Citizen science observations of saproxylic beetles in Scania

Relationships with local species richness and municipal-level drivers

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Citizen science observations of saproxylic beetles in Scania. Relationships with local species richness and municipal-level drivers.

Medborgarforskning och vedlevande skalbaggar i Skåne: samband mellan lokal artrikedom och kommunala faktorer

Andrea Bernro

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Abstract

The loss of biodiversity and decline of forest ecosystems highlight the need for large-scale biodiversity monitoring. Citizen science (CS) can provide extensive data on species occurrences, but observations may be affected by biases. This thesis first examines whether CS observations of saproxylic beetles reflect local species richness, using research data from fast-growing broadleaf (FGB) stands in Scania, Sweden. Second, this thesis investigates how municipal-level factors influence CS observations of saproxylic beetles in Scania. Species richness of saproxylic beetles from 24 FGB research sites was compared with CS data using GIS and simple linear regressions. Relationships between CS observations and municipal-level factors, including human population density, forest cover and protected areas, were also analysed. No significant relationship was found between CS saproxylic beetle richness and local species richness from the FGB stands at any spatial scale. In contrast, several municipal-level factors revealed a significant relationship to CS observations, specifically human population density and protected areas. These results indicate that citizen science observations of saproxylic beetles are strongly influenced by sampling biases and are currently too limited to predict local species richness in local stands. However, citizen science data still provide valuable information on saproxylic beetles and, when combined with structured research data, can contribute to a more comprehensive understanding of forest biodiversity and its spatial patterns.

Keywords: Beetles, saproxylic, citizen science

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Abbreviations

CS	Citizen science
CSP	Citizen science project
FGB	Fast-growing broadleaves
SLU	Swedish University of Agricultural Sciences

1. Introduction

1.1 Saproxylic beetles and forest biodiversity

Over recent decades, it has become increasingly clear that human activities are driving both climate change and an ongoing biodiversity crisis, often referred to as the sixth mass extinction (Cowie et al. 2022). These human-driven processes amplify each other, as the increase in disturbances caused by climate change (Löfroth et al. 2023) places ecosystems and biodiversity under additional stress. Fundamental to biodiversity conservation, forests cover nearly 30% of the Earth's land area and provide habitat for more than half of the terrestrial animal and plant species globally (Morales-Hidalgo et al. 2015). Forests provide critical ecosystem services for both human and non-human organisms (Morales-Hidalgo et al. 2015), but rapid changes driven by human activity may overwhelm forest resilience (Keenan 2015), leading to a decline in ecosystem services.

In Sweden, roughly two-thirds of the land area is forested (Roberge et al. 2020), with a majority being production forest. Swedish forestry has for the last 100 years been dominated by a rotational forestry system, which is easy to manage and provides a predictable flow of raw wood material (Roberge et al. 2020). This intensive forestry means that the stands are single-species and even-aged, with a rotation length of 45-100 years for spruce, depending on the region (Roberge et al. 2020). This rotational forestry system has traditionally been aimed at maximising revenue (Angelstam et al. 2020), and successfully so; with 80% of forest products being exported, the forest industry is one of the largest contributors to the Swedish economy (Roberge et al. 2020).

Intensive forestry practices threaten forest biodiversity, which is reflected in the different species composition of managed and unmanaged forests (Gossner et al. 2016). Where unmanaged forests present a complex and varying ecosystem, forests managed with intensive practices lacks veteran trees (Gossner et al. 2016), deadwood diversity and volume (Lassauce et al. 2011; Gossner et al. 2016), as well as open structures (Gran 2022). In contrast to the standing timber volume, which is 139 m3/ha (Roberge et al. 2020), the average deadwood volume in Swedish forests is only around 8.5 m3/ha (Gran 2022).

Depending on factors such as tree species, decay stage, size and sun-exposure, deadwood provides an array of ecological niches (Löfroth et al. 2023), and can therefore be seen as an excellent indicator for biodiversity within forest ecosystems (Lassauce et al. 2011). Species across many taxa rely on the ecological niches provided by deadwood (Gossner et al. 2016; Löfroth et al.

2023), most of which belong to insect and fungal taxa (Lassauce et al. 2011). The lack of deadwood caused by intensive forestry is particularly a threat to saproxylic beetles (Gossner et al., 2016; Gran, 2022; Lassauce et al., 2011; Lachat et al., 2025; Löfroth et al., 2023). Saproxylic beetles refer to beetles that depend on decaying or dead wood at some time during their life cycle. In Sweden, one-fourth of all forest living species are saproxylic beetles (Gran 2022) that depend not just on dead wood, but on specific types of dead wood as defined by tree species origin, sun exposure, size, and decay stage (Gran, 2022; Djupström et al., 2024). Forestry practices strongly influence all these variables and are therefore directly relevant to the availability and amount of suitable deadwood. Depending on the specific properties of deadwood, the species composition varies. Early successional beetle species make up a large part of saproxylic diversity and, by creating habitat for later successional species, they act as a keystone species (Gossner et al. 2016). The specific ecology of saproxylic beetles depends on the species in question (Gran 2022), but common to all saproxylic beetles is that they are vital parts of forest ecosystems, as they recycle nutrients by breaking down deadwood, and thereby ensure a long-term availability of nutrients in forest systems (Lachat et al. 2025).

1.2 Regional species pools and dispersal range

Even if suitable deadwood is available for saproxylic beetles to inhabit, this may not be sufficient to ensure a high diversity of these species. An important additional determinant is the regional species pool. Regional species pools comprise all species present in a region that could potentially colonise a given habitat (Cornell & Harrison, 2014; Eriksson, 1993; Jarzyna et al., 2025; Zobel, 2016). Before colonisation can occur, the regional species pool is filtered through dispersal barriers and environmental filters (Cornell & Harrison, 2014; Zobel, 2016). These environmental filters include biotic and abiotic factors such as climate, topography, hydrology, nutrients, microclimate, and ecological niches, which together limit the influx of species to the local community (Cornell & Harrison, 2014; Jarzyna et al., 2025). When the regional species pool contains high species richness, the local community can be expected to reflect this with high species richness as well (Eriksson, 1993). Conversely, a regional species pool with relatively few species is likely to result in a local community with low species richness (Eriksson, 1993).

One key factor affecting local species richness is the dispersal ability of species. Among saproxylic beetles, dispersal range varies greatly (Gran, 2022; Lachat et al., 2025). Some beetle species adapted to early successional forest habitats are capable of flying tens of kilometres, although they often prefer shorter dispersal distances to reduce energy costs (Lachat et al., 2025; Ranius et al., 2011). Because many early-successional species can disperse over longer distances (Gran, 2022), habitat quality appears to be more important than the spatial distribution of these habitat patches (Rubene et al., 2014). For beetle species associated with tree hollows, species richness can increase when suitable habitats are found within 200-3000 metres in the surrounding landscape (Ranius et al., 2024). In line with island biogeography theory, few but large habitat clusters tend to support higher species richness than many small clusters (Ranius et al., 2024).

1.3 Citizen science

The interaction between habitat availability, regional species pools and dispersal ability highlights the importance of monitoring saproxylic beetles across broad spatial scales. However, systematically collecting such data through traditional field surveys alone is time-consuming and costly. Citizen science initiatives offer a potential complement by engaging many observers across large areas, generating large volumes of occurrence data that can be used to measure biodiversity. Citizen science (hereafter CS) can be conducted in more or less formal ways (Ward 2014) but always involves the participation of civil society in scientific research (Deacon et al. 2023). Driven by voluntary efforts, personal interest and curiosity, CS can generate large volumes of data and provide valuable information for both researchers and decision-makers (Deacon et al. 2023). By building a broad knowledge base, CS can be particularly useful for documenting rare or invasive species (Ward 2014) and for covering large spatial areas (Díaz-Calafat et al. 2024).

However, several limitations are associated with citizen science data, often expressed as different types of bias. These include: a) geographical bias, where sampling is unevenly distributed (Díaz-Calafat et al. 2024), and frequently clustered around recreational areas (Millar et al. 2019); b) taxonomic and species bias, where certain taxa and species are more frequently reported than others (Ward 2014; Díaz-Calafat et al. 2024; Herrera et al. 2025); c) temporal and observation bias, where sampling effort varies over time (Millar et al. 2019; Díaz-Calafat et al. 2024), and the number of recordings per site and visit is irregular (Millar et al. 2019). In general, these biases can be linked to user behaviour, preferences and taxonomic expertise (Díaz-Calafat et al. 2024). Across taxa, large, colourful, charismatic or active species are often easier to detect and identify (Deacon et al. 2023; Díaz-Calafat et al. 2024). In contrast, some small insects require microscopy or even DNA coding for reliable identification (Díaz-Calafat et al. 2024), which helps explain their underrepresentation in CS data.

