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Mapping edge vegetation in connection to beech forest to locate potential habitats for red-listed beetles in Scania, Sweden

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Bachelor thesis, 15 credits, in Physical Geography and Ecosystem Science

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Abstract

The number of species classified as red-listed has increased by 11% between 2015 and 2020, with beetles and butterflies being especially affected. Among these are the vulnerable longhorned beetle (*Stictoleptura scutellata*) and the endangered false blister beetle (*Ischnomera sanguinicollis*). Forty percent of all known species in Sweden are dependent on hostplants, indicating the value in mapping potential habitats, including food sources for those species. Both *Stictoleptura scutellata* and *Ischnomera sanguinicollis* are dependent on dead wood from beech (*Fagus sylvatica*) for sheltered housing and flowering bushes in close proximity (e.g. edge vegetation) for pollen and nectar.

The management technique in beech forest used in the mid-1800s and early 1900s have resulted in homogenous beech forests, lacking dead wood, old trees and tree structures such as cracks, cavities and torn branches (Maser & Trappe, 1984; Nilsson & Baranowski, 1995; Serup, 2005). These structures are vital habitat for many associated species, including *Stictoleptura scutellate* and *Ischnomera sanguinicollis* (Serup, 2005; Siitonen, 2001).

Eight Natura 2000 classified beech forests (Asperulo-Fagetum and Luzulo-Fagetum types) were visited, with the forest edge being closely analysed and mapped using a Garmin GPSMAP 64 and ArcGIS Pro. Both edges with existing edge vegetation and areas suitable for plantation of edge vegetation were of interest and shown in maps overlying orthophotos of each area. Additional work was done on developing a method suitable for finding areas remotely suitable for plantation of edge vegetation.

All areas visited included some form of edge vegetation, although many areas lacked the space or environment for plantations of more flowering bushes along the edge of the Natura 2000 classified beech forests. Suggestions of plantations of edges was made for all areas, although not always along beech forest edges, as edge vegetation can benefit other species as well, not only *Stictoleptura scutellata* and *Ischnomera sanguinicollis*.

Keywords: Forest, temperate broadleaved forest, beech, biodiversity, edge vegetation, southern Sweden, Scania, beetles, Natura 2000, *Fagus sylvatica*, *Stictoleptura scutellata*, *Ischnomera sanguinicollis.*

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1 Introduction

Biodiversity has a critical role in maintaining healthy ecosystems and has great effect on their productivity, stability, nutrient use and community (Hector & Bagchi, 2007; Midgley, 2012; Naeem & Li, 1997; Tilman & Downing, 1994; Tilman et al., 1996; Wang & Gamon, 2019). A more diverse ecosystem is more resilient, while a monocultural ecosystem, is more fragile and prone to diseases and species loss (Naeem & Li, 1997; Tilman & Downing, 1994).

If species further down the hierarchal food chain within an ecosystem are greatly affected by disturbance or even go extinct, species higher up in the hierarchy are at high risk of being negatively affected as well. Looking into example species, their status and habitat availability can hence give clues to the general state of an ecosystem (Wang & Gamon, 2019).

The number of red-listed species in Sweden increased by 11% between 2015 and 2020 (Eide et al., 2020). Although one factor in the general increase is improved knowledge on the individual species, a decline in butterflies and beetles specifically, is also greatly affected by the worsening situation in agriculture and forestry (Eide et al., 2020). The non-beneficial conservation status of forest and grassland affects habitat availability in both the terms of food accessibility and availability of sheltered housing (Alm et al., 2020; Eide et al., 2020). This in turn influences the beetles and butterflies living in and off dead wood, old trees or grasslands, which have the worst conservation status of all species groups (Alm et al., 2020).

Around 40% of known organisms in Sweden are dependent on hostplants, with beech (*Fagus sylvatica*) being an important host for over 600 species, of which 239 were red-listed in 2019 (Sundberg et al., 2019). For many of these, not only dead wood, but also availability of pollen and nectar are important. Hence, it is the combination of forested areas, which create sheltered housing, and neighbouring areas with nectar-producing vegetation (edge vegetation), which acts as food sources, that are beneficial for beetle preservation. Edge vegetation can also be defined as a boundary between the forest and neighbouring open land cover, as it makes up the actual edge of the forest (Nationalencyklopedin, n.d.).

In northern Europe, edge vegetation includes important host species for insects, which in turn are crucial components in ecosystem processes and forest management (Samways, 1992). Among these are the vulnerable longhorned beetle (*Stictoleptura scutellata*) and the endangered false blister beetle (*Ischnomera sanguinicollis*) (Sveriges lantbruksuniversitet, 2020a, 2020b).

Stictoleptura scutellata and *Ischnomera sanguinicollis* are typically found in beech forests (*Fagus sylvatica*) in southern Sweden and are among many species which benefit from the biodiversity and protection that edge vegetation provide (Fry & Sarlöv-Herlin, 1997; Sveriges lantbruksuniversitet, 2020a, 2020b; Wermelinger et al., 2007). In fact, if compared to more abrupt forest edges, with only tree species present, edges with bushy, flowering vegetation (edge vegetation) provide a wider range of ecosystem services and wildlife habitat (Buckley et al., 1997; Fry & Sarlöv-Herlin, 1997; Wermelinger et al., 2007).

Protection of habitat is a key factor in maintaining a healthy ecosystem and promoting biodiversity. The *Habitats Directive* is a part of Europe's nature conservation policy and was adopted in 1992 (The Council of the European Communities, 1992). It focuses on "the conservation of natural habitats and of wild fauna and flora" and aims to "promote the maintenance of biodiversity, taking account of economic, social, cultural and regional requirements" (The Council of the European Communities, 1992).

With this comes the *Natura 2000* network of core breeding and resting sites for rare and threatened species, as well as rare natural habitat types, spread over all EU countries (European Climate Infrastructure and Environment Executive Agency, n.d.-b; European Commission Directorate-General for Environment & Sundseth, 2008). It was established to promote biodiversity and protect nature types which, from a European perspective, are valuable and need of protection (European Climate Infrastructure and Environment Executive Agency, n.d.-b; European Commission Directorate-General for Environment & Sundseth, 2008).

Projects focusing on promoting biodiversity and restoration of beech forests have been conducted in Europe before, although not with a focus on planting new edge vegetation. An application for funding the transformation of previously cultivated beech forest into a more natural beech forest was sent to the European Union's funding instrument for the environment and climate action (the *LIFE Programme*) (European Climate Infrastructure and Environment Executive Agency, n.d.-a) in the end of 2021, as this can be applied to many areas within Europe. This application includes establishment of edge vegetation in Natura 2000 areas in southern Sweden and was submitted by the County Administration Board of Scania in cooperation with several other organizations and authorities (see *2.1 Funding application summary and the European perspective*). It is based on the current state of several protected areas throughout southern Sweden and the actions needed for these areas to remain (or become) beneficial for native species.

An inventory of edge vegetation in connection to beech forest is therefore needed to map habitat availability and both promote, as well as maintain, high biodiversity in Sweden (Berg et al., 1994). This could be the basis for forest management and species preservation, as well as templates for finding areas suitable for plantation of edge vegetation and simplify the work stated in the LIFE Programme funding application.

1.1 Aim

The aim of this study is divided into three related aims:

1. To locate, quantify and map edge vegetation in relation to beech forest on multiple sites in Scania, Sweden, in order to find potential habitats with housing in connection to food sources for *Stictoleptura scutellate* and *Ischnomera sanguinicollis*.

2. To locate areas suitable for planting of new edge vegetation along beech forests, based on field studies, in order to create more habitats with housing in connection to food sources for *Stictoleptura scutellate* and *Ischnomera sanguinicollis*.

3. Suggest methods for locating areas suitable for planting of new edge vegetation along beech forests.

2 Background

The following section will provide further details concerning the European funding application, existing vegetation and their role, the beetles of interest and climate in Scania.

2.1 Funding application summary and the European perspective

The Nature and Biodiversity sub-program (European Climate Infrastructure and Environment Executive Agency, n.d.-b), is a part of the LIFE Programme (European Climate Infrastructure and Environment Executive Agency, n.d.-a) which aims to protect and restore Europe's nature and reverse, as well as halt, biodiversity loss. It promotes sustainable nature management and includes fundings for relevant projects around Europe (European Climate Infrastructure and Environment Executive Agency, n.d.-a).

At the end of 2021, an application for funding Natura 2000 classified forest management projects in southern Sweden was submitted by the County Administration board of Scania. The goal of the proposed project is to reverse (1) loss of habitat – fragmentation and isolation, (2) lack of heterogeneity and dead wood in woodlands previously used for commercial forestry, (3) loss of species and (4) lack of role models and public awareness.

In total 36 areas in need of flowering edges in southern Sweden were included in the application and are all together incorporated in the proposed project *LIFE's a beech*. These edges are meant to favour more than just two species of beetles above, including birds, mammals and other insects as benefactors as well.

Of interest to this study is that the application includes implementation of edge vegetation as food sources and wood mould boxes as temporary sheltered forms of housing in multiple Natura 2000 areas, eight of which have been included in this study. Wood mould boxes are to be used as a temporary substitute for naturally occurring dead or dying wood found in older forests and can act as habitat for many different species, including *Stictoleptura scutellata* and *Ischnomera sanguinicollis*.

A similar project to *LIFE's a beech* was initiated in Denmark in 2019, also funded by the LIFE Programme, called *LIFE Open Woods* (European Commission, 2022b). It focuses on improvement of the conservation status of forest habitats, with a special focus on the hermit beetle (*Osmoderma eremita*). Projects in Sweden, such as *LIFE Söderaasen* (European Commission, 2022c) focusing on restoration of broadleaved forest on previous clear-cuts and *LIFE Bridging the Gap* (European Commission, 2022a), focusing on establishing temporary housing units (wood mould boxes) in broadleaved forests have also been funded by the LIFE Programme.

Not surprisingly, studies focusing on edge vegetation and its effect on biodiversity have been of interest throughout Europe (and the world). The studies range from spatial distribution of carabids species in Hungary (Magura, 2002) and biodiversity's role in the microenvironment of edge vegetation in the United States of America (Chen et al., 1993; Gehlhausen et al., 2000) to vegetation succession and its effect on butterfly species in England (Buckley et al., 1997). Additional studies in Scandinavia have included the importance of woodland edges in the agricultural landscape (Fry & Sarlöv-Herlin, 1997) and edge vegetations role in urban environments in both Finland (Hamberg et al., 2009) and Sweden (Wiström & Nielsen, 2015; Wiström, Nielsen, & Klobucar, 2015; Wiström, Nielsen, Klobucar, et al., 2015).

In fact, edge vegetation can have great impact on many areas, not only biodiversity. Studies focusing on atmospheric deposition and pollution in relation to forest edges show additional positive traits of edge vegetation. For example, a study conducted in the Netherlands and Flanders concludes that the structure, size and shape of an edge has great impact on atmospheric deposition (Wuyts et al., 2009), while a Danish study came to the conclusion that the distance from a forest edge indicates an exponential decrease in deposition (Beier & Gundersen, 1989).

As the interest in edge vegetation reaches across Europe, it is considered to be reasonable to apply for funding from the European Union, rather than the Swedish state. Especially since LIFE's a beech focuses on Natura 2000 classified areas, which are areas of importance from a European perspective (European Commission Directorate-General for Environment & Sundseth, 2008).

As the application applies to a larger area than just the region of Scania, it includes the County Administrative Board of Scania, Sweden's Agricultural University (SLU), the County Administrative Board of Kronoberg, the County Administrative Board of Blekinge, Swedish Environmental Protection Agency, the Foundation Nordens Ark, the University of Halmstad and the Foundation Skånska Landskap as applicants.

