Multifunctional golf courses

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The project was funded by STERF (Scandinavian Turf Grass Foundation) and Formas (through the research program LAWN).

All photos in the report: Fredrik Eriksson

CONTENT

INTRODUCTION

The origin of golf as a sport was imported to Sweden from Scotland in the end of the 19th century. The first golf course ever built in Sweden was established in 1888 in an estate park outside the town Jönköping in south-central Sweden. The first golf course connected to a sports association was built in Gothenburg 1901 and the Swedish golf federation was formed 1902 (Swedish Golf museum 2015). In 2014, the number of golf courses were, 473 and the number of registered players were 475 000 (about 5 % of the Swedish population). Only Great Britain and Germany has a greater number of players in Europe (Swedish Golf museum 2015). The importance of including natural vegetation in the design and adapting management on golf courses for the conservation of biodiversity has long been known (Green & Marshall 1986). Golf courses that consider conservational issues in the management of their courses, and especially the rough, contribute more to the conservation of species at the landscape level than golf courses that mainly focus on creating a manicured playable surface (Green & Marshall 1986). In recent years, an increasing number of golf courses in Sweden have started to take measures for adding positive values and services to the society outside the game area such as, habitats for biodiversity and recreational values; hence creating multifunctional golf courses. However, the combined effects of a golf course on multiple functions have still not been evaluated.

Multifunctionality of ecosystems and the relations between biodiversity and multiple ecosystem services have recently received increased scientific (Hector & Bagchi 2007; Gamfeldt et al. 2008, 2013; Raudsepp-Hearne et al. 2010; Maestre et al. 2012) and practical interest (Foley et al. 2005; Nelson et al. 2009; Gamfeldt et al. 2013; UK NEA 2011; MAES 2013). From a scientific point of view, studies of this can provide a better understanding of the relations between components of biodiversity, species and multiple functions in ecosystems (Hector & Bagchi 2007; Gamfeldt et al. 2008, 2013; Maestre et al. 2012). For management of ecosystem services, which is presently high on the political agenda (e.g. MAES 2013 at the EU level, IBPES at the global level, the Swedish government and EPA nationally), the importance of understanding "*the ecological, economic and social aspects of the multiplicity of ecosystem services, identify trade-offs and synergies occurring between services …*" and "*… developing standardized methods and criteria for the measurements, mapping and monitoring of biodiversity and ecosystem services …*" (MAES 2013) has been highlighted.

The few investigations of multiple ecosystem services and biodiversity in terrestrial ecosystems that have conducted to date have concerned either synthetic experiments in grasslands (Hector & bagchi 2007; Gamfeldt et al. 2008; Zavaleta et al. 2009), drylands (Maestre et al. 2012), agroecosystems (Sircely & Naeem 2012) and agriculture-dominated landscapes (Raudsepp- Hearne et al.

2010) or forests (Gamfeldt et al. 2013). No such comprehensive studies have been made in urban grassland ecosystems, despite the possible importance and impact of lawn and turfgrass management on ecosystem services like recreation, biodiversity and carbon sequestration for climate mitigation (Colding & Folke 2009, Townsend-Small & Czimczik 2010a, b; Lal & Augustin 2012). The need for knowledge about how to plan, create and manage urban grasslands, such as golf courses, using a multifunctional approach promoting several ecosystem services, has been acknowledged, and the potential for designing golf courses to serve multiple functions has been pointed out by researchers as well as the golf associations (Colding & Folke 2009, Strandberg et al. 2012). It is well known that different management intensities of semi-natural grasslands may affect biodiversity in different ways (Hansson & Fogelfors 2000, Wissman et al. 2008) but the surrounding landscape may also influence on the way that species are utilising habitats promoted by different management (Colding & Folke 2009, Bergman et al. 2004). It has also been suggested that grasslands with different management have different C sequestration potential and carbon balances, especially when management intensity is included (Townsend-Small & Czimczik 2010a and b). Appropriate management could be an important factor for increasing the carbon sink capacity of green areas (Lal & Augustin 2012), but still little is known of how this should be accomplished.

At present, a number of studies have examined the impact of golf courses on the biodiversity of, for example, birds, amphibians, plants and insects or the carbon cycle (Colding & Folke 2009, Bartlett & James 2011). These studies show that golf courses may be a resource for biodiversity as provider of a range of grassland and lawn habitats (e.g. Tanner & Gange 2005, Colding & Folke 2009) and that the intensity of management and tree cover may influence the total greenhouse gas emission (Bartlett & James 2011). However, little is known about how these ecosystem services relate to each other and how they relate to other ecosystem services such as social and recreational values in golf courses and urban lawns.

In this paper we aim to understand how management of different areas in golf courses affect multifunctionality when it comes to carbon sequestration and biodiversity. Both carbon sequestration and biodiversity are political goals and can hence be considered cultural services (Mace et al. 2012; UK NEA 2011), but many components of biodiversity are also underpinning multiple ecosystem services (e.g. Mace et al 2012; Gamfeldt et al. 2013).

MAIN HYPOTHESIS:

- Both plants and pollinators, proxies for the ecosystem service of biodiversity, are correlated to management intensity, with higher biodiversity in less intensively managed vegetation.

- The diversity of plants and pollinators in golf courses is related to the amount of natural or semi-natural habitat of open vegetation in the surroundings.
- C-sequestration potential increases with plant biomass production
- Mitigation of greenhouse gas emissions will decrease with management intensity, because of CO_2 emissions associated with increased inputs of fossil energy sources will increase as management intensifies.
- More intensive management with more inputs show trade-offs between carbon sequestration and biodiversity but not necessarily with grass properties and recreational values for golf players. However, the trade-off depends on how carbon balances relate to management intensity.

METHODS

STUDY SITES

The locations of the golf courses were chosen to represent three separated areas in southern Sweden, where most of the golf courses are situated. The areas studied here are situated close to three of the largest cities in Sweden: Malmö, Gothenburg and Uppsala. Six golf courses were chosen as study sites, two close to each of the three cities. The golf courses included in the survey were: Burlöv GC and Lunds akademiska GC close to Malmö, Delsjöns GC and Torslanda GC close to Gothenburg and Upsala GC and Sigtuna GC close to Uppsala. The surveys were made in 2014 in four grassland management types: green, fairway, rough and high rough at six holes within each golf course. Biodiversity surveys were made on fairway, rough and high rough. In 2013 we conducted a pilot study of biodiversity on golf courses studying the two golf courses close to Uppsala. In that study, greens were included. However, the greens consist of only 1-2 plant species and none of these species was attracting pollinators, no pollinators were detected on the greens. Therefore, in this study, we chose to exclude the greens for the biodiversity survey and instead included the high rough or unmanaged area adjacent to the course to get an estimate of the potential of the course for biodiversity. The carbon sequestration surveys, however, were made on the more intensively managed parts of the golf courses: green, fairway and rough.

