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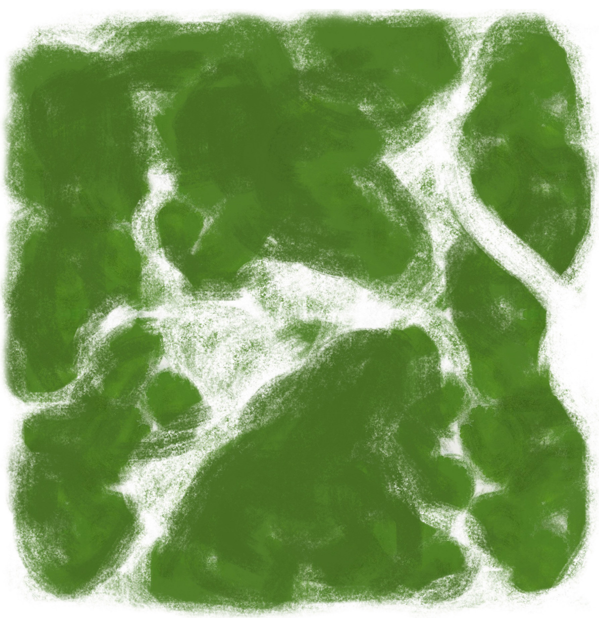
Implementation of school ground vegetation

Interdisciplinary aspects of growing under pressure

Sanna Ignell



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Implementation of school ground vegetation: Interdisciplinary aspects of growing under pressure

Abstract

School ground vegetation offers many benefits for children's health and learning yet faces multiple challenges in implementation. This interdisciplinary thesis investigates these challenges and possible solutions, with a particular emphasis on shrubs, through four complementary studies: a mapping review, an interview study, a greenhouse experiment, and a school ground experiment. Five research questions guided the studies, addressing: (1) current knowledge, (2) the impact of children's play on vegetation, (3) governance factors, (4) species selection, and (5) planting design and methods.

The scientific literature generally overlooks vegetation specifics on school grounds and fails to capture its complexity and dynamic nature. Similarly in practice, knowledge of planting specifics on school grounds in Sweden is often considered low. Governance challenges in the Swedish context, particularly low prioritization and risk-averse discourses, further complicate implementation efforts.

Interaction between children and vegetation is both fundamental and complex, as it compromises plant vitality through wear and tear, while simultaneously being the core benefit for children. Species strategies to handle disturbance from wear and tear as well as drought seem particularly important but depending on the design and species mixtures, other aspects should also be considered. Dense plantings with balanced species mixes and using tougher and spiny plants as nursing plants may increase the resilience against wear and tear. Further, existing vegetation accessible for play may divert wear and tear away from newly planted vegetation. Varying plot sizes, given adequate management, seem to be able to support mixed shrub plantings and thus support overall school ground greening. However, larger plot size appears to increase children's possibility to create play spaces within vegetation.

The studies put together clearly highlight that no factor single handed is determinant for success, and there is a need for careful alignment of planting design, species selection, governance and management for making school grounds greener.

Keywords: School ground vegetation, Schoolyard, School ground greening, Children's environments, Vegetation establishment, Shrubs

Införande av vegetation på skolgårdar: Tvärvetenskapliga aspekter av att växa under press

Abstrakt

Vegetation på skolgårdar erbjuder många fördelar för barns hälsa och lärande, men dess införande är förknippat med flera utmaningar. Denna tvärvetenskapliga avhandling undersöker dessa utmaningar och möjliga lösningar, med ett särskilt fokus på buskar, genom fyra kompletterande studier: en litteraturöversikt, en intervjustudie, ett växthusförsök och ett skolgårdsförsök. Fem forskningsfrågor vägledde studierna och behandlade: (1) aktuell kunskap, (2) hur barns lek påverkar vegetation, (3) faktorer kopplade till governance, (4) artval samt (5) planteringsdesign och metoder.

Den vetenskapliga litteraturen tenderar att förbise vegetationens specifika egenskaper och misslyckas ofta med att fånga dess komplexa och dynamiska natur. Samtidigt upplevs kunskapen kring plantering på skolgårdar i Sverige ofta som låg inom det gröna fältet. Utmaningar kopplade till governance, särskilt låg prioritering och diskurser om risk, försvårar utvecklingen ytterligare.

Interaktionen mellan barn och vegetation är central: den försämrar visserligen växternas vitalitet genom slitage, men är samtidigt en förutsättning för de fördelar som vegetation erbjuder barn. Strategier för artval som tar hänsyn till torka och störningar verkar särskilt viktiga, men beroende på utformning och artblandning bör även andra aspekter beaktas. Täta planteringar med balanserade artblandningar samt användning av kraftiga och taggiga växter som skyddande växter kan öka motståndskraften mot slitage. Dessutom kan befintlig vegetation som är tillgänglig för lek avleda slitage från nyplanterad vegetation. Varierande planteringsstorlekar, förutsatt lämplig skötsel, verkar kunna stödja blandade buskplanteringar. Större planteringsstorlekar tycks dock öka barns möjligheter att skapa lekytor bland vegetationen.

Sammantaget visar studierna tydligt att ingen enskild faktor avgör framgång. I stället krävs en noggrann samordning mellan design, artval, governance och skötsel för en lyckad förgröning av skolgårdar.

Keywords: Skolgårdsförgröning, Skolgårdsvegetation, Barns utemiljöer, Vegetationsetablering, Buskar

Distrust everything I say. I am telling the truth.

– Ursula K Le Guin

This too shall pass.

Contents

List of publications

This thesis is based on the work contained in the following papers, referred to by Roman numerals in the text:

I. Ignell, S., Wiström, B., Levinsson, A., Jansson, M. (2024) "Investigating school ground vegetation research – A systematic mapping review." Urban Forestry & Urban Greening 101, 128494.

II. Ignell, S., Levinsson, A., Wiström, B., Jansson, M. "'It is not a complicated question but it is very complex' - Insights on school ground greening from practitioners." (accepted for publication)

III. Ignell, S., Wiström, B., Sjöman, H., Levinsson, A. "Investigation of shrubs for school grounds in relation to tolerance for drought and biomass-loss." (manuscript)

IV. Ignell, S., Levinsson, A., Jansson, M., Wiström, B. "Shrubs on school grounds - An evaluation of plant growth, survival and patterns of wear and tear." (manuscript)

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The contribution of Sanna Ignell to the papers included in this thesis was as follows:

I. Planned the review study with assistance from the co-authors. Developed the search-strategy and conducted the literature review in dialogue with the co-authors. Analysed, visualised and curated the data in dialogue with co-authors. Wrote the article with feedback and co-writing from the co-authors.

II. Planned the interview study with assistance from the co-authors. Conducted all interviews. Analysed the data in dialogue with co-authors. Wrote the article with feedback and co-writing from the co-authors.

III. Planned the greenhouse experiment with assistance from the co-supervisors. Implemented the experiment with support from the co-supervisors. Collected the data with support from the co-authors. Analysed, curated and visualised all data in dialogue with the co-authors. Wrote the article with feedback and co-writing from the co-authors.

IV. Planned the study with assistance from the co-authors. Lead the practical implementation of the trial. Conducted all field inventories. Analysed, curated and visualised all data in dialogue with the co-authors. Wrote the article with feedback and co-writing from the co-authors.

List of tables

List of figures

1. Introduction

Nature contact for children through the integration of vegetation and natural areas at various scales plays a crucial role for many aspects of children's healthy development (Chawla 2015, Chawla 2020). Evidence supports the benefits of green areas for physical activity, as well as mental health (Fyfe-Johnson et al. 2021). Furthermore, green areas support many different types of play activities for different ages and abilities (Herrington and Brussoni 2015) including risky play (Laaksoharju and Rappe 2017) which is important for the development of physical competence and risk management (Brussoni et al. 2012). Many positive effects of green areas are strengthened through continuous and frequent use by children. Prolonged use lowers the risk of psychiatric disorders (Engemann et al. 2019) and many aspects of wellbeing for children are also supported by their use of green areas being active (Nordbo et al. 2020). Prolonged and direct contact with nature also increase children's nature-related knowledge (Sampaio et al. 2018) and has been linked to both pro-environmental behaviour (Mackay and Schmitt 2019) and pro-biodiversity behaviour (Soga and Gaston 2023).

Urban green space is in global decline (Derdouri et al. 2024). Children's access and active use of green spaces is also decreasing, as indoor play has become increasingly more common in the last decades (Tremblay et al. 2015). The physical activity of youth is more positively affected by nearby parks, since they have more individual freedom of movement than younger children (McGrath et al. 2015). This highlights that access to green environments is age dependent. Even when having public green spaces nearby their home, children with access to private gardens often rely on these as their primary interaction with vegetation in urban settings (Hand et al. 2018). Various factors, including caregiver restrictions (Chawla 2015) and physical barriers like long distances or busy roads (Hand et al. 2018) all play a role in restricting children's independent mobility and play in urban environments. Together, these factors result in challenges for children in accessing vegetated areas where they can explore freely without constant adult supervision (Sugar 2021). Therefore, the challenge lies not only in the quantity of urban vegetation but also in ensuring its accessibility, especially for children lacking private green spaces like gardens or yards.

1.1 The potential of school ground vegetation

School grounds have great potential to offer daily, active interaction with nature for all children (Hand et al. 2018). Schools with outdoor areas that include a high amount of vegetation have been associated with several health benefits for children (Söderström et al. 2013, Puhakka et al. 2019). This includes increased physical activity (Boldemann et al. 2006, Dyment et al. 2009). Vegetation on school grounds have also been found to attract students of all genders more equally than other spaces, promoting inclusivity and gender integration (Dyment et al. 2009, Lucas and Dyment 2010, Änggård 2011). Green school grounds offer more affordances[1] for play than less green ones, leading to more diverse play patterns (van Dijk-Wesselius et al. 2022, van den Bogerd et al. 2025). Schools that offer diverse play environments may encourage more inclusive social structures, support children with varying physical abilities (Dyment et al. 2009) and contribute to a reduction in both physical and verbal conflicts (Raney et al. 2019). Green school grounds may support different forms of learning (Ballantyne and Packer 2009), and outdoor learning can enhance traditional education and thereby have a positive impact on student test scores and social behaviour (Blair 2009). Furthermore, tree cover on school grounds has been correlated with improved academic outcomes (Sivarajah et al. 2018).

In addition to social- and health benefits for children, school ground vegetation may also increase green connectivity in urban areas and thereby act as stepping stones for the movement of species (Ioja et al. 2014) and by enhancing biodiversity (Mnisi et al. 2021). Shrubs, in particular, have shown specific value in enriching urban biodiversity (Sharmin et al. 2024). Other regulatory ecosystem services[2] such as heat regulation (Gillner et al. 2015) and water uptake (Liu et al. 2023) may also be provided by the vegetation to urban areas at large. Additionally, school grounds can possibly provide

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[1] Affordances are features of the environment that suggest or enable possible actions, depending on an individual's capabilities and needs. The concept was introduced in environmental psychology by Gibson (1979) and later expanded upon by Heft (1988), particularly in relation to children's interactions with their surroundings. When used in this thesis, affordance refers to the version by Heft (1988).

[2] The Millennium Ecosystem Assessment (2005) defines ecosystem services as the benefits people obtain from ecosystems: provisioning, regulating, cultural and supporting services. These services are essential for human well-being, directly or indirectly affecting livelihoods, security, health, and overall quality of life.

social benefits to the local community, for example by providing spaces for recreation after school hours (Wales et al. 2022) and adding aesthetic value (Malone and Tranter 2003).

Woody vegetation provides specific benefits such as improving the microclimate on school grounds through shading (Shashua-Bar et al. 2023) and wind shelter (Antoniadis et al. 2016). A lack of adequate shade on school grounds increases health risks from UV radiation (Boldemann et al. 2006) and extreme heat (Antoniadis et al. 2020), which may, in turn, discourage outdoor activity (Boldemann et al. 2006, Bäcklin et al. 2021).

Additionally, woody vegetation accessible for children's play may offer many affordances for play (Laaksoharju and Rappe 2017). Shrubs and smaller trees are especially interesting because of their increased accessibility for children (Fjørtoft 2004) and are especially valuable for activities such as hiding and building dens (Fjørtoft and Sageie 2000, Hedblom et al. 2024). In addition, shrubs are among the most versatile and resilient plant groups in landscape design and offer a rich variety of textures, colours, leaf shapes, branching patterns, flowers, and fruits (Alder and Ostler 1989, Dunnett 2004). These sensory and structural qualities, typically available at a child's height, provide abundant props and materials for diverse forms of play (van den Bogerd et al. 2023, Hedblom et al. 2024, Mårtensson et al. 2025).

Despite the benefits and importance of urban school ground vegetation, vegetation is often lacking or neglected in the development of school environments (Akoumianaki-Ioannidou et al. 2016). Vegetation on school grounds, along with its surrounding factors, has been described as a complex question (Stevenson et al. 2020) and multiple barriers are found to both the integration of school gardens (Burt et al. 2019) and the increased outdoor time in schools (Patchen et al. 2022). According to a report by Statistics Sweden (SCB 2022), school grounds in Sweden are shrinking, particularly in urban areas. The report also identifies the overall low quantity of vegetation on Swedish school grounds.

1.2 Biophysical aspects affecting school ground vegetation

For school ground greening to deliver lasting values, plant survival and growth are crucial. After all, dead plants are, by definition, not green. The first years after planting are especially critical for the survival of woody vegetation. Following planting, vegetation experiences a period of shock due to reduced water absorption capacity (Grossnickle 2005). This transplanting stress is attributed to root injuries, loss of smaller roots, and the disruption of the plant's previously extensive connection with the soil (Kozlowski and Pallardy 2002). A considerable period of time is needed to compensate for this loss. During this establishment phase[3] the vegetation is more sensitive to disturbances and stressors such as drought (Kozlowski and Pallardy 2002).

Urban environments are in general tough growing environments for woody vegetation making their establishment in urban settings particularly challenging (Levinsson 2013) due to factors such as limited space below ground (Grabosky and Bassuk 1995), soil compaction (Day and Bassuk 1994, Czaja et al. 2020) and impervious surfaces (Grey et al. 2018). In addition to this, the urban heat island effect (Oke 1982) leads to increases in the transpiration of plants, and thus also the need for water, while simultaneously resulting in drier soils (Zipper et al. 2017). Such challenges are expected to increase due to climate change and coupled temperature rise (Esperon-Rodriguez et al. 2022).

Adding to this, the challenges associated with urban vegetation establishment generally increase in environments like school grounds. This is mainly due to the increased level of wear and tear and soil compaction caused by active use of the vegetation by children (Gunnarsson and Gustavsson 1989), a type of disturbance that is enhanced in school grounds of limited size (Jansson et al. 2021). Additionally, even low amounts of trampling have been shown to cause significant soil compaction, which may have severe impacts on both the soil and the vegetation (Cole 1987, Hamberg et al. 2010).

To provide benefits, woody vegetation must remain alive and grow, making careful species selection essential so that site-specific conditions are matched (Sjöman et al. 2023). Additionally, since woody species differ in their characteristics, so do the benefits they offer, such as impacts on microclimate (Antoniadis et al. 2016, El-Bardisy et al. 2016) or on academic performance (Sivarajah et al. 2018). Shrubs may be of special interest for school grounds, not only because they provide benefits for play, but also

[3] Following Rietveld (1989), establishment is in this thesis defined as a process after planting including an initial period of stress; a recovery phase; and a final stage of adaptation to the new environment.

because of their ability to endure disturbance, supported by characteristics such as multi-stemmed growth forms and faster growth rates than trees (Götmark et al. 2016, Esperon-Rodriguez et al. 2025). Moreover, methods for vegetation establishment that are successful while also allowing use of the vegetation are important to avoid excluding children from large parts of their school grounds during longer periods (Jansson et al. 2014). There are knowledge gaps in understanding how to successfully implement[4] vegetation in places for children's play (Mårtensson et al. 2021, Beckman et al. 2023), and especially on school grounds (Jansson et al. 2014).