2.2 Climate

The generally open landscape in Scania creates conditions where wind is strong and occurs often (Sveriges meteorologiska och hydrologiska institut, 2022). The prevailing wind direction is mainly south and west, although the wind can change direction depending on high or low pressure and location (Swedens meterological and hydrological institute, 2012). Annual precipitation varies between 500 mm to 1000 mm, depending on altitude, closeness to the coast and general location (Sveriges meteorologiska och hydrologiska institut, 2022). Mean temperatures range from -2°C to 0°C in January, and 15°C to 17°C in July (Sveriges meteorologiska och hydrologiska institut, 2022).

2.3 Beech forest

Many previous studies suggest that temperate broadleaved forests in southern Sweden used to be considerably more abundant previous to the 15th century (Björkman, 1997; Brunet, 2005; Hultberg et al., 2015; Lindbladh & Bradshaw, 1998). In fact, estimations from Fritz et al. (2008) suggest that less than 10% of the areas covered in beech forest by the mid-1600s remains today.

This is partially due to the previous use of beech forests for beechnut production for pig breeding (Lindbladh et al., 2008), which creates pure stands with a low availability of old trees and dead wood (Brunet, 2005). The change in forest technique during the mid-1800s and need for wood as the population grew are also key factors (Björkman, 1997).

These clear-cut forest management techniques eventually made the forests more homogenous, lacking dead wood, old trees and tree structures such as cracks, cavities and torn branches (Maser & Trappe, 1984; Nilsson & Baranowski, 1995; Serup, 2005). Hence, they also decreased the amount of suitable habitat availability for many associated species, including *Stictoleptura scutellate* and *Ischnomera sanguinicollis* (Serup, 2005; Siitonen, 2001). However, a limited and insufficient amount of dead wood can be found today on both living and dead trees (see Figure 1a-c), and creates housing for a wide variety of fungi, animals and plants (Christensen et al., 2005).

As beech is sensitive to frost and creates very light limited environments, an additional trait for beech forests is the low amount of undergrowth during the majority of the year (Nitare et al.,

2000; Thauront & Stallegge, 2008). In early spring however, many beech forest floors (especially in Asperulo-Fagetum beech forests) are covered in wood anemones (*Anemone nemorosa*) and cowleek (*Állium ursínum*), although white butterbulb (*Petasites albus*), garlic mustard (*Alliária petioláta*), sweet woodruff (*Galium odoratum*), wood melic (*Melica uniflora*), yellow archangel (*Lamium galeobdolon*) and other herbs also occur (European Environment Agency, 2019; Thauront & Stallegge, 2008). The forest interior is in other words not beneficial for flowering bushes. A wide range of fungi and lichen are normally found here as well (Nitare et al., 2000).

The two types of Natura 2000 classified forest of interest are the Asperulo-Fagetum beech forest and Luzulo-Fagetum beech forest, referred to as 9130 and 9110 respectively in the Habitats Directive (Directorate-General for Environment, 2013). The Asperulo-Fagetum beech forests are spread throughout Central Europe, reaching north of Scania's northern boarders, while Luzulo-Fagetum beech forest are primarily found in Central and Northern Europe, occurring sporadically in Scania (European Environment Agency, 2019; Thauront & Stallegge, 2008).

The main difference between the two types of beech forests is their soil characteristics, with the Asperulo-Fagetum beech forests having a neutral or near-neutral soil, with mild humus and Luzulo-Fagetum beech forests an acidic and nutrient-poor soil (European Environment Agency, 2019; Thauront & Stallegge, 2008). Asperulo-Fagetum beech forests hence tend to have a richer herb layer than Luzulo-Fagetum beech forests (European Environment Agency, 2019).

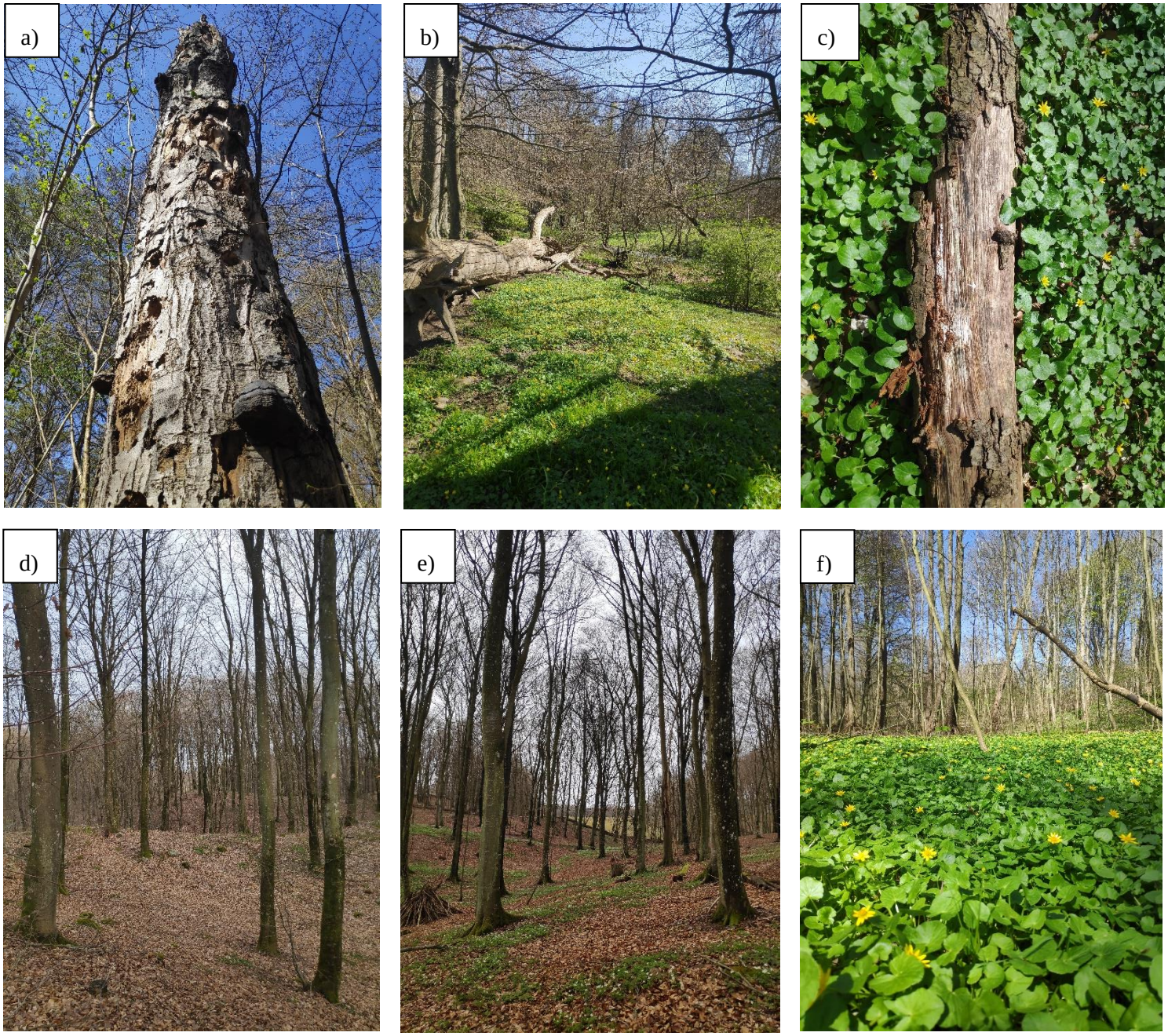

Figure 1. Examples of beech forest undergrowth and dead wood found in field during in-situ inventory. a) fungi and cavities are visible, showing decay and potential housing for multiple species. b) displays an examples of dead wood in close proximity to flowering bushes, although located >10m from the edge of a beech forest, whilst c) is located within a beech forest. d) displays the lack of undergrowth in early spring, while green blankets of fig buttercup (Ranunculus ficaria) starts to be visible in e) and are completely covering the forest floor in f). Photos by the author.

2.4 Edge vegetation

Edges are prone to experience more solar radiation, heat, wind and drought, compared to the interior of beech forests, yet provide a more protected, humid and shaded habitat than open fields (Fry & Sarlöv-Herlin, 1997; Gehlhausen et al., 2000; Wermelinger et al., 2007). This creates an environment where edge vegetation such as flowering bushes and low growing trees thrive and grow.

Compared to the forest interior, the edge vegetation, with its difference in climate and exposure, has more diversity in its structure, growth rate, age, spatial distribution, species and density (Buckley et al., 1997; Fry & Sarlöv-Herlin, 1997). Generally, the forest has younger trees and higher stem densities along the forest edge (see Figure 2a), compared to its interior (Fry & Sarlöv-Herlin, 1997), although old individual trees also occur. Additionally, the trees along the forest edge have higher nutritional quality (Fortin & Mauffette, 2001) and are exposed to more solar radiation than those located further into the forest.

As the term edge vegetation includes many species of flowering bushes and trees, the factors influencing their well-being differs greatly and can grow in slightly different environments. E.g. edge vegetation is highly influenced by adjacent land uses and their aspects, although it is both biotic factors and microclimate, such as soil moisture, that affects the plant community in an edge (Gehlhausen et al., 2000). The effect an edge can have on its neighbouring forest are greatest in southern and western facing edges, while north- and east-facing edges are more similar to the conditions in the forest interior as they are more light limited (Gehlhausen et al., 2000; Hamberg et al., 2010). A beech forest neighbouring a coniferous forest (such as Figure 2c) or other shading land covers, will have difficulty producing a viable edge with flowering bushes as it will also be exposed to light limitations.

The Swedish translation of edge vegetation, *skogsbryn*, emphasizes the connection to a forest (which in Swedish is *skog*), yet many species found along forest edges also thrive in open areas or forest interiors (European Forest Genetic Resources Programme, n.d.; Graham & Woodhead, 2011). Hence, edge vegetation does not necessarily have to be in a set proximity of a forest edge to be functional as habitat, although the name implies it is.

Although hazel (*Córylus avellána*) is not preferred by *Stictoleptura scutellata* or *Ischnomera sanguinicollis*, they are considered edge vegetation as they favour other species and promote biodiversity. They are durable and can live in both sunny and shadowed conditions, being found both along the forest edge, its interior and in open landscapes (European Forest Genetic Resources Programme, n.d.).

Rubus sp., *Rosa sp.*, *Prunus sp.* and other species in the rose (Rosaceae) are favoured by *Stictoleptura scutellata* and *Ischnomera sanguinicollis*, and grow successfully along forest edges and in forest openings. Their thorns protect them from grazing cattle and can be resistant to both drought, flooding, high temperatures and cold winters (Graham & Woodhead, 2011; Potter, 2011).

Seen in Figure 2b is the beetle-appreciated sloe (*Prunus spinósa*), which is often found in edges and can grow into tall and wide bushes. A detailed list of edge vegetation included in this study can be found in Appendix A.

