumped into one for better flow and connectivity.

Sustainable Lawn Management

Mindful planning and management of urban green spaces (UGS) such as lawns have to potential to play an important role in the conservation of global biodiversity (Aronson et al 2017; Burr 2018; Chollet et al 2018). One way to do this is through lawn management practices that support diverse plant and insect communities which in turn will support other wildlife species (Smith 2015; Aronson et al 2017; Chollet 2018). Since traditional lawn management practices cause many negative impacts on biodiversity, changing how we manage lawns can be the key to conserving biodiversity within urban environments (Aronson et al 2017). One major challenge is the social and cultural pressures that did not disappear after the era of Lancelot "Capability" Brown. The mindset of having a maintained lawn to be seen as wealthy and prestigious may have dissipated as equality among the masses increased but these pressures remain prevalent through societal aesthetic standards and policies (Bormann et al 2001; Grewal 2012). In fact, many by-laws state that lawns must be maintained to a certain standard to uphold house property values and keep communities happy by upholding certain aesthetics (Larson et al 2020; Marshall et al 2020; Robbins et al 2001; Robbins and Sharp 2004; Feagan and Ripmeester 2001, 2013 and Nassauer 1997). A common theme from these studies was that municipal authorities have the power to help influence the way people perceive lawns by changing their language and

guidelines around lawn management. Instead of focusing on minimizing potential tripping risks from overgrown vegetation, we must instead focus on the benefits of more eco-friendly lawns. These include sociability, improved mental health and of course, an increase in biodiversity (Marshall 2020). People are more likely willing to adopt sustainable lawn management practices if they aren't afraid of getting into trouble with municipal governments or of social pressures from neighbours (Larson et al 2020; Marshall et al 2020; Robbins et al 2001; Robbins and Sharp 2004; Feagan and Ripmeester 2001, 2013 and Nassauer 1997). Monoculture lawns tend to favour "pest" species (Dorsey 2011; Proske 2022). This is interesting because one big reason there is social pressure to maintain lawns is to avoid the diseases that can come with pests (Dorsey 2011). Another common theme coming from many of these studies is that we must start dismantling this belief that a lawn cannot both be ecologically beneficial and aesthetically pleasing at the same time. If this shift of mindset occurs, homeowners may be more willing to support biodiversity through their lawns.

As intensive mowing is one of the common lawn practices that negatively impacts biodiversity, one way to minimize its effects would be to alter our mowing regimes. Reduced mowing can either be reduced frequency or cutting to different heights. Species richness and abundance of native species were commonly found to increase when mowing was reduced while that pest species richness and abundances were negatively impacted (Braschler et al 2009; Smith 2015; Bonari et al 2017; Lerman et al 2018; Watson et al 2019: Sehrt et al 2020; Wintergerst et al 2021; Proske 2022; Figure 20).

Commented [KP16]: Order by date (if same year then secondly by name)

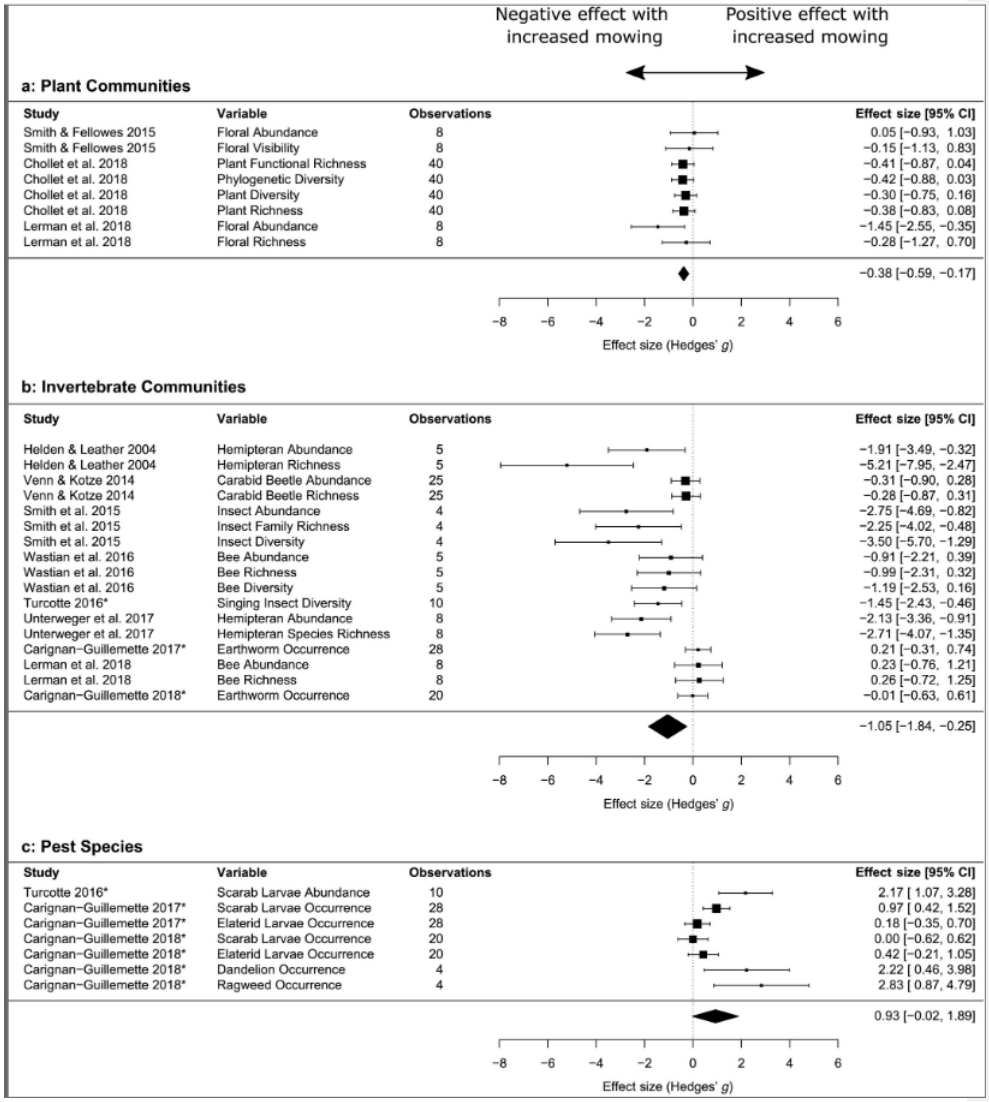

Figure 19. Impact of altered mowing regimes on species diversity (Waston et al 2019)