Several approaches have been proposed to reduce bias in citizen science. These include adopting bottom-up approaches (Deacon et al. 2023), improving protocols for data collection (Díaz-Calafat et al. 2024), designing projects to target data gaps (Deacon et al. 2023) and underrepresented areas (Díaz-Calafat et al. 2024), and raising public awareness on less popular insect orders (Deacon et al. 2023). While it is important to recognise these biases when working with CS data, the benefits of CS can outweigh its drawbacks. Scientists gain free access to extensive datasets, and volunteers acquire knowledge and a deeper understanding of both species and ecosystems, which may motivate them to observe taxa beyond their initial interest (Díaz-Calafat et al. 2024). Combining citizen science and academic data therefore has the potential to provide a more comprehensive representation of biodiversity than either source alone.

One of the most successful citizen science projects globally is coordinated by SLU Artdatabanken (Swedish Species Information Centre) (SLU Artdatabanken 2025b). SLU Artdatabanken manages three different web applications in which citizen science plays a central role: Artfakta, Artportalen, and Fyndata. Artfakta is a knowledge bank with the primary purpose of describing and mapping all species of animals, plants and fungi found in Sweden. Species information is continuously updated with expert input and includes descriptions, geographical range, pictures and phylogenetic relationships (SLU Artdatabanken 2025a). Artportalen is a platform where citizens report their observations. Artportalen serves as both a social platform for knowledge sharing and a key data source for nature conservation and research at all scales. In addition to supporting local authorities with biodiversity information, Artfakta is also the second-largest data contributor to the Global Biodiversity Information Facility (GBIF) (SLU Artdatabanken 2025b). Finally, Fynddata is a web application that allows users to view, analyse and export statistics on reported observations. In addition to Artportalen, multiple databases are integrated into Fynddata (SLU Artdatabanken 2026b). Collectively, these websites provide a wide range of observational data. A key question is the extent to which CS data can provide useful insights or complement empirical studies conducted by scientists. That is the starting point for this thesis.

1.4 Aim of the thesis

This thesis has two main aims. First, to examine the relationships between species richness in data collected through scientific research and in data obtained through citizen science. Second, to explore potential factors influencing the number of CS observations at the municipal level in Scania, and to better understand their spatial distribution and clustering. Building on the extensive citizen coverage in Scania, this enables comparison between registered CS observations and municipal-level

factors. The underlying hypothesis for this project is that a) saproxylic beetle species richness obtained through citizen science (CS) reflects the local patterns of species richness collected in the FGB project in Scania, and b) CS observations in Scania are affected by municipal-level factors, such as human population density, total human population and forest cover.
To test these hypotheses, the following research questions were addressed:
1. To what extent could citizen science observations of saproxylic beetles be used to reflect or predict species richness derived from research data in fast-growing broadleaf (FGB) sites in Scania?
2. How did municipality-level factors (population density, total population, forest cover, protected areas) relate to the number of citizen science observations of saproxylic beetles?

To address these aims, I utilise two complementary data sources: research data from a PhD project on saproxylic beetles in fast-growing broadleaf (FGB) stands in Scania, and regional citizen science observations from SLU Artdatabanken. The FGB study sites serve as local, well-defined habitats used for comparison with the broader regional citizen science data.

2. Materials and methods

2.1 Study area

This thesis focuses on Scania, the southernmost province of Sweden. In contrast to the hemi-boreal and boreal climate that dominates most of Sweden, Scania has a nemoral climate with a mean annual temperature of around 9 degrees, and a mean annual precipitation of approximately 600 mm (SMHI n.d.). Repeated glacial processes have shaped the Scanian landscape, leaving extensive glacial deposits (Douglas Price 2013) and a soil composition dominated by clayey moraines, moraines, sandy moraines and glacial sediments (Sveriges Geologiska Undersökning (SGU) 2023). The clay-rich moraines in south-western Scania provide perfect conditions for agriculture, while the north-eastern parts are mainly forested. These abiotic factors create conditions suitable for many broadleaf tree species, resulting in a heterogeneous landscape in which this thesis is set.

2.2 Data sources

2.2.1 FGB research project

The first dataset used in this thesis originated from a research project on fast-growing broadleaf (hereafter FGB) stands conducted by PhD student Jamie Luna. In Luna’s project, 358 logs of fast-growing broadleaf species (poplar, aspen, hybrid aspen, silver birch and Ekebo birch) were placed at 24 sites in Scania in the spring of 2023. Twenty-one sites were located adjacent to production stands of fast-growing broadleaves (poplar, hybrid aspen and silver birch), and three sites were selected for their natural character and presumed suitability for saproxylic insects. To mimic a post-felling environment, the logs were grouped by tree species and randomly placed along the southern border of the FGB stands in a sun-exposed location. In the summer of 2024, closed eclector traps attached to the logs were emptied, and all collected insects were identified by the expert Oskar Gran. Of the 412 beetle species collected, 200 were classified by Artfakta as saproxylic beetles. Regardless of this official classification, all beetles collected in this research are here considered saproxylic beetles, as they were collected while emerging from lying deadwood.

In this project, the dataset of saproxylic beetles was imported into Microsoft Excel, where records were filtered to retain only beetle taxa identified to species level (412 species, 6622 individuals). The dataset also included data on the 358 logs, such as stand species, tree species and coordinates, which were used in the analysis.

2.2.2 Artfakta and Fynddata

Data used in this thesis on CS species richness were downloaded from SLU Artdatabanken's web applications Artfakta and Fynddata (SLU Artdatabanken, 2026) on the 2nd of April 2026. The following databases were used: Artportalen, iNaturalist, Biologg and Lunds universitets biologiska museum - faunistiska samlingar. The data downloaded from Fynddata included observer names and usernames. These personal identifiers were removed prior to analysis, and no personal data were used in this study.

Artfakta

To construct my dataset of citizen science observations, beetle (Coleoptera) records were first extracted from the Artfakta web application (SLU Artdatabanken, 2026) for the province of Scania. Filters were applied to restrict observations to beetle records associated with forested landscapes, trivial broadleaf biotopes, and substrates classified as wood, bark or deadwood (Table 1). Specific emphasis on landscape, biotope, and substrate was applied to narrow down the results to match saproxylic beetle species that could be found in connection with FGB. No temporal restriction was applied at this stage. This search yielded 215 beetle species geolocated by citizen scientists, which were exported as a CSV file (SLU Artdatabanken 2026a).

Table 1. The filters used to download data from the web application Artfakta in order to isolate potential saproxylic beetles identified by citizen scientists.

Organism	Province	Landscape type	Biotope	Substrate
Beetles	Scania	Forest	Trivial broadleaf	Wood and bark, deadwood

Fynddata

The data exported from Artfakta included a column for taxonID, where a unique number for each species was assigned. These taxonIDs were then used in Fynddata to retrieve observations of the 215 species in Scania over the past five years. All other filters in Fynddata remained at their default settings, and all available datasets were included, with the most relevant being Artportalen, iNaturalist and Biologg. This resulted in 5603 observations, which were exported as a CSV file (SLU Artdatabanken 2026c).

2.2.3 Municipal data

Shapefiles for municipalities and a raster of land-type cover for Scania were downloaded from ArcGIS Online (Infrastruktur Skåne 2024; Naturvårdsverket 2026). Statistical data on population, protected nature areas, and economic indicators were obtained from Statistics Sweden (SCB) database using municipality-level datasets (Statistikmyndigheten SCB 2024; 2025c; b; a). All data from SCB were filtered to include only municipalities in Scania, and the protected nature data were filtered by land area (km^2) and included all protection categories. The downloaded economic data was selected to represent the economic status per municipality and was categorised as "municipal income statement (SEK thousand) current prices by region, income statement item and year".

2.3 Data analysis

2.3.1 Species richness

Specific data were linked (trap number to stand name), and beetle species were filtered from the raw data to obtain species richness per site. This table was imported into ArcGIS Pro, and included data on all 412 beetle species and logs. Data from the logs were imported to calculate distances between logs and determine which buffer zones should be created for the CS survey area. Four different CS survey areas were created using the geoprocessing tool Buffer: 300 meters, 1 kilometre, 2 kilometres, and 5 kilometres. The first survey area of 300 metres was chosen because it was the only distance that included all logs without any overlap between sites. The other distances were chosen to represent longer dispersal ranges of beetles. For my second dataset containing CS data, I extracted species richness for each CS survey area using the Spatial Join geoprocessing tool, removed duplicate observations of the same species within the same site using the Delete Identical tool, and calculated site-level species richness using the Calculate Field and Summary Statistics tools. Both FGB and CS data points were mapped to create a visual representation of all observations (Figure 1). A compiled dataset of FGB and CS species richness across all survey buffers (300 m, 1 km, 2 km, 5 km) was prepared for analyses (Appendix A).

