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Bodil Ub

UNIVERSITY OF GOTHENBURG

DEPARTMENT OF BIOLOGICAL AND ENVIRONMENTAL SCIENCES

AN ATTEMPT TO PROMOTE GROUND-NESTING BEES IN AN URBAN LANDSCAPE

Investigating the use of sand beds as a conservation effort

Bodil Mattsson

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Pictures taken by Bodil Mattsson

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Abstract (English)

Pollinators provide crucial services for the ecosystems by pollinating around 80-90% of all plants. However, pollinating insects are declining worldwide which may cause a parallel decline in plant species leading to large biodiversity losses. One major cause for pollinator declines is habitat destruction which has large implications for ground-nesting bees. This nesting strategy is used by 64-83% of all known bee species. Rapid urbanization is diminishing the bees nesting habitat. To mitigate this problem, the present study aimed to investigate if the addition of sand beds in Slottsskogen, a city park located in Gothenburg, Sweden, could attract ground-nesting bees and serve as a conservation effort. For the analysis, seven sand beds were investigated, each paired up with two controls. Bees and other Hymenopterans were caught during late May-August 2023 through netting for 15 min for each area. In addition, floral inventories were made in a 200-meter buffer zone around the sand beds to examine if important plant species for bees occurred in the area. A generalized linear mixed model and an ANOVA was performed on two different datasets: 1) bees 2) bees + other hymenopterans (total). The results showed no significant effect between sand beds and controls for 1) bees. For 2) bees + other hymenopterans (total), the results showed a significant effect where more insects were caught on the sand beds compared to the controls. The floral inventory found important plant species in the proximity of the sand beds. Not finding many bees in the sand beds can be due to the sand not meeting the proper requirements the bees need. There is a big knowledge gap in the research field of ground-nesting bees and future studies would benefit from including examination on different soil properties and slopes to investigate if alterations in the Slottsskogen sand beds needs to be done to attract more bees.

Keywords: *ground-nesting bees - pollinator conservation - sand beds – conservation in urban parks*

Abstract (Swedish)

Pollinatörer bidrar med viktiga ekosystemtjänster genom att säkra pollinationen av 80–90% av alla växter. Men just nu sker en global minskning av pollinerande insekter, vilket i sin tur kan orsaka en parallell minskning av växtarter. Detta leder till stora biodiversitets förluster. En av de största orsakerna till pollinatörernas minskning är habitatförstörelse som får stora konsekvenser för marklevande bin. Denna strategi för bobyggande används av 64–83% av alla kända bi-arter. Snabb urbanisering leder till en minskad tillgång på habitat för marklevande bin. För att finna en lösning på detta problem syftar denna studie till att undersöka om anlagda sandbäddar i stadsparken Slottsskogen i Göteborg, kan attrahera marklevande bin och bidra med en bevarandeinsats. I analysen har sju sandbäddar undersökts, och för varje sandbädd finns två kontrollytor. Under sen maj-augusti 2023 fångades bin och andra insekter med hjälp av insektshåv under 15 minuters inventeringar för varje område. Växtinventeringar gjordes även inom en 200 meter bufferzon för att undersöka om det fanns några viktiga bi-växter i närområdet till sandbäddarna. En generalized linear mixed model och en ANOVA användes på två olika dataset: 1) bin 2) bin + övriga steklar. Resultaten visade ingen signifikant skillnad mellan sandbäddarna och de två kontrollerna för 1) bin. Däremot påvisades en signifikant skillnad för 2) bin + övriga steklar, där fler insekter kunde fångas i sandbäddarna jämfört med kontrollerna. Växtinventeringen visade på att viktiga bi-växter finns i närområdet. Att det inte gick att hitta så många bin i sandbäddarna kan bero på att sanden kanske inte hade de rätta förutsättningarna som bina behöver. Det finns stora kunskapsluckor inom detta forskningsområde och fler studier behöver göras. Information om vilka specifika krav på jordtyper och olika marklutningar som bina föredrar kan hjälpa till att utforma ännu bättre bevarandeinsatser och förbättra sandbäddarna i Slottsskogen så att fler bin hittar dit.

Nyckelord: *marklevande bin – bevarande av pollinatörer – sandbäddar – bevarandeinsatser i urbana miljöer*

1. **Introduction**

1.1 The importance of pollinating insects and their decline

Pollinating insects are highly important for the ecosystem and provide crucial services, one being the pollination of both wild and domestic plants. It is approximated that between 80-90% of all flowering plants depend on pollination by animals (Ollerton et al., 2011). In 2021, a study estimated the impacts pollinators have on the fertility of plants and came to the conclusion that a third of flowering plants would not produce any seeds, and half of the plants accounted for would suffer an 80% fertility reduction without pollinators (Rodger et al., 2021). Pollinating insects such as wild bees, butterflies, and flies are declining in numbers worldwide (IPBES, 2016). Loss of pollinators may cause a parallel decline the in number of species of plants (Biesmeijer et al., 2006). Losses in biodiversity is a concern for us all as bees are important for both agriculture and natural ecosystems where they provide crucial pollination services, especially regarding agricultural crops that highly depend upon pollinating insects (Biesmeijer et al., 2006; Klein et al., 2007; Ollerton et al., 2011). The agricultural sector saw a burst in pollinator dependent crops between the years 1961 to 2016 as these crops increased by 137%. But with the loss of pollinators the food security of our future could be vastly impacted as this will likely lead to a decrease in crop yields and food density (Aizen et al., 2019; Klein et al., 2007; Nath et al., 2023).

Hung et al. (2018) showed in a comparative study from 2018 that the honeybee *Apis mellifera* is a frequent visitor to only a minority of insect pollinated plant species despite their high abundance and global distribution. If *A.mellifera* is introduced to the same habitat as wild pollinators there is a risk of competition for resources, which may disrupt interactions with plants and their pollinators in many areas. This finding highlights the importance of maintaining diverse populations of wild pollinators to ensure a stable pollination for the majority of flowering plants in natural habitats. (Hung et al., 2018).

Apart from their importance within the agricultural sector, insects are at the base of the food chain and are a major part of the diets of birds, fishes and small mammals. Therefore, their decline will directly affect the ecosystems and will likely put the whole balance of life out of order on earth (Potts et al., 2016; Silva et al., 2021).

1.1.1 Threats to pollinators

Approximately a third of Sweden's 300 species of wild bees are threatened (Naturvårdsverket, 2022). Some of the threats towards pollinators are loss and degradation of habitats, parasites and diseases (spread across and from beekeeping communities), loss of plant species, invasive species and pesticides (Cardoso et al., 2020; Kluser et al., 2010). Climate change is another factor that can have major impacts on pollinators, e.g. due to mismatches that can occur in flowering and pollinator flight periods, leading to pollinator losses that will disrupt the pollination of many plants (Petanidou et al., 2014). A study from 2017 concluded that even short temporal mismatches between the host plants and emerging time for three solitary bee species caused lowered fitness. They could see effects such as reduction in activity and survival rate, reduction in number of female brood cells and lowered number of nests (Schenk et al., 2017).

Habitat loss is one of the greatest threats to bee species richness and abundance. To help counteract it, habitat restoration could be a possible great way to go (Winfree et al., 2009). It is important to have in mind and incorporate the specific needs of certain bee species, such as their habitats requirements, when planning and designing restauration efforts (Tonietto & Larkin, 2018).

1.2 Wild bees and solitary bees

To understand threats and decline of bees it is important to be aware of their life-history traits as they differ highly. There are three ways to classify bee life-histories: solitary, social and parasitic (Michener, 2007). Around 75% of all described bee species are solitary. One single female builds the nest, defends it against parasites and intruders and collects nectar, pollen, or oil for her offspring. Some species live in big communities near each other, with up to a thousand nests in close adjacent, or even sharing one entrance, but still have their own individual brood cells (Danforth et al., 2019; Paxton et al., 1999). However, each single nest is occupied by only one female who has the role of both worker and queen at the same time (Danforth et al., 2019).

Most solitary bees have a narrow temporal activity pattern, ranging from a few days up to some weeks (Danforth et al., 2019). The short active window some species show as adults is partially due to the host-plant association. Narrow host-plant specialists have only a limited time to forage pollen from the host plants (Minckley et al., 1994).

1.3 Ground-nesting bees

A diet consisting of pollen and nectar from flowers is a common trait that most bees share. However, they differ greatly in other life-history traits and ecological characteristics, including their preferred nesting habitats. Amongst the nesting strategies, ground-nesting is the most common amongst wild bees. A study published in 2011 reported that 64% of all bee species use this strategy, and another study from 2020 claimed that the number was as high as 83% (Cane & Neff, 2011; Harmon-Threatt, 2020). Female ground-nesting bees dig tunnels in soil substrates leading to brood cells where she lays her eggs on top of a food deposit (Antoine & Forrest, 2021). A ground-nesting female does not take care of her offspring. Instead, she leaves them with a provision of pollen and after that seals the brood cells. To ensure successful larval development until adulthood, the female need to provide high-quality floral recourses and high-quality nesting locations (Antoine & Forrest, 2021). The nesting locations must be protected against extreme weather, parasites and predators (Roulston & Goodell, 2011).

One of the most important factors for reproduction in ground-nesting bees is the availability of bare ground to be used as nesting site (Potts et al., 2005; Sardinas & Kremen, 2014; Twerd et al., 2021). The nests are highly important as it is the nursery for larval development until adulthood. The longer a female have to search for a new nest, the higher probability of a fitness cost as searching and constructing new nests require time and energy, just as it does for the female to search for a longer time for floral recourses (Antoine & Forrest, 2021; Zurbuchen et al., 2010). In temperate regions most solitary ground-nesting bees spend the winter months in a dormant stage in the larval brood cells as adults and emerge when spring has arrived, meaning that the overwintering location is determined by their mother (Antoine & Forrest, 2021; Danforth et al., 2019). Overwintering as adults makes for faster foraging and nest construction as soon as the weather conditions are good for early-spring solitary bee species (Danforth et al., 2019).