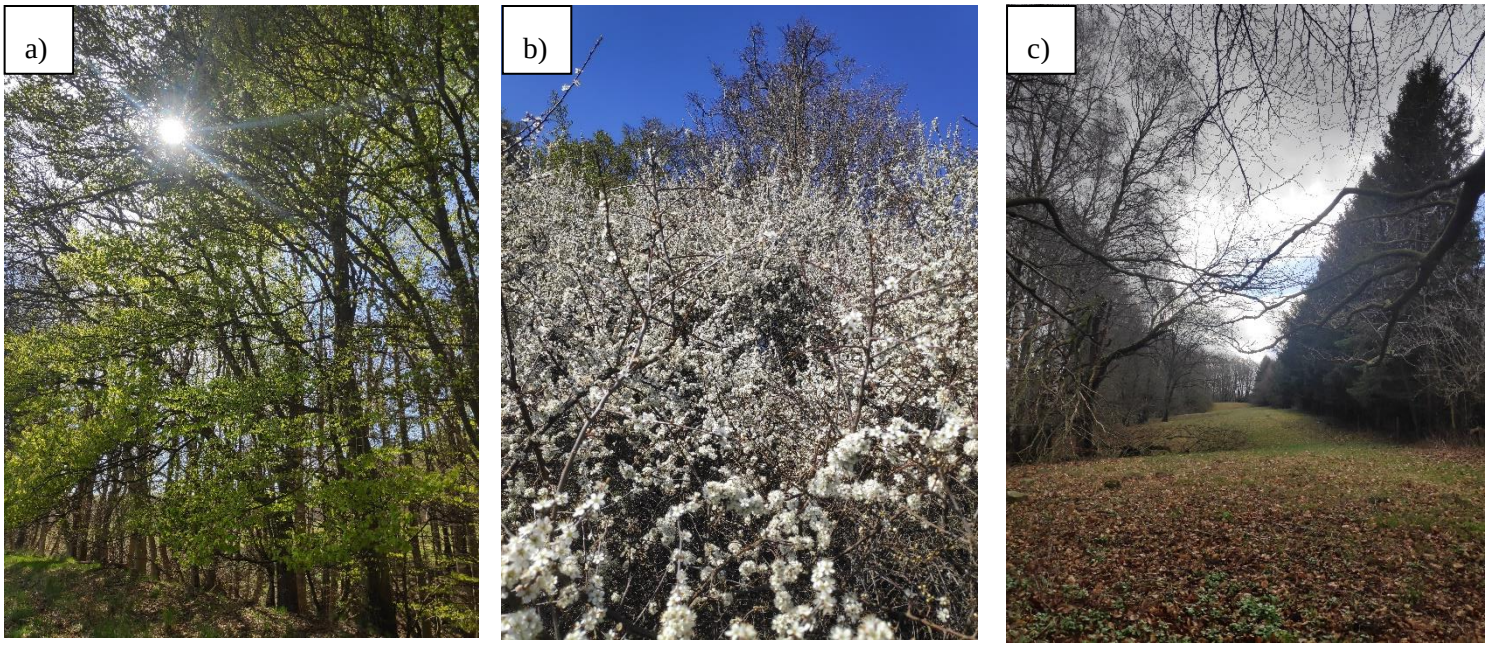

Figure 2. Examples of edges found in field. a) display the higher density of branches normally found on beech trees growing along the forest edge. b) show a >3m high sloe making up the eastern edge of Torup's beech forest. c) display the narrow pasture found in Rövarekulans western area, with tall coniferous trees shading the ground. Photos by the author.

2.5 Affected beetles

Understanding the lifespan of the beetles of interest can simplify the study, as this presents vital information concerning their feeding patterns. Plant species should hence produce nectar during the time needed for beetles to feed. Table 1 show the time of year where different species of edge vegetation bloom, and the adult beetles are active.

Stictoleptura scutellata (Figure 3a) and *Ischnomera sanguinicollis* (Figure 3b) do not migrate over long distances throughout their life, and thus food sources and sheltered housing must be in close proximity of one another. The path between housing and food sources also matter, as they very likely would move up to 100 m through a pasture or open field for food, but not through needle leaf forests (Brunet et al., 2008).

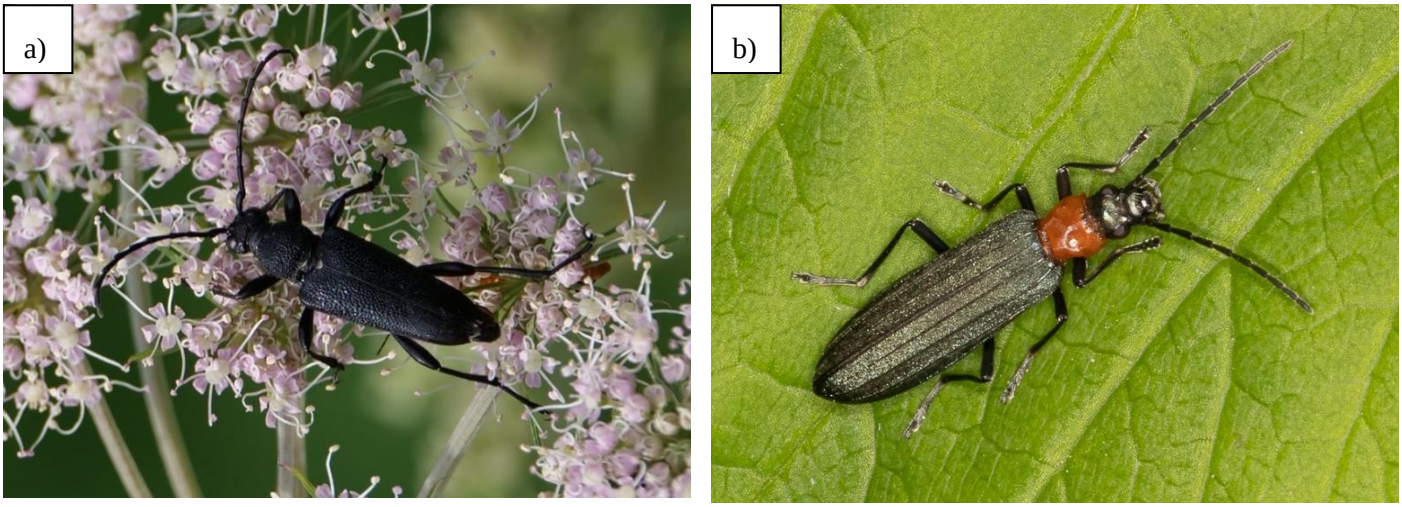

Figure 3. The two beetles of interest a) Stictoleptura scutellata and b) Ischnomera sanguinicollis. Pictures have been derived from SLU (Sveriges lantbruksuniversitet, 2020a, 2020b), with a) being taken by Bengt Andersson and b) by Richard Ek.

Table 1. Beetle and plant activity during summer and spring. Displayed are the time of year where adult Stictoleptura scutellata and Ischnomera sanguinicollis are active in bold. The time of year where species of edge vegetation bloom are also shown, based on (Almquist et al., 2016).

	Spring		Summer		
	Early spring	Late spring	Early summer	Mid-summer	Late summer
Stictoleptura scutellata					
Ischnomera sanguinicollis					
Córylus avellána					
Lonicéra periclymenum					
Lonicéra xylosteum					
Prunus padus					
Prunus spinósa					
Rosa canína					
Rosa dumális					
Rubus fruticósus					
Rubus idaéus					
Salix caprea					
Sorbus aucuparia					
Vibúrnum ópulus					
Crataegus sp.					
Ribes sp.					
Sorbus sp.					
Spirea sp.					

2.5.1 *Stictoleptura scutellata*

The previously endangered, now vulnerable, long horned beetle (*Stictoleptura scutellata*) can be found throughout Europe, Turkey, Caucasus and Northern Iran (Sveriges lantbruksuniversitet, 2020a). In total 263 finds of the beetle have been reported in Sweden, all in southern Sweden, (see Figure 4) since 1997, of which only 18 have been confirmed (Sveriges lantbruksuniversitet, 2020a).

Adult beetles are often seen flying around or crawling on the tree where they spent their larval development, which in Sweden, only occur on beech (Nilsson & Baranowski, 1995). The larval development takes place over three or more years, with the pupation occurring in early June and adults being found in field until August (Nilsson & Baranowski, 1995; Sveriges lantbruksuniversitet, 2020a). The larva mainly inhabit the upper parts of high stumps, although damaged trunk parts on living trees and coarser trunk parks, as well as branches on the ground are of interest (Sveriges lantbruksuniversitet, 2020a). They prefer trunks with a 20 cm diameter or more, but have been found in trunks with 10 cm in diameter (Nilsson & Baranowski, 1995).

2.5.2 *Ischnomera sanguinicollis*

The endangered false blister beetle (*Ischnomera sanguinicollis*) can be found in Southern Sweden (see Figure 4) although is also native to areas in Denmark, Norway and the Baltics. In total 11 findings of the beetle have been reported since 1997 in Sweden, all in the south, of which six have been confirmed (Sveriges lantbruksuniversitet, 2020b).

The larvae develop in dead wood of beech, maple (*Acer sp.*) or elm (*Ulmus sp.*) during two or three years, with the pupation occurring late in summer (Ehnström & Axelsson, 2002; Sveriges lantbruksuniversitet, 2020b). The adult beetle hatch later the same year, although stay in their pupation chamber until the end of May or beginning of June the next year (Ehnström & Axelsson, 2002; Sveriges lantbruksuniversitet, 2020b).

They are found in dead wood surrounding stem cavities in living trees or dead high stumps, such as those seen in Figure 1a-c (Ehnström & Axelsson, 2002).

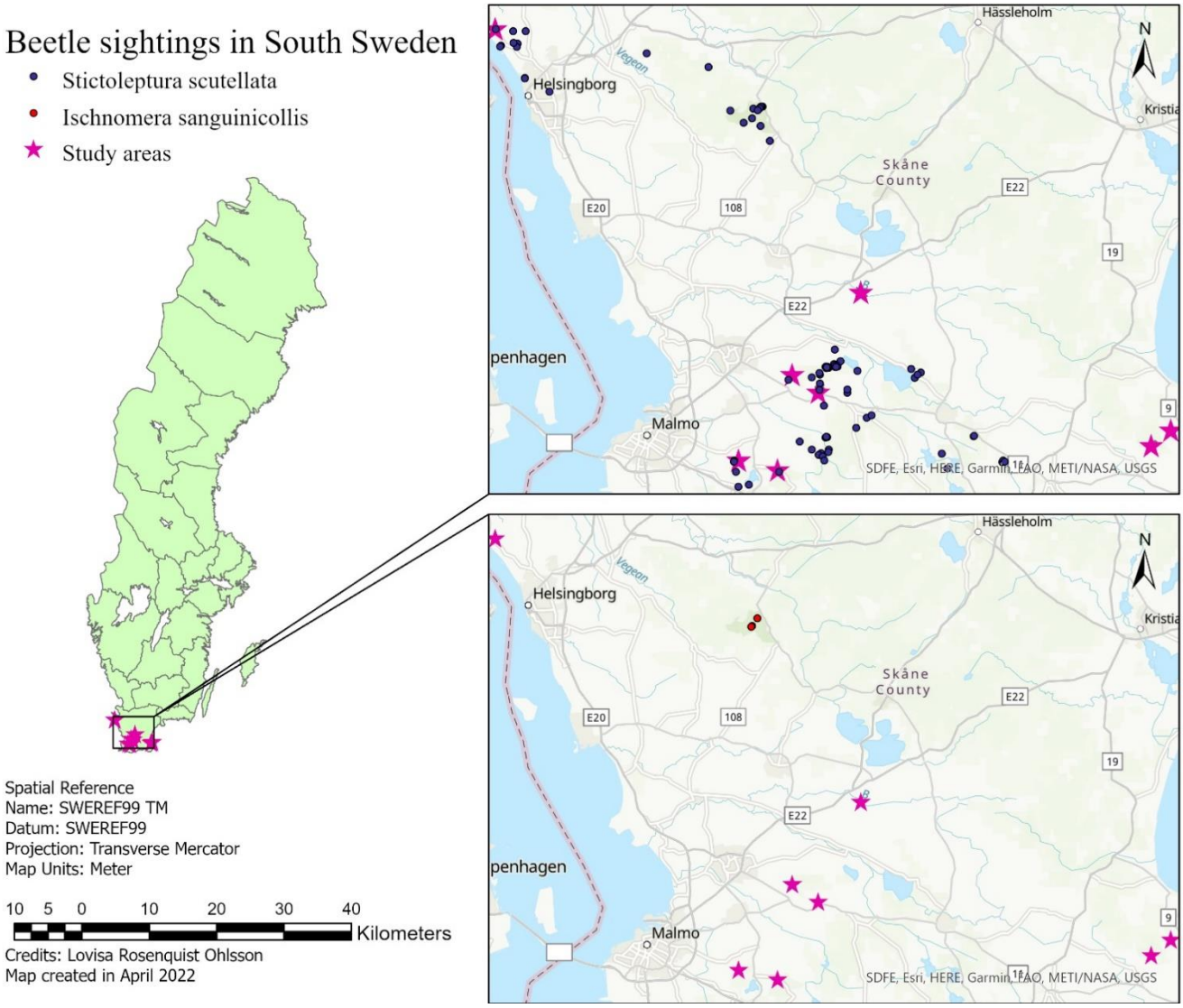

Figure 4. Sightings of the red-listed beetles Stictoleptura scutellata (above) and Ischnomera sanguinicollis (below), in Scania, along with the visited study areas.