1.3 Governance aspects affecting school ground vegetation

In recent decades there has been an international interest in greening of school grounds. This includes a multitude of school ground development projects and organisations. European examples include the Oasis project in Paris (European Environment Agency, 2022), the Forest School initiative in the UK (The Mersey Forest, 2022) and Grün macht schule in Berlin, Germany, active since 1983 (Grün macht Schule 2025). In the United States, the non-profit organization Green Schoolyards America has promoted greener school grounds since its founding in 2013 (Green Schoolyards America, 2024). These initiatives, along with school ground greening efforts more broadly, typically encompass more than just vegetation development, such as participatory approaches. Additionally, "Green school grounds" often incorporate various natural elements, such as weathered wood, sand, mud, varied topography, and reduced impervious surfaces (Kuh et al. 2013, Giezen and Pellerey 2021, van Dijk-Wesselius et al. 2022). But while several natural components enhance school grounds, vegetation remains a core component in these efforts (The Mersey Forest 2022, Green Schoolyards America 2024, European Environment Agency 2022, Grün macht Schule 2025).

Governance of school grounds is often complex with many different types of actors involved (Sekulova and Mallén 2024) including children, parents, school personnel, property and green space managers. Knowledge among

[4] Implementation is defined in this thesis as the scope of activities related to planting vegetation, ranging from planning and design to the actual planting, establishment, and management of the vegetation.

these actors play an important role in the success of school ground greening efforts (Giezen and Pellerey 2021, Sekulova and Mallén 2024). School personnel has specific importance, as the benefits of vegetation contact for children can be enhanced depending on how it is utilised and integrated into pedagogy (Jansson et al. 2014). The perceptions and opinions of these different actors add on to this complexity, with one example being the question of risky play in school settings (Spencer et al. 2021). The actors involved can also vary depending on national context. One such variation in Sweden is that school grounds are in general open for the public after school hours, resulting in an additional actor group, users after school hours. Additionally, policy changes like "Fria skolvalet" (Free School Choice) and "Marknadsskolan" (Market-based School), have shaped the school system in Sweden and can be associated with the integration of New Public Management (NPM) strategies (Skolverket 2003, Henrekson and Wennström 2022, Hood 1991).

The primary users of school grounds are children in their role as students. Much research has investigated how school ground vegetation influences children (e.g. Dyment et al. 2009, Lindemann-Matthies and Köhler 2019), but considerably less has examined how children, in turn, affect school ground vegetation (Jansson et al. 2014). Moreover, there is a general lack of research on planting design in urban environments (Oliveira Fernandes et al. 2025). Research on the specifics regarding the implementation of school ground vegetation is lacking. Interdisciplinary research is of particular importance in this context because of the complexity surrounding this implementation. There is a lack of overview of the existing knowledge on the subject, both within science and practice. There are groups that can be assumed to have extensive practical experiences and knowledge around this, mainly among green practitioners[5]. Practical knowledge and experience in establishing vegetation can provide valuable insights into best practices for planting and maintaining different types of vegetation. Additionally, such practitioners may have intimate knowledge of the processes and organisational structures of which they are a part, and how these affect school ground greening.

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[5] Green practitioner is in this thesis used as a collective term for people who have a high focus on vegetation in their work. Examples are landscape architects, landscape engineers, green space managers, planners and school ground greening advocates.

Prioritizing vegetation on school grounds can ensure that children reap the benefits associated with vegetated areas. This also contributes to the overall increase in vegetation in urban areas, leading to numerous positive impacts on the environment and the well-being of the local environment as a whole. Shrubs are of specific interest because of their high potential for use and contribution on school grounds. Initiated to meet the need for scientific insights into school ground vegetation, this doctoral project examines several important aspects related to the implementation of school ground vegetation, with a particular focus on shrubs.

1.4 Aim

The aim of this doctoral project was to deepen the knowledge around the implementation of school ground vegetation, focusing on shrubs. The thesis consists of four studies, presented in four papers. It starts with a mapping review (Paper I), investigating the existing research on school ground vegetation. An interview study (Paper II) investigates the existing practice-based knowledge, and a greenhouse experiment (Paper III) investigates suitable species and plant strategies for school grounds. These studies formed the basis on which the school ground experiment (Paper IV) was developed.

The findings from the scientific papers in the project address the following core questions, with the main contributing papers in parenthesis:

- What is the state of the art in research and practice on school ground vegetation (Paper I and II)?
- What are the effects of children’s play and use on school ground vegetation (Paper II and IV)?
- How do aspects related to governance affect the implementation of school ground vegetation (Paper II)?
- What species and species characteristics are suitable for school grounds (Paper II, III and IV)?
- What planting designs and methods are suitable for successful establishment of school ground vegetation (Paper III and IV)?

2. Methods

2.1 Research approach and outline

This doctoral project is closely connected to societal needs and has been developed and conducted with a goal of applicability. It is an interdisciplinary project within Landscape architecture, connecting to different research fields and concepts including plant ecology, horticulture, children's environments, and governance and management of urban space. Because of the differing methodological necessities and traditions of each, the project draws on both natural and social sciences (Persson et al. 2018), employing both objectivist and social constructivist approaches as they are described by Swaffield (2006) in the effort to achieve a comprehensive perspective. For instance, the mapping review, the greenhouse and school ground experiments take an objectivist approach, focusing on quantitative investigations. In contrast, the interview study adopts mainly a social constructivist approach, focusing on individual knowledge and the subjective experiences of the respondents. Each study within this project retains its methodological independence, aiming for a pluralistic approach to interdisciplinarity (Persson et al. 2018), and the findings are synthesised in this thesis to enhance the understanding of implementation of vegetation on school grounds.

2.2 Geographical context and age groups included

The geographical scope of each study in this thesis was specified to meet specific research objectives. A global perspective was adopted in Paper I, providing an overview of trends and approaches in school ground vegetation research world-wide. In contrast, the species assessments in Paper III and Paper IV focus on the climate conditions and ecological context of northern Europe. However, many findings from Paper IV, which analyses the effects of children's interactions with vegetation, are broadly applicable to school grounds in general. Paper II is largely Sweden-specific, engaging with local practitioners and their work in a national context. Despite these varying geographical foci, several aspects might be relevant to many contexts.

Similarly, the age groups considered vary slightly across the papers. Paper I, much like its geographical context, adopts a broad approach by including research on school grounds with individuals aged 0 to 20 years. Paper II focuses on children between 7 and 12 years old, but also includes some aspects connected to children in preschool. Age becomes relevant in Paper III as the selection of plant species and treatment decisions assumed that children would interact with the vegetation during play, something which is often seen among children up to around age 11 (Jansson et al. 2014). Lastly, Paper IV is set in schools with children between 6 and 15 years old. This thesis takes a broad interest in school ground vegetation, but with a main focus on its connections to children between 7 and 12 years old.

2.3 Conceptual frameworks

This doctoral project draws on insights from different theories and principles within the natural and social scientific realms. Key frameworks include the CSR model in ecology, which explains plant strategies in response to environmental factors, and the Policy Arrangement Approach, which analyses governance dynamics.

2.3.1 Ecology

To assess the requirements for incorporating woody, focusing on shrubby, vegetation on school grounds, this thesis focuses on different limiting factors and the responses towards them, with particular attention on drought and disturbance. The CSR model provides a framework for classifying species based on their adaptability to challenging conditions such as these and has been utilised accordingly in this thesis.

The specific characteristics of shrubs

Efforts to distinguish shrubs from trees rely on various physical characteristics such as their multi-stemmed, low perennial growth form (Götmark et al. 2016) or difference in resource use and/or response to disturbance in specific biomes (Zizka et al. 2014). Set in the context of school ground greening, following Levinsson et al. (2024) that departs from Du Rietz (1931) and Götmark et al. (2016), this thesis defines shrubs as woody plants with a maximum height of approximately 8 meters, characterized mainly by multi-stemmed growth with branches near or at ground level. These features give shrubs higher accessibility for play than trees, which is of relevance to this project.

How woody vegetation and shrubs handles and responds to drought

Drought affects plant function by limiting water availability, which is essential for various physiological processes (Choat et al. 2012). Severe drought can lead to cavitation, where gas bubbles form in the xylem and disrupt water transport. In extreme cases, this may cause xylem collapse, resulting in terminal effects (Cochard et al. 2013). Additionally, drought may damage roots, impairing their ability to absorb water and nutrients (Trifilo et al. 2023). The lower height of shrubs makes them less vulnerable to cavitation risks from drought or freezing compared to trees (Götmark et al. 2016).

Common drought avoidance strategies among plants (Delzon 2015, Hirons and Thomas 2018) include closing stomata to maintain leaf turgor (Klein 2014) and shedding leaves to reduce water loss (Wolfe et al. 2016). However, these conservative strategies often come at the cost of reduced growth and, over time, a diminished ability to withstand mechanical stress. In contrast, a greater ability to function across a wider range of turgor pressures is considered indicative of drought tolerance (Klein 2014, Meinzer et al. 2016, Hirons and Thomas 2018). Differing stomatal behaviour under drought can be described as a continuum from isohydric to anisohydric strategies (Klein 2014, Roman et al. 2015). Isohydric, drought-avoidant species minimize water loss by closing stomata early thereby avoiding cavitation but also limiting photosynthesis. In contrast, anisohydric, drought-tolerant, species keep stomata open longer, tolerating lower leaf water potential to sustain photosynthesis (Manzoni et al. 2013).

Assessing drought tolerance can be done by measuring plants' responses during drought stress, such as through leaf water potential and stomatal conductance measurements (Scholander et al. 1965, Williams and Araujo 2002). To assess a plant's ability to handle drought one can also examine specific traits. One interesting trait is the turgor loss point, where the leaf water potential at wilting point is determined (Lenz et al. 2006, Sack and Holbrook 2006), which often indicates a plants ability to function across ranges of turgor pressure.

How woody vegetation and shrubs handles and responds to disturbance

In response to disturbance, woody vegetation can regenerate via seeding or resprouting, typically exhibiting a trade-off between these two modes of recovery (Bond and Midgley 2001). Shrubs are often described as well adapted to disturbances (Scheffer et al. 2014) and have, due to their growth form, an advantage over trees in surviving such disturbances through resprouting. They usually grow faster and produce more stems (Wilson 1995, Esperon-Rodriguez et al. 2025) and tend to regenerate more effectively via lateral or basal buds (Wilson 1995, Götmark et al. 2016), meaning they are often more resilient to top shoot damage.

Among many shrub species, resprouting serves as a primary mechanism of vegetative regeneration (Bond and Midgley 2001) especially in communities subjected to frequent disturbances (Pausas et al. 2004). Resprouting ability is not a simple binary trait but instead represent a spectrum. Variation in resprouting ability is seen both between species and across developmental stages within species, where resprouting is more common among angiosperms than gymnosperms (Bond and Midgley 2001) and among young plants compared to older (Boege and Marquis 2005).

Shrubs in larger structures

Plant species growing in close proximity interact through complex processes that can be described as competition and facilitation. These dynamics depend on root depth, shading effects, nutrient exchange, and species-specific resource use, all of which influence the overall vegetative structure. Further, the balance of competition and facilitation may vary depending on life stages of the plants, their physiologies and the level of abiotic stress or disturbance experienced (Callaway and Walker 1997).

Plants sheltering, and hence facilitating, other plants are often referred to as nurse plants (Callaway and Walker 1997). Nurse plants primarily support other plants by mitigating abiotic stress (Filazzola and Lortie 2014), a mechanism particularly relevant to the disturbed conditions of school grounds, where this type of sheltering can enhance plant growth. Shrubs have been described as the most common nurse life-form, especially in environments characterized by substantial abiotic stress (Filazzola and Lortie 2014). Additionally, spiny shrubs (shrubs with thorns, prickles and spines) offer protection by reducing abiotic damage from large herbivores (Hanley et al. 2007, Bustamante et al. 2021). In the context of school grounds this may be translated to shielding plants from wear and tear caused by children.

CSR theory

Choosing appropriate species for specific urban sites is no easy task. Ecological trait-based theories may provide a useful framework, but since many of these theories are primarily designed to explain plant distribution and reproduction, their direct application to species selection in urban areas are challenging (Watkins et al. 2021). However, Watkins et al. (2021) found that the Universal Adaptive Strategy Theory (Grime 1979) is most applicable for guiding species selection in urban forestry because of its focus on species' capacity to tolerate stress and disturbance. This theory was later introduced by Grime (2001) as the CSR theory (where CSR stands for Competitive, Stress, and Ruderal) and after this expanded by Grime and Pierce (2012). For school grounds, where stress and disturbance are particularly prevalent, this theory may be useful.

Grime's CSR theory explains evolutionary trade-offs in resource competition, tolerance to resource limitations, and biomass damage (Grime and Pierce 2012). According to this theory, plant material in habitats is limited by two factors: stress (e.g., shortages water, nutrients, or suboptimal temperatures) and disturbance (e.g., biomass destruction from grazing, trampling, wind, or fire) (Grime 2001). Combining high/low stress and disturbance creates four theoretical habitat extremes, but only three are viable for plants. These correspond to three strategies: competitors, stress-tolerant, and ruderals, visualized in a triangular model (Figure 1) (Grime 2001). In the CSR model, the total CSR value is fixed, meaning an increase in one strategy must come at the cost of another (Grime 1979). No species can maximize all three habitat extremes simultaneously; plants must balance trade-offs between competitiveness, stress tolerance, and disturbance survival. This results in the prerequisite that a plant with for example high C values (indicating strong competitiveness) cannot also exhibit high S values.

The three strategies in the CSR model differ in their adaptive mechanisms. Competitors have an advantage in productive, low-disturbance areas, relying on traits that enhance resource acquisition and limit neighbouring plants' access to these resources (Grime 1979). Stress-tolerating species, in contrast, survive in unproductive habitats by maintaining metabolic functions despite limited resources; they typically invest in durable, slow-growing tissues suited to prolonged stress (Grime 2001). Ruderals populate highly disturbed, productive environments, compensating for their short lifespans with high seed production and rapid regeneration, and only herbaceous plants should be able to be categorized with a very high R-value (Grime and Pierce 2012).

However, pure strategies are improbable to find in nature as plants often exhibit mixtures of strategies, adapting to intermediate levels of stress and disturbance (Grime 2001). In other words, it is highly improbable for a plant to have CSR-values where one of the values are at maximum and the other two at zero, meaning a placement at the absolute edge of one corner in the triangular model. However, plants are categorized as a C/S/R-strategist if the values of the other two are low enough. With more balance of the three values, intermediate strategies appear, such as SR, CS, CR and CSR.

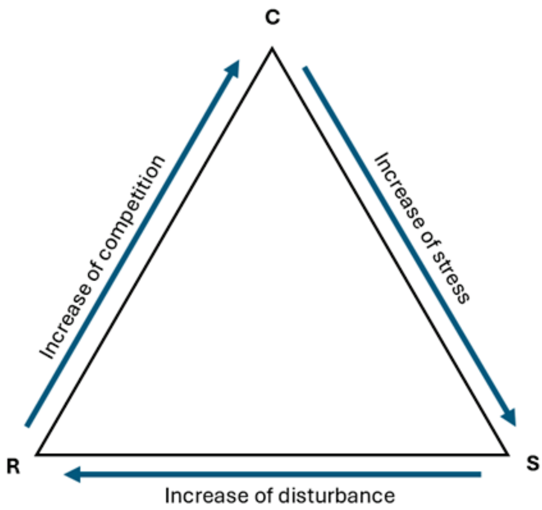

Figure 1. Grimes model of the three strategies, adapted from (Grime 2001).

As with functional traits in general (De Bello et al. 2021), it is important to consider intraspecific variation when it comes to the CSR-theory. Ecotypic variation as well as phenotypic plasticity within species means that individuals may adopt different strategies depending on their environment (Pierce et al. 2013). This variation within a species can be important to consider depending on the purpose of the investigation (Astuti et al. 2018).