1.4 Urban landscapes and its potentials

Urbanization can in some cases, and for some bee species be a threat as urban environments are characterized as areas with mosaics of impermeable and permeable surfaces (Sattler et al., 2010). A high abundance of impermeable surfaces within a city can create problems for bee species with other nesting behaviors than cavity-nesters, that use small cavities in e.g, dead wood and hollow stems, which are found throughout the urban area. One group of bees that might be affected are ground-nesting bees, as they need permeable substrates to dig in (Geslin et al., 2016; Lowenstein et al., 2014; Matteson et al., 2008). Nesting behavior amongst bee communities also seems to change along an urbanization gradient where cavity-nesters are more numerous in urban areas compared to ground-nesters which seems to decrease in frequency. This is likely due to the increase in impervious surfaces leading to difficulties for ground-nesting bees to find suitable habitats for nesting (Fortel et al., 2014). A study from 2021 investigated ground-nesting bees from Curitiba in southern Brazil, where the results showed a 94% decline in nest abundance and 35% decline in species richness between the years 1955 and 2018. The city had gone from 140 000 to almost 2 millions inhabitants during these years (Pereira et al., 2021). However, a recent study from 2020 showed no difference in probability of occupancy between cavity-nesters and ground-nesters along an urbanization gradient. The availability of natural vegetation and nesting substrates can have favored bees in the urban landscape (McCune et al., 2020).

Even though urban environments can be a threat in certain circumstances, they have shown to be of great importance after farming landscapes- if usage and management is done correctly. Green landscapes within urban environments such as allotments and house yards, graveyards, parks, and alleys can with proper management be crucial for the occurrence of pollinator diversity (Stadsmiljöförvaltningen, 2023). Public green spaces, such as parks, are often interwoven in urban landscapes, and provide important resources for ecosystem services and biodiversity within cities (Turo & Gardiner, 2019). Parks are therefore a great candidate to pollinator conservation with its green spaces (Larson et al., 2014).

1.5 Gaps in research

Despite the ground-nesting strategy being so common within every bee family, in all habitats where bees can be found, and in both social and solitary bees, we see a lack in research since ground-nesting bees are underrepresented in many studies (Orr et al., 2022; Winfree, 2010). Floral resources have been the main focus in many studies, and far less attention has been given to nesting habitats, which are critical in determining bee densities. This has resulted in limited information in the preferred micro-habitats for ground-nesting bees. More studies on this are in great need as knowledge within this aspect is necessary to determine how and if restoration of different type of nesting habitats for bees is effective or not (Winfree, 2010). Another aspect we still do not have enough knowledge about is the specific requirements of nesting habitat for many bee species, especially in concern for ground-nesting bees. A better understanding of these requirements and characteristics is needed to help promote bee populations and understand how to take the best conservation actions (Antoine & Forrest, 2021). Despite the evidence that nesting resources for many bees are a primary limiting factor for diversity and population growth, most conservation efforts have been put into restoring floral resources (Menz et al., 2011; Potts et al., 2005; Roulston & Goodell, 2011; Tonietto & Larkin, 2018). This has resulted in a knowledge gap where we today lack understanding in ground-nesting bees ecology and behavior, and there are relatively few field and laboratory studies on ground-nesting bees relative to the number of species (Antoine & Forrest, 2021).

1.6 Conservation and restoration efforts

Some of the relatively few studies that have been made so far on nesting habitat conservation show that there is great potential in restoration of the bees' habitats. In 2019 a study showed that abandoned sand mines in Maryland, USA, could be used as conservation sites for ground-nesting wild bees. They found that the old sand mines hosted a higher proportion of ground-nesting bees compared to their controls, which were roadside meadows. They could also see that bee abundance was negatively correlated with vegetational cover, highlighting the importance of less vegetational ground cover for nesting (Seitz & Leonhardt, 2019). Another study, from 2022, investigated if removal of vegetation from calcareous grasslands in Germany had any effect on ground-nesting bees. Their results showed that the number of bees was fourteen times higher on experimental plots where vegetation had been removed, compared to their controls which had been left undisturbed. The increase in bee number was positively correlated to the surrounding floral cover and was higher on steeper slopes. Temperature seems to also have had an impact as they could see higher nesting activity with warmer soil temperature (Gardein et al., 2022).

Removal of vegetation to create bare ground was also done by Tsiolis et al., (2022) who could show that this management practice created nesting habitats for ground-nesting bees. In addition to vegetational cover, they wanted to investigate what other factors could influence nest site selection and bee density found on the plots and concluded that soil temperature, hydraulic conductivity, and stoniness could have an effect (Tsiolis et al., 2022).

Fortel et al., (2016) investigated how management in urban areas could promote wild bee diversity including ground-nesting bees. They created vegetation free soil squares in different cities across the Grand Lyon community in France containing different soil characteristics and found that ground-nesting species were indeed utilizing these plots. However, they could not see any significant difference related to soil textures. Their research shows that such management implementations can be useful in an urban area. They conclude that useful urban management requires availability of both floral and nesting grounds to sustain and attract a diverse bee community. The structures built to help promote bees can also be a useful tool in creating awareness in urban citizens about ecosystem services and biodiversity (Fortel et al., 2016).

Creating or maintaining suitable habitats for ground-nesters is very important and many studies conclude that more research is needed within this field, where looking at how different factors affect wild bee populations, management and conservation efforts are of importance (Antoine & Forrest, 2021; Gardein et al., 2022; Potts et al., 2005; Seitz & Leonhardt, 2019; Tsiolis et al., 2022).

2. Aim

The aim of this study is to investigate if newly built sand beds can create nesting habitats for ground-nesting bees in Slottsskogen, a city park in Gothenburg, Sweden. The questions this study aims to answer is:

1. "Can newly built sand beds form nesting habitats for ground-nesting bees? And if possible, which bee species can be found?". As previous studies have already shown, creating sand areas attracts ground-nesting bees. It is therefore hypothesized that the sandy areas built for this study will also attract ground-nesting bees.

Additional questions this study aims to answer is:

2. "Which plant species can be found in the areas around the sand beds? Are there any plants that are especially important for bees?"

3. Material and method

3.1 Study site

Slottsskogen is a 135-hectare public park founded in 1874 and with focus on Nordic nature, located on the west coast in Sweden's second largest city, Gothenburg. The park had already from the start long promenade streaks, big lawns, a zoo, cottages, diverse nature types and even a place to dance (GöteborgsStad, n.d-a; Stadsmiljöförvaltningen, 2023).

The largest part of the park consists of natural environment, even though a lot of human-made lawns do exist. Leafy forests with native trees, some up to 300 years old, open landscapes and forest edges can all be found within the park, providing a diverse environment. Old wood is being kept in order to create habitats for fungi, insects and other invertebrates. In addition to the native trees, a few foreign species have been planted such as rhododendron, Chinese sequoia, and Serbian spruce (GöteborgsStad, n.d-b).

Slottsskogen host many important environments for pollinators, however, the extent of them varies. One feature that is lacking is the availability of open sand areas and vegetation-free soil patches. Despite this, there are a few areas that contain some sand, such as areas where people walk a lot which causes the grass to get worn out, in the banks of dams and around the bottom of tree trunks, playgrounds filled with sand, some animal enclosures and a roadside with southwest facing direction. A place in the park called Bragebacken is kept mostly free from vegetation by people using the hill as an exercise track and has proven to host many bees. Sandy soil can also be found on more elevated areas in the park, such as moorlands (Stadsmiljöförvaltningen, 2023).

3.2 Previous inventory & management plan

During the summer of 2022, an inventory was made in the park in collaboration with Gothenburg Natural History Museum where the focus was on finding pollinators and to assess the diversity within the park. A total of 44 species of wild bees were found, with two species being specialist foragers (oligolectic) and the rest were generalists (polylectic). In the inventory report it is stated that it is not the food abundance that is a limiting factor to the oligolectic species, but the lack of available nesting areas such as open sand beds. From this inventory, management plans for future enhancement of pollinators were made and the maintenance measure taken so far has been to increase the amount of sand in the park. Other care measures are to increase the number of foraging plants for specialist bees who only forage from one type of plant family, create more sunlit transition environments between different biotopes to create more shelter and food availability, and increase the span of flowering plants with more spring and autumnal flowering species (Stadsmiljöförvaltningen, 2023). The inventory from 2022 was partly funded by LONA, a government grant which aims to increase nature conservation awareness within municipalities (GöteborgsStad, 2023; Naturvårdsverket, n.d).

3.2.1 How the present study fits in on UN's global and regional goals

The goals set by the United Nations for sustainable development are important for biodiversity protection. One of these goals is number 15 titled 'Ecosystem and biodiversity' which states that up until the year 2030 losses of biodiversity and habitat losses must diminish and the prevention of species extinction must take place. However, countries that agreed to these goals have not yet done enough. This led to a new agreement in December 2022 stating which specific measures that need to be taken for the goal to be fulfilled. National goals (on Swedish level) are anchored in the UN goal 'A rich plant and animal diversity'. The regional goals build upon the national goals in a more detailed manner but have an addition of three sub-goals. One is particularly interesting for the present study: 'a good habitat for pollinators'. It entails that by the year 2025, the habitats for pollinators in Västra Götaland county should not have deteriorated; the numbers of wild bees should have increased (compared to the baseline numbers in 2010) and less than 10% of honey bees will die during winter (Stadsmiljöförvaltningen, 2023). The former part of this goal is important for the present study, as it aims to investigate if conservation efforts to try to enhance the wild bee population in Slottsskogen can have any effect.