Chemical usage was seen to be another big contributor to biodiversity loss when it comes to traditional lawn care practices. It is starting to become common knowledge that overusing

pesticides, herbicides or insecticides can have the opposite desired affected (Hernke and Podein 2011). Chemical controls work quickly for a brief period then become challenging to keep up as nature is always adapting and are harmful to the environment (Hernke and Podein 2011). More sustainable practices are seen to be more effective over the years while doing less harm (Hayk and Guzhen 2014). A few sustainable practices include minimizing chemical usage in the first place, biological controls or integrated pest management, reduced mowing and planting native plants (Helfand et al 2006; Simmons et al 2011; Pooya et al 2013; Zhang et al 2015; Vlaiculescu and Varrone 2022 and Baldi et al 2023). It is essential to reduce the use of chemicals and focus on using organic and natural alternatives to pesticides and fertilizers (Zhang et al 2015). Integrated pest management strategies can also be used to effectively control pests while minimizing harm to the environment from chemicals (Grewal 2012).

Adjusting mowing techniques by cutting the grass at higher lengths or using mulching mowers can help the grass grow stronger and also decrease the need for chemical fertilizers (Chollet 2018; Ignatieva 2020). Homeowners can start by mowing their lawns less frequently, allowing the grass to grow taller between cuts to create a habitat and food source for insects (Chollet 2018; Ignatieva 2020). One important initiative is to promote the use of native plant species in lawns, as they need less water and upkeep and offer important habitats and food for wildlife (Larson et al 2014; Davis et al 2017; Burr et al 2018; Toro and Ribbons 2020; Paudel 2024). Homeowners and policymakers should work together to dismantle the idea that lawns need to meet a certain aesthetic and promote sustainable lawn management that moves away from harmful practices that negatively impact biodiversity (Zhang et al 2015).

Education for homeowners about the benefits of sustainable lawn care practices as well as resources and support will help to encourage widespread adoption. When working together, local

governments, environmental organizations, and landscaping professionals can bring about policy changes and support sustainable lawn practices that help to promote biodiversity within the city (Zhang et al 2015).

DISCUSSION

Commented [KP17]: Discussion should discuss your hypothesis and findings.

The literature reviewed in this undergraduate thesis strongly supports the hypothesis that monoculture lawns have a negative impact on biodiversity by reducing species diversity compared to original landscapes or more ecologically sound lawn management practices. When extensively reviewing studies relating to this topic it became evident that the historical evolution of lawns was driven by societal aesthetics and cultural norms of the time. Leading to intensive lawn maintenance practices such as mowing, chemical usage and watering. These practices, while being implemented to reach that aesthetic, have had destructive effects on natural ecosystems and contribute to the decline of biodiversity within the city. Intensively mowed lawns reduce insect species richness, abundance and genetic diversity which negatively impacts the ecological functions they provide such as pollination, nutrient cycling and ecosystem resilience. Chemical usage from application of herbicides, pesticides and fertilizers further harm biodiversity loss by contaminating soil, soil microbes and insects and causing run-off into surrounding aquatic ecosystems. These findings are important because they highlight the need for more sustainable lawn management practices. Reduced mowing, minimizing, or substituting chemicals used as well as planting native plant species are all ways that homeowners can mitigate the negative impacts of monoculture lawns and restore urban biodiversity. Social and cultural pressures remain a challenge, underscoring the importance of education, community engagement and policy changes that welcome widespread adoption of sustainable lawns.

Overall, this thesis highlights the importance of rethinking the way we manage the lawns within out cities to help promote biodiversity.

CONCLUSION

Lawns that are carefully crafted to fit societal and cultural standards are causing harm to biodiversity due to the high level of maintenance they require. This review emphasizes the importance of finding sustainable options to remediate the negative effects lawns have on the environment. Understanding how people view lawns, their impact on nature, and the rules that govern them can help us promote lawn care practices that benefit the ecosystem. With more knowledge, changes in policies, and involvement from the community, we can turn lawns into diverse habitats that help urban ecosystems thrive and stay strong.

LITERATURE CITED

Arnold, S.E.J., F. Elisante, P.A. Mkenda, Y.L.B. Tembo, P.A. Ndakidemi, G.M. Gurr, I.A. Darbyshire, S.R. Belmain and P.C. Stevenson. 2021. Beneficial insects are associated with botanically rich margins with trees on small farms. Scientific reports 11: 15190. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8313545/. Apr. 25, 2024.

Aronson, M.F,. C.A. Lepczyk, K.L. Evans, M.A. Goddard, S.B. Lerman, J.S. Maclvor, C.H. Nilon and T. Vargo. 2017. Biodiversity in the city: key challenges for urban green space management. Frontiers in Ecology and the environment 15(4): 189-196. https://esajournals.onlinelibrary.wiley.com/doi/full/10.1002/fee.1480?casa_token=7VzqdsMDXZEAAAAA%3AVdLyLk4tcUrVOWjr2curzoe1ngoRR13LcdRGm3Q9B8h96dIDRuh6Z9PqTeZLiOFd8kLoy0cnUBDu. Feb. 13, 2024.

Baldi, D.S., C.E. Humphrey, J.A. Kyndt and T.C. Moore. 2023. Native plant gardens support more microbial diversity and higher relative abundance of potentially beneficial taxa compared to adjacent turf grass lawns. Urban ecosystems 26: 807-820. https://link.springer.com/article/10.1007/s11252-022-01325-5 . Feb. 13, 2024.

