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LAWN ALTERNATIVES IN SWEDEN FROM THEORY TO PRACTICE

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CONTENT

INTRODUCTION

Lawns are one of the most dominant and visible elements of urban green spaces worldwide. They supply many positive ecosystem services. However, they are expensive and consume resources. There is also recent evidence of their contribution to the unification of the urban environment (Ignatieva, 2010) (figure 1).

There is a call for critical evaluation of lawns and efforts to develop alternative solutions. While suggesting different ideas for replacing the conventional lawns, we clearly understand their value and invite readers to apply critical thinking and careful adaptation of all our recommendations to local social and physical conditions.

Figure 1. Lawns contributing to unification of the urban environment. Lawns in Dubai (UAE, desert climate), Mumbai (India, tropical climate), Tokyo (Japan, humid temperate climate) and Malmö (Sweden, temperate climate). Photo credit: M.Ignatieva.

Definition of lawn

Despite the wide use of lawns, there is limited research on this subject. Most studies on the historical development, flora and ecology of lawns, as well as social aspects, come from the Anglo-American literature (Ignatieva *et al.*, 2015). There is no single sufficient definition of lawn, which reflects its complex nature (ecological and social importance).

According to the *Oxford Companion to Gardens* (1991), one of the essential garden history guides, "A lawn is a plant community in the natural sense and lawn cultivation concentrates on maintaining the balance between the different species of grasses" (p. 331).

Botanists, in their definition of lawns, acknowledge first of all the man-made nature of the lawn. They see lawn as a "type of man-made meadow-like plant community which is created by sowing or planting of turf grasses (predominantly perennial graminoids) and which is used for recreational, aesthetic, sport and other purposes" (Laptev, 1983, p. 5). The approach is botanical—a plant community—but, the most crucial point of departure for lawn is its function for people. Lawns are used for recreation and sports, and as a pleasant background for displaying other plants or artefacts. However very often they are appreciated for their own green beauty (figure 4).

Our definition of lawn is the following: "Lawn is a man-made plant community consisting of essentially regularly mown grass, created for fulfilling different human functions (recreation, sport, display and aesthetics). It may include spontaneously occurring forbs (herbaceous flowering plants other than grasses)".

Lawns are in most cases artificially created plant communities, but in some countries they may have emerged from long-term maintenance of meadows, pastureland or natural grass-dominated areas.

Grasses and forbs in above-ground and below-ground parts form a uniform phenomenon—a turf (sod)*, which is the upper level of soil closely covered by grasses and forbs and intertwined with their roots, which are in symbiosis with soil fauna (figure 2). The turf is a crucial feature of lawn, meadow and pastureland.

One of the main characteristics of lawns is their specific construction technique (preparation of soil and seed mixtures) and management regime (mowing, fertilising, watering and aeration) aimed at maintaining selected grass species, controlling weeds and mosses, and keeping the grass uniform height and green colour.

In the lawn concept, 'grasses' refers to plant species from the Poaceae (Gramineae) and plants from the sedge family (Cyperaceae)—herbaceous plants with grass-like morphology. One of the distinctive features of lawns is regular mowing to keep the grass short (figure 3).

* According to the *Oxford English Dictionary* (https://en.oxforddictionaries.com/definition/turf), "turf is grass and the surface layer of earth held together by its roots" or "the upper stratum of soil bound by grass and plant roots into a thick mat" according to the *Merriam-Webster* dictionary (https://www.merriam-webster.com/dictionary/turf). Sod and sward are used as synonyms for turf. Sod is grass and the part of the soil beneath it held together by the roots. The sward is the upper layer of soil, especially when covered with grass. Thus, turf, sod and sward are similar in nature.

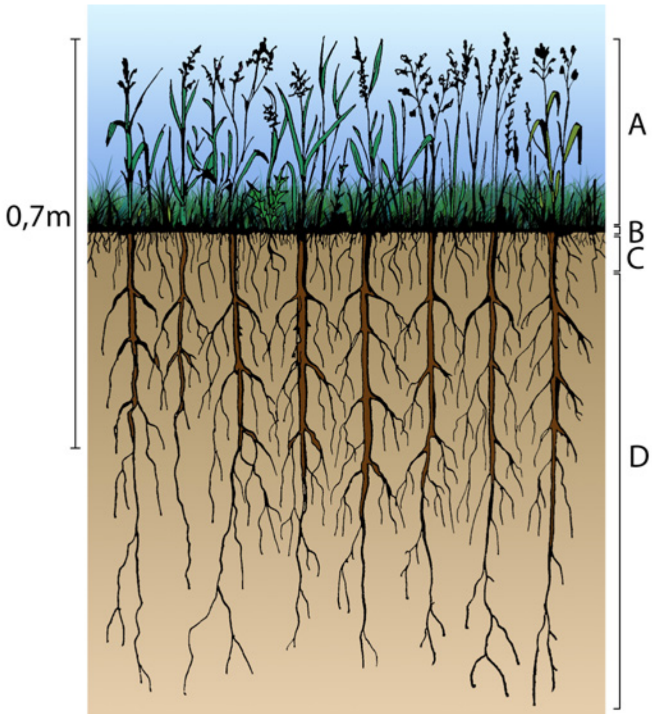


Figure 2. Profile of turf:
a) grasses and forbs;
b) litter layer;
c) turf bed (actual sod);
d) turf base.
Adapted from Laptev, 1983.

Figure 3. Profile of typical regularly mown lawn.
Photo credit: J.Lööf Green.

Biologically, lawns can also be seen as a type of artificially created meadow and, in fact, they have certain similarities to natural meadows. Lawns are the plant communities of grasses and forbs which form turf. However, one of the main differences between lawns and meadow-like communities is the higher plant density. In the case of lawns, there are tens of thousands of shoots per square metre, while in meadows there are about three to seven thousand shoots per square metre. Natural meadows have a complicated multi-layered structure consisting of grasses and forbs of different heights. The structure of lawns, by contrast, is quite simple; they usually consist of one layer.

Another important difference between meadows and lawns is the need for intensive continuous management. Thus, the main features of most types of modern lawn are the primary use of grass species, dense sod and a regular mowing regime.

There are different hypotheses about the origin of lawns. Some believe they derive from certain types of grazed grasslands (natural or anthropogenic) in Europe. Actually, in agriculture, a meadow is also grassland, but is ungrazed or used for grazing only after being mown to make hay for livestock.

Figure 4. Use of lawns for recreation, sport, display and just to enjoy. Photo credit: M.Ignatieva.

CHAPTER 1

LAWN project results

The goal of our LAWN project was to study lawns from different perspectives as social and ecological phenomenon in order to understand their role in sustainable urban planning, design and management. Adopting an interdisciplinary approach allowed us to exchange knowledge between disciplines and to achieve a multi-dimensional understanding of lawns.

The involvement with stakeholders in the LAWN project and our close collaboration with them provided us with first-hand information on planning benefits and on obstacles related to lawn management and maintenance. It gave us an opportunity to offer practical implementation advice, as a complement to our theoretical recommendations.

The LAWN project was funded by Formas (Swedish Research Council) and was run in 2013-2016. The part of the research related to golf courses was conducted with the help of STERF (Scandinavian Turfgrass and Environment Research Foundation).

Study areas were chosen within three Swedish cities (Uppsala, Malmö and Gothenburg) and explored two dominant typologies of neighbourhood (People's Homes (Folkhem) and Million Programme areas). These multi-family residential housing neighbourhoods, with significant areas of lawn, are the most common typology in Swedish cities.

Our overall aim with the LAWN project was to obtain interdisciplinary quantitative and qualitative data on lawns, which allowed us to draw some conclusions about their positive and negative environmental impacts in our modern cities.

WE STUDIED LAWNS FROM THREE SCALE PERSPECTIVES:

- the large scale, including the entire city (estimating the total coverage of the lawn as a land use type);
- the medium, neighbourhood scale (providing typology, coverage of lawns, their functions, values and use by urban dwellers);
- the fine level, with emphasis on individual lawn (biotope) characteristics such as biodiversity and carbon sequestration.

WE RESEARCHED DIFFERENT ASPECTS OF LAWNS:

- general coverage of lawns in Swedish cities;
- historical roots, perceptions, norms, aesthetic and design values of current management practices of lawns;
- how different human interests and values interact (or conflict) from a management perspective and how to find sustainable planning and design solutions;
- motives for decisions about establishment and management of lawns among different stakeholders;
- environmental impact (energy use and climate footprint);
- biodiversity (plants, bumblebees, butterflies and earthworms).

Types of Swedish lawns included in our research

The classification of Swedish lawns is mostly based on the management regime (mainly frequency of cutting) and the height of cut grass. Swedish municipalities usually recognise the ornamental lawn, utility (conventional) lawn (cut numerous times during the growing season) and meadow-like lawn (cut once or twice, rarely three times, during the growing season).

Ornamental lawns, which require the most intensive management, are not very commonly used in Sweden (see table 1 in Chapter 3). That is why, in our research, we included golf courses with lawn types ranging from very intensively managed tees and greens to fairways with intermediate management intensity and roughs with the lowest management intensity.

Herbicides may be used on the lawns in golf courses. However, on public lawns in Swedish cities, herbicides are uncommon. Thus, we researched lawns within the intensity management perspectives: golf lawns, conventional lawns and meadow-like lawns in residential areas (Ignatieva *et al.*, 2015). The lawns we studied have different origins. Some sites were farmland prior to the 1950s, some even rock (in Gothenburg) and some smaller areas were pasture or forest. Conventional lawns and most of the meadow-like lawns (especially the high grass category, see Chapter 3) were sown using the same grass mixtures. However, there were probably small amounts of original meadow (pasture) remnants, especially in Uppsala and Gothenburg (figure 5).

Figure 5. (Left) aerial photo of a 200 m² area in Gothenburg in 1960, with what appear to be meadows, bare rocks and agricultural fields (photo: lantmäteriet). (Centre) by 2014, these have been replaced by housing and forest, with (right) areas of lawn (light green) and forest or shrubs (dark green) (photos: arcmap). Credit: M.Hedblom.

Results of LAWN project

Lawns dominate urban green areas in Sweden, occupying between around 40 and 60% of the total urban green area. Total cover of lawn is around 23% in Swedish cities (mean of the three major cities) and they occupy 0.6-0.9% of the total terrestrial land surface in Sweden. About 26% of Swedish lawns have been actively managed for at least 50 years (Hedblom *et al.*, 2017).

Carbon footprint

Our research on carbon sequestration concluded that lawns have a positive effect on the soil carbon balance. The accumulated amount of carbon in soil was higher in the lawns studied than in meadows and nearby agricultural land, because production of biomass is stimulated by frequent cutting (Poeplau *et al.*, 2016). Above-ground biomass production was also the main driver for observed differences in soil carbon stocks in the golf courses, with greens having the lowest, fairways having intermediate and roughs having the highest biomass production. Correspondingly, soil carbon stocks increased in the same order (Poeplau *et al.*, 2016; Wissman *et al.*, 2016). Overall, our soil studies indicated that carbon sequestration was highest in urban lawns and rough areas in golf courses, which are areas with an intermediate cutting regime that favours above-ground biomass production.

The positive carbon sequestration effect was partly countered by mowing, irrigation and fertilisation, which require fossil fuel energy and labour costs and cause greenhouse gas emissions. According to our data (Tidåker *et al.*, 2017), mowing made the highest contribution to energy use for meadows, utility lawns and roughs (in golf courses). Annual carbon sequestration was higher than emissions from management of meadows, conventional (utility) lawns and roughs, but lower from the fairways. However, carbon sequestration is decreasing over time.

Thus, lawns can be seen as a source as well as a sink for greenhouse gases. The conclusion from our research is that mowing is the main contributor to greenhouse gases from most lawns. Reduced mowing frequency and electric machines can reduce the carbon footprint of lawns.

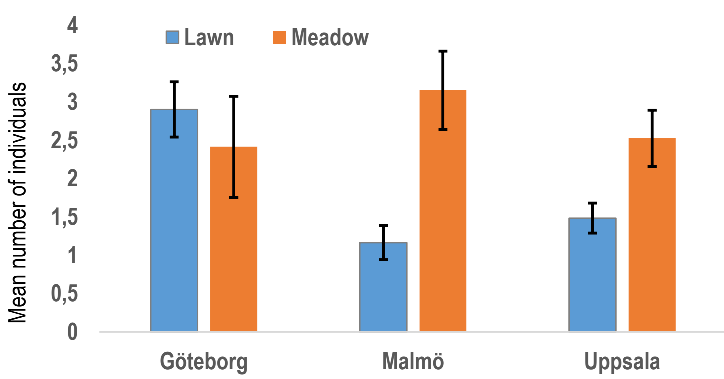
Biodiversity

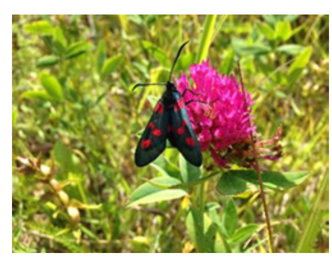
Our original hypothesis was that biodiversity (in the form of higher vascular plant species, earthworms and flower visiting insects, i.e. bumblebees, honey bees, butterflies and burnet moths) would be higher in the meadow-like lawns than in the conventional lawns. For the insects, both abundance and species richness were higher in meadow-like than in conventional lawns in two out of three cities (Malmö and Uppsala). However, in Gothenburg there was no difference in the abundance of flower-visiting insects between meadow-like and conventional lawns, and the species richness was actually higher in conventional than in meadow-like lawns (figure 6).

Plant species followed a similar pattern: diversity of plant species (forbs) was higher in meadow-like lawns than in conventional lawns in Malmö and Uppsala, while the opposite was found in Gothenburg (figure 7). Consequently, the average number of species (species richness) was higher for meadow-like lawns in Malmö and Uppsala compared with conventional lawns, but no such difference could be detected in Gothenburg (figure 8).

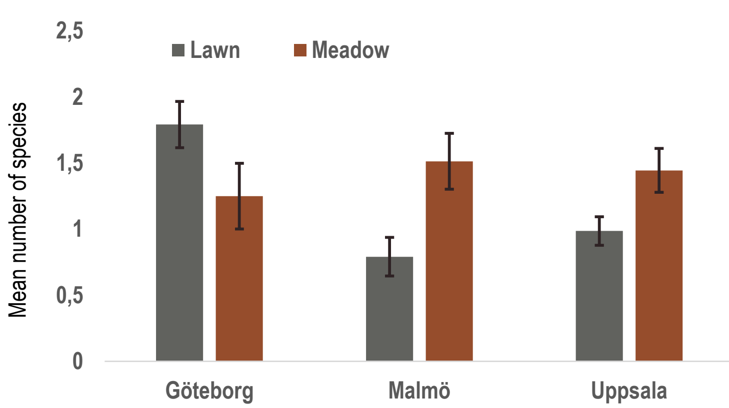
An explanation of the results for Gothenburg may be general low diversity and species richness in both types of managed lawns, but also differences in timing of cutting in the meadow-like lawns. Even though we excluded meadow-like lawns that were recently cut, the time since cutting may have influenced the flowering pattern differently depending on e.g. temperature or precipitation. In all three cities, the influence of *Trifolium repens* was particularly high in conventional lawns, where in many cases it was the only plant that could attract bees and butterflies (figure 9). Other species that were locally common and can attract bees and butterflies in utility lawns

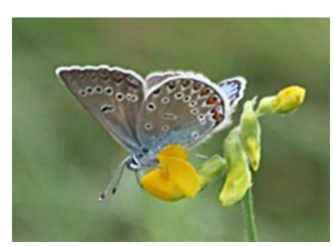
POLLINATOR ABUNDANCE AND SPECIES RICHNESS





Zygaena lonicerae. Photo: Pavel Bína.





Polyommatus amandus.

Figure 6. Pollinator abundance (upper diagram) and species richness (lower diagram) in conventional and meadow-like lawns. Credit: K.Ahrné.

were *Prunella vulgaris*, *Taraxacum sp.* and *Medicago lupulina*. These plants are very plastic and are able to adopt a low growth habit, and have the ability to produce flowers even in frequent cutting regimes.

Vascular plants and flower-visiting insects (bumble bees, honey bees, butterflies and burnet moths) were also surveyed in fairways, roughs and high roughs on golf courses. The diversity (Shannon-Wiener index) of flowering plants differed between the management types, where rough had lower diversity than high rough and fairway had lower diversity than rough. The number of reproductive units (buds, flowers and fruits) per 0.5 m x 0.5 m plot also differed between management types, where rough had lower numbers of reproductive units than high rough, but no such difference could be found between fairway and rough. The reproductive units can be viewed as both an indication of plant reproductive potential (fruits) and as resources for insects (mainly flowers and fruits).

There was an overall effect of management type for number of flower-visiting insect species, number of individual insects visiting flowers and number of flower visits. When comparing individual pairs of management type, number of flower-visiting insect species was highest in high rough and lowest in fairway, but for number of individual insects visiting flowers and for number of flower visits, fairway had lower numbers while rough and high rough could not be separated. Visiting insect individuals were dependent on number of flowers (that attract flower visiting bees and butterflies) in fairways, but this relationship between factors was very weak in rough and could not be detected in high rough.

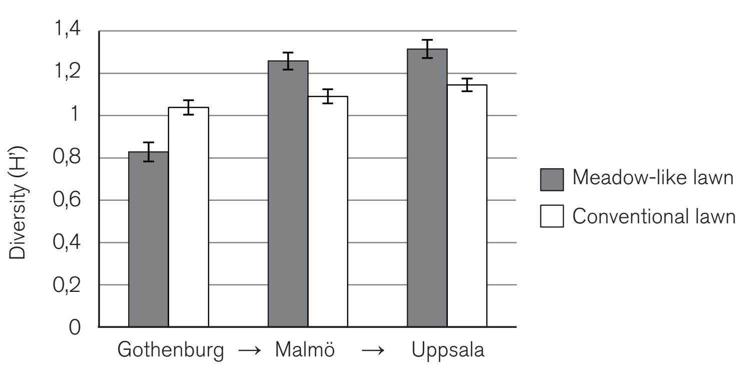


Figure 7. Average plant species diversity in plots (0.5 m x 0.5 m) in two treatments in three cities: Gothenburg, Malmö and Uppsala. Diversity is shown as Shannon-Weiner diversity index H'. Credit: J.Wissman.

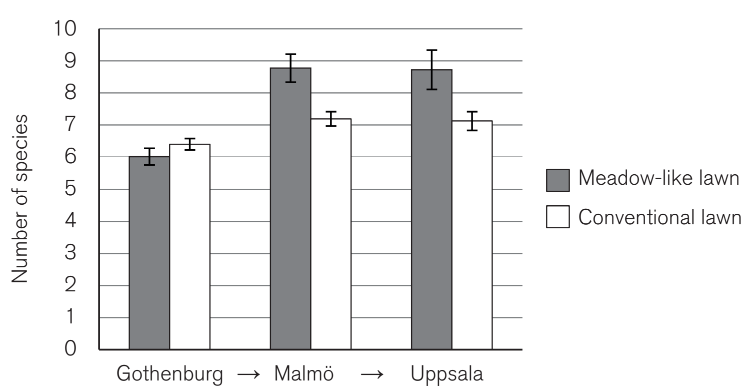


Figure 8. Average plant species numbers (forbs and grasses) in plots (0.5 m x 0.5 m) in two treatments in three cities: Gothenburg, Malmö and Uppsala. Credit: J.Wissman.

Figure 9. *Trifolium repens* is the most important species for attracting pollinators in conventional lawns. Uppsala, July 2015.
Photo credit: M.Ignatieva.

Earthworms are important soil organisms that contribute to beneficial soil structure, soil aeration and water infiltration capacity, and soil fertility (Lee, 1992; van Groenigen *et al.*, 2014). We sampled earthworms on 24 lawns in Uppsala, distributed across four areas (two multi-family, two Million Programme), with three meadow lawns and three conventional utility lawns separated by at least 100 m in each area. The earthworms were sampled in October 2014 using allyl-isothiocyanate (AITC) solution at a concentration of 0.1 mg ATIC/L of water) to extract the earthworms from the soil, according to Zaborski (2003).

Earthworm species richness tended to be higher in meadow-like lawns than in conventional utility lawns. This was also the case for abundance, while no differences in biomass were found between the two types of lawn. Our results suggest complex relationships between earthworms and soil variables that may depend on management practices such as fertilisation. The results indicated that urban lawns are not especially poor in earthworm species and individuals, and that lawn management can potentially influence earthworms. Meadow-like lawns that are cut only a few times each year had a higher richness than the more intensely cut utility lawns.

Conventional lawns have low animal diversity locally but, more importantly, they are more homogeneous (ecologically similar), as demonstrated by lower beta-diversity and more nested communities. This suggests that the reason for the homogeneity of conventional lawns is connected to human factors. Swedish municipalities are responsible for the establishment and management of lawns in most multi-family housing areas. They have 50 years of experience in establishing conventional lawns, suggesting typology of lawns and, most importantly, proposing management regime, with mowing being one of the most influential maintenance methods. Our results on homogeneity confirm recent findings for private residential lawns in the USA showing that the homogeneity of lawn plant species composition is strongly correlated to management (Wheeler *et al.*, 2017).

Social studies

The results of the social studies showed that people's attitudes to lawns are positive, even if they do not always actively use them. For the majority of the people surveyed, lawns were desirable elements of green areas. Lawns were particularly appreciated as important places for different outdoor activities (playing, resting, picnicking, walking and socialising) or just for viewing. However, we also found that in some neighbourhoods there were quite large areas of lawns that are not used. Such areas are empty most of the time, but still constantly mown and maintained. One of the most important conclusions of our social study was that people want to see a variety of green areas that provide conditions for different senses (sound, smell, touch and vision) and not just a monotonous lawn.

We also asked residents about the possibilities to use different types of alternative lawns (figure 10).

Figure 10. Three alternative options for lawns presented with question 5: What do you think about alternative lawns (such as grass-free (flower-rich) lawns, meadows with perennials or annual pictorial meadows? (Hellner and Vilkenas, 2014).

Meadow with perennials *Pictorial meadow* *Grass-free lawn*

In many cases the residents expressed positive attitudes to alternative lawns, but high vegetation (meadow-like lawns or pictorial meadows) was not desired close to houses in most cases, since people believed that high grass harbours ticks and snakes. An estimated 20% of those interviewed also stated that high grass can look untidy.

Many people found grass-free/tapestry lawns (flowering lawns with low-growing forbs) "amazingly beautiful". Perennial meadows framed by mown conventional grass areas received positive feedback from respondents in many cases. (Ignatieva *et al.*, 2017)

The three cities studied have quite a variety of contractors involved in construction and management of green areas, including lawns. Stakeholders in the city authorities assumed that people wanted short manicured lawns. However, all three cities were conscious about the high costs of management and were therefore open to alternatives to traditional lawns. For example, the annual cost of lawn management in Gothenburg in 2014 was 2.78 SEK/m^2 for conventional lawn, compared with 1.35 SEK/m^2 for meadow-like lawn. In Uppsala, the corresponding values were 1.92 SEK/m^2 compared with 0.85 SEK/m^2.

Managers often demonstrated a very narrow practical attitude, where bushes, trees, rocks and benches were seen as "obstacles" to mowing lawns and water elements (e.g. ponds) were seen as objects which require a lot of maintenance (clearing leaves and occasional rubbish). Our surveys showed that people wanted more tables and chairs on the lawns.

However, many local maintenance managers do not like to see leftovers on lawns after picnicking, since it can attract "undesirable" wildlife such as rats, rabbits and wasps.

Since lawn is one of the most common elements of open urban green spaces, people highly value and see them as an important feature.

We believe that implementation of new approaches such as alternative lawns require special planning and design solutions adjusted for each particular neighbourhood. There is a strong tendency in Swedish cities to view presence of design and human care in meadow-like lawns as important (Eriksson *et al.*, 2016).

Our research clearly indicates that social aspects and aesthetics influence decisions on planning and management of various types of lawns. However, there seems to be a need to challenge the existing paradigm of the "ideal" lawn strategy and consider more sustainable, resource-saving and cost-effective practices.

CHAPTER 2

History of Swedish lawns, with explanation of the word 'gräsmatta'

The understanding and definition of lawns have changed over the past four centuries. According to Fort (2000), the word *lawn* appeared in English dictionaries for the first time in 1548 and at that time, it meant an open space between trees, which is actually quite similar to the modern use of lawns. Thus, the very important function of the lawn—to be a connecting element between different landscape elements—was recognised. In France, there was a special word, *gazon*. Linguists believe this word is rooted in the Frankish *wason* and was widely used for designating 'ground covered by grass'. However, etymologists and garden history researchers are still debating the origin of the word *lawn* (Ignatieva *et al.*, under review).

The Swedish word for lawn is *gräsmatta* (pl. *gräsmattor*). It is a compound word that means 'grass carpet'. The use of the word *gräs* from ancient times reflects the development of Swedish agriculture, where grass-covered areas had great significance for stock rearing.

According to a Swedish historian, the oldest known form of deliberately cultivated land was *lövängar*—fenced, grazed meadows with trees (Jacobsson, 2013). *Trädgård*, the current Swedish word for garden, probably meant a meadow with fruit trees (Jakobsson, 2013). Thus, grazed meadows became one of the key features of the Swedish landscape (figure 11). The abundance of large forests also played a role, because the forests were also often used as grazing areas. In medieval times, the Latin word *pratum* (meadow, hay-field) was also used in Sweden. Most likely, in monastery gardens, this word could be used for cut turf obtained from existing meadows or pastures, which contained different grasses and forbs. Images of turf-topped benches and seats can be found in many paintings dating from medieval times in Europe. Swedish churches have some paintings as well, for example from Antwerp (figure 12). In that image, it is possible to see the grassy bench on which the Virgin Mary and St. Clare are sitting. There are also some wildflowers among the grass.

DEVELOPMENT OF LAWNS

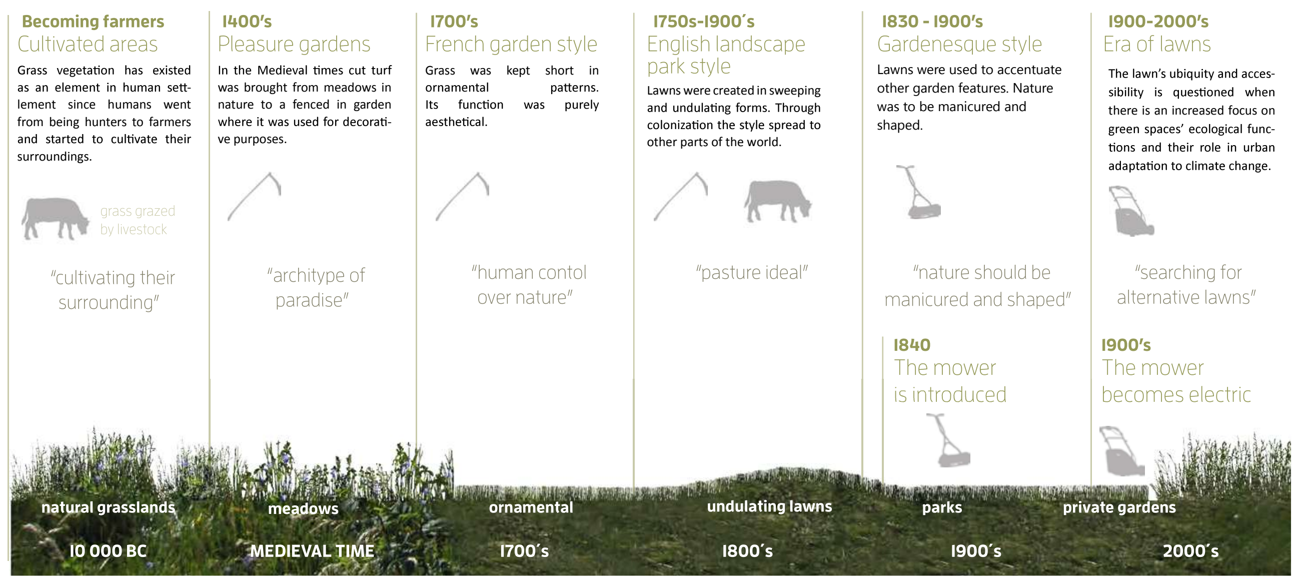


Figure 11. Development of Swedish lawns.
Design: S. Andersson and U. Bergbrant (2015).

The latest research by British scholars (Woudstra and Hitchmough, 2000) reports that in medieval times there were two types of grassy surfaces: grassy patches (lawns) and flower-rich grassy swards. The latter was created by adding native and some exotic herbaceous plants to existing turf.

Another British researcher, Eleanor Rohde, introduced the term '*flowery mead*' to describe flowery, rich medieval lawns, based on images available in tapestries and paintings. She suggested that these 'flowery meads' were "imitations of the natural meadow, and like the natural meadow, they were starred with flowers" (Woudstra and Hitchmough, 2000, p. 30).

In the Swedish Bible (translation from 1526), the compound word *gräsplats* is mentioned (Ignatieva *et al.*, under review). This corresponds with observations by British authors, who argue that areas of uniform cut grass that today we regard as lawns were "referred to as grass plats or plots" in medieval times and up to the 18th century (Woudstra and Hitchmough, 2000, p. 31).

In the 17th century, during the flourishing of French formal gardens in Europe, French terminology relating to lawns as decorative short

Figure 12. (Left) "The Virgin Seated on a Low Wall Picking a Flower for the Christ Child, Saint Agnes, Saint Dorothea, and another female saint (possibly Saint Barbara) in an Enclosed Garden Beyond, an Extensive River Landscape with a City in the Distance", by the master of the Tiburtine Sibyl, 1468. Source: www.artvalue.com/auctionresult--master-of-the-tiburtine-sibyl-the-virgin-seated-on-a-low-wal-1750594.htm. (Right) St. Clare and the Virgin Mary. 1500s. Altarpiece. Antwerp workshop (courtesy of the Swedish History Museum, Stockholm). Photo credit: M.Ignatieva.

grass-dominated surfaces (*parterre de gazon*, *tapis vert*), was also transferred into the Swedish language. Swedish readers probably first saw the word '*gazon*' in *Le jardin de Plaisir* by André Mollet, published in Swedish in 1651 (Mollet, 1651). Gazons were established only in the royal and noble gardens and used in parterres and in borders of parterres where topiary trees and flowering plants were displayed. Gazon was a very time- and money-consuming element. It required use of special seed mixtures (or good quality turf from pastures) and establishment techniques and an intensive maintenance regime (figure 13).

Most authors claim that lawn really came into its own life as a closely-tended, short grass and as the most important garden element, which could cover quite extensive areas, in the middle of the 18^{th} century (Dawson, 1959; Schultz, 1999; Jenkins, 1999). The particular recommendation at that time was to collect the grass from good upland pastures (Dawson, 1959). Smooth, green lawn with fine grasses that are closely mown or grazed became easier to create with the development of nurseries for producing lawn seed mixtures in the second half of the 18^{th} century.

Figure 13. Parterre with lawn (gazon) as the dominant element. Drottningholm Park. Photo credit: M.Ignatieva.

Figure 14. Haga Park (Sweden). This is the most famous Swedish pelouse. April 2014. Photo credit: M.Ignatieva.

Figure 15. People's Homes area in Tunabackar, Uppsala, in June 2013.
Photo credit: M.Ignatieva.

The use of the French word *pelouse* (which means the surface of lawn; Mosser, 2000) in the Swedish language relates directly to the development of landscape parks in Sweden by the end of the 18th century (figure 14).

The word *gräsmatta* was first used in the Swedish dictionary in 1852 in the current meaning of a green grass carpet or "mat-like quilt made by (fine and impenetrable) grass covering the ground" (Lundström, 1852, in SAOB; Ignatieva *et al.*, under review). The appearance of the Swedish word *gräsmatta* is directly correlated to the spread of public parks in Sweden and wide use of lawns as an important decorative element. *Gräsmatta* also shares the 19th century English meaning of lawn as a green carpet that is intended for use.

Widespread development of lawns accompanied the functionalistic movement (Swedish Model) implemented by the Social Democratic Party in the 1930s-1970s. One aim of the Swedish Social Democratic ideology was to create a progressive welfare state, part of which was to provide residential areas with healthy outdoor environments for the working class. As a result of the functionalistic movement, multifamily-house areas called People's Homes (Folkhemsbebyggelsen) were built from the 1930s to the 1950s, and later the Million Programme (Miljonprogrammet) was implemented between the mid-1960s and mid-1970s. Lawns were the dominant element of the outdoor environment (for play, walk and rest) in both these types of residential neighbourhood (figure 15). Lawns as standardised elements fitted perfectly with the modernist aesthetic of prefabricated rationalistic landscape elements and limited variation in design schemes (Ignatieva *et al.*, 2017).

Lawns also played an important role in the private gardens-detached homes sector of Swedish cities. Modern neighbourhoods still widely employ lawn as a major design element of the outdoor environment (figure 16).

Figure 16. Lawn in the garden of a private house in Bräcke, Gothenburg. June 2014. Photo credit: M.Ignatieva.

CHAPTER 3

Types of lawns and grass-dominated areas in Swedish municipalities

Swedish national guidelines for grass maintenance divide grass areas into four types: ornamental lawn, conventional lawn, high grass and meadow. The main differences between these types are grass height and intensity of cutting (figure 17). Meadow-like areas are cut once or twice a year. High grass requires cutting 2-5 times per season, while conventional lawns require more frequent cutting, 12-20 times per season (depending on weather conditions). Ornamental lawn should be cut 18 to 25 times per season and requires the shortest grass carpet, 2.5-6 cm. The function of each type of grass area is different. The ornamental lawn's main goal is to have high aesthetic value (to be an important decorative spatial element), whereas conventional lawn is used for recreation and sport.

Figure 17. Types of grass areas in Sweden (Andren, 2008; Andersson & Bergbrant, 2015).

In 2001, conventional lawns covered roughly 55% of the grassed areas in Swedish towns and cities. This was followed by meadow-like lawns (high grass 30%, meadow 11%) and ornamental lawns (4%) (Svenska Kommunförbundet, 2002).

In each Swedish city, this classification has variations (subcategories) within the conventional (utility) and meadow-like lawn categories that are based on number of mowings and, for conventional lawns, height of the grass (table 1). As the data in table 1 clearly show, in reality in modern towns and cities the high grass category is quite commonly used as an alternative to conventional lawns and is included in the larger category of meadow-like lawns.

Ornamental lawn (also called 'parade' lawn in the Malmö and Gothenburg classification) can still be found in Malmö and Gothenburg, but has almost completely disappeared in Uppsala.

TABLE 1. TYPOLOGY OF LAWNS IN UPPSALA, GOTHENBURG AND MALMÖ (BASED ON MUNICIPAL DATA FROM 2015). THE ORIGINAL ABBREVIATION FOR DIFFERENT TYPES OF LAWNS USED IN THESE THREE CITIES IS RETAINED.

CITY	CONVENTIONAL	MEADOW-LIKE
Uppsala	G1: Cut regularly plus fertilising. None of this type at the moment G2: Cut regularly to keep the grass to a height of grass maximum 8-10 cm	G3: Cut twice a year G4: Cut once a year
Gothenburg	A: Parade lawn; cut and watered continuously C: Cut continuously. For play and sport, or other activity D: Cut continuously	High grass A with collection: sown or natural grass, mowing with collection of clippings three times a year High grass B with collection: sown or natural grass, mowing twice with collections of clippings once a year High grass C: Sown or natural grass, mowing with collection of clippings once a year High grass A: sown or natural grass, mowing three times a year High grass B: sown or natural grass, mowing twice a year High grass C: sown or natural grass, mowing once a year
Malmö	G1: Parade lawn G2: Activity lawn	G0: Free growing grass, meadows G4: High grass, mowing with collection of clippings once a year G6: High grass, mowing two times a year G7: High grass, mowing four times a year G10: High grass with manual collection G11: Ruderal meadow

Parade (ornamental) lawns are the most intensively managed category of lawns in Sweden. They are cut and watered continuously throughout the season. This kind of lawn is used as a special decorative element – a green canvas for displaying plants, architecture or sculpture. For parade lawn, fine grasses as *Festuca rubra*, *Poa pratensis*, *Agrostis capillaris* and *Lolium perenne* are recommended. Any other species (rather than those intended to be in the initial seed mix) are not welcome in parade lawn, since they can destroy the smooth and even appearance of the green carpet (figure 18).

Figure 18. Example of ornamental (parade) lawn. Botanic Garden, Uppsala, October 2013. Photo credit: M.Ignatieva.

Conventional lawns

Conventional lawns (figure 19) are designed to be strong and able to withstand different recreational activities. Thus in the above classification such lawns are also called 'activity' lawns. The established maintenance routine for conventional lawns makes this category very common in cities. The desired grass height is about 4-10 cm. Seed mixtures for such lawns consist of a combination of grass species. In Sweden, *Festuca rubra*, *Agrostis capillaris*, *Lolium perenne*, *Phleum pratense* and *Poa pratensis* have the highest abundance in conventional lawns.

Our LAWN project biodiversity results confirmed that *Festuca rubra* is the most commonly used grass in Sweden. This species is drought-tolerant and withstands cutting really well. As time goes by, the original lawn, based on grass species, is enriched by forbs originating from the seed bank and surrounding plant communities.

The presence of such forbs is very beneficial for the biodiversity of conventional lawns. Our LAWN project studies of conventional lawns showed high abundance of *Trifolium repens*, *Achillea millefolium*, *Ranunculus auricomus* and *Potentilla reptans*.

The main type of conventional lawn maintenance is frequent mowing. Public lawns in Sweden are not irrigated or fertilised and grass clippings are not collected.

Researchers working with urban lawns (Müller, 1990; Thompson *et al.*, 2004; Stewart *et al.*, 2009) have shown that after the establishment of lawns, climate conditions, intensity of use and maintenance regime can affect the plant composition. Müller (1990) found that the most influential factor is cutting regime. The mowing process primarily benefits cutting-tolerant species with a low growth habit.

Figure 19. Example of conventional lawn in Augustenborg, Malmö. August 2015. Photo credit: M.Ignatieva.