3.3 Data collection

3.3.1 Sand beds & wild bee inventory

During the course of the present study, a total of nine sand beds were investigated where two sand areas were created in the spring of 2022 and seven were created in May 2023. The sand beds varied in size and construction, ranging between 1x1 meters to 2x3 meters, and approximately 1 meter in height. Seven sand beds had been created with sand from playgrounds dumped in a pile to create a small hill with tree logs at the sides to ensure stability (Figure 1). Two sand beds were created by stripping off the top layer soil and vegetation on a slope and covering it with approximately 3-5 cm layer of sand (Figure 1). As there were two sand beds that did not have the same conditions as the others, data from these were treated as anecdotal, and they also lack control areas. However, inventories were made on these two sand beds to see if they hosted any hymenopterans, but they are not included in the statistical analysis.

Figure 1. Left) One example of the seven sand beds that was used for the statistical analysis. On these type of sand beds, the sand has been dumped in a pile and is supported on the sides with tree logs. Right) One example of the two anecdotal sand beds. Here, the vegetation has been stripped off to expose the underlying soil. A 3-5 cm layer of sand has been added to the top.

Each sand bed was paired up with two controls, the first control (control 1) was placed on the ground 2-3 meters away from the sand bed, and the second control (control 2) approximately 100-200 meters away, both being 1x1 m. Controls differed from sand beds in such a way that no added sand or removal of existing vegetation had happened. Instead, they were areas with naturally low vegetation cover at the start of the field study. The controls were chosen with care to try to make sure that each had the same condition as its sand bed pair with regard to sun exposure and wind shelter.

Inventories were made in the summer of 2023 from May 29th until 23rd of August by observing the sand bed and its two controls for 15 minutes separately (45 minutes in total was spent for each inventory round per area) and catching eventual bees and other hymenopterans flying in and out of the area with an insect net. Notes were made in a protocol on the number of hymenopterans caught during the inventory and if eventual genera could be determined for the bees. Each sand bed and its two controls were observed once per month, this means that each sand bed plus its controls has been observed 3 times each during the course of the summer.

The data collection could not be carried out in a randomized way as it was difficult to randomly select control areas as they needed to fit certain criteria to match the conditions of the sand beds.

3.3.2 Floral inventory

In addition to the observations of the sand beds, floral inventories were carried out on every occasion an inventory occurred for the sand beds. Plants growing in a 200-meter buffer zone around the sand beds was noted to see if there were any important bee plants growing in the area. The 200-meter buffer zone was chosen since it is within the foraging flying range for solitary bees (Gathmann & Tscharntke, 2002). To help determine which plant species were found in the area the app Seek from iNaturalist version 2.15.3 (316) was used.

To get an overview of which plant species that are especially important to solitary bees already known to Slottsskogen, information was taken from the inventory made by Gothenburg Natural History Museum during the summer of 2022 (Stadsmiljöförvaltningen, 2023). From this report, two modified tables were created (Appendix 3). More bee species were found during the inventory in the previous year. However, not all have been included in the present study, since not all bees found then were ground-nesters, and thus currently not relevant. Only ground-nesting bees have been chosen for a closer look. In Appendix 3 it is visible from which plant genera the bees usually visit to collect pollen and nectar, and whether the bees are polylectic or oligolectic. The information about foraging preferences was collected from Artfakta (Artfakta, n.d-a).

3.4 Sand bed locations

Based on the inventory from 2022 (Stadsmiljöförvaltningen, 2023), Slottsskogen constructed seven new sandy areas in addition to the two already existing sand beds (the ones made during the spring of 2022) to help promote appropriate habitats for the establishment of sand bees and to increase their population within the park. The locations of the sand beds took into account recommendations made by the author of the inventory from 2022 that they should be in a warm and sunlit area, south facing, and at least 25 cm deep so that the bees have enough space to dig their burrows (Stadsmiljöförvaltningen, 2023). Figure 2 shows the locations of the sand beds in Slottsskogen, their 200-meter buffer zones and the paired controls. The map was made in QGIS version 3.30.2.

Figure 2. The locations of the nine sand beds in Slottsskogen. Blue areas were created during spring 2022 and the red areas were created during spring 2023. Buffer-zones of 200 meters are shown in transparent blue and red colors respectively, representing the foraging distance for most wild bee species. Yellow dots indicate the control areas, two for each sand bed (except for the anecdotal areas; 3 and 5). Control 1 was placed at 2-3 meter and control 2 at 100-200 meters away from the sand bed.

3.5 Statistical analysis

The collected data was analyzed in RStudio version 4.2.1 (R-Core-Team, 2022). The *glmer* function from the *lme4* package was used to create a generalized linear mixed model (GLMM) with a tweedie distribution for constructing the data model (Douglas Bates, 2015). This model was chosen because the data was not normally distributed, and the tweedie distribution in particular since the dataset had a large over-representation of zeros. The GLMM considers the non-independent variable part and the correlation in the dataset since each sand bed has been measured multiple times during the study period and the measurements therefore cannot be considered as independent from one another. Sand bed number is included as a random effect.

The model examines if there is an association between treatment (fixed effect) and the number of bees and total number of hymenopterans (response variable) after controlling for the different areas (variance). In the GLMM, an intercept is created and compares sand beds and control 2 to control 1. After the GLMM, an ANOVA was carried out to test the general effect of the treatment using the Type II Wald chisquare tests statistics to obtain the significance level. If the ANOVA showed a significant difference, a Tukey post-hoc test was later performed to see which levels differed from each other using the *glht* function from the *multcomp* package (Hothorn Torsten, 2008). Significant levels were set to $p<0.05$ for all tests.

4. Results

In total, inventories were made on 22 different occasions, with 27 observations on sand beds and 42 observations on the two controls together for all plots. This means that 69 inventories in total were made during the study period and 1035 minutes were spent on observation and inventories. A total of 102 hymenopterans were observed throughout the study, including 16 bee individuals and 86 individuals of other hymenopterans. These numbers include area 3 and 5, which are not taken into consideration for the statistical analysis (14 bee individuals and 82 individuals of other hymenopterans were found when excluding area 3 and 5). Bee genera found during the inventory was: 4 *Andrena*, 3 *Sphecodes*, 1 *Apis*, 1 *Nomada*, 4 *Lassioglossum*, and 1 un-identified for all areas excluding area 3 and 5.

4.1 Sand beds vs controls

The generalized linear mixed model showed that the data for 1) total number of bees and 2) all hymenopterans in total (bees + other hymenopterans) are not normally distributed as the scaled residuals max value was higher than 3 (3.4777 and 3.7088 respectively). This was also confirmed by looking at the data distribution which had a large over-representation of zeros.

4.1.1 Bees

The ANOVA which tests the general effect of the treatment showed no significant difference (Pr>(Chisq)=0.114) between the control areas and the sand beds. Since the ANOVA did not show any significant difference, no post-hoc test was carried out on the dataset for the bees. The median value for all treatments was 0 (Figure 3).

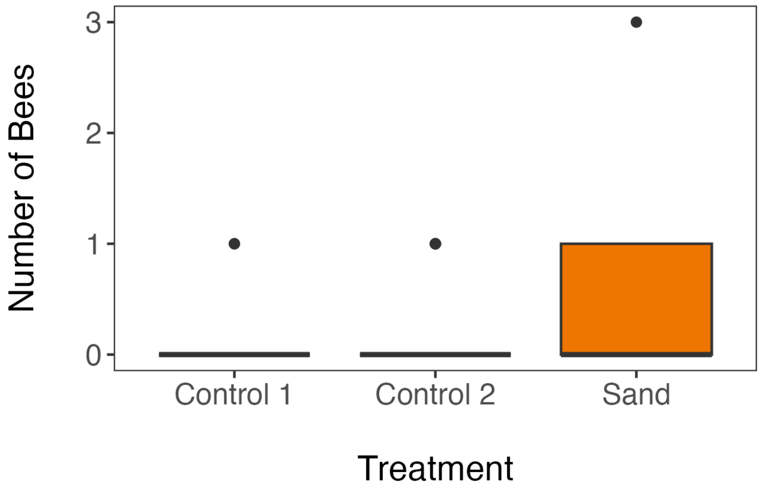

Figure 3. Boxplot showing the distribution of bees found, including outliers, for all treatments and areas (excluding area 3 and 5). Median values for all treatments were 0.

In the study, there was a prevalence of some *Nomada* species which has been included in the statistical analysis. *Nomada* is a bee species that parasitizes on the bees belonging to the genus *Andrena*, and should therefore indicate the presence of *Andrena* within the found area (Potts et al., 2005).

The confidence interval (CI) is relatively wide in relation to the predicted value. This is likely due to the small sample size and indicates instability (Table 1).

Table 1. Summary table of predicted values, standard error (SE) and confidence interval (CI) for number of bees for each treatment.

Treatment	**Predicted**	**SE**	**CI**
Control 1	0.08	0.72	0.02-0.32
Control 2	0.16	0.58	0.05-0.50
Sand	0.31	0.50	0.12-0.82

4.1.2 Total (all hymenopterans)

The ANOVA showed for all hymenopterans in total a significant effect (Pr>(Chisq)<0.001). Due to the significant effect shown by the ANOVA, Tukey post-hoc test was carried out on the dataset ‘total number of hymenopterans’ to see which of the treatments differed (Figure 4). Sand vs control 1 showed a significant effect (Pr(>|z|)<0.001) as did sand vs control 2 (Pr(>|z|) < 0.001). Control 1 vs control 2 showed no significant effect (Pr(>|z|)= 0.329). The median value for control 1 and control 2 was 0, while the median value for the sand treatment was 2.