Bandura, A. 2009. Social cognitive theory of mass communication. Medical psychology 3: 265-299. https://doi.org/10.1207/S1532785XMEP0303_03. Apr. 24, 2024.

Bertoncini, A.P,. N. Machon, S. Pavoine, A. Muratet. 2012. Local gardening practices shape urban lawn floristic communities. Landscape and urban planning 105(1-2): 53-61. https://www.sciencedirect.com/science/article/pii/S0169204611003392?casa_token=GCgrZWUeUhEAAAAA:kT26kTLBvEJfT7XBXt4xy1NSb4ow-JyfxPmORHz2uqA14JJqyGr2_dDvnmufCEuwS6qYCy2-qms. Feb. 15, 2024.

Biggs, R. R.J. Scholes, B.J.E. Brink and D. Vačkář. 2007. Biodiversity indicators. Sustainability indicators: a scientific assessment. https://books.google.ca/books?hl=en&lr=&id=W4o-qunretMC&oi=fnd&pg=PA249&dq=Species+richness,+abundance+and+genetic+diversity+are+all+good+indicators+of+biodiversity+&ots=iizfLzzO6c&sig=LyECBH0zdUf0YXU-t4wh9wnyGog#v=onepage&q=Species%20richness%2C%20abundance%20and%20genetic%20diversity%20are%20all%20good%20indicators%20of%20biodiversity&f=false. Apr.2, 2024.

Bonari, G., K. Fajmon, I. Malenovský, D. Zelený, J. Holuša, I. Jongepierová, P. Kočárek, O. Konvička, J. Uřičář, M. Chytrý. 2017. Management of semi-natural grasslands benefiting both plant and insect diversity: The importance of heterogeneity and tradition, Agriculture, ecosystems and environment 246: 243-252. https://doi.org/10.1016/j.agee.2017.06.010. Apr. 25, 2024.

Bormann, F.H., D. Balmori and G.T. Geballe. 2001. Redesigning the American lawn: a search for environmental harmony. Yale University Press; 2nd Edition, Connecticut. 192 pp.

Braschler, B., L. Marini, G.H. Thommen and B. Baur. 2009. Effects of small-scale grassland fragmentation and frequent mowing on population density an species diversity of orthopterans: a long-term study. Ecological entomology 34(3): 321-329. https://doi.org/10.1111/j.1365-2311.2008.01080.x. Apr. 25, 2024.

Brown, D. and T. Williamson. 2016. Lancelot Brown and the Capability Men: Landscape Revolution in Eighteenth- century England. Reaktion Books Ltd, London, UK. 151 pp.

Brussaard, L. 1997. Biodiversity and ecosystem functioning in soil. Ambio 26(8): 563-570. https://www.jstor.org/stable/4314670. Apr. 25, 2024.

Burns, T.R. 2012. The sustainability revolution: a societal paradigm shift. Sustainability 4(6): 1118-1134. https://doi.org/10.3390/su4061118. Apr. 24, 2024.

Burr, A., D.M. Hall and N. Schaeg. 2018. The perfect lawn: exploring neighborhood socio-cultural drivers for insect pollinator habitat. Urban Ecosystems 21: 1123-1137. https://link.springer.com/article/10.1007/s11252-018-0798-y. Apr. 26, 2024.

Carson, R.L 2022. Silent Spring. Mariner Books Classics 40th edition, Boston, United States. 400 pp.

Chollet. S., C. Brabant, S. Tessier and V. Jung. 2018. From urban lawns to urban meadows: reduction of mowing frequency increases plant taxonomic, functional and phylogenetic diversity. Landscape and urban planning 180: 121-124. https://doi.org/10.1016/j.landurbplan.2018.08.009. Apr. 26, 2024.

Chowdhury, S,. V.K. Dubey, S. Choudhury, A. Das, D. Jeengar, B. Sujatha, A. Kumar, N. Kumar, A. Semwal and V. Kumar. 2023. Insects as bioindicator: A hidden gem for environmental monitoring. Toxicology, Pollution and the Environment 11. https://www.frontiersin.org/articles/10.3389/fenvs.2023.1146052/full#:~:text=An%20increase%20or%20decrease%20in,changes%20in%20topography%20and%20moisture. Feb. 05, 2024.

Conners, D.E. and M.C. Black. 2004. Evaluation of Lethality and Genotoxicity in the Freshwater Mussel Utterbackia imbecillis (Bivalvia: Unionidae) Exposed Singly and in Combination to Chemicals Used in Lawn Care. Archives of environmental contamination and toxicology 46: 362-371. https://doi.org/10.1007/s00244-003-3003-z. Apr. 25, 2024.

Croteau, M.C,. N. Hogan, J.C. Gibson, D. Lean and V. Trudeau. 2008. Toxicological threats to amphibians and reptiles in urban environments. Herpetological conservation 3: 197-210. https://www.researchgate.net/publication/316243667_Toxicological_threats_to_amphibians_and_reptiles_in_urban_environments. Feb. 14, 2024.

Cubie, D. 2022. Greening your homeowner's association: wildlife gardeners are getting HOAs to relax rigid landscaping rules. Garden for wildlife. https://www.nwf.org/Home/Magazines/National-Wildlife/2022/Feb-Mar/Gardening/HOAs. Apr. 24, 2024.

Davis, A.Y., E.V. Lonsdorf, C.R. Shierk, K.C. Matteson, J.R. Taylor, S.T. Lovell and E.S. Minor. 2017. Enhancing pollination supply in an urban ecosystem through landscape modifications. Landscape and urban planning 162: 157-166. https://doi.org/10.1016/j.landurbplan.2017.02.011. Apr. 26, 2024.

Dodson, S,. 2009. Biodiversity in southern Wisconsin storm-water retention ponds: Correlations with watershed cover and productivity. Lake and Reservoir Management 24(4): 370-380. https://doi.org/10.1080/07438140809354847. Feb. 08,2024.

