



Sveriges lantbruksuniversitet
Swedish University of Agricultural Sciences

Fakulteten för landskapsplanering, trädgårds- och jordbruksvetenskap
Område Växtskyddsbiologi

***Elater ferrugineus* and *Osmoderma eremita*, a regional survey and habitat requirements on different landscape scales**

Elater ferrugineus och *Osmoderma eremita*, en regional inventering och habitatkrav på olika landskapsskalor

Benjamin Forsmark



Självständigt arbete vid LTJ-fakulteten, SLU
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Abstract

Habitat destruction and fragmentation is the primary cause behind loss of biodiversity. Population dynamics are affected by factors that act on different spatial scales. To direct nature management efforts, the impact of different factors and at which spatial scale they act needs to be taken into consideration. *Elatér ferrugineus* and *Osmoderma eremita* are rare and threatened (red listed over their entire distribution range) saproxylic beetles associated with hollow deciduous trees. In the present thesis, these beetles have been surveyed using pheromone baited traps at 83 localities in Skåne. A multiscale analysis has been performed testing occupancy data for *E. ferrugineus* against densities of resources of different sorts of trees. This analysis stresses the requirements of *E. ferrugineus* for large non-fragmented areas with high densities of giant trees. Few localities match its requirements, and only eight resident populations appear to persist in Skåne. Four previously unknown localities for *E. ferrugineus* and two novel localities for *O. eremita* have been revealed in this thesis.

Introduction

Biodiversity is severely threatened by landscape changes. Habitat destruction is the major cause behind loss of biodiversity (Hannah 1995). Insects constitute a big part of overall biodiversity and respond rapidly to environmental changes. This makes them vulnerable to all sorts of habitat destruction and habitat degradation (Thomas *et al.* 2004). Many species, known as saproxylic, are involved in the decay and decomposition processes of trees and dead wood. Dead wood is the base of diverse ecosystems with highly adapted organisms, from those feeding directly from the living or newly dead wood all the way up to top predators such as woodpeckers. In Sweden, 12% of the multicellular organisms are dependent on dead wood at some phase of their life cycle (Dahlberg *et al.* 2004). Among these, a highly specialized fauna is associated with old-growth deciduous trees. When trees age, different structures are formed, including tree hollows containing a loose substrate of fungal infested wood mixed with fragments and excrements of inhabiting organisms. This substrate, the wood mould, is essential for a variety of species. Only within the beetles (order Coleoptera), as many as a thousand Swedish species depend on this substrate (Niklasson 2005). Among saproxylic beetles, about 200 species are red listed in Sweden (Antonsson 2001a). Protection of remnant old-growth forests hence has high priority in nature conservation.

Among beetles associated with wood mould in hollow deciduous trees, the click beetle *Elater ferrugineus* (Linnaeus, 1758) and the scarab beetle *Osmoderma eremita* (Scopoli, 1763) studied in this thesis are demanding species which frequently co-occur. Ranius *et al.* (2001) and Ranius (2002b) concluded that these beetles are seriously affected by habitat fragmentation. Both species are red listed all over their global distribution range (Nieto *et al.* 2010). The strong association with old-growth deciduous trees makes *O. eremita* useful as an indicator of primeval forest continuity (Ranius 2002b; Jansson *et al.* 2009a). For *E. ferrugineus*, the same has been assumed, but the difficulty of detecting it has made it hard to study (Nilsson *et al.* 1994; Svensson *et al.* 2004). Their strict habitat requirements make it possible to consider them as umbrella species for a guild of saproxylic invertebrates associated with hollow deciduous trees. In a nature preservation context, findings of beetles with these properties give strong arguments to protect the areas where they have been found.

Until the 18th century, deciduous forests with old-growth characteristics were common in southern Sweden and all over Europe. Since then, rationalization in agriculture and forestry has led to a severe decline in the extent of these forests. A great deal of biodiversity has been lost in this process (Hannah 1995; Eliasson *et al.* 1999). Today, the distribution of these habitats has mainly retreated to larger estates and parks where the inhabiting fauna has found a refuge. As these remaining refuges are aging, the viable substrate of the beetles in the present study is declining. In the last decades, greater attention has been given to the importance of large, hollow trees in the landscape. Efforts are being made to identify and protect existing hollow trees with valuable saproxylic fauna. Over a longer time frame, the aim for conservation efforts must be to

arrange for a transition to a new generation of trees as the current giants are ageing and dying. As it generally takes at least 250-300 years for an oak to become a useful habitat for these insects (Ranius *et al.* 2009), it is quite a challenge for conservation to secure their long-term persistence in the landscape through careful planning. The aim of my study is to determine the amount of resources in the form of large hollow trees, and at what geographical scales, that will be needed to safeguard the existence of *E. ferrugineus*.

Local populations are affected by factors that act on different spatial scales (Ranius *et al.* 2011; Bergman *et al.* 2012). Traditionally, surveys of the habitat of saproxylic beetles have focused on characteristics of specific trees or small stands (Ranius *et al.* 1997; Ranius 2000; Ranius *et al.* 2000; Ranius *et al.* 2009). However, the surrounding environment (the matrix) of a specific patch has an impact on the local populations (Åberg *et al.* 1995). Habitat fragmentation, for example, is a factor on the large scale that affects populations on the local scale. Such factors are not always easily measured and are seldom taken into account in traditional studies where only habitat factors on a local scale are measured.

To fully assess the landscape factors that affect populations, a multiscale approach where factors are measured at several discrete scales must be used (Levin 1992; Graf *et al.* 2005). Recently Ranius *et al.* (2011) studied the relationships between landscape factors and saproxylic invertebrates in Östergötland, and found out that *E. ferrugineus* is dependent on resources at greater spatial scale than *O. eremita*. Bergman *et al.* (2012) assessed the impact of oak densities for 35 saproxylic beetles by a multiscale approach in Östergötland, using many discrete scales ranging from 30 to 5000 m. By this method they could evaluate at which spatial scales each beetle responded to oak densities, showing that *O. eremita* persistence was affected by both small- and large-scale resources

The cryptic lifestyle of saproxylic invertebrates, hidden in cavities in the tree trunks, makes them hard to study. Surveys on these organisms have traditionally been limited to sifting of wood mould for fragments, frass, faeces or larvae, or to pitfall or window trapping, which are time-consuming and often have low accuracy in detecting resident species (Ranius *et al.* 2002). In order to overcome this problem, attractive traps for saproxylic insects based on sex pheromones or other attractants have high potential as monitoring tools. Traditionally, pheromones have almost exclusively been used for the management and monitoring of agricultural and forest pest insects (Blackshaw *et al.* 2006; Johnson *et al.* 2006; Witzgall *et al.* 2010). Rare and threatened insects, being of no commercial value, have remained outside the focus of chemical ecology, and thus identified pheromones are generally lacking for these species. During the last decade, however, pheromones of threatened insects have begun to be identified and employed specifically for nature preservation purposes (Svensson *et al.* 2004; Larsson *et al.* 2009). The use of pheromones makes it possible to make thorough surveys with little effort on rare species for which the pheromones have been synthesized.

In this thesis, I have used pheromone-baited traps to screen the landscape in virtually the entire province of Skåne for the presence of *E. ferrugineus* and *O. eremita* at a large number of sites with hollow trees. The purpose has been to map the recent distribution of the beetles in the landscape and contribute valuable occupancy data and a landscape analysis for conservation and management purposes. *O. eremita* is normally regarded as a very demanding species in this type of habitat, although *E. ferrugineus* likely has stricter habitat requirements based on its comparative rarity. I have performed an analysis comparing occupancy data and evaluated the relationship between the two model species. Furthermore, I have characterized the habitat requirements in terms of hollow tree resources necessary for persistence of *E. ferrugineus* at different spatial scales. This analysis aims to reveal the beetles' spatial scale of response to its environment, and how it is influenced by the extreme patchiness of habitat resources that is characteristic of the Scanian landscape.

Materials and methods

Model Species

The beetles studied in this thesis, *Elater ferrugineus* and *Osmoderma eremita* are rare and seldom seen outside the tree trunks and are consequently difficult to study. Since *O. eremita* received the status High priority in the European union habitat directive, several studies have contributed to the current knowledge about the species concerning its habitat, distribution, and general biology (Ranius *et al.* 1997; Antonsson *et al.* 2003; Ranius *et al.* 2005). *E. ferrugineus* lives as a facultative predator in the same habitat as *O. eremita*, which is considered to constitute a major prey. Compared to *O. eremita*, *E. ferrugineus* has not been studied as extensively, and much of its biology is still unknown. The close relationship between them has been demonstrated in several studies (Svensson *et al.* 2004; Svensson *et al.* 2008; Larsson *et al.* 2011), and their overall habitat preferences appear to be very similar.



Figure 1: The model beetles and pheromone trap (upper left corner) used in this project. Releasing *O. eremita* and beside *E. ferrugineus*. 78 individuals of *E. ferrugineus* in one trap. All pictures were taken at Hallands Väderö 2010, copyright: Benjamin Forsmark.