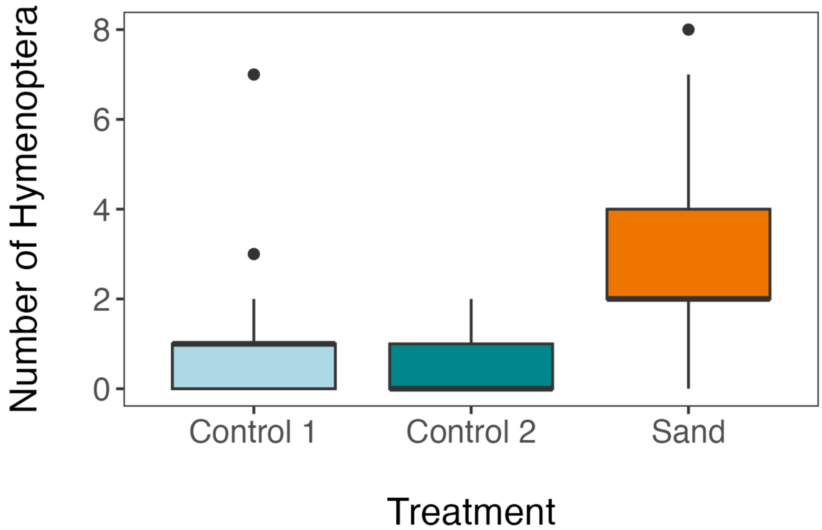

Figure 4. Boxplot showing the distribution of all hymenopterans found, including outliers, for all treatments and areas (excluding area 3 and 5). The median value for control 1 and control 2 were 0. For the treatment sand the median value was 2.

The confidence interval (CI) is relatively wide in relation to the predicted value. This is likely due to the small sample size and indicates instability (Table 2).

Table 2. Summary table of predicted values, standard error (SE) and confidence interval (CI) for total number of hymenopterans for each treatment.

Treatment	**Predicted**	**SE**	**CI**
Control 1	0.97	0.47	0.39-2.45
Control 2	0.57	0.50	0.21-1.54
Sand	2.74	0.43	1.17-6.41

4.2 Floral inventory

A total of 133 different plant genera were found during the study. Each area differed slightly in floral composition due to their different nature types, and the blooming of some plants was not continuous during the three-month study period (June-August). Appendix 2 includes tables for each area, indicating which plant species could be found within the 200-meter buffer zone of each sand bed area during the study months. In these tables, green color represents blooming during the inventory visit.

From the floral inventory, some plant species were found that are important for a diverse group of wild bees. Table 3 shows the most important plant species (in some cases only genus is mentioned since exact determination of species was difficult in some cases) and in which areas they could be found which is marked in green. Yellow color indicates important food source for oligolectic bees.

As seen in table 3, *Calluna vulgaris* is highly important for *Andrena fuscipes* and *Colletes succinctus*, which are two oligolectic bee species already known to Slottsskogen. *Calluna vulgaris* was only found in area 6 and 7. *Hieracium canadense*, *H.umbellatum* and *Leontodon* *autumnalis* are three plant species that are highly important for the oligolectic bee *Panurgus banksianus*.

The bee species *Anthidium punctatum* has a strong favoritism towards *Lotus corniculatus*, however, this bee is not considered oligolectic. Despite not being oligolectic it is included in the figure since *Lotus corniculatus* makes up a large portion of its foraging. *Andrena wilkella* is an oligolectic bee species foraging on Fabaceae. Five plant species important for this bee was found during the inventory: *Lotus corniculatus, Trifolium medium, T. pratense, T. repens,* and *Vicia sepium*.

Succisa pratensis was also found during the inventories for area 4 and 5, which is a plant species highly important for the ground-nesting bee *Andrena marginata*. This bee species is oligolectic and solely collects pollen from Dipsacaceae. In Sweden they particularly collect from *Succisa pratensis* and *Knautia arvensis* (the latter one not found in the inventories made here) (Artfakta, n.d-b). However, this oligolectic bee species has not yet been found in Slottsskogen. There is a good opportunity to attract this species of bee however since its important pollen source *Succisa pratensis* was found.

As seen in Appendix 3, all of the plants listed in table 3 are important to a diverse number of ground-nesting bee species. The most commonly found plant species were *Rubus, Rosa, Prunus, Taraxacum, Achillea millefolium, Trifolium repens, Anthriscus sylvestris* and *Anemone nemorosa*.

Table 3. Summary of the most important bee-plants found in Slottsskogen. Green color indicate presence in the area. Yellow color in the plant column indicate plant species important for oligolectic bee (the respective bee can be seen in the Bee species column). Bee species mentioned here are oligolectic bees that has been found in Slottsskogen during previous years (except for Andrena marginata) (Stadsmiljöförvaltningen, 2023; Artfakta, n.d-a).

Plant species	1	2	3	4	5	6	7	8	9	Bee species
Achillea millefolium										
Aegopodium podagraria										
Allium schoenoprasum										
Anemone nemorosa										
Anthriscus sylvestris										
Calluna vulgaris										Andrena fuscipes, Colletes succinctus
Crataegus marshallii										
Eupatorium cannabinum										
Fragaria vesca										
Hieracium canadense										Panurgus banksianus
Hieracium umbellatum										Panurgus banksianus
Lamium album										
Leontodon autumnalis										Panurgus banksianus
Leucanthemum										
Linaria vulgaris										
Lotus corniculatus										Andrena wilkella, (Anthidium punctatum)
Malus										
Potentilla anserina										
Potentilla argentea										
Potentilla erecta										
Prunus										
Ribes										
Rosa										
Rubus										
Senecio viscosus										
Silene dioica										
Solidago virgaurea										
Succisa pratensis										Andrena marginata (not found in Slottsskogen)
Taraxacum										
Trifolium medium										Andrena wilkella
Trifolium pratense										Andrena wilkella
Trifolium repens										Andrena wilkella
Tripleurospermum perforatum										
Vaccinium myrtillus										
Vaccinium vitis-idaea										
Veronica										
Vicia cracca										
Vicia sepium										Andrena wilkella

5. Discussion

5.1 Sand beds

This study indicates that sand beds could have an effect on attracting hymenopterans and possibly create nesting habitats as a significant difference could be found when comparing sand beds to control areas. However, it is difficult to say that the present study confirms previous findings from other studies. In other studies, a much higher number of bees were found compared to the study made here. For the present study it was only when combining the findings of both bees and other hymenopterans that a significant effect could be detected. Despite this, the lacking significance amongst solely bees, can be due to the small sample size. It is therefore highly motivated to increase the sample size with more sand beds to investigate if a difference amongst bees can be detected.

For both bees and other hymenopterans, control 1 and control 2 had a median of 0, indicating that not many insects were found at all on these plots (figure 3). The median number of bees found on the sand beds was 0 (figure 3), showing that not many bees could be found for this treatment. However, when all hymenopterans were examined together it was shown that they were more numerous on sand beds, as they showed a median of 2 (figure 4). This finding indicates that other species of hymenopterans could be found more frequently on sand beds, showing that sand beds can attract this order of insects, hopefully and possibly for nesting.

5.2 Floral inventory

Many different plant species were found during the study (Appendix 2), some being more important to bees (Appendix 3). Even though important bee-plant species were found, it is highly recommended to consider increasing the number of flowering plants. As an example, only one single flower of *Succisa pratensis* was found and only for area 4 and 5. As previously mentioned, this flower is highly important for the bee *Andrena marginata* as it only collects pollen from Dipsacaceae. This is a species of bee that is also near threatened (Artfakta, n.d-b). With careful management and care, the plant species can increase in number and eventually attract *Andrena marginata* which would hopefully establish nests in the nearby sand beds and increase the population of this bee species.

5.3 Difficulties encountered during the study

During the course of the inventory period, some difficulties occurred which needs to be considered during future studies. It was noted that many of the insects were very shy and did not dare to come out of their nests if they could see me standing outside or in the proximity of the sand beds. This made it difficult to note whether they were bees or some other species of hymenopterans since they were not possible to catch. In addition to this, the insects can sometimes be very fast, flying in and out of the sand beds so swiftly that it becomes difficult to catch them at times. Since the observations only occurred during 15 minutes for each inventory, I sometimes only had one chance to catch them, and if I missed it, there was a risk I did not have another chance for that inventory round.

The survey usually lasted between the hours 13-17. There is a possibility that the insects in the area are more active before noon, and therefore could not be seen during the usual observation hours. The insects can also have had longer foraging bouts than simply 15 min, thus creating the risk of missing them when the observation time was relatively short. It would therefore be a good idea to further investigate if the time of day influences bee abundance when netting, and if prolonging the time spent on inventories can have any effect of increasing the chances of observing more bees.

Moreover, it was difficult to find control areas that had the same properties and conditions as the sand beds within the 200-meter buffer zone. To get a good comparison between the sand beds and their controls it is important that they have similar conditions such as facing the same direction (north, south etc.), similar shelter and wind protection, and sun exposure. This means that for some sand beds and their controls, the conditions are not equal, but I tried choosing areas as closely similar as possible. However, it is difficult finding such similarities in properties between different areas in a natural environment. Especially since the whole point of creating the sand beds is because there is a great lack of vegetation free areas in Slottsskogen.

In addition, the controls were chosen in June on places where the ground was bare, so that it would be similar to the bare surface on the sand beds. Later during the summer these bare areas on the controls quickly grew over with grass and other vegetation, causing the area not to be bare open ground anymore. This could possibly have influenced the choice of nesting ground for some insects since many prefer bare grounds and therefore could skew the results. The controls could not be moved to other places within the buffer zone since they needed to be observed on the same places each month to see if any insects had thought it was a good place for nesting.