Meadow-like lawns (high grass and meadows)

From table 1, it is clear that the meadow-like lawn category in reality is dominated by high-grass plant communities. Meadows cover only small areas in each of the three cities studied. Malmö and Gothenburg have established quite detailed subcategories within the meadow-like type.

HIGH GRASS LAWNS

High grass lawns are cut only a few times a year and the grasses are allowed to grow tall. High grass areas are often located in residual or peripheral areas and not intended to be used for intensive recreational activity. The species composition of high grass areas varies, but grasses dominate in most cases. The most common species in Swedish high grasses are *Phleum pratense*, *Festuca rubra*, *Agrostis capillaris*, *Poa pratensis* and *Dactylis glomerata*. Among forbs, the most common species are *Trifolium pratense* and *Trifolium repens*, *Plantago lanceolata, Lotus carniculatus*, *Medicago lupulina*, *Achillea millefolium* and *Anthriscus sylvestris* (figure 20). High grass areas in general have greater potential for biodiversity compared with conventional lawns, because they usually allow plants to grow and flower (Wissman *et al.*, 2015; for results of the LAWN project, see Chapter 1 of this manual).

It is possible to convert high grass in an urban environment to flower-rich meadow, but it takes a few years. It requires collecting clippings after cutting (to restrict soil fertility). Thus, only a few towns and cities have done this on a larger scale. Mowing regime for high grass depends on cutting frequency, site peculiarities, weather pattern and the intended high grass appearance.

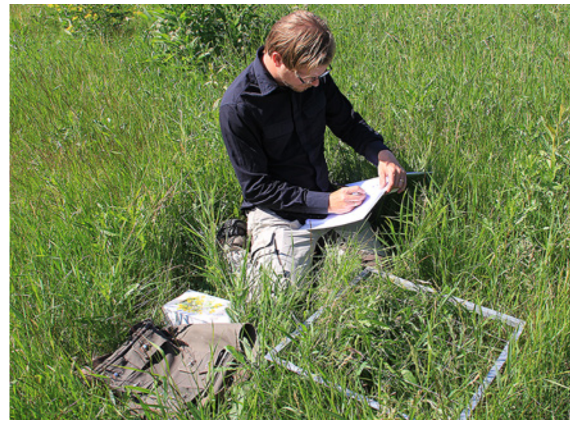


Figure 20. Example of high grass area in Uppsala, in June 2013. Photo credit: M. Ignatieva.

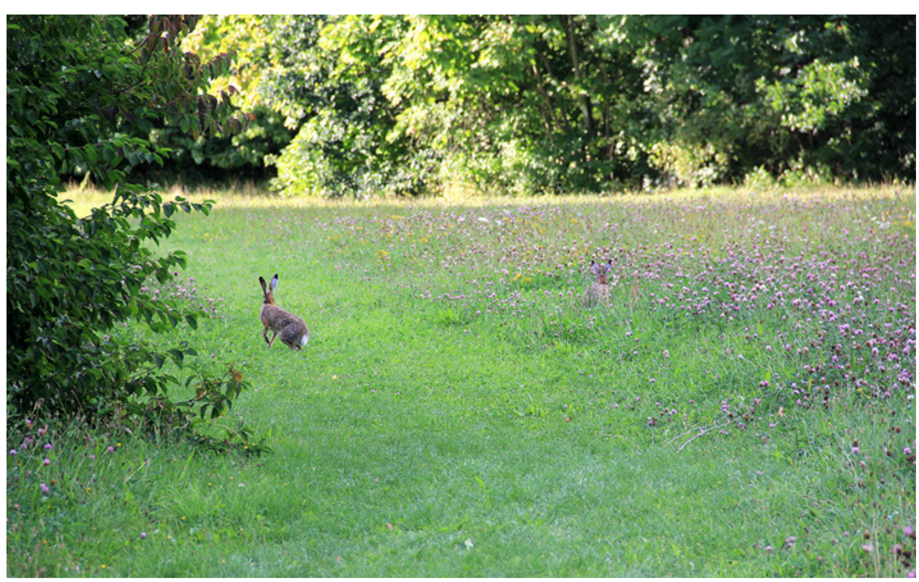
'TRUE' MEADOWS

Nowadays, true meadow-like communities with a high content of flowering perennial plants are rare in urban environments. Such meadows are usually cut once a year.

The composition and structure of meadows can differ and depend on the availability of nutrients in soil, water and maintenance regime. Nutrient-rich soils are the most common in green areas, since the main aim of urban green is to have many conventional grassy lawns. Thus, transforming high grass area to meadow may take five to ten years of consistent management (Jacobson, 1992).

Our LAWN project research showed that in meadow-like lawns, species such as *Trifolium pratense*, *Trifolium repens*, *Galium mollugo*, *Achillea millefolium*, *Plantago lanceolata* and *Medicago lupulina* play quite an important role (figure 21). Accord-

Figure 21. Example of meadow-like lawn in Holma, Malmö. August 2014. *Trifolium pratense* is the most visible flowering plant at this time of the season. Photo credit: M.Ignatieva.



ing to our research, meadow-like lawns also have forb species, which are usually rare guests in urban environments. Such plants are important since they create biodiversity. Perennial flowering plants also give a nature-like feeling in urban environments (figures 22 and 23)

A full-scale project on ecological management was conducted in Bulltoftaparken in Malmö in 2007–2010. There was an attempt to test different forms of ecological management in the park, for example use of a cylinder mower drawn by horses and grazing in some areas (aiming to reduce emissions of greenhouse gases). Conventional lawns were turned into high grass areas (cut only once a year). This project proved that the cost of maintenance for high grass was less than for conventional lawns (0.88 SEK/m^2 compared with 0.99 SEK/m^2) (Johansson *et al.*, 2011).

Summarising existing practices for lawns in the three Swedish cities studied, we can conclude that today the conventional lawn practice is quite dominant, but that there is growing awareness among managers of the importance of introducing a more environmentally friendly maintenance regime and the necessity of reducing the costs of lawn maintenance.

In the next chapters we discuss different typologies of alternative lawns and their suitability in

Figure 22. Meadow-like lawn at the forest margin in a neighbourhood in Uppsala. In June, flowering *Anthriscus sylvestris* creates a white aspect. Uppsala, 2013.
Photo credit: M.Ignatieva.

Swedish urban environments. However, these types of alternatives cannot, and do not, need to completely replace conventional lawns. By suggesting alternatives, we aim to increase awareness of the planning and design of green spaces and of introducing a new paradigm of creating diverse and sustainable urban environment and not just monotonous, regularly cut lawn surfaces.

Knowledge of lawn biodiversity results and of the influence of management regime can also help towns and cities make changes straight away, without any dramatic redesigning or establishing new types of lawns. For example, less frequent cutting (which also reduces energy use), which can be performed after flowering species such as *Trifolium repens*, *Medicago lupulina* and *Prunella vulgaris*, will give an opportunity for pollinators and seed-eating insects to thrive (Wissman *et al.*, 2015).

In the past decade, there has been a discussion on using grazing as an alternative maintenance for some urban grass areas in Sweden (Hellner and Vilkénas, 2014; Andersson and Bergbrant, 2015). However, there are still numerous aspects to consider before introducing such a solution in urban areas.

Figure 23. Meadow-like lawn in the outskirts of the Eriksbo neighbourhood in Gothenburg. June 2014. Photo credit: M.Ignatieva.

CHAPTER 4

Types of lawn alternatives. Existing practices from Europe, USA and Sweden

There is growing awareness, especially among Anglo-American and German researchers focusing on lawns (mostly private lawns), about existing "enormous peer pressure to have a good lawn" (Jenkins, 1994, p. 5). The 'good lawn' very often means a plot dominated by one particular grass (monoculture), without allowing the presence of other species, which is kept constantly mown in order to have a short and tidy sward – the perfect green lawn (Jenkins, 1994).

During the 20th century, there were some attempts at alternatives lawns and at enriching lawns with wild flowers. For example in the UK, William Robinson in his wild garden experimented with hardy native and exotic bulbs and some herbaceous perennials. Hermann Jäger from Germany proposed the use of natural flowers in woods and meadows, while Willy Lange derived his inspiration from nature and provided quite a range of options and an alternative vision for lawns including seed mixtures for flowery meadows which have not only native, but also some exotic perennials.

Since the end of the 20th century there have been explorations of alternatives to the traditional green carpet lawn aesthetics and a search for environmentally friendly and resource-saving solutions (Bormann *et al.*, 2001; Dunnett and Hitchmough, 2004; Smith, 2014). Interestingly, the medieval practice of 'flowery mead', where the turf was full of beautiful flowering plants and weeds, was an inspiration for the low-maintenance "Ecolawn" by Tom Cook at Oregon State University in the USA (Schultz, 1999) and the most recent "grass-free/tapestry" lawns of Lionel Smith in the UK (Smith and Fellowes, 2014). Sheffield planting design school (Nigel Dunnett and James Hitchmough) works with experimental naturalistic plantings using modern ecological knowledge (Woodstra and Hitchmough, 2000).

Existing European sustainable alternatives to conventional lawns

ENGLISH ANNUAL PICTORIAL MEADOWS

Pictorial meadows are made from native and exotic annual plants (*Papaver rhoeas*, *Centaurea cyanus*, *Agrostemma githago*, *Anthemis arvensis*, *Chrysanthemum segetum*, *Eschscholzia californica*, *Linum perenne*, *Linum usitatissimum*, *Coreopsis tinctoria*, *Calendula officinalis* and some other species). Such meadows are recommended for creating colourful flowering sites that are also highly attractive to wildlife. There are quite a few examples of pictorial meadows in Great Britain (Lickorish *et al.*, 1997; Steel, 2013; Hitchmough and Dunnett, 2004). These particular meadows require minimum maintenance (occasional weeding). In the UK, pictorial meadows flower from late spring until early autumn.

At the end of the season, all vegetation is cut and taken away. According to English researchers (www.pictorialmeadowsonline.co.uk), because of the peculiarities of the mild English climate, pictorial meadow annual seed mixes can be sown in March, April and May. In eight weeks, they can already produce bright colourful displays. English practitioners believe that such annual meadows can be created on all types of soil. They suggest a sowing rate of 2.5–3 g seeds per m^2. The advantage of annual perennial meadows is their high aesthetic value during the flowering season and attraction to wildlife (figures 24–26). The disadvantage of pictorial meadows is the necessity to re-sow the site every year and the use of herbicides in many cases.

Figure 24. Pictorial meadow with domination of poppies. June 2007. Sheffield, UK. Photo credit: M.Ignatieva.

Figure 25. Pictorial meadow at Olympic Park, London. Late May 2014. Photo credit: M.Ignatieva.

Figure 26. Pictorial meadow with *Eschscholzia californica* at Olympic Park, London. Late May 2014. Photo credit: M.Ignatieva.

Figure 27. Swales in Olympic Park, London, late May 2014. *Leucanthemum vulgare* is blooming. Photo credit: M.Ignatieva.

Native meadow, perennial mix

The native meadow perennial mix is suggested for creating more traditional meadows in the UK. Such mixtures are recommended in England for "creative conservation", i.e. making new places for wildlife in urban environments and at the urban fringe (Lickorish *et al.*, 1997, p. 1) (figure 27). Many industrial wastelands have been transformed into important wildlife sites. Native meadows are also used in some new neighbourhoods and are even recommended for private gardens. Selection of species for such meadows is very dependent on the type of soil present and the local conditions.

The most popular species are *Leucanthemum vulgare*, *Galium verum*, *Centaurea scabiosa*, *Centaurea nigra*, *Hypericum perforatum*, *Knautia arvensis*, *Achillea millifolium*, *Lychnis flos-cuculi*, *Filipendula vulgaris* and *Primula veris*. Such mixtures usually contain 20% wildflowers and 80% grass and are sown at a rate of 4–5 g/m^2. The maintenance for such meadows is quite easy, namely cutting once a year.

Figure 28. Naturalistic herbaceous plants with prairie plants in Oxford Botanic Gardens. July 2013. Photo credit: M.Ignatieva.

English naturalistic herbaceous plantings

Naturalistic herbaceous plantings are meadow-like communities which are made from perennials grasses and forbs, native as well some exotics. There is particular interest in these at Sheffield landscape architecture school, which believes that people are more attracted to brightly coloured herbaceous plants rather than modest native species (Hitchmough and Dunnett, 2004). Perennial plants from the North American prairie, such as *Rudbeckia* (which grows really well in the English climate) and other beautiful perennials, are claimed to perfectly 'utilise visual and functional characteristics' that are absent in English native flora and increase their attractiveness to humans (figure 28). Another benefit of using such plantings is to increase biodiversity and decrease resource use (low maintenance).

The main focus of the Sheffield school is on the development of different mixed native-exotic meadows. They use a foundation of native grasses and different herbaceous species with added planted exotic forbs from the Himalayas/East Asia, Caucasus or the USA) (Kingsbury 2004; Hitchmough 2004; 2009).

The most famous example of the Sheffield naturalistic planting school is the planting concept for London's Queen Elizabeth Olympic Park. Numerous pictorial meadows and naturalistic herbaceous plantings were realised on a tremendous scale of 25 hectares (figure 29).

Figure 29. Naturalistic herbaceous plantings in London's Queen Elizabeth Olympic Park, in July 2013.
Photo credit: M.Ignatieva.

Figure 30. Experimental grass-free lawns established by Lionel Smith in the grounds of the University of Reading. July 2013. Photo credit: M.Ignatieva.

Grass-free/tapestry lawns

Grass-free lawn is the most recent alternative lawn approach developed in the UK. Lionel Smith at the University of Reading proposes creating perennial grass-free communities that are mown only a few times a season. He believes that such tapestry lawns can be a good substitute for traditional lawns, because they are environmentally friendly (less energy input in maintenance and a biodiversity-rich plant community), while also looking very attractive (Smith and Fellowes, 2014) (figure 30). Grass-free lawns are inspired by the medieval idea of flower-rich turf and meadows, which were common in Great Britain.

Figure 31. Car park on the Campus of the University of Applied Sciences in Erfurt, Germany. July 2013. Photo credit: M.Ignatieva.

Figure 32. "Go spontaneous" design approach in the Park am Gleisdreieck (established in 2013). September 2016. Photo credit: M.Ignatieva.

Germany "Go spontaneous"

Based on long experience of research on urban ecology and spontaneous flora after WWII, Germany developed the Go spontaneous concept—design with spontaneous vegetation. Spontaneous in this case means ruderal vegetation that appears on the site unintentionally and without any design intent. This approach is based on knowledge of natural plant community processes (succession) and aims to "make spontaneous vegetation more attractive" (Kuhn, 2006).

This approach is used for redesigning wastelands, abandoned industrial zones and derelict construction sites. A very important core of this approach is increasing biodiversity by using both native and a combination of native and non-native species (figures 31, 32).

USA prairie gardens

The Midwest of the USA has quite good experience of working with reintroduction of native prairie plants in different urban habitats. In the 20th century, the pioneering design work of Ossian Cole Simonds and Jen Jensen introduced the prairie style into American landscape architecture. One of the best examples of the this style can be clearly seen in the design of the Millennium Park in Chicago, which was established in early 2000. One of the park's planting design themes was the acknowledgment of Chicago's original plant communities.

Plant material in this park is dominated by native prairie species, although reinforced by some non-native perennials (figure 33).

Figure 33. Millennium Park in Chicago. Use of prairie plants.
Photo: CNT/flickr (CC BY-SA 2.0).

"Cues to care" (USA, UK)

"Cues to care" is a concept that was introduced and widely promoted in the late 1990s by Joan Nassauer in the USA. Nassauer (1995) pointed out the contradiction between people's expectation of "the neat and orderly look" of urban environments and the "messy" look of nature. Thus, any of the new suggested ecological plantings can look untidy and neglected. This is why it is important to use certain design tools (for example framing the meadow-like plantings by cut grassy borders) and to demonstrate human presence and maintenance intent. It is believed that without the visibility of care, people will never accept any of the alternative "messy" high grass meadows (figure 34).

Figure 34. "Cues to care" in one of London's new neighbourhoods. Clearly shaped and neat edges of the meadow-like plantings provide cues to the provision of care.
Late May 2015. Photo credit: M.Ignatieva.

Sweden

ALTERNATIVE LAWNS AS A COMPLEMENT TO EXISTING LAWNS

The concept of the lawn was imported to Sweden from other European countries. However, in the 19th and 20th centuries there were attempts to implement some authentic Swedish practice into the development of lawns. One of the traditions included the use of parts of native landscapes preserved in parks and other green areas. This included the preservation of natural or semi-natural vegetation such as forests and woodlands, as well as meadows and pastureland (Florgård, 2009).

Native meadows were also used in work by Stockholm School of Parks developed in the 1930s and 1940s. This school was working actively in the fields of landscape architecture and urban planning and advocated a new kind of park vision, which contrasted to the contemporary regular and well-proportioned ideals where lawn was an essential element (Florgård, 1988). Native species and wildflower meadows were used as a complement to conventional lawns. One of the best examples of a park of this kind is Norr Mälarstrand in Stockholm (Sundström, 2004).

In late 1980s-early 1990's researchers from Swedish University of Agricultural Sciences carried out a series of experiments on methods of establishing species-rich grassland vegetation in urban settings (in Alnarp and Torslunda) (Hammer and Kustvall, 1991). They studied the effect of nursery plants and organic mulches on the growing of 38 forbs and 8 grasses (Mårtensson, 2017).

Sweden has regular horticulture and landscape architecture connections with European countries, particularly Great Britain. It is not surprising that English naturalistic plantings (particularly pictorial meadows) are also well received in Swedish towns and cities. However, nowadays in Sweden there is a need to search for alternatives to lawns, in response to the modern environmental crisis and the process of homogenisation of urban environments, as well as a search for local identity and climate change mitigation (Ignatieva *et al.*, 2015).

The Swedish way of searching for alternative lawn solutions is inspired by its rich garden and horticultural history. Sweden is moving towards prioritising models for inspiration from natural grassland ecosystems and traditional gardens, where meadows played an important role. Thus, it is a call to use mostly native plant material in alternative lawns.

PRATENSIS AB

In 2005, Inger and Mats Runeson started the unique company Pratensis AB to produce exclusively Swedish wildflower seeds. They were concerned that in a time of rapid urbanisation and a growing lawn industry, natural grasslands were becoming particularly vulnerable and could completely disappear. Inger and Mats see growing wildflowers as an effective way of preserving many of the meadows. Seeds are collected directly from native plant communities in different districts of Sweden. The gene pool of the seeds is periodically changed, to ensure the preservation of genetic variety. The uniqueness of Pratensis AB is that this firm is based around local plants that are extremely cost-effective and suitable for the northern climate of Sweden. Pratensis AB offers seeds and plug plants of meadow plants.

There are at least 12 seed mixtures, which can be used for different soil and light conditions. For example, seed mixtures are available for: open, sun-exposed and partly shaded conditions, for normal to dry soils, moist to wet soils, dry calcareous soils, northern Sweden, annuals (for pictorial meadows), normal moist soils but in shady conditions, dry meadows next to the sea and meadows in the mountains.

These seed mixtures consist of meadow grasses and forbs, which usually begin to bloom in the second year after sowing. To obtain a flowering effect in the first year, Pratensis AB recommends adding beautiful annual species, for example cornflowers and poppies. Each seed mixture contains 80% grasses (at least four species) and 20% herbaceous species (up to 25 species).

Specifications on plant establishment and the availability of plant mixtures can be obtained from the Pratensis website: www.pratensis.se/froblandningar.

Examples of perennial meadows established from Pratensis seed mixtures are provided in figures 35–37.

Figure 38 shows an example of establishment of a ‘standard’ meadow mixture over a nine-year period. The inspiration for this meadow is a dry meadow in Götaland and Svealand. In 2008, *Leucanthemum vulgare*, *Leontodon hispidus*, *Rhinanthus serotinus* and *Plantago lanceolata* were the dominant species. In August 2009, *Centaurea jacea* and *Hypericum perforatum* started to be visible. In July 2010 the first *Knautia arvensis* arrived, while *Centurea jacea*, *Leucanthemum vulgare*, *Rhinanthus* and *Leontodon* were still blooming and visible. In July 2011, *Campanula persicifolia* appeared and in July 2012 there was even more *Campanula* and *Knautia*, which together gave a very beautiful appearance. In 2014-2016 these species were still visible in the meadow.

Figure 35. Spetsamossen Park, Växjö. This meadow was established in spring 2014. Photo: July 2015. In this mixture, a greater amount of *Leucanthemum vulgare* was added at the request of the landscape architect. Photo credit: M.Ignatieva.

Figure 36. Växjöbostäder, Växjö. The meadow was established from seed mixture in 2013. Photo: July 2015. Photo credit: M.Ignatieva.

Figure 37. Berthåga kyrkogård meadow in 2015. These meadows were established in 1999-2000 (16 years old in this photo). Photo credit: M.Ignatieva.

Figure 38. 'Standard' meadow in private garden in Småland, which was sown in 2007. Pictures show the development of the lawn from 2007 to 2016. Photo credit: I.Runeson.

PRATENSIS AB – GRASS-FREE LAWN IN PRIVATE GARDEN (SMÅLAND)

Established in April 2014 and viewed on the 29 May 2015 (one year after sowing seeds), A grass-free seed mixture (*Achillea millefolium*, *Armeria maritima*, *Campanula rotundifolia*, *Dianthus deltoides*, *Filipendula vulgaris*, *Fragaria vesca*, *Leontodon hispidus*, *Pilosella aurantiaca*, *Pilosella officinarum)* and other plants (29 species) was sown in April 2014. One year later, in May 2015, a lot of *Bellis perennis* and some *Viola tricolor*, *Pimula veris* and *Armeria maritima* were blooming. Later, *Leucanthemum vulgare*, *Hypochoeris radicata* and *Lotus corniculatus* dominated (figures 39–40).

Figure 39. Grass-free lawn, May 2015 (one year after sowing). Photo credit: I.Runeson.

Figure 40. Mowing the grass-free lawn. 29 June 2015. Photo credit: I.Runeson.

SUNDBYBERG

Sundbyberg in Stockholm decided to establish three types of alternative meadows (figures 41-46). In April 2015, three seed mixtures produced by Pratensis AB were sown: *bumblebee* (22 species of forbs (70%) and four species of grass (30%)), *butterfly* (21 species of forbs (20%) and five species of grass species (80%)) and *grass-free meadow* (18 species of forbs).

Figure 41. Location of sites in Sundbyberg. Photo credit: M.Ignatieva.

Figure 42. Preparation and sowing of seeds on sites in Sundbyberg. April 2015. Photo credit: V.Kroon.

Figure 43. Sundbyberg. Three months after sowing. Annuals (*Papaver rhoeas* and *Centaurea cyanus*) dominated at all sites and attracted visitors. July 2015. Photo credit: M.Ignatieva.

Figure 44. Sundbyberg. One year after sowing. Bumblebee meadow. *Centaurea jacea*, *Leucanthemum vulgare*, *Echium vulgare* and *Anthemis tinctoria* were the dominant species. July 2016. Photo credit: M.Ignatieva.

THE BUMBLEBEE MEADOW MIX WAS SOWN AT A RATE OF 3 G/M^2 AND CONTAINED THE FOLLOWING SPECIES:

Forbs:

Agrostemma githago
Anthemis tinctoria
Campanula persicifolia
Centaurea cyanea
Centaurea jacea
Centaurea scabiosa
Echium vulgare
Galium verum
Geum rivale
Hypericum perforatum
Knautia arvensis
Leucanthemum vulgare
Linaria vulgaris
Lotus corniculatus
Malva moschata
Origanum vulgare
Papaver rhoeas
Primula veris
Silene dioica
Rhinanthus minor
Succisa pratensis
Verbascum nigrum

Grasses*:*

Anthoxanthum odoratum
Briza media
Festuca ovina
Festuca rubra

Figure 45. Grass-free lawn. *Leucanthemum vulgare*, *Centaurea jacea, C. scabiosa* and *Anthemis tinctoria* are the dominant species. July 2016.
Photo credit: M.Ignatieva.

THE GRASS–FREE LAWN MIX WAS SOWN AT A RATE OF 1 G/M² AND CONTAINED THE FOLLOWING SPECIES:

Forbs*:*

Agrostemma githago	*Filipendula vulgaris*	*Viscaria vulgaris*
Anthemis tinctoria	*Galium verum*	*Malva moschata*
Campanula persicifolia	*Hypericum perforatum*	*Papaver rhoeas*
Centaurea cyanea	*Knautia arvensis*	*Plantago lanceolata*
Centaurea jacea	*Leontodon hispidus*	*Plantago media*
Dianthus deltoides	*Leucanthemum vulgare*	*Silene dioica*

Figure 46. Butterfly meadow. *Centaurea, Achillea millifolium* and *Leucanthemum* were the most visible. July 2016.
Photo credit: M.Ignatieva.

THE BUTTERFLY MEADOW MIX WAS SOWN AT A RATE OF 3.5 G/M[2] AND CONTAINED THE FOLLOWING SPECIES:

Forbs:

Achillea millefolium	*Knautia arvensis*	*Plantago media*
Achillea ptarmica	*Leontodon hispidus*	*Prunella vulgaris*
Centaurea jacea	*Leucanthemum vulgare*	*Rumex acetosa*
Centaurea scabiosa	*Lotus corniculatus*	*Rumex acetosella*
Dianthus deltoides	*Lychnis flos-cuculi*	*Scabiosa columbaria*
Helianthemum nummularium	*Viscaria vulgaris*	*Solidago virgaurea*
Hieracium umbellatum	*Plantago lanceolata*	*Viola tricolor*

Grasses*:*

Anthoxanthum odoratum	*Festuca pratensis*	*Poa pratensis*
Festuca ovina	*Festuca rubra*	

Figure 47. Pictorial meadows in Sundbyberg in summer 2016. Photo credit: V.Kroon.

Sundbyberg's visitors and the park managers were particularly impressed by the first-year annual plants blooming. New pictorial meadows were established in Sundbyberg in spring 2016 using a classic mix (pictorialmeadows.co.uk/product/classic/) with 12 species of annuals including *Papaver rhoeas*, *Linaria maroccana*, *Coreopsis tinctoria* and *Rudbeckia amplexicaulis* (figure 47).

Veg Tech

Veg Tech is the leading company in Scandinavia specialising in growing native plants and plant communities and has been in operation since 1987. Veg Tech produces environmentally friendly green roofs (sedum, wildflowers and grasses), green facades and prefabricated (ready meadow mats) with native herbaceous species for landscapes, slopes and wetlands. The company also produces aquatic and beach species for natural stormwater management, conservation, habitat restoration and erosion control. Similarly to Pratensis AB, Veg Tech concentrates on producing Swedish plant materials at its own nurseries in southern Sweden. The company offers prefabricated mats, plug plants and seeds (figure 48).

One of the popular solutions for rapid establishment of meadow vegetation is prefabricated (ready) mat consisting of a mixture of Swedish herbaceous species and grasses. Such meadows are grown in a 3-4 cm layer of soil, reinforced at the base with a mesh of coconut fibre. This reinforcement makes the mat easy to establish.

Different combinations of plants allow the creation of meadows for different types of soil, moisture and sun exposure.

Specifications for plant establishment and availability of plant material from Veg Tech can be obtained from www.vegtech.se.

Figure 48. Veg Tech's prefabricated (ready meadow mats).
Photo credit: M.Ignatieva.

Figure 49. Veg Tech's prefabricated (ready meadow mats).
Photo credit: L.Pettersson.

CHAPTER 5

Our vision for lawn alternatives in Sweden

Our team vision for lawn alternatives for Sweden was inspired by Swedish natural meadows. Although Sweden still has a significant number of native ecosystems, the amount of grassland (natural and semi-natural) has dramatically declined. Our vision for alternative lawns is to create biodiverse, aesthetically pleasing and cost-effective plant communities based on the diverse native Swedish flora. Such biodiverse lawns can help to return real nature to the urban environment. We work closely with Pratensis AB, a pioneer in the conservation of natural Swedish grasslands that is promoting the use of biodiverse alternative solutions for lawns, and with Veg Tech. Our suggestions for lawn alternatives correspond with the character of meager Nordic nature, with its modest colour and texture.

TYPES OF LAWN ALTERNATIVES WHICH WE RECOMMEND FOR SWEDISH CONDITIONS (MUNICIPAL PARKS, MULTIFAMILY RESIDENTIAL AREAS AND PRIVATE VILLAS):

1. Grass-free/tapestry lawns (created by sowing and pre-grown plug planting).
2. Perennial meadows (created by sowing).
3. Pictorial (annual) meadows (created by sowing).
4. Prefabricated (ready) meadow mats.

Grass-free/tapestry lawns

The Swedish version of grass-free/tapestry lawns is based entirely on using appropriate native perennial species that can provide a similar level of dense plant cover to a conventional grass lawn. Such lawns require less cutting, since these plants are naturally not as high as grasses (figure 49). Grass-free lawns can be established by sowing seeds or by pre-grown plug planting. The fastest and most effective way of establishing grass-free lawns is by planting pre-grown plug plants, which can cover the ground quickly and reduce the amount of weeding. The disadvantage of this method is the high construction cost, since a dense carpet needs many plants. However, when a grass-free lawn is established it requires low maintenance compared with a conventional lawn.

If a grass-free lawn is established by sowing seeds, perennial species will flower in the second season. For the first season, it is possible to add annuals to give a flowering effect. A dense carpet effect can be achieved in the third or fourth season depending on local conditions and weather patterns. However, while the aim of such a lawn is to be grass-free, it is quite difficult to get an absolutely grass-free cover, since grasses will probably appear there sooner or later. The grass-free lawn is quite a novel type, and more monitoring and additional research on the vegetation dynamics is needed.

Grass-free lawn, when established, can be walked upon, but people are wary of walking or sitting on such tapestry lawns because they are afraid of damaging the beautiful flowers. However, several plant species which are recommended for use in Sweden are already present in old conventional lawns, for example *Bellis perennis*, *Prunella vulgaris*, *Lotus corniculatus* and *Potentilla anserina*. Tapestry lawns can produce many flowers, which is encouraging for the number of pollinators.

Figure 49. Tapestry lawn at the demonstration site on the SLU Ultuna campus in the third year after plug planting. August 2016. Photo credit: M.Ignatieva.

Perennial meadows

Perennial meadows are made from a mixture of native grasses and perennial herbaceous species (see case studies in Chapter 7). The choice of species composition (seed mixture) depends on existing soil conditions, hydrology, microclimate and, most importantly, the purpose and design intent. The most successful biodiverse meadows are established on nutrient-poor soils (Andren, 2008).

Pictorial (annual) meadows

Pratensis AB recommends using for pictorial meadows: *Agrostemma githago*, *Anthemis arvensis*, *Centaurea cyanus*, *Papaver rhoeas* and *Papaver dubium*.

One important tip for establishment of a successful pictorial meadow is that the potential area should be as free as possible from perennial weeds. Annual wildflowers are more tolerant of fertile soils than wildflower meadow types (established from mixtures of grasses and wildflowers), which are recommended to be established on low fertility soils (Lickorish *et al.*, 1997; Steel, 2013).

Pictorial meadows can also be established on existing soils. One example of such a solution is the pictorial meadows in Sundbyberg.

CHAPTER 6

How to establish biodiverse lawn alternatives in Sweden

Our recommendations are based on the experiences of establishing alternative lawns by Pratensis AB (please see the company's website www.pratensis.se) and alternative lawns at SLU Ultuna Campus, Uppsala, in 2014-2017 (www.slu.se/lawn).

Site preparation

For most types of alternative lawns, a sun-exposed site with poor, well-drained soil is recommended. Practical experience has shown that fertile soil promotes taller plants and grasses and smaller species will be less able to compete. High levels of phosphorus also have a negative impact on many meadow wildflower species. We recommended checking the potential area for the alternative lawn to ensure that it does not have a lot of root-spread weeds such as thistles (*Cirsium arvense*) and other pernicious weeds (*Elytrigia repens* and *Aegopodium podagraria*). One way to reduce the amount of weeds is to let the potential area lie fallow for a year before sowing.

The best results can be achieved when existing conventional lawn can be removed and, if necessary, new soil added (in some cases it is possible to use the existing soil). This method takes a high initial financial investment, but guarantees the success of alternative lawn establishment. Swedish practice has shown that the method of turning conventional grass into meadow-like vegetation by removal of small squares of turf and then sowing seeds does not work as successfully as removal of the existing turf.

Soil quality

Researchers and practitioners in Europe and Sweden all strongly believe that the best soil for establishing meadows is poor soil free of vegetation or roots. If the soil is fertile, several methods can be recommended:

1. **Remove the existing** rich soil (to about 15-20 cm) and bring in new, less fertile soil. If for some reasons only part of the surface can be removed, mix existing soil with the less fertile soil by digging it up and spreading it throughout.
2. **Spread a layer** of less fertile soil (about 30 cm) on top of the rich soil.
3. **Prepare the surface** for sowing by levelling it with a rake. Do not forget to remove rocks and roots, since they can make maintenance more complicated in the future.

Sowing and plugging

TIME OF SOWING

The best time to sow is in August or September. In the most southerly parts of Sweden, October can also be a good time. Seed mixtures can be sown also in early spring (April or May). However, sowing in late spring or early summer may require periodic watering, especially in dry late spring or early summer.

Recommended amount of seeds is only about 3-3.5 g/m². Therefore seeds should be mixed with a suitable filler material such as sawdust, wheat germ or sand, to ensure an even distribution of seeds on the surface. This also helps to see where the seeds have been sown.

Make sure that seeds do not sink down too deep. Use a rake or raked roller very lightly to help the seeds settle into the soil. Keep the area moist for a couple of weeks.

If the intent is to sow large areas, hydro-seeding can be quite effective (figure 51). There is no fertiliser needed in hydro-seeding (as is normally needed when sowing just grass species for slopes).

In the first year only the annuals will flower, but in coming years more and more species will flower and the annuals will disappear.

PLANTING ADVICE

It is possible to plant plug plants as a complement to the meadow seeds in order get a flowering meadow in the first summer.

Our experiments have shown that a combination of sowing and plug plants gives the best results (figure 50). The meadow will already have a decorative effect in the first summer. Pratensis AB suggests planting 4-5 seedlings/m² in addition to the standard sowing of 3-3.5 g/m². Plants should be planted in small groups (at least three specimens in one group) and randomly spread throughout the meadow. Plug plants can be planted before or after sowing.

Planting of meadow plants can be done during the entire growing season, normally from April to the end of October. In some regions there is an early summer drought and then autumn or late summer is a preferable time.

Figure 50. Grass-free lawn in Ultuna Campus in the third month after plug planting. July 2014. Photo credit: M.Ignatieva.

Figure 51. Hydro-seeding of meadow mixtures in Växjö, April 2017. Photo credit: I.Runeson.

Maintenance

During the first year, many annual weeds appear in the soil. These weeds can be cut down to 8-10 cm before their seeds have matured (if these species are undesirable in the meadow).

Weeding by hand is recommended for reducing the number of the nastiest weeds. Perennial meadow flowering species do not bloom during the first year, which is why newly sown meadow often seems rather bare, patchy and unattractive. Diverse annual weeds are the dominant plants in the first year, because of their survival strategy and availability in the soil seed bank. However, several meadow wildflowers sprout in the first year. During the second year, the weeds will be fewer and the first wildflowers start to bloom.

From the second year, lawn alternative maintenance consists of yearly cutting in the end of summer, when most of the plants have finished flowering. Mowing can be done from the end of July-August and can be performed even during September. The clippings must be removed, either directly or after some days.

For small areas, a scythe or other cutting tool can give good results. For large areas, mowing machines are commonly used.

Cutting height for meadow and grass-free/ tapestry lawn is approximately 5-10 cm. The height of cut is also dependent on the type of cutting tool used (figures 52-54). Another recommended cutting tool is a brushcutter/trimmer with a very sharp grass-cutting blade. Small areas of grass-free lawn can be cut with garden shears.

Figure 52. Mowing meadow by scythe in a small meadow area. Photo credit: I.Runeson.

Figure 53. Mowing with special type of mower (slåtterbalk). Photo credit: I.Runeson.

Figure 54. Mowing by grass-trimmer with a sharp grass-cutting blade. Photo credit: I.Runeson.

Growing time

The oldest sown meadows established by Pratensis AB are now about 25 years. If the meadows are maintained in the right way and sown on a poor soil, they can persist and perform really well for a very long time. Many of Swedish natural meadows are several hundred years old. Meadow appearance may change each year because of the dynamic character of vegetation and the influence of weather factors.

Another very good technique, which is used in many countries, is to combine meadows with mown areas of conventional lawns (see Chapter 4 "Cues to care" approach and figure 55).

Economics

The cost for the seed to sow a meadow is about 3-4 SEK/m^2. Adding the cost for plants, the total cost is about 80-100 SEK/m^2 (personal communication with Inger Runeson, Pratensis AB, April 4, 2017).

Figure 55. "Cues to care" in a neighbourhood in Uppsala. June 2015. Photo credit: M.Ignatieva.

CHAPTER 7

Case studies

First experimental trial of alternative lawns was established in the Knowledge Park (Ultuna Campus, SLU, Uppsala) in 2014. In spring 2016, additional three experimental sites with alternative lawns were established within the SLU Climate Fund Project "Towards sustainable lawns: searching for alternative cost-effective and climate-friendly lawns in Ultuna Campus" (figure 57). This project was a continuation of our Formas-funded project "Lawns as ecological and cultural phenomenon: searching for sustainable lawns in Sweden" (see Chapter 1).

Site 1: First experimental lawn alternatives trial with small plots (1.5 m x 1.5 m each)

The first plots (two types of grass-free lawn (sown and established with seedlings), butterfly and bumblebee lawns, chalky and dry meadows, pictorial meadow, gravel and clover lawn) were established in spring 2014 (figure 56). A combination of sowing seeds and planting seedlings was used. Pratensis AB Sweden kindly provided all plant material. The bumblebee is a mixture of species that are attractive to bumblebees, for example *Echium vulgare* and *Galium verum*. The gravel lawn was established on the toughest soil, with a high gravel content, using plants such as *Antennaria dioica*, *Hypochaeris radicata* and *Trifolium arvense*. For more information see the LAWN project webpage: www.slu.se/lawn.