2.3.2 Potential influences on CS observations

The downloaded land-type raster was used to calculate the proportion of forest area within each municipality. To identify forest data across the 50 land-type categories, each category was assigned a value of 1 or 0 with the Raster Calculator tool. The following Python code, with help from ChatGPT, was used:

Con(("landuse_NEW_skåne" >= 111) & ("landuse_NEW_skåne" <= 128), 1, 0). All forest categories were assigned the value 1, including "temporary non-forest on solid ground" and "temporary non-forest on wetland". These two categories were included because they represented clear-cuts or newly planted sites that may have been forested within the last five years. As I analysed observations of forest-associated beetles over the last five years, it was important not to exclude the previously forested categories. The remaining land-type categories were assigned a value of 0. The Zonal statistics to table tool was used to assign the mean forest cover to each municipality. The resulting mean was exported to Excel and added to the municipality shapefile using the Join Field tool. Additionally, data downloaded for the total human population and human population density were added to the municipalities using the Join field tool. Several maps were then created to visualise the spatial relationships between CS observations and municipal-level factors (Appendix B). The original Fynddata dataset linked all CS observations to the municipality in which they were recorded, which facilitated calculation of the number of observations per municipality. All observations were retained in this analysis, including multiple recordings of the same species within the same municipality, to assess which factors could be affecting CS observations. The factors tested against CS observations included total population, population density, mean forest cover, protected areas, and economic factors.

2.3.3 Statistical analysis

All statistical analyses were conducted in Microsoft Excel using the Analysis ToolPak add-in. Simple linear regressions were performed to assess relationships between CS and FGB species richness for the first dataset, and for the second, between CS species richness and municipality-level factors. For each regression, the p-value and coefficient of determination (R^2) were reported. A p-value < 0.05 was considered statistically significant.

To ensure no important patterns were missed in the analysis of saproxylic beetle species richness, linear regression was performed for all CS survey areas (Appendix C), both with and without outlier values. A two-kilometre survey area was ultimately chosen because it a) included a sufficient number of CS observations, b) was a reasonable dispersal distance for saproxylic beetles, particularly early-successional species (Ranius et al. 2011; Lachat et al. 2025), and c) overlapped fewer stands than the five-kilometre survey area. To assess whether stand species or log species had any effect on relationships, additional simple linear regressions were conducted for FGB and CS species richness by stand species (poplar, hybrid aspen, birch, and natural) (Figure 3), and log species (aspen, hybrid aspen, birch, and Ekebo birch) (Figure 4).

In the analysis of potential influences on CS observations of saproxylic beetles, CS observations were corrected for forested area (km^2) per municipality to account for differences in habitat availability across municipalities. This standardised the number of observations per unit of forested area and provided a more ecologically relevant comparison of the municipalities. Due to the presence of several inconsistently high values, the data on total population and population density were log10-transformed to compress the range and facilitate identification of a statistical relationship.

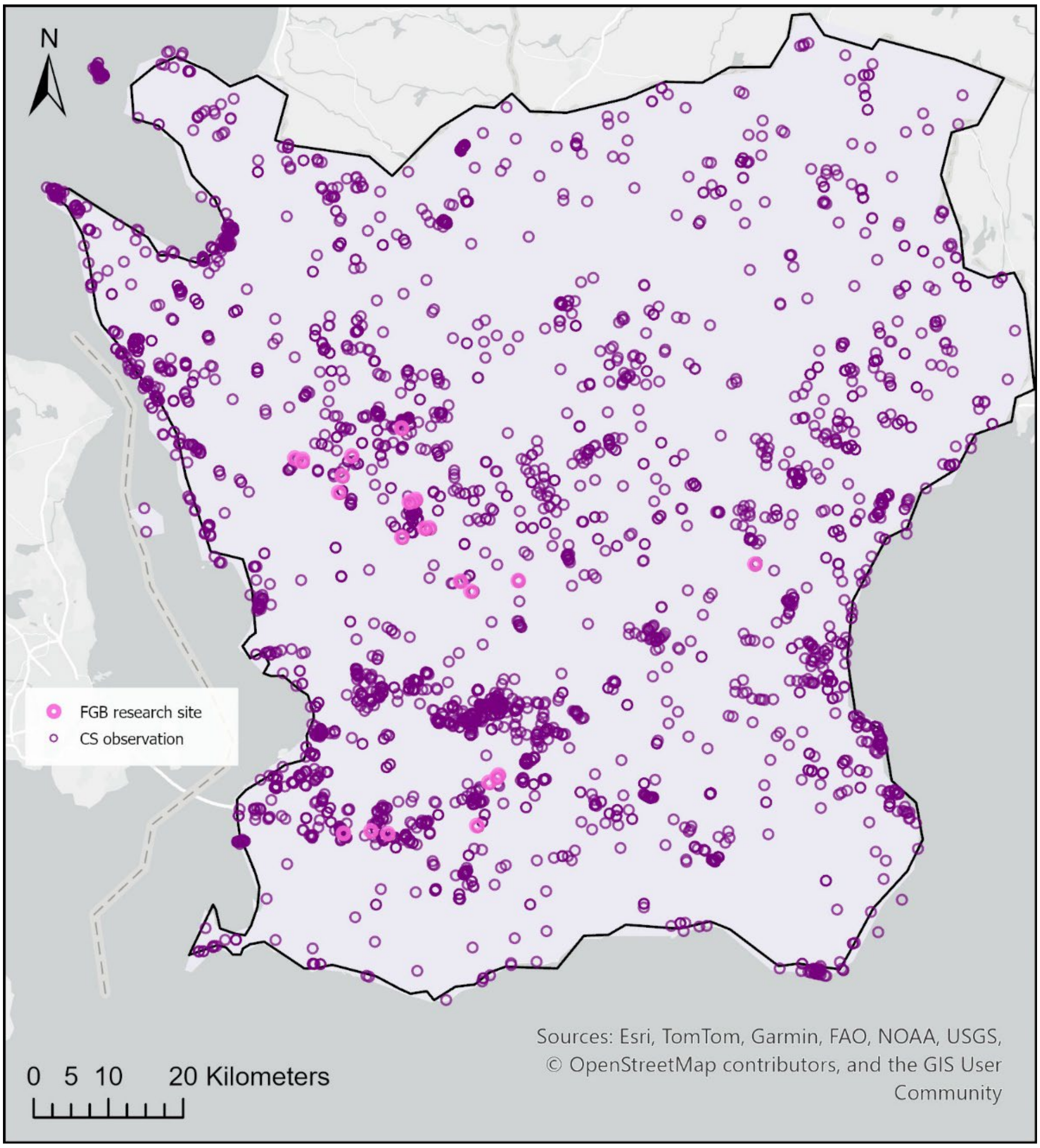

Figure 1. Map of Scania depicting the 24 FGB research sites (pink) and all CS beetle observations (purple) from the last five years. Data on FGB research sites were collected in 2024 as part of the FGB research project, and data obtained from Fynddata included observations of saproxylic beetles between 2021 and 2026.

3. Results

3.1 Species richness

Whereas the FGB species richness identified a total of 412 species and an average of 121 species per site, the CS species richness data varied according to the spatial extent of the surveyed areas. Within a 300-meter radius, all but one CS site featured none or a single beetle species (see Table 2). In contrast, stand two was a notable outlier, hosting 53 CS beetle species within a 300-meter radius and 82 species within a two-kilometre radius.

Table 2. Data on saproxylic beetle species richness collected from fast-growing broadleaves (FGB) study sites and via citizen science (CS) in the Swedish region of Scania. Four survey areas were created to measure species richness at different spatial scales surrounding the FGB study sites. The data was collected in Scania during the summer of 2024 (FGB), and between 2021 and 2026 (CS).

Stand nr	FGB species richness	CS species richness 300 m	CS species richness 1 km	CS species richness 2 km	CS species richness 5 km
1	134	0	12	17	44
2	99	53	80	82	91
3	147	0	4	19	97
4	172	0	0	5	28
5	152	0	0	3	43
6	232	1	2	3	47
7	171	1	1	1	5
8	175	1	3	6	6
9	102	0	1	2	6
10	125	0	1	4	18
11	111	0	1	10	17
12	87	1	1	8	19
13	71	0	1	4	5
14	120	0	1	1	7
15	125	0	1	1	7
16	83	0	3	8	23
17	145	0	1	10	16
18	121	0	9	10	16
19	138	0	0	8	21
20	94	0	1	9	21
21	59	0	1	9	21
22	94	0	3	5	27

23	93	1	2	2	12
24	65	0	7	20	29

A simple linear regression revealed no significant relationship (p-value=0.392, R²=0.03) between CS species richness of saproxylic beetles (x-axis) and FGB species richness of saproxylic beetles (y-axis) (Figure 2).