Over the years, there have been discussions and various forms of critique directed towards the CSR-theory. Critics have not identified logical flaws but validly point out that it only partially represents species and habitat differences and that its inherent simplifications can overlook variations within strategies and tolerance (Wilson and Lee 2000). For example, regarding stress tolerance, the theory fails to distinguish between adaptation types such as tolerance and avoidance (Grubb 1985). It also does not distinguish between different types of adaptation to disturbance (Steneck and Dethier 1994). However, the purpose of a theory is to summarize and therefore it does not include all relevant information, while efficiently summarizing much of it (Wilson and Lee 2000). Whether the theory's generality outweighs the drawbacks of its simplification remains an open question that must be considered when applying it.

2.3.2 Governance

The governance of school grounds is often complex, involving multiple stakeholders with diverse interests and responsibilities (Sekulova and Mallén 2024). To navigate this complexity, the project utilises a framework that offers a structured perspective, shedding light on the interdependence of key governance elements.

The Policy Arrangement Approach

The Policy Arrangement Approach (PAA) (Arts et al. 2006) analyses the dynamic interplay between the four dimensions: actors and coalitions, resources, rules of the game, and discourses, within a policy domain. It emphasizes the temporary stabilization of these dimensions, highlighting how changes in one can influence others, thereby facilitating an understanding of stability and change in policy dynamics and decision-making processes.

The PAA with the interplay of its four dimensions has previously been used to analyse governance arrangements revolving around green space and green practitioners (Lawrence et al. 2013, Molin and Konijnendijk van den Bosch 2014, Fors et al. 2018).

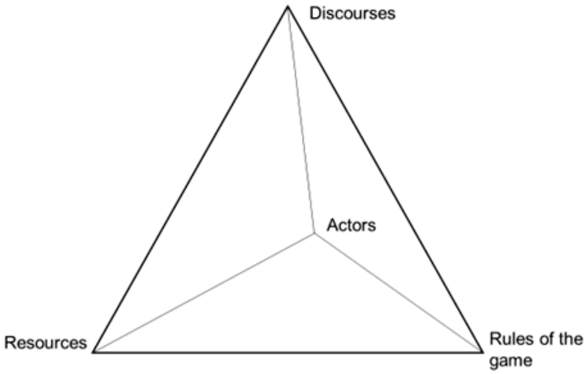

Figure 2. The PAA tetrahedron adapted from Arts et al. (2006).

The tetrahedron serves as the visual model of this approach (Figure 2), illustrating the dimensions and their interdependence. The dimensions can be defined as follows:

- Discourses: This dimension refers to the ideas, beliefs, and values that shape organisational structures. It includes the language used to describe issues, as well as the underlying assumptions and worldviews that inform decisions.
- Actors and Coalitions: This dimension refers to the groups of actors involved. It includes both formal and informal alliances between actors, as well as oppositions between different groups.
- Rules of the Game: This dimension refers to formal rules and regulations as well as informal ones including decision-making procedures, relationships between actors, and norms around participation and exclusion.
- Resources: This dimension encompasses the material and non-material resources that actors have, such as financial means, expertise, and access to information. In the context of school grounds this may also include physical space and material assets. These resources are closely tied to the distribution of power and influence among the actors. Power involves the mobilization, allocation, and utilization of resources, while influence refers to driving outcomes and the way they do so.

2.4 Paper I, Mapping review

School ground vegetation research appears across diverse fields, including landscape architecture (Jansson et al. 2014), biology (Muvengwi et al. 2019), education (Dyment 2004), and medicine (Nury et al. 2017). This spread can make it difficult to gain a cohesive understanding of the research landscape. Faced with this challenge, and recognizing the absence of a comprehensive review, a systematic mapping review of school ground vegetation research was conducted. A mapping review broadly screens scientific literature to analyse research scope, including topics, methods, and geography, without synthesizing study findings (Petersen et al. 2008, Kitchenham et al. 2010). It focuses on when, where, and how research is conducted, using systematic review methods for searching and data extraction (Kitchenham et al. 2010, Booth et al. 2016).

2.4.1 Scope and screening

The search strings were built around three aspects. The first two described the place in focus, a place for childcare or an educational facility, and specifically its outdoor environment. The third aspect considered the vegetation. The searches resulted in 13 403 papers, which after screening were narrowed down to 133. These papers included studies published in English, on school ground vegetation within school boarders accessible to children with the maximum age of 20 years old.

2.4.2 Data extraction and analysis

A range of analysis categories was used to analyse the literature, presented in table 1.

Table 1. Analysis categories used in Paper I.

Analysis Categories	Explanations
Publication Year	Year of publication
Geographical Area of Focus	The area/continent where the research was conducted
Theme	Aim/purpose of the research
Age range	The age of the children attending the school/schools under investigation
Description of Vegetation, Type	Level of specificity when describing the vegetation
Description of Vegetation, Size/Shape	Specification of the spatial qualities of the vegetation (Y/N)
Existing or New Vegetation	Investigation of existing or newly planted vegetation
Vegetation Development, Time Aspect	Inclusion of a time perspective, development of the vegetation (Y/N)

Themes were derived by manually categorizing the articles based on their primary research aims, using an inductive approach to ensure accurate representation of the data corpus (Booth et al. 2016). Table 2 provides a detailed overview of these themes. After formulating the themes, both the primary theme and any associated themes within each article were recorded.

Table 2. Detailed description of themes.

Theme	Description
Eco-literacy	Enhancing the relationship between children and the environment/nature through environmental and natural knowledge.
Microclimate	Atmospheric conditions on school grounds, including temperature and wind patterns.
Children's perspectives	Viewpoints of school children.
Education and cognitive effects	Connections to educational activities', covering attention span and knowledge acquisition.
Gardening	Cultivating vegetables, fruits, and similar produce with school children's participation, often consumed in school or by the community.
Physical activity	School children's physical activity, for example measured using tools like pedometers.
Perspectives of those other than children	Thoughts and experiences of individuals other than school children, like parents or school personnel.
Play	School children's play, for example measured using methods such as behavioural mapping.
Socio-economic factors	Connections to socio-economic aspects of the schools under examination.
Physical health	Aspects of health such as nutrition, exposure to harmful substances, and toxic plants within school grounds.
Spatial layout	Extensive focus on the spatial layout of the school grounds, beyond including just plans or descriptions.
Mental health	The mental health of school children, investigating aspects like well-being and restoration.
Biodiversity	Species diversity within the school grounds.
Social relationships	Interpersonal dynamics among school children.

2.4.3 Statistical analyses

To determine the correlation between the themes, the phi coefficient (φ) was calculated, as seen in (1), for each pair of themes. This calculation was based on the co-occurrence of all themes in the articles, thus the main themes and all other themes present.

$$\varphi = \frac{N_{11}N - N_{1.}N_{.1}}{\sqrt{(N_{1.}N_{.1}N_{0.}N_{.0})}} \qquad (1)$$

Where N is the total number of articles, N_{11} is the number of articles where both themes appear, $N_{1\cdot}$ is the total number of articles where Theme 1 appear (regardless of Theme 2) and $N_{0\cdot}$ its inverse (i.e., total number of articles where Theme 1 is absent). The total number of appearances or absences of Theme 2 is similarly indexed with $N_{\cdot 1}$ and $N_{\cdot 0}$ respectively.

2.5 Paper II, Interview study

Paper II investigates the current knowledge in practice concerning the implementation of woody vegetation on school grounds. This was done through interviews with Swedish green practitioners. This paper complements the investigation of research done in Paper I by deriving information on the knowledge around school ground vegetation from practice. Moreover, it extends beyond this by analysing the structures governing implementation of school ground vegetation. The policy arrangement approach (PAA) (Arts et al. 2006) was used to guide the study as a whole and to deepen the understanding of the results. It provided an understanding of how the different dimensions interacted and affected the implementation of school ground vegetation in Sweden, based on the perspectives of green practitioners.

2.5.1 Selection of respondents

Respondents were recruited via personal networks, university connections, and two specialized email lists. Practitioners who considered themselves highly knowledgeable of school ground greening were selected for the study, resulting in 26 respondents. They primarily worked in urban areas across Sweden, spanning from Malmö in the south to Umeå in the north (approx. 1200 km apart). The represented stages within the school ground greening process among them were: design (n=8), inspection (n=4), management (n=12), maintenance (n=3), and research/teaching (n=2). Including respondents from various stages and covering the entire implementation chain enhanced the likelihood of obtaining comprehensive insights while minimizing the risk of overlooking critical factors in the implementation of school ground vegetation. This broad inclusion of respondents was in line with the broad perspective on implementation of school ground vegetation taken in the project.

2.5.2 Conducting interviews

The method used for interviewing was based on the expert interview method (Meuser and Nagel 2009), a qualitative interview method focused on the knowledge of experts. An expert is in this context defined as a person holding specific knowledge within his or her professional domain. However, this does not necessarily equate to having a high level of influence or authority (Bogner et al. 2018). Conducting this type of interview is easier if the interviewer have expertise in the relevant field (Meuser and Nagel 2009). This can assist discussions to go beyond general knowledge and in fostering trust with respondents, which might be particularly important in conflict-prone topics. An approach where the interviewer appears naïve can, however, be advantageous for the perceived power imbalance. Naïve questions often yield insightful answers, as such interviewers are often seen as trustworthy (Bogner et al. 2018). In this study the interviewer (i.e. the thesis author), held a master's degree in landscape architecture with some work experience in green space management, but had, at the time of the interviews, limited experience in school ground greening. This combination of subject knowledge and the ability to ask naïve questions aided in comprehensive information gathering.

The interviews were semi-structured and performed using a topic list. Following this, closed questions were avoided (Meuser and Nagel 2009). The interviews were conducted in a conversational form which enabled the respondent to guide the conversation towards topics that they thought were important (Scheibelhofer 2008).

2.5.3 Interview analysis

In line with Meuser and Nagel (2009), only the most relevant parts of the expert interviews were transcribed and organized into paragraphs for analysis. The analysis was done following the general framework proposed by Bogner et al. (2018), complemented by reflexive thematic analysis as outlined by Braun and Clarke (2012). Once all transcripts were processed, the coded paragraphs were reviewed, adjusted, and organized into overarching themes using an inductive approach (King and Brooks 2018).

2.6 Paper III, Greenhouse experiment

The purpose of the greenhouse experiment was to investigate reactions towards drought and biomass loss among different shrub and smaller tree species suitable for school grounds, as well as the connection of their reactions to the CSR model. Drought was chosen because of it being an often reported issue at school grounds and biomass loss was included in an effort to mimic children's wear and tear.

2.6.1 Species selection

The species for this experiment were selected based on the principles of the CSR model (Grime 2001) with the CSR combinations C, CR, CS, CSR, SR, and S included. The pure R-category was excluded, as no woody species exhibit this strategy (Grime 2001). Species data were sourced from two datasets, Sjöman et al. (2025) and Pierce et al. (2013), both employing the CSR classification method outlined in Pierce et al. (2013). Stress, according to the CSR-theory, encompasses various environmental factors. Therefore, drought-tolerant species among the included species were identified using the quantitative drought-tolerance model by Niinemets and Valladares (2006). To align with the study's focus on vegetation suitable for school grounds, the search was limited to non-poisonous, low risk of invasiveness (in Sweden according to Tyler et al. (2015)) shrubs and smaller trees. Twelve different species were selected, two species from each of the categories CS, SR, CR, CSR and S. However, only one species was possible to get hold of within the C-category (Table 3), giving a total of eleven species.

Table 3. Species included in the experiment ordered by their CSR-category. Numbers denotes which dataset was used to find the species, 1 representing data from Sjöman et al. (2025) and 2 representing data from Pierce et al. (2013).

Category	C	CS	SR	CR	CSR	S
	Aesculus parviflora[1]	*Syringa vulgaris*[1]	*Caragana arborescens*[1]	*Sambucus nigra*[1]	*Cornus sanguinea*[1]	*Cornus mas*[1]
		Diervilla lonicera[1]	*Salix rosmarinifolia*[2]	*Decaisnea fargesii*[1]	*Ribes rubrum*[2]	*Salix purpurea 'Nana'*[1]

2.6.2 Experimental set up and measurements

The experiment was conducted in a greenhouse at SLU's Alnarp campus located in south of Sweden during the summers of 2020 and 2021. In June 2020, 28 healthy, moderately sized plants per species, totalling 308 plants, were selected and randomly assigned to one of four treatment groups which were: drought, biomass loss, a combined treatment with both drought and biomass loss, and a control. The drought treatment involved withholding water during a four week long period in mid-summer, while the biomass-loss treatment involved removing 50% of crown biomass at the start of the drought period each year. CSR categorization of the greenhouse plant material was performed to further investigate the species selection. These calculations followed the framework of Pierce et al. (2013).

Water status was assessed by measuring midday leaf water potential (Ψl) and stomatal conductance (g_S) (Scholander et al. 1965, Williams and Araujo 2002) throughout the drought period, which provided insight into how plants regulated transpiration and responded to water stress (Gimenez et al. 2005). In 2021, an additional measurement was conducted three weeks post-drought after irrigation to assess physiological recovery. To estimate turgor loss point (Ψ_{P0}) from osmotic potential at full turgor ($\Psi\pi_{100}$), an equation from Sjöman et al. (2015), adapted for temperate species from Bartlett et al. (2012), was applied. Seasonal variations in drought tolerance was investigated through including spring and summer estimations of Ψ_{P0}.

Plant length was measured at planting, in July 2020, June 2021, and at harvest the fall of 2021 to track growth before and after each experimental period. The root:shoot ratio was calculated at harvest by dividing below-ground dry biomass by above-ground dry biomass.

2.6.3 Statistical analyses

Statistical analyses were conducted in R (version 4.5.0) with a significance level of 0.05. Plotting of the residuals was done to ensure model assumptions were met. The experimental design supported full factorial analyses to evaluate the effects of drought and biomass loss treatments. Further, in order to try to evaluate the usefulness of the CSR model and structure the calculated CSR-strategies in the most meaningful way, different interconnected steps and approaches were used to incorporate the CSR aspects in the statistical modelling.

Repeated and non-repeated measurements models

Linear mixed-effects models (lme4; Bates et al. (2015)) were used to analyse Ψl, g_S, length, and root collar diameter. Random intercepts accounted for repeated measures and nested structures within blocks. Initial length was included as a covariate in the length models. Root:shoot ratio, shoot biomass, and Ψ_{P0} were analysed using linear models (R core team 2021). ANOVAs tested overall effects, and Tukey-adjusted post-hoc comparisons (emmeans package; Lenth (2025)) were used to investigate differences further.

CSR classification comparison

To give insights about the robustness of CSR classification based on the different datasets the suitability of CSR, linear models tested their ability to explain Ψ_{P0}, growth, root:shoot ratio, and shoot biomass. Model comparison relied on Akaike Information Criterion (AIC) (Aho et al. 2014), which to a large extent favoured the greenhouse dataset.

Intraspecific variability

Intraspecific variability in CSR values (C, S, and R) was evaluated via one-way ANOVA, partitioning variance into within- and between-species components (De Bello et al. 2021). This allowed evaluation of how much of the total variability explained by intraspecific versus interspecific variability. Based on these analyses species means were used for further analyses.

Specialization index

To account for the interdependent nature of CSR strategies, each species' CSR specialization was calculated using the Williams concentration index (Ricotta et al. 2023). This index measures how specialized a species is within the CSR framework, ranging from 0 (generalist) to 1 (fully specialized) based on Euclidean distance from reference CSR distributions. Species formed three distinct CSR-based clusters: balanced CSR values, high C-values, and high S-values. K-means clustering (k = 3) was used to formally classify species, with these groups incorporated into non-repeated models and visualizations to provide further insights.

Model comparisons between species and CSR

To compare species and CSR strategies as explanatory variables, response models were run using species, CSR groups, and individual CSR components (C-, S- and R-levels, and specialization index). AIC was used to evaluate model fit (Aho et al. 2014), and significance was tested against reference models excluding species and CSR variables.