Figure 56. Demonstration trials on lawn alternatives in Ultuna, in July 2015 (one year old).
Photo credit: M.Ignatieva.

SITES:

1. Experimental lawn alternatives trial
2. Grass-free/tapestry lawn
3. Swedish meadow
4. Meadow turf with picnic turf bench

Figure 57. Location of the Knowledge Park (Kunskapsparken) at SLU Ultuna Campus with experimental sites of lawn alternatives. Credit: J.Lööf Green.

Site 2: Example of grass-free/tapestry lawn at SLU Ultuna Campus, established in April 2016

Our Swedish grass-free/tapestry lawn (410 m^2) is inspired by the medieval idea of the Garden of Eden, with informal 'flowery mead' or meadows planted with a great variety of forbs and flowers. The task is improving biodiversity and returning to nature. This lawn consists of 30 herbaceous plants native to Sweden, which can provide the effect of a low-growing flowering carpet that can be used for recreation and which will be cut only 2-3 times during the summer season (figure 58). Pratensis AB and Veg Tech provided plant material for this site.

Before establishing experimental grass-free/tapestry lawn, this area was covered by conventional lawn, which was cut 16 times per season.

MAINTENANCE PLAN IN 2017

Operation	Month	Estimated time
Cutting dead branches and clearing leaves from autumn	March	3 hours
Occasional weeding	June, July, August	4 hours
Cutting (10 cm) and removing clippings	June, August	3 hours
Litter picking	May-August	1 hour

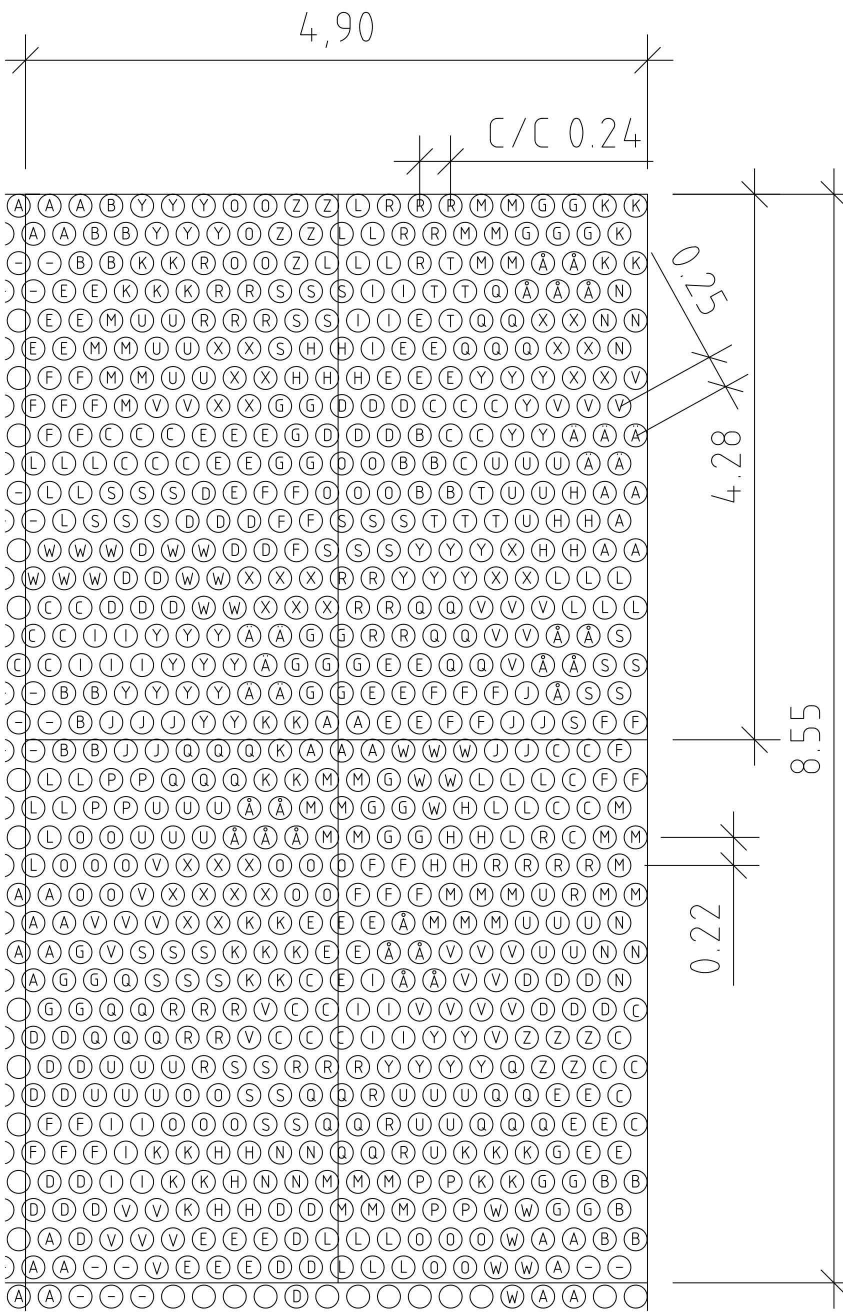
THE COST ESTIMATE FOR MAINTENANCE OF GRASS-FREE/TAPESTRY LAWN IS AS FOLLOWS

- 1 cut and trim: 500 SEK per time (plus cost for machinery operation).
- Trimming and cutting edges: 200 SEK per time (every second time).
- Watering, fertilising and vertical cutting: 2000 SEK.
- Total: around 12000 SEK.

EXPECTATION FOR 2017-2019

We expect that in 2018-2019, the grass-free lawn will look like our first grass-free lawn site in the experimental plot in the Knowledge Garden (1.5 m x 1.5 m) (figure 65).

Grass-free/tapestry lawn has shown a very good development in spring-summer 2017 (next year after establishment)—figures 66-68.



FÖRKLARINGAR

A, Achillea millefolium, rölleka
B, Antennaria dioica, kattfot
C, Armeria maritima, trift
D, Campanula rotundifolia, liten blåklocka
E, Dianthus deltoides, backnejlika
F, Filipendula vulgaris, brudbröd
G, Fragaria vesca, Smultron
H, Galium verum, gulmåra
I, Helianhemum nummularium, solvända
J, Leontodon hispidus, sommarfibbla
K, Leucanthemum vulgare, prästkrage, sen
L, Pilosella aurantiaca, rödfibbla
M, Pilosella officinarium, gråfibbla
N, Polygala vulgaris, jungfrulin
O, Potentilla anserina, gåsört
P, Potentilla erecta, blodrot
Q, Potentilla tabernaemontanii, småfingerört
R, Primula veris, gullviva
S, Saxifraga granulata, mandelblomma
T, Sedum telephium, kärleksört
U, Silene uniflora, strandglim
V, Thymus serpyllum, backtimjan
W, Veronica officinalis, ärenpris
X, Veronica spicata, axveronika
Y, Viola canina, ängsviol
Z, Viola odorata, luktviol
Å, Viola tricolor, styvmorsviol
Ä, Viscaria alpina, fjällnejlika
-, Växt från intillliggande yta

Planteringen ska se slumpartad
ut men ska upplevas som ett lapptäcke.
Mer detaljerad förklaring finns i bilaga 1.

Figure 58. Planting plan for grass-free/tapestry lawn, in April 2016. Credit: J.Lööf Green.

LIST OF PLANTS FOR SITE 2: GRASS-FREE/TAPESTRY LAWN

Achillea millefolium
Antennaria dioica
Armeria maritima
Bellis perennis
Campanula rotundifolia
Dianthus deltoides
Filipendula vulgaris
Fragaria vesca
Galium verum
Helianthemum nummularia
Leontodon hispidus
Leucanthemum vulgare
Lychnis alpina
Pilosella aurantiaca
Pilosella officinarum
Polygala vulgaris
Potentilla erecta
Potentilla anserina
Potentilla tabernaemontani
Primula veris
Prunella vulgaris
Sedum telephium
Saxifraga granulata
Silene uniflora
Thymus serpyllum
Veronica spicata
Veronica officinalis
Viola canina
Viola odorata
Viola tricolor

ESTABLISHING AND PLANTING PROCESS FOR GRASS-FREE/TAPESTRY LAWN (FIGURES 59-64)

Existing turf and 15 cm of soil was removed from the site. Then new soil mix was applied. This soil mix was supplied by the soil firm Hasselfors, it consisted of 50% crushed granite (0-4 mm) and 50% natural sand (0-8 mm) that was mixed with a further 50 vol.-% dark peat. Hasselfors provided the soil for the whole experimental site. No limestone or fertilisers were added.

Figure 59. Removal of conventional lawn. Removed turf pieces were reused in other campus areas. Photo credit: M.Ignatieva.

Figure 60. Process of removing conventional lawns. April 2017. Photo credit: M.Ignatieva.

Figure 61. Spreading specially prepared poor soil from the soil firm Hasselfors. Photo credit: M.Ignatieva.

Figure 62. Plug planting process.
Photo credit: M.Ignatieva.

Figure 63. Grass-free/tapestry lawn in early May.
Photo credit: M.Ignatieva.

Figure 64. Grass-free/tapestry lawn in July 2016.
Photo credit: M.Ignatieva.

Figure 65. Grass-free/ tapestry lawn in the experimental trial (site 1) in the third year after establishment (June 2016). Photo credit: M.Ignatieva.

Figure 66. Grass-free/tapestry lawn (site 2) in the end of May 2017, one year old. *Primula veris*, *Armeria maritima*, *Viola tricolor* and *Bellis perennis* are blooming. Photo credit: M.Ignatieva.

Figure 67. Grass-free/tapestry lawn (site 2) in early June 2017, one year old. *Armeria maritima* is in maximum bloom. Photo credit: M.Ignatieva.

Figure 68. Grass-free/tapestry lawn (site 2) on the 22 June 2017. *Leucanthemum vulgare* and *Pilosella aurantiaca* are the most visible species. Photo credit: M.Ignatieva.

SPECIES AND FLOWERING CALENDAR FOR GRASS-FREE/TAPESTRY LAWN (MAY–SEPTEMBER)

In Swedish conditions, these lawns can provide a flowering effect from May to September (figure 69).

Figure 69. Flowering calendar for grass-free/tapestry lawn. Photo credit: M.Ignatieva.

MAY	JUNE	JULY	AUGUST	SEPTEMBER
Armeria maritima	*Silene uniflora*	*Dianthus deltoides*	*Veronica officinalis*	*Achillea millefolium*
Primula veris	*Fragaria vesca*	*Thymus serpyllum*	*Veronica spicata*	*Galium verum*
Viola tricolor	*Armeria maritima*	*Galium verum*	*Potentilla erecta*	*Leontodon hispidus*
Viola odorata	*Viola canina*	*Potentilla anserina*	*Pilosella aurantiaca*	*Sedum telephium*
Viola canina	*Prunella vulgaris*	*Pilosella aurantiaca*	*Achillea millefolium*	*Thymus serpyllum*
Bellis perennis	*Pilosella officinarum*	*Leontodon hispidus*	*Campanula rotundifolia*	*Campanula rotundifolia*
Fragaria vesca	*Bellis perennis*	*Campanula rotundifolia*		
Saxifraga granulata				

Site 3: Swedish Meadow

Our Swedish meadow site (390 m^2) is inspired by the traditional Swedish *lövängar* (grazed meadows within fruit trees). The original site in the Knowledge Park had cherry trees planted on a conventional lawn that was mown numerous times per season. The aim of site 3 is to demonstrate the beauty of native Swedish meadow plants and their potential for biodiversity and for environmental education at SLU. This meadow seed mixture used consisted of native 30 species (17.5% forbs and 82,5% grasses) and was supplied by Pratensis AB.

LIST OF PLANTS FOR SITE 3: SWEDISH MEADOW

Forbs:		
Achillea millefolium	*Filipendula vulgaris*	*Origanum vulgare*
Anthemis tinctoria	*Galium verum*	*Plantago media*
Campanula persicifolia	*Hypericum perforatum*	*Potentilla tabernaemontani*
Campanula rotundifoilia	*Hypochoeris maculata*	*Primula veris*
Centaurea jacea	*Leontodon hispidus*	*Rhinanthus minor*
Centaurea scabiosa	*Leucanthemum vulgare*	*Saxifraga granulata*
Cichorium intybus	*Lotus corniculatus*	*Scabiosa columbaria*
Echium vulgare	*Malva moschata*	*Silene nutans*
Grasses:		
Helictotrichon pratensis	*Festuca ovina*	*Phleum phleoides*
Briza media	*Festuca rubra*	*Phleum pratense ssp. bertoloni*

MAINTENANCE PLAN IN 2016

Since this meadow mixture is composed mainly of perennial species, most of it will not flower in the first year. Some annuals were included to give some flowers in the first year (figure 72).

The meadow should be cut once a year, in late summer (mid-end of August), to 6-8 cm high and the clippings must be removed. For perennial meadows, fertilisers should never be applied.

Operation	Month
Watering after planting, 2 times per week for 1 hour for first 3 weeks after sowing, once or twice during the rest of the season	End of May-early June if there is a very dry spring and early summer
Occasional weeding, one hour of labour per time	June (1), July (1), August (1) Total 5 hours

MAINTENANCE PLAN IN 2017

The maintenance plan for 2017 consists of cutting and removing clippings in the end of August.

ESTABLISHMENT OF SITE 3: THE SWEDISH MEADOW (FIGURES 70–71)

Existing turf lawn was removed from the site. The soil mixture for site 3 was the same as for site 2 and was supplied by Hasselfors (50% of crushed granite (0–4 mm) and 50% natural sand (0–8 mm), mixed with a further 50 vol-% dark peat).

Figure 70. Site preparation. April 2016. Photo credit: M.Ignatieva.

Figure 71. Sowing. May 2016. Photo credit: M.Ignatieva.

Figure 72. The Swedish meadow with flowering annuals in July 2016. Photo credit: M.Ignatieva.

EXPECTATION FOR 2017 FOR SITE 3

As we expected, the Swedish meadow has shown a very impressive blooming of perennials in the summer of 2017 (figure 73).

Figure 73. The Swedish meadow in June 2017, the second year after sowing. *Lotus corniculatus*, *Echium vulgare* and *Leucanthemum vulgare* are in full bloom. Photo credit: M.Ignatieva.

Site 4: Precultivated meadow-mat with picnic bench

The inspiration for this site of 68m² came from medieval gardens, which had 'flowery meads' and grass turf benches. Prefabricated meadow-mats, supplied by Veg Tech, consisted of 16 species of low-growing perennials and grass species (60% forbs and 40% grasses). This particular type of meadow-mat is designed for use in harsh urban conditions and can survive drought and salt exposure.

The constructors of the bench used larch wood (jointed project of Simon Lindberg and John Lööf Green). Crushed stones, which were used as the foundation of the prefabricated meadow, were also used in the bench 'seat'. The meadow–mats were applied on top of the crushed stones.

LIST OF PLANTS FOR SITE 4

Forbs:

Achillea millefolium	*Linaria vulgaris*	*Silene uniflora*
Armeria maritima	*Lotus corniculatus*	*Veronica officinalis*
Dianthus deltoides	*Rumex acetosella*	*Veronica spicata*
Hieracium pilosella	*Plantago maritima*	*Viola tricolor*
Galium verum	*Potentilla argentea*	

Grasses:

Festuca ovina
Agrostis capillaris

MAINTENANCE PLAN IN 2016

Operation	Month
Watering after planting, 2 times per week for 3 hours for first 3 weeks after planting, once a week for next 3 weeks	End of May-early June if very dry spring and early summer
Cutting and removing clipping	September

MAINTENANCE PLAN IN 2017

We recommend cutting and removal of clippings at the end of the season (September 2017).

ESTABLISHMENT OF SITE 4 (FIGURES 74-78)

- Removal of existing turf
- Application of crushed stone (0-16 mm)
- Application of mat turf from Veg Tech
- Picnic bench: student's project by Simon Lidberg and John Lööf Green.

Figure 74. Establishing the site. April 2016.
Photos credit: M.Ignatieva.

Figure 75. Installation of the picnic bench with precultivated meadow-mat, in July 2016.
Photo credit: M.Ignatieva.

Figure 76. Site 4 in July 2016. the most visible plants are *Dianthus deltoides* and *Lotus corniculatus*.
Photo credit: M.Ignatieva.

Figure 77. The picnic bench in July 2016.
Photo credit: M.Ignatieva.

Figure 78. The same bench in
August 2016.
Photo credit: M.Ignatieva.

CHAPTER 8

Design suggestions for Gothenburg and Malmö

SLU student project for actual neighbourhoods in Gothenburg (master's thesis of S.Andersson and U.Bergbrant, 2015) and design proposal for Malmö, made by J.Lööf Green in 2016, suggested the following design solutions. The proposals deliberately emphasised the possibility of using different types of alternative lawns even in small neighbourhood courtyards. A thorough inventory (function, microclimate, vegetation, soil and site experiential values) and site analysis were the foundation for these designs.

Gothenburg

The redesign proposal (Andersson and Bergbrant, 2015) for alternative lawns in Gothenburg was based on two main documents:

1. *Gothenburg Comprehensive plan* (Översiktsplan för Göteborg, 2014), which highlighted opportunities to create an attractive urban environment characterised by "complexity with mix of features, a visual density and opportunities for interaction between people" (p.35).
2. *Green Strategy* (Grönstrategi, 2014), the vision for the next 20 years, where Gothenburg is seen as a dense green city with healthy urban living environments, rich flora and fauna and a full supply of ecosystem services.

The proposed redesign site is located in the southwest part of Lundby, one of the fastest-growing districts in Gothenburg (figure 79). It is a residential area, with multifamily housing from the 1950s (People's Homes). Prior construction, it was old pasture. There are two park areas and large residential courtyards, covered mainly by conventional lawns, some plantings and benches (and play equipment). There is also a rocky hill in the site. Analysis concluded that "the park areas had vast lawns which were too large in proportion to how much they are used. More functions could be added to the residential courtyards and the large residual area, especially more ecological functions" (Andersson & Bergbrant, 2015, p. 72).

Figure 79. Example of vegetation and habitats inventory. Analysis showed that large parts of the neighbourhood are relatively homogeneous with vast areas of conventional lawns and a very few tree species.

Figure 80. The overall redesign proposal for the site shown in figure 79.

The aim of the suggested design (figure 80) was to transform a homogenous residential area dominated by conventional lawn into an area with rich experience for all senses and high ecological values (improving biodiversity). The proposal contains a greater diversity of habitats such as grass-free lawn, pictorial meadow and different types of meadow. Other types of vegetation, such as trees, shrubs and allotments, have been added in order to complement grass surfaces with spatial qualities, different habitats and an overall increase in heterogeneity of vegetation. Some areas of conventional lawn and edges of areas are transformed into meadow or high grass. Conventional lawns still have their place in the neighbourhood. The principle of 'cues to care' is applied in several cases to show that these areas are taken care of and not neglected.

One of the important principles of proposed strategy is primarily use of native plants, which are promoted local biotopes. This principle is combined with use of recycled materials for benches and tables.

Another proposal was for a "Labyrinth of common meadow" (figure 81). From a playground area at the west side, a half-circle of conventional lawn stretches into meadow and extends the play area. This element gives a clear identity to the 'North Park' area and distinguishes it from the 'South Park' area. The cut paths and edges towards the walkways are managed as a conventional lawn, to ensure access for people and communicate that the area is taken care of.

The proposed pictorial meadow (figure 82) gives a strong identity to this part of the park. The continuous flowering provides an interesting view from the windows of the kindergarten building and is also beneficial for pollinators. The conventional lawn is preserved next to the walkway and the kindergarten building, as well as

Figure 81. "Labyrinth of common meadow".

between the two areas, so that people can come close and see the flowers and wildlife. An explanation board is provided between the two areas.

A proposal on different "layers of vegetation" (figure 83) was made for courtyards, aiming at improving ecological and experiential values.

Figure 82. Pictorial meadow.

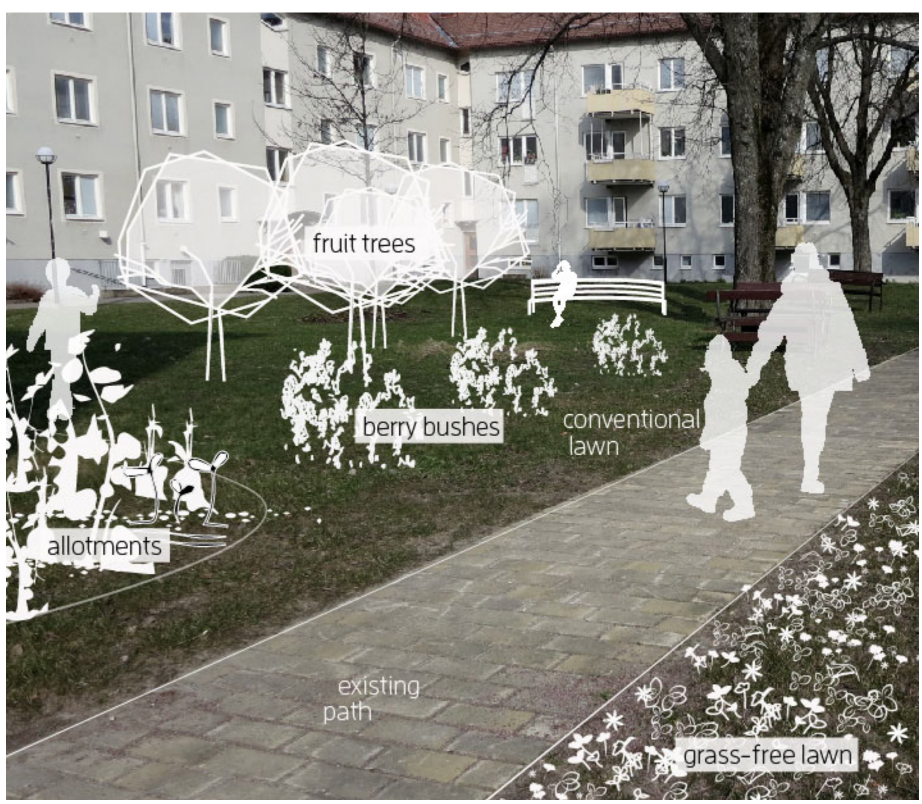


Figure 83. "Layers of vegetation".

The proposal for a "forest edge" (figure 84) is inspired by the concept of natural adjacent forest and aims to increase the experience of nature close to houses. Conventional lawn next to high grass provides a place for activity.

The "meadow courtyard" proposal (figure 85) aims to turn most of the courtyard into common meadow, with paths of conventional lawn and pavement. The proposed design creates a variety of experiential values and contributes to increasing biodiversity.

Other design proposals for Lundby can be seen in figures 86-90.

Figure 84. Proposal for a"forest edge".

Figure 85. Existing courtyard and what the "meadow courtyard" proposal will look like in three years.

Figure 86. Proposal for the "grove meadow". The stepping stones can attract people to enter this shaded meadow and to see the vegetation.

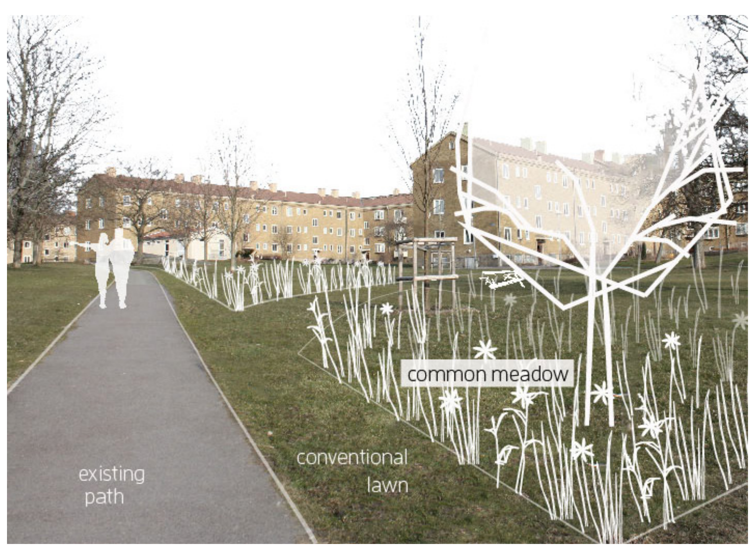


Figure 87. Proposal for the "triangular meadow" in the South Park.

Figure 88. Inventory of a site suitable for turning into an alternative "pictorial meadow and high grass walkway".

Figure 89. Proposal for the first year: rooting pigs can help to prepare the soil for the pictorial meadow.

Figure 90. Proposal for the "pictorial meadow and high grass walkway" in 10 years.

The overall design give the place a purpose of being a valued green space close to residential areas where people can meet up and spend time. One of the essential conditions for possible implementation of the suggested redesign proposal in Lundby is involving citizens, municipal and local managers and landscape architects in the design and implementation process.

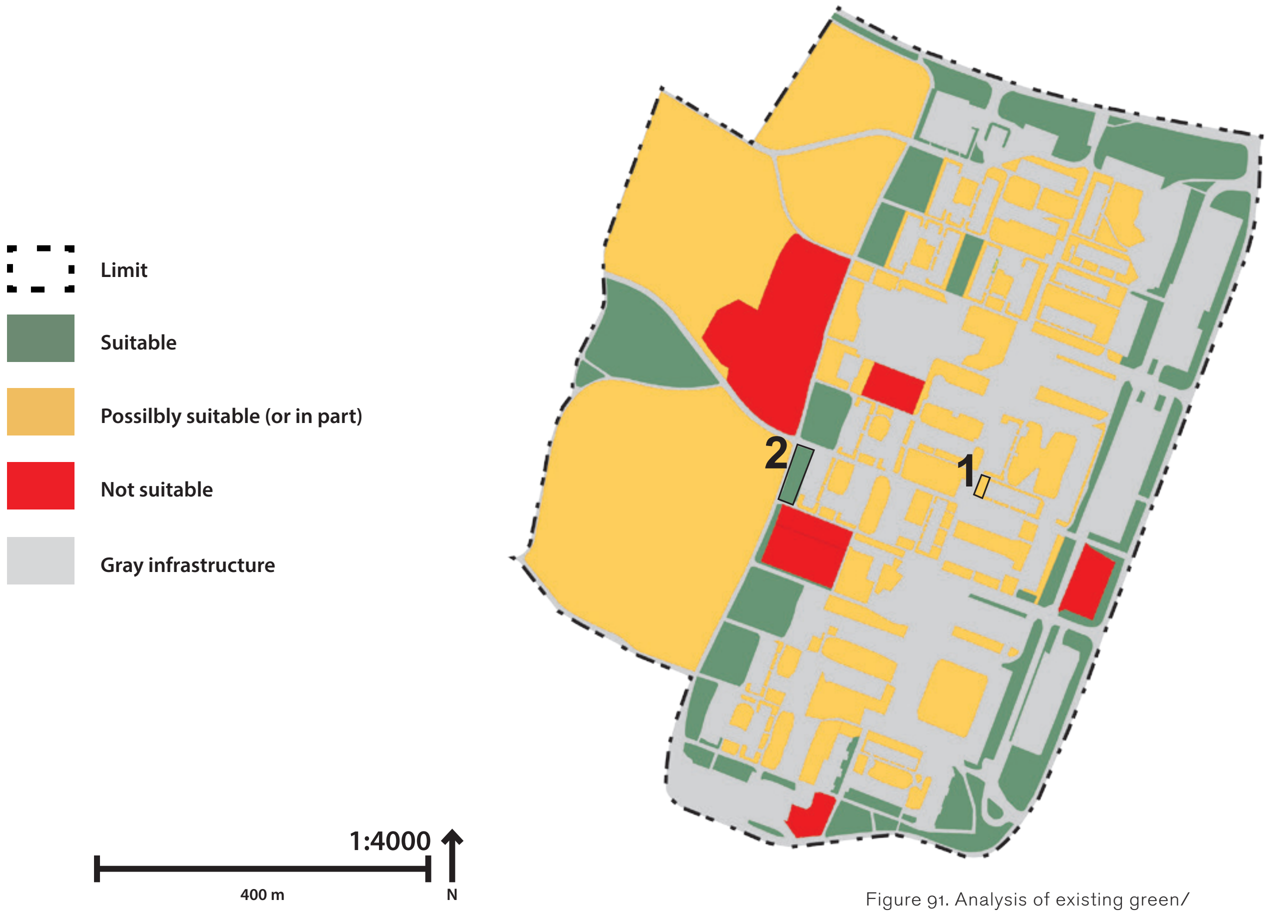


Figure 91. Analysis of existing green/grey infrastructure and suitable areas for establishing alternative lawns. Site 1 and 2 see figures 92 and 93. (design: J.Lööf Green, 2016).

Malmö: Holma Million Programme area

Inventory and analysis were performed in summer 2015. In housing areas from the Million Programme era, lawns are the dominant landscape element. Holma in Malmö, south Sweden, is no exception. During the summer of 2015 a brief survey was made in the field in order to evaluate where the establishment of lawn alternatives was appropriate. These suggestions took into consideration the sociological studies of the LAWN project, which were carried out in 2015.

The survey started with an inventory of the location of green areas, where lawns are the dominant element of Holma. Lawns that according to social surveys were quite intensively used (for sports, picnics and play) were taken into consideration and mapped. These areas continue to be used as conventional lawns. Lawns next to buildings, and building entrances in particular, were considered suitable for some alternative solutions, but with some restrictions (the height of the plants, the width of a mown border). Some of the areas in the Holma Hills (a public park with man-made grassy hills) can be also considered for promoting more plant diversity, as long as the recreational use of the area is respected. Lastly, the rest of the green areas within the residential area, which are not used, or areas adjacent to building entrances were suggested as suitable for some alternative lawns. Below are two locations with suitable areas which were studied in more detail with concrete suggestions on how to design alternatives in Holma. Both an inventory (green-grey relationship) and an analysis of suitable areas for establishing alternative lawns are strongly recommended prior to any planning or landscape design suggestion (figure 91). Suggestions for alternative lawns in Holma are shown in figures 92–93.

Figure 92. Proposal for the alternative design for patchy, dry and damaged conventional lawn located along the main entrance walkway in the Holma neighbourhood (site 1 on the map, fig.91). Suggested meadow with 'cues to care' will reinforce the aesthetic and biodiversity quality of the site and stop unwanted pedestrian traffic-short cuts (design: J.Lööf Green, 2016).

Figure 93. Proposal for an alternative design within one of Holma's pedestrian walkways next to houses (site 2 on the map, fig.91). This narrow strip of lawn is not used for any recreational activity and can be turned into an attractive colourful Swedish meadow with several mown pathways (design: J.Lööf Green, 2016).

CONCLUSIONS

In the most recent trends in redesign of conventional lawns in the world and locally in Sweden, quite a clear tendency can be observed. Alternative solutions are moving away from the dense grass-dominated turf model (the essence of the lawn as artificially man-made sward with domination of a few grass species) towards more natural grasslands where grasses and other forbs can grow happily together and be an important resource for humans and wildlife (supply important ecosystem services). Meadow-like lawns alternatives and annual pictorial meadows are quite straight-forward solutions and are already being successfully used in Sweden. For establishing meadows in urban neighbourhoods and parks, we believe that the method of removing existing conventional lawn and 10-15 cm of soil and adding new soil (poorer soil than is usually used for conventional lawns) and sowing the meadow seed mixtures is the most effective. Even though this involves some initial financial investment, existing practice shows that this investment pays off later because of the management benefits. Meadow-like lawns need mowing only once a year.

As for new innovative Swedish versions of grass-free lawns, they need to be studied further in terms of, for example, dynamics and flowering effect, opportunities to create the turf-like surface which would be suitable for recreation.

Nevertheless, tapestry lawns definitely can be used straight away for creating demonstrative displays for biodiversity, for example in botanic gardens, municipal parks and university campuses. The most effective way of establishing grass-free lawns is plug planting, which gives a strong flowering effect in the first year. A more resource-wise and cheaper way is sowing. In this case, the first year still needs to be considered and annual plants are recommended for achieving a blossom effect.

The next direction in working with grass-free lawns can be studying different plant mixtures and finding effective combinations of low-growing and mat-like herbaceous plants, which can create effective and aesthetically pleasing surfaces for recreation in urban areas.

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APPENDIX

LIST OF ATTACHED PUBLISHED SCIENTIFIC ARTICLES BASED ON THE LAWN PROJECT RESULTS

PEER-REVIEWED ARTICLES

1. Ignatieva, M., Ahrné, K., Wissman, J., Eriksson, T., Tidåker, P., Hedblom, M., Kätterer, T., Marstorp, H., Berg, P., Ericsson, T. & Bengtsson, J. (2015) Lawn as a cultural and ecological phenomenon: A conceptual framework for transdiscipilinary research. *Urban Forestry & Urban Greening,* 14: 383-387.
2. Ignatieva, M., Eriksson, F., Eriksson, T., Berg P. & Hedblom, M. (2017) The lawn as a social and cultural phenomenon in Sweden. *Urban Forestry & Urban Greening*, 21: 213-223.
3. Hedblom, M., Lindberg, F., Vogel, E., Wissman, J. & Ahrné, K. (2017) Estimating urban lawn cover in space and time: Case studies in three Swedish cities. *Urban Ecosystems*, pp. 1-11.
4. Poeplau, C., Marstorp, H., Thored, K. & Kätterer, T. (2016) Effect of grassland cutting frequency on soil carbon storage - a case study on public lawns in three Swedish cities. *Soil*, 2: 175-184.
5. Tidåker P., Wesström, T. & Kätterer, T. (2017). Energy use and greenhouse gas emissions from turf management of two Swedish golf courses. *Urban Forestry and Urban Greening*, 21: 80-87.

PEER-REVIEWED ARTICLE IN THE CONFERENCE PROCEEDINGS

6. Eriksson, F., Eriksson, T. & Ignatieva, M. (2015) Golf courses as part of urban green infrastructure: social aspects of golf courses and extensively managed turfgrass areas from Nordic perspective, *Proceedings from 52nd IFLA Congress*, June 6-7 2015, St. Petersburg Russia, pp. 474-478.

ADDITIONAL REPORTS AND POPULAR ARTICLES IN ENGLISH AND SWEDISH (CAN BE OBTAINED ON LINE OR IN LIBRARIES)

Reports

Wissman, J., Ahrné, K., Poeplau, C., Hedblom, M., Marstorp, H., Ignatieva, M. & Kätterer, T. (2016). Multi Functional Golf courses. Report. *Popular Scientific Articles* - STERF, May 2016.

Popular articles

Ignatieva, M. (2017) "How to Make Urban Green Verdant and Sustainable: Designing 'Wild' Swedish Lawns - The Nature of Cities", https://www.thenatureofcities.com/2017/02/01/19758.

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Short communication

Lawn as a cultural and ecological phenomenon: A conceptual framework for transdisciplinary research

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ABSTRACT

Globalisation and urbanisation are driving the worldwide homogenisation of urban landscapes. The flora and fauna of cities in different parts of the world are very similar, irrespective of geography and climate. One of the most powerful symbols of modern urban landscapes is the lawn. There are just a few management options for urban lawns, regardless of how they are used and where in the city they are situated. Today, lawns occupy much of the green open spaces in cities (70–75%) and are located in private front and rear gardens, public parks, cemeteries, golf courses and along roads. Most people in the Western world view lawns as a ‘natural’ and even compulsory element of the urban landscape, without questioning their social, symbolic, ecological or aesthetic values. In this article we discuss the conceptual framework and methodological approaches being used in an ongoing transdisciplinary collaboration project including stakeholders to study lawns in Sweden as a social and ecological phenomenon. The overall aim is to understand the role of lawns in sustainable urban planning, design and management. The transdisciplinary approach allows us to exchange knowledge between scientific disciplines in order to influence the studies within each subject throughout the project and to achieve a multi-dimensional understanding of the lawn as a phenomenon. The involvement and close collaboration of stakeholders in the project allows us to obtain first-hand information on planning issues connected to lawns and existing planning data from cities and to focus on true implementation aspects rather than just theoretical recommendations.

Introduction

Globalisation and urbanisation are the major drivers of the worldwide homogenisation of urban landscapes. The flora and fauna of cities in different parts of the world are strikingly similar, despite geographical and climate differences (McKinney, 2006; Müller and Werner, 2010). In most of the Western world, urban landscapes have been influenced and shaped by the same landscape few architectural approaches, namely French formal, English Picturesque and Victorian Gardenesque and, in the 20th and 21st century, Modernism (Ignatieva, 2010). One of the most powerful symbols of these landscape architectural approaches, and thus of modern urban landscapes, is the lawn. Only a few management options have been adopted for urban lawns, regardless of how they are used and where in the city they are situated.

The use of lawns in our modern society is seen as a product of our life style (Giddens, 1990). Today, lawns cover a significant part of all green open spaces in cities (up to 70–75%). They can be found in private gardens and public parks, cemeteries, golf courses and along roads. Most people of the Western world view lawns as a ‘natural’ and even as compulsory element of the urban landscape, without questioning their social, ecological or aesthetic values (Stewart et al., 2009).

There is a common positive view of lawns as functional and accessible areas in parks, playgrounds and private gardens. Lawns often have symbolic value and people enjoy them (see, hear, smell etc.), although they may be not permitted to enter or use the lawn area. However, the intensive management practices used on lawns, such as frequent mowing and spraying of herbicides and fertilisers, has raised awareness about their potential negative impact on the urban environment. All previous research on urban biotopes has

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shown that lawns are strikingly similar in terms of plant species composition and, in their modern expression, are important contributors to the homogenisation of urban landscapes and loss of urban biodiversity (Ignatieva, 2011). Most grasses used for lawns are varieties originating from the same few nurseries or seed mixtures, creating habitats that have no equivalent within the native environment. In the US, 23% of the entire urban land area is estimated to be covered by lawns (Robbins and Birkenholtz, 2003), 62 000 t of pesticides are used by homeowners each year and 1.5 billion cubic metres of municipal water are used for irrigation of lawns each summer day. In Sweden too, lawns cover large areas of public courtyards, parks, golf courses, sports fields and traffic environments.