2.6 Study areas

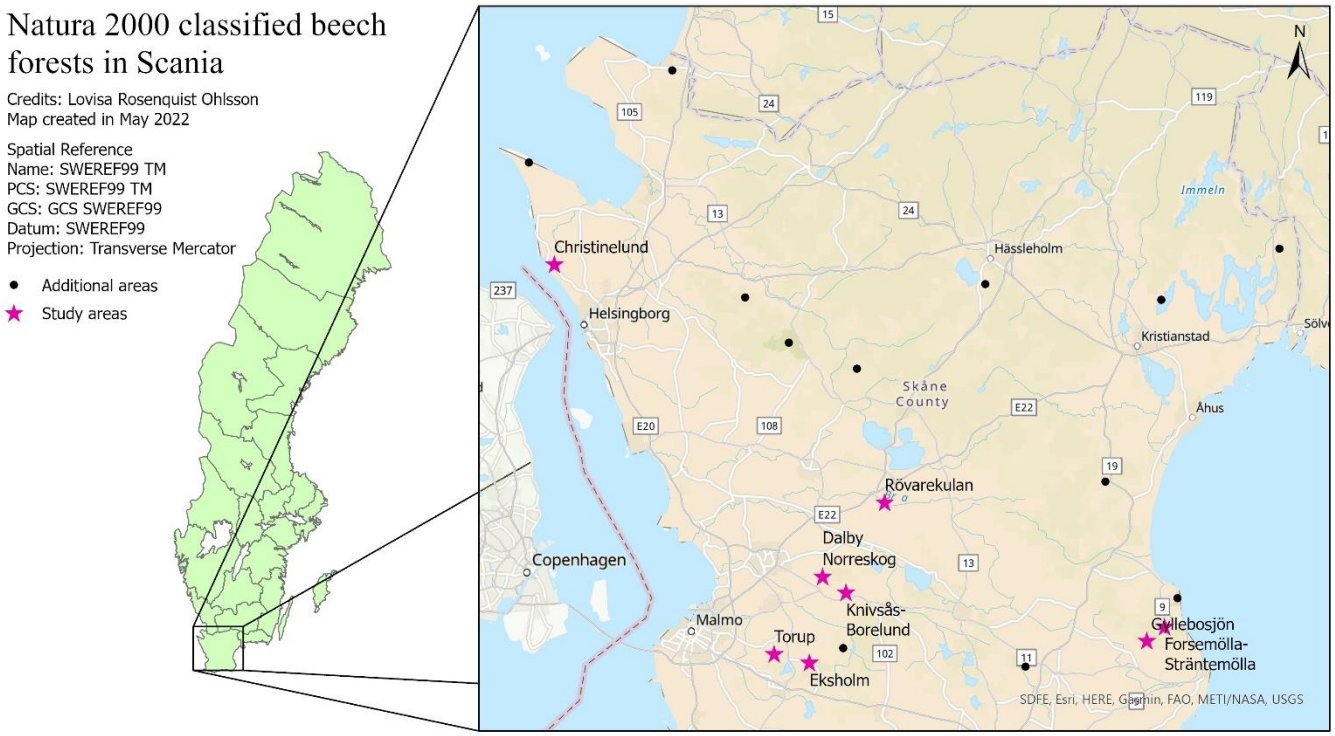

Figure 5. Visited study areas in Scania, presented as stars, and additional areas in Scania which have Natura 2000 classified beech forests within a nature reserve. All areas shown as stars are both nature reserves and Natura 2000 classified.

2.6.1 Christinelund, N6223313 E0351590

Christinelunds ädellövsskog, translated to Christinelund deciduous forest, is a nature reserve founded in 1970 and encompasses multiple Natura 2000 habitats, such as oak-hornbeam and Asperulo-Fagetum beech forests, with the beech forest taking up 6.7 ha of the 33 ha nature reserve (Länsstyrelsen Skåne, 2005a, n.d.-a). It is divided by a road into two subareas of old temperate deciduous forest surrounded by open agricultural land and is entirely privately owned (Länsstyrelsen Skåne, n.d.-a). As it is a very popular area for outdoor recreation, it is identified as an area suitable for a "real-life forest showroom" in the LIFE application, and has been recognized to include some of the first plantations of edge vegetation to introduce the public to the project.

As the top soil layer is thin and poor in nutrients, it results in many species of plants being available (Lantmäteriet, 2014; Länsstyrelsen Skåne, 2005a). Species of trees, such as maple, alder (*Alnus sp.*), linden (*Tilia cordata*) and European bird-cherry (*Prunus padus*) occur, with oak (*Quercus sp.*), beech, elm and ash (*Fráxinus excélsior*) being more common (Länsstyrelsen Skåne, 2005a). The beech forest has a rich epiphytal flora, with the forest floor covered in spring-flowering herbs. Multiple species of birds, mammals, insects, reptiles and amphibians have been found in the area (Länsstyrelsen Skåne, 2005a).

Both the oak-hornbeam forest and Asperulo-Fagetum beech forest has beneficial conservation status. Sightings of *Stictoleptura scutellata* have occurred, see Figure 4 (Länsstyrelsen Skåne, 2005a, 2005b; Sveriges lantbruksuniversitet, 2020a).

2.6.2 Dalby Norreskog, N6172000 E0395640

This 74 ha nature reserve includes both open grassland and Asperulo-Fagetum beech forest, and has been grazed for more than 1000 years (Länsstyrelsen Skåne, n.d.-b). The current Natura 2000 classified forest grew back after removal in the 17th century and was grazed up until 1932 (Länsstyrelsen Skåne, 2005b). Oak and beech share this coarse, nutrient poor soil with birch (*Bétula sp.*), ash, elm, rowan (*Sorbus aucuparia*), hazel and early spring-covering herbs (Lantmäteriet, 2014; Länsstyrelsen Skåne, 2005b).

Six red-listed birds and two red-listed plant species occur in the nature reserve, while roedeers and multiple birds species are common visitors (Länsstyrelsen Skåne, 2005b). Cows and horses can be seen grazing the included pastures, while paths crossing the forest can be used by hikers, bikers and dog owners (Länsstyrelsen Skåne, 2005b).

Both the oak-hornbeam forest and Asperulo-Fagetum beech forest have beneficial conservation status, with sightings of *Stictoleptura scutellata*, see Figure 4 (Länsstyrelsen Skåne, 2005b; Sveriges lantbruksuniversitet, 2020a).

2.6.3 Eksholm, N6157861 E0393469

In 2003 Eksholm became a 26 ha nature reserve, including a 75-125 year old Asperulo-Fagetum beech forest and a 125-175 year old Luzulo-Fagetum beech forest (Länsstyrelsen Skåne, 2018a, n.d.-c). The area has been forested since the 18th century and is a part of a larger deciduous forest landscape reaching north of the lake Fjällfotasjön (Länsstyrelsen Skåne, 2018a). It includes not only beech, but oak, alder, birch, willow and plantations of coniferous trees (Länsstyrelsen Skåne, 2018a).

The Natura 2000 area is characterised by limestone bedrock and glacial clay moraine making up the lime and humus rich soil (Lantmäteriet, 2014; Länsstyrelsen Skåne, 2018a). The nature reserve also includes wetlands, mires and pastures, as well as a lake (Länsstyrelsen Skåne, 2018a, n.d.-c). Birds, bats and insects live in the area, as well as roedeers and other mammals (Länsstyrelsen Skåne, 2018a).

The Luzulo-Fagetum beech forest has a beneficial conservation status, which the Asperulo-Fagetum beech forest does not. Sightings of *Stictoleptura scutellata* have occurred in the area, see Figure 4 (Länsstyrelsen Skåne, 2005b; Sveriges lantbruksuniversitet, 2020a).

2.6.4 Forsemölla-Stråntemölla, N6163766 E0451802

Both Asperulo-Fagetum beech forest and Luzulo-Fagetum beech forest occur in this 53 ha nature reserve, which was founded in 1976 (Länsstyrelsen Skåne, n.d.-g; Naturskyddsföreningen Skåne, 2022a). Oak, maple, alder, linden and hazel can be found among the beech trees, neighbouring pastures and an asphalt road (Länsstyrelsen Skåne, 2016a; Naturskyddsföreningen Skåne, 2022a).

A river has carved into the bedrock, dividing the forest in the northern part and creating waterfalls often visited by hikers (Länsstyrelsen Skåne, n.d.-g). Except for the exposed bedrock, large areas are made up of sediments dating back to the latest ice age (Lantmäteriet, 2014; Länsstyrelsen Skåne, 2016a).

The area has a large biodiversity, with the common dormouse (*Muscardinus avellanarius*) being a famous inhabitant, sharing the area with bats, butterflies, dragonflies, birds and mammals (Länsstyrelsen Skåne, n.d.-g). No sightings of either beetle has occurred since 1997

(Sveriges lantbruksuniversitet, 2020a, 2020b). Unfortunately, none of the Natura 2000 classified areas have a beneficial conservation status (Länsstyrelsen Skåne, n.d.-g).

2.6.5 Gyllebosjön, N6161461 E0448887

As stated in the Swedish name of the area, it consists of a deep lake with both introduced and wild species of fish (Länsstyrelsen Skåne, n.d.-d). Not only fish exist in the area, as bats, dragonflies, multiple species of birds, insects and mammals also lives here (Bengtsson & Schedvin, 2014; Länsstyrelsen Skåne, 2018b).

The 130 ha nature reserve also include swamp-like forests, beech forests of both types (Asperulo-Fagetum and Luzulo-Fagetum) some trees up to 140 years old, and pastures. Beech is the most common tree species, although hornbeam (*Carpinus betulus*), birch, maple, ash, elm and oak occur throughout the area (Länsstyrelsen Skåne, 2018b). Both types of beech forests have a beneficial conservation status, although no sightings of either beetles have occurred since 1997 (Länsstyrelsen Skåne, 2018b; Sveriges lantbruksuniversitet, 2020a, 2020b).

2.6.6 Knivsås-Borelund, N6169399 E0399489

Both Luzulo-Fagetum beech forest and Asperulo-Fagetum beech forests occur within the 159 ha nature reserve, with dead wood frequently occurring in the latter and only a small amount of dead wood is found in the former (Länsstyrelsen Skåne, 2018c). Only the Asperulo-Fagetum forest has a beneficial conservation status (Länsstyrelsen Skåne, 2018c). Sightings of *Stictoleptura scutellata* have occurred, see Figure 4 (Sveriges lantbruksuniversitet, 2020a).

The area hosts both red-listed lichens and fungi, although it is still affected by the previously growing coniferous forest. During the 18th century, the entire area consisted of pastures resulting in today's biodiversity (Naturskyddsföreningen, n.d.-a). Orchids are found in the open grasslands, while anemones take up the forest floor in spring (Länsstyrelsen Skåne, n.d.-e).

An old quarry is today popular among snorkelers and divers, while the terrestrial landscape is frequently visited by hikers and picknick lovers (Naturskyddsföreningen, n.d.-a). The area includes sandy, rocky and coarse sediments from rivers deposited during the last ice age (Länsstyrelsen Skåne, n.d.-e).

2.6.7 Rövarekulan, N6184203 E0405819

The 48 ha nature reserve founded in 1975 is divided by the meandering river Bråån and filled with underlying scale, as well as sandy moraines (Lantmäteriet, 2014; Länsstyrelsen Skåne, n.d.-f). The area is characterized by a 25m deep ravine created by the river and houses over 400 species of vascular plants, including the rare and red-listed *Orobanche reticulata* and *Petasites albus* (Länsstyrelsen Skåne, 2018d).

The area is rich in bird species, lichens, and marine life, such as the thick shelled river mussel (*Unio crassus*), *Phoxinus phoxinus* and *Salvelinus fontinalis* (Länsstyrelsen Skåne, n.d.-f; Naturskyddsföreningen, n.d.-b). Squirrels and other mammals also occur, along with insects and dragonflies (Naturskyddsföreningen, n.d.-b).