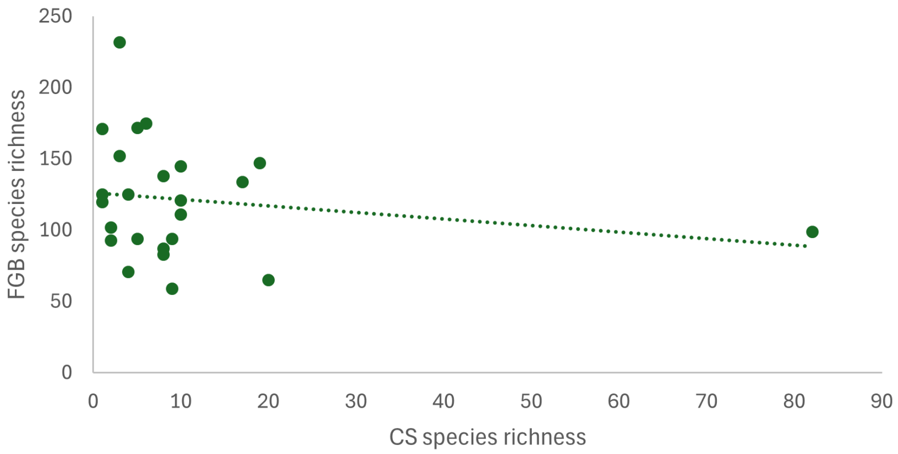

Figure 2. Relationship between CS species richness (x-axis) and FGB species richness (y-axis) for saproxylic beetles within a two-kilometre survey area. Each point represents a study site in Scania, Sweden. The simple linear regression showed no significant relationship (p-value=0.392, R^2=0.03).

No statistically significant relationships were found for any stand species (Figure 3); for the natural stands, the regression was also not statistically significant (p-value = 0.119, R² = 0.97).

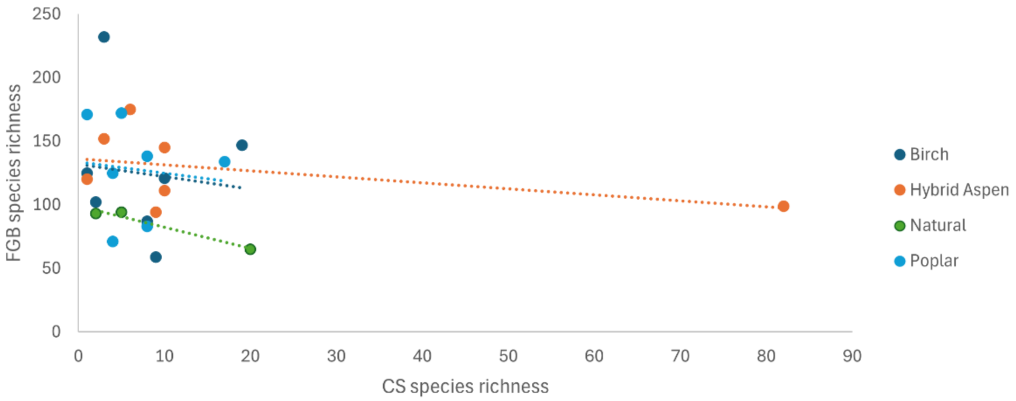

Figure 3. Relationship between CS species richness (x-axis) and FGB species richness (y-axis) for saproxylic beetles within a two-kilometre survey area. Each point represents a study site in Scania, Sweden, and each stand species was assigned a unique colour.

No statistical significance was found between Average CS species richness (x-axis) and average FGB species richness (y-axis) when the log species was considered. For poplar logs, no significant relationship was found (p-value=0.128, $R^2 = 0.11$) (Figure 4).

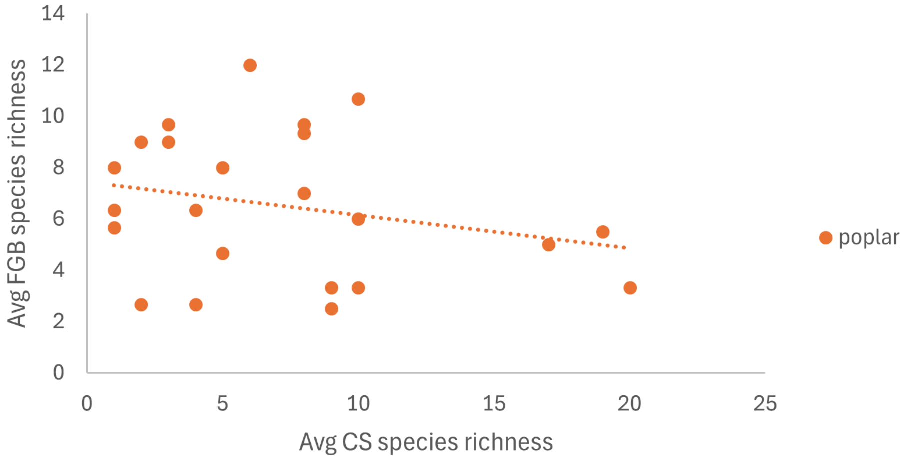

Figure 4. Relationship between CS species richness (x-axis) and FGB species richness (y-axis) for saproxylic beetles within a two-kilometre survey area. Each point represents the poplar logs at each study site. The simple linear regression indicated no significant relationship (p-value=0.128, R^2=0.11).

3.2 Potential influences on CS observations

No significant relationship was found between CS observations and mean forest cover per municipality (p-value=0.135, R^2=0.07) (Figure 5), indicating that mean forest cover does not affect the number of CS observations.

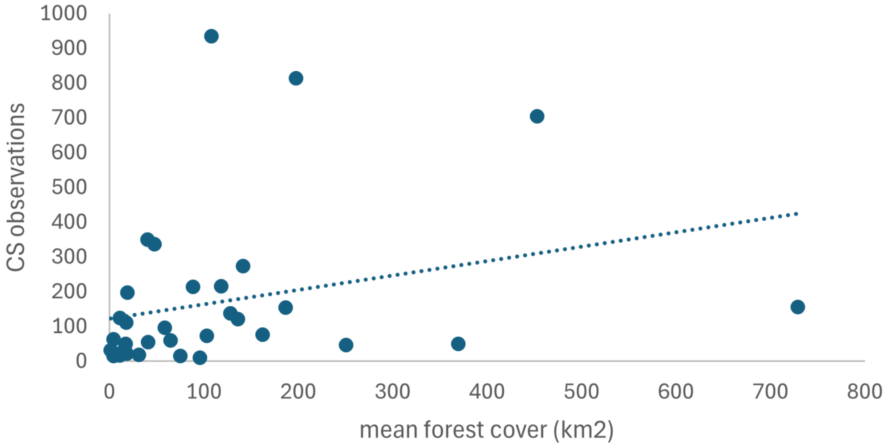

Figure 5. Relationship between mean forest cover (km^2) per municipality in Scania (x-axis) and CS observations of saproxylic beetles (y-axis). Each point represents a municipality in Scania, Sweden. The simple linear regression showed no significant relationship (p-value=0.135; R^2=0.07).

A significant relationship was found between CS observations per km^2 of forest and total population (p-value=0.019) (Figure 6), indicating that municipalities with larger populations tend to have more CS observations. However, the model could only explain 17% of the variance (R^2=0.17).

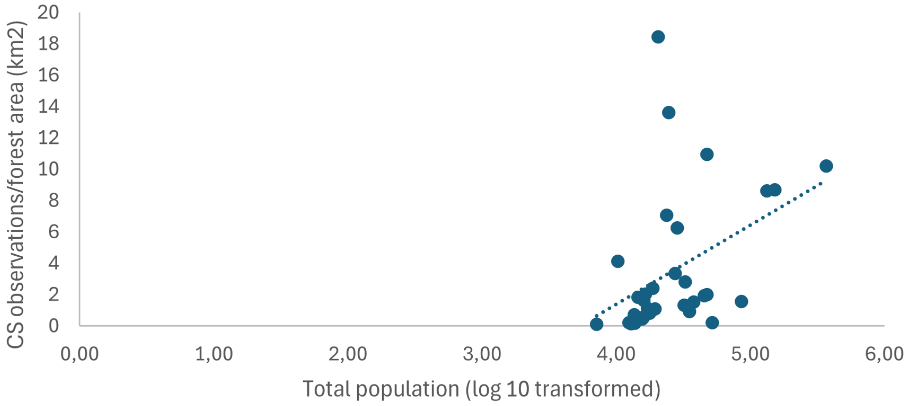

Figure 6. Relationship between total human population per km^2 per municipality in Scania (x-axis) and CS observations of saproxylic beetles (y-axis). The total population has been log10-transformed. Each point represents a municipality in Scania, Sweden. The simple linear regression revealed a significant relationship (p-value=0.019), but only 17% of the variance could be explained by the model (R^2=0.17).

The simple linear regression revealed a significant relationship between CS observations per km^2 of forest (y-axis) and the population density (x-axis) per municipality (p-value=<0.001) (Figure 7). The model explained 63% of the variance (R^2 =0.63).

Figure 7. Relationship between human population density per municipality (x-axis) and CS observations of saproxylic beetles per forest area (km^2). The population density has been log10-transformed. Each point represents a municipality in Scania, Sweden. The simple linear regression revealed a significant relationship (p-value=<0.001), and the model explained 63% of the variance (R^2=0.63).

The simple linear regression indicated a significant relationship between CS observations and municipal income statement (p-value=0.015) (Figure 8), but only 18% of the variance could be explained by the model (R^2 0.18).