Elater ferrugineus (Linnaeus, 1758) (order Coleoptera, family Elateridae) is the second largest (17-24mm) click beetle in the Swedish fauna (Figure 1). The larva of the beetle lives as a predator in the loose wood mould of hollow deciduous trees, where it feeds on the larvae of other saproxylic beetles (Palm 1955; Hansen 1966; Tolasch *et al.* 2007). The larva lives several years within the hollow before metamorphosis. The flight period typically spans from the beginning of July to the middle of August. The occurrence of the beetle is highly correlated with the occurrence of *O. eremita* (Ranius 2002b) and some other large scarabs, that are thought to constitute an important part of the larval diet. Svensson *et al.* (2004) showed that *E. ferrugineus* uses the sex pheromone of *O. eremita* as a kairomone (prey or host signal) to locate a suitable tree for their brood. It is therefore likely to find *E. ferrugineus* in the same habitat as *O. eremita*. Ranius (2002a) concluded that *E. ferrugineus* is among the most susceptible to habitat fragmentation, even more so than *O. eremita*. Today, it is considered *Vulnerable* in the Swedish red list (Gärdenfors 2010). Due to its rarity it has hardly been studied at all. Up to this investigation, *E. ferrugineus* has been reported from very few Swedish localities, and only 5 localities in Skåne, whereof only three in the last twenty years (Nilsson *et al.* 1994; Molander 2006). Recently, the active component of its female-produced sex pheromone was identified as 7-methyloctyl (Z)-4-decenoate (Tolasch *et al.* 2007; Svensson *et al.* 2011a). The compound has been shown to be highly attractive to males (Svensson *et al.* 2011a). The use of this pheromone makes it possible to survey and study the beetle to a far greater extent than previously possible.

The larvae of ***Osmoderma eremita* (1763)** (order Coleoptera, family Scarabeidae) feed off the solid, but often fungal infested, wood enclosing trunk cavities of deciduous trees. Through this activity the cavity is enlarged and wood mould is formed (Ranius *et al.* 1997; Ranius *et al.* 2005). By making loose wood mould available in the tree hollow, *O. eremita* together with a few other Scarab beetles (*Gnorimus*, *et al.*) pave the way for other insects. Ranius (2002b) demonstrated a positive correlation between presence of *O. eremita* and a high biodiversity of other saproxylic insects. The population size is larger in trees with more wood mould. The amount of wood mould depends on the age and the size of the tree (Ranius *et al.* 2009). After approximately 4 years, depending on substrate quality, the 25-35 mm large imago beetle emerges from its pupa (Figure 1). The beetle is very attached to its natal tree. Only 15 % of the individuals leave the tree as adults (Ranius *et al.* 2001; Hedin *et al.* 2007). Moreover, the beetle is a poor flyer and the longest recorded flight distance in Sweden is about 500 m (Ranius *et al.* 2001; Hedin *et al.* 2007; Larsson *et al.* 2011). Its reluctance to leave the tree and low flying propensity makes it a poor disperser and colonizer.

The beetle is considered Near Threatened in the Swedish red list (Gärdenfors 2010). In 1992, *O. eremita* was listed in the European habitat directive as a protected species with the highest priority (Anonymous 1992). Since then a national survey has been performed in Sweden. In total, 130 sites were considered to house a population (Antonsson *et al.* 2003). In Skåne, where the present study has been done, 16 recent (+5 from 1936 and earlier) localities are known to house the beetle (see Figure 2 and Appendix).

Adult *O. eremita* are well known for their characteristic, fruity odour. Svensson *et al.* (2003) demonstrated that this odour is a male-produced pheromone attracting dispersing females. The identification of this pheromone constitutes the first identification of a pheromone of a threatened species specifically for conservation purposes.

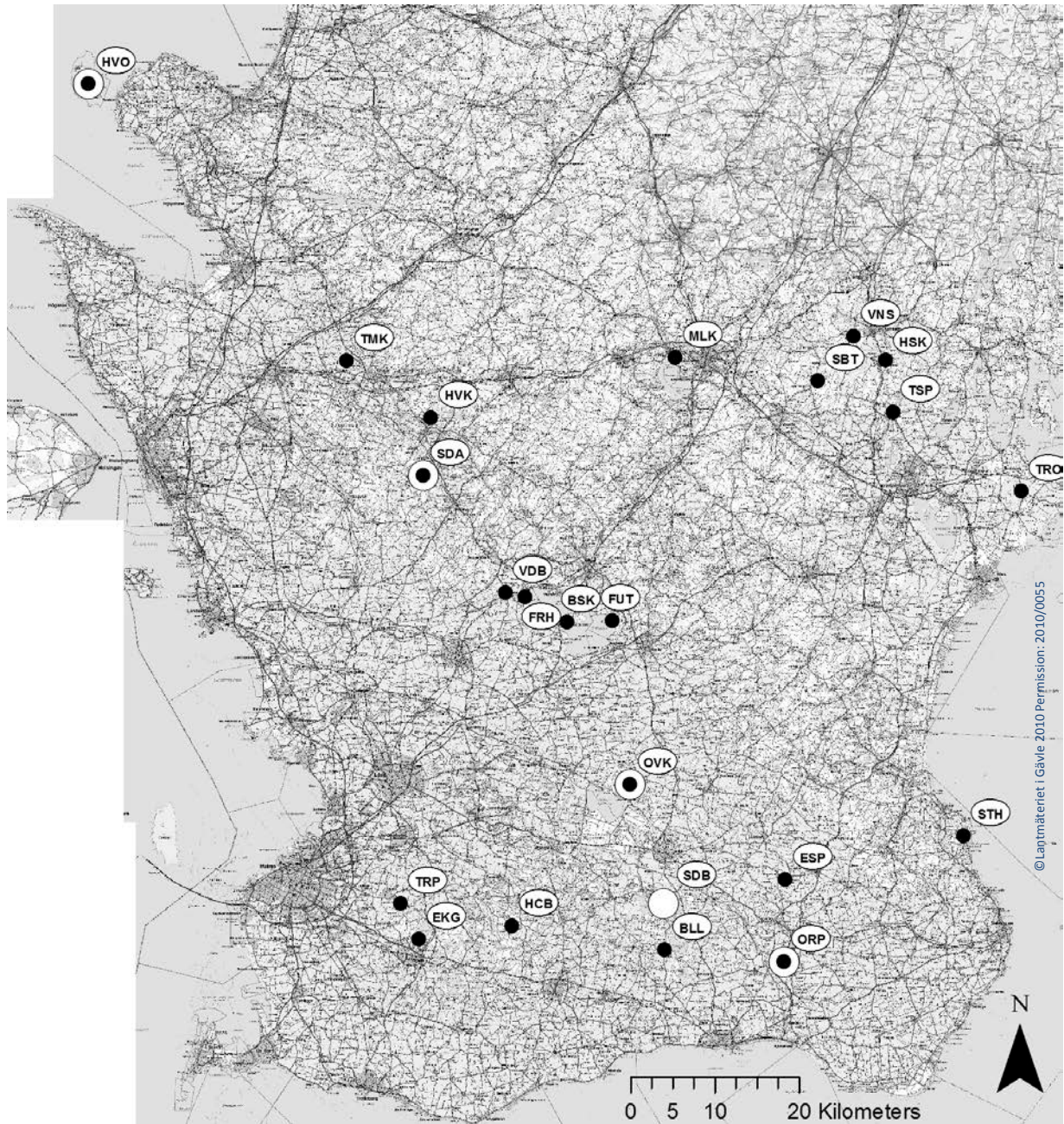


Figure 2: Previously known localities for *E. ferrugineus* (white circles) and *O. eremita* (black circles). At five localities (ESP, HVK, ORP, TRO and VDB), *O. eremita* has not been reported in the last 70 years, and *E. ferrugineus* has not been reported from Söderåsen (SDA) since 1882. Full name of localities to be found in appendix. Maps reproduced with permission: ©Lantmäteriet i Gävle 2010. Permission 2010/0055.

Giant tree database

During 2002 to 2009, surveys of giant trees have been performed in the county of Skåne. The purpose has been to map the distribution of suitable habitat for saproxylic fauna. Parts of the survey have been performed by the nature preservation agency (naturskyddsföreningen) and certain municipalities. However, most of the surveys have been performed by the county administrative board of Skåne, who also has compiled and provided me with the dataset. In this project, the dataset was initially used to locate sites potentially constituting a suitable habitat for the species in question. For the spatial analysis the dataset was divided into different characteristics and reorganized into densities at varying spatial scale from each site (see Habitat factors). 56,000 trees of 64 species, including subspecies and exotic trees have been mapped. However, a few species constitute the majority of the material. The two dominating species are oaks and beeches contributing 21,500 and 12,000 trees each. In most cases, data on tree species, diameter, occurrence of hollows and spatial localization (coordinates) has been collected for each tree. In a few cases, extensive data deficits were found in the tree data, and sites affected by this had to be excluded in the spatial analysis. For the purpose of visualizing the density of giant trees in different areas of Skåne, the tree dataset was converted into a raster using the ArcGIS “point to raster - conversion tool” (Figure 3).

Study area and field sites

The present study has been performed in the county of Skåne, the southernmost region of Sweden. The studied area covers approximately 11'000 km². The region is highly affected by anthropogenic activities. With dominance in the northern part, only 30% of the region is forested (Brunet 2005). Since most parts of these forests are subject to active forestry, trees rarely grow old and form the substrates essential to saproxylic fauna. Only a fraction of these forests are habitable for the beetles. A habitable forest has to be old and not too dense. To cope with the climate, sun-exposed stems are considered to be of particular importance. These are found in sparse woodland and cattle pastures where grazing cattle kept the landscape open. These are of the highest interest for saproxylic fauna (Ranius *et al.* 2000).

An array of localities with varying qualities for saproxylic fauna has been surveyed. In total, 83 localities were sampled during the field seasons (summer) 2010 and 2011 (Figure 3). The surveyed sites cover a spectrum of dead wood habitats of varying size, age and tree species composition. All localities (Nilsson *et al.* 1994; Antonsson *et al.* 2003; Molander 2006) where either *E. ferrugineus* or *O. eremita* been recorded from 1851 and forth has been sampled, with exception for four localities where neither beetle been observed during the last century and where the habitat has been destroyed. All data were not collected within the timeframe of this thesis, but to a great extent originate in previous surveys (field season 2010 and 2011) where I collected data for other experimental purposes.