I tried to make inventories with 4 weeks apart for each area (once a month), but due to the weather such as rain or strong winds this was not always possible. Therefore, a randomization of survey times and days was difficult to make. A lot of rain came during the summer the present study was made, especially during July. Bees and other Hymenopterans are used to shifting weather conditions since they have evolved and adapted in the Swedish climate. Despite this, they might have gotten affected by the amount of rain that occurred. The sand beds might not have met good enough conditions regarding hydrology and humidity, and therefore not being good nesting grounds for solitary bees. The weather itself could also influence the chances of observing the insects. The foraging round could potentially be shorter or stop completely if moderate to heavy rainfall occurs, diminishing the chances of seeing an insect on its way to or from its nest. To confirm this, further testing is however needed.

5.4 Future studies

There are multiple different aspects to consider for a future study. Below are some categories of additional aspects described to keep in mind and investigate when designing a future study on the properties of ground-nesting bees.

5.4.1 Soil properties

In this study, sand and soil properties were not investigated which could have an impact in the choosing of nesting location. Future studies would benefit from including research on the specific soil properties ground-nesting bees show. After a foraging round, the bees return to the same nest. Nest location is therefore a key determinant of the abundance of pollinators in a given landscape (Lonsdorf et al., 2009). The abiotic characteristics of the soil that ground-nesting bees dig their nests in is important. However, the aspect of habitat requirements and what effects these have on nesting behavior is understudied for many species of wild bees (Leonard & Harmon-Threatt, 2019; Lybrand et al., 2020). Knowledge on nesting information covers only 26% of selected wild bee species (Harmon-Threatt, 2020). Since we know too little about nesting requirements, we do not know if different species may have different requirements that needs to be met. Furthermore, survival chances in the nest are affected by temperature, water content, and available oxygen- all of which soil properties can influence (Harmon-Threatt, 2020).

Some ground-nesting bees seem to prefer sandy-loam or sandy-clay-loam. Pure sandy categories of soil materials do not seem to be as preferable (Tsiolis et al., 2022). This shows that a mix of different substrates could benefit the enhancement of ground-nesting bees. Future studies would benefit from experimenting with different types of sand-clay-loam compositions to see which could work best for the bees in Slottsskogen. The present study used only sand, and it might be because of this that not many bee species was found nesting in the sand beds. Fast hydraulic conductivity in sandy soils can also increase the risk of nest collapse (Tsiolis et al., 2022). This could be an additional reason to why such few bees were observed in the sand beds in the present study.

The use of terms like 'sandy-loam' and 'hard versus soft' that are most often reported in scientific papers are however not suitable and does not provide enough information to apply this to a conservation perspective as the qualitative description covers a wide range of soil textures (Harmon-Threatt, 2020). It is therefore encouraged to expand the qualitative descriptions into quantitative ones, measuring for example the grain size of the sand, and hence get a more detailed description of what soils we are dealing with. This will also make the studies far more reproducible and conservation efforts more precise since 'sandy-loam' does not say much at all about the soil texture.

Moreover, in the study made by Tsiolis et al., (2022) the majority of found bees belonged to four species, and it could be possible that these are just fast colonizers rather than having a specific preference for the soil types. If longer studies would be conducted, perhaps those bee species who are slow colonizers would also find their way to the nesting grounds (Tsiolis et al., 2022). This further emphasizes the importance to conduct a study over a longer period of time, to both look into if the soil characteristics choices are due to fast versus slow establishers or if the different species actually prefer different types of soil materials.

One way to examine the specific nesting recourses ground-nesting bees need is to conduct studies with similar designs like Lybrand et al., (2020) did. They located active ground-nesting bee nests and sampled soil from these sights. In this way they found out the requirements these bees are actually dependent upon by sampling where they know they live and thrive (Lybrand et al., 2020). Their study was made in Oregon, which means that the bee community there might differ from the ones in Sweden, therefore it would be a good idea to conduct studies like the one previously mentioned on different localities in Sweden. This will increase the knowledge of the specific soil requirements that our local bees exhibit. It is very important to have this knowledge when taking conservation measures, like constructing new sand beds, to ensure that the local bees have their needs met. Bees found in Sweden has evolved to possibly exhibit different soil preferences than bees from other parts of the world. Thus, generalizing what works for one bee species in one part of the world, and applying that to our regions would not be sufficient. However, this is yet another area that should be further studied. There is already one location in Slottsskogen that host many ground-nesting bees (Bragebacken) (Stadsmiljöförvaltningen, 2023). Taking soil samples from this already known site could be part of a future project to increase the knowledge on the specific needs of the solitary bees in Slottsskogen, since we know that this is a site where the bees already nest.

There is some evidence towards certain bee species showing nest site fidelity, also known as philopatry (Alcock, 1996; Potts & Willmer, 1997). If more bee species seem to display nest site fidelity it increases the importance of figuring out what specific requirements the bees like and need. It also emphasizes the importance of managing and caring for the already existing areas where they nest as they cannot easily search for a new nest if philopatry is strong. This is another aspect that would be highly interesting to study further.

5.4.2 Slopes

There seems to be divided results whether sloped areas attract more bees for nesting or if it does not really matter and flat ground could also be a viable option. In the study by Tsiolis et al., (2022) there was no significant difference between flat and sloped ground in regards of peak nest density (Tsiolis et al., 2022). Lybrand et al. (2020) also found active nests on both slopes and flat ground. However, the area which contained the highest number of emergence holes (which indicates nesting activity) was found on one of the sloped areas within their study site (Lybrand et al., 2020). South facing slopes which enhance the temperature needed for both larval development and for gaining enough thoracic warmth needed for flight in the mornings has been proven to attract ground-nesting bees (Potts & Willmer, 1997). The different results from these studies call for further investigation to confirm if slope does influence nest density and establishment of ground-nesting bees or if a flat surface works just as fine. If the bees seem to have a preference for either category, it will benefit urban nature city planners to take these preferences into consideration when creating more sand areas. Different bee species might also have dissimilar preferences, some might like a sloped surface while others might prefer a flat ground – another area in need of more studies.

5.4.3 The question of timing

This study began relatively late, whereas many sand bees are active already in the early spring (April-July) (Tsiolis et al., 2022). Starting earlier would therefore increase the chances of catching active early spring bees and get a more comprehensive understanding of the bee communities. This study started at the end of May, which means that there is a possibility that some early spring active bees were missed.

The study made by Tsiolis et al., (2022) showed no significant difference in peak nest density on plots (1m^2) over the course of their study expanding three years. However, it is clear in their paper that the counted bees over the years are dissimilar (122 in 2018, 397 in 2019 and 351 in 2020) (Tsiolis et al., 2022). This could possibly indicate that establishment can take a bit of time for bee communities to thrive and settle, since the count in the first year was much lower than the following two years. It is therefore suggested that when planning a similar study, to begin inventories earlier in the spring to make sure that the early bee species have a chance to be observed, and that studies are conducted over multiple years to see if longer time increases the populations on the study areas.

5.4.4 Precise species determination

Early on during the inventories, it was a conscious choice to not kill the bees for exact species determination. Therefore, only genus has been reported here. It would be interesting to know more precisely which species that are actually nesting in the sand beds in Slottsskogen to get a more detailed understanding of which species lives there. As seen in Appendix 3, there are some species found in Slottsskogen that are oligolectic, and it would be of high value to know if any of these are nesting in the sand beds that were constructed for this study. Future studies can therefore include a more exact species determination. But it would be better to wait a couple of years to investigate which species lives in the sand beds on a more detailed level, so that they have had enough time to reproduce. If only a small number of bees are found in the sand beds (as was the case for this study) it is a shame to kill them for species determination since they then no longer have any chance to do so, which is the main goal of the construction of these nesting habitats.

Nonetheless, it is important to identify pollinators on a closer species level, and as accurately as possible, since poor taxonomic determination level may disguise or distort patterns in community assemblages (Daniels et al., 2020). This requires expertise knowledge and years of experience of pollinator identification in the field, and even then, a comprehensive species determination can be very difficult (Michener, 2007).

The other hymenopterans were not investigated on a closer taxonomic level in the present study, simply because I did not have enough knowledge on other genus and species within this group. It could be of interest to know more about the whole insect community nesting in the sand beds. Therefore, it is suggested that determination on a closer species level for all insects found within the sand beds are to be conducted during future studies.

5.4.5 Sampling methods

Another aspect that future studies would benefit from is to consider the sampling technique. The collection of specimens in this study was made with insect nets. However, there are other options that could possibly work better. Catching bees with insect nets has shown during the inventories of this study to be quite challenging. Two other methods are emergence and pan traps. There is also evidence that the three different methods are dissimilar in which bee assemblages they collect. Pan traps seem to collect more specimens than both netting with insect nets and emergence traps (Sardinas & Kremen, 2014). However, pan traps can attract bees from other areas and not necessarily those living in the nearby ground. It is a passive method where the effectiveness depends on the floral abundance in the area (Morandin & Kremen, 2013). In the study made by Sardinas and Kremen (2014), the emergence trap captured predominantly small bees, while the netting and pan traps captured bees with a wider range of body sizes. The authors advocate for the use of emergence traps to be a viable method for quantifying wild bee nesting rates as well as associating specific nesting requirements with ground-nesting bee species. In their study, the emergence traps collected a high number of individuals and had a low estimate of unseen species. This was confirmed when comparing with species found during netting and using pan traps since eight species in emergence traps were not found in either pan traps or during netting (Sardinas & Kremen, 2014). Another aspect important to keep in mind is the collector bias. By using the passive collecting method of pan traps, the results do not become as collector biased as for example when netting, which highly depends on the skills of the collector to catch the bees (Westphal et al., 2008). A downside to the pan traps would be that rare and endangered bee species can be attracted to the trap and die, putting their population closer to extinction. Considering that the three methods of trapping bees differ, and the benefits and downsides vary, it is important to consider the different outcomes these may bring when creating a new study design.