Like everywhere else in the Western world, lawns in Sweden are widely advertised by urban planners, landscape architects, developers and mass media as a very useful consumer product for the market. In the present project we regard lawns as specially constructed plant communities with a domination of a limited number of grass and herbaceous species which are densely planted and depend on a special management regime (regular mowing). The lawn is designed for social (sport and recreation), historical, aesthetical and cultural purposes (viewing, picnicking, playing golf and football, walking). There are intensively managed lawns (frequently cut short) which we call "conventional" and less-frequently cut lawns which are "meadow-like lawns". The latter lawns are closer to natural grassland in the sense that they are mowed and had bigger number of species. The environmental impact of lawns largely depends on the intensity of management (Cameron et al., 2012). If fertilisers, pesticides and herbicides are used, the surrounding surface water and groundwater may be affected. Bolund and Hunhamma (1999) present six major groups of important urban ecosystem services: air filtering, micro-climate regulation, noise reduction, rainwater drainage, sewage treatment and recreational/cultural values. Out of these six, the one where lawns are most important is the rainwater drainage. In vegetation-free cities, up to 60% of the rain water ends up as surface runoff. In areas with a permeable surface, such as a lawn, only 5–15% of the rain water becomes surface runoff, whereas the rest evaporates or infiltrates into the ground providing important soil-moisture for trees and other vegetation that further contributes to many of the abovementioned ecosystem services.

Although lawns may have positive effects on the environment, e.g. through carbon sequestration in soil (Qian et al., 2010; Zirkle et al., 2011), the total effect on the environment may be negated by the frequent use of mowers powered by fossil fuels. Lawns in general could also serve as a habitat for grassland fauna, including bees and butterflies that utilise urban environments (Ahrné et al., 2009; Ockinger et al., 2009; Matteson and Langellotto, 2010). Despite the important role of lawns in the urban landscape, there are few comprehensive studies including their social, ecological, cultural, historical and symbolic values, as well as their management and overall environmental impact. Most existing studies have been conducted in Europe, the US and New Zealand, where lawns are causing problems with invasive species because most lawn grasses originate from Europe (Müller, 1990a,b; Thompson et al., 2004; Stewart et al., 2009). In urban planning and policy documents, the emphasis is often placed on sustainable planning and the importance of promoting ecosystem services, but since these scopes are inherently complex, they are difficult to implement in practice. In order to provide urban planners with valuable information on how this could be achieved, one way could be to focus on a major urban green element, for example lawn, and study it from different scientific perspectives in collaboration with practitioners. However, this calls for interdisciplinary projects.

Transdisciplinary research on lawns

Here, we describe the conceptual framework and methodological approaches of an ongoing project on lawns (Tress et al., 2003). The project is a transdisciplinary collaboration including stakeholders. The main research question "What is the phenomenon of lawn in Sweden?" involves studying lawns from different perspectives. The overall aim is to understand the role of lawns in sustainable urban planning, design and management. Ecological knowledge, social values and norms influence the management of urban green areas (Andersson et al., 2007) and may thus influence their biodiversity, environmental impact and the ecosystem services they provide. Without understanding the social motives behind the strong attachment of modern Western society to lawns, introducing potential alternative solutions and changing conventional management routines can be difficult. The transdisciplinary approach allows us to exchange knowledge between scientific disciplines in order to influence the studies within each subject throughout the project and to achieve a multi-dimensional understanding of the lawn as a phenomenon. The involvement and close collaboration of stakeholders in the project allows us to get first-hand information on planning obstacles relating to lawns and existing planning data from cities, and to focus on true implementation aspects and not just theoretical recommendations.

To frame the project, we are using a multiscale approach and studying lawns from different perspectives: from the large scale including the entire city (estimating the total coverage of lawn as a land use type) through the medium neighbourhood level (providing typology, coverage of lawns, their functions, values and use in parks or backyards) to the fine level of the lawn itself, with emphasis on biotope characteristics such as biodiversity and carbon sequestration. The study areas were chosen within dominant typologies of neighbourhood areas in Sweden, multi-storey housing areas and residential private houses. The pioneering character of our research is emphasised by the broad perspective, including qualitative studies of social, cultural and historical values and a number of classical quantitative biological studies (biodiversity of plants, pollinators and decomposers, and carbon balance), as well as design considerations. All these aspects are being synthesised to assess the environmental impact of lawns and their importance for ecosystem services in three Swedish cities. Another very important part of this interdisciplinary research project is the involvement of urban planning and design dimensions, with practical output for practitioners and decision makers who are formulating and implementing municipal policies.

More specifically, the aim of the project is to obtain interdisciplinary quantitative and qualitative data on lawns which will allow us to estimate the values of different lawns and draw conclusions about their negative and positive environmental impacts in our modern cities. Our ambition is not to avoid or prohibit lawn as a phenomenon, but to critically analyse it, connect it to people's needs and suggest a new planning, design and management paradigm.

Specific objectives of the project are:

- To classify and identify main types of lawns and their current management practices.
- To estimate the proportion of lawns related to other green and blue areas in the city, such as forests, agricultural land and water bodies.
- To understand the motives for decisions about the establishment and management of lawns among different stakeholders.
- To examine historical and social roots, perceptions, norms and aesthetic, symbolic and design values of current management practices of lawns.

- To understand the role of lawns in urban hydrology and water management.
- To analyse the environmental impact (energy use and carbon footprint) and biodiversity (plants, bumblebees, butterflies and earthworms) of lawns.
- To identify how to establish and manage lawns so as to promote their provision of ecosystem services in cities (e.g. pollination), while simultaneously reducing their environmental impact and addressing people's needs.
- To study how different human interests and values interact (or conflict) from a management perspective and how to find sustainable planning and design solutions.

We will deliver the results directly to stakeholders by providing an urban greening manual, demonstration sites and different management packages for municipalities and communities with recommendations on how to design, establish and manage sustainable lawns.

Research framework and methodology

We aimed to have a spatial overlap in choice of sites among research disciplines, but at the same time to create a model that can be relevant for answering questions within different fields (Fig. 1). The first few months were specifically dedicated by participants to creating an understanding of each other's disciplines and perspectives. Another important part of the approach was to establish stakeholder and focus groups involving local municipality experts. A special role was given to a scientific focus group that consisted of leading international and local experts on lawns, including an expert in plant–pollinator interactions, a horticultural scientist, an expert in grass-free lawn and a sociologist. We also involved non-academic participants such as different stakeholders in the project.

The *quantitative* methods used in natural sciences with replicate samples and reproducible research layouts are also being combined with *quantitative and qualitative* methods employed in social science, using interviews and surveys based on estimations and stakeholder values. These in turn are being combined with *case study methods* used in planning science, where unique cases are studied with method triangulation for validating the results (Yin, 2013).

The process of choosing the case studies for field work was directly correlated with three historical and cultural peculiarities that dominate Swedish urban planning structure. Multi-family residential housing neighbourhoods with significant amounts of lawn area are the most common typology in Swedish cities. We also included a category of Swedish private houses (detached housing with private gardens). There are about 2 million such detached houses in Sweden, making private houseowners an important stakeholder group with potentially a wide range of views and motives for planning, nurturing and maintaining their private lawns (Lundgren, 2001; Berg, 2004).

We chose three case study cities, situated in the south (Malmö, 280 000 inhabitants), east (Gothenburg, 530 000 inhabitants) and west (Uppsala, 200 000 inhabitants) of Sweden, in order to cover differences in climate conditions and local culture. Within each city, three types of lawns were identified for study: (1) residential lawns in private (detached house) gardens; (2) utility lawns (common conventional, frequently mowed lawns); and (3) meadow-like lawns in multi-family residential housing areas (cut only a few times a year). Utility (conventional) and meadow-like lawns are two main classes differing in management intensity that have been adopted by all Swedish municipalities. The classification of lawns is mostly based on the management intensity (including frequency of cutting, using herbicides and pesticides). Usually there is also one more type of lawns, the parterre lawn, which has the highest management intensity. Parterre lawns are uncommon in Sweden. Instead we included golf courses with lawn types ranging from very intensively managed tees and greens, to fairways with intermediate management intensity and roughs with the lowest management intensity. Golf courses are also included because of their more intensive use of purchased inputs, and because of their potential for more sustainable management by providing habitats for grassland species (Colding and Folke, 2009).

For calculating the percentage of the lawn coverage in the case study cities, we decided to use existing data obtained by LiDAR (Light Detection And Ranging), a remote sensing technology that measures distance by illuminating a target with a laser and analysing the reflected light, complemented with stakeholder knowledge of current managed areas.

As carbon balance studies are labour-intensive, we decided to limit our detailed research to three lawn types differing in management intensity (utility and meadow-like lawns in multi-storey residential areas and golf courses). We researched only 'mature' lawns, i.e. at least 10 years old.

Methodological approach

Social, cultural and historical research

In view of the complexity and novelty of this transdisciplinary research project, during the first year we carried out a pilot study to test the suggested methodology and to establish contacts with keynote stakeholders. For the social, cultural and historical research, we looked at the origin and history of lawns worldwide and particularly in Sweden (we visited sites of alternative lawns in Europe), motives behind management and establishment of different types of lawns, characteristics of Swedish lawns and the perception among people of different types of lawns, the origin of seed mixes and the peculiarities of planning, design and management practices for lawns. The methodology included: (1) A literature review and archive survey; (2) questionnaires on management and choice of plant material, targeting stakeholders (who plan and manage the specific lawns), people living in multifamily houses and golf players; (3) interviews with private gardeners, public planners, decision makers, politicians, landscape architects and horticulturalists to obtain information concerning their vision, planning, management and perception of lawns; (4) observational studies on how frequently and for what activities the selected lawns are utilised; and (5) surveys: short interviews with lawn visitors to get an idea of how lawns are perceived and utilised. In the social science part of the study we also integrated some questions from other teams. One of the most challenging parts of the methodology was to put together and integrate different studies (sub-projects).

Biodiversity and environmental impact

Biodiversity and environmental impacts of differently managed lawns being studied are species diversity and composition of plants, bees, butterflies and earthworms, energy use and carbon footprint. Carbon sequestration is being modelled, as is the balance between sequestration and emission of greenhouse gases (GHG), including hidden carbon costs (GHG emissions associated with production of mineral fertilisers, pesticides, mowing etc.) in the different lawn types.

Within each of the three cities, we surveyed three replicates of each of the public lawn types (utility and meadow-like lawns) in six multi-storey housing areas. We also surveyed three management types (fairway, rough and high rough) at six holes in two golf courses per city. At all study sites, all species of vascular plants

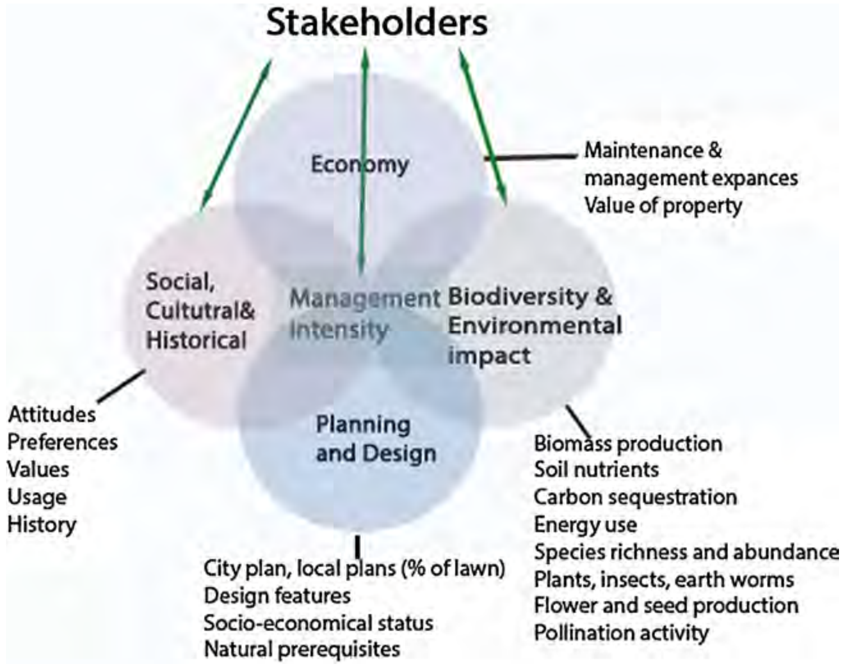

Fig. 1. Components of the transdisciplinary project on lawns. The four main areas overlap greatly in terms of research questions, interactions and, spatially, field sampling.

were recorded (vegetative cover and counts of reproductive parts) within small plots (0.5 m × 0.5 m). We also recorded the amount of flowers or fruits produced, as this is important for the connection between plants and pollinators. Species richness and abundance of bumblebees and butterflies, as well as number of flowers visited by the pollinators, were noted in larger plots (3 m × 3 m). In these plots we also estimated total number of flowers. The survey of all plots and points was conducted on two occasions during the flying season to include plants with different flowering periods and pollinators with different flight periods. We focused on the grass surface, but also estimated the availability of flowering plants within a larger distance from the inventory plots, e.g. in flowerbeds. Since the organisms studied may also be influenced by the surrounding urban landscape, we included GIS analyses of the landscape at a larger scale, examining landscape composition and connectivity among grasslands.

Soils were sampled and organic carbon and nitrogen concentrations, soil bulk density and roots determined. Carbon sequestration is calculated using the Introductory Carbon Balance Model (ICBM model) (Andrén and Kätterer, 1997). Input to the model is the lawn biomass production and climate data (temperature and precipitation). Above-ground lawn biomass is determined through manual cutting of sub-plots within each of the two lawn types and the golf courses. The cutting frequency mimics the management practice used on the particular lawn type. Root biomass production estimation is based on shoot/root ratios obtained in earlier calibrations of the ICBM model (Kätterer et al., 2011), as are other model parameters such as stabilisation coefficient and rate constants for degradation.

The energy use and emissions of GHG are being assessed in a life cycle perspective, i.e. including all relevant activities in the management chain, from production of e.g. purchased inputs to disposal according to a standardised ISO procedure. The energy use related to the management of different lawn types such as irrigation, mowing and fertilization is being investigated through interviews and questionnaire surveys of stakeholders, combined with a literature search, and divided into different energy sources. In addition to CO_2 emissions related to the management, nitrous oxide emissions both from production of nitrogen mineral fertiliser and soil are estimated and carbon sequestration is modelled using the ICBM model. Earthworms are important for soil conditions and soil fertility and are being sampled in Uppsala using the mustard extraction technique at all biodiversity sites (Pelosi et al., 2009).

Alternative design

In the first year we established a demonstration trail representing different experimental sites of alternative lawns at Ultuna Campus, Uppsala, as an important educational facility for academics as well as public communities. For example, these sites contain plant communities suitable for bumblebees and butterflies, as well as meadow plants suited for wet and dry conditions. This work relies heavily on active participation and consultation within the focus and stakeholder groups and is based on exchange of scientific and practical information from leading European scientists and Swedish practitioners working with sustainable lawns.

The final year of the project is intended for critical evaluation of existing design, establishment and management practices of conventional lawns in Swedish cities and their economic, social and environmental effectiveness. We have also decided to analyse existing European sustainable alternatives to conventional lawns, such as meadow lawns (established from biodiverse mixtures (up to 25–30 species of different grass and herbaceous species), grass-free lawns (made by using specific mowing tolerant plants instead of grass, (Smith and Fellowes, 2014) and pictorial lawns (made from annual decorative plants) (Hitchmough, 2009) and their appropriateness of using in Swedish cities. The economic and environmental benefits of such alternative lawns have been actively discussed in recent years. The final stage of this project will result in suggestions of different practical design solutions for planning, design and establishment techniques as well as management schemes for different types of lawns in all three case study cities. We are not necessarily against the conventional lawns but call for critical evaluation and suggestion of wiser resource use in the urban environment.

Initial results and implications for future research

The involvement of different disciplines and of stakeholders is the strength of this project, but also makes it complex. It took time and a lot of effort in the beginning to understand how to combine the methodologies from different disciplines and adapt them to collective goals and objectives. Series of joint meetings, reading each other's articles, collecting background information, building networks and creating a database of local contacts were essential starting points for the project. Stakeholder and focus group meetings identified an urgent need for lawn research. All municipal managers are very supportive as well because they understand the necessity of changing the current costly and unsustainable management paradigm. However, due to the complex character of Swedish home ownership and management practice (many owners and contractors are involved in maintenance and management), the process of obtaining data was not an easy task and took a longer time than expected.

The pilot study in the first year worked well and by the end of first season the methodological approaches in all packages had been adjusted and in some cases significantly changed. For example, we found out that in a large city such as Gothenburg, it would be very time-consuming (costly) to manually interpret the coverage of all lawns using orthophotos. In the pilot study we tried to use normalised difference vegetation index (NDVI) and infra-red-spectra to estimate the area of grass in Gothenburg. However, we found that the NDVI was not capable of capturing vegetation in shaded areas and it was also difficult to distinguish grass from trees and other vegetation, thus making it less usable. Moreover, not all cities have red spectra in their aerial photos. Using existing LiDAR data proved to be the best method of estimating total grassland cover. In Sweden there is national coverage of LiDAR data, and in addition some cities (e.g. Gothenburg and Uppsala) have their own LiDAR with higher resolution. We used the municipal management maps of grasslands as references when interpreting the intensity in the LiDAR data.

In the social survey, the questionnaires for lawn visitors and managers/politicians were changed several times until they were worked effectively. Establishment of a website and demonstration trail were effective visualisation and popularisation tools and attracted the attention of stakeholders and the public at large. Some municipalities would like to establish new larger demonstration sites in botanic or community gardens.

Working with an interdisciplinary approach initially needed numerous physical meetings (as well as reading of selected articles from each of the disciplines) to understand the intentions of other participants for the project, identify possible synergies and be able to cooperate. It was also important to understand that in such projects aiming at both a broader and a detailed perspective, there will be compromises within each of the scientific subjects and they might not be able to perform as detailed studies as they would like.

For the success of the research aim to use the knowledge gained in the project and implement it on the ground, it is crucial to have close collaboration with stakeholders and let them be part of the research planning process. Only informing stakeholders about main results in a fact sheet or a scientific paper is not sufficient if sustainable development is to be implemented: closer meetings and mutual understanding during the scientific process are necessary. We plan to continue working closely with stakeholders. Our final goal is to influence and even change the attitude towards lawns among professionals and the public.

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The lawn as a social and cultural phenomenon in Sweden

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ABSTRACT

Lawns have a significant influence on the cityscape as one of the essential elements of green spaces and an important part of people's everyday lives. Most people in the Western world view lawns as a compulsory element of the urban landscape, almost an icon, without questioning their social, symbolic, ecological or aesthetic values. This research is a part of the conceptual framework and methodological approaches that are being used in an ongoing transdisciplinary collaboration project to study lawns in Sweden as a social and ecological phenomenon.

The overall aim of this study was to investigate social and cultural perceptions of lawns, as well as motives behind decisions about the establishment and management of lawns in Sweden. Two multi-family housing typologies, the 'Million Programme' and 'People's Homes', were examined due to their dominance in Swedish cities. We also studied how an alternative vision of conventional lawns can be applied and accepted by urban residents. We estimated lawn cover in multi-family housing areas and links to people's perception and use of lawns. Questionnaires, semi-structured interviews and observational studies were used (N = 300). Our results showed that people like lawns even if they do not always directly use them. Lawns cover the most significant amount of outdoor spaces in all multi-family residential areas and accompany people everywhere from the house to the schoolyard or park. The total lawn cover in the study areas was 27.8%. Lawns were particularly valued as important places for different outdoor activities (playing, resting, picnicking, walking, socialising) and enjoying the green colour. However people do not want to use a vast monotonous lawn, but a variety of spaces that provide good conditions for different senses (sound, smell, touch and sight) and activities. Alternative lawns were also appreciated by many citizens, politicians, planners and managers. The implementation of new types of lawns requires special planning and design solutions adjusted for each particular neighbourhood.

1. Introduction

Lawns occupy a significant proportion of green spaces in many cities worldwide today (Stewart et al., 2009). According to the most recent EU study "Green Surge – A typology of urban green spaces, ecosystem provisioning services and demands" (Braquinho et al., 2015), green spaces are defined as "any vegetated areas found in the urban environment, including parks, forests, open spaces, lawns, residential gardens, or street trees". In 44 identified types of urban green areas, the lawn is one of the most common elements, for example in large urban parks, botanical and zoological gardens, historic parks/gardens, institutional green spaces, green playground/school grounds, street green or green verges and house gardens. The complex character of urban green areas is well recognised and there is a growing body of research investigating the roles of green spaces in social, economic, cultural and environmental aspects of sustainable development (Haq, 2011). Even if lawns are one of the most dominant elements in green areas in all countries (irrespective of climatic differences), this phenomenon itself is not well researched, and especially not its socio-cultural component. At a time of climate change and the search for a sustainable urban environment, there is an urgent need to have interdisciplinary empirical quantitative and qualitative studies on lawns: the values of different lawns are revealed and conclusions drawn about their negative and/or positive environmental impact (Ignatieva et al., 2015).

There are many different definitions of 'lawn', but we define it here as an artificially created or modified plant community (phytosociological composition) consisting predominantly of grass (more technically graminoids), but it may have spontaneously occurring herbaceous species (which are also called 'lawn weeds'). Lawns are used for recreation and sports, and as a pleasant green backdrop for displaying other plants or functional (playgrounds)

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and decorative elements (pieces of art, fountains, benches and pavilions). One of the main characteristics of lawns is their construction technique (preparation of soil and seed mixtures) and management regime (mowing, herbiciding, fertilising, watering) aimed at maintaining grass species, controlling weeds and mosses, and keeping a certain grass height.

The lawn is quite a recent ecological and cultural phenomenon. Lawns are an artificially created grass-dominated plant community designed mostly for pleasure and/or decorative purposes. It most probably appeared in medieval times in Europe (Fort, 2000; Ignatieva, 2011). A broader use of lawns is connected to the development of the most influential landscape architectural styles, such as picturesque and gardenesque (18th –19th centuries), in Europe, the US, Australia and New Zealand. The 20th century Modernism movement used lawns as a massive prefabricated element in all green areas (public and private). Lawns today are seen as a symbol of globalisation and the market economy (Ignatieva, 2010).

An ecological component assessment of lawns (floristical and phytosociological composition, urban biotope) has been a primary subject in lawn research since the 1990s in Germany (Müller, 1990) and later in England (Thompson et al., 2004), New Zealand (Ignatieva et al., 2000; Stewart et al., 2009) and recently in other countries (Bertocini et al., 2012; Pooya et al., 2013).

The US and UK are trying to raise awareness of broad-scale research – an estimation of lawn cover in cities (Milesi et al., 2005; Gaston et al., 2005; Edmondson et al., 2014) because of the dominant role of lawns in suburban private gardens and public green spaces. For example, the combined area of lawn (turfgrass) represents an estimated 23% of urban land cover in the USA (Robbins and Birkenholz, 2003). In the early 1990s the area cultivated with lawns in the US was up to three times greater than that of irrigated corn crops. Awareness of the environmental impact of intensively managed lawns in US suburbia resulted in a rising number of scientific and popular publications on the history of American and English lawns and an analysis of socio-cultural and even anthropogenic reasons (speculation that people love lawns because of the evolution of humans in savanna-like landscapes in East Africa) behind an obsession for the perfect short-cut green lawn in modern society (Schultz, 1999; Teyssot, 1999; Fort, 2000; Macinnis, 2009). In recent years, particularly in the US, England and Germany, there is a growing number of papers discussing the 'evils' of modern monotonous and homogenous lawns and the need for alternative sustainable solutions as well as the education of local citizens in favour of a new vision of lawns in urban nature (Borman et al., 2001; Pollan, 1991).

The social norms and psychological and social predictors of lawn fertiliser application have been studied in the private gardens of American suburbia (Kaufman and Lohr, 2002; Carrico et al., 2012). However, there are still very few proper empirical social studies on perceptions, norms and aesthetic values of current use and management practices of lawns, especially in non-American countries.

Swedish cities share the same lawn pattern as many other cities around the world. Lawns are widely advertised by urban planners, landscape architects, developers and mass media as a very useful consumer product for the market. It is the dominant component of green areas in multi-family housing, public parks and gardens, street verges and cemeteries as well as in private gardens and on golf courses. However, no studies of the biodiversity, environmental impact or public use of lawns, for example, have been conducted in Sweden (Ignatieva et al., 2015).

The overall aim of this study was to investigate social visions and perceptions of lawns and motives for decisions about the establishment and management of lawns in common housing areas in Swedish cities. The main research question involved studying lawns from different perspectives. This also included an examination of how sustainable (alternative) design and management of lawns could be applied and accepted by urban residents, an estimation of lawn cover in typical multi-family housing areas, and people's perception and use of lawns. Without understanding the social motives behind the strong attachment of modern western society (including Sweden) to lawns, it is impossible to introduce potential alternative solutions and change conventional management routines. The transdisciplinary approach (in this particular case between data on lawn cover in Swedish residential areas and visions of lawns by local residents) allows us to exchange knowledge between scientific disciplines and achieve a multi-dimensional understanding of the lawn as a phenomenon.

2. Lawns in Sweden

The history of lawn establishment in Sweden is similar to that in many other European countries. Grazed meadows have existed for millennia and during the Iron Age it became possible to harvest hay in larger amounts. It is difficult to say exactly when grass-dominated plots (lawns) for entirely decorative purposes appeared in European gardens, including Sweden (Ignatieva and Ahrné, 2013). In Medieval European gardens of the 12th–15th century, cut turf from meadows with their various grass and herbaceous flowering plants was used in monastery (and castle) gardens. Lawns were first used in Sweden as entirely decorative short-cut grass areas during Renaissance and Baroque times (1600–1750s). The establishment and maintenance of lawns was expensive and resource-consuming and lawns were initially used only in limited amounts as a parterre element or *tapis vert* (green carpet) in the grand parks of royalty and the nobility. During the English landscape park era (1750s–1840s), rather large undulating lawns were still the prerogative of the nobles. Public parks first emerged in the second part of 19th century, marking a new era of Swedish lawns. They started to be an important decorative and recreational element and served the needs of the common people rather than those of the privileged higher social classes. Swedish parks at that time were valued as places for good health and 'moral education'. They provided a pleasant environment for strengthening the family' by taking people's minds away from drinking and gambling (Wärn, 2013).

From the second part of the 19th century, the process of transformation of an agrarian country to a highly industrialised nation began, resulting in accelerated urbanisation. After the Second World War, Sweden's undamaged industry needed even more urban labour to produce goods for the destroyed Europe. New urban development plans and a new generation of housing areas with apartment blocks were built all over Sweden. The planning structure of Swedish cities before and after the war directly reflected the economic and political situation and were connected to the "Swedish Model" implemented by the Social Democratic Party (in power from 1932 to 1976) with the aim of creating a more equal society. This policy resulted in creating the progressive welfare state. One concrete goal was to provide simple, but good-standard apartments and healthy outdoor environments for the working class (Dahlberg, 1985). Influences also came from the international functionalism movement, strongly expressed in the Stockholm Exhibition in 1930. The basic idea was that form or design should follow the function of dwelling both indoors and outdoors in new housing areas. Functionalistic planning and architectural values and policies included equal access to high-quality public spaces and provision of sun, light and air and an improvement in the population's health. As a result, functionalistic multi-family housing areas – "People's Homes" (*Folkhemshusen*) in 1940–1959 and the "Million Programme" (*Miljonprogrammet*) in 1960 until the mid-1970s – were established all over Sweden. 500,000 apartments were built in 15 years during the People's Home programme and

Fig. 1. The People's Homes area of Tunabackar in Uppsala, with bright lush inner courtyards covered by large public lawns. (Photo: Per G Berg).

900,000 homes in 10 years for a nation with a population of seven million. In both forms of housing, lawns cover large areas. Following the ideological and social goals of providing a cheap and functional space, lawns were seen as an excellent outdoor element for play, walking and recreation. Lawns were a standard element that fitted well into functionalistic aesthetics of a simplified, rationalistic (prefabricated) style with limited variation in design schemes.

2.1. People's Homes and the Million Programme

The People's Homes project originally consisted of mostly rented apartments in three-storey houses in natural settings or in closed blocks around lush inner courtyards (Fig. 1). Lawns were initially used to cover large spaces next to the houses because of their simple and cheap maintenance.

Green resources then became common in courtyards, with a plethora of garden rooms, large trees, pergolas, lush playgrounds and appropriated ground-floor gardens. The initial idea for the lawns was to constitute the green floor of the individual courtyards and the core of larger common green parks (Persson and Persson, 1995). In many cases, lawns were built on former agricultural or meadow land. Playgrounds, flower beds, pathways, street furniture, gravel ball parks, shallow paddling pools and, in later decades, picnic places were all surrounded by lawns.

During the Million Programme most houses were initially low-rise, but later comprised larger-scale high-rise areas. The strongest green-blue infrastructure values for these areas were considered to be their closeness to nature in the periphery (urban fringe) of the city. Forest patches and larger lawn areas were suggested as an asset in the Million Programme as well, but the courtyards between buildings had only small patches of lawn. Larger lawn areas were therefore established in large-scale residential parks and adjacent groves, meadows and garden plots. The weakest expression of green planning in the Million Programme was inner courtyards planted with exotic standard plant material (*Berberis* and *Dasiphora*) growing on very thin topsoil within monotonous lawn areas.

3. Methodology

3.1. Case studies

Our research was conducted in three case-study cities (Göteborg, Malmö, Uppsala, see Fig. 2) in 2013–2016. Göteborg, on the south-west coast, is the second largest city in Sweden, with a population of 533,000 (1 January 2015). The topography, with rough, barren rocky outcrops and cliffs, has influenced the city's spatial development. Malmö is the third largest city in Sweden, with a population of about 319,000 (1 January 2015). Unlike Göteborg with its hilly landscape and remnants of natural vegetation, Malmö has plain topography and many of Malmö's neighbourhoods have artificial turfed green hills to fill this topographical 'gap'. Uppsala is the

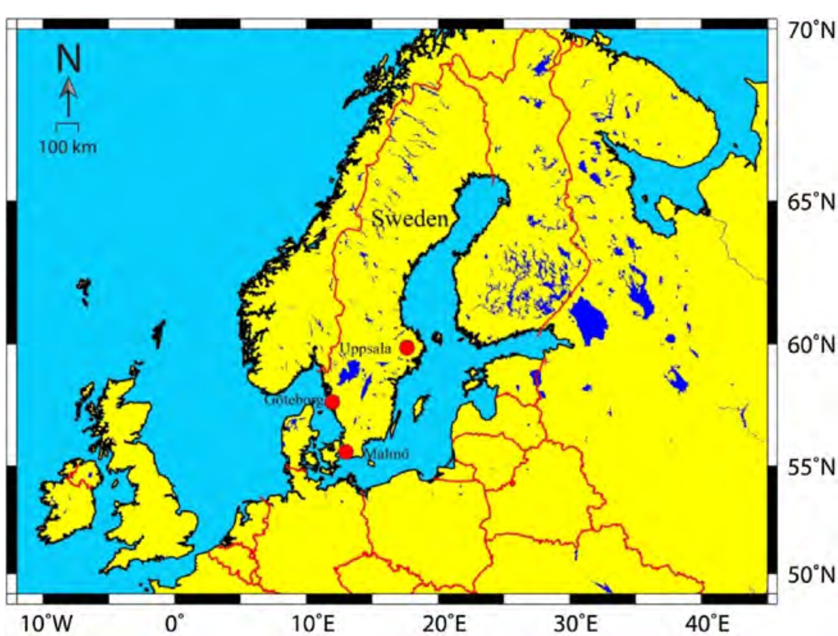

Fig. 2. Location of the case study cities in Sweden.

Fig. 3. The Million Programme area Eriksbo (1967–1971) in Angered, Göteborg. Light green is lawn (and small amount of meadows or sports lawn) and dark green is trees, shrubs and an all-weather soccer pitch. The reddish and whitish blocks are roofs and the grey is roads or parking lots. Houses and outdoor spaces were renovated and partly rebuilt in 1985–1990.

fourth largest city in Sweden, with a population of around 207,000 (1 January 2015). The city has many remnants of forests, which have mostly been transformed into accessible recreational spaces. The city covers 48.8 km^2, of which 10.5 km^2 are covered by natural plant communities (Park plan for Uppsala City, 2013).

The cases in each city were strategically selected from well-researched (Berg, 2004; Berg et al., 2010) dominant townscape types (Million Programme and People's Homes areas) representing ordinary housing (Johansson, 1991; Reppen et al., 2012) for up to a third of the Swedish population – areas where lawns inside and adjacent to housing areas are still dominant elements in the green spaces (Persson and Persson 1995). The cities represent some of Sweden's major urban regions, but in various landscape settings in different parts of Sweden.

In each city, we studied one People's Homes area and two Million Programme areas: Kyrkbyn, Eriksbo and Angered in Göteborg, Augustenborg, Holma and Rosengård in Malmö and Tunabackar, Gottsunda and Eriksberg in Uppsala. These particular neighbourhoods were selected based on consultations with stakeholders from municipalities involved in the LAWN transdisciplinary project who had pronounced interest of knowing more about these areas in particular. Downtown and industrial areas of the cities were not included in the analysis.

3.2. Types of lawns

There are two types of lawns officially identified by Swedish municipalities (Hellener and Vilkénas, 2014). The majority are 'conventional' lawns, which are cut at least 10 times per season to a height of 4–10 cm according to official municipal definitions (Andersson and Bergbrant, 2015). The other type is "meadow-like" lawns, which are cut once or twice per season. Meadow-like lawns currently cover only a tiny area and are mostly located next to remnant natural vegetation on the outskirts of neighbourhoods or within public parks. There are also sports lawns, such as football fields, which are often more intensively managed. They represent a small proportion of the total urban lawns.

To estimate lawn cover we used aerial photos and ArcMap background data from May 2015 for manual mapping. The outer border of each specific housing type was strategically chosen, which affected lawn cover, since it was estimated by dividing area of lawn by total area. The outer borders of People's Homes were easy to detect, while the borders of the Million Programme housing areas were more difficult to define as these areas often lie on the urban fringe of cities adjacent to nature, making the borders less distinct. Furthermore, vast green areas are present in the surroundings and it is difficult to see whether these belong to the housing areas or the surrounding landscape (Fig. 3). In each location, the total area of lawn, meadow, sports lawn, trees, shrubs, gravel (mainly all-weather sports pitches), bare rock (rocky outcrop, very common in Göteborg), bare soil, water and agricultural fields was mapped (Fig. 3). Roads, parking lots and dwellings were not included (but were indirectly estimated when everything else was removed).

For the social part of this study of lawns, we used questionnaires, semi-structured interviews and observational studies (Sjoberg and Nett, 1968) at 10 sites in the case-study neighbourhoods in our three cities. Our focus was particularly on lawns and the specific qualities provided by lawns. Lawns are the dominant element of green areas in all the researched neighbourhoods. Green areas here consist of lawns with scattered groups of shrubs and trees, with the intrusion of flowerbeds and playgrounds. Designed pedestrian paths and cycle ways were also typically surrounded by lawns.

We started our research with a pilot study in 2013 in Uppsala and tested the questionnaire. Ten questions were related directly to the main research questions on lawns (perception, expectations, use of lawns, their management and attitudes towards using some alternatives to conventional lawns with more biodiverse and less resource-intensive options) and the last question (11) aimed to connect lawns as a phenomenon to the wider context of green area qualities (Table 1). We asked randomly selected people (who were passing by or sitting on lawns, playing, sunbathing or relaxing, or sitting on the benches next to lawns) to answer questions (Somekh and Lewin, 2005). We tried to cover people of different cultural and ethnic backgrounds, ages and genders. Before starting the interview, we asked people whether or not they lived in the vicinity of the site. Interviews were performed in the late spring and summer months (due to the nature of the Swedish climate and use of lawns) on weekdays and at the weekends, at different times of day (morning, afternoons, late afternoons), aiming to cover as many categories of local residents as possible. We also asked the respondents

Table 1
Questions on social activities in housing areas.

1	How do you perceive the value of having access to a lawn/grass areas in your neighbourhood?
2	Are there lawns here or nearby that you usually visit? If yes, then which one/ones?
3	What do you think about the maintenance of grass areas in your neighbourhood in general?
4	What do you think about lawns that are cut only 1–2 times per year (for example meadow-like lawns)?
5	What do you think about alternative lawns (such as flower-rich lawns, meadows with perennials or annual pictorial meadows?
6	If you could decide, how would you like to design grass areas in your neighbourhood?
7	How would you rate the following statements regarding the grass area in this neighbourhood (rating from 1-disagree to 5-agree): well maintained, safe place for children and adults, beautiful and friendly place, suitable for leisure activities, a great place for rest and recreation, an important place for socialising with neighbours and friends?
8	Do you think that lawns generally create a good habitat for living creatures, such as insects, birds and mammals?
9	How often do you use lawns for different purposes (rating from 1-disagree to 5-agree): exercise/sports, sit/rest, social activities with neighbours/friends/family (party, meal, barbeque *etc.*), to get to other areas (shortcut), to experience nature, to look at (aesthetic value), other?
10	In which season do you use lawns most?
11	Is there anything you would like to add concerning lawns and green areas?

how long they had lived in the neighbourhood, their occupation and their type of household (single or family with children). All answers were written down by the interviewers on printed questionnaires. At each of the 10 sites, we conducted 30 interviews with residents (300 interviews in total).

The field data collection was based on the principles that 50% of the respondents in the six sites should be female and 50% male. We aimed to have 30 respondents at each site who were equally spread among the following age categories (15–24, 25–50, 51–65 and 66+). People were asked to answer questions related to alternative lawns, illustrated by pictures (such as flower-rich/grass-free) lawns with low-growing herbaceous plants, meadows with perennials that are framed by conventional short-cut lawns, or meadows with annuals (pictorial meadow) (Fig. 4).