Dornelas, M., D.A.T. Phillip and A.E. Magurran. 2011. Abundance and dominance become less predictable as species richness decreases. Global ecology and biogeography 20(6): 832-841. https://doi.org/10.1111/j.1466-8238.2010.00640.x. Apr. 25, 2024.

Dorsey, J.W. 2011. Lawn control, lawn culture, and the social marketing of sustainable behaviors. Ecopsychology 2(2). https://doi.org/10.1089/eco.2009.0041. Apr. 25, 2024.

Duelli, P. and K.O. Martin. 2003. Biodiversity indicators: the choice of values and measures. Agriculture, ecosystems & environment 98(1-3): 87-98. https://www.sciencedirect.com/science/article/pii/S0167880903000720?casa_token=WY_lbxbNEc0AAAAA:t5toMz6lXwBxWJw0EZi4dMxoGi0rb8sE63p4Bsc9Uc-R90W3OLsyrWcD3DDUHmlhKYBbvXq574k. Feb. 12, 2024.

Feagan R and M. Ripmeester. 2001. Reading private green space: Competing geographic identities at the level of the lawn. Philosophy & geography 4(1): 79-95. https://www.tandfonline.com/doi/abs/10.1080/10903770124446?casa_token=stA111ZU_-IAAAAA:93uMVFWVWZpA3sl57X_cO2G5Jn8A7v0Hiy_nTZBWEKzI55yAyWDOdpax5FrqBfz-TxX093nspds . Feb. 16, 2024.

Feagan R and M. Ripmeester. 2013. Contesting natural(ized) lawns: A geography of private green space in the Niagara region. Urban geography 20(7): 617-634. https://www.tandfonline.com/doi/abs/10.2747/0272-3638.20.7.617?casa_token=4LieRBDlix4AAAAA:TsywspNQVp3WDzL7Kn6NlmdaH9SXHTt_lRdoh2YNDtxL5VE3POl1HSnsc__WabB3LLTQ4PAlYsw . Feb. 16, 2024.

Fedor, P. and M. Zvaríková. 2019. Biodiversity indices. Encyclopedia of ecology 1: 337-346. https://books.google.ca/books?hl=en&lr=&id=x1h7DwAAQBAJ&oi=fnd&pg=PA337&dq=biodiversity+indices&ots=csW4wNB2Db&sig=KOuqwdmNNmAT_gwM49nMycSWUBE#v=onepage&q=biodiversity%20indices&f=false. Apr. 25, 2024.

Fenoglio, M.S,. A. Calviño, E. González, A. Salvo and M. Videla. 2021. Urbanisation drivers and underlying mechanisms of terrestrial insect diversity loss in cities. Ecological Entomology 46(4): 757-771. https://resjournals.onlinelibrary.wiley.com/doi/abs/10.1111/een.13041. Feb. 07, 2024.

Ferguson, M.J. and J.A. Bargh. 2004. How social perception can automatically influence behavior. Trend in cognitive sciences 8(1): 33-39. https://doi.org/10.1016/j.tics.2003.11.004. Apr. 24, 2024.

Fisher, A.A. 2018. Will carbon sequestration redeem the lawn? Ecological gardening. https://www.ecologicalgardening.net/2018/02/will-carbon-sequestration-redeem-lawn.html. Apr. 12, 2024.

Gaudio, A. 2020. Renaissance Era: A Resource Guide. Library of Congress. https://guides.loc.gov/renaissance-era-resources#:~:text=The%20Renaissance%20arrived%20at%20different,had%20come%20to%20an%20end. Jan. 03, 2024.

Geoffrey, G. and E. Scudder. 2017. The importance of insects. Insect biodiversity: Science and society, Second. Chapter 2. https://onlinelibrary.wiley.com/doi/abs/10.1002/9781118945568.ch2. Feb. 04, 2024.

Gentanjaly V.L., P. Rai, R. Sharma and Kushawha. 2015. Beneficial insects and their value to agriculture 3:2320-6063. https://www.researchgate.net/publication/312553606_Beneficial_Insects_and_their_Value_to_Agriculture. Apr. 25, 2024.

Gotelli, N.J. and R.K. Colwell. 2001. Quantifying biodiversity: procedures and pitfalls in the measurement and comparison of species richness. Ecology letters 4(4): 379-391. https://doi.org/10.1046/j.1461-0248.2001.00230.x. Apr. 25, 2024.

Grewal, P.S. 2012. From integrated pest management to ecosystem management: the case of urban lawn. Integrated pest management: principles and practice 450-476. https://books.google.ca/books?hl=en&lr=&id=0V7QBa4PIXsC&oi=fnd&pg=PA450&dq=sustainable+lawns+integrated+pest+management&ots=ZXD7lPplvh&sig=F1M98FMDN6MIO9Uk-I5HHyZ9oNA#v=onepage&q=sustainable%20lawns%20integrated%20pest%20management&f=false. Apr. 26, 2024.

Harmon M.E., K.J, Nadelhoffer and J.M. Blair. 1999. Measuring decomposition, nutrient turnover, and stores in plant litter. Standard soil methods for long-term ecological research: 202-240. https://books.google.ca/books?hl=en&lr=&id=n3FUQdCjSpEC&oi=fnd&pg=PA202&dq=nutrient+uptake+by+plants+decomposition&ots=QIY4d5kHQT&sig=S4eMm1zARcVthK9ZyqbpasGRB0A#v=onepage&q=nutrient%20uptake%20by%20plants%20decomposition&f=false. Apr. 25, 2024.

Hayes, W.M., B.J. O'Shea, M.A. Pierre, A. Wilson and J.E. Bicknell. 2023. Bird communities across different level of human settlement: a comparative analysis from two northern amazonian ecoregions. Science of the total environment 903 (166535). https://doi.org/10.1016/j.scitotenv.2023.166535. Apr. 24, 2024.

Hayk, K. and Z. Guzhen. 2014. Preferences for sustainable lawn care practices: the choice of lawn fertilizers. Research in agricultural & applied economics 4757. https://ageconsearch.umn.edu/record/170210/?v=pdf. Apr. 26, 2024.