5.5 Future management suggestions

Keeping the sand beds free from vegetation is something that needs proper management as vegetation cover can significantly influence bee nesting (Tsiolis et al., 2022). For both the sand beds and control areas in the present study, vegetation quickly started to grow, especially on the controls. Since the controls in particular were not kept vegetation free, this could possibly have influenced the results by not being open bare soil as the sand beds, and not attracted bees and other hymenopterans. But the sand beds also had their issues with vegetation finding its way to the areas and starting to grow, however, not as much as on the controls. Another possible problem was that in the middle of the summer, it was noted that plants had been purposefully planted in some of the sand beds. Planting vegetation in the sand beds is not recommended as the planting itself can disrupt already existing nests in addition to creating unwanted vegetative cover.

It can take a long time, even years to get to know if a taken conservation effort has had any positive effects. This study was only conducted over one summer, when seven out of nine sand beds had just been constructed. It may be the case that the bees in Slottsskogen take a longer time to find and establish in a new place. It is therefore important to keep caring for the sand beds, making sure they stay free from vegetation in a nature friendly way for example by carefully removing vegetation by hand. Management of the surrounding nature is also important, such as making sure the sand beds get enough sun exposure by trimming down bushes and tree canopies that would otherwise give too much shade. Conducting yearly inventories on a local scale, such as for each sand bed, is a good way to evaluate if the management has had any proven effect (Stadsmiljöförvaltningen, 2023).

Creating more sand beds would be a good addition to a future management plan, preferably testing out different soil material compositions. Examples can be to mix sand with loam, silt and clay, mixing sand with just loam or just clay, and trying out different proportions of each. After this has been done, it is important to follow up to see if any effect, whether it be positive or negative, can be found. If some compositions with certain proportions seem to attract more bees than others, it is highly encouraged to increase the use of these ones. The addition of other soil materials can also construct more stable sand beds. Follow up studies can be done through inventories following multiple years in a row to evaluate the effect. If future studies would be made, careful consideration of the method choices discussed in a previous section is encouraged.

Additional management measures that can be taken if the use of more sand beds is not a good option, is to increase the sand within the park in other ways by for example open up already known sandy areas by scraping of vegetation, adding sand to flowerbeds, and filling up gaps between stone plates and pavement areas with sand. If doing this, the depth required should preferably be at least 25 centimeter (Stadsmiljöförvaltningen, 2023).

5.5.1 Future management of floral composition

In addition to creating proper management plans for the nesting grounds, it is important to also consider taking more measures to ensure stable food security for bees and other pollinators in Slottsskogen. The availability of food resources in the proximity of the nests is critical for bee conservation (Potts et al., 2010; Wright et al., 2018). A high flower density and diversity is an important aspect that can determine the pollinator diversity, even more so than habitat type (Scriven et al., 2013). Plant richness, as well as nesting resources, has also been proven to be positively correlated with bee richness and bee community composition (Grundel et al., 2010). As seen in Appendix 2, the floral composition between the nine areas differs, some have more plant species and others have less. Some areas also contain plant species that are extra important for oligolectic bees, some of which have previously been found within the park. Increasing the number of plants such as *Calluna vulgaris, Hieracium canadense*, *H.umbellatum*, *Leontodon autumnalis, Lotus corniculatus, Trifolium medium, T. pratense, T.repens, Vicia sepium,* and *Succisa pratensis* is encouraged to secure the pollen source for the oligolectic bees who depends on these flowers (see table 3). Planting native and perennial flowers is shown to increase oligolectic bee abundance (Grundel et al., 2010).

Another care measure that would benefit the park is to grow plants that will prolong the blooming season, so that there are blooming flowers in early spring to late summer/early autumn. This will ensure the food source for many active early spring bees such as for example *Andrena cineraria, A.haemorrhoa, A.clarkella, and A.helvola,* as well as for some bee species still active during late summer such as *A. argentata, A. marginata, A. flavipes*, and *A. fuscipes* (Artfakta, n.d-a). Example of early spring species are *Crocus, Salix*, and *Scilla*. Autumn flowers that can be planted are for example *Symphyotrichum novi-belgii, Calluna vulgaris, Thymus, Salvia,* and *Hylotelephium telephium* (Stadsmiljöförvaltningen, 2023). These can preferably be planted in flower gardens, making sure to keep some open space on the ground where some sand has been mixed into it to help create nesting establishment as well as food source. The size of the flower gardens needs to be considered, however, as there is evidence that smaller sizes of flower patches attract other pollinating species than common honeybees *Apis mellifera* and the bumblebee *Bombus terrestris,* which can fly long distances to find their food source. These two species take advantage of the mass flowering events that occur in lager flower beds. Therefore, creating multiple smaller sized flower beds will ensure the food resources needed for other pollinators that do not take advantage of the mass flower events, hence creating more diversity at one location. Small and constant flowering is especially important for solitary bees as they do not store much food (Daniels et al., 2020). It is encouraged that urban natural resource managers spread out the planting into smaller multiple flower gardens instead of concentrating it all on one large flower garden (Simao et al., 2018). Planting a diversity of flowers within the small flower beds could be successful to attract more solitary bee species. This is something that needs further investigations however to prove the efficiency.

Moreover, planting flower gardens requires a lot of maintenance. A much less costly suggestion is to reduce current management interventions. This could be to avoid cutting the grass too early in the park, and in some places perhaps not cut it at all. By letting the grass grow, other plants and flowers will do the same, increasing the spontaneous vegetation which can create habitat for insects (Daniels et al., 2020; Stadsmiljöförvaltningen, 2023). It could also be a good idea to sow a mixture of native seeds into the grass that is being kept to further increase the floral diversity and number. Saving blooming trees and bushes instead of cutting them down is another low-cost maintenance measure that can be taken. Planting more blooming bushes would be a great addition to the already existing ones (Stadsmiljöförvaltningen, 2023). Both management actions and landscape characteristics are very important to keep in mind for a diverse and abundant bee fauna (Kremen et al., 2007).

Conclusions

In conclusion, this study aimed to investigate the possibility of using sand beds as a conservation effort for ground-nesting bees in the city park Slottsskogen. Despite not finding a significant amount of bees within the sand beds compared to control areas, they were proven to provide a habitat for other insects of the order Hymenoptera as this group showed a significant effect within the sand beds. However, the Slottsskogen management should not worry. Establishment of ground-nesting bees can take time; it is therefore important to continue to take care of the sand beds and monitor them during the upcoming years. Since a lot of important floral species that many wild bees depend on were found in the proximity of the sand beds, there is great chances of bees finding their way to the sand beds and to establish populations. In addition, there is still a lot to be discovered in the research field of ground-nesting bees as this subject has been vastly understudied and big knowledge gaps exist. It is therefore suggested to investigate further on a more detailed level which soil properties and materials the bees depend on; if different slopes are preferable; prolonging the inventory rounds to begin earlier in the spring to have the chance of catching early spring active bees; and investigate which collection method is the most appropriate. Future management strategies need to be implemented for the sand beds as to ensure open and vegetation-free surfaces. In addition to managing the sand beds, planting more flowers in the proximity of the sand beds will be a good conservation effort.

When more knowledge gaps are being filled, conservation efforts can have even greater effects with helping this important group of insects increase in number. Wild bees provide crucial pollination services that we all depend upon for secure food stability. Therefore, conservation efforts need to be optimized in order to maintain a broad biodiversity and for a future to look forward to.

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Appendix 1. Popular science summary

Sand – a potential key to saving the busy bees

No more apples to pick in the autumn, no more blueberries in your morning porridge, and no more tomatoes in your lunchbox salad. This is the sad truth we're facing if we don't take action against pollinator declines that is currently happening worldwide. Wild bees are just as important as the famous honeybee when it comes to the rigorous task of pollinating flowers. But how do we take action? It can be as simple as sand, and I will explain why.

I am sure that you have noticed the fuzzy busy bees out in your garden or in the city park during the warm summer days, and if you're like me, you can get quite mesmerized by their work spirit. But have you ever wondered where the bees return to after their foraging round? Where do they live? In fact, 60-80% of all bees live under ground! They are so-called ground-nesters. But in a world of rapid urbanization, many of their nesting habitats, like open sand areas, are diminishing. This will have fatal consequences when the bees can't find suitable ground to lay their eggs in for the next generation to take over. The hardships of our busy friends will become hardships of our own. Conservation efforts are therefore a keystone in ensuring a healthy and abundant bee population.

A sandy study

This is precisely what my study aimed to do. With the help of the staff in the city park Slottsskogen, located in Gothenburg, we constructed nine sand beds. We wanted to examine if these sand areas could potentially be a good resource for conservation purpose and attract ground-nesting bees. All with the hopeful intention that they would dig burrows and lay their eggs within the sand. Three months during the summer of 2023 was spent on inventories, catching bees and other insects flying in and out from the sand beds. Compared with control areas (which was areas that did not had any sand added to it) no difference in bee abundance could be seen. Even though the sand beds didn't attract as many wild bees as I had hoped for, it attracted a lot of other insects. These insects chose to dig their burrows in the sand beds rather than in the control areas.

Why is bee conservation so important?