Both Asperulo-Fagetum beech forest and Luzulo-Fagetum beech forest are found in the 48 ha nature reserve, with hornbeam, ash, maple, alder and birch occurring frequently (Länsstyrelsen Skåne, 2018d, n.d.-f). Both types of beech forests have a beneficial conservation status, although no sightings of either beetles have occurred since 1997 (Länsstyrelsen Skåne, 2018d; Sveriges lantbruksuniversitet, 2020a, 2020b).

2.6.8 Torup, N6159289 E0387681

The area is owned by Malmö municipality and has been frequently visited by citizens for recreational purposes for 200 years (Länsstyrelsen Skåne, n.d.-h). Both Asperulo-Fagetum beech forest and Luzulo-Fagetum beech forest are found in the 180 ha nature reserve, along with groups of coniferous trees and oak (Naturskyddsföreningen Skåne, 2022b). The Asperulo-Fagetum beech forest has both beneficial and non-beneficial conservation status, distributed within the nature reserve (Länsstyrelsen Skåne, 2016b). Luzulo-Fagetum has non-beneficial conservation status (Länsstyrelsen Skåne, 2016b).

Torup has been an important area for wood-dependent beetles for a long time and was a part of an study specifically focusing on beetles and their preservation in the late 1990s (Arup et al., 2001), making the area good for long-term observation. The area is especially important to the high variety and amount of insects, bats and fungi (Länsstyrelsen Skåne, n.d.-h; Naturskyddsföreningen Skåne, 2022b). Sightings of *Stictoleptura scutellata* have occurred (see Figure 4) (Sveriges lantbruksuniversitet, 2020a), along with an additional 58 red-listed insects (Länsstyrelsen Skåne, 2016b).

3 Methodology

In order to achieve the stated aim, field work, processing of the collected data and remote sensing analyses were conducted. The following sections explain the data acquisition, processing and general methodology of the study.

3.1 Site selection

The study was carried out in eight of the 24 areas within Scania, included in the LIFE application. Areas varied in size from 23.9 ha to 123.9 ha and are all both formally protected as nature reserves and Natura 2000 classified. All areas of interest are hence expected to be important for biodiversity in an otherwise fluctuating and heavily human influenced landscape (Eide et al., 2020; European Commission Directorate-General for Environment & Sundseth, 2008).

Accessibility was an important factor when choosing areas, as this in turn would affect the time left for in situ inventory. The difference in size and location of each beech forest throughout Scania could potentially show a difference in the amount of edge vegetation and was hence also a factor when deciding on suitable study areas. In other words, the following areas were deemed appropriate due to their size, location and accessibility during field work. All study areas can be found in Figure 5.

3.2 In-situ inventory of edge vegetation

All areas of interest were visited to conduct in-situ inventory of the edge vegetation and forest. All forest edges of the eight study areas were visited to find edge vegetation, and their characteristics, including their location, species, spread and height. Forest edges lacking any form of edge vegetation were also of interest, as these might be suitable for plantation of new edge vegetation or display characteristics of soil, aspect, climate and others that affect edge vegetation negatively.

To later be able to use this information while mapping the areas in ArcGIS Pro (ESRI, 2020), the GPS coordinates in SWEREF 99 TM for all edge vegetation and areas of interest were noted, using a Garmin GPSMAP 64. Excel (Microsoft, 2019) was used to organize all notes

and coordinates, before converting them into points in ArcGIS Pro using the *XY Table To Point* tool. The spread and height of edge vegetation was measured using a measuring tape.

To simplify the classification of species of edge vegetation and trees in field, keys (Almquist et al., 2016; Vedel & Møller, 2004) and the mobile application Google Lens (Google Commerce Ltd, 2022) were used. Google Lens is an image recognition tool that identifies objects in an image using visual analysis (Google, n.d.).

3.3 Forest density and stem diameter

To acquire the density of trees within each study area, a 30 x 30m square was measured during field work. The size of the area (30 x 30m) was decided based on the geomorphology of many areas, which include steep changes in elevation, making it difficult to measure a 100 x 100m square. As some areas had a rather low density of trees, 10 x 10m, which is often considered a standard (West, 2015), was deemed too small to give a reliable dataset. As some study areas had a very varying tree density and stem diameter within the area, multiple 30 x 30m squares were measured at certain study sites to ensure a more representative dataset. These sites were randomly sampled.

The number of beech trees taller than 4 metres within each square was noted, as was the diameter of these trees, giving a mean stem diameter for all areas. Each stem diameter were measured 1.5m above ground using a diameter tape, which indicated both the diameter and circumference of the stem. Additionally, as the state of trees and occurrence of dead wood matter greatly to the young beetles, occurrence or lack of, dead wood in all areas were noted. This was however, not quantified or calculated.

3.4 Digital available data

Geographical data of the areas of interest were obtained as shapefiles from the Swedish Environmental Protection Agency website (Naturvårdsverket, 2022). These include both nature reserves and Natura 2000 borders. The conservation plan for each area was also obtained.

Orthophotos with red, green, blue and infrared bands (0.25 and 0.5m resolution) as well as DTMs (Digital Terrain Model) with 1m resolution were all derived from Geodataportalen (Lantmäteriet, 2018a, 2018b, 2018c).

Soil data of all areas were acquired from Geodataportalen (Lantmäteriet, 2014) as shapefiles, providing information on soil characteristics and locations of exposed bedrock.

3.5 Mapping

Maps of each site, displaying beech forests and its adjacent edge vegetation, as well as flowering bushes in neighbouring open land covers within the Natura 2000 site, were made using ArcGIS Pro (ESRI, 2020).

An interpretation key (Table 2) for different land use classes and types of edges was made based on an updated CORINE land cover guide (Kosztra et al., 2019) and adjusted to the study's aim. As only beech forest, edge vegetation and open land with existing flowering bushes were of interest, many land cover classes were excluded in the final results. Table 2 only display land use classes and names, while a full description of each class can be found in Appendix B.

The edges were divided into 4 categories, with forest edges not falling within these categories not being mapped:

1. ***Existing*** edges refer to areas where edge vegetation was found and is not in need of new plantations. This could be both due to distance to appropriate habitat, or the lack of space. Edge vegetation in these areas will most likely maintain their size or continue to grow during the coming years.

2. ***Existing and suitable*** edges show areas where some edge vegetation was found, but also have room for more edge vegetation to be planted.

3. ***Suitable*** edges display areas where no edge vegetation was found, but are suitable for plantations of edge vegetation. These areas found in the boarders between protected beech forest and protected open land, preferably south, west or east facing.

4. ***Unlikely*** edges refer to areas where edge vegetation is currently growing, but will not be beneficial for additional plantations. This could be due to the neighbouring land use, which might be a light limiting forest, annually harvested farm land or other privately owned land influencing the edges. Edge vegetation in these areas will most likely disappear in the future.

Table 2. Interpretation key used for mapping edge vegetation, beech forest and flowering bushes in neighbouring open areas. Note that semi-natural open grasslands and pastures lacking flowering bushes are colourless in the key and maps. Descriptions of each class can be found in Appendix B.

Class code	Class name	Subclass code	Subclass name
10	Beech forest	11	Asperulo-Fagetum
		12	Luzulo-Fagetum
20	Edge vegetation	21	Existing
		22	Existing and suitable
		23	Suitable
		24	Unlikely
30	Semi-natural open grassland	31	With flowering bushes
		32	Without flowering bushes
40	Pasture	41	With flowering bushes
		42	Without flowering bushes

4 Results

Descriptions of the study areas and species found during field work are described in the following sections. Presentation of existing edge vegetation and beech forests are found in both text and maps.

4.1 Field findings

Although all areas visited are Natura 2000 classified as Asperulo-Fagetum beech or Luzulo-Fagetum beech habitats, not all forests included solely beech, as occasional other deciduous and coniferous trees were also found. Neighbouring forests included different species of birch, alder, willow (*Salix sp.*), elm, oak, maple, ash and European bird-cherry. These trees were also found within the Natura 2000 areas, although seldom.

Detailed information on species found in each area can be seen in Table 3, along with mean densities and stem diameters.

Table 3. A summary of each study site with type of edge vegetation found, as well as number of beech trees per ha and mean tree trunk circumference, standard deviation within parentheses. Areas missing density and circumference values are due to loss of data during processing.

Site	**Tree density [n/ha]**	**Stem diameter [m]**	**Type of edge vegetation found**
Christinelund	-	-	*Salix sp.* , *Rosa sp.* , *Lonicéra sp.* , *Rubus sp.* , *P. spinósa* , *C. avellána* , *V. ópulus*
Dalby Norreskog	-	-	*Rubus sp.* , *Rosa sp.*, *Lonicéra sp.*, *C. avellána*
Eksholm	-	-	*Rubus sp.*, *Lonicéra sp* .
Forsemölla-Sträntemölla	100 (54.4)	0.4 (0.7)	*Rosa sp.* , *Rubus sp.* , *Lonicéra sp.* , *S. aucuparia V. ópulus*
Gyllebosjön	66.7 (5.5)	0.8 (1.1)	*Rubus sp.* , *Rosa sp.* , *Lonicéra sp.* , *C. avellána*
Knivsåsen- Borelund	-	-	*Rubus sp.* , *Rosa sp.*, *C. avellána*
Rövarekulan	177.7 (49.9)	0.6 (0.8)	*Rubus sp.* , *Rosa sp.* , *Lonicéra sp.* , *Crataegus sp.* , *C. avellána* , *V. ópulus*
Torup	44.4 (5.5)	0.71 (0.8)	*C. avellána*, *Crataegus sp.* , *Ribes sp.* , *Rubus sp.* , *Lonicéra sp.* , *Sorbus sp.*, *P. spinósa*

4.1.1 Christinelund

Salix sp., *Rosa sp.*, *Lonicéra sp.* and *Rubus sp.* as well as sloe and hazel were found along the edges of both beech and mixed forest. The interior of the forest had sporadic occurrences of hazel, guelder-rose (*Vibúrnum ópulus*) and *Rubus sp.*, as well as ash and birch.

The southern edge, shielding open land from mixed forest, included *Lonicéra sp.* and *Rubus sp.*, as well as sloe (Figure 6). The southern edge is considered to be *Existing*, as it lacks the room for further plantations. The majority of the northern edge is considered to be *Suitable* as currently existing trees would have to be cut down for plantations of edge vegetation, but occasional Salix sp., Rosa sp. and guelder-rose occur. The east edge, as well as parts of the northern edge is considered to be *Existing and suitable*.

Generally, dead wood and high stem diameters occurred frequently throughout the forest, creating many possibilities for sheltered housing. Data on tree density and mean stem diameter for this area was lost in data processing. Glades within the forest occurred.

4.1.2 Dalby Norreskog

In general, this area lacked edge vegetation, except for a small part of the eastern forest edge, which included *Lonicéra sp.* and *Rubus sp.* The neighbouring pasture to the North however, included a group of flowering bushes and trees such ad *Rubus sp.*, hazel, and rowan, as well as multiple junipers (*Juniperus sp.*) approximately 85 m from the forest edge.

The western edge had no visible edge vegetation (Figure 6), but is considered *Suitable* due to its aspects and neighbouring pasture. It is a part of the protected area and can hence be managed by the County administrative board of Scania, along with the forest.

The areas eastern edge neighboured a newly cleared coniferous forest. This edge mostly consisted of *Rubus sp.*, yet very few and young. Two specimens of cultivated *Rhododendron sp.* were also found here. This is considered to be an *Unlikely* edge as the neighbouring land most likely will be turned into forest yet again, creating an unbeneficial, light-limited environment for edge vegetation.

Wood mould boxes are recommended for this area as the forest lacked dead wood and suitable housing for beetles. Dalby Norreskog is only a small beech forest, with generally large trees and high density of trees, hence lacking openings for younger beech trees to grow. Data on tree density and mean stem diameter for this area was lost in data processing.