He, F., X.S. Hu. 2005. Hubbell's fundamental biodiversity parameter and the Simpson diversity index. Ecology letters 8(4): 386-390. https://doi.org/10.1111/j.1461-0248.2005.00729.x. Apr. 25, 2024.

Heinen, R., A. Biere, J.A. Harvey and T.M. Bezemer. 2018. Effects of soil organisms on aboveground plant-insect interactions in the field: patterns, mechanisms and the role of methodology. Frontiers in ecology and evolution 6. https://doi.org/10.3389/fevo.2018.00106 . Apr. 25, 2024.

Held, D.W. and A.P. Potter. 2011. Prospects for managing turfgrass pests with reduced chemical inputs. Annual review of entomology 57: 329-354. https://www.annualreviews.org/content/journals/10.1146/annurev-ento-120710-100542. Feb. 15, 2024.

Helfand, G.E., J.S. Park, J.I. Nassauer and S. Kosek. 2006. The economics of native plants in residential landscape designs. Landscape and urban planning 78(3): 229-240. https://www.sciencedirect.com/science/article/pii/S016920460500112X?casa_token=iX-7x4waQOEAAAAA:NxoPynkbf_EpbgMhXZcrNm66INJe5Qnc0aN3OfpEWyvJaij-mlH6nSj8-CQDuGCjWfSO7w5L . Feb. 07, 2024.

Hernke, M.T,. and R.J. Podein. 2011. Sustainability, health and precautionary perspectives on lawn pesticides, and alternatives. EcoHealth 8: 223-232. https://link.springer.com/article/10.1007/s10393-011-0697-7. Feb. 13, 2024.

Hidrayani, Purnomo, Rauf, A., Ridland, P. M., & Hoffmann, A. A. (2005). Pesticide applications on Java potato fields are ineffective in controlling leafminers, and have antagonistic effects on natural enemies of leafminers. International Journal of Pest Management, 51(3), 181–187. https://doi.org/10.1080/09670870500189044 . Apr. 25, 2024

Humbert, J.-Y,. J. Ghazoul, G.J. Sauter and T. Walter. 2010. Impact of different meadow techniques on field invertebrates. Journal of Applied Entomology, 134(7): 592-599. https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1439-0418.2009.01503.x. Feb. 04, 2024.

Ignatieva, M., K. Ahrné, J. Wissman, T. Eriksson, P. Tidåker, M. Hedblom, T. Kätterer, H. Marstorp, P. Berg, T. Eriksson and J. Bengtsson. 2015. Lawn as a cultural and ecological phenomenon: a conceptual framework for transdisciplinary research. Urban forestry & urban greening 14(2): 2015. https://doi.org/10.1016/j.ufug.2015.04.003. Apr. 24, 2024.

Ignatieva, M., D. Haase, D. Dushkova, A. Haase. 2020. Lawns in cities: from a globalised urban green space phenomenon to sustainable nature-based solutions. Land 9(3): 73. https://doi.org/10.3390/land9030073. Apr. 24, 2024.

Irwin, E.G and N.E. Bockstael. 2007. The evolution of urban sprawl: evidence of spatial heterogeneity and increasing land fragmentation. PNAS Evolution of urban sprawl 104. https://www.pnas.org/doi/abs/10.1073/pnas.0705527105. Feb. 11, 2024.

Janssen A., and P.C.J. van Rijn. 2021. Pesticides do not significantly reduce arthropod pest densities in the presence of natural enemies. Ecology letters 24(9): 2010-2024. https://doi.org/10.1111/ele.13819. Apr. 25, 2024.

Johnson, M.P. 2001. Environmental Impacts of Sprawl: a survey of the literature and proposed research agenda. Environment and planning A: economy and space 33(4), 717-735. https://doi.org/10.1068/a3327 . Apr. 13, 2024.

Johnson, M.T.F. and Munshi-South, J. 2017. Evolution of life in urban environments. Science 358 (6363). https://www.science.org/doi/10.1126/science.aam8327#:~:text=Fragmentation%20and%20urban%20infrastructure%20also,to%20genetic%20differentiation%20between%20populations. Apr. 30, 2024.

Joyce, S. 1998. Why the grass isn't always greener. Environmental health perspectives 106(8): A378-A385. https://ehp.niehs.nih.gov/doi/10.1289/ehp.98106a378. Feb. 12, 2024.

Karlsson M. and M. Gilek. 2020. Mind the gap: coping with delay in environmental governance. Ambio 49: 1062-1075. https://link.springer.com/article/10.1007/s13280-019-01265-z. Apr. 24, 2024.

Kempel, A. R. Brandl and M. Schädler. 2009. Symbiotic soil microoorganisms as players in aboveground plant-herbivore interactions – the role of rhizobia. Wiley online library. https://nsojournals.onlinelibrary.wiley.com/doi/pdf/10.1111/j.1600-0706.2009.17418.x?casa_token=s5Agfo59XGoAAAAA%3AqNkvRyrSHolpHSZpO5yHK_62BMIdmQBfVy2eNQBJ7PxCSD0UEQJs5y1Z2U9HTSqsPTFaFCdhl-QzV7oP. Apr. 25, 2024.

Kevan P. and H.G. Baker. 1983. Insects as flower visitors and pollinators. Annual review of entomology 28: 407-453. https://www.researchgate.net/publication/230662607_Insects_as_Flower_Visitors_and_Pollinators. Apr. 25, 2024.

Klink, R.v,. H.M.M. Menz, H. Baur, O. Dosch, I. Kühne, L. Lischer, H. Luka, S. Meyer, T. Szikora, D. Unternährer, R. Arlettaz and J.Y Humbert. 2019. Larval and phenological traits predict insect community response to mowing regime manipulations. Ecological Applications 29(4). https://esajournals.onlinelibrary.wiley.com/doi/abs/10.1002/eap.1900. Feb. 04, 2024.