As the beginning states, no more apples, no more blueberries and no more legumes - our future without bees. By taking conservation measures, such as restoring their nesting habitats, we can hopefully begin to halter the pollinator decline and ensure an increasing bee population instead. On top of that we get a future to look forward to! But it is important to evaluate if these conservation measures are working, or perhaps doesn't even work at all. By doing studies like the one done here, we can evaluate if it has had any effect.

The big research gap

Sand beds can still be a good conservation effort for bees, but some tweaking is needed. Despite the large percentage of bees living under ground, there is a big knowledge gap in this research area. Perhaps the sand used in this study wasn't appropriate? Could an addition of clay and other soil materials make the beds more attractive to ground-nesting bees? Many questions remain unanswered, and the only way to gain knowledge is to do more studies in the field of wild bee conservation. This study has been merely a small part of the big scheme to understand how conservation efforts can help bring this important group of insects back on its 'wings'.

Appendix 2. Flora found in each study area

Area	Species	June	July	August
1	Acer campestre			
	Achillea millefolium			
	Aegopodium podagraria			
	Alliaria petiolata			
	Alnus glutinosa			
	Amelanchier			
	Anemone nemorosa			
	Anthriscus sylvestris			
	Aquilegia vulgaris			
	Artemisia vulgaris			
	Bellis perennis			
	Calystegia sepium			
	Caragana arborescens			
	Cerastium tomentosum			
	Cirsium arvense			
	Convallaria majalis			
	Corylus avellana			
	Crataegus marshallii			
	Cyanus segetum			
	Digitalis purpurea			
	Epilobium			
	Fagus sylvatica			
	Fraxinus excelsior			
	Galeopsis bifida			
	Galium aparine			
	Geranium robertianum			
	Glechoma hederacea			
	Hosta			
	Hypericum			
	Impatiens parviflora			
	Juglans californica			
	Laburnum anagyroides			
	Lapsana communis			
	Lathyrus linifolius			
	Lavandula angustifolia			
	Lonicera			
	Lonicera caprifolium			
	Lotus corniculatus			
	Myosotis scorpioides			
	Papaver			
	Persicaria lapathifolia			
	Persicaria maculosa			
	Philadelphus coronarius			
	Plantago major			
	Polygonum aviculare			
	Prunella vulgaris			
	Prunus			
	Quercus robur			
	Ranunculus acris			
	Rhododendron			
	Ribes			
	Robinia pseudoacacia			
	Rosa			
	Rubus idaeus			
	Rubus subg. Rubus			
	Rumex obtusifolius			
	Sambucus nigra			

Area	Species	June	July	August
2	Acer campestre			
	Achillea millefolium			
	Aegopodium podagraria			
	Alchemilla vulgaris			
	Alliaria petiolata			
	Allium schoenoprasum			
	Alnus glutinosa			
	Anemone nemorosa			
	Anthriscus sylvestris			
	Artemisia absinthium			
	Artemisia vulgaris			
	Bellis perennis			
	Calystegia			
	Cerastium fontanum			
	Cirsium arvense			
	Corylus avellana			
	Crataegus marshallii			
	Epilobium			
	Fagus sylvatica			
	Fraxinus excelsior			
	Galium			
	Geranium robertianum			
	Geum urbanum			
	Glechoma hederacea			
	Impatiens parviflora			
	Juglans californica			
	Laburnum anagyroides			
	Lapsana communis			
	Lonicera caprifolium			
	Malus			
	Mentha			
	Myosotis scorpioides			
	Origanum vulgare			
	Plantago major			
	Polygonum aviculare			
	Potentilla anserina			
	Prunella vulgaris			
	Prunus avium			
	Prunus domestica			
	Pyrus			
	Quercus robur			
	Ranunculus acris			
	Ribes			
	Rubus idaeus			
	Rumex obtusifolius			
	Salvia			
	Sambucus nigra			
	Scorzoneroides autumnalis			
	Sisymbrium officinale			
	Symphoricarpos			
	Syringa vulgaris			
	Taraxacum			
	Tilia cordata			
	Trifolium repens			
	Tripleurospermum inodorum			
	Urtica dioica			
	Vicia sepium			

	Sambucus racemosa			
	Scorzoneroides autumnalis			
	Sisymbrium officinale			
	Sorbus aucuparia			
	Spiraea douglasii			
	Stellaria graminea			
	Symphoricarpos albus			
	Syringa vulgaris			
	Taraxacum			
	Tilia cordata			
	Trifolium medium			
	Trifolium repens			
	Tripleurospermum perforatum			
	Urtica dioica			
	Vaccinium myrtillus			
	Veronica chamaedrys			
	Vicia cracca			
	Vicia sepium			
	Wisteria sinensis			

Area	Species	June	July	August
3 (anecdotal)	Acer platanoides			
	Achillea millefolium			
	Anemone nemorosa			
	Anthriscus sylvestris			
	Artemisia absinthium			
	Artemisia vulgaris			
	Betula			
	Chamerion angustifolium			
	Cirsium arvense			
	Convallaria majalis			
	Convolvulus arvensis			
	Cotoneaster			
	Fagus sylvatica			
	Geum macrophyllum			
	Glechoma hederacea			
	Hieracium umbellatum			
	Hylotelephium telephium			
	Hypericum perforatum			
	Impatiens parviflora			
	Laburnum anagyroides			
	Lamium album			
	Lathyrus			
	Leucanthemum			
	Lonicera periclymenum			
	Melampyrum sylvaticum			
	Penstemon			
	Pinus sylvestris			
	Plantago lanceolata			
	Polygonum aviculare			
	Populus tremula			
	Prunus			
	Quercus robur			
	Rosa			
	Rosaceae			
	Rubus idaeus			
	Rumex acetosa			
	Sisymbrium officinale			
	Solidago			
	Solidago virgaurea			
	Sorbus aucuparia			
	Symphoricarpos			
	Tanacetum vulgare			
	Taraxacum			
	Tilia cordata			
	Trifolium hybridum			
	Trifolium pratense			
	Trifolium repens			
	Tripleurospermum perforatum			
	Ulmus glabra			
	Urtica dioica			
	Vaccinium myrtillus			
	Veronica			
	Vicia			

Area	Species	June	July	August
4	Acer platanoides			
	Achillea millefolium			
	Achillea ptarmica			
	Aegopodium podagraria			
	Anemone nemorosa			
	Anthriscus sylvestris			
	Arctium			
	Artemisia vulgaris			
	Berberis			
	Betula			
	Campanula rotundifolia			
	Cirsium arvense			
	Convallaria majalis			
	Corylus avellana			
	Crataegus monogyna			
	Fraxinus excelsior			
	Geranium robertianum			
	Geum urbanum			
	Glechoma hederacea			
	Hieracium umbellatum			
	Hylotelephium telephium			
	Hypericum			
	Impatiens parviflora			
	Ionactis linariifolia?			
	Lathyrus linifolius			
	Linaria vulgaris			
	Lonicera caprifolium			
	Lotus corniculatus			
	Malva			
	Matricaria discoidea			
	Mercurialis perennis			
	Plantago lanceolata			
	Plantago major			
	Polygonatum			
	Potentilla erecta			
	Prunella vulgaris			
	Prunus			
	Quercus robur			
	Ranunculus acris			
	Rosa			
	Rubus idaeus			
	Rubus subg. Rubus			
	Rumex			
	Satureja vulgaris			
	Scrophularia nodosa			
	Solidago			
	Sorbus aucuparia			
	Stachys sylvatica			
	Stellaria graminea			
	Succisa pratensis			
	Symphyotrichum			
	Taraxacum			
	Tilia cordata			
	Trifolium medium			
	Trifolium repens			
	Ulmus glabra			
	Urtica dioica			
	Veronika			
	Vicia cracca			
	Vicia sepium			
	Viola			

Area	Species	June	July	August
5 (same as 4)	Acer platanoides			
	Achillea millefolium			
	Achillea ptarmica			
	Aegopodium podagraria			
	Anemone nemorosa			
	Anthriscus sylvestris			
	Arctium			
	Artemisia vulgaris			
	Berberis			
	Betula			
	Campanula rotundifolia			
	Cirsium arvense			
	Convallaria majalis			
	Corylus avellana			
	Crataegus monogyna			
	Fraxinus excelsior			
	Geranium robertianum			
	Geum urbanum			
	Glechoma hederacea			
	Hieracium umbellatum			
	Hylotelephium telephium			
	Hypericum			
	Impatiens parviflora			
	Ionactis linariifolia?			
	Lathyrus linifolius			
	Linaria vulgaris			
	Lonicera caprifolium			
	Lotus corniculatus			
	Malva			
	Matricaria discoidea			
	Mercurialis perennis			
	Plantago lanceolata			
	Plantago major			
	Polygonatum			
	Potentilla erecta			
	Prunella vulgaris			
	Prunus			
	Quercus robur			
	Ranunculus acris			
	Rosa			
	Rubus idaeus			
	Rubus subg. Rubus			
	Rumex			
	Satureja vulgaris			
	Scrophularia nodosa			
	Solidago			
	Sorbus aucuparia			
	Stachys sylvatica			
	Stellaria graminea			
	Succisa pratensis			
	Symphyotrichum			
	Taraxacum			
	Tilia cordata			
	Trifolium medium			
	Trifolium repens			
	Ulmus glabra			
	Urtica dioica			
	Veronika			
	Vicia cracca			
	Vicia sepium			
	Viola			