Field trapping

At each locality, beetles were sampled by the use of one or several pheromone baited funnel traps (Svensson *et al.* 2008) (Figure 1). The trap is constructed from two black plastic discs intersected over a funnel to a plastic jar. The trap mimics a tree hollow and the pheromone lures the beetles to fly into it, and fall down in the plastic jar where it is kept alive until the trap is emptied and the beetle released. Each trap was baited with 500 μ l of neat, racemic gamma-decalactone, the male-produced sex pheromone of *O. eremita* (Svensson *et al.* 2004; Svensson *et al.* 2008). The *O. eremita* pheromone was loaded in a 4 ml-glass vial with a dental roll as a wick to disperse the pheromone in copious amounts. In parallel, the trap was baited with 2 μ l of neat, single-component, female-produced sex pheromone of *E. ferrugineus* (Tolasch *et al.* 2007; Larsson *et al.* 2011) loaded in a PCR tube pierced with an insect pin size 3 to release the pheromone. The trap was hung from a branch in a suitable tree in a position as central as possible in the stand. In a few cases, the central point was not possible to reach due to landowners' restrictions or landscape barriers etc.; then the trap had to be placed in a more peripheral position in the stand. In a few cases more than one trap were put up at each locality. In most cases, this was done to get appropriate coverage at large localities. At five localities: Torup (TRP), Snogeholm (SNH), Sövdeborg (SDB), Örup (ORP), Övedskloster (OVK) during 2010, trapping was partly performed for the purpose of mark-recapture experiments (compare Larsson *et al.* (2011) and Svensson *et al.* (2011b)). In these trials, between eight and fourteen traps were active at the time. Closely situated traps compete for captures. This leads to a smaller average capture rate at these localities. The distance between traps at different localities is at least two kilometers and at these distances, competition will not be a problem (Larsson *et al.* unpublished).

Traps were put up during June and then left out to the end of August. In some cases, trapping at individual localities was terminated when enough individuals of the target species were captured to indicate the presence of a local population. In other cases, traps were repeatedly removed and replaced as part of a mark-recapture scheme, thus shortening the total time that active traps were present. For the purpose of comparing trap effort, the capture period has been calculated as the time a trap has been active (in place and baited) during the flight period of the beetles.

Habitat factors

Only few investigations on the species have been performed. Previous research (Palm 1955; Tolasch *et al.* 2007) suggests *E. ferrugineus* depend entirely on hollow deciduous trees. Its frequent co-occurrence with *O. eremita* (Larsson *et al.* 2011), indicates habitat parameters assessed for *O. eremita* would generally be valid also for *E. ferrugineus*. The characteristics of a tree hollow affect the suitability for saproxylic fauna. In an assessment (Ranius *et al.* 2009) concluded that an increasing volume of wood mould, the growth rate and age of the tree affects the resident population sizes of *O. eremita*. The size and position of the stem also plays a role; a thick sun-exposed stem gives a warmer and drier microclimate which is beneficial for *O. eremita* (Ranius *et al.* 1997). A tree needs to reach a certain age before hollows can be formed. Ranius *et al.* (2009) assessed the time it takes to form hollows in *Quercus robur*, and found that hollows were more frequent in trees older than 200 years. The older a tree gets, the longer time it has been more exposed to stochastic events, such as adjacent trees falling over it, shedding of branches, or atmospheric violence as being struck by lightning or broken down by storm, and to fungal attacks. These events often initiate the formation of hollows. As the trees are aging, their trunks get thicker which is another important factor for saproxylic fauna. The size enables a large mould-filled hollow to form; a large tree sometimes has hollows even though none may have been found when the tree survey was performed. All trees from those containing only a single visible hollow, to dead standing logs totally perforated by hollows were regarded “hollow” in this thesis.

The frequency of different tree species in the database partly reflects their ability to form hollows, with oaks and beeches being among the most common, but also reflects their general presence in the landscape. Harder wood decays slower than softer, and generally forms more durable hollows. The tree has to reach a certain degree of trunk decay to form hollows. The decay stadium affects the structure of the wood, as well as its chemistry and different biotic factors. These beetles are incapable of inhabiting fresh wood and are hence dependent on other species to open the cavity. In this analysis the trees in the database were grouped based on three parameters; tree species, occurrence of hollows, and size (trunk diameter at breast height) (Table 1). To get manageable groups, the tree dataset was initially divided into eight groups of trees (Table 1). The categorization of the tree material was at first based on numerically prominent taxa of trees. Smaller groups of trees have been sorted based on wood types and phylogeny, assuming the different species affects the ability to form hollows and also the amount of wood mould. The first (*Quercus*) and the second (*Fagus*) category contain only one genus (practically only one species) each. The third and the fourth group (Hardwood 1 and 2) are polyphyletic groups, categorized based on the density of the wood. The hardest trees are in category three and the softer in the fourth. The following three categories are paraphyletic, aggregated based on their close relationship. At last, the eighth category contains conifers. These are not considered inhabitable by *E. ferrugineus* but were included as a negative control.

Each group was further subdivided into four additional groups based on hollow stage and size. Classification of hollow stages in the tree database follows that of (Antonsson 2001b), but were in my study reclassified as non-hollow or hollow. The trees were finally divided into groups based on size. A tree was classified as large if its diameter at breast height exceeded 100 cm.

Table 1: Tree categories tested for impact on *E. ferrugineus* occupancy. Radius refers to the characteristic scale where the factor has the highest explanatory effect on occupancy of *E. ferrugineus*. Categories where responses were significant at the 5% level ($Z > 1.97$ / $WALD > 3.88$ correspond to $P < 0.05$) are shaded grey.

Tree category	Species	Hollow stage	Size	Number of trees	Radius	P-value	Z-value	WALD
All trees	All	All	All	55673	4658	0.016	2.42	5.8564
		Hollow	Large	7582	1751	0.011	2.54	6.4516
			Small	22856	5357	0.01	2.57	6.6049
		Without hollow	Large	6206	4658	0.022	2.29	5.2441
			Small	16171	4658	0.064	1.85	3.4225
Quercus and Fagus	all	all	all	33799	9370	0.001	3.51	12.3201
Quercus	Quercus sp.	All	All	21566	7085	0.105	1.62	2.6244
		Hollow	Large	3645	1152	0.015	2.43	5.9049
			Small	5805	3522	0.331	0.97	0.9409
		Without hollow	Large	3642	4658	0.051	1.95	3.8025
			Small	7737	142	0.279	-1.08	1.1664
Fagus	Fagus sp.	All	All	12233	7085	0.017	2.39	5.7121
		Hollow	Large	2367	7085	0.019	2.35	5.5225
			Small	4235	6161	0.015	2.44	5.9536
		Without hollow	Large	1566	4658	0.018	2.37	5.6169
			Small	3506	3063	0.005	2.78	7.7284
Hardwood 1	Ulmus glabra Carpinus betulus Castanea sativa	All	All	2143	8148	0.003	3.01	9.0601
		Hollow	Large	117	4051	0.276	1.09	1.1881
			Small	1125	9370	0.001	3.24	10.4976
		Without hollow	Large	106	2664	0.297	-1.04	1.0816
			Small	500	70	0.082	1.74	3.0276
Hardwood 2	Acer platnoides Aesculus hippocastanum Fraxinus excelsior Tilia cordata	All	All	16377	658	0.058	1.9	3.61
		Hollow	Large	1137	5357	0.092	1.68	2.8224
			Small	9767	658	0.062	1.87	3.4969
		Without hollow	Large	762	658	0.149	1.44	2.0736
			Small	3789	1001	0.22	1.23	1.5129
Rosaceae	Malus sp. Prunus avium Pyrus communis Sorbus intermedia Sorbus intermedia	All	All	1246	7085	0.027	2.21	4.8841
		Hollow	Large	14	2665	0.276	1.09	1.1881
			Small	1000	7085	0.017	2.38	5.6644
		Without hollow	Large	8	187	0.064	1.85	3.4225
			Small	125	658	0.331	0.97	0.9409
Salicaceae	Salix sp. Populus sp.	All	All	1594	123	0.073	1.79	3.2041
		Hollow	Large	269	4051	0.25	-1.15	1.3225
			Small	839	7085	0.053	1.93	3.7249
		Without hollow	Large	66	3063	0.058	1.9	3.61
			Small	234	187	0.224	1.22	1.4884
Betulaceae	Alnus glutinosa Betula sp.	All	All	1375	9370	0.003	3	9
		Hollow	Large	36	4051	0.137	1.49	2.2201
			Small	1006	9370	0.003	3.01	9.0601
		Without hollow	Large	20	4051	0.071	1.81	3.2761
			Small	238	658	0.279	-1.08	1.1664
Pinaceae	Larix decidua Picea abies Pinus sylvatica	All	All	385	2316	0.047	1.99	3.9601
		Hollow	Large	11	871	0.059	1.89	3.5721
			Small	79	3063	0.071	1.81	3.2761
		Without hollow	Large	44	215	0.137	1.49	2.2201
			Small	167	4051	0.039	2.07	4.2849
Others	-	-	-	1516	-	-	-	-

Landscape analysis

In this analysis, the amounts of different categories of trees (Table 1) at different spatial scale levels were evaluated as explanatory variables of the landscape distribution of *E. ferrugineus*. In practice, 45 concentric circles with increasing radii were fitted around each site from the position of the trap (or a central trap in case of several traps per locality). The radius of the inner circle was set to 20 m, based on the accuracy in the measurements of the coordinates in the tree layer. The radii of the outer circles were then fitted at gradually increasing intervals to the largest radius at 9000 m (Figure 4). The tree density (number of stems per unit area) for each category of trees was then calculated separately within each circle (using a macro developed by Per Milberg executed in Microsoft Excel 2010™). The correlation between occupancy of a population of *E. ferrugineus* and the density of trees in each category was tested by a binary logistic regression in MINITAB™. For each category of trees, the output will be 45 Z-values (one for each radius). The Z-values obtained in this test shows the association between the factor and the occurrence of a population, where a positive value indicates a positive correlation. The squared Z-value gives an effect value (WALD) that gives the explanatory strength on population occurrence of specific factors at specific spatial scales. A strong explanatory strength indicates the factor has a high impact on the occurrence of a local population of *E. ferrugineus* (in this thesis regarded significant if $WALD > 3.88$ (corresponding to $P < 0.05$)). The radius where the factor has the highest explanatory strength (highest WALD-value) is where the factor has the highest effect on the occurrence on *E. ferrugineus*. This radius is hereafter referred to as the characteristic scale of response.