2.7 Paper IV, School ground experiment

Considering the gap in longitudinal research on school ground vegetation identified in Paper I, an in-situ experiment was conducted on school grounds. This enabled testing of species from the Paper III and examination of issues raised in Paper II, fostering integration across the project and shedding further light on the complexity of school ground environments.

This study tested different plot sizes, which appeared as an interesting factor from Paper II and included five species of different CSR strategies from Paper III. It was carried out in collaboration with Stadsfastigheter, a unit within Malmö local government responsible for managing municipal properties.

2.7.1 Research design and measurements

Plots of three different sizes, including five different species, were planted and monitored over two years on three sites on two different school grounds, Rörsjöskolan and Lindeborgskolan, in Malmö, Sweden. One large distinction between the two schools lied in the extent of accessible vegetation within their respective school grounds. The experiment included three sites, one at Lindeborgsskolan (site L) and two at Rörsjöskolan (sites R1 and R2). Site L was centrally located, near vegetation, and pathways, with good visibility for school staff. Site R1 was positioned at the edge of a large grass field, along pathways near a school entrance, and was highly visible. In contrast, Site R2 was located between two buildings near the school perimeter, making it less visible. The plot sizes included were 2x2m, 4x4m and 6x6m.

To avoid hidden treatment effects, randomization of the species was done using latin squares with some spatial restrictions to avoid grouping of individual species, as positioning in the plot was thought to have effect on wear and tear as well as growth patterns. It was important that species were mixed, to ensure good conditions for studying interactions, and that all species were present in as equal amounts as possible in the corners, along edges and in the centre of the plots.

The substrate used was a mixture of 70% pumice and 30% compost, as often used by the municipality on school grounds to reduce the risk of compaction and improve aeration and water availability. A 60 cm-high municipal-standard fence was designed to limit direct passage through the plots without completely restricting access. Although children were not officially allowed to play within the plots during the establishment phase, monitored by teachers at both schools, they still clearly interacted with the vegetation.

Different measurements were taken throughout the experiment in order to capture the growth of the vegetation and the effects of wear and tear. Wear and tear was estimated as a percentage of each plant's aboveground biomass, reflecting current damage only. A plant was recorded as dead when all aboveground biomass was estimated to be dead, and a notation was made if a plant previously estimated dead produced new shoots. Length were measured from the soil surface to the top of the plant, excluding leaves, and the crown projection area (CPA) was estimated by measuring the crown radius in four directions (Pretzsch et al. 2015). Soil compaction was measured with a penetrometer at field capacity (Duiker 2002). Additionally, observations were recorded during site visits.

2.7.2 Statistical analyses

All statistical analyses for Paper IV were conducted in R (version 4.5.0) with a significance level of 0.05. Model assumptions were validated using residual plots, and model selection was based on AIC values (Aho et al. 2014).

Growth Analyses

Growth variables, CPA and length, were analysed using linear mixed-effects models (lme4 package; Bates et al. (2015)), with log-transformed response variables to meet model assumptions. Initial differences at planting were accounted for by including baseline measurements as covariates. ANOVAs tested main effects, and Tukey's adjusted post-hoc comparisons (emmeans package; Lenth (2025)) were used to investigate differences further.

Wear and Tear Analyses

Wear and tear were modelled using zero-inflated beta regression mixed model (glmmTMB package; Brooks et al. (2017)) to account for excess zeros (i.e. no wear and tear). The model distinguished between occurrence of wear and tear (zero-inflation) and level of wear and tear (beta distribution). Post-hoc tests with Tukey's adjustment were conducted (emmeans package; Lenth (2025)). Heat maps visualised cumulative wear and tear and plant mortality patterns. Spatial autocorrelation (Moran's I) was applied (spatstat and spdep packages; Baddeley et al. (2016), Bivand et al. (2013)) to assess clustering, even dispersion, or randomness in wear and tear patterns within plots.

Plant Death Analyses

Spatial connectivity of dead plants was analysed using graph-based methods (igraph package; Csardi and Nepusz (2006)) to identify clusters and paths formed by child movement in plots. Dead plant locations were extracted, and pairwise distance matrices identified connected groups using a 1.5-unit threshold.

The effect of cumulative wear and tear on plant death was assessed via binomial logistic regression (glm2 package; Marschner (2011)). ANOVA test evaluated predictor significance and post-hoc trend analyses (emtrends, Lenth (2025)) estimated species-specific slopes for cumulative wear and tear at each site.

3. Results and discussion

The complexity of school ground vegetation and its associated aspects has previously been lifted (Stevenson et al. 2020) and is also reflected in the papers presented in this thesis. This thesis focuses on a few pieces of this complex puzzle, and how they are connected, when investigating how to ensure successful implementation of vegetation for the benefit of children and more.

3.1 What is the state of the art in research and practice on school ground vegetation?

The results from Paper I show that many studies on school ground vegetation lack specificity in their descriptions of both content (types of plants) and spatial aspects (size, shape, and distribution of vegetation). Given the diverse fields and focuses within school ground research, specifying these details as clearly as possible can enhance both relevance and cross-study comparisons (Paper I). General terms like "nature" or broad categories like "trees" or "shrubs" are often used, making it difficult to compare studies or synthesize results effectively. This has also been seen by Hedblom et al. (2024), around the concept of nature and biodiversity in studies on children's environments. In research on children and vegetation the aspects of interest can vary depending on the focus of a study, whether it be the size, shape, or composition of vegetated areas (Fjørtoft and Sageie 2000) but specifying the content and spatial characteristics of the vegetation is of importance for the applicability of research findings (Paper I). Furthermore, most studies focus on already established vegetation (Paper I), overlooking the processes involved in planting and establishing vegetation, processes that are particularly interesting due to their complexity (Paper II). Results from Paper I indicate that there is a need for more detailed and coherent research on school ground vegetation, especially regarding its spatial characteristics and dynamic changes.

Knowledgeable actors are important for effective school ground greening (Sekulova and Mallén 2024) and the results from Paper II describe how there is a lack of knowledge concerning school ground vegetation within the green field in Sweden. The respondents emphasized gaps in understanding how play affects plant survival and noted limited available information on suitable species and planting strategies for school grounds (Paper II). They highlighted the complex knowledge needed for green school ground design, aligning with research (Giezen and Pellerey 2021, Sekulova and Mallén 2024), yet described how this complexity was often overlooked in the green field. Thus, more research on school grounds vegetation could be of great value for practise.

Further, Paper I highlighted the breadth of research on school ground vegetation and identified several research gaps through correlation analysis of research themes. The need to advance research through interdisciplinary approaches and focus on strategic research gaps has previously been emphasised, specifically to capture and address the complexity of green school grounds (Stevenson et al. 2020). Finding research gaps and filling them through interdisciplinary research can be an effective way of developing knowledge about school ground vegetation and improving its long-term success.

3.2 What are the effects of children's play and use on school ground vegetation?

The presence of children is described by green practitioners to highly affect whether establishment of vegetation is successful or not (Paper II) and is seen to have a large effect on the vegetation on one of the schools, Rörsjöskolan, in Paper IV. This emphasises how understanding the nature of children's use of vegetation is necessary to understand vegetation establishment on school grounds. In Paper II, the impact of children was compared to that of browsing or grazing animals, a parallel also noted in previous studies (e.g. Gunnarsson and Gustavsson 1989, Hedblom et al. 2024, Wiström et al. 2024).

Wear and tear increases with the density of children (Jansson et al. 2021) and efforts to protect the vegetation during establishment are thus of importance (Paper II). However, as many benefits of vegetation for children are dependent upon their active use of it, ways to ensure successful establishment with as little restrictions towards usage as possible is preferable. Aside from the essential role educators play in facilitating children's engagement with vegetation (Atmodiwirjo 2013), respondents in Paper II also highlighted their role in ensuring the survival of newly planted vegetation. According to some of them, educators actively teaching children how to interact with vegetation might even eliminate the need to restrict access during the establishment phase. At the same time, respondents noted that schools often lack an understanding of the importance of protecting newly planted vegetation. As a result, educational efforts from school staff to promote careful behaviour are often absent, contributing to high levels of wear and tear, meaning that fencing newly planted school ground vegetation is generally needed in Sweden. In Paper IV the establishment fences used did not hinder children from playing in the plots, resulting in wear and tear. The fences did however offer some protection as they prevented children from running directly into the plantings, similar to what was seen in Jansson et al. (2014). Using low fences may thus be a way to reduce some wear and tear without fully restricting access.

The much higher prevalence of wear and tear on Rörsjöskolan than Lindeborgsskolan in Paper IV could be attributed to the large difference in accessible vegetation between the schools. Given that Rörsjöskolan had considerably less accessible vegetation before the experiment, the findings suggest that the presence of such vegetation plays a notable role in limiting damage to newly planted areas, a connection also described by the respondents in Paper II. Gunnarsson and Gustavsson (1989) similarly concluded that damage from wear and tear in newly planted vegetation was highly affected by the absence of alternative vegetated play areas nearby. In Jansson et al. (2014) the heavy use of a planted meadow in hilly terrain seemed to have saved the newly planted woody plants from extensive damage. This emphasises the importance of mature accessible vegetation on school grounds. In situations where school grounds lack accessible mature vegetation entirely, meadow plantings or similar strategies may be employed to divert wear and tear away from newly planted woody vegetation, thereby aiding in its protection during the establishment phase.

In Paper II, many respondents described that children rarely restrict their movement to designated paths. However, others on the contrary suggested that paths can effectively guide children's movement. The results in Paper IV indicate that designed paths may influence movement to some extent, as paths between plots where intensively used. However, letting children create their own paths and letting wear and tear be part of the dynamic, was promoted by a few respondents in Paper II and has also been lifted in the literature (Wiström et al. 2024). A mosaic of vegetated areas and path structures can be seen to naturally form where children play and interact with nature (Tregay and Gustavsson 1983, Gustavsson 2004, Wiström et al.

2019). This was possibly seen in the larger plot sizes at Rörsjöskolan (Paper IV) where a clear connectivity of dead plants gave form to path structures and inner rooms.

Across all sites and plot sizes in Paper IV wear and tear was more prevalent at the corners and edges of the plots. Thus, even when children do not play within newly planted vegetation this indicates that some wear and tear, primarily in the outer parts of plots, might still be expected when planting at school grounds. The relatively high edge-to-area ratio in small plots may heighten their vulnerability compared to larger plots, especially when children's play within the vegetation is limited, which was seen at the second school in Paper IV, Lindeborgsskolan. According to Gunnarsson and Gustavsson (1989), wear and tear tends to be destructive (i.e. without clear intentions for play) during the early stages after planting and in smaller plots. This type of destructive wear and tear could explain the damage observed in the 2x2 m plots in Paper IV.

In addition to wear and tear, children's use may also result in higher amounts of trampling and thus a higher degree of compaction (Paper II) which, even in low amounts, can have severe effects on the soil and because of this also the vegetation (Cole 1987, Hamberg et al. 2010). In the in-situ experiment (Paper IV), compaction was however not discovered, probably because of the substrate composition with a high pumice content, and the short-term focus on the initial two years after planting.

3.3 How do aspects related to governance affect the implementation of school ground vegetation?

Governance structures around school grounds vary both within and between countries and are often complex, involving many actors (Stevenson et al. 2020, Sekulova and Mallén 2024). The results from Paper II reveal a multifaceted reality shaped by several factors that can be described as both direct and indirect, with the latter being most closely linked to governance aspects.

Paper II shows that the discourse around vegetation varies, where green practitioners often find themselves interacting with actors that, instead of seeing its benefits, perceive it as a risk or nuisance. This risk-focused discourse has, according to respondents in Paper II, increased over the years among school staff and parents and often leads to the removal of existing vegetation or resistance towards planting new vegetation on school grounds. However, risky play has been shown to be of benefit to child development (Obee et al. 2020) and highly secure play spaces tend to offer the least variety in play affordances (Fjørtoft and Sageie 2000). This risk aversion described in Paper II may therefore lead to school grounds that offer fewer benefits and limited opportunities for children's play. Shifting the viewpoint to aiming for school grounds to be "as safe as necessary" rather than "as safe as possible" as described by Brussoni et al. (2012) may support an appropriate level of risky play while also reducing restrictions and limitations related to the vegetation.

Respondents in Paper II emphasized designing school grounds with a child-centred perspective arguing against park-like environments, which, while aesthetically pleasing to adults, may not provide sufficient play value for children. Most respondents mentioned advocating for extensive maintenance and loose materials but often faced opposition by the schools, describing this as untidy. Messy environments with loose elements (twigs, branches, gravel, sand, clay) encourages play (Kylin 2003, Kuh et al. 2013), are described as beneficial for children´s creativity and self-esteem (van Dijk-Wesselius et al. 2018, van den Bogerd et al. 2023) and may simultaneously increase biodiversity (Hedblom et al. 2024). But this can still often be seen missing in school grounds (Sekulova and Mallén 2024), sometimes as a result of design and management being centred around adult values and needs (Herrington and Studtmann 1998, Malone and Tranter 2003). To support children's play and creativity, management of vegetated play areas could instead be flexible and responsive, with a different approach from standard practices (Paper II, Kylin 2003, Wiström et al. 2019). Children's use and coupled wear and tear can both shape vegetation structures as a whole and affect the growth pattern of specific species (Paper IV). But instead of only seeing this as a problem, a management approach that encourages, rather than restricts, such interaction with the environment could positively affect children's engagement (Ruff 1987, Malone and Tranter 2003, Gustavsson et al. 2005) while also offering a flexible way to shape various play affordances (Wiström et al. 2024).

An issue brought up by the respondents in Paper II is the undervaluation of green practitioners' knowledge in municipal planning and management. Respondents described how limited financial and human resources contributed to conflicts and failures in vegetation management, which has also been described outside of Sweden, for example in the US (Stevenson et al. 2020). Paper II highlights that school ground vegetation is often deprioritized in construction processes, missing opportunities for early establishment. While experts can exert influence through their specialized knowledge and skills (Bogner et al. 2018), green practitioners working with school ground vegetation in Sweden generally appear to hold limited power compared to non-green practitioners. Paper II also describes how schools and parents often hold more influence than green practitioners, limiting the latter's ability to advocate for vegetation. For example, despite the benefits of existing vegetation (Paper II and IV) green practitioners frequently encounter pressure from parents and schools to remove established vegetation (Paper II). The influence of the schools and parents might be linked to New Public Management (NPM) principles adopted within the school system in Sweden where market-driven education policies results in parents having greater influence over school decisions (Paper II).

The level of power green practitioners had varied by municipality in Paper II, suggesting that where a risk-focused discourse is weaker or where green practitioners can be backed by policies and strategic documents, they may have more authority. Strategic documents and policies have previously been described as crucial for long-term success in school ground greening (Fjørtoft and Sageie 2000, Stevenson et al. 2020). Further, increasing knowledge and understanding of the importance of school ground vegetation could aid in creating a common discourse among actors, minimizing the effects of differing levels of power or influence. Additionally, increasing the knowledge around species-specific tolerance towards different environmental factors, such as drought, can contribute to more precise management of school grounds (Paper III).

3.4 What species and species characteristics are suitable for school grounds?

Species selection for school grounds is described as particularly challenging because of the many different requirements it should meet, both biophysical and social (Paper II). While several different species might tolerate drought and disturbance on a moderate level (Paper III) school ground conditions are often considerably harsher (Paper II). The CSR model may serve as a valuable tool in urban forestry for identifying plant species based on their strategies for coping with stress and disturbance (Watkins et al. 2021). Results in paper III showed how the model seemed to correlate with different traits and adaptations towards drought, as turgor loss point, root:shoot ratio and stomatal behaviour under drought. However, the CSR model did not describe responses fully. Further, aspects like the variation within species may complicate its application (Paper III, De Bello et al. 2021). In addition to this, the CSR theory, due to its simplicity, does not distinguish between different types of adaptions to stress and disturbance (Wilson and Lee 2000). So, while the CSR model can be a good starting point, other traits should also be considered. This could include turgor loss point for drought (Paper III) which might give insight into iso- and anisohydric behaviour (Paper III, Fu and Meinzer 2018). Stem architecture and size may also be of relevance where multiple stems (Wilson 1995) and a low-growing form (Ganthaler and Mayr 2015) can offer advantages under drought, as discussed in Paper III.