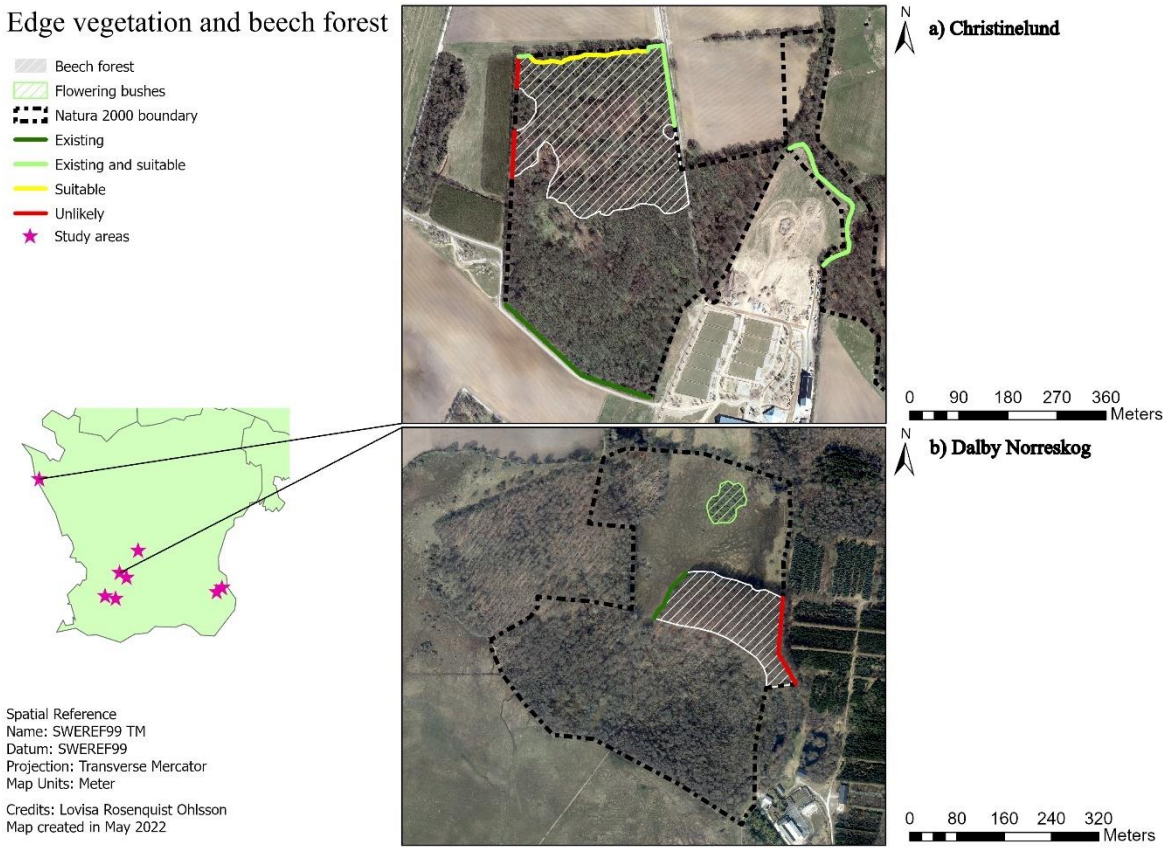

Figure 6. Edge vegetation and beech forest cover in Christinelund (a) and Dalby Norreskog (b). Based on in-situ observations and orthophotos from Lantmäteriet (2018c).

4.1.3 Eksholm

The few meters of edges available included a scarce cover of *Rubus sp.* and *Lonicéra sp*. The possibility to plant edges is high, as the neighbouring pastures in the northern area are south-facing, see Figure 7. Hence, this area is classified as an *Existing and suitable* edge.

Additional *Rubus sp*. were found by the line of trees north of the lake, although not enough to be classified as an edge.

Dead wood occurred throughout the forest, creating housing for not only insects, but also birds and small mammals. Data on tree density and mean stem diameter for this area was lost in data processing.

4.1.4 Forsemölla-Sträntemölla

Here, a mosaic of beech and oak forests is framing pastures and open lands with species suitable as edge vegetation throughout the area as individual bushes. The larger amount of edges, including *Rosa sp.*, *Rubus sp.*, *Lonicéra sp.*, rowan and guelder-rose, were found in the central pastures, north of the large road and to the south of an apple-filed grove. They were mostly south facing and hence considered to be *Existing and suitable*, see Figure 7.

This area provided many options for plantations of edge vegetation, with the southern forest also including south-facing edges with already existing edge vegetation (*Existing and suitable*).

The mean stem diameter on beech trees were on average ca. 0.4 m, although multiple trees with a larger diameter occurred, see Table 3. Dead wood occurred scarcely and wood mould boxed are hence recommended. Individual oaks were found in the interior of the beech forest south of the road, both dead and alive.

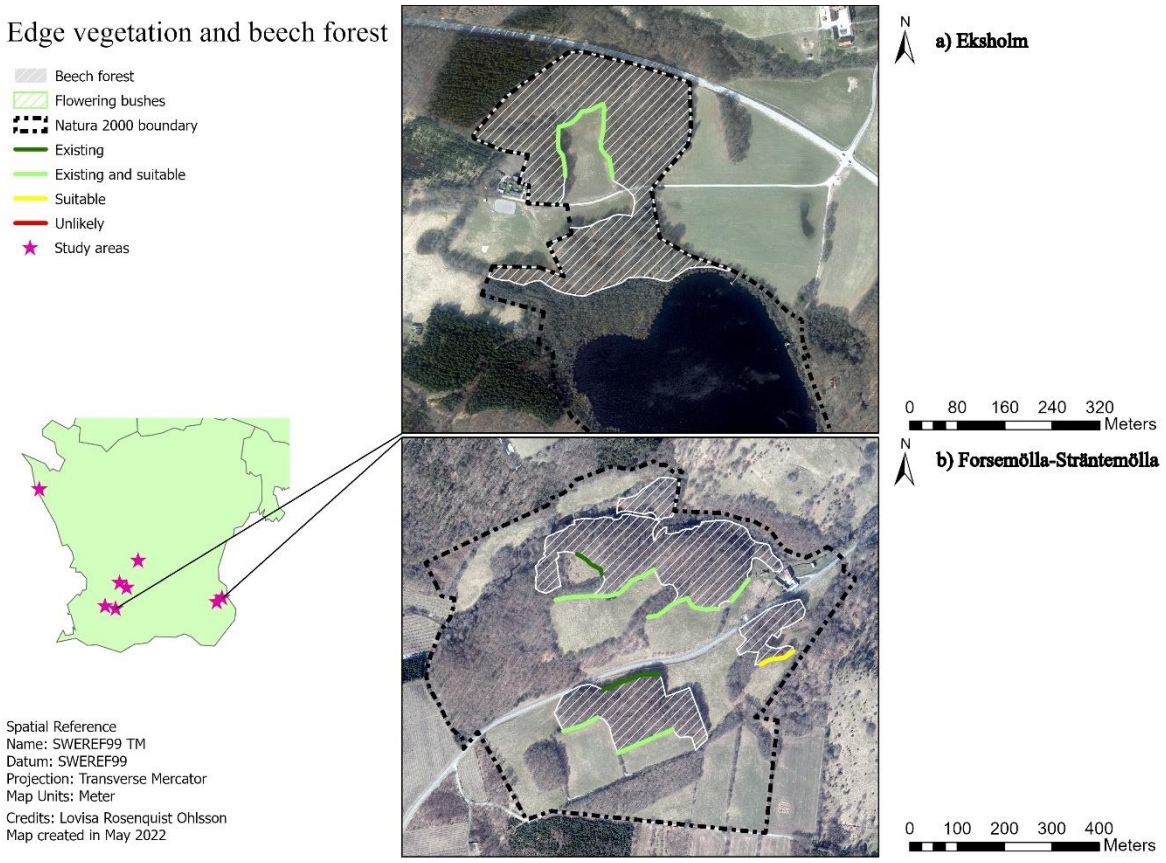

Figure 7. Edge vegetation and beech forest cover in Eksholm (a) and Forsemölla-Stråntemölla (b). Based on in-situ observations and orthophotos from Lantmäteriet (2018c).

4.1.5 Gyllebosjön

The area includes a broad age distribution among the beech trees, most of which have an average stem diameter of 0.8 m, with many younger trees occurring as well (see Table 3). Maple, oak, and elm were found in the forest, along with the parasitic toothwort (*Lathraea squamaria*) and spring-flowering herbs in the field layer. The area lacked dead wood to the extent that artificial wood mould boxes are recommended for alternative beetle housing.

Rubus sp., *Rosa sp.*, *Lonicéra sp.*, and hazel were found along multiple edges, with hazel also sporadically occurring in the forest interior. Along the road on the northern border, hazel and *Lonicéra sp.* occur scarcely. The northern edge is considered to be *Existing* as it is north-facing and lacks the space needed for further plantations.

The parking space in the centre of the area (Figure 8), south of the lake and visible by the *Suitable* classified edge is surrounded by young birch and occasional beech trees. These trees can easily be cleared to make room for plantations of edge vegetation closer to the forest, as it otherwise has a limited number of options.

Although neighbouring pastures are found south of the forest, these are not protected or managed by the County administrative board of Scania, and can hence not be used for edge plantations without cutting valuable beech trees. It is however, classified as *Existing and suitable*, as it includes trees suitable for cutting.

4.1.6 Knivsås-Borelund

Both *Rubus sp.*, *Rosa sp.* and hazel were found along the forest edge, with *Rosa sp.* and *Rubus sp.* being the main forms of edge vegetation in the larger eastern edge (see Figure 8). The actual edges of the forest were very narrow, but neighbouring pastures included a slightly larger population in relatively close proximity (5-50 m) to the forest. Here, juniper and other bushes were also found.

Young trees of beech and birch were growing along the eastern edge in a dense cluster on very moist soil. The eastern edge is hence considered to be an *Existing and suitable* edge, as there is room for more edge vegetation between the already existing vegetation. A number of hazels were also found here as well as sporadically in the northern areas of the forest and edge.

The south-facing edge on the western side of the forest neighbours a pasture with tall grass and occasional *Rubus sp*. As a path divides the forest and pasture, there is little to no room for plantations of edge vegetation, unless planted in the enclosed pasture. Hence, this edge is considered an *Existing* edge.

The forest interior had many specimens of dead or fallen wood, with larger trees occurring along the majority of the forest edge. Data on tree density and mean stem diameter for this area was lost in data processing.