Due to data deficits in the tree material, 5 sites had to be completely excluded in this analysis (Borgen, Forsakar, Hallands väderö, Pålsjö skog and Sörbytorp). For Bosjökloster tree data were available, but lacked information about diameter and hollow stage of trees. Therefore this site was only included in analyses comprising all trees of a given taxonomic group, but excluded from analyses comprising trees of specific diameters and hollow stages. Trapping data from 77 or 78 sites were thus used in this analysis.

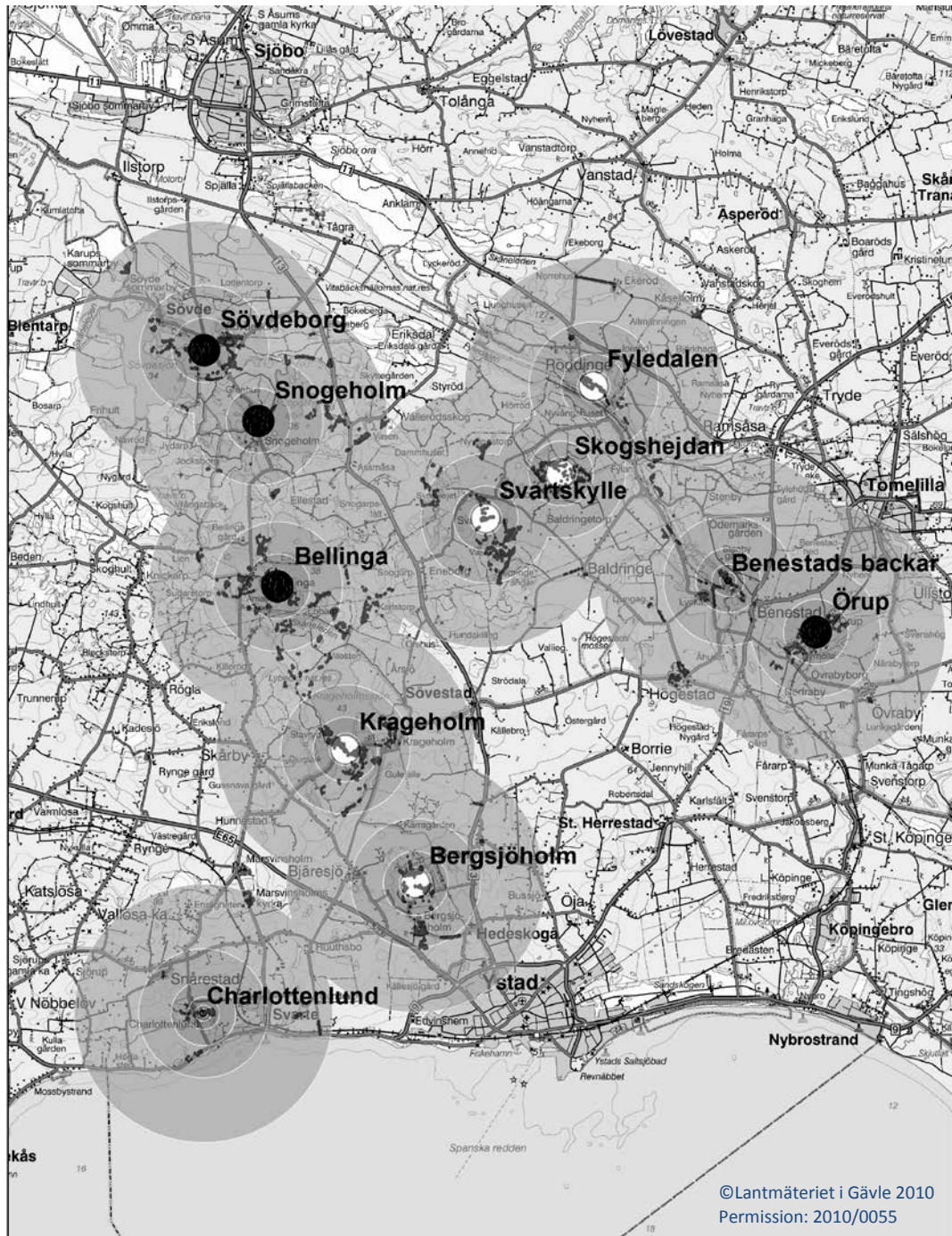


Figure 4: The figure shows the circles around and capture data from 11 (of the total 78) localities in southern Scania. Tree densities were calculated within each circle. Only five circles spanning from radii of 100 to 3000 m are shown in this figure, whereas 45 radii from 20 to 9000 m are included in the analysis. Black dots represent a local population, and white dot represent stray captures. 6000 trees from the tree database, shown as small black dots, are also mapped. Note the clustering of giant trees primarily around large estates, which is typical for the Scanian landscape. Maps reproduced with permission: ©Lantmäteriet i Gävle 2010. Permission 2010/0055

Result

Captures of *E. ferrugineus*

In total, approximately 1700 individuals of *E. ferrugineus* were captured on 21 localities from beginning of July to the first half of August (Figure 5). A considerable majority of the captures were recorded at a few localities, indicating that these are inhabited by a local population, whereas the others likely only recorded dispersing individuals. To direct management actions, and for the landscape analysis performed in this study, it is essential to differentiate localities where only stray captures of dispersing beetles had been captured from localities where a local population is situated. The high dispersal rate and long flight distances recorded for *E. ferrugineus* males (Larsson *et al.* unpublished), together with the high efficiency of the pheromone traps, makes it possible to record captures in traps several kilometers from a local population. The question for my landscape analysis was what factors in terms of tree densities affect the capacity of a site to sustain a population of *E. ferrugineus*. To separate stray captures from a local population, the number of captures per effort (individuals/trap/day) has been calculated for each locality (Figure 6). Based on this analysis, only 8 localities were considered to house a local population of the beetle (Figure 5 and Figure 6). Captures are mapped in Figure 7.

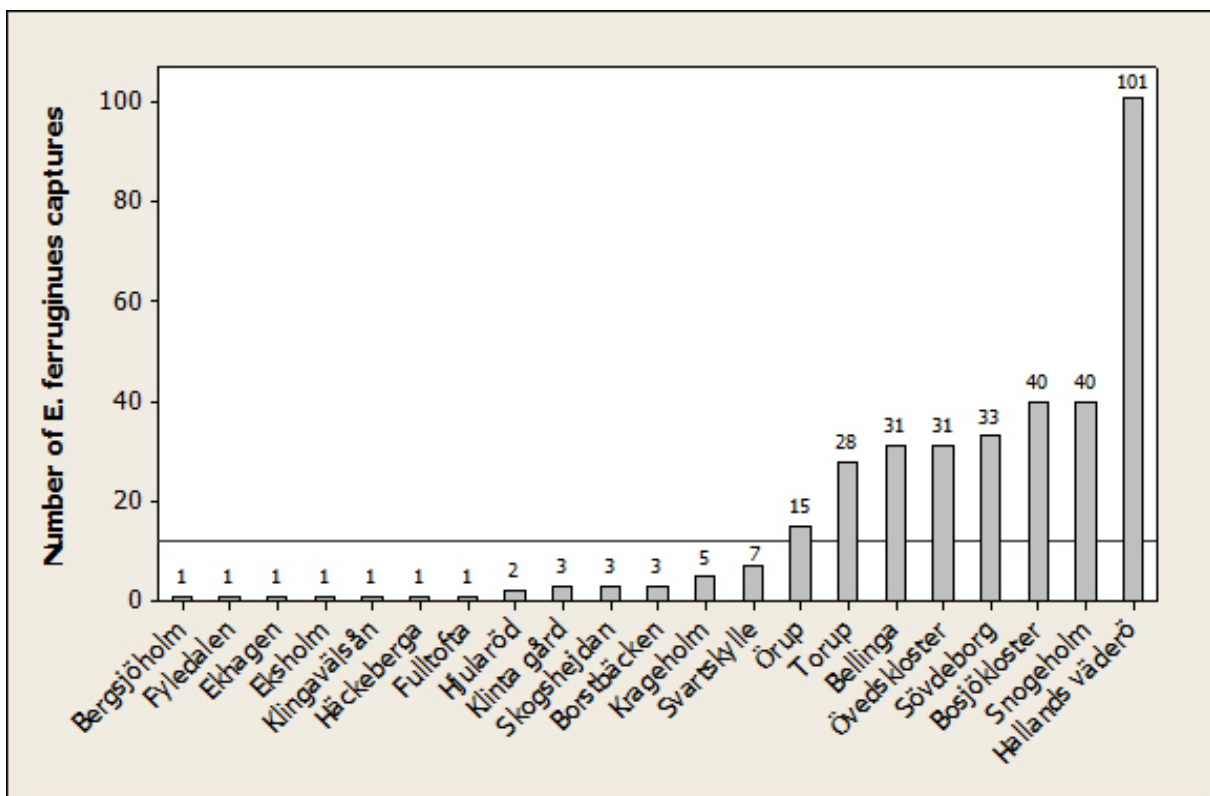


Figure 5: Localities where *E. ferrugineus* was captured. The eight localities to the right are considered to house a local population of the beetle. The number of captures is specified at each bar (the maximum number of captures in a trap is presented for localities where more than one trap has been used or where beetle sampling has been performed during both years).