The golf courses vary in age between 22 and 80 years and the years when they were inaugurated were: 1936 - Lunds akademiska GC, 1964 – Upsala GC (at its present site), 1965 - Delsjön GC, 1971 - Sigtuna GC, 1981 - Burlöv GC and 1994 - Torslanda GC. Several of these courses have expanded since their start. They are also situated in different environments: *Delsjön* is situated in a forested area between the city of Gothenburg and the nature reserve of Delsjön that was formed in 1984. It is one of the oldest golf courses in the Gothenburg region. *Lunds akademiska GC* is situated about 6 km from Lund in the nature reserve Kungsmarken surrounded mainly by agricultural land. *Burlöv GC* is situated on the border between the municipalities of Malmö and Burlöv. The golf course is traversed by a river and large parts of the course are founded on land that has previously been used for agriculture. At *Torslanda GC* there was previously an airport that was closed in 1977. It is located close to the sea and surrounded by rocky and urban area. *Upsala GC* is situated about eight kilometers west of Uppsala on former agricultural land in a mixed agriculture and forest landscape. *Sigtuna GC* is situated 3 km from central Sigtuna adjacent to a lake and surrounded by agricultural land.

MANAGEMENT PRACTICES

The management of the different parts of the golf courses varies between courses. The frequency of cuttings of the greens varies between 2-7 times per week during the high season. Fairways are cut 2-3 times per week and roughs are cut when needed, once or twice a week. For the high rough, the number of cuttings varies from a couple of times a year to once a week. The exact water volumes used for irrigation was difficult to obtain for some of the golf courses and these estimates have therefore associated with high uncertainty. Irrigation was mainly applied to the greens and fairways and sometimes to the roughs and it varied between about 1350--6300 m^3 ha^{-1} $year^{-1}$. The roughs were usually not directly irrigated except for at one golf course (Delsjön) where the irrigation equipment used on the fairway also reached the rough. Fertilisers were applied only to greens and fairways.

PLANTS

The plants were examined within two plots (0.5 m x 0.5 m) in three management types (fairway, rough and high rough). In each management type, one of the plots was placed in the centre, one at the margin and one plot was randomly chosen. Within each plot, we recorded: a) the number of reproductive parts of flowering plants (thus herbs, grasses and sedges were excluded here), b) the number of 0.1 m^2 sub-plots within the 0.25 m^2 plot where each of the flowering plant species, vegetative or reproductive, were present (hence, a number of 1-25), c) the grass and sedge species present in the 0.25 m^2 plot, d) vegetation height, as the height a wooden square with the weight of 0.5 kg were situated when applied gently on the vegetation, e) the depth of litter, i.e., the depth from the mineral soil up to the top of the litter or moss layer, f) the time since last cutting, e) and an approximation of the species richness of the entire area of vegetation within the management type (classified within three classes less than two species, between three and ten species and more than ten species). All measurements were repeated two times during the summer, one in June and one in July with approximately 1 month in between, for covering both early flowering and later flowering species. The season of flowering in Sweden is generally between May and September but most plant species flower between early June and mid-August. Reproductive parts were measured as the number of buds, flowers and fruits, where all flowers and fruits were measured as single units, and thus individual flowers in an inflorescence of, e.g., an *Asteraceae* species were counted.

POLLINATORS, NECTAR AND POLLEN RESOURCES

Bumblebees, honeybees and butterflies were studied on days with dry weather (no rain), temperatures above 15°C and without strong wind (less than 5 m/s). Insects were observed in the three management types: fairway, rough and high rough at the same six holes as the plants (described above). The insects were surveyed in two 2 m x 2 m plots within each management type. One plot was placed in the center zone of the grass area and one in the border zone (2-5 m from the border) for covering assumed variation within each management type. When differences in flower density within management type were obvious, plots were placed in the most flower rich parts of the grass areas to maximize the potential for pollinator observations. All the plots were placed in open areas with negligible influence of shading trees or bushes. Notes were made when observing visiting insects and their visitation rate within each plot for 5 minutes. Within the plots, species of flowering plants were investiagated and the approximate number of flowers of each species was estimated as a measure of potential nectar and pollen resources. Specimens were collected for species determination when it was not possible to determine the species at a distance. Corresponding to the plant inventories, these surveys were repeated two times during the season, once in June and once in July on each of the 6 golf courses.

LANDSCAPE

Variables on plants and pollinators were correlated to the surrounding landscape where the amount of potentially species rich grasslands in one and six kilometre zones around the courses was used. The vegetation in the buffer zones was quantified by using SMD, Swedish Land Cover Data (Swedish environmental protection agency 2014).

PRODUCTIVITY AND CARBON SEQUESTRATION

Aboveground net primary production (NPP) of three different management regimes (green, fairway, rough) was determined with two different methods. Fairways and roughs were surveyed by repeated sampling of aboveground biomass using a 50 cm x 50 cm square frame. The plots were sampled at two to four random locations within each of three plots per golf course and lawn type (three holes per golf course) using a 50 cm x 50 cm square frame. 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 replicates was divided by the number of days between the last mowing and sampling to obtain a daily growth rate. This growth rate was extrapolated to cover all days between two samplings, to fill the gaps between previous sampling and mowing, for which no growth rate was determined. The daily growth rate of greens was surveyed by collecting the mowing residues of the total green area as compiled by the green keeper. The average area of the greens was 460 m^2. Due to the extremely high mowing frequency on golf courses, the selected plots were not sampled after each mowing event, but on average 10.7 (greens), 7.6 (fairways) and 6.1 (roughs) times per year. The time between mowing and sampling was usually very short (1-4 days).

Based on these daily growth rates, we calculated cumulative growth until the last sampling. Since this day did slightly vary between plots and sites and did not equal the last day of the vegetation period, we fitted a simple vegetation model (Yan & 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 formula reads as:

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

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}, which is the maximal growth rate at T_{opt}. Instead of using R_{max}, which was used in the formula 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. Daily average temperatures were obtained from the closest weather stations run by the Swedish Meteorological Service (SMHI). The sampling on the golf courses did not start after the first mowing, but only several weeks after the start of the vegetation period (around day 140 in Uppsala and around day 170 in Gothenburg and Malmö. Therefore, we had to estimate the proportion of NPP that was produced before that day. This was done by using the unscaled vegetation model for each city, which predicted the cumulative growth curve as a function of daily temperature. We divided the cumulative growth at the first sampling date by the cumulative growth at the last sampling date and obtained a proportion of how much of the total growth (until the last sampling date) was missed. This was 21% in Uppsala, 8.3% in Malmö and 5.9% in Gothenburg.