Beyond drought, other limiting factors should also be considered depending on each specific location and situation. As indicated in Paper IV, shade tolerance and growth form affect the balance of competition and facilitation in mixed woody plantings (e.g. Pelc et al. 2011, Tanentzap et al. 2011, Wiström 2015). Furthermore, resprouting ability seems particularly important as a trait for handling disturbance, as seen in Paper IV and in ecological studies on browsing (Guillet and Bergström 2006). Careful species selection depending on specific site conditions is important (Paper II) but also in relation to other species included when designing mixed plantings (Paper IV).

Species choice is also restricted caused by their perceived suitability of being near children. In practice, species may be filtered out because of being spiny, allergenic or poisonous (Paper II), which further limit an often already short list of possible species to plant on school grounds. Spiny plants are known to deter browsing (Bustamante et al. 2021) and following the reasoning of how wear and tear by children resembles browsing pressure, they may also help protect against wear and tear (Gunnarsson and Gustavsson 1989). This viewpoint on spiny plants was supported by several respondents in Paper II. According to Jingwen et al. (2022), children are accepting the presence of spines and thorns, suggesting that restrictions around them may reflect adult concerns rather than genuine necessity. The "as safe as necessary" approach (Brussoni et al. 2012) could justify the inclusion of spiny plants on a reasonable level and, rather than being seen as hazards, could be seen as a having a specific value in aiding vegetation establishment and encouraging careful play (Jingwen et al. 2022).

Attractive species, for example those with large leaves, and evergreen plants tend to draw more interest from children meaning that they are in higher risk of wear and tear (Paper II) but can also be seen as indicative of their higher play values. Species-specific wear and tear has also been described by Gunnarsson and Gustavsson (1989), but they argue that species-specific constructive (i.e. intentional) wear and tear becomes less relevant when the goal is to create paths, as plants along these routes will inevitably be damaged. However, in this context, plant size may become important, as low-growing species might encourage path formation and thereby be subjected to higher levels of wear and tear (Paper IV).

In the context of school ground vegetation, the ability to regrow and increase in height under wear and tear is crucial, making the resprouting ability of a species important (Paper IV). Because of their adaptation toward disturbance (Scheffer et al. 2014), and their growth rate and form (Wilson 1995, Esperon-Rodriguez et al. 2025) shrubs seem good for the use on school grounds with high levels of wear and tear. Plants in children's environments may be particularly in risk to loss of the top shoot because of wear and tear (Gunnarsson and Gustavsson 1989) and the higher capacity of shrubs for shoot production from lateral or basal buds (Wilson 1995, Götmark et al. 2016) further emphasises their suitability. However, the ability to regrow can depend on different environmental factors as drought (Paper III) and site-specific stressors should thus be considered in species selection.

A well-balanced mix of plant species offers several benefits in mixed plantings, particularly when combining fast and slow-growing species, tough and spiny as well as species attractive for play and more neutral species (Paper II, Gunnarsson and Gustavsson 1989). Carefully selecting species combinations is essential for maintaining balanced growth and ensuring tolerance to different environmental factors (Paper II, III and IV). Due to the limited availability of written resources on suitable species for school grounds, it is essential to continue gathering and spreading relevant knowledge. Therefore, efforts to screen and collect data on woody species' tolerance and reactions to various stressors (as aimed for in Paper III and done by e.g. Hirons et al. 2020, Levinsson et al. 2024) is important to gain knowledge and aid species selection for challenging environments such as school grounds.

3.5 What planting design and methods are suitable for successful establishment of school ground vegetation?

School ground design affects both children's play (van den Bogerd et al. 2025), their environmental learning (Malone and Tranter 2003) and the establishment of vegetation (Paper II and IV). The complexity of school grounds, with factors like soil type, location, teachers' and children's behaviour varying widely, makes it challenging to determine the best general planting design and method. These should therefore be tailored to each specific context. For example, in Sweden urban school grounds are in general smaller with more hard surfaces and less vegetation than other school grounds (SCB 2022) and may necessitate specifically careful planning and management when implementing school ground vegetation.

One takeaway from Paper II and IV is that when school grounds lack accessible vegetated areas, introducing them should be a priority. This is not only important as it provides many values for children and urban areas at large but results also indicate that on school grounds without this type of vegetational areas, any new vegetation may be subjected to more wear and tear as children actively engage with it despite restrictions. This suggests that the first accessible vegetation implemented requires particularly careful design and management in order to endure the high degree of wear and tear it is likely to face. And following this, with enough accessible vegetation in place, this may allow for new plantings to be designed and managed with less emphasis on withstanding wear and tear. Therefore, the introduction of more sensitive vegetation, with lower tolerance towards wear and tear, should occur only once sufficient vegetated play areas have been provided.

Vegetation is particularly sensitive during establishment (Rietveld 1989) and closing off sections of the school grounds to facilitate plant establishment was promoted by respondents in Paper II. On schools in use this could result in negative responses from children, even if it is unclear if this has long-term effects on children's relationship towards an area (Jansson et al. 2014). The fact that many school grounds have limited size in Sweden and are shrinking in general (SCB 2022) also complicate this method. But, when possible, this could be a good way to give the vegetation a head start during establishment. Using the same concept when building new schools does not provoke the same conflicts with children's use or school ground size, but requires that the vegetation is prioritized during construction, something that seldom is the case in Sweden according to the respondents in Paper II.

On school grounds in use, instead of restricting access in order to limit wear and tear another possibility is to view the vegetation structures as half-finished from start, with the clear intention that they should be developed by the children through their active use (Gustavsson 2004, Wiström et al. 2024). However, children's use, and wear and tear, during the establishment period is likely to result in considerable vegetation loss due to high plant mortality (Paper IV). Careful design can possibly lower the impact of wear and tear so that the vegetation structures as a whole survives. For instance, the low fence used on the school grounds in Paper IV seemed to stop some wear and tear, leading to overall survival of the vegetation. Similarly, the use of dense planting distances has also been described to reduce wear and tear (Paper II, Gunnarsson and Gustavsson 1989). Planting plants with a range of sizes may capture children's attention and encourage more careful use (Paper II), allowing for the inclusion of larger individuals of drought-tolerant species as highlighted in Paper III. Furthermore, incorporating spiny shrubs may reduce abiotic damage (Hanley et al. 2007) and thereby act as nurse plants to more sensitive ones in a mixture (Paper II, Gunnarsson and Gustavsson 1989, Filazzola and Lortie 2014). Paper IV indicated that edges experienced greater wear and tear, also seen in Jansson et al. (2014) and Tregay and Gustavsson (1983), suggesting that sensitive species should be positioned within the interior of a plot for better protection. However, careful attention should be paid to species composition in mixed plantings. Dense plantings may lead to earlier onset of interaction and competition, and in mixtures with size variation, larger species may outcompete and suppress smaller ones from start (Tregay and Gustavsson 1983).

The respondents in Paper II were interested in identifying the smallest planting size feasible for school grounds as school staff often request vegetation removal or pruning to improve visibility, which can conflict with efforts to establish larger plantings. The smallest plot size included in Paper IV (2×2 m) proved successful in general, even if the smaller size resulted in more edge-related wear and tear than the larger plot sizes. A network of small plantings interspersed with pathways could help maintain visibility while still accommodating larger vegetation structures. The paths were heavily used on the different sites in Paper IV indicating some value and successful guiding of movement. But as the path structure did not completely prevent wear and tear, the influence of paths might be limited (Paper IV).

Scale is important when designing play environments (Gustavsson 2004, Wiström et al. 2024) and may differ a lot between children and adults (Francis 1988, Gustavsson 2004, Wiström et al. 2019). Case studies suggest that child-scaled and diverse environments, rather than vast open spaces, better support engagement and play (Ruff 1987, Fjørtoft and Sageie 2000, Wiström et al. 2019) and that a greater number of unique nature-based play areas may increase physical activity and prosocial interactions (Raney et al. 2023). At Rörsjöskolan in Paper IV, where wear and tear in the newly planted vegetation was higher, connectivity between dead plants in larger plantings helped shape paths and inner rooms, resulting in new areas for play. The inner rooms formed within Rörsjöskolan's plots of 4x4 m and 6x6 m indicate a scale well-suited for active use by children. However, the size required for room-building may be influenced by factors such as the presence of supervising adults, as evidenced by the development of rooms within a 4x4 m planting where adult oversight was more limited. Vegetational structures of this plot size for shrub plantings might thus be especially interesting as a minimum size when the goal is to allow children to be part of the development of the areas through their active use.

4. Methodological reflections

The doctoral project which this thesis is based on involves many different methods, and spreads over many different scientific fields and concepts. This has been challenging and has introduced limitations for each specific study and the project at large.

It is possible that some relevant papers were omitted in Paper I, potentially impacting the study's outcomes. It was decided to take on a broad stance in this study, to investigate the research made on the topic. This sort of mapping review provided an overview which was helpful in giving direction to the project. However, a review that synthesised results of specific relevance to the project, for example how vegetation design affect play pattern, might have provided more depth to the understanding and thereby the following studies and thesis.

The in-depth interviews in Paper II proved to be an effective method for gathering extensive information. The respondents were highly engaged and eager to share their experiences. However, a survey could have allowed for a broader reach, and an easier gathering of practical specifics such as appropriate species for school grounds. Nevertheless, given the lack of existing research on the experiences of green practitioners regarding school ground vegetation, the width and depth of insight provided by interviewees was considered particularly valuable. A key challenge in quality assurance is the reliability of practitioner knowledge, as it is often experience-based and difficult to evaluate fairly (Defila and Di Giulio 2015). Also, communication effectiveness varies by individual, influencing how information is perceived. This variation was hard to assess but being familiar with the field was helpful as well as the conversational form of the interviews.

The experiment in Paper III faced several practical challenges, including issues with mites, incorrect plant deliveries, and variation in size between species. This effected the ability to generalize some of the findings, especially in relation to the combined effects of drought and disturbance. For practical reason this study was also initiated at the very start of the doctoral project, meaning that its research design did not incorporate the knowledge gained during the later stages of the project. Compaction or drought did not appear as an issue in the plots during the observation period in Paper IV, but wear and tear and resprouting seemed more important. If knowing this from the start, the experiment in Paper III could have focused more on responses and strategies towards disturbance such as repeated pulses of biomass loss. However, as compaction and coupled drought have been put forward as specific problems on school grounds by respondents in Paper II the results from Paper III are still valuable. The relevance is also probable to increase because of climate change giving drier conditions, particularly in urban areas.

The difficulties of Paper IV were largely due to it being an in-situ study. For example, neither the researchers nor the municipal green manager had the authority to decide where the plants would be purchased. Instead, this decision was made by the contractor which, in the end, resulted in different species on the two schools. The indirect factors discussed in Paper II were also evident in this study, where fear of negative reactions from parents or the schools, for example regarding fruit staining, prevented the use of certain species. The often complex governance structures surrounding school grounds might make experiments as in Paper IV especially complicated. This highlights the value of an interdisciplinarity approach to the research on school ground vegetation, where many different aspects are considered.

4.1 My role as a researcher in this project

Beginning one's research career with interdisciplinary research means that one must use and understand a blend of orientations within different types of research (Felt et al. 2013). The fact that the project involves many different methods and connects to different fields with different ontologies results in limited amount of time to go deep in one direction. Instead, this provided the opportunity to investigate an issue through various lenses, perhaps giving more spread instead of depth. Normative concerns and priorities often affect interdisciplinary research (Lélé and Norgaard 2005), and working with this project has prompted me to recognize these. Coming from a background in natural sciences, the years in this project have most strikingly increased my understanding within social sciences. I am very grateful for the opportunity to work intimately with all these methods and perspectives in this project. From the challenge, rewards have followed.

5. Conclusions

This thesis contributes to the understanding of implementing school ground vegetation by examining it through four interconnected studies, highlighting both the challenges of implementing and the potential of school ground vegetation.

Paper I highlights a notable lack of specificity in current research on school ground vegetation making it difficult to compare results or draw clear conclusions. Previous research tends to focus on already established vegetation, often neglecting the processes of planting and establishment. Paper II highlights knowledge gaps within the green field considering planting processes, species selection, and play-related impacts on school ground vegetation. Respondents also noted the overlooked complexity in designing school grounds within the green field.

Children's interaction with vegetation significantly influences the success of plant establishment on school grounds as shown in Paper II and IV. School personnel has a vital role in teaching children how to interact with vegetation, potentially reducing wear and tear (Paper II). Schools with less accessible vegetation might experience greater wear and tear in newly planted vegetation than those with more accessible vegetation. Protective fencing may limit damage but not completely prevent play within newly planted vegetation. Size of vegetation plots matter, as larger plots of shrubs (6x6 m and possibly 4x4 m) might be sufficient for play as shown by the creation of inner paths and rooms. Smaller plots (2x2 m), even if successful, are more vulnerable to wear and tear of edges (Paper IV). However, this use and coupled wear and tear is not inherently negative. In lower amounts wear and tear could be seen not only as a challenge, but as part of the natural development of school ground vegetation. With the right design and species selection, vegetation could be allowed to be shaped by children's play offering a management approach that incorporates and encourage, rather than restricts, interaction with the vegetation.

As shown in Paper II, complex actor relations, limited resources, and undervaluation of green expertise impede school ground implementation. The knowledge of green practitioners is often undervalued, and vegetation is frequently perceived by other actors, such as school staff and parents, not as a benefit, but as a risk or nuisance. This contributes to resistance toward both the implementation and retention of vegetation. Risk aversion can lead to less varied and engaging school grounds, reducing opportunities for children's play and development. A discourse less focused on risk and supportive policy frameworks could aid green practitioners in implementing school ground vegetation.

Papers II, III, and IV underscore the complexity of choosing suitable species, balancing species abilities to handle the harsh site conditions with social factors like child safety, visibility, and play value. Variations in site conditions, school ground size, existing vegetation, and the behaviour of both school personnel and children necessitate that species selection, as well as design and management strategies, be adapted to the specific context of each school ground. Dense plantings with mixed species, larger plots, and positioning tougher plants at edges can reduce or limit the effect of wear and tear. Additionally, spiny plants, often avoided due to perceived risks, may help protect new plantings by discouraging destructive wear and tear. Similarly, species with strong resprouting capacity or those tolerant to drought could be especially valuable in these settings. Screening of species using the CSR model together with measuring other traits, as turgor loss point for drought tolerance and resprouting ability for surviving disturbance, could be a way to match different species to different situations.

5.1 Future perspectives

School grounds are complex environments. They were when this doctoral project started five years ago and certainly still are now in the end of it. They are also important environments. Children spend a significant portion of their time on school grounds, and school grounds take up physical space in urban areas. Therefore, what school grounds contain matters, and the composition and development of school grounds deserves continued attention in research.

Future research could explore more deeply how children interact with school ground vegetation and the effects these interactions have. Longitudinal studies would be specifically interesting because of the changing nature of vegetation. To couple this with investigations on how children themselves describe these experiences could further deepen the understanding of the nature of children’s play in vegetation and its effects on both the children and the vegetation.

Furthermore, gathering insights from a wider range of practitioners could complement and strengthen the findings from Paper II concerning both practical and governance related factors affecting school ground vegetation implementation. It would also be valuable to explore the perspectives of other actors surrounding school ground vegetation, such as school personnel or parents, to develop and provide other perspectives on the complexities of implementing school ground vegetation.

Informed species selection relies on a thorough understanding of their characteristics. Thus, research into species' tolerance to environmental stressors is crucial for expanding knowledge and facilitating appropriate choices for challenging environments such as school grounds. But in mixed plantings not only the sole species is of importance but also the effects of the interaction of different species. Expanding the research on such dynamics in school ground environments with additional factors such as wear and tear would expand the knowledge around how to design vegetated play environments, making it easier to develop green school grounds that are available for children's play.