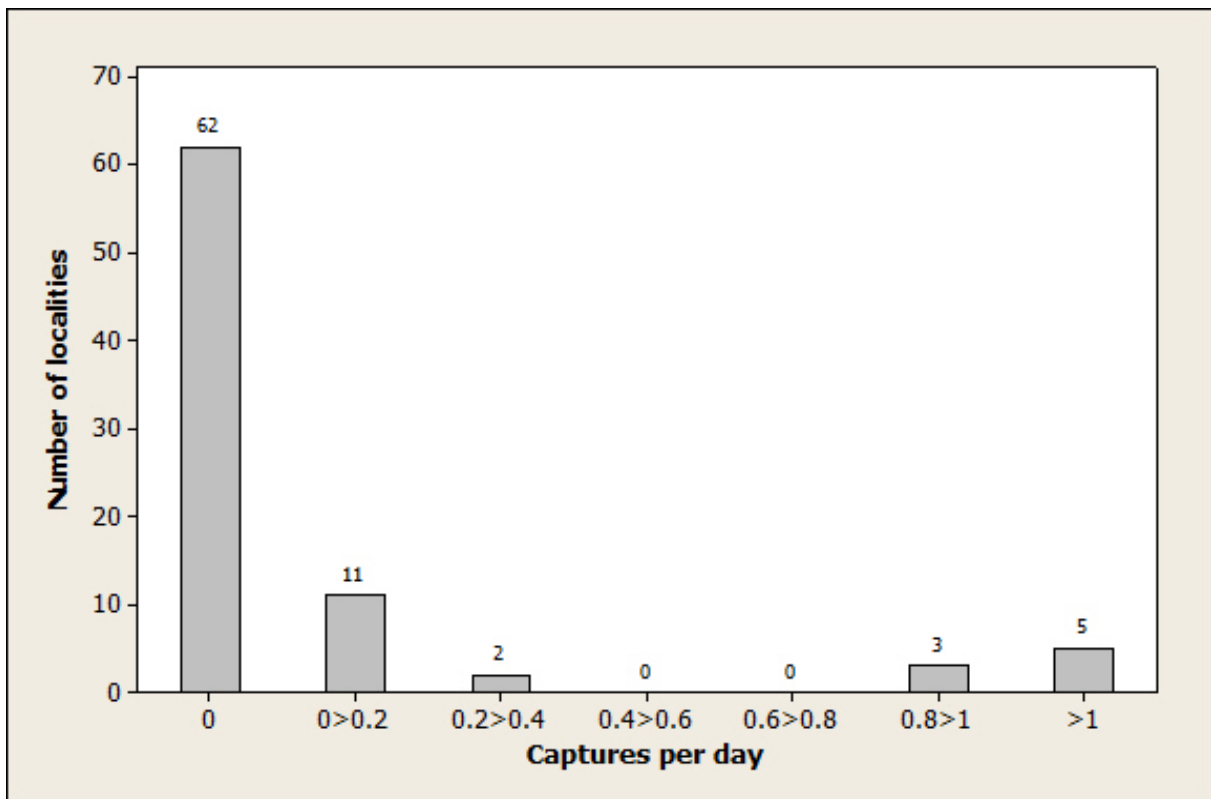


Figure 6: Frequency of *E. ferrugineus* captures per day in a single trap per locality. Localities where more than 0.8 captures per day were recorded (to the right of the gap in the frequency distribution) are considered to house a local population.

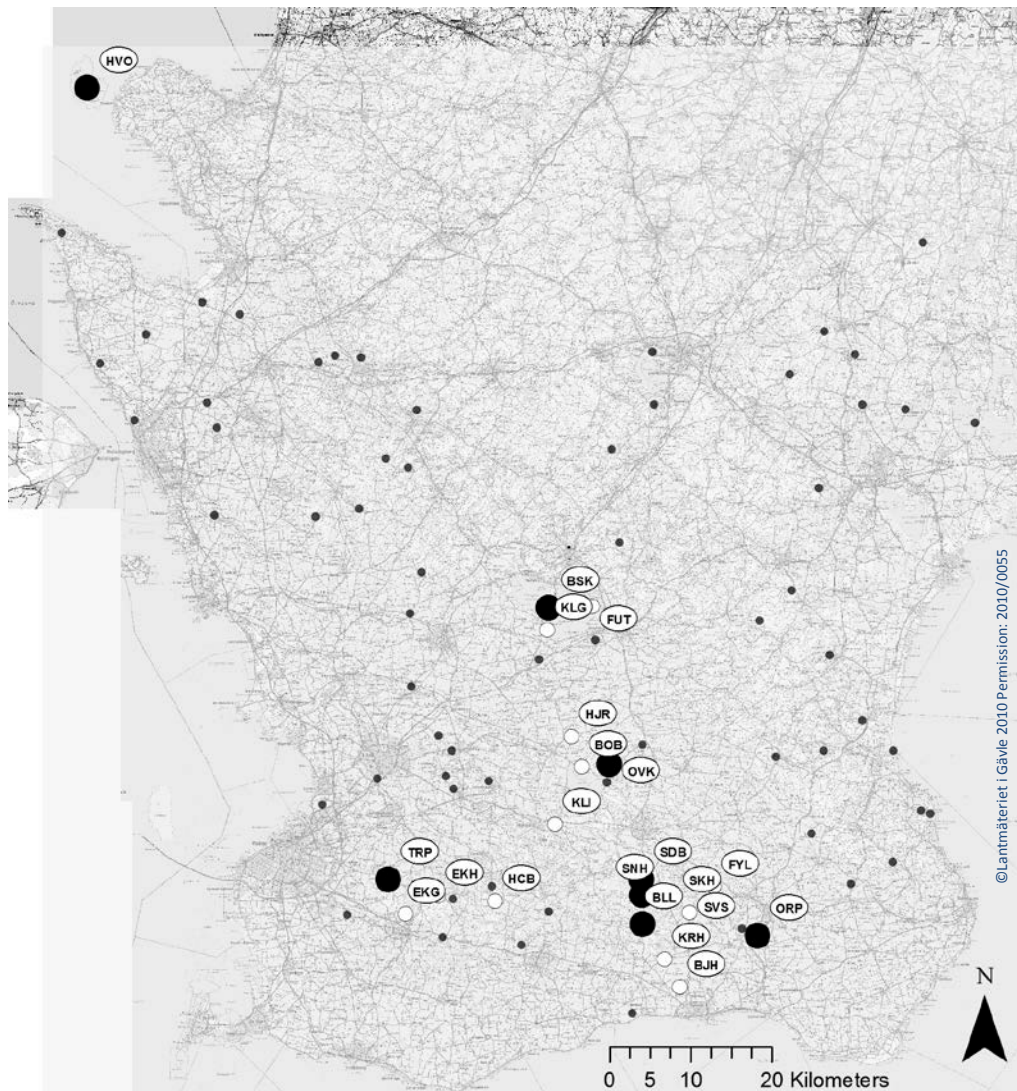


Figure 7: Captures of *E. ferrugineus* at different field sites. Only a small minority of sites captured the species. Big black dots show local populations and white dots show where considered stray captures of dispersing individuals were captured. Sites where no captures been recorded are displayed as small black dots. Full name of localities are listed in appendix. Maps reproduced with permission: ©Lantmäteriet i Gävle 2010. Permission 2010/0055.

Captures of *O. eremita*

In total, 44 individuals of *O. eremita* were captured at 11 localities from mid-July to mid-August (Figure 8). The short flight distances of no more than a few hundred meters recorded for the species, (Ranius *et al.* 2001; Hedin *et al.* 2007; Larsson *et al.* 2011) makes me conclude that all individuals of *O. eremita* captured derive from a local population close to the trap position. At several localities where the beetle previously had been reported (compare Figure 2 and Figure 8), the beetle was not captured in this survey. The low dispersal rate and flight distances make the trapping efficiency relatively low. The trapping effort directed towards *O. eremita* in this survey might be too low to definitely regard the beetle as absent from a site. The beetle was consequently excluded from the spatial analysis.