Soils were sampled in autumn 2014 to a depth of 20 cm using a thin auger (2.2 cm diameter). At each golf course, three holes, consisting of fairway, rough and green, were sampled. Ten randomly distributed soil cores on each lawn type and hole were taken and pooled to a composite sample (n=3 for each lawn type and golf course). Soils were dried at 40°C, sieved to 2 mm and visible roots were manually removed. Soil pH was determined in H_2O and samples with pH values exceeding 6.7 were analysed for carbonates. 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 pre-treatment 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 7.5 cm diameter and 10 cm depth in an approximate depth of 5-15 cm and subsequent drying at 105°C and weighing. Four samples were taken in each plot. To account for the fact that soil organic carbon (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:

$SM = BD \times D \times 100,$

where *BD* is the soil bulk density [g cm^{-3}] and *D* is the sampling depth [cm]. The lowest soil mass measured at each site was then used as the reference soil mass (RSM) to which all other plots at that site were adjusted. The reference soil mass of each site is given in table 2.

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

$SOCstock = RSM \times \frac{C}{100}$

Statistic analysis

The analyses of differences in NPP and soil carbon between different treatments were made in R. To analyse the differences between diversity indexes for plants, reproductive parts and flowers that attract pollinators as well as for NPP and soil carbon between treatments, Mixed models procedure (JMP pro 11) were used. Treatment was set as fixed factor and golf course and hole nested within golf course as random factors. Differences between treatments were performed using Students all pairwise comparisons within a mixed model procedure in JMP pro 11.

The data on pollinator visitors, abundance and species could not be related to any distribution, therefore nonparametric tests were used. To analyse the difference in diversity, the Shannon-Weiner diversity index was used as the measure of diversity of plants in the analyses. Shannon-Weiner diversity index was calculated using the formula:

$$H' = -\sum_{i=1}^{s} [(p_i)\ln(p_i)]$$

where p_i is the relative proportion of a species *i.* The index was calculated for each single 0.5 m x 0.5 m plot where their presence in the sub-plots was used as a value of abundance.

To get a visual view of the correlation between factors determining species composition between treatments, and between golf courses and additionally, if this species pool contained species that are indicators of species rich grasslands or species that indicates fertilised species poor grasslands, a principal components analysis on correlations were made in JMP pro 11, multivariate methods. Plants were categorized using habitat and preference limitations from descriptions in Swedish Museum of Natural History (2013) as, a) indicators of nutrient poor, dry and species rich vegetation: positive indicators, b) indicators of fertilized, highly productive and species poor vegetation: negative indicators.

SOCIAL ASPECTS OF GOLF COURSES

Social aspects of golf courses were studied in a related project: *Lawn as a cultural and ecological phenomenon* financed by FORMAS and the results of these studies are shortly described in the discussion.

RESULTS

PLANTS

A visualization of the different correlations that categorizes different management types and courses show that positive indicator species were negatively correlated to both fairway and slightly to rough (figure 1). High rough had very few species in common with the other two management types.

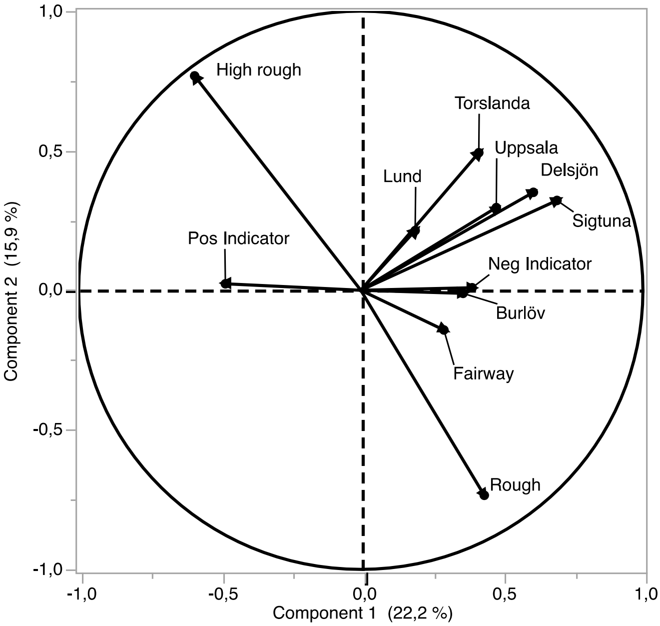


Figure 1. Principal component analysis on the correlations between golf courses and different management types in terms of species composition and indicator species.

The diversity of flowering plants differed between the management types (Mixed models, DF = 2, F = 76.29, P < 0.001) where rough had lower diversity than high rough (t-ratio = -6.78, P < 0.001) and fairway had lower diversity than rough (t-ratio = -5.98, P < 0.001).

The number of reproductive units (buds, flowers and fruits) per 0.5 m x 0.5 m plot differed between the management types (Mixed models, DF = 2, F = 7.39, P = 0.001) where rough had lower numbers of reproductive units than high rough (t-ratio = -2.28, P = 0.025), but no such effect could be found between fairway and rough (t-ratio = -1.55, P = 0.1251).

When determining the potential for attractiveness to pollinators only the plant species visited by pollinators were included in the analysis. This analysis was made for the plants that were present in the 4 m^2 plots (where the pollinator observations were made). There was a difference in number of flowers per plot among management types (figure 2, Mixed models, DF = 2, F = 17.99, P < 0.001). In general, the roughs had lower number of flowers per plot than the high roughs (t-ratio = -2.08, P = 0.0373), and fairways had lower number of flowers per plot than roughs (t-ratio = -3.88, P < 0.001). The results for the golf courses Burlöv GC, Torslanda GC and Upsala GC followed the general pattern, even if the variation within golf courses in number of flowers per plot was high for the high rough at all three golf courses and for the roughs at Burlöv GC. For Delsjön GC and Sigtuna GC there was no difference in number of flowers per plot between roughs and high roughs and for Lunds akademiska GC there was no difference in number of flowers per plot between fairways and roughs.