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Popular science summary

Vegetation on school grounds provides numerous benefits for children's health, learning, and well-being, while also contributing positively to environmental quality. Despite these advantages, implementing school ground vegetation is complex and challenging. This thesis explores the challenges associated with school ground vegetation, with a particular focus on shrubs, through four complementary studies: a mapping literature review, an interview study, a controlled greenhouse experiment, and a field experiment on school grounds. Guided by five research questions, the thesis addresses current knowledge, the effects of children's play on vegetation, governance factors, species selection, and planting design and methods.

Scientific literature often generalizes "green spaces" without adequately addressing the specific characteristics, dynamics, and maintenance needs of vegetation. Similarly, practical knowledge in Sweden tends to underestimate the complexity involved in establishing and maintaining school ground vegetation. Governance issues, including a low prioritization of school ground greening and a risk-averse mindset, further complicate implementation.

The results highlight that the interaction between children and vegetation is both vital and challenging. While children's play activities inevitably cause wear and tear on plants, this interaction is also essential for realizing the full benefits of vegetation for children.

Selecting plant species that tolerate drought and mechanical disturbance is particularly important, although other plant traits should also be considered depending on the design and species mix. Strategic design approaches, such as using dense plantings, balancing species mixtures, and placing more robust species at edges, may enhance vegetation resilience. Furthermore, the size of planting areas influences children's opportunities to engage meaningfully with the vegetation.

Overall, the findings emphasize that no single factor determines the success of school ground greening efforts. Rather, an integrated approach, aligning planting design, species selection, site management, and governance structures, is essential to create sustainable green spaces in school environments.

Populärvetenskaplig sammanfattning

Vegetation på skolgårdar erbjuder många fördelar för barns hälsa, lärande och välbefinnande, samtidigt som det bidrar positivt till miljön. Trots dessa fördelar är utveckling av skolgårdsvegetation komplex och ofta utmanade. Den här avhandlingen undersöker svårigheterna kring utveckling av vegetation på skolgårdar, med särskilt fokus på buskvegetation, genom fyra kompletterande studier: en kartläggande litteraturöversikt, en intervjustudie, ett kontrollerat växthusförsök och ett fältförsök på skolgårdar. Avhandlingen utgår från fem forskningsfrågor och belyser aktuell kunskapsnivå, hur barns lek påverkar vegetation, hur vegetationsutveckling styrs, val av växtarter samt utformning och metoder för plantering.

En viktig slutsats är att den vetenskapliga litteraturen ofta generaliserar "gröna ytor" utan att tillräckligt belysa vegetationens dynamiska natur. På samma sätt tenderar praktiken Sverige att underskatta komplexiteten i att etablera och upprätthålla vegetation på skolgårdar. Styrningsproblem, som låg prioritering av skolgårdsgrönska och en riskavert inställning, försvårar ytterligare arbetet.

Resultaten lyfter att interaktionen mellan barn och vegetation både är avgörande och utmanande. Barns lek orsakar visserligen slitage på växterna, men den interaktionen är också en förutsättning för att barnen verkligen ska kunna dra nytta av grönskan.

Att välja växtarter som tål torka och slitage är särskilt viktigt, men även andra växtegenskaper bör beaktas beroende på plats och artblandning. Strategiska designlösningar, som tätare planteringar, välbalanserade artblandningar samt placering av tåligare arter i ytterkanter kan öka vegetationen motståndskraft mot slitage. Planteringsytans storlek påverkar dessutom barns möjligheter att utveckla meningsfulla lekmiljöer i vegetationen.

Sammantaget understryker resultaten att ingen enskild faktor avgör framgången för skolgårdsgrönska. Istället krävs ett helhetsgrepp där planteringsdesign, artval, skötsel och styrning samverkar för att skapa hållbara gröna miljöer på skolor.

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Thank you, Leo, my best hype-man, I would not be here without you. You have been the perfect PhD companion, co-parent, fiancée, and husband during these years. I love you so much.

And to all the different people that I might have temporarily forgotten when trying to compose this list in the clouded moments right at the end, thank you!

I

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Review article

Investigating school ground vegetation research: A systematic mapping review

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ABSTRACT

Vegetation on school grounds has several values and functions that contribute to aspects as children's well-being, pedagogy and microclimate among others. Research on school ground vegetation is conducted within many different research fields and deals with a variety of research themes. A systematic review was conducted to explore scientific literature on the topic of school ground vegetation broadly, enabling an overview of this diverse field and the discovery of trends or gaps within this research. The objective was also to investigate to what extent actual vegetation is in focus in this literature. The results highlight a low level of specificity when describing vegetation, concerning both spatial aspects and content, with general terms such as "nature" or vegetation types (trees/shrubs/grass, etc.) being common, leading to difficulties in interpretation and synthesis. A multitude of themes are present, describing different research foci. Several themes show limited interaction with other themes, such as the theme "microclimate", which may be of notable relevance for future research because of global warming. More coherence in how to describe vegetation on school grounds is needed to compare results. Also, more connections between research themes could address research gaps and be beneficial for future research endeavours.

1. Introduction

Children spend a considerable part of their time in child-care institutions and educational facilities, environments that therefore have a great possibility to influence their daily lives (van Dijk-Wesselius et al. 2018, Lindemann-Matthies and Kohler, 2019). School-based greenness has been shown to be of great benefit to children in several ways, including positively affecting academic performance (Browning and Rigolon, 2019), environmental relationships and overall well-being (Puhakka et al. 2019). School ground vegetation has also been shown to be attractive to children and may result in more gender-equal play (Lucas and Dyment, 2010). Another important aspect of green spaces in educational environments is thermal comfort. Exceedingly hot outdoor temperatures affect the amount of usable space on school grounds as well as the health of the children and possible pedagogical activities (Bäcklin et al. 2021). In urban areas, vegetation may provide shade and thereby cooling, making the environment more comfortable (Antoniadis et al. 2020). Beyond its direct benefits to children, urban school vegetation also contributes to broader environmental goals. Vegetation on school grounds can serve as green stepping stones and thereby enhance green connectivity in urban areas (Iojă et al. 2014). Such green spaces may moreover serve as habitats for various species, thus promoting urban biodiversity as well as enabling species' movement across urban areas (Muvengwi et al. 2019).

The connections described above have been found largely because of the research made concerning school ground vegetation. The arguments for researching school ground vegetation often centre around the vegetation's positive impact on children (Sylvia, 2010, Moore et al. 2015, Paddle et al. 2016, Luis et al. 2020), but the types of research conducted have many different foci and belong to various research fields, such as landscape architecture (Jansson et al. 2014), biology (Muvengwi et al. 2019), education (Janet, 2004) and health (Nury et al. 2017).

The latter years have included an increased focus on school ground greening both in research and in a multitude of school ground development projects and organisations across the globe. An example of a recently initiated project is the Oasis project in Paris (European Environment Agency, 2022). Started in 2019 the project goal is to rebuild the school grounds of Paris in order to meet the challenges of climate changes with higher temperatures and extreme weather events. A big focus in this project is on implementing school ground vegetation.

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Another example from Europe is the Forest school project, where the focus has been on increasing outdoor learning in the UK by for example implementing wooded outdoor classrooms (The Mersey Forest, 2024). In the United States, the non-profit organization Green Schoolyards America has been dedicated to implementing and promoting greener school grounds since its founding in 2013 (Green Schoolyards America, 2024). Similar school ground greening projects have been initiated for several decades and the projects themselves have been the topic for research (Dyment and Reid, 2005, Sterling, 2005, Giezen and Pellerey, 2021).

The width of research fields involved in the topic of school ground vegetation also demonstrates that vegetation on school grounds is expected to fill several functions. Multifunctionality, as defined by the Landscape Institute (2009) concerning the role of urban vegetation, refers to the capability of a given area to provide a variety of functions, delivering benefits that are societal, environmental, and economic. This expected multifunctionality of school ground vegetation has been highlighted within the topic of school ground greening (Iojă et al. 2014, Syed Ayub et al., 2015).

Multiple reviews have already been conducted concerning children and vegetation. Some of them focus on the effect of vegetation on cognitive aspects and academic performance (Browning and Rigolon, 2019, Mason et al. 2022, Vella-Brodrick and Gilowska, 2022) or physical activity and other aspects connected to health (Trost et al., Ye et al. 2022). Focus on how vegetation affects children's development and children's experiences of nature also occur (Islam et al. 2020, Bakri and Aoul, 2021, Sakhvidi et al. 2022). Many previous reviews focus on learning environments specifically (Trost et al. 2010, Browning and Rigolon, 2019, Bakri and Aoul, 2021, Mason et al. 2022). There is, however, a lack of overview of all research that has been conducted concerning vegetation on school grounds across research fields and foci. Whether geared towards enhancing educational outcomes, promoting environmental awareness, or exploring the level of biodiversity, the aims of the different studies within this topic serve as a driving force behind the research. Understanding these aims may provide an in-depth picture of the research made and reveal patterns, overlaps, and research gaps. There is no existing review, to the knowledge of the authors of this paper, which has been made with the purpose of mapping all scientific literature concerning school ground vegetation, independent of field or research foci.

An essential factor in analysing research on school ground vegetation concerns the attributes surrounding the vegetation itself. The term vegetation encompasses everything from perennials to trees, spanning complex plant systems, monocultures, solitary trees and shrubs (Merriam-Webster.com, 14 Dec 2023). In order to effectively connect and apply research findings on the impact of school ground vegetation on children and the environment, it is of value that vegetation is well described in studies, where the level of specificity in the description of the vegetational content and the spatial characteristics of vegetated areas can be helpful. Additionally, there is a need to recognise that vegetation is dynamic and changes over time (Gustavsson, 2004). It is therefore of interest to examine if the literature explores the vegetation both in detail and across a timespan.

School grounds are utilised by a diverse range of age groups, spanning from preschool children to high school students. This wide age range significantly influences the utilisation and, by extent, requirements of the vegetation present in these areas as the age of children has been shown to affect how they interact with vegetation (Jansson et al. 2014). Consequently, research focusing on the need for vegetation among 10-year-olds may not be relevant or applicable to 16-year-olds, given the distinct differences in their requirements. Therefore, it is essential to conduct comprehensive research on vegetation on school grounds catering to all child age groups. Exploring the distribution of existing studies on school ground vegetation across age groups is thus of specific interest.

Understanding the global context is crucial as well, as it encompasses cultural, geographical, and climatic factors that shape these environments. The impact of school ground vegetation on children has been shown to depend on the design and management of school grounds (Malone and Tranter, 2003), processes themselves heavily influenced by prevailing policy frameworks and governance structures (Randrup et al. 2020). These structures dictate the resources allocated for the creation and management of such green spaces, impacting their quality and accessibility. Budgeting has been shown to affect the quality of green spaces in general, such as in a report concerning the situation around park management in the UK (Neal, 2016). Another factor is the choice to keep the management of green spaces in-house or contracting out (Lindholst et al. 2020). A comprehensive understanding of school ground vegetation thus requires a multi-faceted approach, including the policy-driven factors that shape these environments.

In addition to governance factors, climatic factors affect school ground vegetation as well. For example, the successful establishment of vegetation is largely contingent on temperature (Kozlowski, 1962). Extended periods of favourable temperatures for growth result in increased biomass production, allowing for greater opportunities to recuperate from wear and tear, an often-appearing hardship on school grounds (Jansson et al. 2014). Temperature has also been shown to affect physical activity on school grounds (Pagels et al. 2014), and seasonal variance of school ground vegetation (fall foliage colour, a mix of evergreens *and* deciduous species, etc.) may have restorative effects (Paddle et al. 2016). Extended growing seasons also imply that children have prolonged access to deciduous vegetation in its leafy state. This may influence how children engage with the vegetation and the effects it may have on them. While some studies have shown that research, in general, is predominantly carried out and published by the Global North (Collyer, 2016, Albanna et al. 2021), it remains unclear if this holds for studies on schoolyard vegetation, specifically because of the multitude of possible geographical variations affecting school ground vegetation. Despite the presence of schools worldwide, research on them might not necessarily be uniformly spread.

This study aims to investigate patterns of research concerning school ground vegetation and identify possible research gaps, with a specific focus on exploring how vegetation and its spatial and temporal qualities are portrayed. For this reason, a mapping review was deemed suitable.

This mapping review explores the following questions: I. What are the characteristics of the research concerning the topic of school ground vegetation? II. How are vegetation and its spatial and temporal qualities reported and described in research concerning school ground vegetation?

2. Methods

A mapping review consists of a broad screening of the scientific literature with a specific question in mind and an analysis of the extent of the research itself, such as addressed topics, methods used, the geographical context in which the research is conducted, etc. (Kitchenham et al. 2010, Booth et al. 2016, Cooper, 2016). As is proper for a mapping review, this study does not examine and synthesise the results of the reviewed studies (Petersen et al. 2008, Kitchenham et al. 2010). In essence, it emphasises the when, where and how of the research, rather than the specific findings themselves. In a mapping review, those methods typical of other systematic reviews for searching and data extraction are used (Kitchenham et al. 2010). To ensure clarity, validity and auditability in this process (Booth et al. 2016), this mapping review was made with a clear systematic approach. A PRISMA review protocol was developed at the start of the process and a PRISMA flow diagram was used to record the filtering of the literature.

2.1. Search scope

The literature included in this study was limited to scientific publications in English up to and including the year 2022, excluding grey literature. The scope was limited to publications in English because of the language spoken by the authors as well as time and economic constraints considering translation.

Searches were made in two scientific databases and separately in one journal: Web of Science, Scopus and the journal *Children, Youth and Environments* on JSTOR. JSTOR only has issues from *Children, Youth and Environments* up until 2020, and therefore each issue between 2020 and 2022 was manually screened for relevant articles. The two databases were included because of their separate focus and the fact that the subjects concerning vegetation on school grounds can differ widely. The journal *Children, Youth and Environments* publishes much literature concerning vegetation and school grounds but is not included in either Web of Science or Scopus and thus had to be searched separately.

The search strings used were made as alike as possible but had to be adapted to each database. The search strings were built around three aspects. The first two described the place, a place for childcare or an educational facility and specifically its outdoor environment. The third considered the vegetation aspect (full search strings can be found in the Appendix). The process of building the search strings was made in dialogue with a university librarian with special knowledge of methods for systematic literature searches. This has been highlighted as an important factor for high-quality literature searches and reporting (Cooper et al. 2018).

2.2. Search and screening of articles

The first search was made in April 2021, and a complementary search was made in January 2023 to find articles published in 2022. The literature from these searches was screened for duplicates and irrelevant document formats (e.g., Front matter), which were then removed. This resulted in a bulk of literature consisting of 13 403 papers.

In the next stage, the web-based software Rayyan (Mourad et al. 2016) was used to screen for inclusion. All papers were screened separately by reading the title and, if deemed necessary, also the abstract. If there were any doubts, the article was read more thoroughly. The inclusion criteria for the literature reviewed in this study were chosen after discussions among the authors of this study to ensure that the most relevant articles were included. In this stage, also articles of other languages than English were filtered out.

Research concerning schools and vegetation can be made on different spatial levels. Some studies have looked at greenness across whole school districts (Wu and Jackson, 2017) and others have investigated the effects of vegetation surrounding schools (Srugo et al. 2019) or the areas within the school borders. This review focuses solely on the literature concerning vegetation within school borders. This demarcation was made as there are aspects that are special to the vegetation within these borders, such as the increased opportunity for interaction by the children and thereby the possible effects of this interaction (Browning and Rigolon, 2019). In addition, spatial demarcation is reasonable when the purpose is to investigate the level of specificity concerning the description of vegetation. Studies on a district level will naturally more often use broader descriptions (as in Wu and Jackson, 2017) than studies on the school ground level (as in Muvengwi et al. 2019). This limitation filtered out studies that examined, for example, green roofs, which are not accessible to children, and vegetation surrounding schools or within a school district.

Lastly, the age limit for students attending school was set at 20 years old, allowing for an analysis of the spread of research between age groups. No lower age limit was set, which resulted in the inclusion of preschools. No quality assessment of the literature was made since all research made on school ground vegetation was of interest for this review.