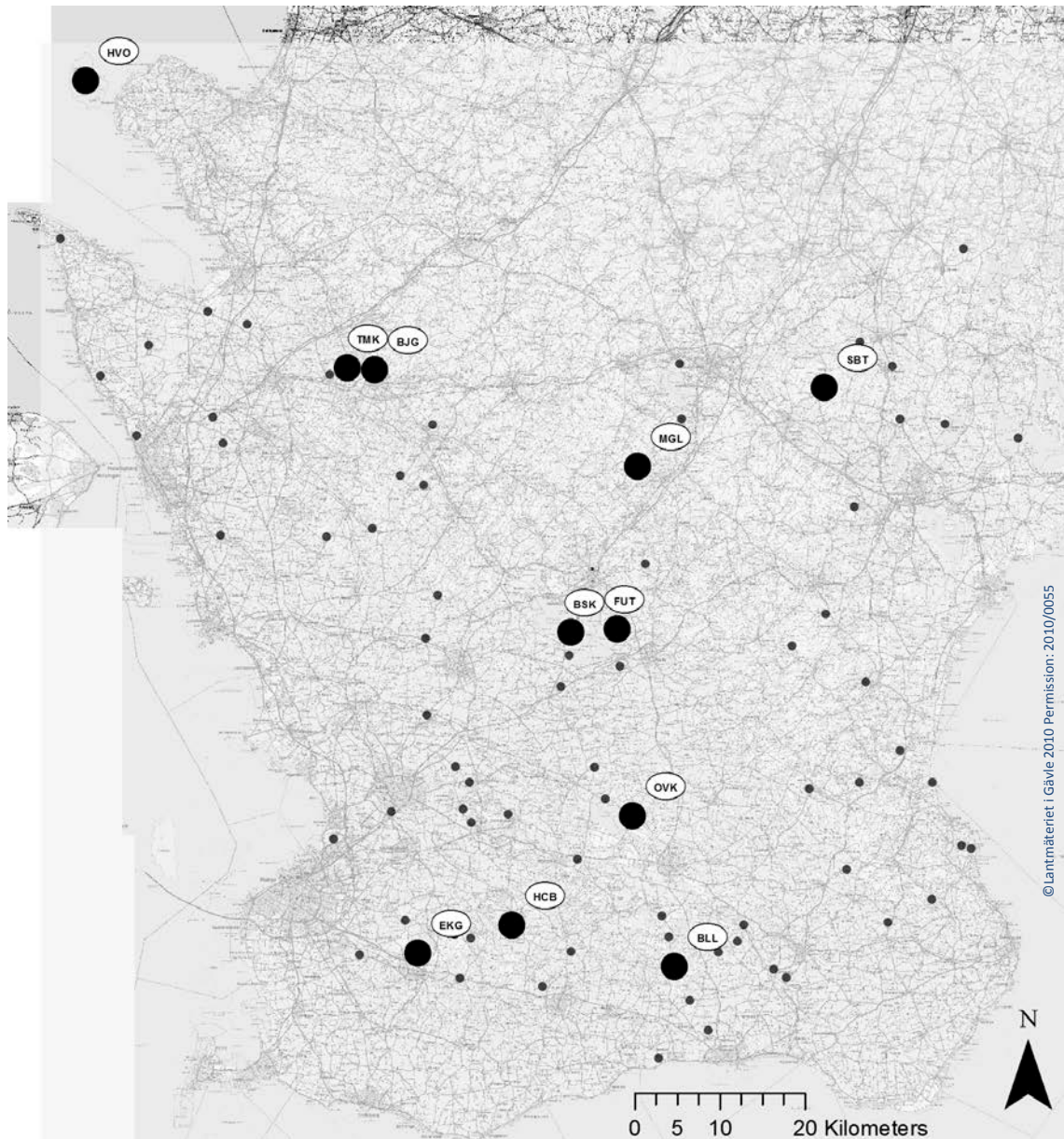


Figure 8: Captures of *O. eremita* are displayed as big dots and absences as small dots. Full name of localities to be found in appendix. Maps reproduced with permission: ©Lantmäteriet i Gävle 2010. Permission 2010/0055

Distribution of *E. ferrugineus* and *O. eremita*

Except for Hallands väderö, the distribution of *E. ferrugineus* was limited to a region from the towns Höör in the north, Svedala in the west and Tomelilla as its easternmost distribution limit. The beetle appears to be completely absent from the northern Scanian mainland (Figure 7). Four of the eight localities where *E. ferrugineus* was considered resident were at previously unknown sites: Bellinga (BLL), Bosjökloster (BSK), Snogeholm (SNH), and Torup (TRP) (Figure 9). Two of the *O. eremita* captures were previously unknown sites: Bjärsgård (BJG) and Maglö ekar (MGL). The distribution was not restricted to the southern parts, as for *E. ferrugineus*, but the beetle was captured at several locations in the northern parts of Skåne. The distribution of the beetle appears to be more scattered in the landscape, and captures were recorded even in small isolated localities all over the region.

At four localities: Bellinga (BLL), Bosjökloster (BSK) Hallands väderö (HVO) and Övedskloster (OVK), both beetles were found together whereas at most *O. eremita* localities *E. ferrugineus* was absent (Figure 8). At the other four localities where *E. ferrugineus* was found: Snogeholm (SNH), Sövdeborg (SDB), Torup (TRP), and Örup (ORP), *E. ferrugineus* was found in the absence of *O. eremita*. Some of these might reflect our failure to detect the latter species, although recent extinctions of *O. eremita* cannot entirely be ruled out, considering the extensive trap effort at these sites. At 7 sites: Bjärsgård (BJG), Ekhagen (EKG), Fulltofta (FUT), Häckeberga (HCB), Maglö ekar (MGL), Sörbytorp (SBT) and Tomarps kungsgård (TMK), *O. eremita* was captured but no *E. ferrugineus* population appears to persist at these sites. *O. eremita* has previously been reported from 21 localities in Skåne. 9 of these were verified in this project and two previously unknown localities were identified: Maglö ekar (MGL) and Bjärsgård (BJG). Pheromone trapping in this project did not record any *O. eremita* at 8 previously known localities: Hanaskog (HSK), Herrevadskloster (HVK), Mölleröds kungsgård (MLK), Stenshuvud (STH), Torsebro (TSP), Torup (TRP), Vanås (VNS) and Örup (ORP) (Figure 9). The trapping effort in this project is not enough to definitely consider the beetle absent from these sites. Four previously known localities were not surveyed in this project: Fairyhill (FRH) close to Bosjökloster (BSK) and three localities where the beetle latest where recorded during the nineteenth century (see Appendix).

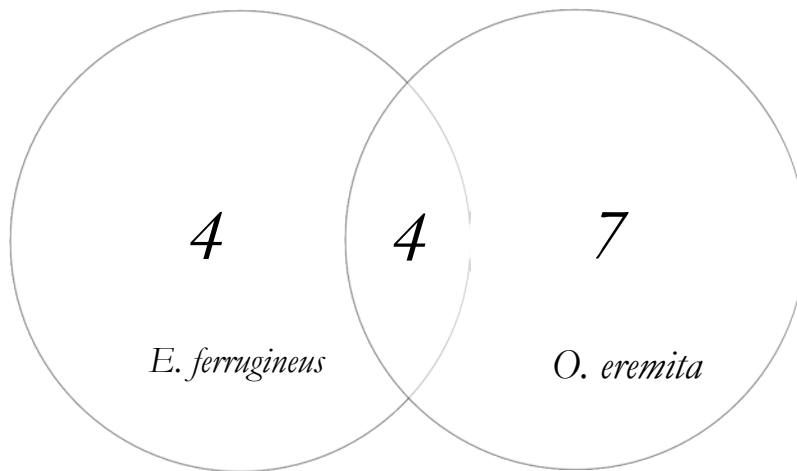


Figure 9: Venn diagram showing population overlap of the species in this investigation. The number of sites where the species were found together are specified in the intersect region (Bellinga, Bosjökloster, Hallands väderö, and Övedskloster). In the four localities where only *E. ferrugineus* was found, *O. eremita* might still be present, whereas the absence of *E. ferrugineus* at 7 localities most likely reflects a true absence of the species.

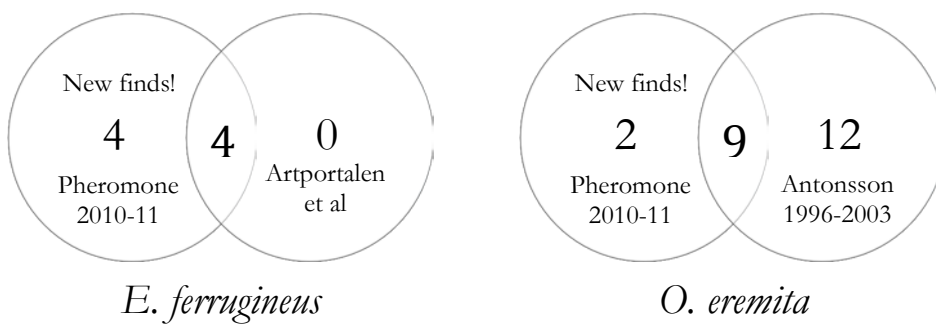


Figure 10: Records of *E. ferrugineus* and *O. eremita* at different sites in this investigation, compared with records from previous surveys.

Landscape analysis

In the fragmented Scanian woodland, as traps were usually placed within large stands of trees, tree density generally showed a decreasing trend at greater distances from the trap. The average tree density decreased from the smallest radius with 12.39 trees ha⁻¹ to 0.08748 trees ha⁻¹ at the largest radius. At sites where *E. ferrugineus* was found, the average density at the smallest radius was 12.52 trees ha⁻¹, and 0.1316 trees ha⁻¹ at the largest radius, indicating that the greatest explanatory differences between sites were found at larger radii.

The landscape analysis with gradually expanding radii showed that *E. ferrugineus* responded significantly to tree densities at specific scales. Many categories of trees showed a slight negative, but non-significant ($Z > -1.97$) correlation to tree densities at the smallest radii, especially for small and non-hollow trees (Figure 11). However, the absence of significant negative responses indicates that none of the tested categories have a negative impact on occupancy of *E. ferrugineus* (Table 1). The explanatory strength tended to increase with increasing radii, but remained in most cases insignificant out to 1000 m (Figure 11 and Figure 12). Significant explanatory strength ($Z > 1.97$ /WALD > 3.88) was recorded in 19 out of 47 categories, and overall at very large spatial scales. Only 4 categories were significant at < 1000 m (large hollow Quercus, large hollow beeches, all large hollow trees and all rosales) and 11 groups were significant at the largest radii. Groups based on tree characteristics, regardless of tree species, showed a significant response in all cases except for small nonhollow trees. The characteristic scale of response varied between 1751 to 4658 m from large hollow to large nonhollow trees. Significant response for oak density was only recorded with large hollow trees. Response was recorded already at 560 m for this category, and was significant out to 6000 m. Characteristic scale of response for this group was 1152 m. A sum of densities of all beeches and oaks resulted in significance from 2000 m, with increasing WALD-values all the way out to the largest radius. In Hardwood1, dominated by *Ulmus glabra* and *Carpinus betulus*, significant responses were recorded from 2000 m to all trees and small hollow trees. The scale of response extended to the largest radii with an increasing explanatory power. For Hardwood2, mostly constituted by *Tilia cordata* and *Fraxinus excelsior*, no significant response was recorded, even though the groups were large. A counter-intuitive significant response to conifers was recorded. In two cases, small nonhollow and all conifers, *E. ferrugineus* responded positively and significantly to tree densities at a spatial scale between 2000 and 4000 m.