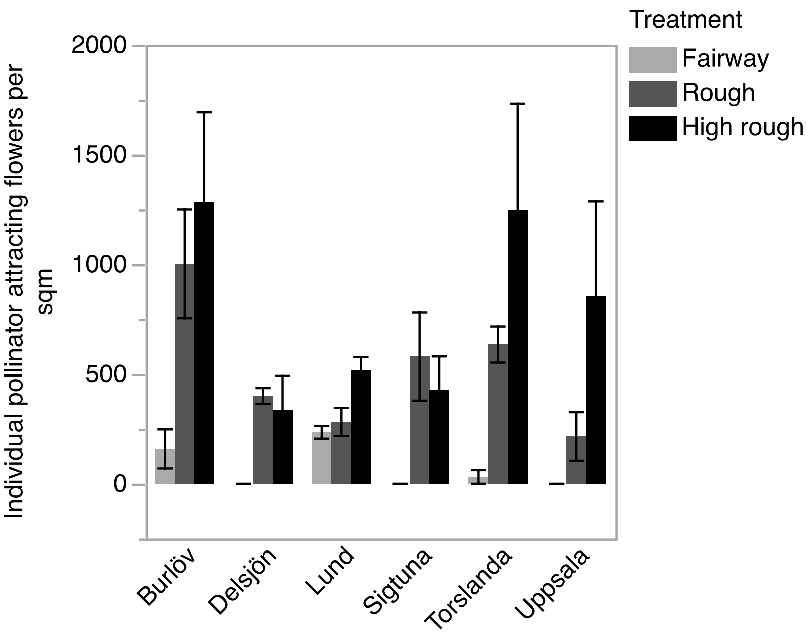


Figure 2. The amount of flowers that attract pollinators per m^2. Two plots, one in Uppsala and one in Delsjön was removed due to extreme values of flowers (5 632 flowers of *Tripleurospermum perforatum* per m^2 in Uppsala and 15 770 flowers of *Tanacetum vulgare* per m^2 in Delsjön).

In general, the golf courses had none or very low numbers of flowers in the fairway except Burlövs GC where it varied within the golf course and Lunds akademiska

GC where it was generally relatively high. The total number of plant species found in plots in the six golf courses varied from 40 in Burlöv GC to 71 in Lunds akademiska GC (Appendix 1).

Insects

Total number of species of pollinators varied between 8 species in Torslanda GC (5 species of bumble bees, 2 species of butterflies and honeybees) to 18 species in Sigtuna GC (7 species of bumble bees, 10 species of butterflies and honeybees) (Appendix 2). Honeybees were present in all golf courses, the number of bumble bee species varied between 5 and 7 species in all golf courses and the number of butterfly species varied between 2 and 11 species. The highest number of butterfly species was found in Lunds akademiska GC.

There was an overall effect of management type both for number of flower visiting insect species (bumble bees, butterflies and honey bees), number of individual insects visiting flowers and number of flower visits (table 1, figure 3 A-C). When comparing individual pairs of management type, number of flower visiting insect species were highest in high rough and lowest in fairway, but for number of individual insects visiting flowers and number of flower visits fairway had lower numbers while rough and high rough could not be separated (table 1, figure 3). For individual golf courses, the pattern for number of flower visiting species differed from the general pattern for Torslanda and Delsjön where there was no difference between rough and high rough. For number of flower visiting pollinator individuals there was no significant difference between fairway and rough at Lunds akademiska, whereas the other golf courses followed the general pattern. For number of flower visits per plot there was no difference between any of the management types for Torslanda and Lund, while the results for the other golf courses followed the general pattern.

Table 1. Wilcoxon Rank Sums test and Wilcoxon each pair comparison for: number of visiting species, visiting individuals and flower visits in the three different treatments (fairway, rough and high rough), the measurements of flower visitors were done in 4 m^2 with 5 min observations two times in the season, in six golf courses, six holes each with two plots per treatment. In the analysis golf course was used as blocks.

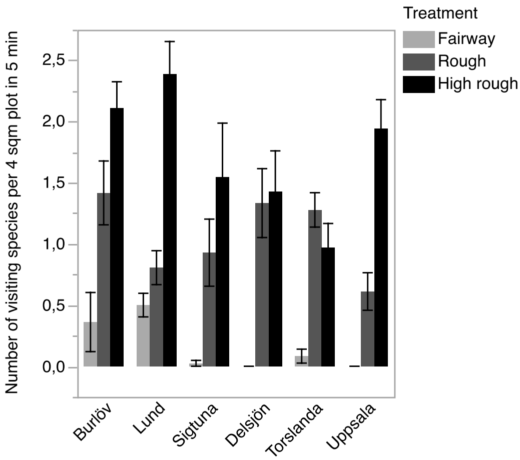
Over all	**ChiSquare**	**DF**	**P**
Visiting species	66.88	2	<0.001
Visiting individuals	58.10	2	<0.001
Flower visits	35.74	2	<0.001

Number of visiting species

Each pair comparison		**Z**	**P**
Rough	Fairway	6.57	<0.001
High rough	Fairway	7.09	<0.001
High rough	Rough	3.44	<0.001
Number of visiting individuals			
Rough	Fairway	6.00	<0.001
High rough	Fairway	6.70	<0.001
High rough	Rough	3.15	0.002
Number of flower visits			
Rough	Fairway	4.99	<0.001
High rough	Fairway	5.67	<0.001
High rough	Rough	-0.20	0.840

Figure 3 A-C. Mean number of flower visiting species, mean number of flower visiting individuals and mean number of flower visits in 4 m² plots in fairway, rough and high rough (inventoried in 5 min per plot, two plots per hole, six holes per golf course and in six golf courses in southern Sweden).

A



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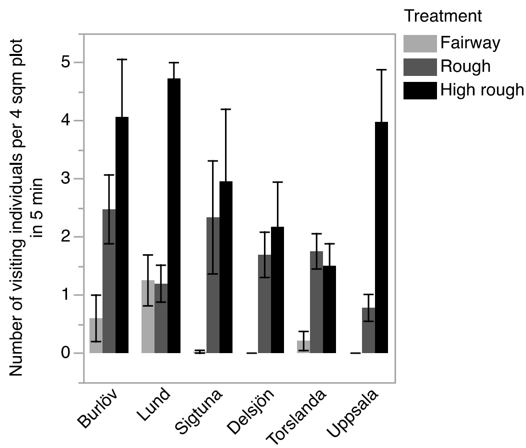