Kozlowski, G. and L. Bondallaz. 2012. Urban aquatic ecosystems: Habitat loss and depletion of native macrophyte diversity during the 20th century in four Swiss cities. Urban Ecosystems 16: 543-551. https://link.springer.com/article/10.1007/s11252-012-0284-x . Apr. 24, 2024.

Lancelot "capability" brown (1716-1783). Great British Gardens. (n.d.). https://www.greatbritishgardens.co.uk/lancelot-capability-brown.html

Landsberg, S. 2004. The Medieval Garden. British Museum Press, London. 144 pp.

Larson, J.L., A.J. Kesheimer and D.A. Potter. 2014. Pollinator assemblages on dandelions and white clover in urban and suburban lawns. Journal of insect conservation 18: 863-873. https://link.springer.com/article/10.1007/s10841-014-9694-9. Apr. 26, 2024.

Larson, K.L., K.C. Nelson, S.R. Samples, S.J. Hall, N.D. Bettez, J.Cavender-Bares, P.M. Groffman, M. Grove, J.B. Heffernan, S.E. Hobbie, J. Learned, J.L. Morse, C. Neill, L. Ogden, J.O'Neil-Dunne, D.E. Pataki, C.D. Polsky, R.R. Chowdhury, M.K. Steele and T. Trammell. 2015. Ecosystem services in managing residential landscapes: priorities, value dimensions, and cross-regional patterns. Urban ecosystems. https://www.researchgate.net/publication/279861650_Ecosystem_services_in_managing_residential_landscapes_priorities_value_dimensions_and_cross-regional_patterns. Apr. 24, 2024.

Larson, K.L., R. Andrade, K.C. Nelson, M.M. Wheeler, J.M. Engebreston, S.J. Hall, M.L. Avolio, P.M. Groffman, M. Grove, J.B. Heffernan, S.E. Hobbie, S.B. Lerman, D.H. Locke, C. Neill, R.R. Chowdhury and T.L.E. Trammell. 2020. Municipal regulation of residential landscapes across US cities: patterns and implications for landscape sustainability. Journal of Environmental Management 275, 111132. https://www.sciencedirect.com/science/article/pii/S0301479720310598?casa_token=OiOxi6H85GQAAAAA:YMZ3rOvBUVSCia4oWko8kQZyewDXNbOSPwsnUewryM-S-4JS76i-tHOb1etDdO5_EnFBcuQ5. Feb. 13, 2024.

Lerman, S.B., A.R. Contosta, J. Milam and C. Bang. 2018. To mow or to mow less: lawn mowing frequency affects bee abundance and diversity in suburban yards. Biological conservation 221: 160-174. https://doi.org/10.1016/j.biocon.2018.01.025. Apr. 25, 2024.

MacDougall, AS., K.S. McCann, G. Gellner and R. Turkington. 2013. Diversity loss with persistent human disturbance increases vulnerability to ecosystem collapse. Nature 494: 86-89. https://www.nature.com/articles/nature11869. Apr. 25, 2024.

Marshall, A.J., M.J. Grose and N.S.G. Williams. 2020. Of mowers and growers: perceived social norms strongly influence verge gardening, a distinctive civic greening practice. Landscape and urban planning 198. 103795. https://sciencedirect.com/science/article/pii/S0169204619314008?casa_token=JhkPfhDwk3wAAAAA:elbSeYrRgi8EHi0qlC2AUbPuA2_nYIgr9Vm0k3xBAU81Cbgzr2R6lLDRy1KLlID2rv5HcxTg . Feb. 07, 2024.

McColloch J.W., Wm.P. Hayes. The reciprocal relation of soil and insects. Ecology 3(4): 288-301. https://doi.org/10.2307/1929431. Apr. 25, 2024.

Meftaul, I.M., K. Venkateswarlu, R. Dharmarajan, P. Annamalai, M. Megharaj. 2020. Science of the total environment 711. https://www.sciencedirect.com/science/article/pii/S0048969719346030?casa_token=pS1InZva4wIAAAAA:eoqp6DC0jQPiOw47S-gVUKttWb7p2dhXUDkNjp4-2KsdEDpFIvasw_VOK_cI2J3dZajcHdazh2M. Feb. 10, 2024.

Miglani, R,. and S.S. Bisht. 2019. World of earthworms with pesticides and insecticides. Interdiscip Toxicol 12(2): 71-82. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7071835/. Feb. 14, 2024.

Nassauer, J.I. 1997. Cultural sustainability: aligning aesthetics and ecology. Island press. https://scholar.google.com/scholar?hl=en&q=%0A%0A%0ANassauer%0A+%0AJ%0A%0A%0A+%0A1997%0A+%0ACultural+sustainability%3A+aligning+aesthetics+and+ecology%0A+%0A+%0Ain%3A+J.+I.+Nassauer+%28Ed.%29+Placing+Nature%3A+Culture+and+Landscape+Ecology%0A%0A+%0App.%E2%80%8965%E2%80%9383%0A+%0A+%0A%28Washington%2C+DC%3A+Island+Press%29%0A . Feb. 16, 2024.

Nolan, K.A. and J.E. Callahan. 2005. The Shannon-Weiner species diversity index. Beachcomber biology 27: 334-338. https://www.researchgate.net/publication/267230639_Beachcomber_Biology_The_Shannon-Weiner_Species_Diversity_Index. Apr. 25, 2024.

Overmyer, J.P., R. Noblet and K.L. Armbrust. 2005. Impacts of lawn-care pesticides on aquatic ecosystems in relation to property value. Environmental pollution 137(2): 263-272. https://doi.org/10.1016/j.envpol.2005.02.006. Apr. 25, 2024.

Parikh G., D. Rawtani and N. Khatri. 2020. Insects as an indicator of environmental pollution. Environmental claims journal 33(2): 161-181. https://doi.org/10.1080/10406026.2020.1780698. Apr. 25, 2024.

Paudel, S. and S.L. States. 2023. Urban green spaces and sustainability: exploring the ecosystem services and disservices of grassy lawns versus floral meadows. Urban forestry & urban greening 84 (127932). https://doi.org/10.1016/j.ufug.2023.127932. Apr. 24, 2024.