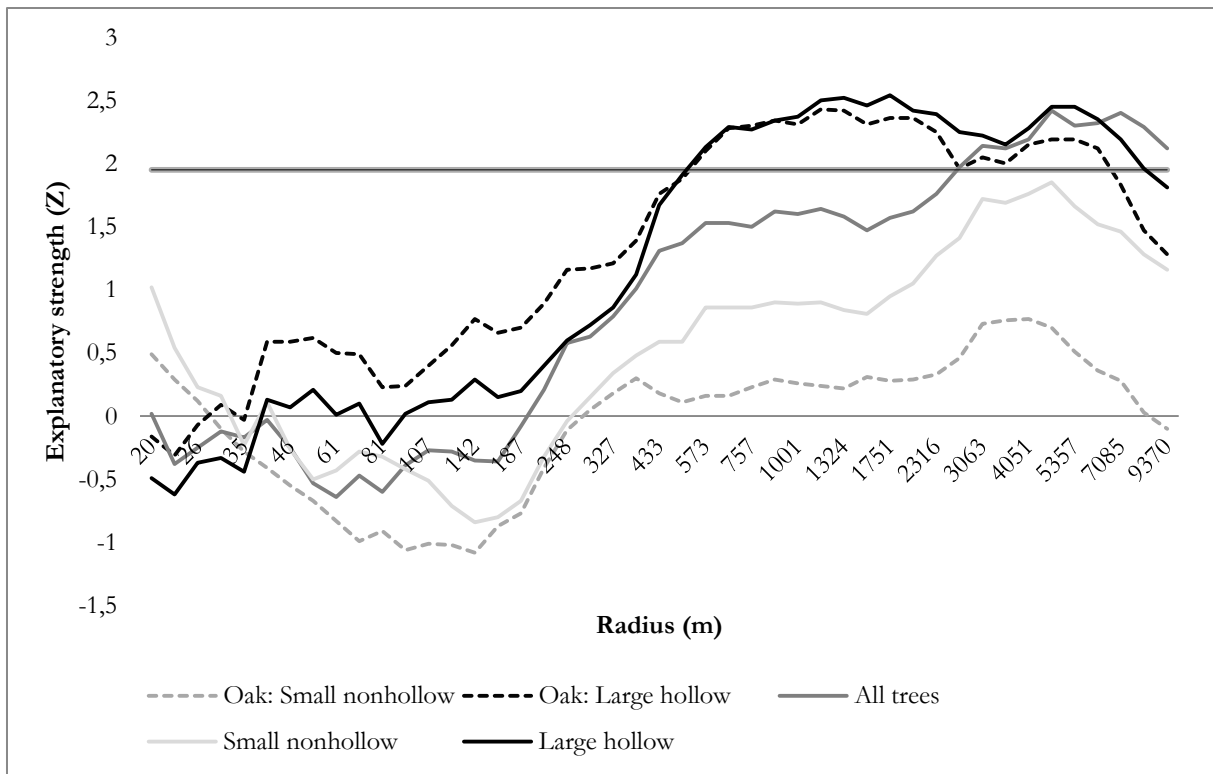


Figure 11: Example of responses to tree densities of two categories of oaks and three compound categories. Explanatory strength increases with Z-value, and the highest Z-value is where the strongest response is recorded, referred to as the characteristic scale of response. A positive Z-value indicates a positive correlation between occupancy of local *E. ferrugineus* populations and the resource. A response is significant when $Z > 1.97$ (corresponding to $P < 0.05$).

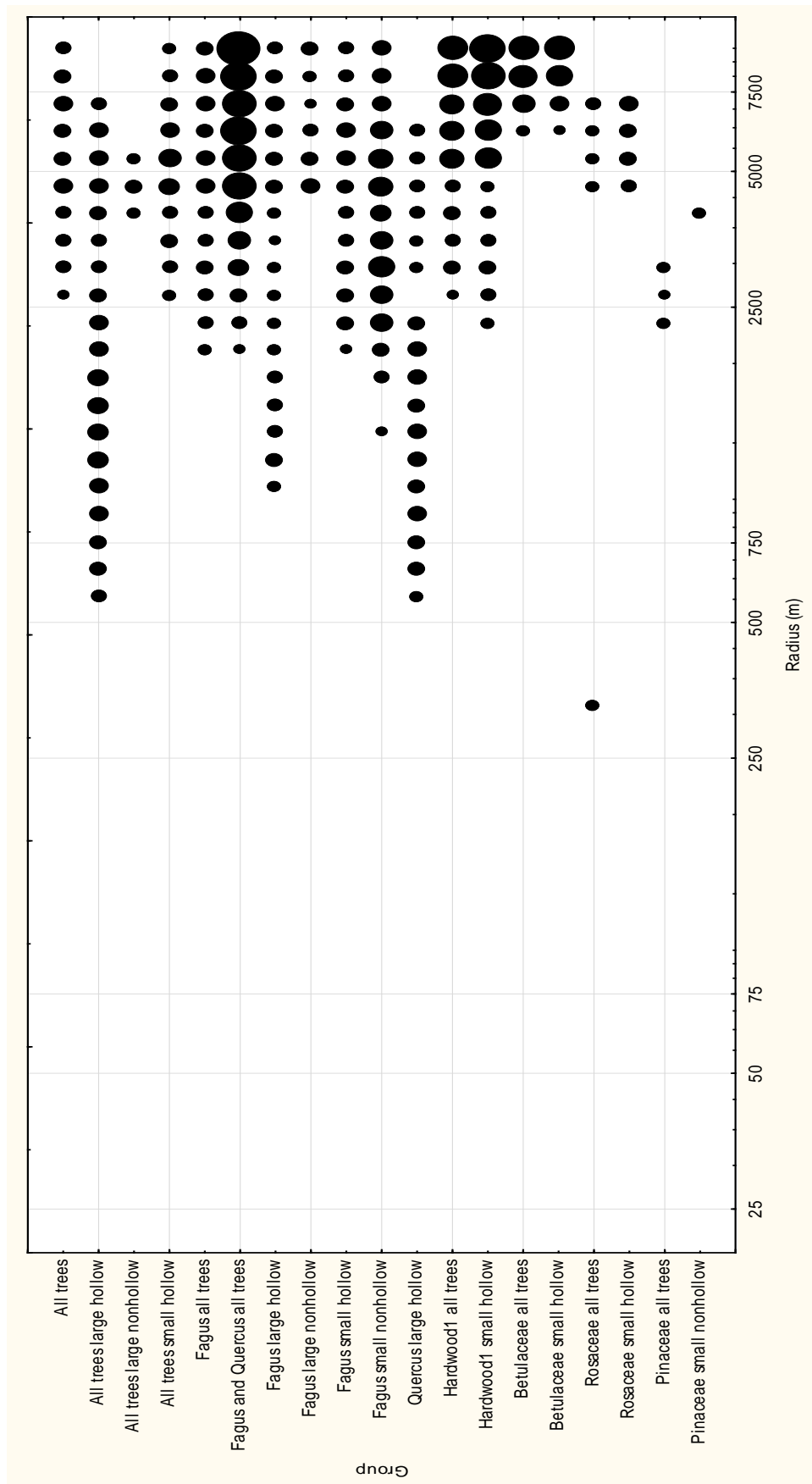


Figure 12: Categories of trees and the scales where significant responses in occupancy of *E. ferrugineus* populations were recorded. The size of each circle is proportional to the Wald value (i.e. explanatory strength). At each trap site, the density of trees of different categories was estimated within 45 concentrically expanding circles (20 to 9000 m) from the trap.

Discussion

General

In this thesis, four novel localities for *E. ferrugineus* have been identified, which doubles the number of known localities for the beetle in Skåne. In addition, the continued presence of the species at Örup (ORP) has been confirmed, which was considered uncertain after the destruction of the local elm forest by Dutch elm disease a few decades ago. The sites surveyed in this project cover virtually all Scanian localities with a potential to house *E. ferrugineus* populations. The high number of new localities identified in this project stresses the efficiency of pheromone trapping compared to conventional trapping methods. By the use of pheromone trapping it has been possible to screen large areas with very low effort. The region of Skåne, covering 11'000 square km², would be entirely possible for one person to survey with regards to all potential sites for *E. ferrugineus* within one or two field seasons.

Previous surveys and amateur collection of *O. eremita* have already revealed many relatively recent localities; nevertheless, the use of pheromone trapping in the present project has contributed with two novel localities for the species. Pheromone trapping of *O. eremita* is not in itself efficient enough to consider the beetle as absent (Svensson *et al.* 2009; Larsson *et al.* 2011). Furthermore, the distribution of the beetle, scattered all over the landscape and found even in small isolated stands of hollow trees, strongly suggests that more localities might be found. At three localities (Snogeholm, Sövdeborg and Örup) where *E. ferrugineus* has been found in the absence of *O. eremita*, the trapping effort for the latter species has not been as extensive. At these localities, thorough trapping efforts should be directed towards the beetle to determine its occurrence. In Örup, however, it is quite possible that *O. eremita* actually is absent as the locality has undergone a severe change since the elm disease struck the forest. In Örup, several captures of the saproxylic scarab *Gnorimus nobilis* were recorded in this project, suggesting these beetles constitute an alternative prey for *E. ferrugineus*, as a substitute to the *O. eremita* larvae.