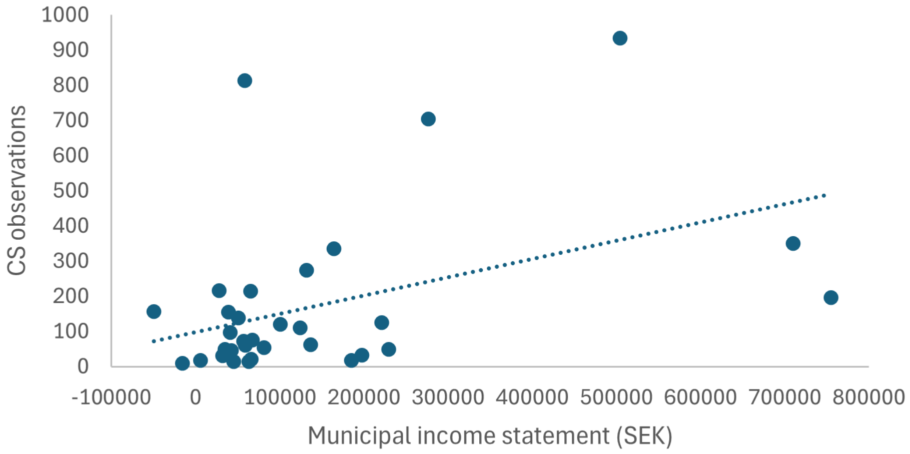

Figure 8. Relationship between income statement (SEK thousand), current prices by region, income statement item, and year for municipalities in Scania (x-axis) and CS observations of saproxylic beetles (y-axis). Each point represents a municipality in Scania, Sweden. The simple linear regression revealed a significant relationship (p-value=0.015), but only 18% could be explained by the model (R^2=0.18).

The simple linear regression indicated a significant relationship between CS observations and protected land area (km^2) (p-value=<0.001), with 41% of the variance explained by the model (R^2 0.41) (Figure 9).

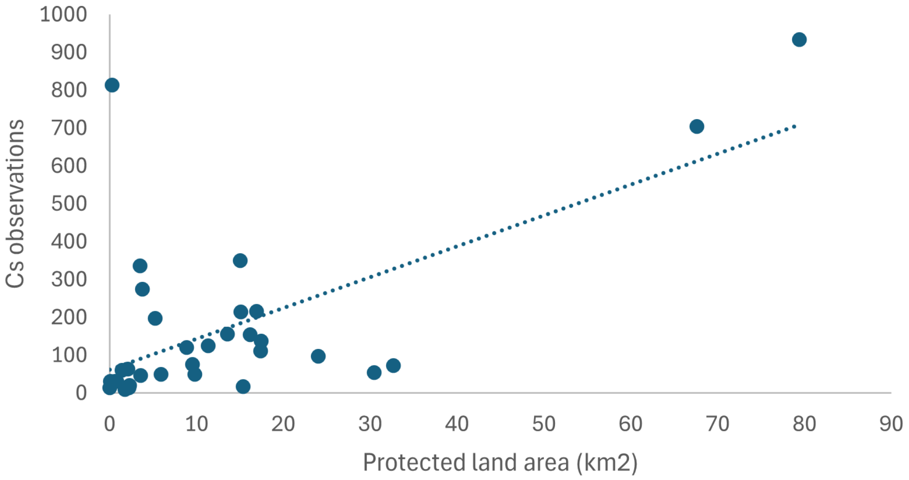

Figure 9. Relationship between protected land area (km^2) in municipalities in Scania (x-axis) and CS observations of saproxylic beetles (y-axis). Each point represents a municipality in Scania. The simple linear regression revealed a significant relationship (p-value=<0.001), and the model explained 41% of the variance (R^2=0.41).

4. Discussion

In this study I compared the species richness of saproxylic beetles in citizen science (CS) data with that in data collected through scientific research. This was done to investigate whether CS data at the regional scale can predict or reflect species richness at the habitat scale. Second, this thesis investigated factors influencing the number of CS observations at the municipal level. The hypotheses that were addressed in this project were that a) saproxylic beetle species richness obtained through citizen science reflects the local patterns of species richness collected in the FGB project in Scania, and b) CS observations in Scania are affected by municipal-level factors, such as human population density, total human population and forest cover. The main findings rejected the first hypothesis, as no significant relationship was found between CS and FGB species richness of saproxylic beetles. The second hypothesis failed to be completely rejected, as significant relationships were found between CS observations of saproxylic beetles and human population density and protected land area.

Species richness

The initial calculation of saproxylic beetle species richness from CS observations and FGB research sites revealed that species richness from CS was substantially lower than that from FGB, and no pattern was found between the two datasets (Table 2). This indicates that citizen science observations of saproxylic beetles could not be used to reflect or predict species richness collected from research data in fast-growing broadleaf (FGB) sites in Scania, at least in this study. However, this result does not imply that there is no relationship between CS observations and local species richness; it can only be used to indicate that the CS observation data used in this thesis were insufficient to show such a relationship, if one existed.

With each increase in survey area, saproxylic beetle species richness in CS observations increased; as could be expected. Larger radii increased the probability of observations, which was reflected in higher saproxylic beetle richness. While this increase in CS saproxylic beetle richness indicated a rich regional species pool, the analysis did not reveal any significant relationship with the empirical data form the FGB stands. This regional species pool, as presented in the CS observations, may suffer from spatial and observational biases, with irregular recordings per site and visit (Millar et al. 2019). For the three shorter CS survey inclusion distances, stand number two showed more than four times the species richness of the other stands and was deemed to be an outlier. After running several analyses across all survey areas, including and excluding stand number two, the results showed that the outlier did not affect the relationship between CS and FGB species richness. In contrast to the other stands, the area around stand number two appears as a cluster of saproxylic beetle records, indicating very uneven sampling efforts among the CS survey points. While the reason for this cluster is unknown to us, it may be due to a targeted sampling effort by one or a few knowledgeable citizen scientists. Also known as observation bias, where user behaviour and knowledge directly affect the number of recordings per site and visit (Millar et al. 2019).

I also did not find a significant relationship between CS and FGB species richness of saproxylic beetles when the data was divided by stand or log species. While the FGB study involved the placement of logs near natural stands presumably to ensure a higher species richness pool for colonisation of the logs than would occur near the production stands, the results provided placed the natural stands in the lower third of species richness found (Table 2). This result was also surprising as all of the natural stands involved were protected areas where recreational activities were frequent, and CS observations could be expected to be high (Millar et al. 2019). This, however, was not reflected in this study, as CS species richness of saproxylic beetles was relatively low across all survey areas, except for stand 24, and for a two-kilometre CS survey radius (Table 2). As there were only three natural stands, and the lower number of replicates lacked statistical power, no reliable conclusions can be drawn from this result.

Taxonomic bias

Citizen science biases can, in general, be linked to user behaviour, preferences and taxonomic expertise (Díaz-Calafat et al., 2024), and this is particularly evident in taxonomic bias. Taxonomic bias implies that some taxa are reported more frequently than others (Díaz-Calafat et al., 2024; Herrera et al., 2025; Ward, 2014), and this can be observed when taxa are represented to varying degrees. Taxa and species that are large, colourful, charismatic or active tend to receive more attention, partially because they are often easier to detect and identify (Deacon et al., 2023; Díaz-Calafat et al., 2024).

While insects in general are underrepresented in both conservation efforts and citizen science (Deacon et al. 2023), as is evident in the IUCN Red List (Cowie et al. 2022). This preference extends to other taxonomic orders as well, with Coleoptera receiving less attention than Lepidoptera and Hymenoptera (Deacon et al. 2023; Díaz-Calafat et al. 2024). Species of Lepidoptera (butterflies and moths) and Hymenoptera (bees, sawflies, ants and wasps) tend to be large and colourful, thereby attracting more attention than less charismatic orders. Further, the importance of bees and butterflies as pollinators is widely recognised, whereas the key ecosystem functions that saproxylic beetles provide (i.e., nutrient cycling, microhabitat creation, and pollination) are less well known. In addition to limited public awareness, saproxylic beetles may require microscopy for accurate identification (Díaz-Calafat et al., 2024), further complicating citizen science recording. Other taxa might have shown a different outcome in this study, with a stronger relationship to academically sourced data on species richness. More popular taxa are more likely to attract larger numbers of interested citizen scientists with relevant expertise. Additionally, some taxa, like birds, are easier to observe. Although only a fraction of insect species have been identified, all bird species are known (Cowie). Their larger size and audible calls make birds easier to observe and identify.

Geographical bias

Geographical bias in citizen science occurs when observers report more observations in certain locations. This is evident in uneven sampling distributions (Díaz-Calafat et al., 2024) and in observations frequently clustering around accessible areas (Millar et al., 2019). Three recent reviews of citizen science biases have concluded that citizen science observations tend to be biased toward moderately populated areas (Herrera et al. 2025), roads (Díaz-Calafat et al. 2024; Herrera et al. 2025), recreational areas and protected areas (Millar et al. 2019; Díaz-Calafat et al. 2024). However, in general, CS tend to be less clustered and provide a more stable environmental cover data than academically sourced data (Díaz-Calafat et al. 2024).