Pooya, E.S., A. Tehranifar, M. Shoor, Y. Selahvarzi and H. Ansari. 2013. The use of native turf mixtures to approach sustainable lawn in urban landscapes. Urban forestry and urban greening 12(4): 532-536. https://www.sciencedirect.com/science/article/pii/S161886671300085X?casa_token=m62B41nZG1IAAAAA:bPhSPYNaH70nqS320FgJ8fJc66m7rE22JFQFS6lt-_2EeQGR6lv7Duoji2OQPmBi6UNLKcrL . Apr. 5, 2024.

Prather, C.M,. S.L. Pelini, A. Laws, E. Rivest, M. Woltz, C.P. Bloch, I.D. Toro, C.K. Ho, J. Kominoski, T.A.S. Newbold, S. Parsons and A. Joern. 2012. Biological Reviews 88(2): 327-348. https://onlinelibrary.wiley.com/doi/abs/10.1111/brv.12002. Feb. 04, 2024.

Proske, A,. S. Lokatis, J, Rolff. 2022. Impact of mowing frequency on arthropod abundance and diversity in urban habitats: A meta-analysis. Urban Forestry & Urban Greening 76. https://www.sciencedirect.com/science/article/pii/S1618866722002576. Feb. 04, 2024.

Purvis, A. and A. Hector. 2000. Getting the measure of biodiversity. Nature 405: 212-219. https://www.researchgate.net/publication/12497295_Getting_the_Measure_of_Biodiversity. Feb. 05, 2024.

Relyea, R.A. 2005. The lethal impact of roundup on aquatic and terrestrial amphibians. Ecological applications 15(4): 1118-1124. https://esajournals.onlinelibrary.wiley.com/doi/full/10.1890/04-1291. Feb. 02, 2024.

Renaissance gardens of Villandry. Springhill Stories. 2018. https://springhillstories.com/2018/08/28/visit-renaissance-gardens-of-villandry/

Robbins, P., A. Polderman and T. Birkenholtz. 2001. Lawns and Toxins: An ecology of the city. Cities 18(6): 369-380. https://www.sciencedirect.com/science/article/pii/S0264275101000294?casa_token=Onuw92szJ3YAAAAA:ph64LXoDmcDNZA0nC9WAYshgWpE4NKowTQSWHMnH51azz99JWAnx4cVNXmgB3OJJtQfatRsnaM0. Feb. 07, 2024.

Robbins, P. and T. Birkenholtz. 2003. Turfgrass revolution: measuring the expansion of the American lawn. Land use policy 20(2): 181-194. https://doi.org/10.1016/S0264-8377(03)00006-1. Apr. 24, 2024.

Robbins, P. and J. Sharp. 2004. The lawn-chemical economy and its discontents. Antipode 35(5): 955-979. https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1467-8330.2003.00366.x?casa_token=b-J0IWp8JL0AAAAA:WgU34XcPAagV4zsF2he9DwEr7t63Au6rTvXSuWg7H8Ss8ZhURe-x4qLMp0qoZvJHI1vYCY22xa44 . Feb. 16, 2024.

Robbins, F.P. 2008. Lawn people: how grasses, weeds, and chemicals make us who we are. Bibliovault OAI Repository, the University of Chicago Press. https://www.researchgate.net/publication/37708081_Lawn_People_How_Grasses_Weeds_and_Chemicals_Make_Us_Who_We_Are Apr. 24, 2024.

Robinson D.T. 2012. Land-cover fragmentation and configuration of ownership parcels in an exurban landscape. Urban Ecosystems 15: 53-69. https://link.springer.com/article/10.1007/s11252-011-0205-4. Apr. 24, 2024.

Rouse, J.D., C.A. Bishop, J. Struger. 1999. Nitrogen pollution: an assessment of its threat to amphibian survival. Environmental health perspectives 107(10): 799-803. https://ehp.niehs.nih.gov/doi/abs/10.1289/ehp.99107799. Feb. 03, 2024.

Sánchez-Bayo, F. 2021. Indirect effect of pesticides on insects and other arthropods. Toxics (8): 177. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8402326/. Feb. 14, 2024.

Sehrt, M., O. Bossdorf, M. Freitag and A. Bucharova. 2020. Less is more! Rapid increase in plant species richness after reduced mowing in urban grasslands. Basic and applied ecology 42: 47-53. https://www.sciencedirect.com/science/article/pii/S1439179119302932?casa_token=ZJZtSLYVFxYAAAAA:GrVu_VY74fAxOEGHcP-8RiDIRZNYHW3znqW13l8wP_YmZmfbzKFemCTG_zEkTWBEzVXbIHD-Lea1. Apr. 25, 2024.

Shochat, E., W.L. Stefanov, M.E.A. Whitehouses and S.H. Faeth. 2004. Urbanization and spider diversity: Influences of human modification of habitat structure and productivity. Ecological Applications 14(1): 268-280. https://esajournals.onlinelibrary.wiley.com/doi/abs/10.1890/02-5341. Feb. 03, 2024.

Simmons, M., M. Bertelsen, S. Windhager and H. Zafian. 2011. The performance of native and non-native turfgrass monocultures and native turfgrass polycultures: an ecological approach to sustainable lawns. Ecological engineering 37(8): 1095-1103. https://www.sciencedirect.com/science/article/pii/S0925857411001005?casa_token=8judP9i4LXEAAAAA:66ypLKmzUv7oiz6WUKPtN3LHxFh8rST9t8aF_UTvqPE8sWzTlCU_iXphNujrxAswgS1k1v7U . March. 09, 2024.

Smith, L.S., M.E.J. Broyles, H.K. Larzleer and M.D.E. Fellowes. 2015. Adding ecological value to the urban lawnscape. Insect abundance and diversity in grass-free lawns. Biodiversity Conservation 24: 47-62. https://link.springer.com/article/10.1007/s10531-014-0788-1#citeas. Feb. 04, 2024.