2.3. Data extraction and analysis

After screening the literature, 133 articles remained. In the next stage, the full articles were read, and the analysis categories were developed according to the mapping review process (Fig. 1). The process of developing the analysis categories was made through discussions within the author team with the aim of answering the research questions of this study. After the analysis categories were finalised, the main author continued answering them for each article. As the coding was done by only one of the authors, it was re-evaluated several times for each article throughout the process to ensure consistency. In the case of uncertainty, the coding was discussed among the whole author team.

To give insight into the level of activity in the research field and how this has changed over time, the publication growth rate was calculated. This can be used to compare to the overall growth rate of scientific publications. Since the level of activity was seen to increase drastically from 2003 and onwards, the growth rate was calculated with 2003 as the start year. The growth rate was analysed according to Compound Annual Growth Rate (CAGR) = $((y_n / y_0)^\wedge(1/n) - 1) * 100$, where y_0 represents the value at the start, y_n represents the value at the end of the period, n represents the number of years.

The themes were developed by manually grouping the articles based on the main research purposes of the studies. This inductive method ensured that the resulting themes accurately represented the underlying population. This approach was crucial because it would have been insensitive to the content of the article to apply a predetermined list of categories. The process involved active discussions among the group of authors to ensure the themes were thoroughly developed.

A detailed description of the themes is shown in Tables 1 and 2. After the themes had been formulated, both the main theme and all present themes in the articles were recorded by the main author. To ensure consistency, the articles were analysed multiple times and when any doubt arise this was discussed among the author team.

To determine the association between the themes, the phi coefficient was calculated for each pair of themes. This calculation was based on the co-occurrence of all themes in the articles, thus the main themes and all other themes present. The phi coefficient is a measure of association between two binary values. It is calculated by dividing the number of articles where both themes appeared by the square root of the product of the number of articles where each individual theme appeared. Further, the main themes of the articles were analysed in connection to the categories Description of vegetation and Age of the children studied.

3. Results

Out of the 13,402 unique articles identified through database search, 214 remained after the first screening. After full-text articles were assessed, 133 articles were deemed appropriate for further analysis and thus included in the review.

3.1. Publication year & geographical area

As a whole, research activity on the subject matter has increased during recent decades (Fig. 2). The trend observed since 2003 reveals a CAGR in publications of 13.5 %. On a geographical level, studies that take place in Europe and North America dominate, encompassing 69 % of the total body of literature (36.8 % from Europe and 32.3 % from North America). In North America the studies originate from two different countries while in Europe they origin from 17 different ones. Including the literature from Australia and New Zealand (at 9.7 %) in this group brings the total to 78.9 %. Still, literature on school ground vegetation was found in large parts of the world (Fig. 3). One study did not provide information on the geographical area of the study and was thus disregarded in this analysis.

3.2. Themes

In total, 14 themes were identified within the data corpus, with their prevalence varying significantly from “eco-literacy” being the main

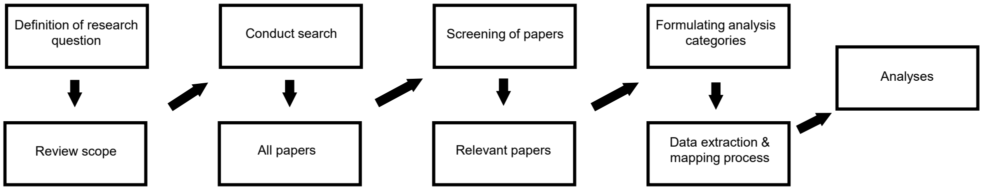

Fig. 1. The mapping review process adapted from Petersen et al. (2008).

Table 1
Analysis categories and short explanation.

Analysis Categories	Explanation
Publication Year	Year of publication
Geographical Area of Focus	The area/continent where the research was conducted
Theme	Aim/purpose of the research
Age range	The age of the children attending the school/ schools under investigation
Description of Vegetation, Type	Level of specificity when describing the vegetation
Description of Vegetation, Size/Shape	Specification of the spatial qualities of the vegetation (Y/N)
Existing or New Vegetation	Investigation of existing or newly planted vegetation
Vegetation Development, Time Aspect	Inclusion of a time perspective, development of the vegetation (Y/N)

Table 2
Detailed description of themes.

Theme	Description
Eco-literacy	Enhancing the relationship between children and the environment/nature through environmental and natural knowledge.
Microclimate	Studies researching atmospheric conditions on school grounds, including temperature and wind patterns.
Children's Perspectives	Concentrates on the diverse viewpoints of school children.
Education and Cognitive Effects	Educational activities' effects, covering attention span and knowledge acquisition.
Gardening	Cultivating vegetables, fruits, and similar produce with school children's participation, often consumed in school or the community.
Physical Activity	School children's physical activity, often using tools like pedometers.
Perspectives of those other than children	Thoughts and experiences of individuals other than school children, like parents or school personnel.
Play	School children's play using methods such as behavioural mapping.
Socio-economic Factors	The socio-economic context of the schools under examination.
Physical Health	Aspects of health such as nutrition, exposure to harmful substances, and toxic plants within school grounds.
Spatial Layout	Extensive focus on the spatial layout of the school grounds, beyond just plans or descriptions.
Mental Health	The mental health of school children, investigating aspects like well-being and restoration.
Biodiversity	Species diversity within the school grounds.
Social Relationships	Interpersonal dynamics among school children.

theme in 20 articles to "social relationships" in just one article. Table 3 shows the number of articles identified within each main theme.

The correlation table (Fig. 4) presents the correlation between the different themes represented as the phi coefficient. This includes all themes present in the articles, and thus not only the main themes. The association between "physical health" and "gardening"; "perspectives of those other than children" and "children's perspectives"; "physical

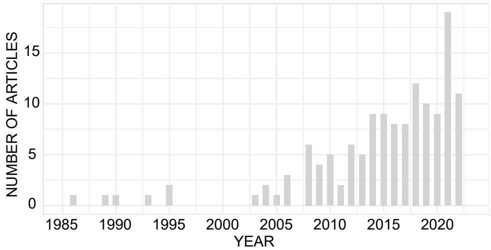

Fig. 2. The number of annual publications on the subject of school ground vegetation.

activity" and "spatial layout"; "education and cognitive effects" and "eco-literacy" as well as "microclimate" and "spatial layout" are strongest, with a phi coefficient above 0.3. The theme with the highest number of relatively strong interactions is "gardening" with four interactions above 0.25. There are also several themes that do not interact at all, displayed as a phi coefficient of 0. The three themes "microclimate", "socio-economic factors" and "physical health" had the lowest levels of interaction with other themes, showing no interaction with six other themes. The themes "play" and "social relationships" follow, displaying no interaction with five themes, respectively.

3.3. Age of children

The overall mean age of the children using the school grounds in the articles is approximately 9 years (9.02) with a median of 9. As shown in Fig. 5, the research is spread across the whole age span of 0–20 years, with less research made on the low and high ages. Seven of the studies did not specify the age of the children and are therefore not included in this analysis.

Relating the main themes of the articles to age ranges shows that the majority of the themes centre on the average age of 9 years (Fig. 6). However, research conducted within the themes of "spatial layout" and "biodiversity" focuses on children with an average age above 11 years (Fig. 6). Conversely, research within the themes of "social relationships", "play", "perspectives of those other than children", and "physical health" pertains to children with an average age below 8 (Fig. 6).

3.4. Description of vegetation

3.4.1. Type

On a linguistic level, the description of vegetation reveals a non-unified naming convention. For example, several articles (n = 26) gather all vegetation under a catch-all phrase here represented as "nature" (other examples of words used are greening, green area, vegetation, and natural elements), whereas others have used more detailed descriptions ranging from naming specific species (n= 38) to types of vegetation being represented in the research (n = 63), dividing the vegetation into trees, shrubs, grass, etc. A few forewent the catch-all

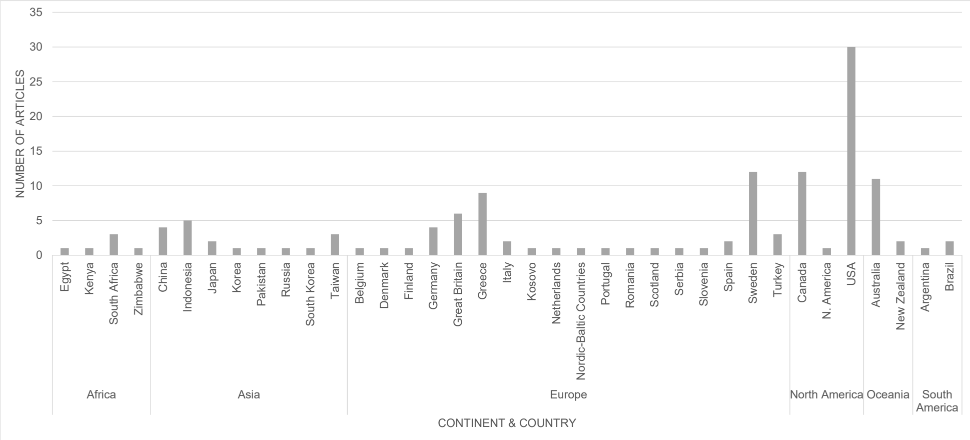

Fig. 3. Geographical location of the studies.

Table 3
All main themes present in the data number of articles are sorted as each main theme.

Main theme	Number of articles
Eco-literacy	20
Microclimate	16
Children's perspectives	14
Gardening	13
Education and cognitive effects	13
Physical activity	12
Perspectives of those other than children	8
Physical health	7
Socio-economic factors	7
Play	7
Mental health	6
Spatial layout	6
Biodiversity	3
Social relationships	1
Total	**133**

phrase and specifications, opting instead to describe vegetation in a quantitative measure as coverage (n = 6).

After examining this in the context of the main themes, some patterns were found (Fig. 7). Certain themes, namely "eco-literacy", "microclimate", and "gardening", are more represented within the group of articles that are species specific as these themes make out nearly 60 % of this group. In the case of "gardening", this species specificity pertains to the explicit mentioning of the cultivated produce, such as vegetables or other crops. Within the "eco-literacy" theme, specificity often relates to the level of knowledge concerning vegetation among children. The "microclimate" theme stands out as the only one incorporating species to explore their specific performance on the school grounds.

Within the group of articles that use catch-all phrases such as "nature", the themes "education and cognitive effects" and "children's perspectives" are common. The main theme "play" is the only one where all studies use the same degree of specificity, vegetation types, to describe the school ground vegetation.

3.4.2. *Size and/or shape of vegetation*

Almost 36.6 % of the studies did not specify the size or shape of the school ground vegetation in any way, while for ~3 % of the studies, this analysis question was not applicable. For 61.2 % that did include descriptions to a varying degree, some included pictures of the vegetated areas in question, some specified areas in square meters or the percentage of total school ground area, while others included plans where it was possible to visually interpret the size and/or shape of the vegetated areas. The level of specificity varied greatly and no clear pattern could be seen when analysing this in connection to the main themes. However, "mental health" is the only main theme where all articles specify size and/or shape to some degree.

3.4.3. *Vegetation development & existing or new vegetation*

A large majority (90.2 %) of the studies lack a time perspective as they do not investigate the development of the vegetation or its function and use to any extent. Also, there is a tendency to examine already established vegetation rather than study proposed designs or newly planted vegetation. 75.1 % of the literature focuses on existing vegetation, around 7.5 % includes both existing vegetation and a design proposal, and approximately 16.5 % specifically investigates newly planted vegetation.

4. Discussion

The results from this systematic mapping review reveals many disparities within the scientific literature on school ground vegetation. There is a wide variety of research themes, which shows a high degree of variation in the driving forces behind school ground vegetation research. There is also variation in the way in which different articles include vegetation in their research and the depth to which they consider it.

The 13.5 % growth rate of publications on school ground vegetation from 2003 and onwards surpasses the estimated average annual growth of scientific publications (5.1 %) when calculated from 1952 to today (Bornmann et al. 2021). It may be unlikely that this upward trajectory will be sustained indefinitely, following the argument by Bornmann et al. (2021) that since human resources and capital are limited, the growth of scientific research must also be limited. However, this recent growth is still notable and shows a high interest in this specific subject. The underlying cause that led to this growth is probably a combination of multiple influences. It can be viewed as a case of bridging the gap with more established research subjects. It may also be within reason to connect this to the interest in practice. With a multitude of school ground greening projects of varying scale across the globe and the research on them (Dyment and Reid, 2005, Sterling, 2005, Giezen and Pellerey, 2021), the interest in this topic seems to exist not only within

	Gardening	Biodiversity	Children's Perspectives	Spatial Layout	Eco-literacy	Education and Cognitive Effects	Mental Health	Microclimate	Perspectives of Those Other Than Children	Physical Activity	Physical Health	Play	Socioeconomic Factors
Biodiversity	0.11												
Children's Perspectives	0.08	0.17											
Spatial Layout	0.03	0.05	0.20										
Eco-literacy	0.17	0.15	0.17	0.09									
Education and Cognitive Effects	0.28	0.10	0.18	0.09	0.31								
Mental Health	0.06	0.09	0.06	0.10	0.16	0.27							
Microclimate	0.00	0.00	0.13	0.44	0.08	0.00	0.00						
Perspectives of Those Other Than Children	0.25	0.12	0.37	0.07	0.22	0.15	0.00	0.09					
Physical Activity	0.10	0.07	0.10	0.31	0.13	0.05	0.08	0.28	0.05				
Physical Health	0.34	0.17	0.06	0.00	0.00	0.05	0.00	0.06	0.12	0.07			
Play	0.00	0.13	0.27	0.27	0.20	0.16	0.07	0.00	0.00	0.06	0.00		
Socioeconomic Factors	0.26	0.00	0.00	0.09	0.14	0.05	0.00	0.12	0.17	0.00	0.00	0.00	
Social Relationships	0.07	0.00	0.00	0.00	0.13	0.07	0.11	0.00	0.08	0.10	0.00	0.17	0.20

Fig. 4. Correlation table showing the level of association between themes. Red shows a relatively high correlation and blue shows a relatively low correlation between themes (self-correlation not included).

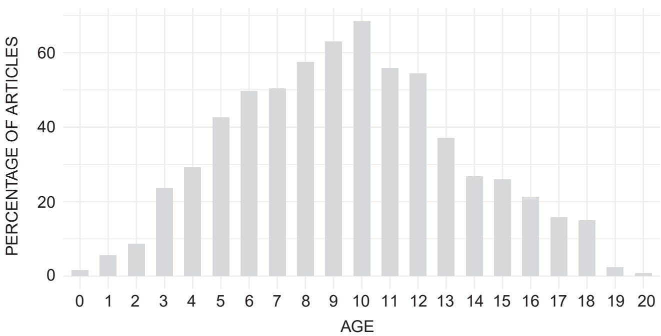

Fig. 5. Percentage of articles that includes the specific ages.

academia as results from this study show, but probably also more broadly. 2007 marks the year when the urban population surpassed the rural one globally (Ritchie and Roser, 2018). With this urbanisation, it is understandable that school grounds are getting more attention as more children are now growing up in cities and urban areas, meaning school grounds are where they spend a majority of their total outdoor time (Wen et al. 2009).

On a geographical level, the dominance of Europe (17 countries), North America (USA and Canada), Australia and New Zealand, comprising 78.9 % of the literature corpus. The studies conducted in North America predominantly emanate from the United States, whereas those originating from Europe encompass a representation of 17 countries. This is important to highlight. The impact that school ground vegetation has on children has been shown to depend on the design and management of school grounds (Malone and Tranter, 2003), processes themselves heavily influenced by prevailing policy frameworks and governance structures (Randrup et al. 2020). Given that these structures may differ between countries, it follows that the condition of school ground vegetation may also exhibit variations on an international scale.