These geographical biases are reflected in all relationships found between CS observations and municipal-level factors. While linear regressions found no significant relationship between CS observations and municipality-level factors, this does not mean that there is no relationship at all. As research shows, citizen science and academic research cover different spatial areas of the landscape, with academic research being more clustered and biased toward inaccessible areas (Díaz-Calafat et al. 2024).

In my results, I did not find a significant relationship between the CS observations of saproxylic beetles and mean forest cover (Figure 5). This result was unexpected, as forest-living beetles could be more predicted to be more common in areas with high forest cover, due to the higher associated availability of their primary habitat. I therefore suggest that this result is more likely a product of geographical and observational biases affecting the results. Forests are essential habitats for saproxylic beetles, but studies demonstrate that CS observations display an uneven spatial and temporal distribution, with a higher concentration around roads and moderately populated areas (Millar et al. 2019; Díaz-Calafat et al. 2024) and a lower concentration in inaccessible areas (Herrera et al. 2025). Areas with higher forest cover are located in the northeast of Scania, while the human population density is higher in the west. In this case, it seems that geographical bias may be outweighing the importance of forest cover, as municipalities with high forest cover and low human population density may remain undersampled.

Unstructured citizen science, the most common form in Sweden, is expected to produce more observations in areas with higher population density, due to a greater likelihood of observing and reporting species (Herrera et al. 2025). This is reflected in my analyses, as both the total human population (Figure 6) and human population density (Figure 7) per municipality indicate a significant relationship with the number of CS observations. While only 17% of the variance in CS observations and total human population per municipality is explained by the model, 63% of the variance in human population density is explained. The relationship between CS observations and human population density appears to reach a saturation point when urban landscapes become too hostile for hosting a large number of species (Deacon et al. 2023). There seems to be a balance between the number of potential observers and proximity to large urban areas (Deacon et al. 2023; Herrera et al. 2025). A significant positive relationship between protected land area and CS observations of saproxylic beetles was found (p-value=6.612E-05), with 41% of the variance explained by the model (Figure 9). While protected areas often provide a higher habitat quality, they also tend to overlap with recreational areas, reinforcing the idea of geographical biases in CS data collection (Millar et al. 2019; Díaz-Calafat et al. 2024).

Further, I compared the number of CS observations of saproxylic beetles within a municipality to the municipal income statement (income statement (SEK thousand), current prices by region, income statement item, and year for municipalities in Scania) (Figure 8). The analysis of CS observations of saproxylic beetles and municipal income statement reveals a significant relationship (p-value=0.015), but only 18% of the variance is explained by the model. The relationship between citizen science and economic factors is also examined in a 2023 global study by Deacon, in which 107 citizen science projects (CSP) worldwide served as the basis for a meta-analysis of underlying biases related to country wealth, taxon representativeness and demographic participation. Deacon finds that the number of CSPs per country is positively related to the country's national GDP and GDP per capita (Deacon et al. 2023). Because higher GDP is associated with better access to technology, higher educational levels, and greater overall political stability and socio-economic welfare, more CSPs can be conducted. While Sweden has a relatively high GDP per capita, the number of active CSPs is quite low (Deacon et al. 2023), suggesting that Sweden relies more on unorganised citizen science than on organised CSPs. Adapted to local boundaries, the relationship between CS observations and the municipal income statement could reflect a higher overall education level and greater access to leisure time, factors that could positively affect the level of involvement in citizen science (Deacon et al. 2023). While the economic income statement per municipality may explain some variation in the analysis, population density and geographical bias seem to explain more in this study.

To summarise, CS observations of saproxylic beetles in Scania are not evenly distributed with the amount of forest cover per municipality; rather, they seem to correlate with municipalities that are more densely populated, contain more protected areas, and, to a lesser degree, have higher municipal income levels. This pattern is consistent with previous studies on bias (Ward 2014; Millar et al. 2019; Deacon et al. 2023; Díaz-Calafat et al. 2024).

4.1 Limitations to the study

The data downloaded on saproxylic beetle observations obtained through citizen science may not be the best representation of beetles found within fast-growing broadleaf stands. As the CS data were filtered to include only saproxylic beetles recognised by Artfakta, the FGB dataset treated all collected beetles as saproxylic, as they were in fact emerging from deadwood, despite only half of the species being officially classified as saproxylic. As all FGB species were treated as saproxylic beetles and therefore included in the analysis, this may present a possible mismatch with the CS data. This mismatch would most likely not be in favour of the analyses, as fewer species were included. To address this limitation and obtain a larger dataset that more accurately reflects the beetles found in the FGB study, the CS dataset could be filtered more thoroughly on a species-by-species basis, and as determined by expert assessment.

Citizen science provides valuable regional context and large-scale data, with great potential to document many species and thousands of observations. However, this study was heavily influenced by citizen science biases, indicating that CS observations of saproxylic beetles may in some circumstances be too limited to capture local richness at the habitat scale. This supports the view that citizen science alone cannot always reliably predict local beetle richness within specific habitats. To reduce these biases, recommendations from researchers include targeting data gaps and underrepresented areas (Díaz-Calafat et al., 2024), as well as increasing public attention towards less popular insect orders (Deacon et al., 2023).

5. Conclusions

In this study, I analysed citizen science data from two perspectives. First, whether citizen science observations of saproxylic beetles could be used to reflect or predict species richness, as derived from research data, in fast-growing broadleaf stands in Scania. Second, how municipal-level factors influence the number of citizen science observations of saproxylic beetles. My findings indicated that coverage of saproxylic beetles by citizen science data in Scania was insufficient for our purposes to predict species richness from the research data assessed. The inability to do so was most likely due to biases and limitations associated with citizen science assessments of this taxon. Second, my findings suggest that citizen science observations of saproxylic beetles are influenced by certain municipal-level factors, such as human population density and the extent of protected areas. Citizen science has an important and valuable capacity to complement scientific research for the understanding of biodiversity. Around 1000 observations per year are recorded in Scania, just on saproxylic beetles associated with trivial broadleaves. Regardless of the biases associated with citizen science, these observations provide significant information that adds to the knowledge base that researchers and policymakers benefit from. Without these voluntary efforts, we would have far less information on our ecosystems and biodiversity.

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Appendix A – compiled dataset of species richness

Table A1. Compiled data from the FGB research project and Fynddata, prior to GIS analysis. The on saproxylic beetles was collected in Scania, Sweden during 2024 (FGB data), and between 2021 and 2026 (CS data). CS_rich_x shows species richness of CS data on different CS survey areas; 300 metres, one kilometre, two kilometres and five kilometres.

Trap nr	Stand nr	Tree species	FGB_richness	CS_rich_300	CS_rich_1k	CS_rich_2k	CS_rich_5k
1-15	1	Poplar	134	0	12	17	44
16-30	2	HybridAspen	99	53	80	82	91
32-45	3	Birch	147	0	4	19	97
46-60	4	Poplar	172	0	0	5	28
61-75	5	HybridAspen	152	0	0	3	43
76-90	6	Birch	232	1	2	3	47
91-105	7	Poplar	171	1	1	1	5
106-120	8	HybridAspen	175	1	3	6	6
121-135	9	Birch	102	0	1	2	6
136-150	10	Poplar	125	0	1	4	18
151-165	11	HybridAspen	111	0	1	10	17
166-180	12	Birch	87	1	1	8	19
181-195	13	Poplar	71	0	1	4	5
196-210	14	HybridAspen	120	0	1	1	7
211-225	15	Birch	125	0	1	1	7
226-240	16	Poplar	83	0	3	8	23
241-255	17	HybridAspen	145	0	1	10	16
256-270	18	Birch	121	0	9	10	16
271-285	19	Poplar	138	0	0	8	21
286-300	20	HybridAspen	94	0	1	9	21
301-315	21	Birch	59	0	1	9	21
316-330	22	Natural	94	0	3	5	27
331-345	23	Natural	93	1	2	2	12
346-360	24	Natural	65	0	7	20	29