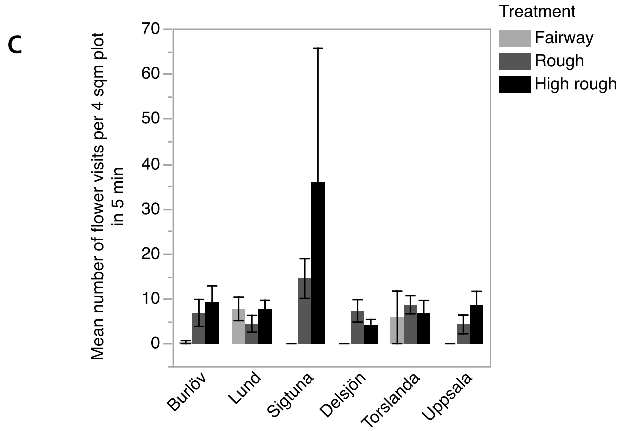

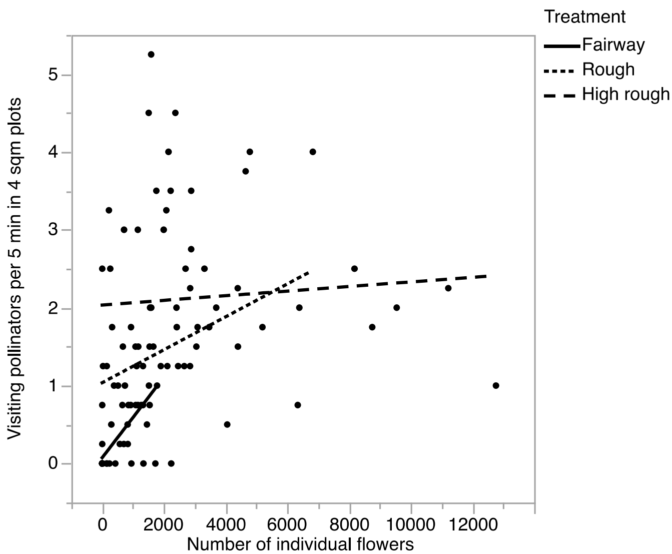

Figure 4. Visiting insect individuals in 4 m² plots / 5 min and its dependence on the number of flowers, attractive for pollinating bees and butterflies in three different management regimes.

Visiting insect individuals were dependent on number of flowers (that attract flower visiting bees and butterflies) in fairways (DF = 1, F = 20.05, P <0.001) but this relation between factors was very weak in rough (DF = 1, F = 3.56, P = 0.073) and could not be detected in high rough (DF = 1, F = 0.16, P = 0.696, two outliers were removed).

PRODUCTIVITY AND CARBON SEQUESTRATION

Aboveground net primary production (NPP) was significantly affected by management intensity (p<0.001), with greens having the lowest (1.0±0.6 Mg C ha-1 yr-1), fairways having intermediate (4.3±2.1 Mg C ha-1 yr-1) and roughs having the highest (5.0±1.4 Mg C ha-1 yr-1) biomass production (figure 5A). The difference between roughs and fairways was thereby also significant (p=0.045). SOC concentrations in greens (9.3±4.3 g kg-2) were significantly lower than in fairways (40±13 g kg-2) and roughs (45±12 g kg-2) (p<0.001) (figure 5B, table 2). The difference between roughs and fairways (p=0.057) was in the same direction as observed for NPP. On average, roughs had 10.1 Mg C ha^{-1} more soil carbon than fairways.

Table 2. The calculated soil organic carbon stocks (Mg ha-1) in three different management types and six golf courses, in southern Sweden.

Golf course	RSM	Green		Fairway		Rough	
		Stock	SD	Stock	SD	Stock	SD
Burlöv	2360	30.5	14.7	68	2.9	58.5	11.2
Lund	1780	18.1	13.1	77.6	12.4	75.4	19.4
Sigtuna	1740	18.6	3.1	89.6	7.8	90	7.3
Uppsala	1480	12.1	4.7	61.2	5.8	79.7	18.2
Torslanda	1700	10	1.6	34.6	11.8	77.6	12.2
Delsjön	2000	11	0.7	79.8	40.4	90.5	28.1
Average	1843	16.7	7.7	68.5	19.3	78.6	11.7

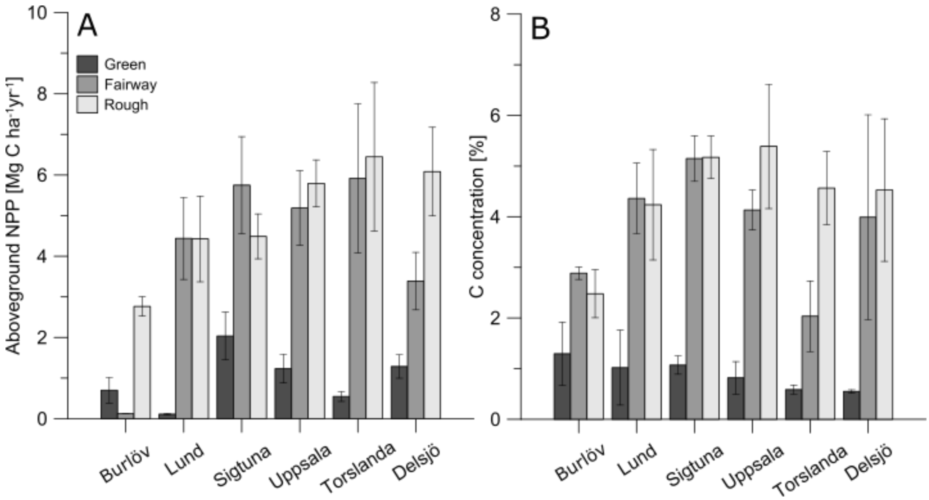

Figure 5. A) Net primary aboveground biomass production and B) organic carbon concentrations in the soils in the six golf courses.

LANDSCAPE

The proportion of semi-open grasslands within the buffer zone differed much where Lund and Torslanda had roughly 5 times as much as the rest of the golf courses (table 3).

Table 3. The proportion of open semi-natural grasslands within buffer area, at 1 and 6 km distance.

Golf course	*Buffer size 1 km* Open semi-natural grassland in buffer (%)	*Buffer size 6 km* Open semi-natural grassland in buffer (%)
Burlöv	2,8	5,7
Delsjön	3,0	1,7
Lund	31,3	5,7
Sigtuna	14,2	4,6
Torslanda	35,3	20,4
Uppsala	9,1	3,8

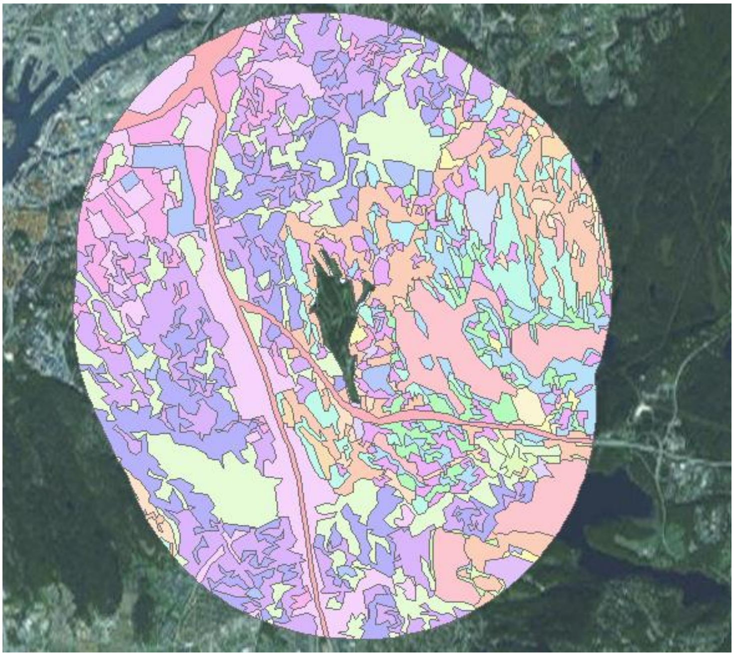

Figure 6. Example of a buffer zone at 6 km distance from the golf course. Colors represents vegetation types, roads, resedential areas etc. tha gap in the center is the golf course, in this case Delsjön.