Observation studies were carried out in places where we could observe people's movements. At each site, we conducted observation studies in three different spots. We recorded activities and their frequency for 10 min on selected days in June, July and August. Data were collected by using a pre-coded schedule in which different kinds of activities were listed, such as walking/passing through, walking with a dog, cycling, picnicking (and social gathering), playing, sitting and exercising (Whyte, 1984). We also wrote additional notes about how long people stayed in each site and if they were alone or in company. We also recorded weather conditions (sunny, cloudy, rainy, cold, and warm). The aim was to discern and identify usage patterns linked to the character of lawns in the different case study sites.

Politicians, municipality managers, city planners, landscape architects and property managers were interviewed about policies, lawn management and biodiversity (a total of 23 interviews). We also asked about their level of education, their responsibility in the particular municipality, plans and resources (budget, staff availability etc.) for lawn management, their understanding of lawns and their role in modern green areas, and the opportunities for environmentally-friendly lawns and the presence of wildlife, such as bees and butterflies. Furthermore, we sought to determine the 'perfect' lawn from the stakeholders' point of view. The qualitative data from interviews were analysed by: 1) sorting the data into themes and codes, 2) counting the number of occurrences of the themes and codes, and 3) selecting statements that were representative of the majority and minority of interviewees.

4. Results

4.1. Lawn cover

In all our case studies lawns occupied quite significant areas. The total lawn cover ranged between 17.7% and 47.7% (average 27.8%) in the multi-family areas (both Million Programme and People's Homes) (Fig. 5). The Million Programme areas in all cities had on average 24.8% lawn (lawns, meadows and sports areas), 18.7% forest and shrubs and 49.9% infrastructure. The People's Homes areas had on average 33.1% lawn, 12.4% forest and shrubs and 54.4% infrastructure.

*Sport lawns were not considered in the social study but mapped as one of the lawn types existing in cities.

4.2. Social study

We succeeded in obtaining the planned balance (50% male and 50% female) and age distribution in all six case studies. Since humans often have a complex personality and different lifestyles they need different spaces for different activities depending on the weather, time of the day and even individual moods at a particular moment.

We could not find any specific patterns between the answers of males and females in our data. In all three cities, people appreciated lawns in their residential areas and surroundings. There was no significant difference depending on age, but there was a tendency for younger (5–15 years) and elderly people (65+) to have more opinions and expectations concerning lawns and also the green outdoor environment. The majority (more than 70%) of the youngest and eldest respondents in our study who commented on lawns also had many opinions about how lawns could be more attractive.

Households with small children also had many suggestions about how lawns and the green spaces between buildings could be used much more efficiently. Households with middle-aged people (who have full-time work) and who had no children or older children (that mainly stay at home) did not, in most of the cases, mention anything specific that they would like to change. They seemed to be satisfied with the existing conditions of lawns. Parents of small children and the elderly often stressed the importance of accessibility, closeness and functionality of playgrounds, benches and other elements located on lawns. People from all kind of households mentioned the importance of having an extra "outdoor space" close to home.

One of the very first impressions in the study was very good familiarity with local lawn areas among respondents. People were actually even surprised to be asked about lawns, since all their life it has been one of the most familiar and commonly seen elements of their outdoor environment. The lawn cover estimate for each neighbourhood studied corresponded with our social data reporting that lawns surround residents everywhere. As one of Kyrkbyn's residents said: "I see it as a given element. I would miss lawns if they were not here". Respondents often associated lawns with summer and most lawns were designed for summer activities.

When we asked about the value of having access to lawns in outdoor spaces, the majority of interviewees responded that such access is "very valuable" and "very important". One resident said that lawns "become more important as you get older" and are "especially important for those who have no opportunity to go to other green places outside their house". Lawns seem to be appreciated for their aesthetic value, even if they are not directly used for

Fig. 4. Three alternative options for lawns presented to respondents that were linked to question 5 in Table 1. (Pictures: J. Vilkenas and A. Helner, 2014).

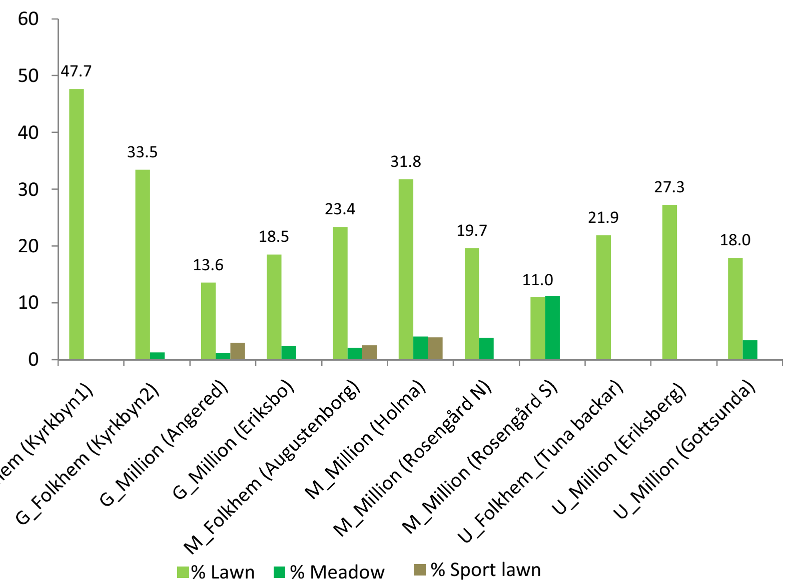

Fig. 5. Total lawn cover by lawn, meadow and sports lawn in each of the study areas (G = Göteborg, M = Malmö, U = Uppsala). Two of the areas were separated into two units (Kyrkbyn I and II in Göteborg and Rosengård N and S in Malmö) to illustrate the potentially large differences in meadow areas and within areas.

activities. One interviewee said: "Since I use a wheelchair I am not outdoors that often. But I enjoy the view from my balcony".

Lawn enthusiasts argued that lawns are "important places to meet friends", "important for different kind of activities" and "especially important for families with children". Urban residents at all sites valued well-maintained lawns in their neighbourhood and were satisfied with municipal management of their grass areas. Only a few respondents were unhappy with noise from a mower or with rubbish left on the lawn (Fig. 6).

In all our research areas, lawns were used for different kinds of outdoor activities during the summer: walking/passing through, playing, sitting, sport, meeting friends, sunbathing and family partying/barbequing. The use of lawns (the particular activity performed most) varied in the different case studies depending on how the lawns were valued.

People greatly appreciated lawns for different kinds of pastimes (Fig. 7). We found that people living in sites with huge open lawns close to the buildings did not use these lawns for any kind of activity, but liked them as a viewing space. This is not surprising, since people see these open green carpets on a daily basis. Many people preferred to have green places in close proximity to their houses, or lawns with a "cosy" or "lush" character.

Observational studies confirmed the questionnaire data on the use of lawns for outdoor activities (Figs. 8 and 9). People mostly passed through or cycled on pathways alongside or through lawns that had no specific attractions such as benches, playgrounds or flowerbeds.

The results showed that people often use the lawns as passages. Some lawns were also often used for walks (especially popular among dog owners). The time citizens spent directly on lawns depended on the quality of the grass and weather conditions. "Popular" lawns all had spots where people were protected from the wind or sun (Fig. 10). Social activities were more frequent in good weather.

The observation studies also showed that residents preferred places where they had a nice view, social activities or something over and above just plain lawn, for example decorative perennials, shrubs or water features.

In the daytime, families with children often used lawns between 10.00 and 15.00. Children were out after school and at the weekends. Dog owners were seen quite frequently from early morning to late evening. Elderly people over 65 used green spaces during the daytime. The weather conditions were important even for dog owners (in bad weather the lawns were used for a very short walk). There were several quite similar patterns in observation studies in all case studies in the Million Programme and People's Homes sites in all three cities.

Lawns were mostly used in late spring and summer because of the Swedish climate with its defined winter and summer seasons. The questionnaire data supported this finding. Quite a few people

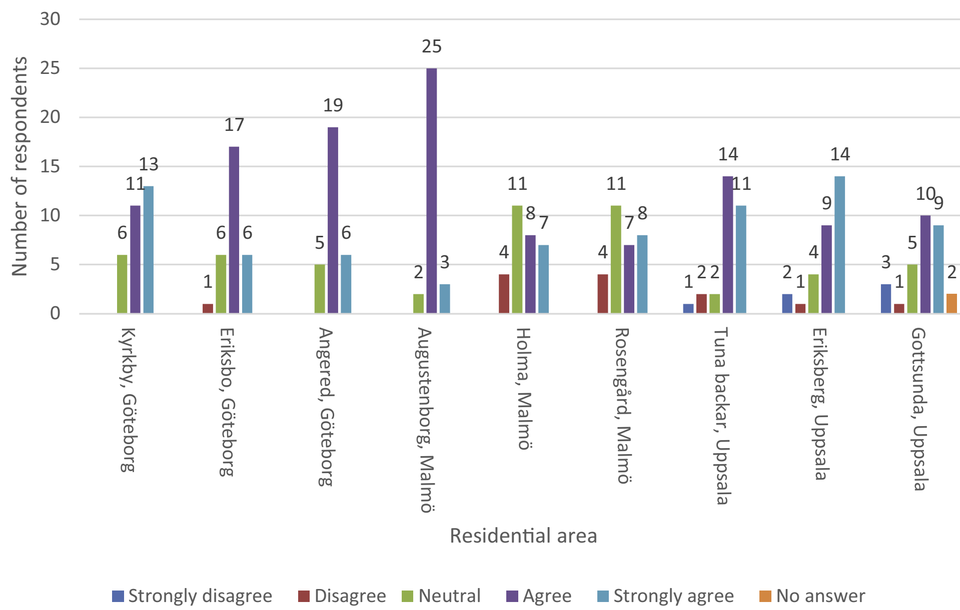

Fig. 6. Importance of well-maintained lawns in multifamily houses (Million Programme and People's Homes).

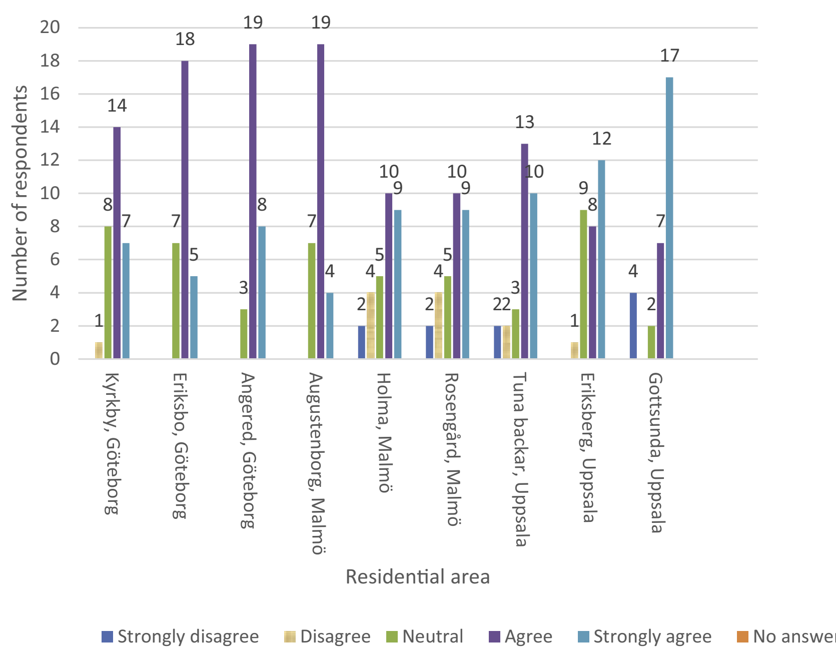

Fig. 7. The value of the lawns as a suitable place for leisure activities.

mentioned the importance of lawns on hot summer days in particular, but some people said that they used the lawn "all year round if the weather is good" and in places where they can enjoy the sun and also get some shade. Some respondents said that they avoided places that are windy, noisy, unattractive, less well managed or containing "unpleasant people".

When asked about lawns as an important aesthetic place, most respondents really appreciated lawn as an "enjoyable" and "beautiful place" (Fig. 11).

Many of the spontaneous comments also confirmed that people like well-maintained green places between and around buildings.

When we asked if lawns generally create a good habitat for small creatures, such as insects, birds and mammals, many participants replied that lawns do not have much value for biodiversity and are not a good place for many living creatures. One of the participants said that the lawn "is not a place for nature, it is cut too often", another said it was "too sterile an environment" and "too monotonous". Others said that the well-managed lawn is nice because you can have a good line of sight. Aesthetic values were often highly appreciated and places with such values were frequently used or visited. The green colour of lawns was also mentioned by people as a valuable feature.

We could see no significant differences in answers between cities as we researched two similar housing types in each city. However we observed some particular attitudes to lawns

in People's Home areas related to particular local geographical or design features. For example, Augustenborg (Malmö) is one of the best examples of the urban eco-concept, with the installation of stormwater management devices such rain gardens, detention ponds, green walls and green roofs. Green areas between

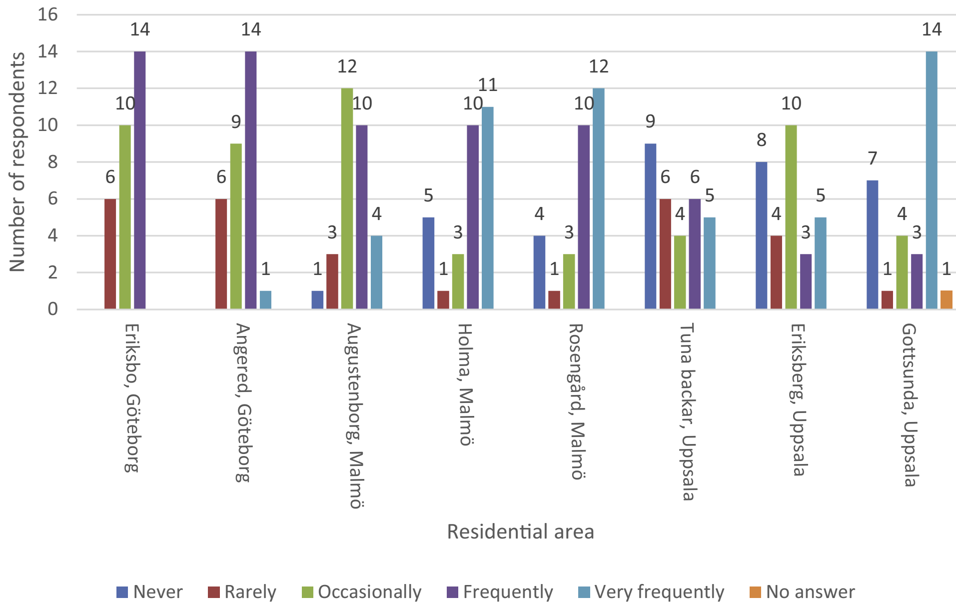

Fig. 8. Usage of lawns as a passage in multifamily housing areas.

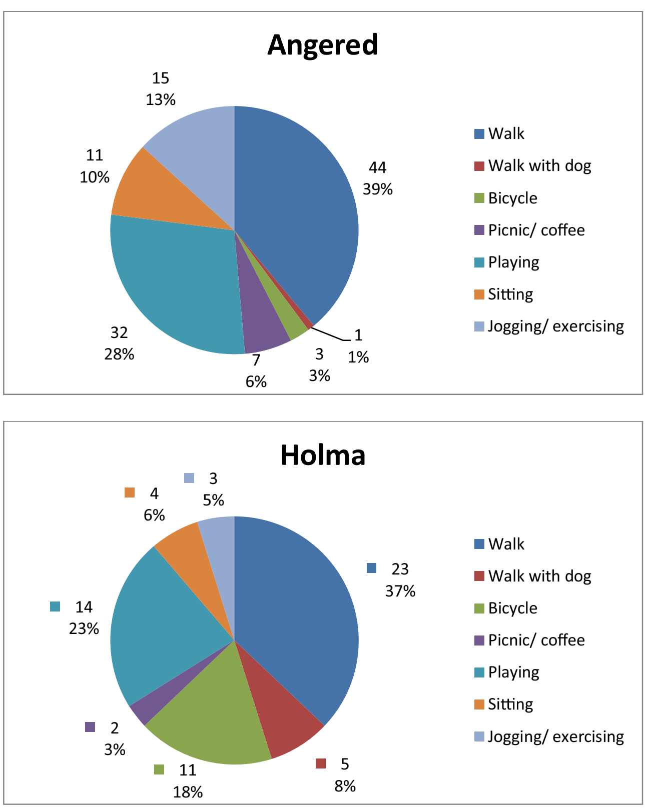

Fig. 9. Two examples of typical activities on a sunny summer day in the two Million Programme areas in Malmö. People often preferred 'mobile' activities on or beside the lawn (pathways).

houses have small ponds. Local dwellers were very proud of their neighbourhood having such an "eco" status and they enjoyed and especially actively used those lawns leading to the ponds. In Kyrkbyn (Göteborg) people were particularly concerned about losing a specific lawn adapted to the local nature, such as a spot (located on an elevated rock) which was about to be removed due to the construction of a new building (densification).

Fig. 10. 'Direct' use of lawn; relaxed reader in Augustenborg (People's Home, Malmö) on a warm day in August 2015.

In Million Programme areas, due to their planning character, there are a lot of unused monotonous lawns (more than in the People's Home areas) and even some "dangerous" lawns which people avoid using because of "suspicious activity".

The most attractive and actively used lawns were those with topographic variation Holma Hills (in Malmö) covered with a conventional short-cut lawn or those turned into a neighbourhood attraction (fountain or playground as in Angered (Göteborg)). In residential areas, lawns with 'attractions' (organised or planned for activities or for the senses) were used much more actively for recreation.

Regarding the answers to question 5 (Fig. 4) about alternative lawns, people had quite a range of opinions. There were some nature enthusiasts who would like to see flower-rich meadows and said that "it is certainly good for the environment" and "it could save money and is worth having", but many people still preferred more tidy, conventional lawns but also argued that meadows could be "very good in some places". Some respondents believed that such places looked untidy and some were even afraid of snakes or ticks in tall grass close to buildings. This opinion can probably be explained by the fact that residents had not previously considered or seen such alternatives.

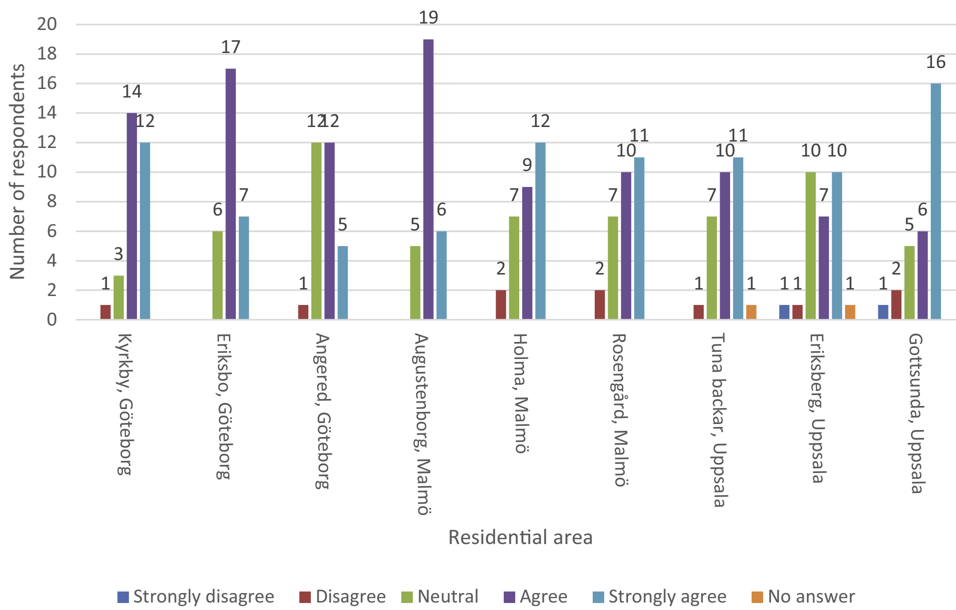

Fig. 11. Aesthetic value of lawns in multifamily housing areas.

Many people found grass-free lawns (lawns with low, flowering native herbaceous species) "amazingly beautiful" (for example 19 of 30 respondents in Kyrkbyn, Göteborg). However, people expressed a fear about walking on such lawns because of possible damage to plants and about picking the flowers, which could destroy the beautiful flowering carpet. One reason for this reaction could be a lack of information or the novelty of this kind of 'lawn'. For many respondents, these kinds of flowery lawns were similar to flowerbeds.

Perennial meadows framed by mown grass areas received positive feedback from respondents in many cases. For example in Kyrkbyn, 22 out of 30 respondents were positive about this design and said that it would be good to have such a meadow since "we have a large area that is not used". They mentioned that "meadows can be good for children; I think more people would be able to appreciate it".

Our third alternative scenario of pictorial annual meadows received less enthusiastic feedback. Respondents thought that this type would be good to use "in large areas not used for other activities" or "outside residential areas". One comment from many people was that they did not want to have such meadows close to buildings.

When we asked what people would like to suggest for improving green areas, they mentioned "have more Swedish flowers", "more colour", "opportunities to have nice seating areas with tables and benches, pieces of art, more trees and water features".

4.3. Managers' and decision-makers' vision of lawns

Managers in all three municipalities had quite similar visions of lawn management. The majority of lawns in Sweden are conventional, regularly-cut grass communities, cut 12–20 times per season to a height of 4–10 cm (Andrén, 2008). However, each municipality surveyed had its own subcategories of conventional lawns and meadow-like lawns, depending on the management regime (number of cuts and removing or leaving clippings on the surface).

Swedish municipalities normally do not use herbicides or pesticides in their management of lawns. Due to the organisational and bureaucratic peculiarities of Swedish municipalities, it was difficult to obtain details about the management and maintenance of lawns. Construction and management were performed in several stages by numerous contractors that often did not follow managers' instructions exactly. A common finding in our interviews with garden managers was their concern about high costs related to lawn management (very frequent mowing of conventional lawns). All three municipalities spent twice as much money per unit area on the management of conventional lawns compared with meadow-like lawns, which was why managers were quite open to considering alternatives to traditional lawns.

Many professional stakeholders interviewed, including landscape architects and park managers, believed that residents want to have short, manicured lawns (Eshraghi, 2014). Managers in Swedish municipalities have a quite practical maintenance "thinking". For example shrubs, trees, rocks and benches were seen as "obstacles" to mowing lawns with water features, such as ponds, requiring great maintenance efforts. The dichotomy is that on the one hand, people in multi-family areas want to have more tables and benches on the lawns, but lawnkeepers often do not like residents eating on these lawns and leaving food leftovers, since this attracts "undesired" wildlife such as rats, rabbits and wasps. On the other hand, some stakeholders stressed that people are interested in places where they live and would like to participate in improving them.

The politicians interviewed were in complete solidarity with the managers and professionals; their definition and understanding of a perfect lawn was a smooth grass surface looking perfectly "green" and "good". "We have to have lawns. They have been here for hundreds of years". However, some of the interviewees in Uppsala stated that plain lawns can be boring and it would be nice to enrich them with other elements such flowers and trees (Eshraghi, 2014). All politicians and professionals (involved in lawn planning, design and management) strongly believed in the recreational, aesthetic, physical values of lawns and its mental health values for citizens. It was also revealing that the majority of politicians and even professionals interviewed were aware of the environmental issues that conventional lawns can cause, but would still prefer "familiar" conventional lawns.

5. Discussion

Our social studies showed that people like lawns even if they do not always directly use them. For the majority of people, lawns are

Fig. 12. "Cues to care" in the Portland neighbourhood in London, UK where meadow is framed by traditional lawn that is actively used by local residents (May 2015).

just a given element of green areas. Lawns cover the most significant amount of outdoor area in most multi-family residential areas and accompany people everywhere. This conclusion corresponded with the main outcome of research by Kaufman and Lohr (2002) on social norms (and the reasons behind it) of well-maintained lawns in front gardens in central Iowa. When the Iowa Turfgrass Industry was asked about the percentage of homes that have a front lawn, the answer given was that it is a universal phenomenon. Despite differences in the planning structure of US and Swedish cities, lawns are a part of the modern urban social psyche. Kaufman and Lohr also argues that from a social point of view, grass "with its aesthetically pleasing colour and uniform texture, fosters a sense of well-being" (Kaufman and Lohr, 2002 p. 293). Another outcome of this US research can be also correlated with our conclusion that having a well-maintained lawn is considered to be the "normative" practice. It is particular supported by the results of our interviews with politicians, urban planners and gardeners in Sweden. The only difference is that private homeowners in the US dominate residential areas and keep their lawns well maintained. The dominancy of the well-kept green carpet can most likely be explained by common knowledge conveyed in the mass media and national and local guidelines on green areas planning, design and management.

Another interesting parallel between the US and Sweden is that not all people adhere to the 'norms' of a manicured lawn. They are called conformists and nonconformists (Kaufman and Lohr, 2002), In our study, when asking question about different options for alternative solutions to lawns, in each case study we had 'nature enthusiasts' who preferred more nature-like 'messy' lawns.

The question of introducing and establishing alternative lawns in the urban environment is being discussed today in Germany, Switzerland, France, Austria and Sweden (Ignatieva and Ahrné, 2013), England (Woudstra and Hitchmough, 2000; Smith and Fellowes, 2014), Australia and New Zealand (Ignatieva, 2010). In the USA, the search for an alternative solution to front garden lawns is especially acute in states such as California, Arizona and Florida with their shortage of water (The Florida yards and neighborhoods handbook, 2015). In Sweden 'pictorial meadows' with annual plants and meadows with native grasses and perennials are established in a few public parks and traffic islands. In our research, alternative lawns were appreciated by many citizens as well as politicians, planners and managers. However, the implementation of new approaches requires special planning and design solutions adjusted for each particular neighbourhood. For example, the residents interviewed here believed that meadows definitely had aesthetic and biodiversity values, but were not useful for some activities and should be located on the periphery of the garden or green area. However, some people were keen to know more about alternative options to conventional lawns. There is a paradox here in people's perception of lawns ("essential", "norm" feature) and the use of lawns in reality. The preference for the middle choice in Fig. 4 (Image 2) out of the three alternatives clearly shows the importance of the 'cues to care' approach when there is a clear indication of the presence of design and human care in meadow-like lawns in residential neighbourhoods (Fig. 12). The 'cues to care' approach was introduced by J. Nassauer as one of the possible solutions for suburban American front gardens (Nassauer, 1995).

There was quite surprising interest and a positive response from Swedish residents to grass-free (tapestry, low-growing flowering perennial herbs) lawns, possibly because modern people are hungry for colour and variety in their cities. Another explanation is a growing awareness and gradual acceptance of 'wild' urban nature (Weber et al., 2014) in some European countries.

Fig. 13. Suggestion for lawn modification in a People's Homes area in Göteborg, with shaded meadows and pictorial annual meadows (Andersson and Bergbrant, 2015).

In other projects related to the recent densification programmes in Swedish municipalities, planners, researchers and residents are concerned with a growing shortage of green space in which to meet, play and enjoy (Berg et al., 2015). The lack of green spaces in dense neighbourhoods also results in less light, more noise and social crowdedness in courtyards and streetscapes. One of the most important conclusions of our research is that people do not want to see a monotonous lawn, but a variety of spaces that provide good conditions for different senses (sound, smell, touch and sight) and social activities. This outcome is directly connected with the initial organisation of the urban planning structure and the creation of varied well-functioning private, semi-private and public outdoor spaces that can be attractive for a whole range of activities (voluntary or self-imposed or social) (Gehl, 2001). Lawns that serve as social meeting and activity points should be intensively managed, while lawns and green spaces that are not used should be considered for alternative designs (Fig. 13). Many urban lawns could have been developed as attractive places and spaces for a variety of activities if planners and landscape designers had originally thought about including elements for the senses and for being active.The planning and design of lawns should be guided by people's need for variety, but also by cost efficiency and environmental benefits.

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Estimating urban lawn cover in space and time: Case studies in three Swedish cities

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Abstract Lawns are considered monocultures and lesser contributors to sustainability than diverse nature but are still a dominating green area feature and an important cultural phenomenon in cities. Lawns have esthetical values, provide playground, are potential habitat for species, contribute to carbon sequestration and water infiltration, but also increase pesticides, fertilization, are monocultures and costly to manage at the same time. To evaluate the potential impact of lawns, whether positive or negative, it is of interest to estimate the total lawn cover in cities and its change over time. This is not a straightforward process, e.g., because many lawns are small and covered by trees. In this study we review the existing literature of lawn cover in cities and the different methodologies used for cover estimation. We found both pros and cons with NDVI and LiDAR data as well as manually interpreted aerial photos. The total cover of lawns in three case study cities was estimated to 22.5%. By extrapolating these percentages to all Swedish cities lawn cover was estimated to 2589 km^2 (0.6% of the terrestrial surface). The approximated total municipal management cost of lawns in all Swedish cities was 910,000,000 USD/year. During 50 years lawn area almost doubled in relative cover and 56% of them were continuously managed. Since lawns constitute large parts of the urban greenery and are costly to manage it is highly relevant to consider their social, ecological and cultural value compared to alternatives, e.g., meadows with less intensive management.

Keywords LiDAR · Orthophoto · Grassland · Meadow · Turf · Management

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Introduction

The existing research of urban green areas and their sizes, qualities and areal changes over time have been focusing on urban greenery in general and rarely on urban lawns (also called grasslands, turf grass, meadows) although lawns are common in cities all over the world. Lawns are however mostly noticeable in the western world in particular but through modernization processes in, e.g., China there has been a fairly recent rapid increase in the establishments of lawns (Ignatieva et al. 2015).

The lawn has supposedly become such an important component of cities due to the numerous ecosystem services lawns provide (Johnson 2013); e.g., good opportunities for activity as sport fields promotes good health, visual esthetic values that increase well-being, carbon sequestration, urban heat regulation (Wang et al. 2016) area for water infiltration (Armson et al. 2013), noise reduction (Fang and Ling 2003) and as substrate for biodiversity, especially when managed as meadows (Ignatieva et al. 2015). However, lawns also have negative effects due to the high use of pesticides (e.g., 17% of the insecticides used in USA are used for lawns; Milesi et al.

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2005, but the usage of pesticides vary a lot between different regions of the world), fertilizers, vast water consumption (Runfola et al. 2013) and potentially high management costs. Thus, it is of interest to know the areas of lawns in cities to be able to understand the extent of the potentially positive and negative effects.

The basic problem in estimating size and distribution depend on the fact that lawns are very scattered (small parcels) within the cities. The majority of the existing literature of lawn cover in cities is based on either aerial photos (orthophotos; Akbari et al. 2003; Attwell 2000) or LiDAR data (a surveying method that measures distance to a target by illuminating that target with a laser light, the acronym stands for LIght Detection And Ranging; Han et al. 2014). However, many studies seem to combine different techniques such as aerial photos with other remote sensing data (Robbins 2003; Milesi et al. 2005). Many studies use vague explanations on how lawn areas were defined (Stewart et al. 2009) or equaling lawns with other herbaceous vegetation such as flowerbeds and vegetable patches; (Edmondson et al. 2014). Even detailed studies of urban grasslands such as the one made by Fischer et al. (2013) do not map domestic gardens separately because they are so numerous, scattered and small and thus limits the size to >500 m^2 and, e.g., assume that smaller parks includes grasslands.

Areas of lawns may vary in different urban settings, e.g., residential gardens in the city of Koge in Denmark had 31.4% lawn cover, single family housing areas 31.8%, high density and low rise houses 43.5%, apartments 35.5% and city center 31.3% (calculated from Table 1 in Attwell 2000). Studies do, however, seem to be skewed towards non-public residential areas where residential gardens in Christchurch in New Zealand had 47% cover (Stewart et al. 2009), in the city of Sacramento in USA 24.5% (Akbari et al. 2003), in Sheffield in U.K. 41.5% of the gardens had >75% cover of lawn (Gaston et al. 2005). Robbins (2003) estimated total cover of lawns in private lots on a larger scale (Ohio county in U.S.A) to be 23%. They (Robbins 2003) used black and white aerial pictures of 63 gardens removing tree cover, garden cover (supposedly e.g. flower beds), sidewalks, driveways, porches and considered the remaining area as lawn and extrapolated this onto state size of lots. Milesi et al. (2005) is the only study, to our knowledge, that estimated total cover of lawns in one country (of all types of urban settings). They (Milesi et al. 2005) used an indirect approach removing impervious surfaces, trees and other undeveloped areas and assumed surface of turf grass to be the inverse of that area. Milesi et al. (2005) used a combination of nightlight measures to estimate impervious surface in combination with aerial photos along transects in 13 major urban centers which later were extrapolated to the whole of USA. The results revealed turf grass on 1.9% of the total area of USA (approximately 163,800 km^2).

Milesi et al. (2005) argue that turf grass rarely can be identified using satellite data due to low resolutions. However, since 2005 remote sensing techniques, including high intensity of LiDAR data where multilayers of urban vegetation can be detected, has developed a lot (Han et al. 2014). However, Han et al. (2014) argue that LiDAR data need to be validated in field and that laser data varies in intensity and thus also varies in potential to be used for mapping of urban greenery. In a review of satellite remote sensing in urban settings, Patino and Duque (2013) conclude that many scientists working on regional levels remain skeptical that satellite remote sensing will provide useful information on local scales. Thus, despite the available developed techniques the area of lawns still remains difficult to estimate.

Further, few studies investigated lawn continuity over time although lawns are an old cultural phenomenon, e.g., in Western Europe where they date back to medieval times (Ignatieva et al. 2015). Robinson (2012) has, as one of the few, estimated land cover composition change between 1960 and 2000 at parcel level in an exurban residential area in Michigan USA. The study found an increase in residential areas over time, as well as an increase in tree cover, but that lawns became proportionally smaller when parcels became larger (potentially due to the costs of maintenance of fertilization and the intensity of labor). Huang et al. (2014) used Robinson's results to estimate carbon uptake over time. Fischer et al. (2013) found that historical parks have higher species richness than other grasslands in the city suggesting that there may be a positive relationship between continuity in management of lawns and biodiversity.

The overarching aim of this paper is to use and evaluate different methods to estimate urban lawn cover in space and time in urban areas. We extrapolate lawn cover of three cities to estimate total national cover of lawns in Sweden and a theoretical management cost. We test NDVI (normalized difference vegetation index), LiDAR and aerial photos and discuss the potentials of each method for estimating urban lawn cover. We estimate how large proportion of present lawns that have been managed for more than 50 years using black and white aerial photos from the 1960's. Finally we discuss how of present lawn area and the changes over time affect the potentials for different ecosystem services.

Methodology

Study sites

Three major cities in Sweden are used as case study cities, Gothenburg (550,000 inhabitants and sized 45,000 ha), Malmö (270,000 inhabitants and sized 7681 ha) and Uppsala (140,000 inhabitants and sized 4877 ha). The cities are located in the Southern third of Sweden (South of the river Dalälven), where more than 86% of the Swedish population lives (Statistics Sweden 2012). These cities are among the four largest cities in Sweden (only Stockholm is larger) and are located in different parts of Sweden and in different landscape context. Malmö is situated in an agriculture dominated area in the south, Gothenburg in a forested area with a lot of bare rocks on the west coast and Uppsala is based in a landscape consisting of mixture of forest and agricultural land (approximately 50% each) in eastern Sweden. They represent potentially different climate conditions and local cultures in management and establishment of lawns (Ignatieva et al. 2015). These three cities are further studied in a major transdisciplinary project about lawns where two urban Multi-family residential housing neighborhoods that are rather unique for Sweden are investigated; Million program Housing and Post war "Peoples home" where approximately 50% of the Swedish population live (see Ignatieva et al. 2015). In Sweden 85% of the population live in urban areas (Statistics Sweden 2012).

Public lawns in Swedish cities are managed both by municipalities and private owners. It is common that, e.g., people in multifamily housing own the lawns and manage them but still allow the public to use them. In, e.g., Uppsala the Swedish church and two Universities are major land owners beside the municipality, and manage their own lawns of which all are open for public use. Ownership of urban green areas in Gothenburg (G), Malmö (M) and Uppsala (U) is; Private person (G = 20%; M = 22%; U = 18.1%); Official institutes such as municipalities, universities etc. (G = 56%; M = 54%; U = 56%); Stock companies (G = 10%; M = 9%; U = 9%); Private or municipal tenants (G = 7%; M = 10%; U = 10%); Other or Unknown ownership (G = 7%; M = 4%; U = 8%) (from Statistics Sweden 2015). Thus it is difficult to know the area of lawns of an entire city through municipality protocols of lawn area management only. The municipality of Gothenburg manages a lawn area of 427.5 ha, in Malmö 516.3 ha and Uppsala 681.4 ha (information from nature and planning departments in Gothenburg, Malmö and Uppsala). The lawn areas that are municipality managed do not use fertilization or pesticides for maintenance (information from nature and planning departments in Gothenburg, Malmö and Uppsala municipality).

Mapping methods - LiDAR and NVDI

Light detection and ranging (LiDAR) data is based on illuminating a target with a laser beam, usually within the near infrared (NIR) wave lengths (reflecting a target on the ground that reflects up to e.g. an airplane with device). Each LiDAR return contains an intensity value (0 to 255) which depends on the reflectivity of the surface. Vegetation provides a relatively high intensity value due to its high reflectivity in the NIR wave lengths. The Normalized difference vegetation index (NDVI) is a value that can be calculated from the amount of light reflected in an image band of wavelengths in the near-infrared and red light. The index usually use images from space satellites, and indicates the amount of living vegetation. Normalized difference vegetation index is used for vegetation analyzes. This works because the vegetation often has high reflection in the NIR band and low reflection in the red visible band.

Gothenburg had high intense LiDAR data available and was thus used to test a method for estimating lawn cover. A smaller area (2 km^2) of the south central Gothenburg was chosen as a study area for LiDAR and NDVI studies (this area had suburban character, a mixture of multifamily housing and small private houses in Sweden; see Vogel 2014 for details). Orthophoto and LiDAR datasets was provided by the Building and Planning authority of the city of Gothenburg (Stadsbyggnadskontoret). The LiDAR data was collected at a height of 550 m with a swath angel of 20^o. It covered all of the study area and had 13.65 returns per m^2, each point with a 0.13 m diameter footprint (the area of the pulse when it hits the ground). The LiDAR data was classified into 10 classes, where class 1 (unassigned) and class 2 (ground) were of specific interest to this project and was gridded at a resolution of 1 m. Especially class 1 showed after a closer inspection to reflect pulses near ground level or on ground level, indicating potentials for high level of return pulses for lawns.