Appendix B – supplementary GIS maps

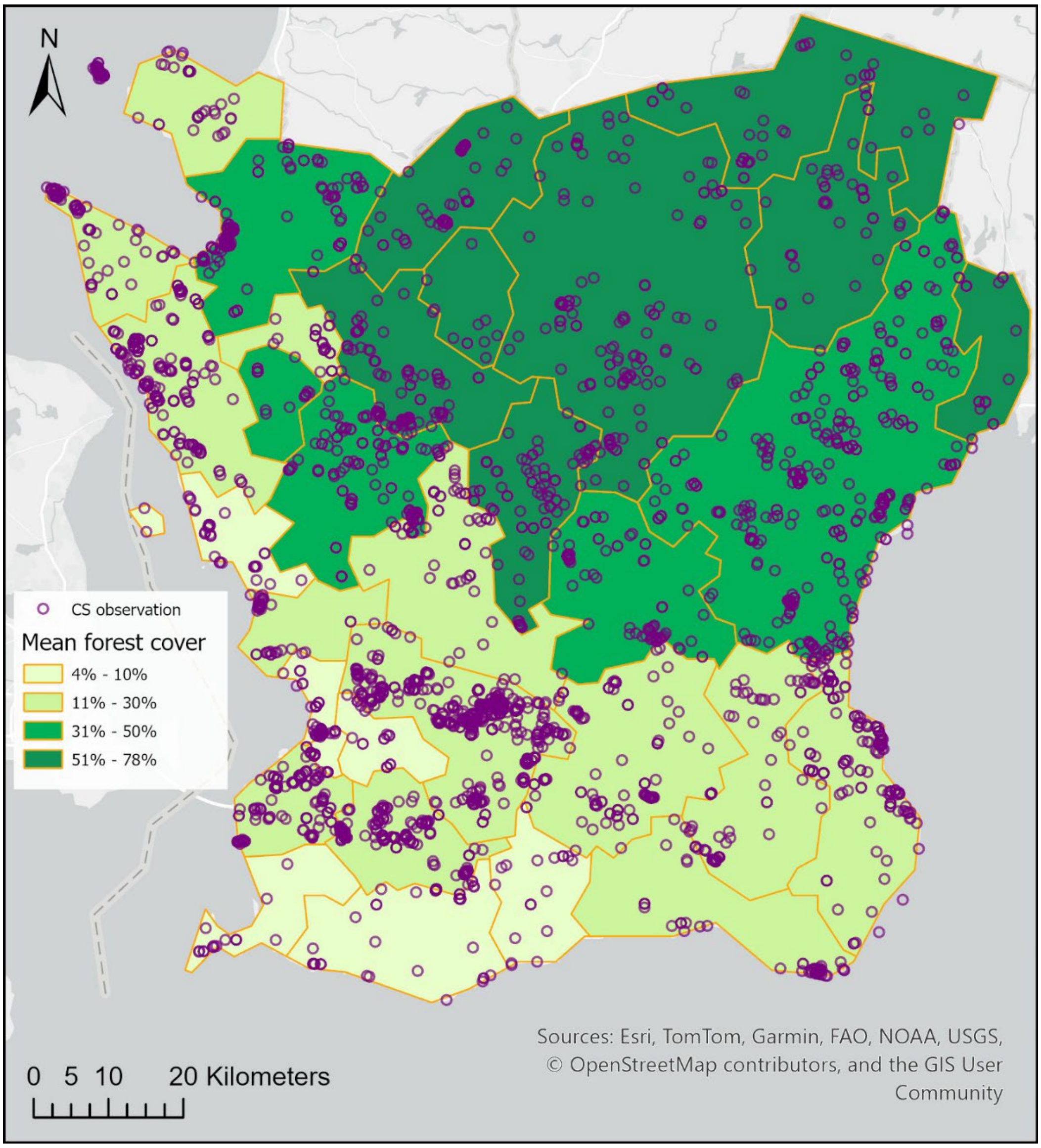

Figure B1. Map of Scania depicting CS observations of saproxylic beetles and mean forest cover per municipality. No strong spatial patterns are evident.

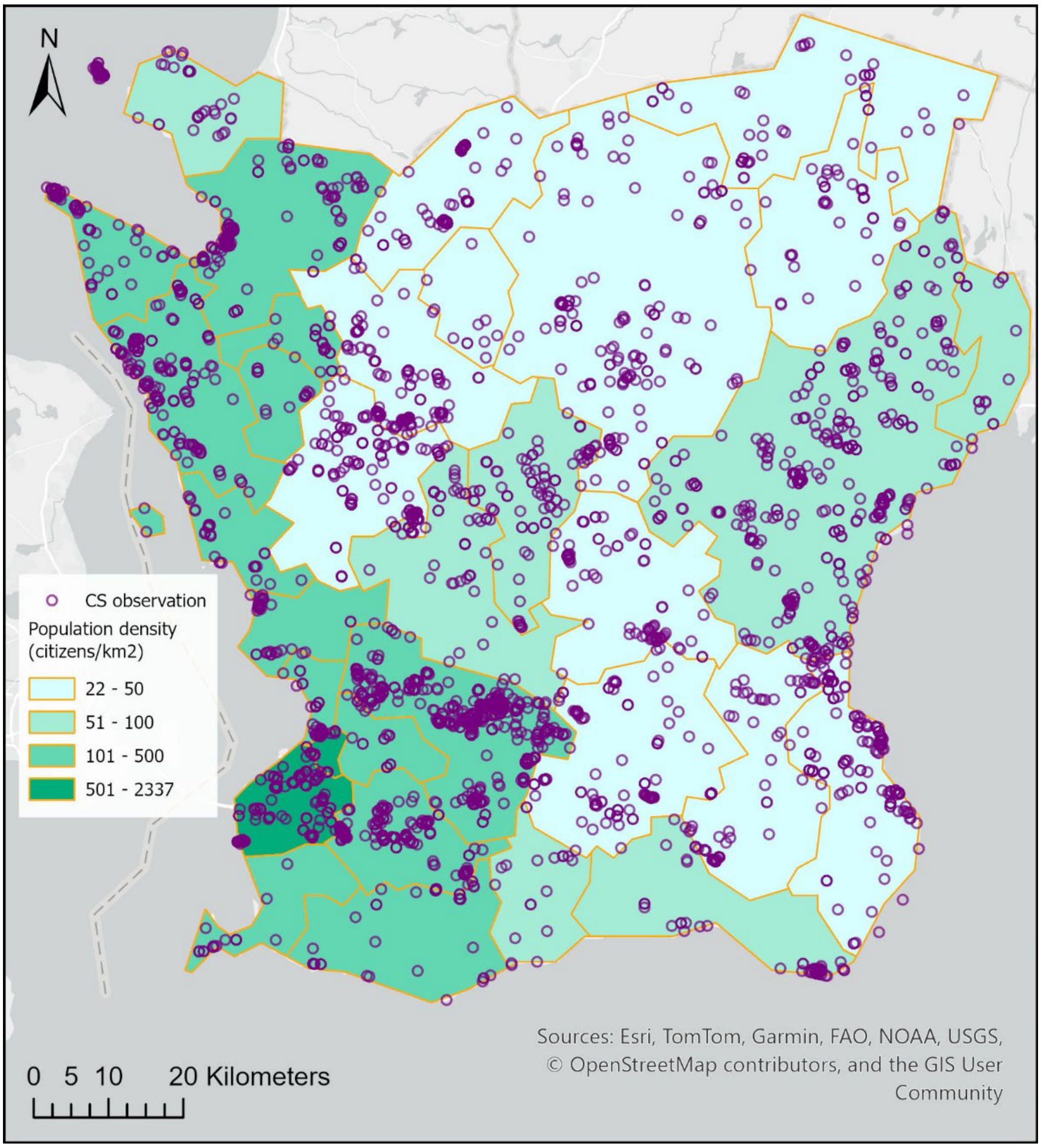

Figure B2. Map of Scania depicting CS observations of saproxylic beetles and population density (citizens/km^2) per municipality in Scania. No strong spatial patterns are evident.