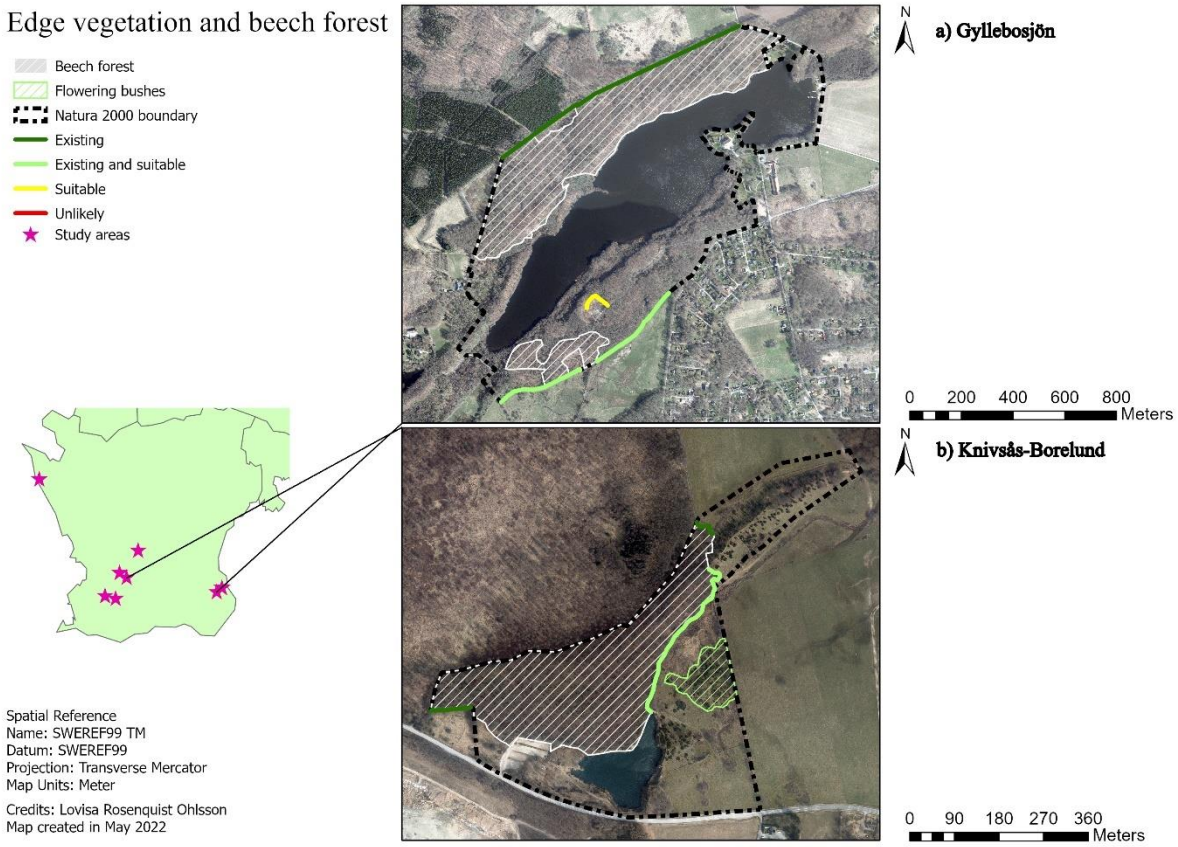

Figure 8. Edge vegetation and beech forest cover in Gyllebosjön (a) and Knivsås-Borelund (b). Based on in-situ observations and orthophotos from Lantmäteriet (2018c).

4.1.7 Rövarekulan

The beech forest included sporadic willow, maple, birch, alder, ash and European hornbeam, while edges mainly consisted of *Rubus sp.*, *Rosa sp.*, *Lonicéra sp.*, *Crataegus sp.*, hazel and guelder-rose.

The nature reserve encompassed multiple pastures (see Figure 9), which all either already include, or have the possibility to include flowering bushes. Many of the edges neighbouring these pastures were deemed *Existing and suitable* as there were specimens of *Rubus sp.*, *Rosa sp.*, *Lonicéra sp.* and other edge vegetation, as well as room for more to be planted.

The *Existing* edge in the north-facing eastern edge, neighbouring an agricultural field, only grew up to 1 m. South-facing edges north of the lake are considered to be *Suitable*, as there is space for plantations of edge vegetation and the outer boarder of the forest consists of a mixed broadleaf forest.

Although the stem diameter and tree density greatly differ within the area, the mean stem diameter was 0.6 m (Table 3). Multiple areas with fallen trees and dead wood occur, as well as areas with trees with a stem diameter higher than 0.8 m. A large amount of dead wood was found in the area, especially along forest edges and in the northern part of the forest.

Two areas were included to measure density in different areas of the forest, they include 99 and 266 trees per hectare, clearly showing the difference in density throughout the area.

4.1.8 Torup

Several species of edge vegetation was found throughout the area, not only along the forest edge. Within the beech forests, hazel and *Crataegus sp.* was found sporadically, while *Ribes sp.*, *Rosa sp.*, *Rubus sp.*, *Lonicéra sp.*, sloe and *Sorbus sp.* was found along the forest edge.

The north-eastern edge, in the northern Natura 2000 classified area neighbours agricultural land. The beech forest continue beyond the Natura 2000 boarders and have young specimens of *Rubus sp*. and *Rosa sp*. This area is considered *Suitable*, as it is an ideal area for edge vegetation plantations, if beech trees along the edge are cut or the land owner of the neighbouring farmland agrees to manage it.

Additional *Suitable* areas can be seen in the central area of the forest. Here, a coniferous stand is present today. If these trees are cut, edge vegetation can be planted and openings in the forest can be made.

Dead wood and coarse beech trees were frequent throughout the area. Among beech trees were occasional oaks, and other deciduous trees, with coniferous stands occurring in smaller groups, seen as openings in the Natura 2000 boarders in Figure 9. Tree density can be found in Table 3.

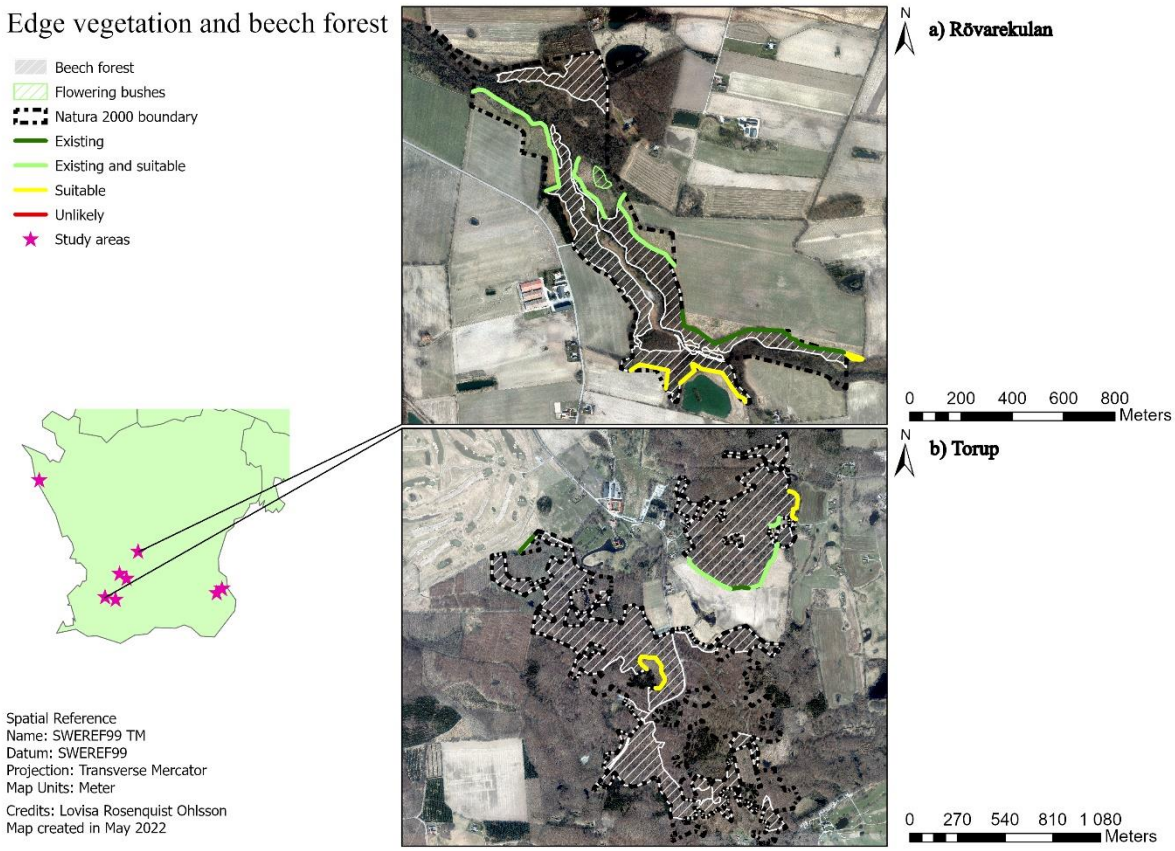

Figure 9. Edge vegetation and beech forest cover in Rövarekulan (a) and Torup (b). Based on in-situ observations and orthophotos from Lantmäteriet (2018c).

5 Discussion

The following sections will cover implications of results, evaluation of methods, limitations, sources of error and suggested future research.

5.1 Implications of results

Although the amount of *Suitable* areas differed in relation to the size of the forest, all study sites had some form of edge vegetation. The size of the forest affects the size of the edges, as it may be less proportionally. Although areas such as Dalby Norreskog, Knivsås-Borelund, Eksholm and Forsemölla-Stråntemölla offered very good options for plantations of edge vegetation, with Forsemölla-Stråntemölla and Knivsås-Borelund even offering multiple sites.

In other areas, such as Torup and Gyllebosjön, the forests reached all the way to the Natura 2000 borders in multiple areas, with neighbouring areas being private land or valuable forests. This makes the implementation of edge vegetation very problematic, as it would require cutting of beech along the forest edge or plantation on land that the County administrative board of Scania does not have the right to manage.

Trees growing along the edge of the forest normally receive more solar radiation, depending on their aspect, and hence grow faster and bigger than those growing in the interior (Chen et al., 1993). These trees are viable potential hosts and are therefore not ideal individuals to cut. Birch, conifers and young beech trees, however, can be cut to open up areas suitable for edge vegetation, such as the area surrounding the parking lot in the central part of Gyllebosjön

(Figure 8) and multiple areas in the forest interior of Torup (Figure 9). In other words, areas where the edges have been taken over by trees not beneficial for the Natura 2000 conservation status are examples of areas where the benefit of new food sources, i.e., planted edge vegetation, weighs more than the loss of individual trees. These areas cannot be altered freely, as they are protected under the Natura 2000 classification and must therefore be managed with caution.

One could also argue that the beetles of interest, as well as other rare species of insects which stay close to their home-tree their entire life, might benefit more from cutting of individual beech trees and implementation of edge vegetation than loss of habitat. Since biodiversity is promoted when homogenous landscapes, rather than monoculture landscapes, are prioritized (Christensen et al., 2005), this is a rather reasonable argument.

The amount of dead wood and suitable housing differed depending on the study site. Although dead wood occurred in the majority of the areas, many areas still need wood moulded boxes to create enough housing for *Stictoleptura scutellate* and *Ischnomera sanguinicollis*, as well as other organisms. Rövarekulan and Eksholm for example, had a lot of available dead wood, while Dalby Norreskog and Forsemölla-Sträntemölla had large areas (in comparison to the size of the beech forest) lacking it. The latter are hence good example of sites in need of mould wood boxes.

Since only eight areas where included, statistical analysis cannot be conducted. However, general conclusions can be draw. The aspect and neighbouring land use seems to play major roles in the well-being and extent of edge vegetation, as the most developed edge vegetation were found in south-facing edges. These south-facing edges neighbouring open pastures indicated healthier and wider edge vegetation (such as Knivsås-Borelund in Figure 8), than east or west facing edges neighbouring agricultural fields (Christinelund, Figure 6 and Rövarekulan, Figure 9 respectively). North facing edges, such as those found in Dalby Norreskog (Figure 6), generally included younger edge vegetation. This indicates the importance of the land use of neighbouring land when planting edge vegetation. Private land can very well be turned into commercially grown forest in the future, although it today might be agricultural fields or open pastures.

The largest flowering bushes were found in Torup (see Figure 9), along the southern edge, neighbouring an open field. There were a multiple metre wide gap between the beech forest and the neighbouring field, creating an opening for flowering bushes to grow. Which understandably is yet another factor influencing the condition of edge vegetation.

Hence, the prime forest edges for plantation of edge vegetation neighbours open, protected pastures. This is a land cover that can include a wide range of species beneficial for edge vegetation and would benefit from a transitional zone between open land and forested areas. These areas can be found in a very time efficient manner using analysing algorithms provided by GIS programs such as ArcGIS Pro (ESRI, 2020).

Additionally, the non-native *Rhododendron sp.* was found in two areas (Rövarekulan, and Dalby Norreskog), growing close to, or in, the beech forest. These and other invasive species should be closely monitored or removed, in order to prevent its overtaking of native edge vegetation. Juniper is another species, found in Knivsås-Borelund, Dalby Norreskog, Forsemölla-Sträntemölla and other areas, which might play a role in the success of planted edge vegetation and should be incorporated when plantations are carried out.