The orthophotos had a resolution of 0.25 m. The photos contained both IR and visible bands. A vector polygon dataset of all grass areas maintained by the municipality was used as a complement to the analyses. However, the municipality in Gothenburg (and Sweden in general) only manages their own lawns which are a fraction of total urban lawns.

To be able to extract the lawns from the intensity raster (LiDAR), an intensity threshold value was required. Based on manual comparison of the intensity raster and lawns visible on the orthophotos, and distribution of the intensity values of pixels in the municipal maintenance grass areas, the threshold was set to 150 (see Vogel 2014 for details). Since not only grass show intensity values >150, but also areas such as white paint on roads and other highly reflective surfaces, it was necessary to find a way to minimize the number of pixels indicating false grass surfaces. To do this, the raster was first run through a Majority filter tool; if a pixel has another value than at least 3 of its 4 cardinal points, the pixel gets the value of these 3 neighbors. In this process, outliers such as single non-grass pixels inside a grass area or grass pixels in the middle of a road, was removed. A region group tool was used, which groups any connecting clusters of pixels of the same value and gives the group a unique ID. To further filter out non-grass areas registered as grass, a grass area threshold value was set at 7 m^2 and all groups with an area smaller than this was removed. The threshold was set to 7 m^2 after visually comparing the results of different thresholds between 10 m^2 and 5 m^2 in the study area with the intention of keeping the threshold as low as possible while still removing the majority of non-grass surfaces registered as grass.

Mapping methods – aerial photos

In this study we used ArcMap 10.2 and the aerial photos included in the ArcMap background data from May 2015. The map features 0.3 m resolution imagery in parts of Western Europe (DigitalGlobe). The lawns were manually mapped (polygons) in three gradients from the urban fringe to the center part of the three cities Gothenburg (length of gradient =10,200 m), Malmö (length of gradient =7000 m) and Uppsala (length of gradient =5100 m; see Fig. 1). Gradients were located to cover largest possible length of urban areas, not crossing major rivers or lakes and leap in different directions (south–north in Gothenburg, east–west in Malmö and north-south in Uppsala). Four ha squares were interpreted every 500 m making the total interpreted area in all three cities 132 ha (N = 33 squares × 200 × 200 m). In Gothenburg n = 15 squares, Malmö n = 10 squares and Uppsala n = 8 squares.

All three cities have an outer border (urban fringe) defined by the statistics Sweden (Statistics Sweden 2013) and were clearly visible in the photos. The center (end) of transects were the medieval inner cities (e.g., in Uppsala the center is in the Castle originally built in 1549 A.D.). Prior to aerial photo interpretation a pretest using drones with high resolution photos was made showing that ArcMap background data had lower resolution but still enough for the purpose of interpreting lawns (i.e., drones would not add additional important information of lawns at the scale of cities but perhaps for local, in detail, studies of single urban green areas).

In each 4 ha square the total area of lawn, meadow (grass that according to municipalities in Sweden are only cut once or twice a year, information from nature and planning departments in Gothenburg, Malmö and Uppsala municipality), sport lawn (soccer fields), trees, shrubs, gravel (sport fields with gravel), bare rock (mountain rocks, very common in Gothenburg), bare soil, water, agricultural fields, bare soil and allotments (small scale gardening) were mapped. Land cover not classified as any of these categories was considered infrastructure (e.g., roads, houses, parking lots, industrial areas etc.). Subsamples of some areas in Uppsala were visited in the field to confirm cover under trees. In areas available for everyone, such as around churches and parks the areas underneath the trees were often (not always) covered by lawns. When some areas were hidden by shadows or trees Google earth street view was used to get an overview of the area. This was mainly done for areas shadowed by houses and trees in all areas except for gardens since it was difficult to see due to hedges and shrubs.

To investigate land-use and lawn cover in historical maps the same 4 ha squares were manually interpreted using black and white aerial pictures from Lantmäteriet (Swedish authority for property registration and geographical information). The photos varied in age between 1956 and 1963 depending on city and location along the gradients, but will hereafter be referred to as the 1960's photos (although in some cases dating further back). The orthogonal projections of aerial (ortho) have a resolution of 0.5 m (local variations may apply depending on flight height). Photo shooting took place mainly from 4600 m above sea level with scale at around 1:30,000 where scanning was made with 15 μm providing a resolution of 0.5 m / pixel.

Present cover that overlapped with cover in the 1960's was considered to be continuity lawns.

Fig. 1 Illustrates the methodology of how interpreted squares were chosen in the cities, Here illustrated by Uppsala city. The gradient of N = 8 squares (200 m^2, 4 ha) reaching from the urban fringe (upper corner) to the center of Uppsala (lower part of photo)

Results

LiDAR and NDVI

Using LiDAR a significant number of pixels indicated grass although located at roads where there is no grass in reality (for details see Vogel 2014). After filtering and limiting smallest grassland to 7 m^2 a lot of "road" grass disappeared. In the investigated area of 430.3 ha 56.9 ha were detected as grass, i.e. 13.6%. The IR (NDVI) captured vegetation very well but had major faults in distinguishing grass from shadows (see Fig. 2).

By comparing the municipally managed areas (with rather precise cover of lawn) with LiDAR data the results showed that the LiDAR detect about 42.6% of the total municipal lawn areas, the rest of the existing municipal lawns were classified as forests. Thus, LiDAR detected 13.1% although in this subsampled areas of Gothenburg it should be closer to 31% (Vogel 2014).

Lawn cover in three cities

Using manual interpretation revealed similar problems as the LiDAR data revealing that it was difficult to estimate lawn cover under deciduous trees. However, in contrast to LiDAR many of the aerial photos of the cities were taken prior to

Fig. 2 Detailed comparison of filtered LiDAR-based grass raster and NDVI raster. (**a**) show the basic orthophoto. (**b**) show the orthophoto overlaid by the filtered LiDAR based raster. (**c**) show the NDVI raster. The red circles indicate areas of interest. It is apparent from looking at all 3 circles that NDVI, in contrast to LiDAR, does not capture vegetation in shaded areas. When comparing (A) and (C) it can also be noted that it is hard to distinguish trees from grass in (C), (**d**) shows the intensity of LiDAR (modified from Vogel 2014)

leafing (May) which meant that it was possible to see the potential lawn cover under deciduous trees. Further, field visits and Google earth street map view helped in interpreting the maps in some situations. However, when there was coniferous trees (not revealing the substrates underneath) the area was interpreted as tree cover and not lawn.

The total cover of lawn in percent, based on a mean of all three cities was in 2015; 22.5%. In Gothenburg 15.0% (equivalent to 6750 ha lawn), in Malmö 20.5% (equivalent to 1578 ha lawn) and Uppsala 31.9% (equivalent to 1557 ha lawn). If merging all city area and lawn areas together (giving Gothenburg substantial relative more weight in the test since it has 15 transects) the total lawn area would be 20.8%. The lawn cover varied a lot between cities and along the gradients depending on the dominating type of housing areas (Fig. 3). Since the gradients were randomly positioned it was difficult to estimate the specific type of urban setting (e.g. residential areas, churchyards, parks etc.) affecting lawn cover along the gradient (in many places residential areas and multifamily housing were located together) although a general pattern was that lawn cover decreased along the gradient (Figs. 3 and 4). The lawns consisted of three different types, lawn (16.5%), meadow (3.3%) and sport lawn/soccer field (1%) in all cities combined.

The total cover of lawn in percent in 1960, based on a mean of all three cities was 12.6%. (Gothenburg 13.8%, Malmö 6.1% and Uppsala 17.8%). Here, the much lower cover of lawn partly depends on higher proportion of agricultural areas and allotments in the 1960's. (see Fig. 5 and Continuity of lawns below). Due to the low resolution of the black and white photos, taken 1960, it was difficult to distinguish meadows from lawns.

Based on our lawn estimations of each city, lawn consisted of 51.8% of the total green cover in these three cities (based on green cover estimation in Statistics Sweden 2015 which does not define lawns in specific). Thus, of all green areas in Gothenburg 52.5% was lawn, in Malmö 44.3% and Uppsala 58.9%.

Total lawn in Sweden

Since the LiDAR data missed approximately 57.4% of the "true" cover of lawns when comparing with the precise data from the municipality management plans, manual aerial picture interpretation was used to estimate cover of lawns in cities instead. Total urban land in Sweden is 1,150,450 ha (Statistics Sweden 2013) and assuming that the 22.5% cover of lawn is representative for all cities in Sweden results in a total area of lawn of 258,851 ha (2589 km^2). This represents 0.64% of the

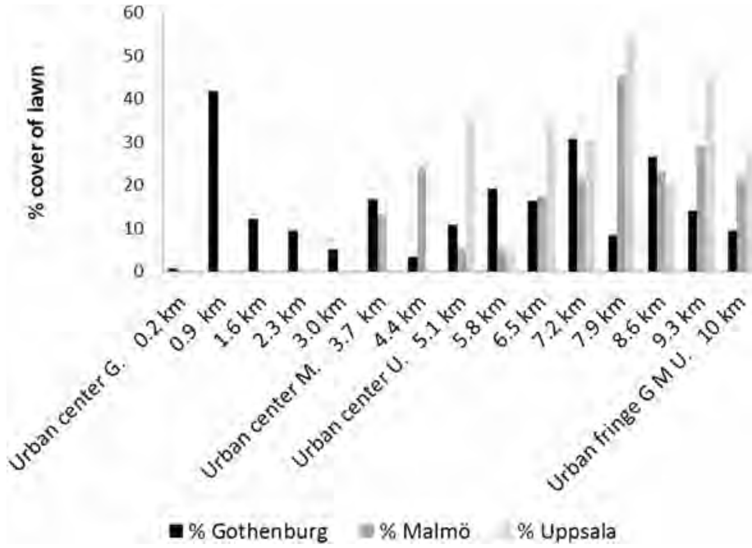

Fig. 3 Cover of lawn in each of the three cities along a gradient from urban center to the urban fringe in 2015. G = Gothenburg (total distance of gradient is 10 km) have 15 squares M = Malmö (6.5 km) have 10 squares and U = Uppsala (5.1 km) have 8 squares

Swedish terrestrial surface (2589 km^2/407340 km^2; Statistics Sweden 2013). However, large parts of the mapped areas were covered by coniferous forest, thus it was difficult to detect if lawns were underneath (even when using Google earth street view). If assuming the proportion of grass underneath is similar to the undetected lawns found under trees in Gothenburg when municipal management maps were used in Vogel (2014) would add 8.3% lawns in Sweden. Thus, that would increase the lawn estimation in cities to 30.8% (22.5% + 8.3% = 30.8%) with an area of 354,339 ha (3543 km^2, 0.9% of terrestrial surface). If all tree cover equaled lawn cover, the total terrestrial cover would be 407,259 ha (4072 km^2; 1% of terrestrial surface) but the true value is probably somewhere halfway (see discussions). No records of lawns underneath shrubs have been reported from any of the cities, thus we treat shrubs as totally lawn free areas.

Continuity of lawns

12.6% of the urban land is lawns with a continuum of at least 65 years. Thus 56% of the lawns in 2015 were equal to the ones in 1960 (12.6% / 22.5% = 56%). However, the outer 5 of the 15 squares in Gothenburg were agricultural areas or forest in 1960 and thus without lawns (Fig. 6). The patterns of continuity of lawn are difficult to compare along the gradients since the gradients were of different lengths in each city.

If all urban fringes in the 1960's are merged together (Fig. 6) the patters of continuity over the gradient resembles with highest continuity of lawns in the outer borders of the cities and lower towards center Uppsala center is an exception where the final square is in a botanical garden making the continuity of grass very high.

Management and costs

The total lawn cover estimated in this study was 9885 ha based on 22.5% coverage. Thus, on average 16.3% of the lawns in these cities are managed by the municipalities (in Gothenburg 6.3%, Malmö 32.7%, Uppsala 43.8%), the rest are privately managed.

Fig. 4 Illustrating three areas in the outer fringe of southern Gothenburg in 2015 on the left (upper square industrial area, middle multifamily housing and lower shows private houses) and the very same area in the 1960's where no houses or industry areas exists (only forests or agricultural areas)

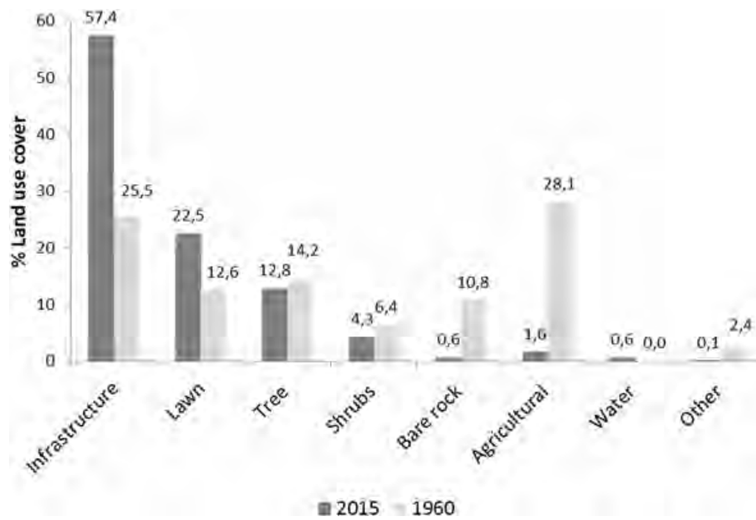

Fig. 5 Average land use cover of each of the three city areas in Gothenburg, Malmö and Uppsala in 2015 and in 1960. "Lawn" consists of all grassland types found in cities such as lawns, meadows and soccer fields. "Bare rock" is mainly occurring in Gothenburg. "Other" consist of areas that seemed to be gravel or bare soil

The costs of managing lawns in Gothenburg is 27,368 SEK/ha (3234 USD/ha), in Malmö it is on average 39,261 SEK/ha (4640 USD/ha) and in Uppsala 9601 SEK/ha (1134 USD/ha) (information from the Park and Nature department of each municipality). The average costs of all three cities is then 32,336 SEK/ha (3822 USD/ha). Thus, the management costs of lawns in all Swedish cities would be 8.37×10^9 SEK (32,336 SEK/ha × 258,851 ha) which is approximately 9.10×10^8 USD/year. The management costs only include cutting and maintaining lawns (dressing by occasionally adding soil and by cutting leaves in autumns) and not additional fertilization, no watering or pesticides since municipalities in Sweden do not use them.

Discussion

Total lawn cover in cities

The estimate of lawn cover with our method was on average 22.5% of the total city area and if extrapolated, 0.6% of the total terrestrial surface of Sweden (compared to USA where lawn was estimated to cover 1.9% of the area; Milesi et al. 2005). Although mapping was made in aerial photos prior to leaf setting on deciduous trees it was still not possible to detect lawn under coniferous trees (unless seen by Google earth street view or field visits). Some areas were found to be forests with bare-rock and no undercover vegetation (especially in Gothenburg), thus making lawn cover and total tree cover ratios equally was

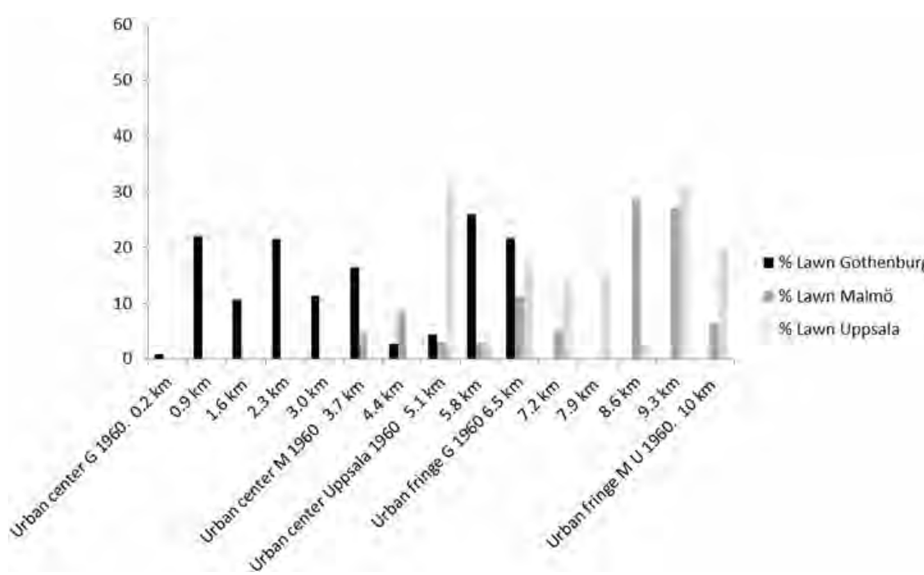

Fig. 6 The lawns cover along an urban gradient from the urban fringes to urban centers in 1960 in three cities. The urban fringe and centers in Malmö and Uppsala were the same in 1960–2015 (the gradient distances were the same, 8 respectively 10 squares). The urban fringe in Gothenburg was 3.5 km further out in 2015 (10 squares in 1960 and 15 squares in 2015)

not an option. However, most probably some of the mapped trees had lawn underneath and thus the lawn cover would most accurately be described as between 22.5% and 30.8% (0.6–0.9% of total terrestrial land use in Sweden).

The national cover is rather speculative since we only use subsamples of three cities (0.2% of total urban area in Gothenburg, 0.5% in Malmö and 0.7% in Uppsala) and the variation of lawns is supposedly substantial between different locations in each city and also different locations in Sweden depending on urban development and size of cities. However, total areas of the case study cities are 6.1% of the total urban cover in Sweden (based on Statistics Sweden 2012) and these cities are further presumably rather representative for urban green cover in the cities in southern Sweden (>86% of the population live) due to that their locations in three different dominating landscape types.

Comparisons between cities within Sweden and in other countries are difficult because many studies only focus on single cities or parts of the cities. If we assume that the 1.9% lawn cover in Milesi et al. (2005) was representative for cities in USA the lawn cover would be 42% (based on an urban cover of 4.5% in USA). Thus, it might be possible that the urban lawn cover in USA is twice in cities although the explanation could be due to that cities or urban areas were not clearly defined in Milesi et al. (2005) and presumably conditions that not exists in Sweden (such as low urban density and large parcels in urban sprawl areas) were included in their study.

Different methodologies and tree cover

In this study we used both LiDAR data and manually interpreted aerial photos. Each method has its pros and cons. LiDAR can easily detect numerous small and scattered lawn areas over large areas with low effort in time which contrasts the labor intensive digitizing of lawns manually (Robinson 2012) from aerial pictures. However, the methodology of LiDAR setting e.g., linking lawn to different intensity could initially be time consuming. The intensity of the LiDAR further varied quite much in the larger scale (of the entire city of Gothenburg) which depended on inaccurate calibration between the collection events (Vogel 2014). This meant that it was not possible to use the same grass thresholds (a value of >150 where grass was detected) for the whole of Gothenburg and further the data was separated into tiles making it impossible to manually set different intensity thresholds. This could however be avoided if the operators of LiDAR made intensity more even. A major obstacle with LiDAR was the difficulties in detecting lawns underneath trees with detection rate as low as approximately 43%. However, we see large potentials in further developing a grass area identification LiDAR model including estimations of grass covered by trees.

The manual photo interpretation method makes it possible to detect variations in the landscape and rather exact map lawn borders. In our case we could also use photos that revealed grass under trees to a large extent. However, it is time consuming to manually make polygons of each small lawn (approximately 4500 polygons in this study), and in addition LiDAR data is objective as opposed to aerial interpretation which is a subjective evaluation of borders and features. As for the black and white photos from the 1950s and 1960s the resolution made it difficult in some cases (not all) to detect differences between shrubs versus trees and lawns versus potential garden plots (in figures merged to “allotments”).

Thus, using LiDAR in our study underestimated lawn cover due to shade effects and tree cover. Tree cover is handled very differently in studies of lawns. Huang et al. (2013) used LiDAR and IR (infrared) orthophotos in a 300 ha area in Shanghai (China) to develop an automated method for calculating total urban green volume where all green areas not classified as trees were considered to be grasslands. Milesi et al. (2005) had an opposite approach assuming that tree cover was equivalent to lawn cover. However, in the case of Milesi et al. (2005), this might provide an overestimation of lawns since, e.g., studies in USA showed that in non-residential areas 50–70% of the areas under the canopies were paved surfaces and 35% in residential areas (Akbari et al. 2003). This bias of potential overestimation due to tree cover is especially pronounced if cities with large areas covered by such trees as in Northeastern USA where on average one third of urban land is covered by trees (Dwyer et al. 2000). This illustrates the problem with estimating true lawn cover in relation to trees.

Due to the labor intensive mapping we used a subsample of 4 ha areas along gradients and not total cover. Gradient analyses are to some extent questioned since cities of today does not clearly have a center and a border but are conglomerates where smaller cities are merged into each other (McDonnell and Hahs 2008). However, Swedish cities in general and these three cities in particular, do have clear urban fringes and defined medieval city cores.

The semi-objective sampling using 4 ha every half km is supposedly better than subjectively defining housing typologies since the borders of the housing area sets the limits for lawn estimations. For example, in a study investigating three typologies of housing in Sweden (residential gardens and two types of multifamily housing areas) the average cover of lawns were 27.8% (5.3% higher than in this study; Ignatieva et al. 2017).

Land use of lawns along gradients

Lawn cover varied between cities (15–32%) and along the gradients (5–55%) in 2015 (Fig. 3). General patterns along the gradients were that cover declined towards the city centers (in Gothenburg not as evident as in the other cities). This is most probably because cities in Sweden are denser towards the center. However, some clear exceptions are seen in Fig. 3 where high peaks in the center of Uppsala are due to a botanical garden and a high peak close to the center of Gothenburg is a major urban park. The general pattern of housing types along gradients was; residential areas and industrial areas in the fringes followed by multifamily housing (often highest coverage of lawns) and closer to centers with dense multifamily housing.

The lower cover of lawns in Gothenburg (7.5% lower than average) could be explained by large parts of bare rock (due to Gothenburg's location close to sea) and that it as a major city (with approximate 500,000 inhabitants) includes many industrial and densely populated areas along the gradient. An explanation to the high cover of lawns in Uppsala (9.4% higher than average) could be that the gradient did not cover any industrial areas or that it included multifamily housing areas such as the million program housing known for high lawn coverage.

Lawn cover along the gradient in the 1960's was much lower than in 2015 (Fig. 5). This is most probably due to a higher proportion of agricultural areas along the gradients. Further, it seemed as numerous residential areas had more garden plots (allotments in figures) or bare soil (bare soil was typology "other" in Fig. 5). Surprisingly, in Gothenburg, some places having bare rocks in 1960 had residential areas with lawns in 2015.

Continuity of lawns

56% of the lawns (or meadows) in Swedish cities in the 1960's remained lawns 50–60 years later (12.6% of the average cover of lawns in cities 2015 were the same as the ones in 1960). The highest cover of lawns with long continuity was found in all three urban fringes in the 1960's which resembles the patterns of lawns in 2015. As visual sized by the photos from 1960 many residential areas had allotments/garden plots instead of lawns and many gardens has since the 1960's densified and added one or more houses in the same garden reducing original lawns.

Since all three cities are old (at least a 500 years e.g. Uppsala have houses dating from 1280 A.D.) some of the present lawns may have been pastures or meadows for much longer than 50 years. The continuity of lawns as grasslands is important to biodiversity since they may have older seedbanks (Gustavsson et al. 2007), e.g., historic urban parks in Berlin have high species richness due to their habitat continuity (Fischer et al. 2013; Maurer et al. 2000). Thompson et al. (2004) found that lawns in cities had relatively well-defined plant communities with a species pool comparable in size to that of semi-natural grasslands. Although not suggested in Thompson et al. (2004) their unexplained higher diversity in lawns further from the city border of Sheffield may have been an effect of long continuity.

Ecosystem services and management

In Europe (and Sweden as well) there is an outspoken densification trend leading to reduction in available green areas per person (Statistics Sweden 2005) at the same time as new research highlight their importance for ecosystem services (Haase et al. 2014). Lawns in Swedish cities dominated the urban green with more than half of the areas being lawns and thus being potentially important as ecosystem service supporters.

However, management of lawns is costly. Reducing the cutting frequency to once or twice a year could make the lawns more meadow like and potentially provide a higher species richness of plants and butterflies and increase public enjoyment (Garbuzov et al. 2015). Already today 3.3% of the lawns were less often mowed (meadow typology). With longer continuity and low frequencies of mowing, in combination with removal of the grass-cuttings, existing grasslands could get more similar to semi-natural grasslands. It is obvious that urban lawns and meadows have an important role to play in the future landscape when it comes to grassland biodiversity. It is important to educate decision makers and practitioners of the connection between management for biodiversity and for beneficial ecosystem services. The management costs for lawns in this study varied highly between cities where e.g. Malmö had almost 4 times higher costs than Uppsala per hectare, this large variation should be further investigated.

The trend of increased densification of cities reduce availability of urban green per person in Gothenburg from 281 to 272 m^2 per persons during 5 years (exemplified year 2000–2005), in Malmö 154–153 m^2 and in Uppsala 261–251 m^2; Statistics Sweden 2005). Urban green is used for recreation and important to human well-being. However, lawns are not considered being as high contributors to well-being as forests (Tyrväinen et al. 2014) and more nature like areas (Ode-Sang et al. 2016). Studies even show not even private house lawns are seldom used (Norlin and Wissman unpublished).

Since lawns constitute such large part of the green areas in cities they are also an important part of the urban green areas citizens encounter in their everyday life. Thus, it is crucial for an ever increasing urban population to fully consider the social and ecological value and constraints of lawns. Finally, in order for decision makers to value lawns for their ecosystem services in relation to other urban green areas and the increasing need of green infrastructure reliable methods to measure lawn area and changes in time are important.

Conclusions

The methodologies tested in this study both had pros and cons. LiDAR data was very low in labor intensity (once the semi-automated procedure was established) while manually interpreted aerial photos took long time handling. Aerial photos enabled good detailed accuracy as for estimating borders and sizes of lawns while LiDAR made automatic estimations that sometimes included shadows and roads. The manually made polygons of lawn also have drawbacks since they are based on the interpreter's subjective interpretation in aerial photos while the estimates using LiDAR are objective. Major obstacles were how to do estimates of lawn cover beneath trees. LiDAR severely underestimated lawn cover under trees and aerial photos made it possible to find photos taken prior to leaf in spring. However, we predict that the future lies within LiDAR where new models will be able to identify estimations of grass overgrown by trees.

The estimated lawn cover was estimated to be between 22.5% and 30.8% (0.6–0.9% of total terrestrial land use in Sweden) depending on forest cover. Approximately 56% of the lawns were managed during the last 50 years. The yearly cost of managing lawns in the whole of Sweden (based on approximation of lawn covers of three cities and their average lawn cost per ha) was 9.14×10^8 (USD per year). Half of the urban green areas in cities constituted of lawns. Thus, it is important to consider social, ecological and cultural values of lawns compared to alternative urban greenery or alternative management of lawns as e.g., meadows with less intensive cutting regimes.

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Effect of grassland cutting frequency on soil carbon storage – a case study on public lawns in three Swedish cities

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Abstract. Soils contain the largest terrestrial carbon pool and thus play a crucial role in the global carbon cycle. Grassland soils have particularly high soil organic carbon (SOC) stocks. In Europe (EU 25), grasslands cover 22 % of the land area. It is therefore important to understand the effects of grassland management and management intensity on SOC storage. City lawns constitute a unique study system in this context, since they provide a high functional diversity and thus a wide range of different management intensities per unit area. In this study we investigated frequently mown (on average eight times per season) utility lawns and rarely mown (once per season) meadow-like lawns at three multi-family housing areas in each of three Swedish cities: Uppsala, Malmö, and Gothenburg. The two different lawn types were compared regarding their aboveground net primary production (NPP) and SOC storage. In addition, root biomass was determined in Uppsala. We found significantly higher aboveground NPP and SOC concentrations and significantly lower soil C : N ratio for the utility lawns compared with the meadow-like lawns. On average, aboveground NPP was 24 % or 0.7 Mg C ha^{-1} yr^{-1} higher and SOC was 12 % or 7.8 Mg ha^{-1} higher. Differences in SOC were well explained by differences in aboveground NPP ($R^2 = 0.39$), which indicates that the increase in productivity due to more optimum CO_2-assimilating leaf area, leading to higher carbon input to the soil, was the major driver for soil carbon sequestration. Differences in soil C : N ratio indicated a more closed N cycle in utility lawns, which might have additionally affected SOC dynamics. We did not find any difference in root biomass between the two management regimes, and concluded that cutting frequency most likely only exerts an effect on SOC when cuttings are left on the surface.

1 Introduction

Soils contain the largest terrestrial carbon pool (Chapin et al., 2009). The balance of soil organic carbon (SOC) inputs and outputs is therefore critical for the global carbon balance and thus for the concentration of greenhouse gases in the atmosphere. Globally, 3650 Mha or 68 % of the total agricultural area is used as pasture or meadows (Leifeld et al., 2015). In Europe (EU 25), grassland covers 22 % of the land area (Soussana et al., 2007). Grassland soils store among the highest amounts of SOC, which is primarily related to the high belowground carbon input by roots and their exudates (Bolinder et al., 2012). Soils rich in SOC are potential hotspots for CO_2 emissions when a management or land-use-change-induced imbalance in carbon input and output occurs. It is therefore important to understand the effect of management practices on grassland SOC storage. It has been demonstrated that the type, frequency, and intensity of net primary production (NPP) appropriation (harvest) can play a crucial role for the carbon balance and SOC stocks of grassland ecosystems (Soussana et al., 2007).

One direct management intensity effect on SOC which is mediated by grazing, cutting, or fertilisation regime is obviously the change in carbon input via the degree of biomass extraction and altered photosynthetic activity (Wohlfahrt et al., 2008). Furthermore, above- and belowground allocation patterns may change with cutting frequency (Seiger and Merchant, 1997). Recently, Leifeld et al. (2015) reported faster root turnover in moderately and intensively managed alpine grasslands than at less intensively grazed sites. They concluded that management is a key driver for SOC dynamics and should be included in future predictions of SOC stocks. Nutrient status, species composition, and diversity are highly management-dependent and interfere with the carbon cycle in several ways, including effects on the decomposer community and its substrate use efficiency (Ammann et al., 2007; Kowalchuk et al., 2002).

Management effects on SOC are presumably smaller than land use change effects such as conversion from permanent pasture to arable land (Poeplau and Don, 2013) and might not be visible in the short term. To assess those changes, it is therefore important to find suitable study systems with long-lasting strong contrasts in management intensity over a limited spatial scale and with limited soil variability. For agroecosystems, this situation is usually created in long-term experiments which are designed to study such questions. In a global compilation of all existing agricultural long-term field experiments, only 49 out of > 600 experiments are listed as including permanent grassland (pasture or meadow) (Debreczeni and Körschens, 2003). Thus, the current quantitative and mechanistic understanding of grassland management effects on SOC stocks is certainly limited, since existing studies are often strongly confounded by external factors such as elevation gradients (Leifeld et al., 2015; Zeeman et al., 2010). As an alternative to long-term plot experiments, urban areas can be appropriate study systems. Lawns, public green areas, and parks are omnipresent in urban areas and are usually managed in a similar way for a long time, so that, depending on the prior land-use-type equilibrium, SOC stocks might be approximated (Raciti et al., 2011). Over a comparatively small spatial scale, a wide range of different management intensities can be present.

Urban areas are more rapidly expanding than any other land-use type (Edmondson et al., 2014). Turfgrass lawns cover the majority of all green open spaces in urban landscapes (70–75 %) according to Ignatieva et al. (2015). It has been estimated that turfgrass lawns cover approximately 16 Mha of the total US land area, which in the 1990s was 3-fold the area of irrigated maize (Milesi et al., 2005; Qian et al., 2010). Although robust global estimates of the coverage of turfgrass lawns are scarce, these few existing figures indicate the potential importance of lawn management for the global carbon cycle. Furthermore, several studies have reported higher SOC stocks under urban land use as compared to surrounding soils, which might be a feature of high management intensity in urban ecosystems (Edmondson et al., 2012; Pouyat et al., 2009). There is thus a need to quantify the carbon footprint of differently managed lawns, for which SOC is of major importance. In the transdisciplinary Swedish LAWN project (http://www.slu.se/lawn), lawns were studied from social, ecological, and aesthetic perspectives (Ignatieva et al., 2015).

In this study, as part of the LAWN project, we analysed two types of lawn under different management intensity (cutting frequency) associated with multi-family housing areas which were intensively monitored at three sites in each of three Swedish cities. The objectives of the study were (i) to examine how cutting frequency affected NPP, SOC, and soil carbon to nitrogen ratio (C : N) and (ii) to reveal involved mechanisms causing differences in SOC between the two management regimes.

2 Materials and methods

2.1 Study sites

Public lawns in multi-family housing areas were investigated in three different cities – Gothenburg, Malmö, and Uppsala – and at three different sites in each city (Table 1). The nine selected multi-family housing areas were established at approximately the same time during the early 1950s. At each site, triplicate plots of two different lawn types were studied: utility lawn and meadow-like lawn, with each plot comprising one complete lawn. The utility lawn was kept short during the year and was mown on average every 18 days within the mowing period (eight times), which approximately corresponds with the growing period (May to mid-October in Uppsala, and April to late October in Gothenburg and Malmö). The meadow-like lawns were only cut once, or twice in the single case of one lawn in Uppsala (Tuna Backar). Grass cuttings were left on the surface on both lawn types. None of the lawns received any fertiliser. Grass species composition did not differ greatly between the cities, with about 5–10 different grass species abundant in utility lawns and meadow-like lawns. Utility lawns consisted of sparser, low-growing species such as *Poa annua*, *Agrostis capillaris*, *Lolium* spp., and *Festuca rubra*, while the most abundant grass species in meadow-like lawns were *Phleum pratense*, *Alopecurus pratensis*, and *Arrhenatherum* spp. (J. Wissman, personal communication, 2015). The size of the individual lawns was highly unequal with a range of 0.05–2.5 ha due to the heterogeneity of urban landscapes. To obtain representative average values for the whole individual lawn, we conducted all samplings described below adjusted to the size of the lawn, instead of using a “fixed grid”.

Table 1. Site characterisation with year of establishment; mean annual temperature [MAT, °C] and mean annual precipitation [MAP, mm] (1961–1990); and clay, silt, and sand content [%] as well as soil pH for utility lawns (U) and meadow-like lawns (M) for all three Swedish cities studied.

City	Site	Age	MAT	MAP	C : N	Clay		Silt		Sand		pH*	
						U	M	U	M	U	M	U	M
Uppsala	Eriksberg	1949	5.5	527	12.8	36	46	43	44	21	10	∼ 6	∼ 6
	Sala Backe	1950			12.5	45	45	47	51	8	4	∼ 6	∼ 6
	Tuna Backar	1951			13.1	33	23	47	45	20	32	∼ 6	∼ 6
Malmö	Kirseberg	1950	8.4	540	12.7	12	10	49	46	39	45	7.2	7.2
	Sibbarp	1953			13.8	15	15	48	47	38	38	7.4	7.8
	Augustenborg	1952			13.9	13	10	49	45	38	45	7.4	7.7
Gothenburg	Guldheden	1950[a]	7.4	714	14.1	16	14	45	44	39	42	5.5	5.4
	Kyrkbyn	1955			12.0	16	22	62	55	21	23	5.8	5.7
	Björkekärr	1950[a]			12.8	14	16	49	58	37	27	5.5	5.7

[a] year only approximate. * pH values for the Uppsala sites were not measured, and the values shown are estimates based on typical values for soils in Uppsala (e.g. Kätterer et al., 2011).

2.2 Estimation of aboveground net primary production and root biomass

Aboveground NPP in the utility lawns was estimated by repeated sampling of aboveground biomass after the first mowing in spring by the local authority. Sampling was conducted on average 12 ± 6 days after each mowing event. For the meadow-like lawns, biomass was collected on several occasions even before the mowing to determine total growth at that specific time. After the first cut, meadow-like lawns were treated as utility lawns. The plots were sampled at four locations using a 50 cm × 50 cm square frame. Sampling locations were selected to be representative of the total lawn area, so therefore sampling under trees or in proximity to other vegetation was avoided. Repeated sampling was not conducted on the identical sampling locations. The harvested biomass was dried at 70 °C, weighed, and multiplied by 4 to obtain the biomass for 1 m^2. The mean of the four replicates was divided by the number of days between the last cutting and sampling to obtain daily growth rate. This growth rate was extrapolated to cover all days between previous sampling and next mowing for which no growth rate was determined. On average, this period accounted for 7 ± 6 days after each cutting event, and thus data coverage (time for which the actual growth rate was measured) was more than 82 ± 6 % for the period between 1 January and the last sampling date, which was on average on 5 October ± 7 days. On the basis of these daily growth rates, we calculated cumulative growth until the last sampling. Since this day varied slightly between plots and sites, we fitted a simple vegetation model based solely on the plant response to air temperature, as developed by Yan and Hunt (1999) to each growth curve in order to determine the regrowth after the last sampling until the end of the vegetation period. The original equation is

$$r = R_{\max} \left(\frac{T_{\max} - T}{T_{\max} - T_{\text{opt}}} \right) \left(\frac{T}{T_{\text{opt}}} \right)^{\frac{T_{\text{opt}}}{T_{\max} - T_{\text{opt}}}}, \qquad (1)$$

where r is the daily rate of plant growth, T is the measured temperature at any day, $T_{\max}$ is the maximum temperature (which was set to 30 °C in this study), T_{opt} is the optimal temperature (which was set to 25 °C in this study), and $R_{\max}$ is the maximal growth rate at T_{opt}. Instead of using $R_{\max}$, which is used in Eq. (1) to scale the temperature response function to actual observed maximal plant growth at optimal temperature, we scaled the model by forcing the cumulated r through the cumulated NPP value on the date of the last sampling, as illustrated in Fig. 1 using the example of the Björkekärr site in Gothenburg. The good fit indicates that (i) the growth dynamics, and thus absolute growth, were well captured by the method used and (ii) the model fits provide an unbiased and standardised extrapolation of aboveground NPP for the entire growing period. Daily mean air temperature values for the closest weather stations of the Swedish Meteorological Service (SMHI) to Malmö and Gothenburg were downloaded from http://www.smhi.se/klimatdata. Daily average air temperature values for Uppsala were obtained from the Ultuna climate station run by the Swedish University of Agricultural Sciences (SLU).