The area grassland habitat surrounding the golf courses did neither show any correlation with plant biodiversity, nor pollinator abundance, visitation rate and species number. All R^2-values but one were below 0.34 (N=6) for the 24 relationships tested between the amount open semi-natural grasslands in the buffer zones and the Shannon-Weiner index for plants, number visits per plot in 5 min, number of visiting individual pollinators and number of visiting pollinator species. The great number of regressions has to be handled with care to avoid significances by chance. Thus, the only relationship that had a high R^2-value also had a significant linear regression analysis: a positive correlation between (R^2 = 0.84, N = 6, F = 0.20,37, P = 0.011, equation: Number of pollinator visits per 5 min in 4 m^2 plots = -1.3 + 0.23 x 1 km buffer). But, according to Bonferroni-corrections, this value was well above the corrected significance level, thus there is a risk for a type 1 error – a false significance.

DISCUSSION

In accordance with our hypothesis, species diversity of flowering plants as well as flower richness and pollinator species richness was higher in less intensively managed vegetation. However, the diversity of plants and pollinators was not significantly related to the amount of open semi-natural habitat in the surroundings. The results for SOC sequestration show that plant biomass production as well as SOC contents was highest in roughs, intermediate in fariways and lowest in greens. The realtive low biomass production measured in greens could have been due to a difference in sampling methodology and needs to be further investigated. According to our results there was no trade-off between carbon sequestration and biodiversity. Less intensive management led to both higher SOC sequestration and higher diversity of plants and pollinators. However, the difference in annual SOC sequestration between management types had a relatively low impact on the total difference in greenhouse gas balance.

In a related FORMAS project, social aspects of golf courses were studied at the same six golf courses. For many players, visits to the golf course acted as experience of nature and beautiful surroundings as well as a meeting place in a social context, a way to stay in shape (fitness) as well as a way to relax (recreation) in addition to the game (Eriksson et al., 2015). Many interviewers also stressed the importance of having golf facilities which are designed in the environmentally friendly manner. These results indicate that there is an interest in promoting biodiversity and an environmentally friendly management. Looking at the home pages of the studied golf courses, several of them also highlight their beautiful nature and the work done promoting the environment indicating that this is also something they want to communicate.

MANAGEMENT AND PLANT DIVERSITY

The high numbers of flowering species and reproductive units of plants in high rough show that these areas have a great potential for being a valuable contributor to the conservation of individual plant species and also as a resource for pollinators, seed eating animals and to support a greater variety of fauna than both rough and fairway. Plant diversity was higher in rough than fairway, which probably reflects the less intense cutting frequency and higher cutting heights in roughs. The roughs contained a very low proportion of any indicator species. The high rough contained a relatively high number of positive indicators but also some negative indicators. Fairways contained a high proportion of negative and no positive indicators. Although positive indicators were present in all courses, this vector positions itself opposite to many of the golf courses in the principal component analysis (figure 1). This may be due to the fact that the positive indicators were related to high rough, which in turn were very variable. This implies that some high roughs had a diverse flora whereas others may be old fertilized arable land which contained very few numbers of flowering species due to high nutrient values. The huge difference between plant species richness in Lunds akademiska GC and Burlövs GC was probably not due to differences in landscape parameters at a larger scale since the two golf courses are situated in very similar landscapes and are only 16 km apart from each other. The difference could probably be explained by differences in management and in the natural potential of the particular sites. Lunds akademiska GC is situated in a nature reserve with a natural history of continuous meadow management of several hundred years while Buröv GC is built on former farmland. Additionally, Lunds akademiska GC is managing the roughs according to several regulations that are set up inside the protected area that consider the management history of meadow management.

MANAGEMENT, FLOWER RESOURCES AND POLLINATORS

Species richness of plants in flower and flower visiting insects decreased with management intensity. Fairways had few species of plants in flower as well as few flowers per unit area and the dominating species was white clover *Trifolium repens*. Roughs had more species and a higher number of flowers per unit area than fairways, but the dominating plant species was still white clover. High roughs had a higher number of plant species and, even if they did not have significantly higher number of flowers per unit area, the flowers were distributed among a higher number of plant species. The species richness of pollinators was higher in high roughs then in roughs, while the number of pollinator individuals and number of flower visits were not significantly different between the two management types. Increasing flower abundance in high roughs, however, did not increase pollinator abundance at the same rate as increasing flower abundance in fairways and roughs did. Increased flower abundance in fairways and roughs primarily meant higher abundances of white clover which is a very attractive plant for honey bees and bumble bees. The pollinators visiting flowers in fairways and roughs was also primarily honey bees and a few bumble bee species. Increasing flower richness in high roughs meant increasing abundances of flowers of different species that may not always be as attractive for the most common pollinators here. Another explanation could be that flower resources was not the only thing determining the presence of bumble bees and butterflies so that after reaching a certain level of flower abundance adding more flowers would not increase abundances of pollinators if not, e.g., the availability of nesting sites (for bumble bees) or larval food plants (for butterflies) is also increased.

Most butterflies observed were found in the high roughs often adding species not present in the other management types. It was also the number of species of butterflies that varied most between golf courses. Honeybees and between 5 and

7 species of bumble bees were found in all golf courses, whereas the number of butterfly species varied between 2 and 11 species among the six golf courses. The lowest number of butterfly species was found at Torslanda GC, which is founded on an old airport. Butterflies are known to be sensitive to environmental factors such as climate, local management and environmental conditions, they are also dependent on the availability of larval food plants and react quickly to changes in habitat quality. They are therefore considered good indicators of habitat quality and environmental change in general (vanSwaay et al. 2006) and have been suggested as indicator group for detecting effects of restoration measures of semi-natural calcareous grasslands in particular (Rákosy & Schmitt, 2011).