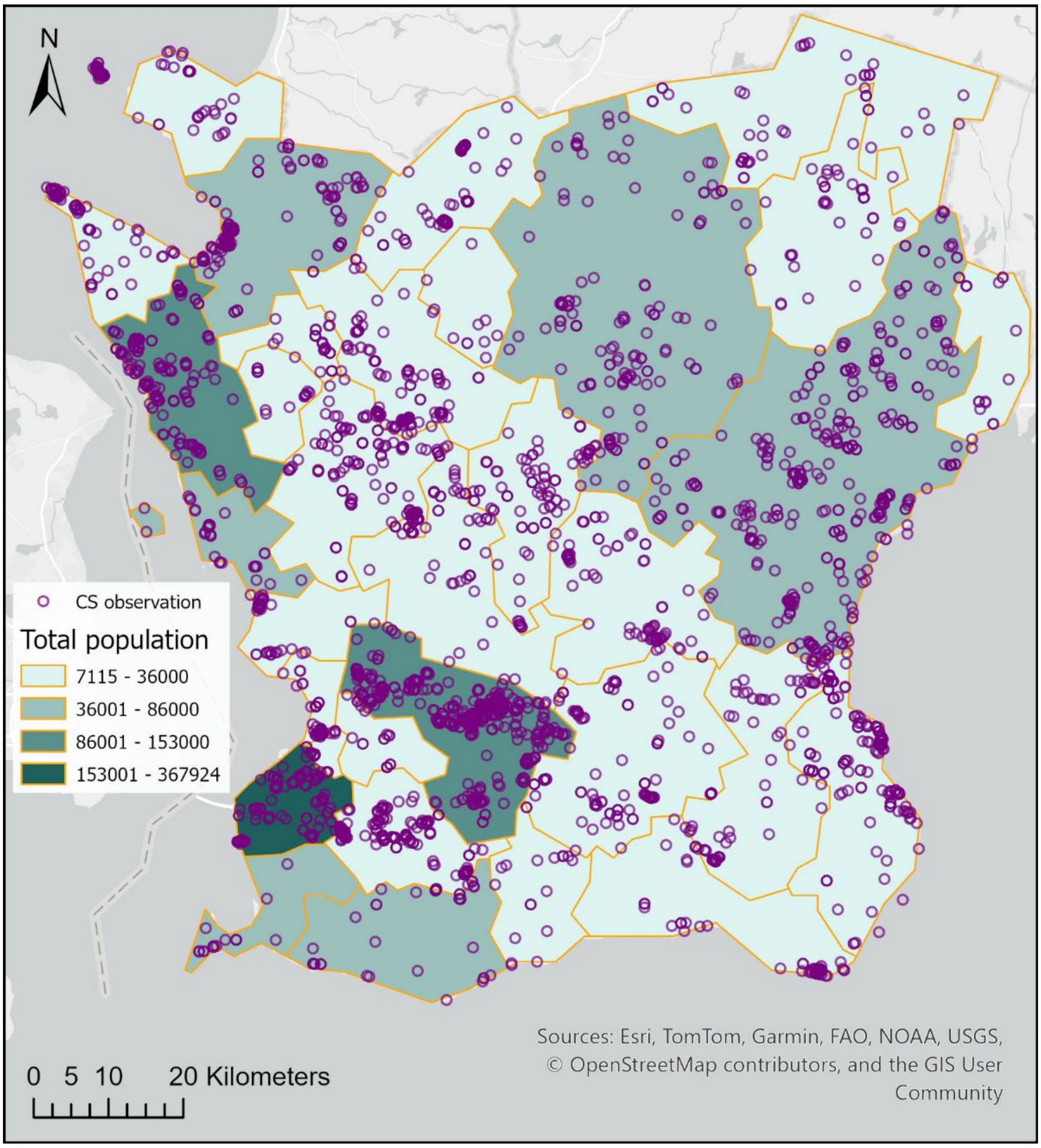

Figure B3. Map of Scania depicting CS observations of saproxylic beetles and total human populations of the municipalities in Scania. No strong spatial patterns are evident.

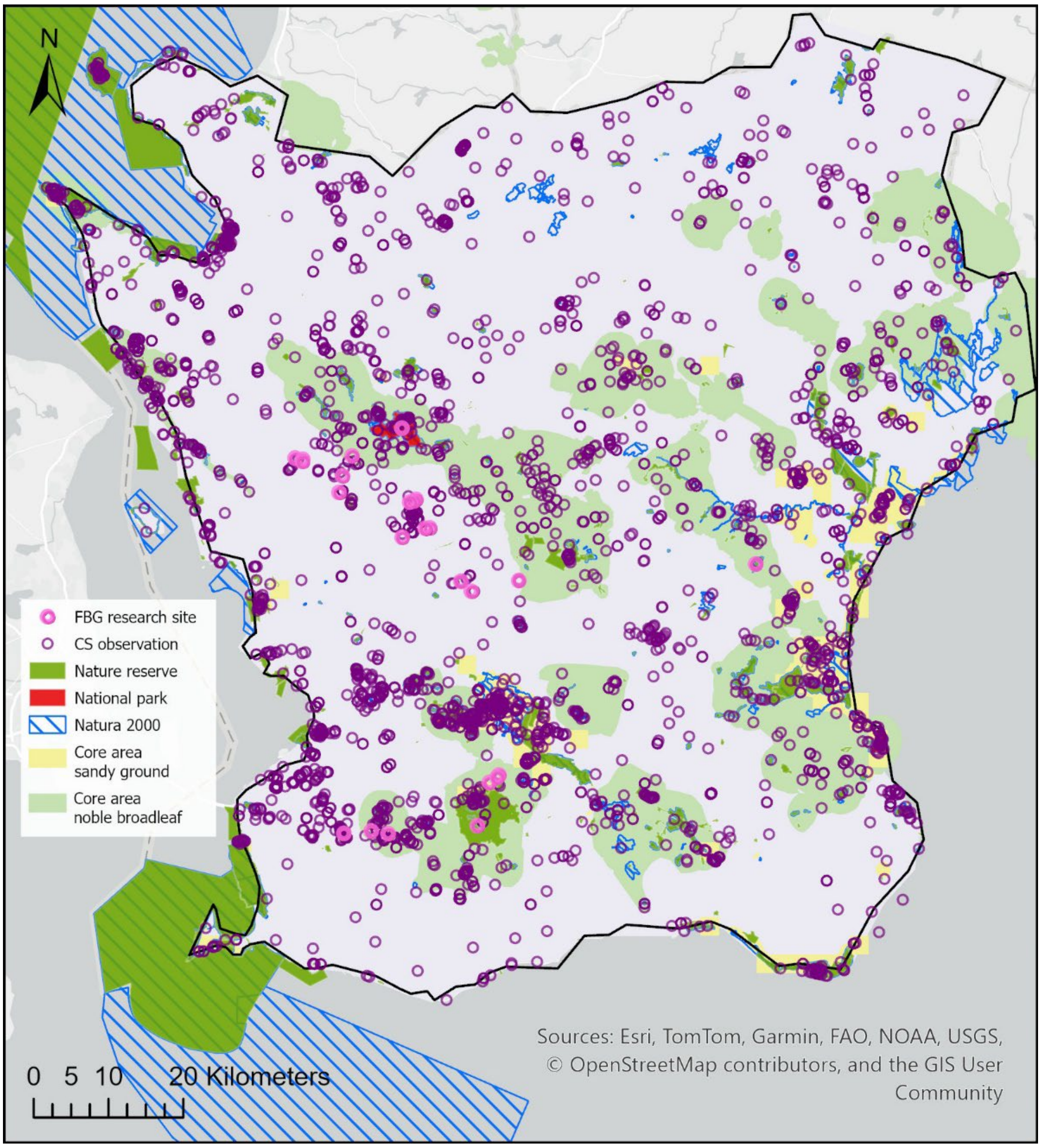

Figure B4. Map of Scania depicting CS observations of saproxylic beetles and protected areas within the region of Scania. No strong spatial patterns are evident.

Appendix C – supplementary linear regressions

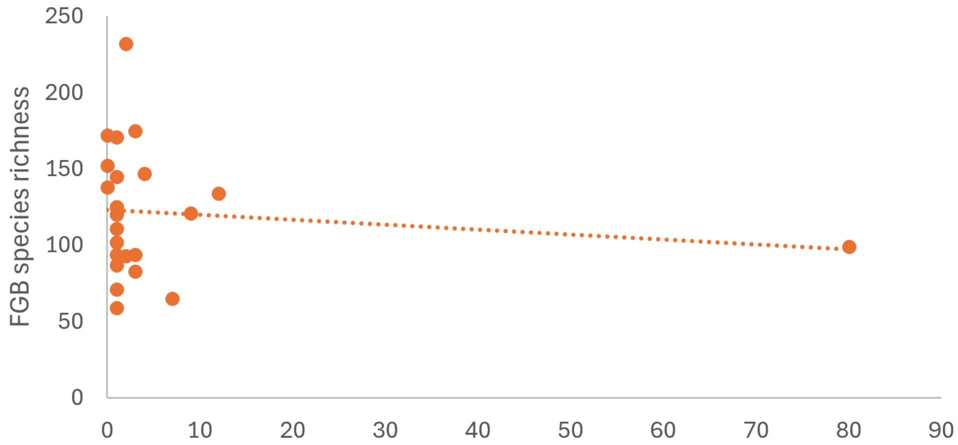

Figure C1. Relationship between CS species richness (x-axis) and FGB species richness (y-axis) of saproxylic beetles on a one-kilometre survey area. Each point represents a research site in Scania, Sweden, where the data was collected. The simple linear regression indicated no significant relationship (p-value=0.550, R²=0.02).

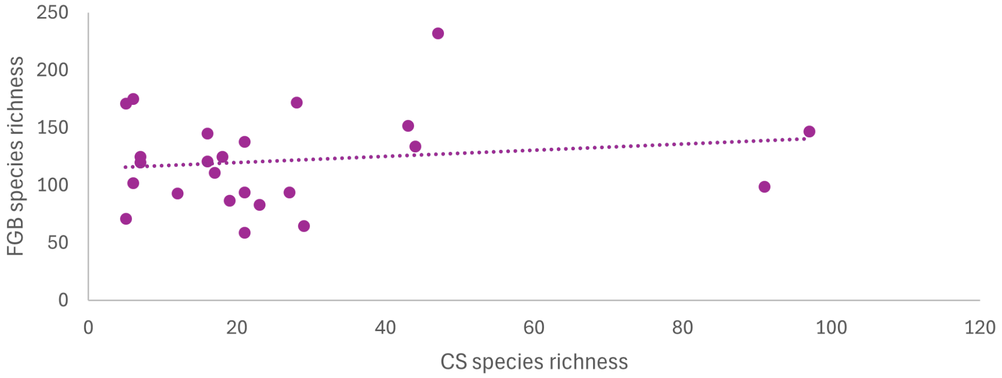

Figure C2. Relationship between CS species richness (x-axis) and FGB species richness (y-axis) of saproxylic beetles on a five-kilometre survey area. Each point represents a research site in Scania, Sweden, where the data was collected. The simple linear regression indicated no significant relationship (p-value=0.461, R^2=0.02).

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