Root biomass was only determined once, and only in Uppsala. In each lawn, four cylindrical soil cores of 7 cm diameter and 10 cm depth were taken at 0–10 cm soil depth. Aboveground plant material was removed and soil cores were thoroughly rinsed and then put in a water bucket to completely separate roots from soil. Roots were dried at 105 °C weighed and analysed for carbon (C) and nitrogen (N) content. Assuming a carbon content of 45 % for plant biomass, we were able to determine and subtract the adhering soil in the weighed root samples mathematically, as described in Janzen et al. (2002).

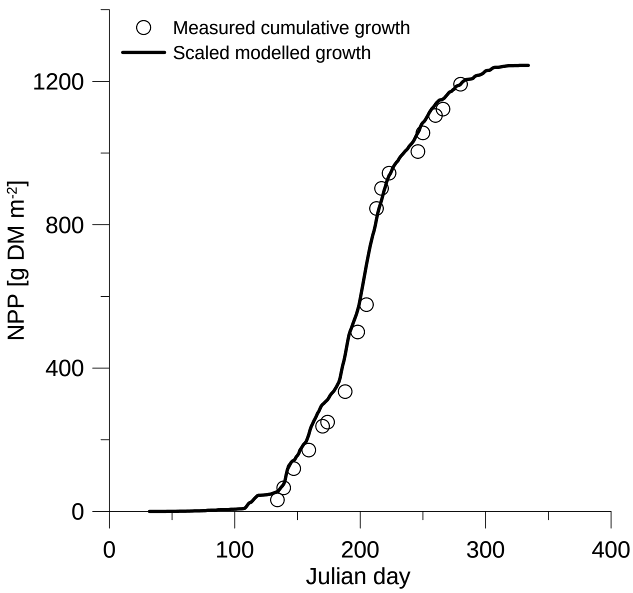

Figure 1. Example of the vegetation model (Eq. 1) fit to a calculated cumulative growth curve for a utility lawn in Björkekärr, Gothenburg.

2.3 Soil sampling, analysis, and SOC stock calculation

Soils were sampled in autumn 2014 to a depth of 20 cm using an auger (2.2 cm diameter). In each plot, 10 randomly distributed soil cores were taken and pooled to one composite sample. Soils were dried at 40 °C, sieved to 2 mm, and visible roots were manually removed. Soil pH was determined in water and samples with a pH value exceeding 6.7 were analysed for carbonates. Soil texture was determined with the pipette method according to ISO 11277. As a slight modification, wet sieving prior to sedimentation was done to 0.2 mm compared to 0.063 mm prescribed in the ISO method. Total soil carbon and nitrogen were determined by dry combustion of 1 g of soil using a LECO TruMac CN analyser (St. Joseph, MI, USA) and carbonate carbon was determined using the same instrument after pretreatment overnight at 550 °C. Organic soil carbon was calculated as the difference between total carbon and carbonate carbon. Soil bulk density [$g\,cm^{-3}$] was determined by taking undisturbed cylindrical soil cores of 7 cm diameter and 10 cm height in an approximate soil depth of 5–15 cm, drying them at 105 °C, and weighing them. Four samples were taken in each plot. To account for the fact that SOC stocks under contrasting management regimes should be compared on the basis of equivalent soil masses (Ellert and Bettany, 1995), we conducted a simple mass correction in which we first calculated the soil mass (SM) [$Mg\,ha^{-1}$] of each plot using the equation

$$SM = BD \times D \times 100, \tag{2}$$

where BD is the soil bulk density [$g\ cm^{-3}$] and D is the sampling depth [cm]. The lower average soil mass measured at each pair was then used as the reference soil mass (RSM) to which the other treatment of each pair (three pairs per site) were adjusted.

SOC stocks [$Mg\,ha^{-1}$] were then calculated using the equation:

$$\text{SOCstock} = \text{RSM} \times \frac{C}{100} \tag{3}$$

where C is carbon concentration [%]. At one site in Gothenburg (Kyrkbyn), one pair of lawn types had a large difference in soil texture, with 15 % clay in the utility lawn and 30 % in the meadow-like lawn. The SOC concentration varied by a similar amount (2.46 % compared with 4.58 %), which was an outlying high difference when compared with that of all other pairs. We attributed this to differences in soil texture and excluded this pair from the analysis. Apart from slight differences in soil texture, the basic assumption was that the underlying pedology and initial soil carbon stocks were similar for both lawn types, or at least not systematically biased. Differences in soil texture between lawn types at each site was further not correlated to differences in SOC concentration ($R^2 = 0.02$).

2.4 Statistics

All statistical analyses were performed with R software version 3.1.2. We used linear mixed effect models to analyse the effect of lawn management on aboveground NPP and SOC concentration and stocks using the R package nlme (Pinheiro et al., 2009). Management (utility vs. meadow-like lawn) was used as the fixed effect, while city and site were used as nested random effects (site nested in city). We used Tukey-type multiple comparison post hoc analysis (R package multcomp) to test the management effect at each site for significance ($p < 0.05$). Average differences in SOC stocks between the different lawn types at each site (dependant variable) were calculated and related to different explanatory variables (independent variables), such as average clay content, differences in clay content between lawn types (absolute and relative), soil pH, mean annual temperature (MAT), mean annual precipitation (MAP), and differences in aboveground NPP. Generalised linear models with Gaussian error distribution were used for multiple regression analysis. Model performance was evaluated using the Akaike information criterion (AIC). The variable “clay content” had to be transformed to approximate normal distribution. For both model approaches (mixed effect model and generalized linear model) we used residual plots to study whether (i) the regression function was linear, (ii) the error terms had constant variance, (iii) the error terms were independent, (iv) there were outliers, or (v) the error terms were normally distributed. All values in the text and diagrams represent mean ± standard deviation.

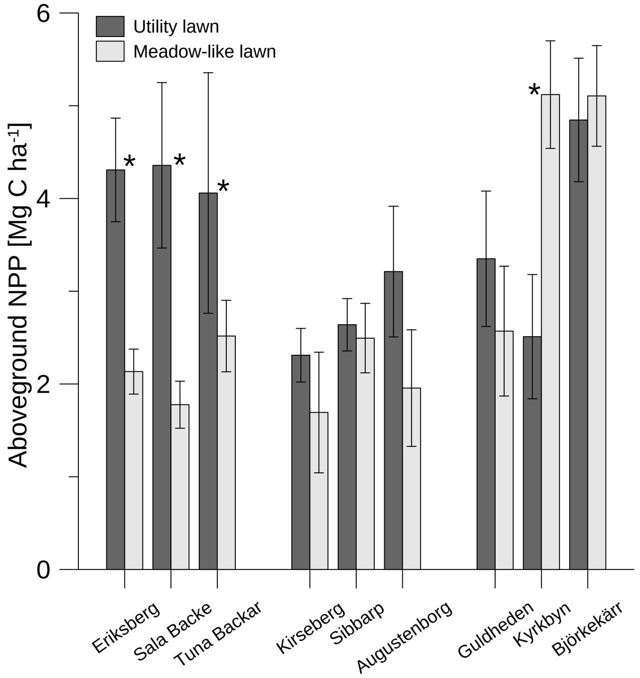

Figure 2. Bar plot showing estimated aboveground net primary production (NPP) of the two different lawn types at each site. Error bars indicate standard deviation and stars indicate significant difference between treatments at the specific site ($p < 0.05$).

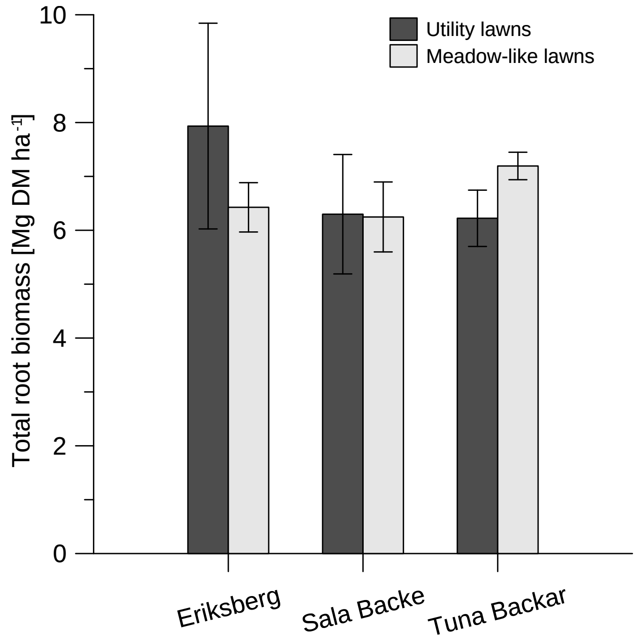

Figure 3. Bar plot showing total root biomass at 0–10 cm depth for the two different lawn types at the study sites in Uppsala. Error bars indicate standard deviation.

3 Results

Effect of lawn management on net primary production and soil carbon and nitrogen

The intensively managed, i.e. frequently mown, utility lawns produced significantly ($p = 0.003$) more aboveground biomass (NPP) than the meadow-like lawns, which were cut only once a year (Fig. 2). At seven out of nine sites, NPP was higher in the utility lawns than in the meadow-like lawns. The difference between the lawn types was most pronounced in Uppsala, where the average NPP of the utility lawns (4.2 ± 0.9 Mg C ha^{-1}) was twice that of the meadow-like lawns (2.1 ± 0.3). In contrast, two out of three sites in Gothenburg showed higher NPP on the meadow-like lawns. Across all sites, the NPP of the utility lawns was 24 % higher. Total root biomass, as investigated at the three sites in Uppsala, was not significantly influenced by management intensity and indicated a smaller ratio of belowground to aboveground NPP in meadow-like lawns (Fig. 3).

Concentrations of SOC were also positively affected by greater cutting frequency. Utility lawns had significantly higher ($p = 0.01$) SOC concentration than meadow-like lawns (Fig. 4). Again, the difference between the two lawn types was most pronounced in Uppsala, with an average SOC concentration of 3.9 ± 0.6 % in the utility lawns and 2.9 ± 0.9 % in the meadow-like lawns. In both Malmö and Gothenburg, we found one site with higher average SOC concentration in the meadow-like lawns. The calculated SOC stocks are listed in Table 2. The average SOC stock difference between the two differently managed lawn types was 7.8 Mg ha^{-1} or 12 %. The very similar patterns observed for the variables NPP and SOC suggest that the SOC changes were driven by NPP and thus carbon input. In fact, the difference in SOC stock between management regimes at each site was significantly correlated to the difference in NPP (Fig. 5). No other parameter added significant explanation to the model fit. Although clay content did not improve the model fit of the generalized linear model, difference in SOC stock also increased with average clay content ($R^2 = 0.26$, $p = 0.1$, not shown). This correlation is, however, strongly driven by the sites in Uppsala, which showed the highest increase in both NPP and SOC. Thus, local management differences, which are, however, not available in detail, might also have influenced the observed treatment effect on SOC to some degree.

The soil C : N ratio of the meadow-like lawns (13.2 ± 1.2) was significantly higher ($p = 0.007$) than that of the utility lawns (12.6 ± 0.7), indicating that the soil organic matter under the utility lawns was relatively enriched in nitrogen (Fig. 6).

Table 2. Soil bulk density (BD) [$g\,cm^{-3}$] and SOC stocks [$Mg\,ha^{-1}$] according to Eq. (3). Standard deviation is given in brackets.

City	Site	Utility lawn		Meadow-like lawn		Utility lawn		Meadow-like lawn	
		BD		BD		SOC stock		SOC stock	
Uppsala	Eriksberg	1.13	(0.04)	1.13	(0.16)	74.8	(11.4)	63.1	(8.7)
	Sala Backe	1.14	(0.03)	1.1	(0.07)	96.2	(9.3)	69.8	(24.2)
	Tuna Backar	1.15	(0.07)	1.21	(0.06)	72.4	(13.3)	47.6	(19.5)
Malmö	Kirseberg	1.03	(0.07)	1.02	(0.08)	69.4	(4.5)	52.7	(0.95)
	Sibbarp	1.04	(0.06)	0.98	(0.06)	75	(8.3)	96.4	(3.5)
	Augustenborg	1.03	(0.06)	1.18	(0.15)	59.1	(9.4)	50.3	(22.4)
Gothenburg	Guldhelden	0.87	(0.14)	0.88	(0.21)	86.2	(2.3)	78.4	(21.3)
	Kyrkbyn	0.99	(0.09)	0.88	(0.06)	68.2	(8.1)	77.9	(7.8)
	Björkekärr	0.96	(0.1)	0.99	(0.08)	67	(14.4)	61.2	(3.1)

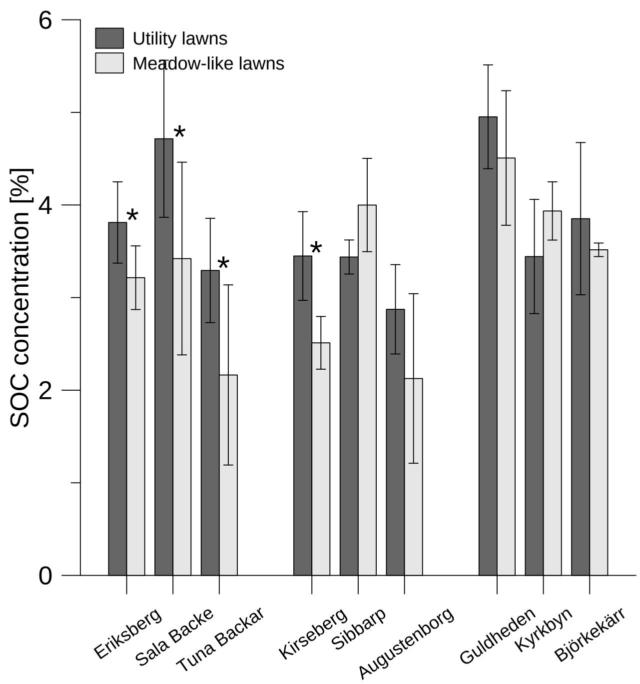

Figure 4. Bar plot showing measured soil organic carbon (SOC) concentration in the two different lawn types at each site. Error bars indicate standard deviation and stars indicate significant difference between treatments at the specific site ($p < 0.05$).

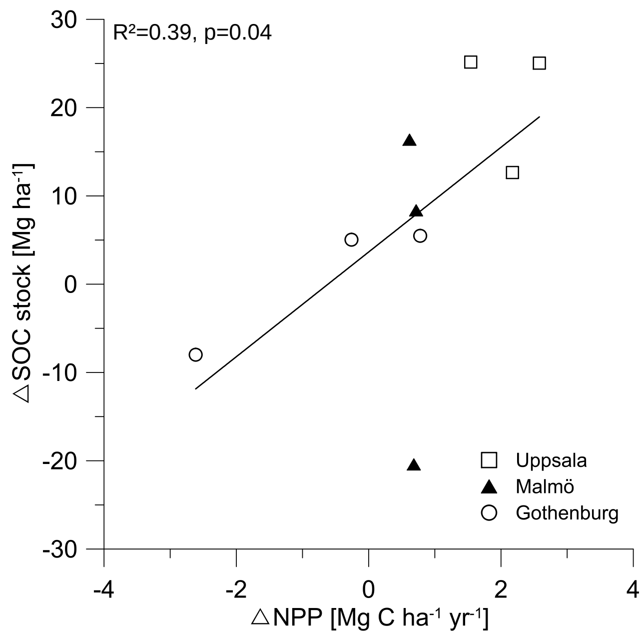

Figure 5. Difference in soil organic carbon (SOC) stock between utility and meadow-like lawns as a function of difference in aboveground NPP for all sites.

4 Discussion

4.1 Effect of cutting frequency on aboveground productivity

We showed that cutting frequency significantly altered the aboveground biomass production in urban lawns. This can be explained by the fact that canopy CO_2 assimilation is a function of the amount of assimilating plant matter (Wohlfahrt et al., 2008). Wohlfahrt et al. (2008) showed that when the green area index (GAI) of an alpine grassland exceeded $4\,m^2\,m^{-2}$, the gross primary production (GPP) decreased due to shading, but also due to plant phenology. Directly after cutting (three cuts per season), their grassland had a GAI of 0.5–2 $m^2\,m^{-2}$, while directly before cutting it had a GAI $> 6\,m^2\,m^{-2}$. The meadow-like lawns in our study were only cut once, which indicates that the period in which the GAI of the canopy exceeded the optimum for CO_2 assimilation was very long. In contrast, the GAI of the utility lawn remained relatively close to the optimum throughout the entire growing period. Furthermore, Klimeš and Klimešová (2002) found that frequent mowing promoted the dominance of efficiently regrowing plant species, which might provide an additional explanation for the higher NPP in our util-

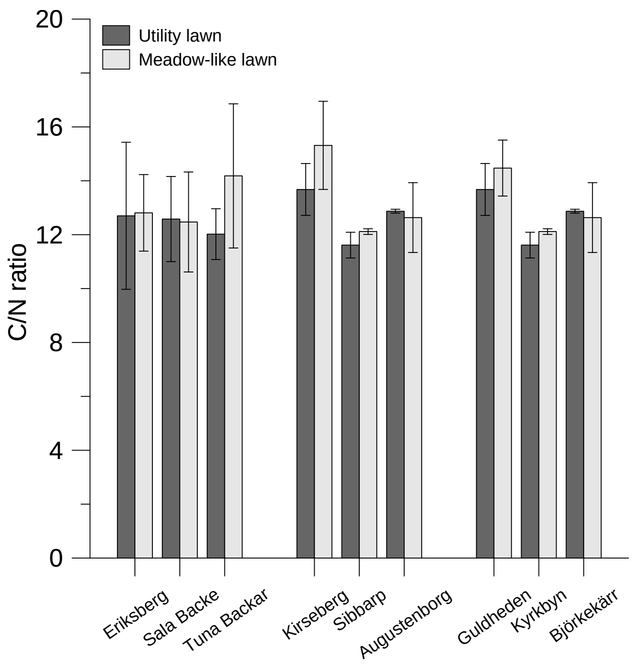

Figure 6. Bar plot showing measured C : N ratio of the two different lawn types at each site. Error bars indicate standard deviation.

ity lawns. Our results are also in agreement with Kaye et al. (2005), who found 5-fold higher aboveground NPP in an urban lawn than in a short-grass steppe. However, the urban lawn in that study was fertilised and irrigated, while the urban lawns in our study were not. In a long-term field experiment on cutting frequency effects on grass yield, Kramberger et al. (2015) found the lowest yield in plots with the highest cutting frequency (2-week intervals) and the highest yield in plots with moderate to low cutting frequency (8- to 12-week intervals). This is in contrast to our results from Uppsala and Malmö, but in line with the results from Gothenburg, where we found higher aboveground biomass in the meadow-like lawns. However, we are unable to explain the much higher NPP of the meadow-like lawns in Kyrkbyn.

4.2 Effect of cutting frequency on soil organic carbon in relation to similar management contrasts

The higher aboveground NPP in the utility lawns had a significant positive effect on soil carbon. This was expected, since the clippings were not removed and were thus able to contribute directly to soil organic matter formation. For this reason, the results of our study are not directly applicable to mown grasslands or leys, which are usually harvested. The responses of SOC to management intensity in those systems are not well studied, but studies performed to date show mixed results ranging from no effect (Kramberger et al., 2015) to significantly positive effects of high cutting frequency (Ammann et al., 2007). In the latter case, the difference in SOC stocks between intensively and extensively managed grassland was attributed to differences in N fertilisation, which caused N deficiency and thus N mining in the extensive grassland, leading to stronger mineralisation of stable organic matter. The effects of grazing intensity on SOC are much better studied than the effects of mowing intensity. Both positive (Reeder et al., 2004; Smoliak et al., 1972) and negative (Abril and Bucher, 2001; Su et al., 2005) effects of low compared with high grazing intensity on SOC have been reported. However, many of the studies reporting negative effects of intensive grazing refer to overgrazing in semiarid areas, which is associated with strongly reduced vegetation cover and soil erosion. The actual effects seem to be context-specific, as found in a global meta-analysis conducted by McSherry and Ritchie (2013). The found positive correlation of difference in SOC and average clay content across sites has to be interpreted with caveats, since a clear causality is not given. It is realistic that more of the C input is stabilised in clay-rich soils (Poeplau et al., 2015b). However, this correlation did not hold within the three sites at each city, which indicates that the correlation found of clay and difference in SOC, as well as of clay and difference in NPP, across all sites might also resemble a random city effect.

Overall, our findings and those of previous studies (Christopher and Lal, 2007; Poeplau et al., 2015a) confirm that plant input driven by NPP is the major driver for SOC dynamics. Root carbon input is recognised as being of major importance for building up soil organic matter, since a higher fraction of root-derived carbon is stabilised in the soil than in aboveground plant material (Kätterer et al., 2011). In temperate grasslands, up to 70 % of the total NPP is allocated to roots and their exudates (Bolinder et al., 2007). However, in the present study, management intensity did not significantly influence root biomass, indicating that root production was relatively favoured in the meadow-like lawns. A similar finding has been reported in a study which found higher root biomass under diverse swards than under conventional, intensively managed ryegrass-clover pastures (McNally et al., 2015). Altered root production could therefore not explain observed differences in SOC stocks in our study. However, the informative value of the obtained root data is certainly limited, since root biomass was only determined in one city, to a depth of 10 cm and at one point in time. It can thus not be assumed that the measured root biomass measured is representative of root growth throughout the season (Ziter and MacDougall, 2013). Furthermore, potential management effects on the depth distribution of belowground biomass cannot be inferred.

The proportion of aboveground plant material stabilised in the soil has been estimated to be 13 % in a Swedish long-term agricultural field experiment (Andrén and Kätterer, 1997). Similar values, i.e. around 10 %, have been reported in other studies (Lehtinen et al., 2014; Poeplau et al., 2015b). It can be assumed that lawn clippings undergo slightly lower stabilisation than straw in agricultural systems, due to the lack of mixing of residues with stabilising mineral soil particles (Wiesmeier et al., 2014). The mean annual difference in SOC sequestration between the two lawn types we studied was 120 kg C ha^{-1} yr^{-1}. Assuming a constant stabilisation rate of 10 % across all sites, the calculated difference in SOC sequestration due only to different amounts of recycled clippings would have been 69 kg C ha^{-1} yr^{-1}, which is only slightly more than half the observed difference. Several studies report accelerated root turnover in more intensively managed grassland (Klumpp et al., 2009; Leifeld et al., 2015). However, accelerated root turnover could result in either more or less root-derived SOC, depending on the effect on total root growth and exudations throughout the year, which is difficult to investigate (Johnen and Sauerbeck, 1977).

Interestingly, the soil C : N ratio was significantly lower in the utility lawns than in the meadow-like lawns, although neither system was fertilised and both were equally exposed to N deposition. Furthermore, the proportion of N-fixing leguminous plants was higher in the utility lawns than in the meadow-like lawns only in Gothenburg. This might indicate that nitrogen cycling was more closed in the utility lawns. Potentially, more nitrogen is lost via leaching in the meadow-like lawns, because N mineralisation and plant N demand occur asynchronously (Dahlin et al., 2005). The peak in N mineralisation usually occurs around midsummer (Paz-Ferreiro et al., 2012), which might be too late for plant uptake when the grass is not mown and would lead to N losses from the system. Another pathway of N loss is ammonia (NH_3) volatilisation, which increases in later development stages of the plant due to ontogenetic changes in plant N metabolism (Morgan and Parton, 1989). Whitehead and Lockyer (1989) showed 10 % N losses from decomposing grass herbage by NH_3 volatilisation. The consequences of N deficiency for SOC dynamics are twofold: (i) decreased NPP and thus decreased carbon input (Christopher and Lal, 2007) and (ii) increased heterotrophic respiration due to N mining in more recalcitrant organic matter (Ammann et al., 2007). In an incubation experiment, Kirkby et al. (2014) showed that more aboveground residues were stabilised in the soil when nitrogen was added. Thus, negative effects of lawn management on soil N storage can feed back onto SOC, which might also explain a certain proportion of the observed differences in SOC.

4.3 Implications for urban soil management

During the past decade, several studies have investigated biogeochemical cycles in urban soils, since their relevance for the global carbon cycle and as a fundamental ecological asset in an urbanising world is becoming increasingly evident (Lehmann and Stahr, 2007; Lorenz and Lal, 2009). Compared with data on agricultural land with similarly textured soils in the surroundings of the study sites extracted from a national soil inventory database, we found on average 55 % (utility lawns) and 35 % (meadow-like lawns) higher SOC stocks in the lawns we investigated. Furthermore, it has been found in several studies that urban soils have higher carbon stocks than native soils in adjacent rural areas, which can be attributed in particular to more optimised, but also resource-consuming, management, including fertilisation and irrigation (Edmondson et al., 2012; Kaye et al., 2005; Pouyat et al., 2009). However, in the present study we were able to show that SOC storage in urban lawns can be increased at comparatively low cost under temperate climate conditions by optimising NPP and leaving residues on the lawn. Losses of carbon and nutrients are thereby minimised. Milesi et al. (2005) used the BIOME-BGC model to compare different lawn management scenarios and found that applying 73 kg N and recycling the clippings was more efficient for SOC sequestration (+40 %) than applying 146 kg N and removing the clippings. For the sites in Uppsala, Wesström (2015) calculated that the management of utility lawns creates 54 kg ha^{-1} yr^{-1} more C emissions than the management of meadow-like lawns. With this value subtracted from the annual difference in SOC sequestration that we found (120 kg C ha^{-1} yr^{-1}), the utility lawns in our study sequester a non-significant amount of 66 kg ha^{-1} yr^{-1} more carbon than the meadow-like lawns. However, for a full greenhouse gas budget, the effects of lawn management on other trace gases, primarily nitrous oxide (N_2O), have to be considered (Townsend-Small and Czimczik, 2010). In that case, management of the clippings will most likely play a key role, since coverage of the soil with organic material increases soil moisture and the availability of labile carbon but decreases soil oxygen, all of which favour N_2O formation (Larsson et al., 1998; Petersen et al., 2011).

5 Conclusions

This investigation of urban lawns in three Swedish cities showed that cutting frequency alone can exert a significant influence on soil carbon, mainly by increasing net primary production and thus carbon inputs. However, this is most likely only true when cuttings are left on the lawn, since belowground production did not show any differential response to cutting frequency. Moreover, the observed difference in soil carbon could not be fully explained by the expected stabilisation of aboveground-derived carbon input differences, which might denote that either root-derived carbon dynamics or nitrogen mining also play an important role. If clippings are left on the lawn, nitrous oxide emissions might comprise a significant fraction of the greenhouse gas budget of lawns and have to be accounted for to judge the climate mitigation potential of contrasting lawn or grassland management strategies.

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Energy use and greenhouse gas emissions from turf management of two Swedish golf courses

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ABSTRACT

Turf management on golf courses entails frequent maintenance activities, such as mowing, irrigation and fertilisation, and relies on purchased inputs for optimal performance and aesthetic quality. Using life cycle assessment (LCA) methodology, this study evaluated energy use and greenhouse gas (GHG) emissions from management of two Swedish golf courses, divided into green, tee, fairway and rough, and identified options for improved management. Energy use and GHG emissions per unit area were highest for greens, followed by tees, fairways and roughs. However, when considering the entire golf course, both energy use and GHG emissions were mainly related to fairway and rough maintenance due to their larger area. Emissions of GHG for the two golf courses were 1.0 and 1.6 Mg CO_2e ha^{-1} $year^{-1}$ as an area-weighted average, while the energy use was 14 and 19 GJ ha^{-1} $year^{-1}$. Mowing was the most energy-consuming activity, contributing 21 and 27% of the primary energy use for the two golf courses. In addition, irrigation and manufacturing of mineral fertiliser and machinery resulted in considerable energy use. Mowing and emissions associated with fertilisation (manufacturing of N fertiliser and soil emissions of N_2O occurring after application) contributed most to GHG emissions. Including the estimated mean annual soil C sequestration rate for fairway and rough in the assessment considerably reduced the carbon footprint for fairway and turned the rough into a sink for GHG. Emissions of N_2O from decomposition of grass clippings may be a potential hotspot for GHG emissions, but the high spatial and temporal variability of values reported in the literature makes it difficult to estimate these emissions for specific management regimes. Lowering the application rate of N mineral fertiliser, particularly on fairways, should be a high priority for golf courses trying to reduce their carbon footprint. However, measures must be adapted to the prevailing conditions at the specific golf course and the requirements set by golfers.

1. Introduction

Mitigation of climate change and reducing the current dependency on fossil fuels are interlinked challenges shaping policies in many sectors. The European Union (EU) has committed itself to reducing greenhouse gas (GHG) emissions, increasing the share of renewable energy supply and improving energy efficiency, all by 20% by 2020 (European Commission, 2007), and this commitment requires immediate measures in all sectors of society.

There are more than 500 golf courses, occupying approximately 28,000 ha, in Sweden (Statistics Sweden, 2013). Golf is associated with several benefits, e.g. it provides recreational value for the many people who play the game, enhances local biodiversity through extensively managed roughs in areas with intensively managed agriculture (Tanner and Gange, 2005) and promotes soil carbon (C) sequestration (Qian and Follett, 2002; Selhorst and Lal, 2011). Managed turfgrass systems achieve significantly higher C sequestration than arable land and extensively managed grassland (Qian and Follett, 2012). However, turfgrass maintenance on golf courses is reliant on repeated mowing, which requires fossil energy and releases GHG emissions to the atmosphere, mainly as carbon dioxide (CO_2). High turfgrass quality also requires other maintenance practices such as irrigation, fertilisation, vertical cutting, aeration and sand dressing, all with associated environmental impacts. Furthermore, nitrogen (N) from fertilisers and plant residues enhances nitrification and denitrification, which may increase emissions of nitrous oxide (N_2O). Intensive turfgrass management combining frequent irrigation and fertilisation can

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enhance N_2O losses, particularly if water is applied immediately after fertilisation (Gu et al., 2015). However, soil N_2O production is associated with high variability depending on soil properties and management, which poses a great challenge when estimating N_2O emissions (Li et al., 2013). Emissions of N_2O are particularly worrisome since N_2O is a potent greenhouse gas with high global warming potential (GWP). The GWP of a certain gas is a measure of how much heat is trapped in the atmosphere relative to the amount of heat trapped by CO_2 over a specific time interval (IPCC, 2007). The concept of GWP for different GHG makes it possible to add them together to obtain total GWP for an entire system.

Energy use and GHG emissions are not only associated with the maintenance activities performed on the golf courses, since there are also indirect environmental burdens related to production of purchased inputs such as mineral fertilisers, fuel, machinery and transport of sand used for dressing. Life cycle assessment (LCA) is a comprehensive methodology addressing both direct and indirect energy use and emissions along the entire value chain in order to identify environmental hotspots. LCA is a commonly used standardised procedure for identifying opportunities for improved environmental performance and providing decision support for stakeholders in strategic planning and development (ISO, 2006). Carbon footprinting, a subset of a full LCA including only GHG emissions caused by a product or a service during its life cycle and summarised as CO_2-equivalents, is attracting increasing interest in the context of global warming mitigation (Röös, 2013).

A number of studies have evaluated GHG emissions from public and private lawns (e.g. Townsend-Small and Czimczik, 2010; Zirkle et al., 2011; Selhorst and Lal, 2013; Kong et al., 2014; Gu et al., 2015), while fewer studies are available for golf courses. Bartlett and James (2011) modelled GHG emissions from two golf courses in the UK and determined the balance between soil C sequestration and emissions from turf management. They assumed the same sequestration rate for the treeless components of the golf courses (green, tee, fairway and rough), independent of time since construction, mowing frequency and fertilisation rate, and found that the main contribution to GHG emissions came from mowing and production of fertilisers. Selhorst and Lal (2011) included C release due to different maintenance practices, summarised for the entire golf course, but excluded GHG emissions other than CO_2.

Depending on the prevailing climatic and edaphic conditions, turf management differs between locations. In addition, the different playable areas on a golf course are managed with differing intensity. In order to devise and implement efficient and well-adjusted measures for sustainable turf management, more knowledge is required about current energy use and GHG emissions from different components of the golf course and how these are distributed among different management activities.

The objective of the present study was thus to evaluate energy use and GHG emissions from annual management of two Swedish golf courses divided into green, tee, fairway and rough, and identify options for improved management. Particular emphasis was placed on maintenance operations and purchased inputs.

2. Material and methods

LCA methodology was used for evaluation of primary energy use and GHG emissions associated with turf management on golf courses during one year. Emissions of GHG were summarised as CO_2-equivalents (CO_2e) according to IPCC (2007), with a time horizon of 100 years. The results were presented both per hectare and for the entire courses.

Information on management practices was obtained through interviews with course managers of the golf courses. A brief description of different activities performed on the two golf courses is presented below, while a more detailed description can be found in Wesström (2015).

Table 1
Area of the different playable components included in the study, based on information provided by the golf course managers.

Course	Green (ha)	Tee (ha)	Fairway (ha)	Mowed rough (ha)	Total (ha)
Sigtuna	1.5	1.0	10	40	52.5
Uppsala	2.5	1.5	22	50	76

2.1. Description of the golf courses and their management

The golf courses included in the study are parkland courses situated in eastern Sweden. One of the golf clubs is located in the county of Uppsala and was established at its present site in 1964. It currently consists of one 18-hole course and two 9-hole courses, with a total playable area of 76 ha (Table 1). The other golf club is located outside the town Sigtuna, in between Stockholm and Uppsala. It has one 18-hole course constructed in the end of the 1960s, one 6-hole course and four practice greens. The golf courses are surrounded by a mosaic landscape characterised by agricultural land and forest. The total playable areas of the courses in Sigtuna and Uppsala were 52.5 and 76 ha, respectively (Table 1).

The golf season is approximately 26 weeks in Uppsala and 28 weeks in Sigtuna. Maintenance strategies differ considerably between the playing areas, in order to provide optimal performance and aesthetic quality for each specific area.

2.2. Application of fertiliser, pesticides, sand and water

The application rate of mineral fertilisers varies slightly between years. Sigtuna follows a specific fertiliser regime where the weekly fertilisation of greens and tees is pre-ordained. Here, we used data from 2013, which was considered to be a representative year. At Uppsala, fertiliser application is determined by the course manager and the data used in this study were representative of recent years. Fertilisers are applied manually to greens and tees on a regular basis throughout the season. Fairways are fertilised mechanically several times a year, while roughs do not receive any mineral fertiliser.

Fungicides and herbicides are occasionally used at both courses, while insecticides are not used at all. The rough in Uppsala receives herbicides once every other year.

The irrigation frequency is determined by precipitation. In general, greens, tees and fairways are irrigated approximately three times per week, while roughs are not irrigated at all. The irrigation water used in Sigtuna is pumped from a nearby lake and distributed via an underground pipe system, complemented with a hose when necessary. In Uppsala, the water is pumped from a nearby pond that also receives drainage water from the course. The amounts of water applied to the different parts of the course in this study were based on estimates by the managers, since no measured data were available. Sand for dressing is applied on greens and tees at both sites, and on fairways in Uppsala. This sand is transported 160 km to Uppsala and 50 km to Sigtuna. The amounts of mineral fertiliser, sand and pesticides applied and the volume of water used for irrigation are presented in Table 2.

2.3. Mowing and other maintenance practices

Greens are mowed seven times a week at Uppsala and five to six times a week at Sigtuna during the season. Tees and fairways are mowed three times a week at both sites during the season. Roughs are mowed once a week during the season, using a rotary mower. On all areas, seasonal mowing is complemented with some additional off-season mowing. The grass clippings from greens and tees

Table 2
Annual amounts of mineral fertilisers (N, P and K), sand, pesticides (active substance) and irrigation water applied per hectare to different parts of the golf courses in Sigtuna and Uppsala.

	Site	N (kg)	P (kg)	K (kg)	Pesticide (kg)	Sand (Mg)	Irrigation (10^3 m^3)
Green	Sigtuna	214	37	139	1.35	187	3.6
	Uppsala	190	80	190	1.35	120	3.0
Tee	Sigtuna	176	27	108		40	3.6
	Uppsala	220	40	220	1.35	33	3.0
Fairway	Sigtuna	89	12	40	0.39		1.8
	Uppsala	160	40	160	0.64	30	1.4

are collected by the mower at both sites and are either composted or spread out on other grass-covered areas. Clippings from fairways and roughs are not collected, but left on-site.

Aeration is performed with different frequency and machinery on different parts of the golf course. Deep-tine aeration and hole pipe aeration are mainly used on greens and tees. Verticutting is performed on greens at both sites, but only on tees at Sigtuna. Topdressing is most frequently used on greens. The seasonal management practices performed are summarised in Table 3.

In Sigtuna, 150 L of engine oil and 160 L of hydraulic oil are used annually for maintenance of the machinery, while the corresponding values in Uppsala are 60 and 150 L, respectively.

Mean fuel consumption for different operations is summarised in Table 4. All machinery was assumed to use diesel except for a pedestrian mower for greens and a walk-behind aerator for aeration of greens and tees, which consumed petrol. Data on mowing of greens and fairways in Uppsala were obtained from a previous study of fuel consumption per cycle of maintenance on the main golf course (Caple, 2008), while the course manager provided estimates for mowing in Sigtuna. No measurements were available for mowing the rough in Uppsala and therefore the estimated fuel consumption per occasion (6 L ha^{-1}) at Sigtuna was also used for Uppsala. Fuel consumption for aeration was based on assumptions made by the golf course managers. The difference in assumed fuel consumption was due to different machinery being used for aeration. Data on fuel consumption for verticutting and dressing were based on measurements (Caple, 2008). Since a higher rate of sand was applied to tees and fairways in Uppsala, higher fuel consumption per hectare was assumed for these areas compared with dressing of the greens, based on estimates made by the course managers.