POLLINATOR SPECIES RICHNESS AND LANDSCAPE EFFECTS

Previous studies have found effects on local species richness of bumble bees and butterflies of habitat availability at a landscape scale (Bergman et al. 2004, Ahrné et al. 2009). In this study, however, we could not find any effect on pollinator species richness, abundance or flower visits of amount semi-natural grasslands in the surroundings. Previous studies of butterflies have found differences among species groups in their sensitivity to habitat availability and decline (Warren et al. 2001, Kivinen et al. 2007). In general specialist species are more sensitive to habitat decline then mobile generalist species (Warren et al. 2001) and declining species are more sensitive to habitat availability then species with stable or increasing populations (Kivinen et al. 2007). Except for the Red Listed burnet moths *Zygaena filipendulae* and *Z. viciae* that were found on one golf course each, the butterflies found in this study are relatively common and widespread. Among bumble bees landscape effect has also been found to differ among species, with bumble bees with intermediate nest sizes being most influenced by habitat fragmentation (Rundlöf et al. 2007). We did not have enough observations to be able to relate abundances of different pollinator species to landscape factors. In addition, the golf courses here were primarily chosen to compare effects of differences in management practices and to be representative for three metropolitan areas within different climate zones and not to represent a gradient of semi-natural grasslands within the surroundings. They were situated in different parts of Sweden within different landscape settings, where the Malmö region consists mainly of urban and agricultural areas, the Gothenburg region consist of urban, forested and rocky areas and the Uppsala region consists of a mixture of agricultural, forested and urban areas. It is possible that with more replicates in each region and more detailed landscape measurements we might have detected landscape effects. Thus, this result should not be interpreted as if the landscape surrounding golf courses was not important.

PRODUCTIVITY AND CARBON SEQUESTRATION

We found a clear gradient of NPP and SOC along the management gradient, with greens having the lowest production and SOC contents. Although NPP is a major driver for SOC sequestration (Christopher & Lal 2007), the results in this study have to be treated with caveats, since a direct causality might not be given. The low NPP values on the greens are most likely related to a methodological bias: While on fairways and roughs regrowth was measured by cutting the grass within small areas (0.25 m^2), the regrowth on greens was measured by collecting the clippings of the whole area as compiled by the green keeper. It is likely that this led to strong underestimations of the total production in greens, which is indicated by the fact that the fairway in Burlöv, being the only fairway for which the same method was applied, had similarly low NPP-values. Furthermore, the soil under the investigated greens does not consist of the native substrate, but consists of mostly sandy, an imported substrate. Finally, the clippings were exported from the greens and partly even brought to the closest rough, while on fairways and roughs the clippings were not removed. Thus, greens differed greatly in C inputs and soil properties, which precluded a direct comparison of the three differently managed lawn types. However, NPP and SOC in fairways and roughs followed similar patterns, revealing a strong link between them. While in Lunds akademiska and Sigtuna, NPP as well as SOC were higher in the fairway or showed no difference between lawn types, in Upsala, Torslanda and Delsjön both parameters were higher in the rough. The management scheme of rough, which are cut once a week thus seemed to be more favourable for biomass production than the very intense management scheme of fairways, which are cut up to three times a week. This is in line with the results of Kramberger et al. (2015), who found the highest NPP in lawns with an intermediate to low cutting frequency (8-12 weeks interval). However, the productivity of common agricultural grasslands with a cutting frequency of 0-4 times per year is often found to increase with increasing management intensity (Ammann et al. 2007). The results of our study suggest, that the correlation of management intensity and NPP might be best described by an optimum curve. In a life cycle assessment on the golf courses in Uppsala, Wesström (2015) calculated that the management of the different lawn types would cause total CO_2-C emissions of 2.05 Mg ha yr^{-1} (greens), 0.60 Mg $ha^{-1}yr^{-1}$ (fairways) and 0.11 Mg $ha^{-1}yr^{-1}$ (roughs). This reveals that i) roughs are by far the most climate friendly lawns on golf courses and ii) the difference in annual SOC sequestration has a relatively low impact on the total difference in greenhouse gas balance. With an average golf course age of 61 years, the measured average difference between roughs and fairways (10.1 Mg ha^{-1}) would account for an average difference in annual sequestration rate of 0.16 Mg $ha^{-1}yr^{-1}$, which corresponded to only 23% of the difference in CO_2-C emissions. The cumulative difference in carbon balance between fairways and roughs was thus on average 0.65 Mg $ha^{-1}yr^{-1}$ less CO_2-C emissions from roughs, assuming that management related carbon costs did not differ widely across golf courses.

POTENTIAL FOR IMPROVEMENT OF HABITATS WITHIN GOLF COURSES

We have shown that there is a potential to improve the quality of habitats in golf courses for plants, pollinators and to some extent SOC sequestration through less intense management. The quality of the high roughs as habitat for plants and pollinators was variable and could probably be increased. For bees and butterflies it is important, in addition to flower resources, to also consider other factors of the environment such as availability of nesting sites and food plants for larvae. In this study, we mainly encountered common and widespread butterfly and bumble bee species suggesting that the quality of the habitats for these insect groups was mediocre. It appears that there is also a social potential in moving towards more environmentally friendly management. In the description of the different golf courses on their home pages there are often descriptions of the nature of the course. For example, Delsjön golf course is described as: *"..a medium difficult park- and forest course in a wonderfully beautiful and well managed nature, .."* and in the description of Sigtuna golf course its old oaks, rich birdlife and the view of the lake through well managed tree curtains are mentioned as giving the course its feeling and character. It is also mentioned that the club is working for increasing biodiversity and conservation of nature. Also, other golf courses are mentioning their work for biodiversity and the environment, e.g., in Burlöv golf course ponds have been created with the intention to favor biological diversity and serve as a biological filter for water flowing into the river and both Upsala and Sigtuna golf course are GEO certified meaning that the management of the courses has been examined regarding its influence on the nature and environment (The golf environment, 2016). Lunds akademiska golf course mention their unique flora in their description and also organizes guiding tours informing about plants and the birds of the area. Thus, the golf clubs value and highlight the scenery at their specific golf course, and have an interest in promoting themselves as biodiverse and environmentally friendly, but are also willing to take actions towards becoming more so. In the interviews made with golf players on the same golf courses in another study within the related LAWN-project (Ignatieva et al. 2015) also revealed an interest in promoting biodiversity and an environmentally friendly management (Eriksson et al. 2015). Given that there is a decline in meadows and other types of flower rich grasslands, due to changes in agricultural practices and that one of the most important threats towards Red Listed species in Sweden is overgrowth of open grasslands (Sandström et al. 2015), also golf courses should be considered for the conservation of grassland species. Compared with other urban grasslands many golf courses cover considerable areas and thus have the potential to create relatively big and connected habitats. Besides adding habitat for biodiversity, naturalistic golf courses may also engage people in wildlife habitat preservation issues (Terman 1997).

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APPENDIX 1.

Plant species present in six golf courses in Sweden.