Area	Species	June	July	August
6	Acer platanoides			
	Anemone nemorosa			
	Betula			
	Calluna vulgaris			
	Carpinus betulus			
	Convallaria majalis			
	Cotoneaster			
	Crataegus			
	Fagus sylvatica			
	Fraxinus excelsior			
	Hieracium canadense			
	Hylotelephium telephium			
	Lathyrus			
	Lonicera periclymenum			
	Malus			
	Melampyrum sylvaticum			
	Pinus sylvestris			
	Potentilla erecta			
	Prunus spinosa			
	Quercus robur			
	Rhamnus frangula			
	Rhododendron			
	Rhus aromatica?			
	Rosa			
	Rubus idaeus			
	Rubus subg. Rubus			
	Sorbus aucuparia			
	Stellaria graminea			
	Ulmus			
	Vaccinium myrtillus			
	Vaccinium uliginosum			
	Vaccinium vitis-idaea			
	Viola riviniana			

Area	Species	June	July	August
7	Acer platanoides			
	Achillea millefolium			
	Aegopodium podagraria			
	Alchemilla vulgaris			
	Amelanchier			
	Betula			
	Calluna vulgaris			
	Campanula rotundifolia			
	Cirsium			
	Crataegus			
	Epilobium			
	Fagus sylvatica			
	Fraxinus excelsior			
	Geranium robertianum			
	Geum urbanum			
	Glechoma hederacea			
	Hylotelephium telephium			
	Hypericum perforatum			
	Impatiens parviflora			
	Larix decidua			
	Leontodon autumnalis			
	Lotus corniculatus			
	Parthenocissus			
	Pinus sylvestris			
	Plantago major			
	Populus tremula			
	Potentilla anserina			
	Potentilla argentea			
	Prunella vulgaris			
	Quercus robur			
	Ranunculus acris			
	Rosa canina			
	Rubus idaeus			
	Sambucus nigra			
	Sedum spurium			
	Solidago			
	Sorbus aucuparia			
	Symphoricarpos			
	Syringa vulgaris			
	Taraxacum			
	Tilia cordata			
	Trifolium medium			
	Trifolium repens			
	Ulmus			
	Urtica dioica			
	Vaccinium myrtillus			
	Veronica			
	Viola			

Area	Species	June	July	August
8	Acer platanoides			
	Achillea millefolium			
	Aegopodium podagraria			
	Aesculus hippocastanum			
	Alchemilla vulgaris			
	Alliaria petiolata			
	Anthriscus sylvestris			
	Artemisia vulgaris			
	Bellis perennis			
	Betula			
	Buddleja davidii			
	Carduus crispus			
	Cirsium			
	Crataegus			
	Crataegus monogyna			
	Dasiphora			
	Epilobium montanum			
	Fagus sylvatica			
	Fragaria vesca			
	Fraxinus excelsior			
	Galeopsis bifida			
	Geranium robertianum			
	Geum urbanum			
	Hosta			
	Hypericum perforatum			
	Impatiens glandulifera			
	Impatiens parviflora			
	Laburnum			
	Lactuca muralis			
	Lapsana communis			
	Lilium martagon			
	Lonicera caprifolium			
	Lotus corniculatus			
	Matricaria suaveolens			
	Medicago lupulina			
	Myosotis scorpioides			
	Parthenocissus			
	Plantago major			
	Potentilla simplex			
	Prunella vulgaris			
	Prunus			
	Quercus robur			
	Ranunculus acris			
	Rhododendron			
	Rosa			
	Rubus idaeus			
	Rumex			
	Sambucus nigra			
	Scorzoneroides autumnalis			
	Sisymbrium officinale			
	Stellaria media			
	Symphoricarpos			
	Taraxacum			
	Tilia cordata			
	Trifolium pratense			
	Trifolium repens			
	Ulmus glabra			
	Urtica dioica			
	Vicia sepium			

Area	Species	June	July	August
9	Acer platanoides			
	Achillea millefolium			
	Aegopodium podagraria			
	Aesculus hippocastanum			
	Ageratum houstonianum			
	Alchemilla vulgaris			
	Alnus glutinosa			
	Anthriscus sylvestris			
	Argentina anserina			
	Artemisia vulgaris			
	Berberis thunbergii			
	Betula			
	Cardamine pratensis			
	Cirsium			
	Convolvulus arvensis			
	Corylus avellana			
	Cotoneaster lucidus			
	Crataegus monogyna			
	Epilobium			
	Eupatorium cannabinum			
	Fagus sylvatica			
	Fraxinus excelsior			
	Galeopsis			
	Geum macrophyllum			
	Hypericum maculatum			
	Impatiens parviflora			
	Kniphofia uvaria			
	Leontodon autumnalis			
	Lonicera xylosteum			
	Lycopus europaeus			
	Matricaria suaveolens			
	Myosotis scorpioides			
	Persicaria amphibia			
	Petunia			
	Plantago major			
	Polygonum aviculare			
	Prunus			
	Quercus robur			
	Ranunculus acris			
	Rosa			
	Rubus idaeus			
	Rumex			
	Senecio viscosus			
	Silene dioica			
	Solanum dulcamara			
	Sorbus aucuparia			
	Spergularia rubra			
	Spiraea douglasii			
	Spiraea japonica			
	Tanacetum vulgare			
	Taraxacum			
	Tilia cordata			
	Trifolium hybridum			
	Trifolium repens			
	Urtica dioica			
	Veronica			

Appendix 3. Bee species found in Slottsskogen and the plants they forage on

(Sources: Stadsmiljöförvaltningen, 2023; Artfakta, n.d)

Species found in Slottsskogen from 1970-2022	Foraging type	Plants	Ground-nester
Andrena cineraria	Polylectic	Taraxacum, Salix, Prunus, Rubus, Ribes, Comarum, Silene, Lamium, Thlaspi,	Yes
Andrena fulva	Polylectic	Taraxacum, Salix, Crataegus, Prunus, Ribes, Scilla, Vaccinium myrtillus, Gagea	Yes
Andrena haemorrhoa	Polylectic	Taraxacum, Lamium, Prunus, Crataegus, Salix, Rubus, Ribes, Sinapis, Ficaria, Leucanthemum	Yes
Andrena helvola	Polylectic	Taraxacum, Prunus, Crataegus, Ribes, Malus, Anemone nemorosa, Pyrus	Yes
Andrena nigroaenea	Polylectic	Taraxacum, Barbarea, Prunus, Malus, Crategus, Ribes, Allium, Sinapis, Eranthis, Berteroa, Echium, Reseda, Bunias, Erica, Astrantia, Doronicum	Yes
Colletes succinctus	Oligolectic	**Calluna vulgaris**	Yes
Lasioglossum morio	Polylectic	x	Yes
Macropis europaea	Oligolectic	**Lysimachia vulgaris, Lysimachia punctata**	Yes
Nomada flavoguttata	x	x	Yes (OBS! Parasitic)
Nomada fulvicornis	Polylectic	Taraxacum, Salix, Prunus, Barbarea	Yes (OBS! Parasitic)
Nomada marshamella	Polylectic	Taraxacum	Yes (OBS! Parasitic)
Nomada panzeri	x	x	Yes (OBS! Parasitic)
Panurgus banksianus	Oligolectic	**"Hawkbit"** (fibblor-swedish), Hypochaeris radicata, Picris hieracioides, Leontodon, Hieracium, Cichorium intybus	Yes

Species found during inventory 2022	Foraging type	Plants	Ground-nester
Andrena cineraria	Polylectic	Taraxacum, Salix, Prunus, Rubus, Ribes, Comarum, Silene, Lamium, Thlaspi,	Yes
Andrena fucata	Polylectic	Taraxacum, Aegopodium, Vicia, Rosa, Ribes, Rubus, Chamaenerion	Yes
Andrena fuscipes	Oligolectic	**Caluna vulgaris**	Yes
Andrena haemorrhoa	Polylectic	Taraxacum, Lamium, Prunus, Crataegus, Salix, Rubus, Ribes, Sinapis, Ficaria, Leucanthemum	Yes
Andrena helvola	Polylectic	Taraxacum, Prunus, Crategus, Ribes, Malus, Anemone nemorosa, Pyrus	Yes
Andrena minutula	Polylectic	Taraxacum, Aegopodium, Salix, Prunus, Rubus, Potentilla, Ficaria. Pulsatilla	Yes
Andrena nigroaena	Polylectic	Taraxacum, Barbarea, Prunus, Malus, Crataegus, Ribes, Allium, Sinapis, Eranthis, Berteroa, Echium, Reseda, Bunias, Erica, Astrantia, Doronicum	Yes
Andrena subopaca	Polylectic	Taraxacum, Aegopodium, Barbarea, Anthriscus, Potentilla, Pilosella, Linaria	Yes
Andrena wilkella	Oligolectic/polylectic	**Fabacaea** (Hieracium pilosella, Geranium sylvaticum, Daucus carota)	Yes
Anthidium punctatum	Polylectic	**Lotus corniculatus**	Yes & No
Halictus tumulorum	Polylectic	x	Yes
Lasioglossum calceatum	Polylectic	Taraxacum, "Hawkbit"	Yes
Lasioglossum laucopus	Polylectic	x	Yes
Lasioglossum morio	Polylectic	x	Yes
Lasioglossum rufitarse	Polylectic	Vaccinium myrtillus, Vaccinium vitis-idaea	Yes
Lasioglossum semilucens	Polylectic	"Hawkbit" (fibblor-swedish), Veronica, Jasione, Fragaria	Yes
Sphecodes ephippius	Polylectic	Taraxacum, Pilosella, Senecio, Potentilla, Tripleurospermum, Daucus, Solidago	Yes (OBS! Parasitic)
Sphecodes geoffrellus	Polylectic	Taraxacum, Barbarea, Tussilago, Senecio, Leontodon, Achillea, Daucus, Solidago	Yes (OBS! Parasitic)
Sphecodes monilicornis	Polylectic	Taraxacum, Pilosella, Eupatorium, Achillea, Senecio	Yes (OBS! Parasitic)