Survis, F.D. and T.L. Root. 2017. The rain-watered lawn: informing effective lawn watering behavior. Journal of environmental management 199: 109-115. https://doi.org/10.1016/j.jenvman.2017.04.081. Apr. 24, 2024.

Sushinsky, J.R., J.R. Rhodes, H.P. Possingham, T.K. Gill and R.A. Fuller. 2012. How should we grow our cities to minimize their biodiversity impacts. Global change biology 19(2): 401-410. https://doi.org/10.1111/gcb.12055. Apr. 24, 2024.

Tasser, E., E. Sternbach and U. Tappeiner. 2008. Biodiversity indicators for sustainability monitoring at municipality level: an example of implementation in an alpine region. Ecological indicators 8(3): 204-223. https://doi.org/10.1016/j.ecolind.2007.01.005. Apr. 25, 2024.

The history of lawns. Planet Natural. 2018. https://www.planetnatural.com/organic-lawn-care-101/history/

Thomas P.L and K.F. Stein. 2014. Speaking truth to power: the legacies of Rachael Carson. The English journal 103(6): 81-84. https://www.jstor.org/stable/24484389

Toro, I.D and R. Ribbons. 2020. No Mow May lawns have higher pollinator richness and abundances: An engaged community provides floral resources for pollinators. PeerJ 8. https://www.researchgate.net/publication/344340220_No_Mow_May_lawns_have_highe

r_pollinator_richness_and_abundances_An_engaged_community_provides_floral_resources_for_pollinators. Feb. 04, 2024.

Turkan, Z., E. Köksaldı. 2021. An important period of the historical development of garden art: "Renaissance Garden Style". Revista Amazonia Investiga 10(38): 252-269. https://www.researchgate.net/publication/351645537_An_important_period_of_the_historical_development_of_garden_art_Renaissance_garden_style. Jan. 03, 2024.

Ulyshen, M.D. Wood decomposition as influenced by invertebrates. Biological reviews 91(1): 70-85. https://doi.org/10.1111/brv.12158. Apr. 25, 2024.

Unterweger P.A., C. Rieger and O. Betz. 2017. The influence of urban lawn mowing regimes on diversity of Heteroptera (Hemiptera). Heteropteron 48: 7-21. https://tobias-lib.ub.uni-tuebingen.de/xmlui/handle/10900/74622. Apr. 26, 2024.

Vandergast, A.G,. A.J. Bohanak, D.B. Weissman, R.N. Fisher. 2006. Understanding the genetic effects of recent habitat fragmentation in the context of evolutionary history: phylogeography and landscape genetics of a southern California endemic Jerusalem cricket (Orthoptera: Stenopelmatidae: Stenopelmatus). Molecular Ecology 16(5): 977-992. https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1365-294X.2006.03216.x?casa_token=XWV9gEMsei4AAAAA%3AHowWM6yrRJXZ81zL3R6kTvs5gRCB_9Gme_gDdPaDyKZGWsfKWq4f4m3yNnfY5DuNQHw1KZTc2s4XkEk. Feb. 09, 2024.

Vandergast, A.G,. E.A. Lewallen, J. Deas, A.J. Bohanak, D.B. Weissman and R.N. Fisher. 2009. Loss of genetic connectivity and diversity in urban microreserves in a southern California endemic Jerusalem cricket (Orthoptera: Stenopelmatidae: Stenopelmatus n. sp. "santa monica"). Journal of insect conservation 13: 329-345. https://link.springer.com/article/10.1007/s10841-008-9176-z. Feb. 11, 2024.

Vlaiculescu, A and C. Varrone. 2022. Chapter 14 – Sustainable and eco-friendly alternatives to reduce the use of pesticides. Pesticides in the natural environment – sources, health risks, and remediation. 329-364. https://www.sciencedirect.com/science/article/abs/pii/B9780323904896000148 . Mar. 24, 2024.

Watson, C.J., L. Carignan-Guillemette, C. Turcotte, V. Maira and R. Proulx. 2019. "Ecological and economic benefits of low-intensity urban lawn management". Journal of Applied Ecology. (on line) vol. 57, no. 2, pp. 436-446. Accessed 04 Nov. 2023.

Weston, D.P., R.W. Holmes, J. You and M.J. Lydy. 2005. Aquatic toxicity due to residential use of pyrethroid insecticides. Environmental science and technology 39(24): 9778-9784). https://doi.org/10.1021/es0506354. Apr. 25, 2024.

Wintergerst, J., T. Kästner, M. Bartel, C. Schmidt and M. Nuss. 2021. Partial mowing of urban lawns supports higher abundances and diversities of insects. Journal of insect

conservation 25: 797-808. https://link.springer.com/article/10.1007/s10841-021-00331-w. Feb. 15, 2024.

Yang, L.H and C. Gratton. 2014. Insects as drivers of ecosystem processes. Current opinion in insect science 2: 26-32. https://www.sciencedirect.com/science/article/pii/S2214574514000339?casa_token=KRoYk5Mh1pkAAAAA:zmnM_5XcUwmIdSfHWI8sOfCNYnSirksspfvmI80ylQ2aLb2mjyS0TX5hJHgimCXmlHLC8f0MAHg. Feb. 06, 2024.

Zhang Y., B. Zheng, G. Sun and P. Fan. 2015. The American lawn revisited: awareness education and culture as public policies towards sustainable lawn. Problems of sustainable development 10(1): 107-115. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2560287. Apr. 26, 2024.

Zubrod, J.P., M. Bundschuh, G. Arts, C.A. Brühl, G. Imfeld, A. Knäbel, S. Payraudeau, J.J. Rasmussen, J.Rohr, A.Scharmüller, K.Smalling, S.Stehle, R.Schulz, and R.B. Schäfer. 2019. Fungicides: an overlooked pesticide class? Environmental science and technology 53(7): 3347-3365. https://doi.org/10.1021/acs.est.8b04392. Apr. 25, 2024.