2.4. System boundaries

The system studied included production of purchased inputs (fertiliser, fuel and electricity), transport of sand, production, maintenance and repair of machinery, and turf management for different activities according to current practices during one representative year (Fig. 1). Fuel consumption per maintenance cycle included travelling between courses parts for the machinery in use.

The contribution from production and application of herbicides and fungicides was omitted in the assessment, since it contributed less than 1% to the total energy use and GHG emissions. Reseeding was also omitted, since its contribution was considered negligible.

Construction of the courses was not included due to lack of information about the resources used during construction, as it was performed many decades ago.

A considerable amount of clippings is either composted, spread out directly on other grassed areas or left on-site after mowing. The emissions of N_2O associated with turnover of these clippings were considered in the sensitivity analysis, since high variability can be expected and no measurements were available. Indirect emissions of N_2O caused by N losses through volatilisation and leaching were not accounted for, since these emissions were considered minor compared with the direct emissions of N_2O.

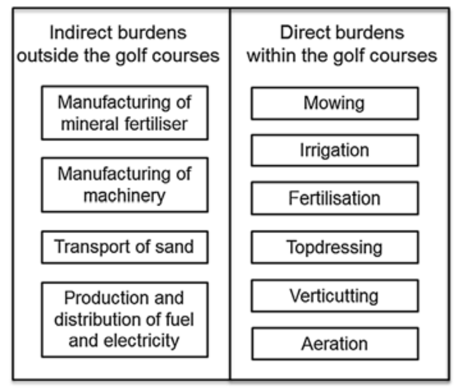

Fig. 1. Activities included in the study causing direct and indirect energy use and GHG emissions within and outside the golf courses.

2.5. General assumptions and data used

Data on GHG emissions from fuel combustion relating to transport and maintenance operations were taken from Gode et al. (2011) and included production, distribution and combustion. Only emissions data for standard diesel were used, although also synthetic diesel was used for some applications. Electricity consumption for irrigation was estimated by the course managers to be 0.45 kWh m^{-3} at Uppsala and 0.5 kWh m^{-3} at Sigtuna. Emissions data for the Swedish average electricity production were taken from Gode et al. (2011), assuming an electricity mix primarily based on nuclear power and hydropower. A factor of 2.1 was used for converting electricity into primary energy, considering a transformation efficiency of 50% and distribution losses in the grid. In the sensitivity analysis, the impact of electricity produced from natural gas was evaluated as an alternative to prevailing production conditions in Sweden.

Different machines and devices are used on golf courses for the many management operations performed. A thorough inventory of all machinery used, its material composition, annual use, life-time etc. was not possible due to lack of site-specific information from the golf courses. Instead, a rough estimate was made by assuming that energy use and GHG emissions from manufacturing, maintenance and repair of machinery comprised 17% of the total energy use and GHG emissions from all turf operations performed. This estimate was based on the distribution between manufacturing and operation phases calculated for Swedish crop production in the same region (Tidåker et al., 2016). The engine oil and hydraulic oil used were assumed to be included in this estimate.

Data on energy use for fertiliser production were taken from Brentrup and Pallière (2008), based on average figures for European production in 2006, while data on GHG emissions were taken from Kool et al. (2012). Data for urea ammonium nitrate were chosen, since the fertiliser products used contained a mixture of urea, ammonium and nitrate. The average diesel requirement for transport of sand was set at 0.4 L km^{-1}, assuming a truck and trailer with empty return transport.

Table 3
Frequency of annual maintenance cycles performed on different parts of the golf courses in Sigtuna and Uppsala.

	Site	Mowing	Aeration	Verticutting	Topdressing
Green	Sigtuna	160	6	14	14
	Uppsala	198	6	8	13
Tee	Sigtuna	88	1	3	3
	Uppsala	82	6	0	1
Fairway	Sigtuna	88	2	0	0
	Uppsala	82	3	0	1

Table 4
Fuel consumption (litres ha^{-1} $occasion^{-1}$) during management operations on different parts of the golf courses in Sigtuna and Uppsala.

		Mowing	Aeration	Verticutting	Topdressing
Green	Sigtuna	3.3	42	11	8.7
	Uppsala	3.6[a]	42	11	8.7
Tee	Sigtuna	8	42	11	8.7
	Uppsala	10.5	21		18
Fairway	Sigtuna	3	9		
	Uppsala	3.2[b]	9		18

[a] On the main course, 188 mowing operations were performed using a pedestrian mower (3.6 L petrol ha^{-1}), and 10 operations were performed using a ride-on mower (7.1 L diesel ha^{-1}).
[b] Mean fuel consumption included the assumption that half the mowing regimes were performed with a groomer with higher diesel use.

Direct emissions of N_2O from soils were estimated using the IPCC default emissions factor (2006), which is 1% of the total N added as mineral fertiliser. In the sensitivity analysis, this emissions factor was applied to the grass clippings.

3. Results

3.1. Energy use per hectare of green, tee, fairway and rough

Energy use was highest for greens, followed by tees and fairways (Table 5). Energy use for green management was roughly three times higher per hectare than for fairways on the same golf course. The lowest energy use was associated with maintenance of rough (7.6 GJ for Sigtuna and 7.1 GJ for Uppsala), which only included mowing and manufacture and maintenance of machinery. Mowing was the single most energy-consuming activity performed for all types of areas. However, the contribution from mowing per hectare was less than half of all energy use (26–45%) associated with maintenance of green, tee and fairway, since irrigation and manufacturing of mineral fertiliser in particular made important contributions. For greens, transport of sand added significantly to the total energy use.

Energy use for maintenance of fairways was considerably higher for Uppsala, which was largely explained by the higher application rate of N fertiliser and sand transport over a longer distance.

3.2. Emissions of GHG per hectare of green, tee, fairway and rough

Emissions of GHG from maintenance of one hectare of green were 6.2 Mg CO_2e for Sigtuna and 6.8 Mg for Uppsala (Fig. 2). Among management activities, mowing contributed most to GHG emissions (23% for Sigtuna and 27% for Uppsala). A major source of GHG emissions was associated with mineral fertiliser (in particular N), both through manufacturing, in which CO_2 and N_2O is released, and through emissions of N_2O from soil after application. In total, mineral fertiliser accounted for 38% of the GHG emissions at Sigtuna and 32% at Uppsala. For Uppsala, the contribution from transport of sand was also considerable.

Emissions of GHG from tees amounted to 4.7 and 6.1 Mg CO_2e ha^{-1} $year^{-1}$ for Sigtuna and Uppsala, respectively. These emissions were dominated by mowing (41 and 39% for Sigtuna and Uppsala, respectively), followed by manufacturing of mineral fertiliser, direct soil emissions (N_2O) and irrigation. Manufacturing of mineral fertiliser and soil emissions of N_2O after application accounted for 41% at both sites.

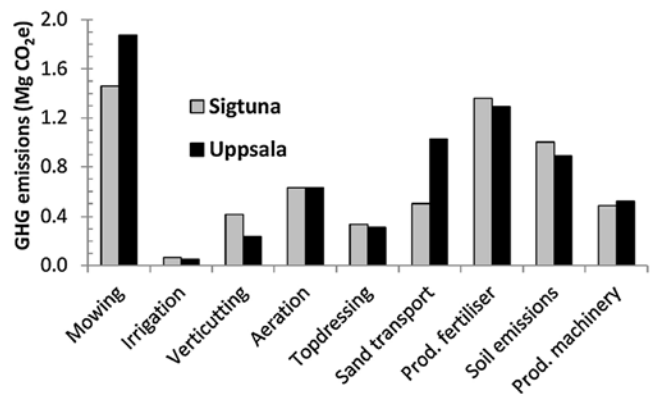

Fig. 2. Emissions of GHG (kg CO_2e ha^{-1} $year^{-1}$) divided into different maintenance activities for greens at the golf courses in Sigtuna and Uppsala.

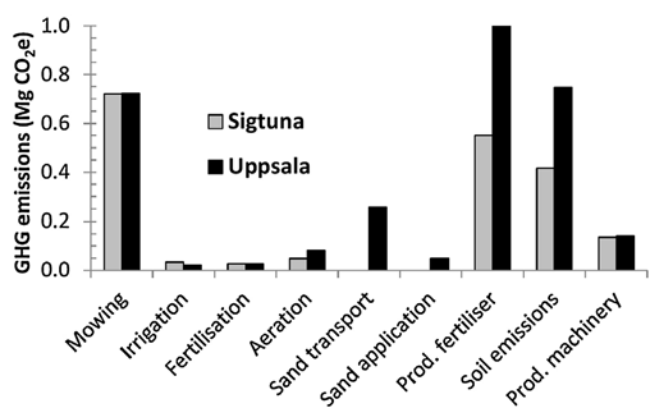

Fig. 3. Emissions of GHG (Mg CO_2e ha^{-1} $year^{-1}$) divided into different maintenance activities for fairways at the golf courses in Sigtuna and Uppsala.

Emissions of GHG associated with maintenance of fairways differed greatly between the sites and were 1.9 Mg CO_2e ha^{-1} $year^{-1}$ for Sigtuna and 3.1 Mg CO_2e ha^{-1} $year^{-1}$ for Uppsala (Fig. 3). A considerable share of the GHG emissions was related to mineral fertiliser, including both the fertiliser manufacturing phase and soil

Table 5
Primary energy use (GJ ha^{-1} $year^{-1}$) split into different maintenance activities for green, tee and fairway at the golf courses in Sigtuna and Uppsala.

	Green		Tee		Fairway	
	Sigtuna	Uppsala	Sigtuna	Uppsala	Sigtuna	Uppsala
Mowing	21	27	27	33	10	10
Irrigation	14	10	14	10	7	5
Verticutting	6	3	1			
Aeration	9	9	1	5	1	1
Topdressing	5	4	1	1		1
Transport of sand	7	15	2	4		4
Fertilisation					0.4	0.4
Mineral fertiliser production	13	13	10	14	5	10
Production of machinery	6	7	5	7	2	2
Total	81	89	61	74	25	33

Table 6
Relative contribution of different maintenance activities to total primary energy use and GHG emissions for the entire golf courses in Sigtuna and Uppsala.

	Energy use (%)		GHG (%)	
	Sigtuna	Uppsala	Sigtuna	Uppsala
Mowing	57	46	54	39
Irrigation	14	10	1	1
Verticutting	1	1	1	1
Aeration	3	4	3	3
Top dressing	1	2	1	1
Transport of sand	2	9	2	7
Production of mineral fertiliser	11	20	16	24
Direct soil emissions			12	17
Production of machinery	11	9	10	7
Total per ha & year	100	100	100	100

emissions of N_2O occurring after application. In total, emissions relating to fertilisation were 50% for Sigtuna and 58% for Uppsala, while the corresponding figures for mowing were 37 and 23%, respectively.

The contribution to GWP per hectare from maintenance of roughs was 0.54 Mg CO_2e for Sigtuna and 0.50 Mg CO_2e for Uppsala. The only aspects accounted for were mowing and production of machinery.

3.3. Energy use and GHG emissions for the entire golf courses

For the golf courses studied, the largest proportion of area was occupied by rough, followed by fairway, green and tee. The results per hectare were therefore converted to values for the entire course in order to obtain information on how total energy use and GHG emissions are distributed between the different playing areas and which activities to prioritise in order to improve the overall environmental performance. In Table 6, energy use and GHG emissions are split into different activities expressed for the entire golf courses, using the areas presented in Table 1.

Mowing was by far the single most energy-consuming activity, and also made a major contribution to GWP (Table 6). Fertilisation affected both energy use and GHG emissions. Emissions of GHG relating to fertilisation (manufacturing and soil emissions) from Uppsala contributed considerably (41%) due to the higher N application rate on fairways and the higher proportion of fairway within the total area. The corresponding value for GHG emissions related to fertilisation at Sigtuna was 28%.

Expressed as area-weighted average per hectare and year for the entire golf courses, the energy use was 14 GJ for Sigtuna and 19 GJ for Uppsala. The corresponding contribution to GWP was 1.0 and 1.6 Mg CO_2e, respectively.

Greens constituted a minor proportion of the golf courses (approximately 3%), but contributed a considerably larger share of the total energy use and GHG emissions (14–17%) due to their intensive management (Fig. 4).

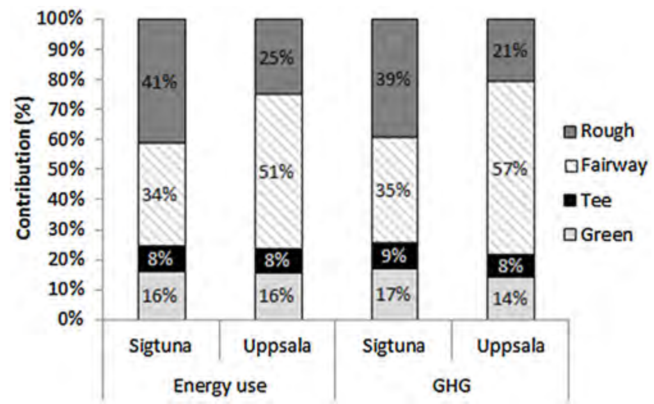

Fig. 4. Relative contribution to primary energy use and GHG emissions split into green, tee, fairway and rough for the golf courses in Sigtuna and Uppsala.

The contribution to energy use and, in particular, to GHG was considerably higher for fairways than its share of the total area within golf courses (19% of the area at Sigtuna and 29% at Uppsala), while the extensively managed rough made a significantly lower contribution than its share of the golf courses (76% of the area at Sigtuna and 66% at Uppsala). For Sigtuna, rough was the area associated with the highest energy use and GHG emissions. For Uppsala, more than half of all energy use and GHG emissions was related to fairway management.

3.4. Sensitivity analysis

Emissions of GHG from electricity production are strongly influenced by its origin. The low carbon footprint from the Swedish electricity mix reflects its large share of hydropower and nuclear power, both associated with low GHG emissions. The assumption in the sensitivity analysis that the electricity used for irrigation was produced on the long-term European margin, i.e. considered to be produced from natural gas, increased the GHG emissions on average by 10% at Sigtuna and 8% at Uppsala. The highest relative increase was obtained for fairways at Sigtuna (Table 7).

Emissions of N_2O were accounted for by assuming that 1% of the N applied as fertiliser was emitted as N_2O—N. However, grass clippings from golf course surfaces are either removed and composted, spread on other surfaces or left on-site. During decomposition of these clippings, N_2O will be emitted. According to model simulations of N_2O emissions from urban lawns, expected N_2O—N losses range between 0.75–3.57 kg ha^{-1} $year^{-1}$ for lawns fertilised with 0–89 kg N, and recycling of lawn clippings has been identified as an important source of N_2O emissions (Gu et al., 2015). The proposed default emissions factor for N_2O—N according to IPCC (2006) for composting in windrows with infrequent turning for mixing and aeration is 1%. This is within the same order of magnitude as

Table 7
Emissions of GHG (Mg CO_2e ha^{-1}) on changing the assumptions as regards electricity mix, N_2O emissions from decomposition of grass clippings and soil carbon sequestration in the sensitivity analysis.

	Green		Fairway		Rough	
	Sigtuna	Uppsala	Sigtuna	Uppsala	Sigtuna	Uppsala
Original setting	6.2	6.8	1.9	3.1	0.5	0.5
Electricity from natural gas	6.9	7.4	2.3	3.4		
Including N_2O from clippings	6.9	7.2	3.5	4.9	1.3	1.4
Including C sequestration			0.8	2.0	−0.6	−0.6

the value reported for garden waste composting in Danish studies (Boldrin et al., 2011). An emissions factor of 1% was used in the sensitivity analysis in the present study, irrespective of how the grass clippings were handled. The N content in clippings, information required for estimating N_2O emissions, was not measured within this study. However, data on net primary production (NPP) of above-ground biomass for the different management areas on the golf courses in Sigtuna and Uppsala were available in another study within the same research programme estimating NPP through frequent sampling during the growing season in 2014 (unpublished data). That study showed that NPP was significantly lower in greens (4.5 and 2.7 Mg dry matter ha^{-1} in Sigtuna and Uppsala, respectively) than in fairways and roughs, but did not differ significantly between fairways and roughs and was on average 11.5 Mg dry matter ha^{-1} in Sigtuna and 12.5 Mg ha^{-1} in Uppsala. Accumulated N uptake in clippings was assumed to correspond to 3% of NPP, which is a rather conservative estimate of the N concentration in frequently cut turfgrass clippings (e.g. Kopp and Guillard, 2002) and is considered the limit for achieving functioning and healthy looking turf in Sweden (Ericsson et al., 2012). In the unfertilised rough, the N concentration in clippings was assumed to be lower (1.5% of NPP) due to less frequent cuttings, as also reported for more mature grass swards in Sweden (Kätterer et al., 1998). As shown in Table 7, inclusion of N_2O from decomposition of clippings had a strong impact on GHG emissions from fairway and rough.

Soil organic C stocks are generally higher in grassland soil than in arable soil (Poeplau and Don, 2013). Since the golf courses studied here were established on arable land, which probably had a history of mixed farming, it is likely that C stocks in the turf have increased since establishment of the golf courses about 50 years ago. The topsoil (0–20 cm depth) in the fairway and rough areas currently contains about 80 Mg C ha^{-1} on average over the two sites (unpublished data), which is 23% more than the C content in mineral agricultural topsoils in the region (Andrén et al., 2008). If this difference in C storage is attributed to turf management over 50 years, soil sequestration in fairway and rough areas would amount to 0.3 Mg C ha^{-1} $year^{-1}$. Thus including soil C sequestration reduced the GHG emissions from fairways considerably and turned roughs into a sink for GHG.

4. Discussion

Energy use and GHG emissions per hectare were considerably higher from greens and tees than from fairways and, in particular, from extensively managed roughs (Table 7). For example, GHG emissions from greens were about two- and three-fold higher than those from fairways at Uppsala and Sigtuna, respectively. Bartlett and James (2011) reported similar differences between greens and fairways in their study on turf management at two British golf courses. Emissions of GHG per hectare from fairways at Sigtuna were of the same magnitude as reported for British parkland courses, while emissions from fairways at Uppsala were about 60% higher. Emissions of GHG per hectare from greens were slightly lower than reported for the British courses, while emissions from roughs were more than two-fold higher in the British study. However, there were some important differences in the maintenance activities performed in the different studies and in the processes included within the system boundary. Dressing, transport of sand and production of machinery were not included in the British study, which explains some of the differences. Moreover, the application rate of N mineral fertiliser and mowing frequency were higher for greens, tees and fairways on the Swedish golf courses included in this study. On the other hand, the GHG emissions from the British parkland rough were significantly higher due to N fertiliser application and high basal respiration (an aspect not included in this study). Emissions of GHG associated with the playing areas (tee, green, fairway and rough) in the study by Bartlett and James (2011), which amounted to 1.7 Mg CO_2e ha^{-1} $year^{-1}$ on average, were similar to those in Uppsala (1.6 Mg CO_2e ha^{-1} $year^{-1}$) but higher than those in Sigtuna (1.0 Mg CO_2e ha^{-1} $year^{-1}$). However, as emphasised above, the GHG emissions were distributed differently among the different playing components, in particular for the roughs.

Mowing made the single highest contribution to energy use for all areas. Introducing electrified machinery for some management operations would be an effective measure for reducing fossil fuel dependency and GHG emissions from golf turf management, provided that electricity is produced with renewable sources and a low carbon footprint.

Another important contributor to both energy use and GHG was mineral fertiliser, in particular N. Most GHG emissions were related to manufacturing of N mineral fertiliser, but N_2O emissions occurring after application also contributed considerably. Since the rather intensively managed fairways constitute a large part of golf courses, the environmental footprint for the entire golf courses was particularly determined by management of the fairways, especially for Uppsala. There was a marked difference in the N rate used on fairways at the two sites. Determining how the N application rate could be reduced on fairways while maintaining turf quality is thus an important step in reducing the environmental burden from golf courses. Assuming that a reduction in N application rate would also reduce turfgrass growth, the need for mowing, and thus the energy use and emissions related to mowing, would decrease.

Irrigation made an almost negligible contribution to GHG emissions due to the low GHG emissions associated with the current Swedish electricity mix. In regions where electricity is produced from natural gas, the contribution from irrigation would increase considerably, as shown in the sensitivity analysis. In regions where electricity is produced from coal, the carbon footprint from electricity would be even higher.

Intensive management, involving irrigation, mowing, fertilisation and recycling of grass clippings, are all activities associated with N_2O emissions (Gu et al., 2015). However, it is unclear how to account for N_2O emissions from grass clippings left for decomposition, since these emissions exhibit high temporal and spatial variability. The assumption in the sensitivity analysis that 1% of the N in grass clippings was emitted as N_2O—N strongly affected the GHG emissions from turf management. Handling of grass clippings is thus a potential hotspot within turfgrass management that needs further examination. Li et al. (2013) observed inconsistent responses when grass clippings were added in turfgrass systems, with soil aeration conditions as one important factor influencing the results. The grass clippings from fairways in Sigtuna and Uppsala were estimated to contain 345 and 375 kg N ha^{-1}, respectively, which made clippings an important source of N in the turfgrass system. Gu et al. (2015) advocate recycling of grass clippings as a means of lowering the N application rate. Exploiting the fertiliser value of recycled clippings in different conditions and reducing the application rates of mineral N fertilisation could be an effective management option for reducing N_2O fluxes from golf courses.

Soil C sequestration is an important measure to offset GHG emissions from turf management. An assumed soil C sequestration rate of 0.3 Mg ha^{-1} year^{-1} for fairways and roughs in the present study resulted in a considerably lower carbon footprint for the Uppsala course (0.5 Mg CO_2e), while the GHG emissions from Sigtuna were totally eliminated. In a recent Swedish study, frequently cut urban lawns were found to contain 55% more soil C than surrounding arable soils (Poeplau et al., 2016). Perennial plants such as turfgrass generally have denser root systems than annual crops (Wang et al., 2014) and root-derived C is preferentially stabilised in soil (Kätterer et al., 2011). This is the main reason why an increased frequency of perennial forages in crop rotations (Bolinder et al., 2010) or a land use change from arable to permanent grassland leads to soil C sequestration (Kätterer et al., 2008). High C sequestration rates following conversion of farmland to golf courses have been reported in several studies. For example, Selhorst and Lal (2011) reported sequestration rates as high as 0.44 Mg C (corresponding to 1.6 Mg CO_2e) ha^{-1} year^{-1} on average over a period of 91 years in fairway and rough areas on farmland converted to golf courses in Ohio. Even higher sequestration rates (0.9 and 1.0 Mg C ha^{-1} year^{-1}) were reported by Qian and Follett (2002) for fairways and greens on 16 golf courses in the USA. However, their study was more short-term (25–30 years) and this sequestration rate will probably not persist in a longer time perspective, since soil C sequestration rates are known to decrease with time until a new steady state soil C content is reached (Andrén and Kätterer, 2001). Compared with those values, the estimated sequestration rate for fairway and rough of 0.3 Mg C ha^{-1} year^{-1} for our two Swedish sites was fairly low, although only slightly lower than the median C sequestration (0.42 Mg ha^{-1} year^{-1}) recorded in ley-arable rotations in 15 long-term field experiments under Nordic conditions (Kätterer et al., 2013). While the uncertainty in our estimates is high, since we had to rely on several assumptions due to lack of data, the higher sequestration rates for similar systems reported in the studies cited above suggest that our estimated sequestration rate of 0.3 Mg C ha^{-1} year^{-1} is rather conservative and its inclusion in this LCA would not have overvalued the importance of soil C sequestration.

5. Conclusions

Energy use and GHG emissions per unit area were highest for greens, followed by tees, fairways and roughs. However, when considering the entire golf courses, both energy use and GHG emissions were mainly related to fairway and rough maintenance due to the larger area they occupied. Mowing was the most energy-consuming activity and contributed 21 and 27% of the primary energy use of the golf courses. Irrigation and manufacturing of mineral fertiliser and machinery also resulted in considerable energy use. Mowing and emissions associated with fertilisation (manufacture of N fertiliser and soil emissions of N_2O occurring after application) contributed most to GHG emissions. Emissions of N_2O from decomposition of grass clippings are a potential hotspot for GHG emissions from turf management that needs further investigation, since the high spatial and temporal variability of these emissions makes it difficult to estimate their actual contribution. Including the estimated mean annual soil C sequestration rate for fairway and rough in the assessment considerably reduced the carbon footprint for fairway and turned the rough into a sink for GHG. Appropriate measures for reducing energy use and carbon footprint from lawn management are thus: i) reduced mowing frequency when applicable, ii) investment in electrified machinery, iii) lowering the mineral N fertiliser rate (especially on fairways) and iv) reducing the amount and transport of sand for dressing. Lowering the mineral fertiliser rate is of particular importance, since GHG emissions originate from both the manufacturing phase and from N turnover after application. However, measures must be adapted to the prevailing conditions at the specific golf course and the requirements set by golfers. There is also a need for more golf courses that prioritise and market a low environmental footprint even at the expense of e.g. current aesthetic preferences. A life cycle perspective as applied in this study can be used as a tool for decision-support for golf courses aiming at improving their environmental performance.

Conflict of interest

We declare that no conflicts of interest of any kind (direct or indirect) exist.

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ARTICLE NO 6

Golf courses as a part of urban green infrastructure: social aspects of golf courses and extensively managed turfgrass areas from Nordic perspective

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1. Introduction

Originating in Scotland in the 15th century, the game of golf became very popular first in Europe, later in all English colonies and finally, by the end of the 20th century, around the world. With urbanisation in new urban districts, quite large open areas are designated for golf courses and are considered to be an important part of urban green infrastructure (Zhang 2014). However, the high level of resource input and intensive maintenance and management practice of golf courses is criticised by some ecologists and environmentalists. A paradigm shift is now required towards creating multi-functional sustainable public spaces.

In the Nordic countries managed turf-grass areas and golf facilities have been increasing since the second part of the 20th century. The Nordic golf federations have more than 900,000 members, playing golf on 1071 courses that cover a total area of more than 65,000 ha (Golf around the World 2015). The popularity of golf is partly connected to the growing market economy, increasing incomes and economic stability. There are probably many other factors connected to the modern Western lifestyle, which might explain the popularity of golf (such as health aspects, experience of nature, and social interaction, etc.). Swedish golf courses are seen by many golfers as an arena for meeting, socializing and enjoying nature. Many golf courses are located in or near attractive nature and landscapes such as lakes and forest margins.

We researched golf courses within the interdisciplinary project "Lawn as a cultural and ecological phenomenon" run by scientists from SLU, Sweden and funded by the Swedish Research Council (FORMAS). One of the goals of this project was to study the range of different managed lawns from the most intensively managed urban conventional lawns to the more meadow-like lawns. The parterre lawn, requires the highest management intensity, but parterre lawns are uncommon in Sweden. Instead golf courses were included in our project. Golf courses have a wide range of lawn types and playing surfaces, from very intensively managed greens and tees to fairways with intermediate management practices and roughs with the lowest management intensity. Golf courses in this sense can be seen as a microcosm where all types of planted grass communities (lawns) are presented (fairway, rough and high rough).

During the last decade in Sweden there has been a driving force to develop greater numbers of multifunctional golf courses, which can provide a whole range of ecosystem services such as improving biodiversity (creating habitats for grassland and wetlands), and providing recreational areas, which are accessible for the public. STERF (Scandinavian Turfgrass and Enviromental Research Foundation) is one of the main promoters of this movement (Strandberg et al., 2011). An important peculiarity of Swedish golf courses is the use of only small or very small amounts of fungicides, herbicides and fertilizers.

This particular research related to golf courses was supported by STERF.

2. Methodology

Our data collection methods in this research are surveys, interviews, observational studies and document studies. Six golf clubs (GC) were selected in three geographic regions of

Sweden (Gothenburg, Malmo / Lund and Uppsala / Sigtuna): Sigtuna GC, Uppsala GC, Malmö Burlöv GC, Lund University GC, GC Delsjön and Torslanda GC.

A total of 180 golfers and 12 golf course employees are included in the study. Observational studies in the golf environment were aimed at getting an idea of where the visitors went to when they were not playing golf. We have also studied the selected golf clubs' websites and published writings.

3. Results and discussion

The social part of this study has been focused on the golfers' and the golf course managers' perspectives. The main research question was "What is appreciated by golfers in their golf course when it comes to green environment and ecological, cultural and social values?" The interviews indicated that the time spent on the golf course includes much more than just the game itself. For many players visits to the golf course also act as an experience of nature and the beautiful surroundings, as a social context (interaction), a way to stay in shape (fitness), as well as a way to relax (recreation).

The Golf course as a social arena

Golfers indicated that in golf clubs they are able to meet friends and make new social contacts in golf clubs. Players stressed that here they feel included in a social context where all share the same interest - the game of golf. The restaurant as well as shops and other activity arenas on the golf course are important social meeting points. Many golfers also use other golf courses within and outside Sweden. Partly they do this in order to try other golf courses (challenges) and to extend the playing season (which is short in Sweden) by traveling to warmer countries. One of the players said: "*Golf is an important part of my life. This is where I and my wife (sic) meet after work. Here we meet our friends. Here we spend a lot of time, sometimes even the whole day. Then there must be more than just good courses. Periodically, the golf club is our second home during the summer season*".

The Golf course as an experience arena (perception)

Natural values often mentioned by the golf players were: quiet, peaceful environment (silence), sound (hearing of birds), seeing butterflies and small animals as well as the presence of plants. The existence of the "natural environment" is perceived as a very important feature for choosing a specific golf club. For example, one of the golfers said: "*It is so beautiful to have birch trees and flowering meadow as a background for this golf course*". Another player said: "*When I finish playing in this well-kept environment of golf, I want to enjoy being in the surrounding nature. I am so happy to do a little walk in the beautiful surroundings. I have my favorite place where I meet my friend – a hare. The place also has a rich birdlife which I do not notice (sic) as much when playing on the golf* fairways".

Golfers also enjoy the pleasant smells and sounds of nature as well as the presence of water (lake, pond and river).

Vision of biodiversity

The environmental aspect seems to be important for many of golfers. The majority of respondent players said that the golf course was a great environment for biodiversity for animals and plants. For example, 114 from the 180 interviewees said that the golf course was a good environment for biodiversity. Some of the players were skeptical. One of them said: "*No, voles and hares and things like that should not be here. They should stay away from the golf course. The grass must be free from weeds. Greens must be well maintained. I have my garden at home.*"

The Golf course as an activity sport´s arena

For golfers generally, the game itself, of course, is the primary reason for being at a particular golf course. However, many players noticed that the game is combined with other added values. Many of those interviewed described their vision of a "good" and well-functioning golf course as:

-the golfing environment should be maintained in an environmentally friendly manner

-the golf holes in various parts should be of high quality

-the golf course should be located in a beautiful and quiet environment

-the golf course design should be of good quality in terms of management and playability

-the golf course must be neither too demanding nor too easy.

-the golf course should have necessary features/services that golfers need during a day's stay.

Golfers appreciate some additional features such as good communications, easy access and closeness to home. Many of the golfers also mentioned the importance of cultural aspects.

Lawns and their significance for golfers

A golf course consists of four main parts: tee, fairway, rough and green. The tee is a smooth flat lawn area which is always cut very short. The fairway is an intensively short-cut, elongated lawn area in the direction towards the green that is surrounded by a rough area that consists of higher grass that is cut less frequently. A green is a high-intensity trimmed lawn which is mown daily during peak season. Tees and fairways are not cut as frequently (approximately 3 times per week). The rough is the part of the golf course that is least maintained and cut about once per week or less (interviews with green keepers and managers on golf courses in the Swedish Lawn project, February 2015).

Many of the interviewees valued not only the game, but also the green (both in terms of the quality of playing surface, which sometimes even becomes tanned by the sun or because of the intensive maintenance) but also the 'natural' green areas found in the local environment. In other words, "wild" nature embedding the golf course, is often seen as a valuable additional complement to the professionally designed and well-kept playing surfaces of the golf course.

The manager's vision of golf courses

Interviews with employees were conducted in all six golf courses. All golf course managers have high ambitions when it comes to offering a good quality golf course. The main challenge for all golf courses was to find the balance: how to offer good playing surfaces and well-maintained and attractive golf courses in tight economic conditions. Several golf clubs mentioned the problem of competition between different clubs. Membership fees are not always sufficient for the high ambitions that the clubs want to offer when it comes to course quality and service. The common feature in all studied cases was increasing demands from players in terms of quality of the golf holes (tidy and smooth to play on) and at the same time requirements from municipalities and county councils to address the environmental issues. One of the interviewees said: "*Our players want the best possible quality of the golf course for minimal expenses. A sound principle we try to live up to. Without bragging, I think we can handle it quite well.*"

Two of the golf courses that are included in our study are nature conservation areas. Here the use of pesticides is completely prohibited. It is known that sometimes turf grass suffers from diseases caused by fungus and in this case pesticides are usually used. But in the case of golf courses in nature conservation areas it can be used only occasionally and under strict control. Irrigation and fertilization are also controlled in these areas. Delsjön GC is one of those golf clubs that has been given permission to build a pond to meet irrigation needs. In the second case, Lund University GC, a certain quantity of water is taken from the nearby lake for irrigation purposes. In both cases the golf courses must apply for permission for all major construction jobs, the supply of soil, and tree cutting. The golf courses' business in nature conservation areas is very much driven and controlled by the authorities. One of the employees said; "*In this way we have been forced to become an eco-friendly golf club. Sometimes such policy pays off in the end and our players really appreciate this nature conservation component. We see this as a competitive advantage and believe in this positive trend where more and more of the maintenance of managed turf grass areas and golf courses are controlled by environmental goals*".

We can also conclude that golf course managers expressed high ambitions when it came to environmental issues. This applies to mowing, watering, and use of pesticides and fertilizers on golf courses. For example, one interviewee said: "*We investigate the situation carefully before we invest in any machines or change our maintenance routines. The aim is to meet the environmental requirements. But this is sometimes difficult to do. Today there* *are, for example, good electric mowers but they devour batteries at a furious pace, and these batteries are very expensive. So it will not be as environmentally friendly in all cases in the end. The hybrid machines available today are certainly good but too expensive so far. So we compromise as much as possible to balance both environmental requirements and our economic reality* ".

One course manager said: "*Previously, we had a strict schedule for the days we would irrigate and run different kinds of management, how often, etc. Now we have introduced the principle – "if and when it is necessary" - which gives both economic and environmental savings. It's about common sense instead of overly strict procedures*".

All golf course managers have a desire for creating a "*beautiful green natural environment*" with flowering plants, shrubs, trees and ideally, with water presence. For example, one of the course managers said: "*It would be fun to make the environment a bit more inviting by planting more plants. But we cannot do anything without permission from the County Administrative Board. Plants that do not belong to the natural and original environment are not allowed here since this area is classified as a nature conservation area. But we have many other values for example a beautiful meadow which reaches its peak around midsummer.*"

When it comes to grass quality the wish list of course managers and green keepers is:

- A long summer season with just enough rain and sun.
- Sustainable and easy maintained grass species and varieties that are tolerant to diseases and can compete with weeds.
- Playing surfaces without diseases caused by fungus and weeds.

When we asked about a "good" golf course design, both players and managers had quite similar answers:

- The golf holes provide good playing quality and are framed by 'natural' scenery with shrubs, trees and, in an ideal case, with some waterbodies.
- The course should be a bit hilly (not only flat).
- Birdlife is also a desirable element in the environment.
- Fairways should provide enough challenging and exciting experiences while walking during the game.

It also appeared that there is sometimes a conflict between green keepers and players' expectations of a golf course. "*Here we have players who enjoy the sweet and cute bunnies moving in our course. We as green keepers see them as pests because rabbits definitely will give us troubles. Some players complain if they see a snake. And I am often happy if snakes are here because they help us to keep away mice and voles.*"

4. Conclusion

Our results show that the golf course environment is often seen as a multidimensional, valuable environment. Most of the interviewees were not only dedicated golfers who enjoy the game itself. They combine golf exercise with a lot of other values. That is why golf courses have great potential to support multiple values: for example, biodiversity and carbon sequestration as well as social wellbeing of people. The green environment of golf courses is often seen as a part of nature and the visit to the golf course as an outdoor activity in nature.

Perception and cognitive processes are an important part of the total experience for golfers. Green spaces and places in golf courses are giving signals of different kinds to the senses. Our impressions from what we are seeing, hearing and smelling impact upon our feelings of well being (Gehl, 2001). Outdoor acitivities in public places and spaces, like possibilities for pleasant walks and access to places for standing, sitting, meeting, talking and to find a convenient place for relaxation and pleasure after the game, are important according to the golfers we interviewed. Golf courses include large areas of land that are not used for the game of golf. Therefore, there could be potential for better use of the land in many cases in order to provide new opportunities to create an active outdoor life for other groups in addition to golfers. Some of the managers and green keepers mentioned the possibility of opening and inviting others to the golf courses (not only golfers). In this way golf courses can be valuable green areas for recreation in close proximity to urban areas.

Further work will focus on environmentally-friendly design and management on golf courses that can be part of the bigger urban-green infrastructure picture. This could be an important strategical tool for the future of golf. Golf courses could also have the potential to contribute to supporting wild flora and fauna, particularly in urban and peri-urban settings where they could contribute significantly, for example, to wetland creation (Strandberg 2012; Strandberg 2014) and in preserving "a functioning biotope or ecosystem" which "is of crucial importance in preserving the original vegetation" (Florgård, 2009: p 380).

Fig. 1. A golf player practicing putting March 2015 at Burlöv golf course (in Malmö, Sweden).

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The goal of this manual is to share a vision of lawns based on the results of the transdisciplinary LAWN project “Lawn as ecological and cultural phenomenon. Searching for sustainable lawns in Sweden” (2013-2016) funded by Formas.

First, we present the results of this project and discuss existing lawn alternatives from Europe and North America. We then analyse and discuss experiences in Sweden, including our own experimental sites at SLU Ultuna Campus in Uppsala. We also provide practical advice on establishing and managing different types of lawn alternatives suitable for Swedish conditions.

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