5.2 Evaluation of applied methodology and extension to other areas of interest

The methodology used in this study is very time consuming and costly, excluding it from being the prime methodology. Transportation to and from the site, and especially throughout the entire study area, is very time consuming even if using a vehicle. Large parts of the forest edges that were not suitable or lacked edge vegetation completely were visited although not necessarily producing useful data. This meant hours of work on something that instead could have been used to include more study areas.

However, solely using aerial or satellite imagery can make it difficult to find areas with edge vegetation, as well as areas suitable for plantation of edge vegetation. It will also be nearly impossible to determine specific species of the edge vegetation and very high-resolution data is needed for their height and volume to be determined. Large specimens of species such as sloe, with its characteristic white flowers, could be recognized in high-resolution areal imagery taken during the time of bloom (see Table 1). But smaller specimens and species hidden under trees are very difficult to locate from above.

Hence, a hybrid of the two methods is more reasonable, with remote sensing being used to find potential areas with existing edge vegetation or suitable for plantations. Here, forest edges neighbouring open land, such as pastures or grasslands, as well as facing east, south or west, may be noted and later visited. Lowering the amount of field work to only include areas with a higher chance of positive results also lowers the cost and can therefore include more areas.

It would also make it possible for the funding to be applied in a more efficient way, with favouring factors playing a bigger role in site localization of suitable areas. As it is not only the neighbouring land cover that is of importance, but also the space available for edges to grow, the boarders of each protected area should be taken into consideration before going out in field.

The owner of both the neighbouring land and the actual forest is another factor to keep in mind when suggesting plantations. It is important for the land owner to understand the importance and need of edge vegetation in order for it to be beneficial for species within the ecosystem. Hence focusing on not only open areas, but areas where cutting of trees can be conducted are equally important.

Another example of a more time-efficient method for inventory is using a drone, which can offer detailed areal images from many angles. It flies faster along a forest edge, than an observer in field travels by foot, smoothly crossing both natural and man-made obstacles. Machine learning and artificial intelligence software can simplify the processing of such images, making this an even more time efficient alternative method.

5.3 Limitations and sources of error

Firstly, a field study incorporating inventory of plant species should be conducted during late spring or summer, preferably when these species are in bloom and/or leafing out, to simplify the determination of species. All field studies during this project were conducted in early spring, when most edge vegetation lacked flowers, fruit and leaves, which made the determination of species difficult and more time consuming than necessary. The risk of misclassification also increase with less typical features showing in each individual plant.

Related, is the issue with inventory occurring with days, or weeks in between different study areas. Even a few days between field studies can have a big impact during spring, as this is when leaves and buds develop. Consequently, areas visited later in the season may have shown more individuals or species, than those visited in the very beginning, simply because they had more time to grow leaves and buds.

The author's limited knowledge on Swedish flora has also been a limitation, as this could have resulted in misclassification of species throughout the inventory. Although keys were used, the combination of limited knowledge and time of year, might have made the keys insufficient in some cases.

Secondly, time has, as always, been a limiting factor in the sense that only eight protected areas where visited and included in the study. This in turn is not enough data for any statistical analysis to be made. Preferably all Natura 2000 classified beech forests in South Sweden should be included to yield significant values and conclusions. The limited time resulted in the exclusion of areas which had sightings of *Ischnomera sanguinicollis*, which has been seen primarily in Söderåsen National Park, as it is a very big area compared to the ones included in this study (Sveriges lantbruksuniversitet, 2020b).

As tree density and stem diameter were only collected in one or two locations per site, it is not reliable data in the sense that it represents the entirety of each forest. The additional data loss for 50% of the areas adds to the problem with including this while analysing which areas generally are more prone to include edge vegetation.

The limited time has also resulted in costs not being included in this study, which would be a very important factor when planning and implementing edge vegetation. Suggested costs have been included in the LIFE application, to give an idea of the funding needed. However, these costs have not been divided into sub-projects related to the actions focusing on edge vegetation, but rather into groups of which organisation or institute is supposed to be compensated for their work.

Additionally, the sighting data of both beetles were derived from an open source, of which only 0.07% of *Stictoleptura scutellata* and 55% of *Ischnomera sanguinicollis* had been confirmed (Sveriges lantbruksuniversitet, 2020a, 2020b).

Lastly, one individual bush does not make up an entire edge, and is hence not enough to be classified as sufficient edge vegetation. However, studies indicating a suitable amount of edge vegetation, specifically for *Stictoleptura scutellate* and *Ischnomera sanguinicollis* have not been conducted before, which is a limitation. As edge vegetation benefits a wide range of animals, not only the beetles included in this study, they can still promote biodiversity. However, it rather seems to be the quality and type of edge vegetation that have an impact, not solely the amount of flowering bushes (Fry & Sarlöv-Herlin, 1997).

5.4 Future research

To further investigate areas using the same methods as done in this study in Blekinge, Halland and Småland would be a reasonable way of expanding the scope and infallibility of the study, as these regions also have Natura 2000 classified beech forests and are included in the LIFE application (Björkman & Karlsson, 1999; Christensen et al., 2005; Vedel & Møller, 2004). Incorporating other species of wildlife and what effect specific plant species might have on *Stictoleptura scutellate* and *Ischnomera sanguinicollis*, or other species' habitat can also be included in further studies.

Likewise, studies on the amount of dead wood and suitable housing in each forest suggested in the LIFE application should be investigated before implementation of edge vegetation in these areas. It might not be beneficial for insects, and hence the edges could be adjusted to better suit other animals.

Introduction of red-listed animals in areas with beneficial conservation status and sufficient habitats should also be considered. Creating housing and food sources for species that are locally extinct seems rather insufficient if these species are not able to re-populate the area. As this is a wide and very different study area from that of this report, it was deemed too time consuming to include in this study. Studies correlating forest age with biodiversity or status of red-listed species, such as Fritz et al. (2008) is also a suggestion of future studies. This might show additional value to older forests and the need for their preservation.

This study has not considered what effects individual species of edge vegetation has on biodiversity or forest health. Former studies however, suggest that diverse, gradual edges promote biodiversity, prevent growth of alien species and highly influence the atmospheric deposition of nitrogen and pollutants (Hamberg et al., 2009; Magura, 2002; Wuyts et al., 2009). Soil characteristics, regional climate and additional factors can also be further investigated, as these might affect the well-being of edge vegetation as well.

These, and other factors, can in turn influence which specific of edge vegetation could affect other animal- and plant species and if these in turn have an effect on red-listed beetles. This study has not taken into account plant species that might have a negative effect on the beetles of interest but could be beneficial for successful plantations of edges and forest management. Such species could be coniferous trees and bushes, creating additional light limitations. Species altering soil characteristics or attracting animal species which can outcompete or prey on *Stictoleptura scutellate* and *Ischnomera sanguinicollis* may also be of interest when planting edge vegetation in an area.

Additional studies should be made on the growth of planted edge vegetation, if these will be affected by tree species potentially taking over areas with edge vegetation and if pre-commercial thinning or forest cutting might be necessary. This method, however, is generally favoured within Swedish forestry focusing on controlling pioneer broad-leaved species of affecting plantations of coniferous species (for example *Pinus sylvestris* and *Picea abies*) (Wiström & Nielsen, 2017).

As the needs of edge vegetation is different from that of forests, their implementation and management must also differ. It cannot include commercial management styles as it does not have the same purpose. Management of edge vegetation, already existing or planted, must be analysed and reviewed in order for them to prosper and increase biodiversity.

6 Conclusion

Factors influencing the well-being of edge vegetation are most likely (1) aspect, with south being the preferred direction, (2) neighbouring land cover, with open land, mainly pastures, being most favourable, and (3) sufficient space between the forest and neighbouring land use for the edge vegetation to grow.

As aspect and neighbouring land use are the greater factors in locating suitable areas, these can help determine areas of interest for in-situ inventory before going out in field, evolving the methodology used for the project. Here, a combination of remote sensing and field work is deemed the most efficient form of locating existing or suitable edges, with drones being a suggestion to further the efficiency of inventory.

Only five of the visited study areas had sightings of *Stictoleptura scutellate*, with none including *Ischnomera sanguinicollis*, yet all areas visited showed some form of edge vegetation, although in ranging form and size. However, none of the areas had enough edge vegetation for it not to be recommended to implement more flowering bushes.

If cuttings of non-beech trees are carried out, all areas can implement edge vegetation, although not always in direct connection to Natura 2000 classified beech forests. They all do, however, have the possibility to plant edge vegetation that can benefit other species, such as mammals, reptiles, other insects and birds.

7 References

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Appendix A. Species suitable as edge vegetation

Table A 1. Species suitable as edge vegetation found in field during in-situ inventory.

Scientific name	Genus	Swedish name	English name
Córylus avellána	*Córylus*	Hassel	Hazel
Lonicéra periclymenum	*Lonicéra*	Vildkaprifol	Common honeysuckle
Lonicéra xylosteum	*Lonicéra*	Skogstry	Fly honeysuckle
Prunus padus	*Prunus*	Hägg	European bird cherry
Prunus spinósa	*Prunus*	Slån	Sloe
Rosa canína	*Rosa*	Stenros	Dog rose
Rosa dumális	*Rosa*	Nyponros	Glaucous dog rose
Rubus fruticósus	*Rubus*	Björnbär	Blackberries
Rubus idaéus	*Rubus*	Hallon	Raspberries
Salix caprea	*Salix*	Sälg	Goat willow
Sorbus aucuparia	*Sorbus*	Rönn	Rowan
Vibúrnum ópulus	*Vibúrnum*	Skogsolvon	Guelder-rose
	Crataegus	Hagtorn	Hawthorn
	Ribes	Ripsväxter	
	Rosa		
	Rubus		
	Sorbus	Oxel	
	Spirea	Spirea	Spirea

Appendix B. Interpretation key

Table B 1. Interpretation key used when mapping each study site. Descriptions are based on an updated CORINE land cover guide (Kosztra et al., 2019) and adjusted for the purpose of this study.

Class code	Class name	Sub- class code	Subclass name	Description
10	Beech forest	11	Asperulo-Fagetum	Polygons. Forest composed principally of trees, where beech species make up >90% of the trees. Trees >2m in height. The soil is typically neutral or near-neutral, with mild humus.
		12	Luzulo-Fagetum	Polygons. Forest composed principally of trees, where beech species make up >90% of the trees. Trees >2m in height. The soil is typically acidic and nutrient-poor.
20	Edge vegetation	21	Existing	Polylines. Forest edges with enough edge vegetation available for there to not need new plantations of edge vegetation.
		22	Existing and suitable	Polylines. Forest edges with edge vegetation available, yet the posibilitiy for there to be new plantations of edge vegetation.
		23	Suitable	Polylines. Forest edges lacking edge vegetation, but suitable for plantations of edge vegetation.
		24	Unlikely	Polylines. Forest edges with edge vegetation available, yet not suitable for there to be new plantations of edge vegetation.
30	Semi-natural open grassland	31	With flowering bushes	Polygons. Permanent grassland characterized by agricultural use or strong human disturbance, with species suitable as edge vegetation away from the forest edge. More organized than semi-natural grasslands. Typically used for grazing-pastures, or mechanical harvesting of grass–meadows.
		32	Without flowering bushes	Polygons. Permanent grassland characterized by agricultural use or strong human disturbance, without species suitable as edge vegetation away from the forest edge. More organized than semi-natural grasslands. Typically used for grazing-pastures, or mechanical harvesting of grass–meadows.
40	Pasture	41	With flowering bushes	Polygons. Grasslands under no or moderate human influence, with species of shrub that is suitable as edge vegetation. Low productivity grasslands. Often situated in areas of rough, uneven ground, steep slopes; frequently including rocky areas or patches of other (semi-)natural vegetation.
		42	Without flowering bushes	Polygons. Grasslands under no or moderate human influence, without species of shrub that is suitable as edge vegetation. Low productivity grasslands. Often situated in areas of rough, uneven ground, steep slopes; frequently including rocky areas or patches of other (semi-)natural vegetation.