This study only looked at English literature and any possible research published in other languages is thus not included. However, the wide geographical spread of the articles in this review indicates that it has captured at least a part of the discourse in each of the countries in question. And moreover, it is especially interesting to investigate literature in English as this can say something about the production and spreading of knowledge worldwide. In line with the scientific society in general (Collyer, 2016, Albanna et al. 2021), the scientific publishing of school ground vegetation in English predominantly occurs within the context of the Global North. As a result of not being represented in the scientific literature in English, the Global South risks being excluded

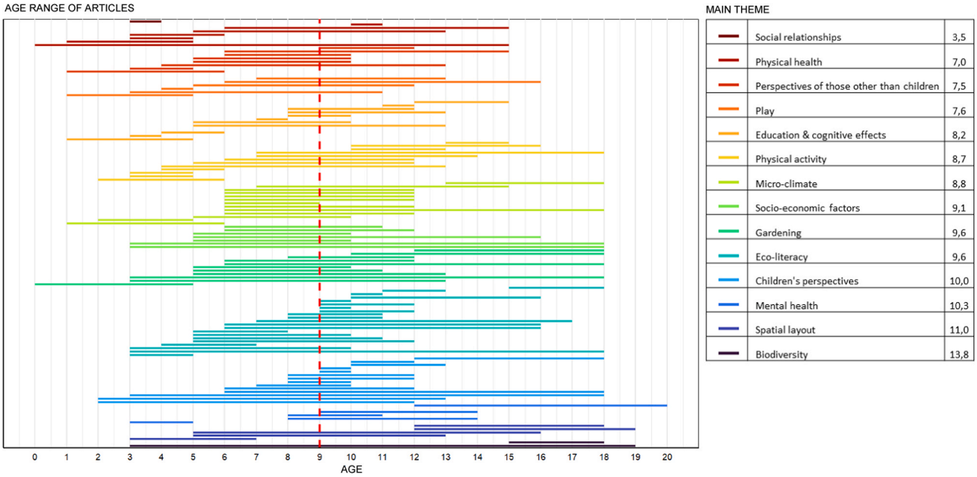

Fig. 6. Age ranges of all articles grouped by main theme. The Red dashed line shows the overall mean. The table shows the mean age for all themes.

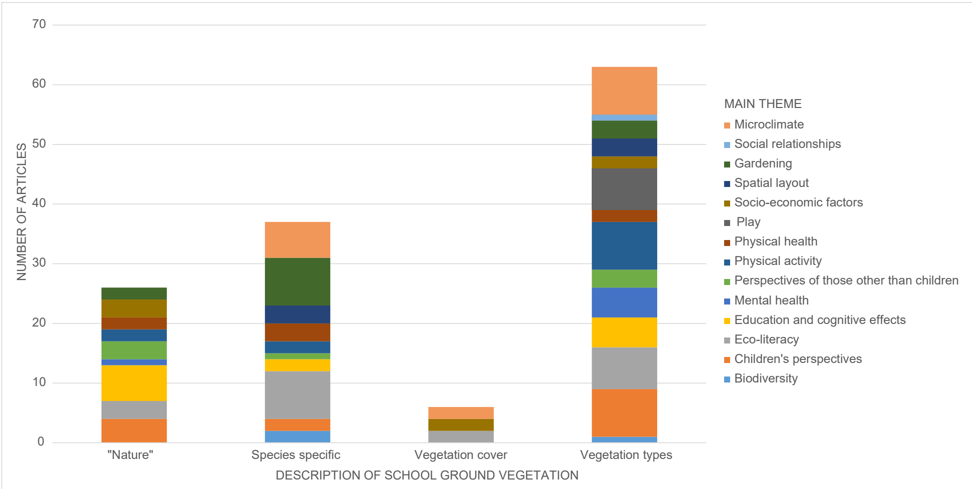

Fig. 7. Showing main themes of the articles and level of vegetation description specificity.

from the production of scientific knowledge and its influence (Collyer, 2016). This may lead to a limited understanding of the needs, impacts and uses of school ground vegetation in these areas. Furthermore, with urbanisation occurring at a faster rate in the Global South than in the Global North (UNDESA, 2018), it is crucial to ensure that school ground vegetation in these regions is not neglected. This importance is only heightened by the fact that cities in the Global South are more vulnerable to the consequences of climate change (Pörtner et al. 2022).

Also, since most research on school ground vegetation relates to the particular climatic and socio-economic contexts of the different countries predominantly within the Global North, results connected to vegetation performance and the effects of vegetation and environment on children should be interpreted with this in mind. The characteristics and appearance of vegetation vary considerably across regions of the world, and caution should be exercised when drawing parallels between studies in distinctly different climates.

There is a low level of uniformity when it comes to the level of specificity when describing vegetation in the studies on school ground vegetation. As this inconsistency also can be found within the main themes in this study, it indicates discrepancies among studies with the same focus. The main theme “play” is the only one where all studies use the same degree of specificity, using vegetation types to describe the content of vegetation on the school grounds. All in all, this implies that there are different dispositions, from being concerned (or unconcerned) with the particular species or type of vegetation to those more concerned with the amount of vegetation. It is clear that a majority of the research includes at least some degree of specificity regarding the vegetation being studied. But issues may arise when wanting to connect results from different studies or acquire detailed knowledge on school ground vegetation. Vegetation can be highly variable, and general descriptions such as "nature" risk over-simplifying these structures. The results of the studies leaning on general descriptions can be hard to interpret as it is often impossible to know exactly what "nature" consists of in each particular study. This can also be said for the description of vegetation types. Even if this is more detailed than words such as "nature", it should be noted that vegetation within a vegetation type can vary vastly.

The importance of investigating the effects of school ground vegetation in high detail is also because the performance and thereby benefits often vary greatly between different species (Sjöman et al. 2023). One example of how vegetation provides benefits is through providing shelter from wind and sun radiation. Trees affect the microclimate partly by their canopy cover (Dobbs et al. 2011) and structure (Nowak et al. 2013). Indeed, the literature included in this review shows that the canopy and structure of different types (El-Bardisy et al. 2016) and species (Antoniadis et al. 2016) of trees have different effects on the microclimate of school grounds. Moreover, varied sizes, ages, and species of vegetation offer diverse benefits when it comes to its effects on children, ranging from impacts on biodiversity to its possibility of facilitating children's play (Laaksoharju and Rappe, 2017) and effects on academic performance (Sivarajah et al. 2018). In the example of the theme "play", where all studies specified vegetation types, linking their findings may remain challenging due to the fact that two examples of the same vegetation type may still be immensely different from each other.

Additionally, species diversity is connected to the resilience of the vegetational community towards pests, diseases and changes in the environment (Roebuck et al. 2022, Raupp et al. 2006). This makes diversity on school grounds important both for the resilience of the specific school ground but also for the larger area of which the school is a part of. Given the high variation among vegetation as a whole, it is crucial to investigate at a more detailed level than currently is being done. This approach not only aids in comprehending the studies and their outcomes but also to provide a deeper understanding of the effects and contribution of school ground vegetation.

The inclination to generalise and simplify can also be shown in the tendency to study vegetation at a single point in time, as over 90 % did not study the development of vegetation to any degree. This risks oversimplifying the dynamic nature of vegetation and in prolongation overlook the importance of long-term management of the vegetation. As Malone and Tranter (2003) argue, the type of approach towards management on school grounds may have a great effect on how children interact and use the vegetation. This is also true outside of the school ground context where children's use of green structures has been seen to change as the vegetation develops (Gunnarsson and Gustavsson, 1989). At the same time there is a tendency to study already established vegetation. There are many greening initiatives around the world but not a lot of research being made on such newly planted vegetation. To study vegetation from the very implementation of it gives an opportunity to deepen the understanding of it and the effects it has on people and the surroundings.

The same simplification tendency is represented by the fact that more than a third (36.6 %) of the studies did not specify the size and/or shape of the vegetation to any degree. This is found within all main themes except for the main theme "mental health" in which all studies showed some level of specificity. In certain studies, the size and shape may be of lesser importance, for example, when the sole aim is to conduct a species composition survey. However, for many of the themes present among the literature on school ground vegetation, the size and/or shape of the vegetation may matter much for the functions it can provide, as indicated by several studies (for microclimate in Zhang et al. (2017), for play in Sylvia (2010), for education and cognitive effect in Sivarajah et al. (2018), for physical activity in Puhakka et al. (2019), etc.). To investigate this relationship more, it is necessary to know the specifics of the research, including the spatial qualities of the vegetation. Otherwise, it might be difficult to fully understand the results and conclusions of the research. Studying vegetation dynamics outside of the school ground context has provided a deeper view on the processes affecting vegetation which in its turn may inform management schemes going ahead (Li et al. 2020). The same would be possible for school ground vegetation if the spatiotemporal dynamics would be considered to a greater extent.

It may be understandable that there is a lack of interdisciplinary research within the field when considering the linguistic disparity within this topic. This is further evidenced by the correlation analysis of main themes, many of which completely lack association (displayed as 0 in the correlation table, Fig. 4). There is a high number of themes present within this research subject and therefore some lack of association between themes can be expected. These gaps can represent the need for future research. As global temperatures continue to rise due to climate change (Pörtner et al. 2022), exploring the microclimate of school grounds in relation to "education and cognitive effects" and "mental health" can provide valuable insights into the impact of a warmer learning environment on children's mental well-being and their ability to engage effectively in learning activities. In the same sense, the influence of microclimate connected to rising temperatures on play patterns and how they may vary with different types of school ground vegetation also remains an interesting and largely unexplored area of study. Interestingly, the themes "mental health" and "physical health" show no overlap despite their interconnectedness (Ohrnberger et al. 2017). By studying both of these in connection to school ground vegetation, a clearer and more comprehensive picture of the effect of vegetation on children's health could be found. Moreover, when it comes to the multifunctionality of school grounds, the themes "biodiversity" and "play" display two functions of school grounds which are generally not researched together, thus presenting an interesting possibility for future research.

The difference in occurrence between the themes "physical health" and "physical activity" is interesting to note. Twelve studies had a main focus on "physical activity", whereas only seven studies had a main focus on the broader theme "physical health". The studies within the theme "physical health" consider subjects as toxic and injurious plants, ingestion of hazardous substances, effects on skin microbiota, and promoting the consumption of more fruit and vegetables. This is different from the studies within the theme "physical activity", evidently all focused on physical activity. When it comes to aspects of health for children, there is a relatively high focus on studying physical activity in connection to school ground vegetation, while diversifying the focus within physical health further might prove beneficial to explore.

The ages of the children in the studies are spread from 0 to 20 years with a mean of 9.02. When looking at age ranges for the articles of each main theme, there are a few themes that divert from the overall corpus. Within the main theme "perspectives of those other than children", there is a higher focus on the lower ages shown with a mean age of 7.5. This indicates that for these ages it might be thought especially interesting to investigate parents' and pedagogical staff's perspectives. A higher average age for the main theme "mental health" than "education and cognitive effects" indicates a greater interest in looking at learning capabilities in lower ages and factors such as restoration in higher ages.

4.1. Limitations to the study

Grey literature was excluded in this mapping review. Even if interesting information can be found concerning school ground vegetation in, for example, fact sheets and government documents, it is of specific value to investigate the characteristics of scientific literature. Furthermore, google scholar was not used for literature searches even if it is a commonly used search engine in academia. Because of drawbacks inherent to its structure and programming it is less suitable for being used in systematic reviews (Boeker et al. 2013). Google scholar may be of good use when searching for specific articles or for grey literature but as of now the drawbacks outweighs the benefits for its use in systematic reviews focusing on scientific literature.

This review only includes scientific literature in English. It is important to note that this decision on scope may have resulted in the omission of relevant studies in the countries represented in this review, as well as in other areas of the world. In the medical field meta-reviews have shown that only including English literature has no effect on conclusions of the reviews in question (Dobrescu et al. 2021, Morrison et al. 2012). But as this review also investigates the geographical spread of the scientific literature these results might partly be explained by this focus on English literature. Readers should thus be aware of this limitation and its possible consequences.

This study relies on database searches and searches for *Children, Youth and Environments,* and therefore the limitations of these may affect the results. The search strings used were developed to be as inclusive as possible while at the same time limiting the number of irrelevant publications. It is, however, possible that some relevant articles may have been omitted from the conducted searches, possibly attributed to variations in terminology used.

Lastly, it is important to note that caution should be exercised when drawing conclusions based on themes that are supported by only a small number of articles. It can be challenging to make definitive statements from these findings, as there is a possibility that the observed trend is more coincidental than representative of a consistent pattern.

5. Conclusion

This review underscores the high diversity and variability present in the research concerning vegetation on school grounds. The variability in content and language poses challenges in connecting and synthesising research findings across different fields, making it difficult to draw comprehensive conclusions. To mitigate these issues, more focus on describing the content and spatial qualities of school ground vegetation in detail could greatly enhance the clarity with which results are interpreted and connected.

Given the growing interest in this area of research, it can be anticipated that future studies will strive to bridge the gaps between disparate themes and fields, thereby creating a more integrated understanding of the topic. The correlation analysis in this review can prove instrumental in this, displaying research gaps between, for example, the theme “microclimate" and “play”/”biodiversity”/”education and cognitive effects”/”mental health”, “mental health” and “physical health” as well as “socio-economic factors” and “physical activity”/”physical health”. To conduct research around themes that do not yet overlap in the research may be of special interest in the research field of school ground vegetation due to its expected multifunctionality and the value of interdisciplinary approaches in further developing the field.

Lastly, this review also shows that the majority of existing research in English has primarily concentrated on the Global North (Europe, North America, Australia and New Zealand). This presents an opportunity and also a need to explore regions beyond these geographical areas. Expanding the scope of study to other parts of the world can provide valuable insights and contribute to a more comprehensive understanding of the topic. The geographical context should also be taken into consideration when results from different studies are connected because of the possible big differences within climate and socio-economic aspects.

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Ethical statement

The research was conducted ethically and in accordance with relevant guidelines and regulations.

Declaration of Competing Interest

No conflicts of interest

Appendix 1

PRISMA 2009 Flow Diagram. *From:* Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). *P*referred *R*eporting *I*tems for *S*ystematic Reviews and *M*eta-*A*nalyses: The PRISMA Statement. PLoS Med 6(7): e1000097. doi:10.1371/journal.pmed1000097. **For more information, visit** www.prisma-statement.org**.**

Appendix 2

Search strings

For Web of Science, the following search string was used:

((school* OR preschool* OR daycare OR childcare OR *“child-care”* OR kindergarten) AND (ground* OR yard* OR play* OR area* OR environment*) AND (vegetation OR tree* OR bush* OR plant* OR “green area*” OR “green structure*” OR greenness))

For Scopus, the following search string was used:

TITLE-ABS-KEY ((*school** OR *preschool* OR *daycare* OR *childcare* OR “*child-care”* OR *kindergarten*) AND (*ground* OR *yard* OR *play** OR *area* OR *environment*) AND (*vegetation* OR *tree* OR *bush* OR *plant* OR *"green area"* OR *"green structure"* OR *greenness*))

Lemmatisation is automatically included when searching in Scopus so * was only used when a compound word was meant to be included as school*yard* or play*ground*.

Because of the word limit when searching in JSTOR, searching the journal “Children, Youth and Environments” had to be divided into two search strings and shortened. The part including space (ground/yard/environment etc.) was excluded since the focus of the journal itself can be expected to include this aspect already. The search strings used were the following:

(school* OR preschool* OR daycare OR childcare) AND (vegetation OR tree* OR bush* OR plant* OR "green area" OR "green structure" OR greenness)

And:

("child-care" OR kindergarten) AND (vegetation OR tree* OR bush* OR plant* OR "green area" OR "green structure" OR greenness)

Appendix 3

List of included articles

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This interdisciplinary doctoral thesis explores, through four interconnected studies, challenges and solutions concerning the implementation of school ground vegetation. Key findings emphasize the impact of children's play, influence of governance factors, and the importance of careful species selection and planting design. Together, the studies show that no single factor determines success of school ground vegetation. Instead, effective greening of school grounds requires the careful alignment of planting design, species choice, management, and governance.

Sanna Ignell undertook her doctoral studies and earned both her BA in Landscape Engineering and MA in Landscape Architecture at the Swedish University of Agricultural Sciences.

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