			Golf Course			
Species	**Burlöv**	**Lunds**	**Delsjön**	**Torslanda**	**Upsala**	**Sigtuna**
Achillea millefolium	X	X	X	X	X	X
Achillea ptarmica		X		X		
Aegopodium podagraria			X			
Agrostis capillaris	X	X	X	X	X	X
Agrostis stolonifera		X				
Agrostis vinealis		X				
Alchemilla vulgaris		X	X		X	X
Allium oleraceum					X	
Alopecurus pratensis	X	X	X	X	X	X
Anthoxanthum odoratum		X				
Anthriscus sylvestris	X				X	X
Arenaria serpyllifolia				X		
Arrhenatherum elatius					X	
Artemisia vulgaris				X		
Avenula pratensis			X			
Bellis perennis	X	X				
Briza media		X				
Bromus hordeaceus				X		
Bunias orientalis					X	
Campanula persicifolia					X	
Campanula rotundifolia		X	X			
Capsella bursa-pastoris					X	
Carex Unidentified		X	X	X		
Centaurea jacea	X	X		X		
Centaurea scabiosa					X	
Cerastium fontanum		X	X	X	X	X
Cerastium Unidentified	X	X				
Chamaenerion angustifolium				X		

Chenopodium album				X		
Cirsium arvense	X	X	X	X	X	X
Cirsium palustre			X			
Cirsium vulgare	X	X			X	
Cynosurus cristatus		X				
Dactylis glomerata	X	X	X	X	X	X
Deschampsia cespitosa		X	X		X	X
Dianthus deltoides					X	
Elytrigia repens			X	X	X	X
Epilobium				X		
Equisetum arvense			X		X	X
Festuca brevipila	X			X		
Festuca ovina	X	X				
Festuca rubra	X	X	X	X	X	X
Filipendula ulmaria		X				X
Filipendula vulgaris		X			X	
Fragaria vesca					X	
Galeopsis Unidentified					X	
Galium aparine					X	X
Galium boreale		X			X	
Galium mollugo		X			X	
Galium uliginosum						X
Galium verum	X	X			X	X
Geranium sanguineum		X				
Geranium sylvaticum					X	
Geum rivale			X			X
Geum urbanum					X	
Glechoma hederacea		X			X	
Gnaphalium Unidentified				X		
Holcus lanatus	X	X	X			
Hypericum maculatum	X	X	X	X	X	
Hypericum perforatum			X			
Hypericum perforatum					X	
Hypochaeris radicata		X				X
Jacobaea vulgaris	X					

Juncus conglomeratus		X				
Juncus effusus			X	X		
Knautia arvensis	X	X				
Lamiaceae				X		
Lamium album					X	
Lamium purpureum		X			X	
Lathyrus linifolius		X				
Lathyrus pratensis	X	X	X	X	X	X
Leucanthemum vulgare	X				X	
Lolium perenne	X		X	X	X	X
Lotus corniculatus	X	X		X	X	X
Luzula campestris		X				
Lythrum salicaria				X		
Medicago lupulina	X					
Mentha arvensis						X
Myosotis scorpioides			X			
Odontites vulgaris				X		
Ononis spinosa		X				
Pastinaca sativa	X					
Phleum pratense	X	X	X	X	X	X
Pilosella officinarum		X			X	
Pimpinella saxifraga		X			X	
Plantago lanceolata	X	X		X	X	
Plantago major		X	X	X	X	X
Plantago media					X	
Poa annua	X	X	X	X	X	X
Poa pratensis	X	X	X	X	X	X
Polygonum aviculare				X	X	
Potentilla argentea				X	X	
Potentilla erecta		X				
Potentilla reptans					X	X
Primula veris	X					
Prunella vulgaris	X	X				
Quercus robur			X			
Ranunculus acris	X	X	X	X	X	X

Ranunculus auricomus		X	X	X		X
Ranunculus repens			X	X		
Rhinanthus angustifolius	X	X				
Rhinanthus minor		X				
Rosa Unidentified				X		
Rubus idaeus			X			
Rubus saxatilis			X			
Rumex acetosa		X	X		X	
Rumex Unidentified				X		
Salix repens		X				
Schedonorus pratensis		X			X	X
Serratula tinctoria		X				
Sinapis Unidentified				X		
Stellaria graminea	X	X	X	X		X
Stellaria holostea			X			
Stellaria media		X	X		X	X
Succisa pratensis		X				
Tanacetum vulgare				X		
Taraxacum vulgare	X	X	X	X	X	X
Tragopogon pratensis	X	X			X	
Trifolium arvense	X					
Trifolium hybridum				X		
Trifolium medium		X			X	
Trifolium montanum		X			X	
Trifolium pratense		X		X	X	X
Trifolium repens	X	X	X	X	X	X
Tripleurospermum inodorum				X	X	
Tussilago farfara					X	
Urtica dioica				X	X	X
Veronica arvensis		X			X	X
Veronica chamaedrys		X	X	X	X	X
Veronica officinalis			X			
Veronica serpyllifolia			X			X
Vicia cracca		X	X	X	X	X
Vicia hirsuta	X					

Vicia sativa subsp. nigra	X					
Vicia sepium			X			
Vicia tetrasperma	X					
Viola canina		X			X	
Viola Unidentified		X				X

APPENDIX 2

Presence of flower visiting bees (bumblebees and honey bees) and butterflies in six golf courses.

	Golf Course					
Species	**Burlöv**	**Lunds**	**Delsjön**	**Torslanda**	**Upsala**	**Sigtuna**
Honney bee						
Apis mellifera	X	X	X	X	X	X
Bumblebees						
Bombus bohemicus		X				
Bombus hortorum			X	X	X	X
Bombus hypnorum	X					
Bombus lapidarius	X	X	X	X	X	X
Bombus lucorum	X	X	X	X		X
Bombus pascuorum	X	X	X		X	X
Bombus pratorum			X			X
Bombus ruderarius / B. lapidarius /B. rupestris	X			X		X
Bombus soroëensis	X			X	X	X
Bombus subterraneus	X					
Bombus terrestris	X	X	X	X	X	X
Butterflies						
Aglais urticae		X		X	X	
Aphantopus hyperantus		X	X		X	X
Argynnis aglaja						X
Coenonympha pamphilus	X	X				
Glaucopsyche alexis						X
Gonepteryx rhamni			X			
Heliconiinae Unidentified		X			X	
Hesperia comma						X
Inachis io	X	X				X
Lasiommata megera			X			
Lycaena phlaeas		X			X	

Maniola jurtina	X	X				
Ochlodes sylvanus					X	X
Pieris brassicae			X			
Pieris napi	X	X	X		X	X
Pieris rapae						X
Polyommatini Unidentified	X	X	X			X
Polyommatus icarus	X	X				X
Satyrinae Unidentified	X	X	X			
Thymelicus lineola		X			X	X
Vanessa atalanta				X		
Zygaena filipendulae	X					
Zygaena viciae		X				
Zygaenidae Unidentified	X	X				