Landscape analysis interpretation

E. ferrugineus responded to tree densities at very large spatial scale. Tree densities at radii below 500 m had very low explanatory strength, which indicates that no resources at small spatial scale are sufficient to support a population. The beetle was absent from every isolated site with limited area and connectivity to adjacent sites; even from sites with very high local densities of large trees, which suggests that no amount of local resources can sustain a resident population, and explains why resources near potential sites had no explanatory value. *E. ferrugineus* was mostly found at a few adjacent sites in areas with high overall densities of large trees, which suggests that a high overall tree density is necessary to sustain local populations. In comparison with current studies (Musa *et al.* unpublished) in the county of Östergötland, the Scanian *E. ferrugineus* respond to tree densities at a greater scale. Tree factors appear to have an impact already at a significantly smaller scale in Östergötland than in Skåne, where only modest impact of tree resources could be detected within several kilometers from resident populations, and where the greatest effects were identified at the furthest distances away from traps. A reasonable explanation for this extreme result for Skåne is the high degree of isolation of most sites in the landscape.

The Scanian presence of *O. eremita* appears very different from *E. ferrugineus*, as local stands of trees seem perfectly able to sustain a resident population at least for a limited time. Bergman *et al.* (2012) assessed the scales at which *O. eremita* responds to oak densities in the county of Östergötland. The authors found that *O. eremita* responds to oak densities already from 70 m all the way out to the largest scale in their analysis (6000 m). This indicates that persistence of this beetle is facilitated by substrate on the local scale, as well as all the way up to landscape level. The sedentary lifestyle of *O. eremita*, with low population fluctuations (Ranius 2001; Hedin *et al.* 2007), its reluctance to leave the tree (Ranius *et al.* 2001) and its short flight distances (Ranius *et al.* 2001; Svensson *et al.* 2011b) makes it viable in a small stand for an extended time period. Ranius *et al.* (2001) suggested at least 10 hollow trees and a good regeneration is a minimum to sustain a healthy *O. eremita* population in the long run. However, all requirements necessary to sustain a population in the long run may not be met. These factors might act on a larger temporal scale and the loss of essential habitat factors might not yet have had an impact. Due to this, many *O. eremita* populations found in this project might be suppressed under a temporal extinction debt. As demonstrated by Bergman *et al.* (2012), different species have entirely different spatial demands for resources in fragmented landscapes. This might be the explanation for the high number of Scanian localities for *O. eremita*.

Defining local populations

A population can be defined as “a group of individuals of the same species living in a certain defined area” (Lawrence 2008). In traditional surveys of saproxylic beetles, individuals are often found in their natal tree. The formidable efficiency of the *E. ferrugineus* pheromone in combination with the high dispersal ability of the males makes it possible to capture beetles several kilometers from their natal area. The area from where the beetles derive will be hard to define. In theory, the further away from a locality with a resident population a trap is put up, the fewer beetles will be captured.

In the spatial analysis, including stray captures at sites close to local populations would lead to multiple sampling from the same population, e.g. Krageholm (KRH) and Bergsjöholm (BJH) south from Bellinga (BLL), Ekhagen (EKG) south from Torup (TRP), and several sites around Bosjökloster (BSK). In this thesis, captures of *E. ferrugineus* were detected at 21 out of 83 sites. Of these 21, eight sites captured a much higher number of *E. ferrugineus* than the rest. Comparing captures in a single trap per day yielded a bimodal distribution of captures, which were interpreted as stray captures and resident populations, respectively (Figure 5 and Figure 6). This analysis provided an unambiguous classification of most sites into either a resident population or stray captures (Figure 7). Localities where beetle trapping was considered to consist entirely of stray captures generally captured 3 beetles or less when situated close to a known local population where high captures have been recorded. Two potential exceptions are represented by Svartskylle (SVS) and Krageholm (KRH). Svartskylle (7 captures) lies centered between four large resident populations of *E. ferrugineus*, and therefore the relatively high number of stray captures does not seem unlikely. Krageholm (5 captures) lies due south of several resident populations, and here *E. ferrugineus* was captured only in 2010 and not in 2011. In all cases of presumed stray catches where trapping was performed during both years: Krageholm (KRH), Borstbäcken (BOB), Bergsjöholm (BJH) and Härkeberga (HCB), individuals were captured only during one of these years.

In cases where many traps are put up at each locality, competition between traps likely leads to smaller average capture frequencies. This bias cannot be adjusted for by using a capture per trap effort, or even by choosing the trap with the highest number of captures, as in the present study. Due to this competition, the differences between captures of residents and non-residents at localities where many traps have been used are underestimated in the present study. To get comparable capture data from several traps where the trapping period might vary, the number of captures in the present study was normalized as captures per day. By using a capture per effort measure (Figure 6) it was possible to make a reasonable comparison of captures between sites. To do this, the time period that each trap has had a possibility to capture beetles has to be calculated. The true flight period of the beetle has to be taken into consideration, since a trap is often put up before and not taken down until after the flight period has ended. For *E. ferrugineus*, the first captures were recorded from 1 July and the last in 10 August.

The use of the giant tree dataset

Another important parameter to take into consideration in the landscape analysis is potential spatial correlations between different types of trees. Many different types of trees in the data material appeared to have explanatory value in predicting the presence of *E. ferrugineus* at larger radii. Stands of trees included in this study are seldom homogeneous in terms of ages and tree species. In many cases, densities of different trees are likely to correlate. Preliminary investigations suggest that this is the case, although the extent of co-variance has not been explored here (unpublished data, outside the scope of this thesis). If there is a correlation between many groups of trees, it will not be possible to determine from which specific group of trees a response derives. This might be the explanation of the unexpected positive response to conifers. At localities where *E. ferrugineus* has been found, also other sorts of trees, including conifers, have had a possibility to grow old. Note that the tree material used in this analysis originates from surveys specifically directed towards giant trees and does not reflect the composition nor constitute a comprehensive image of all trees in the region. Forested land and areas of active forestry have not been covered in the giant tree survey, and smaller trees have been ignored across the board. However, none of these groups are likely to house the right habitat for these beetles, and would most likely have given a negative response if included in the analysis. The division between large and small trees was set to 1 m based on assumed suitability for saproxylic fauna. A larger tree is older and is more likely to contain hollows filled with wood mould. The definition of a large tree as one with a trunk diameter exceeding 1 m in diameter is, however, arbitrary and should in ideal cases have been species specific.

For the multiscale analysis, only present day resource distributions in the giant tree material have been taken into account. For example, lack of continuity might have led certain populations to local extinction, and even if the forest is regenerated it will not easily regain its former biodiversity (Speight 1989). This effect will give a false negative response to tree densities if included in the spatial analysis.

For a factor to give any effect in the binary logistic regression, it has to be differentiating between presence and absence. Small nonhollow trees are abundant at most localities and play an important role as replacement trees at a much greater temporal scale, but since they are abundant at all localities they will yield no prominent responses.

The choice of trap placement is essential also for the density calculations at the smallest and largest radii. The amount of large trees in the closest proximity will have a large impact on tree densities at the smallest radii. At increasing radii, density differences between localities start to level off.

Statistics

The resources evaluated in the spatial analysis derive from the same dataset. All 46 groups were selected from the same tree dataset and may for various reasons not be statistically independent. Multiple comparisons at the same dataset might lead certain groups to be significant as a matter of chance. A few groups, as Rosaceae and conifers scarcely reached significance and could be explained by this, and correlation (previously discussed) between groups. As a result, significance thresholds might be considered too generous and should perhaps be lowered. On the other hand, the main variable considered in the analysis has been comparisons of effect sizes in the form of Wald values, rather than an arbitrary threshold for significance.

When tree densities were calculated, all trees from the position of the trap out to the specific radius were included. Due to this, tree densities at large radii are not statistically independent from densities at smaller radii. A very dense forest close to the trap could give a false raise in tree densities at the larger radius. Because of this, responses observed at large radii could be the result of very dense stands close to the centroid. The problem could have been solved by calculating tree densities within certain radius interval. Another intrinsic problem in this analysis is overlap of circles of adjacent localities in the tree density calculations. Circles of the closest situated localities will start to overlap already from a radius of 1000 m, and as the radius increases the tree densities of these localities will start to become more uniform. Successively, as the overlap of circles and the interference between adjacent localities increases, WALD-values might be influenced. However, the impact of this issue has been considered beyond the scope of the present thesis.

Indicator species

O. eremita has been evaluated as an indicator for species richness in tree hollows (Ranius 2002b; Jansson *et al.* 2009a). In these studies, a strong correlation between *O. eremita* and species richness has been shown. However, they also concluded that *O. eremita* is not the most demanding species in that habitat, and some species might be lost if *O. eremita* is the only beetle taken into consideration. A species at higher trophic levels is presumably more sensitive to habitat fragmentation and decreasing resources (Holt 2002). As *E. ferrugineus* lives as a predator, *inter alia* of *O. eremita*, *E. ferrugineus* can be considered a more demanding species. In this project, *E. ferrugineus* was absent at several localities where *O. eremita* was found, suggesting that these habitats are insufficient to house *E. ferrugineus*. By this, *E. ferrugineus* can be considered higher up in a hierarchy of extinction dynamics, where *O. eremita* is less sensitive to habitat destruction. Since the pheromone of *E. ferrugineus* has been accessible for nature preservation purposes, the possibilities to survey the beetle has radically increased, which is reflected by the 100% increase in known Scanian localities as a result of this project. The high detectability in combination with its high habitat requirements could make *E. ferrugineus* a good indicator species. However, its correlation to biodiversity has not been assessed. In this project, only half of the localities where *E. ferrugineus* was found, *O. eremita* were found as well. As the presence of *O. eremita* has been shown to correlate with high biodiversity (Ranius 2002b), localities where *E. ferrugineus* been found in the absence of *O. eremita* might be less valuable in terms of biodiversity. However, the lack of finds of *O. eremita* at these sites can be explained by the low pheromone trapping efficiency for *O. eremita*. If the beetle actually is absent at these localities, a break in the continuity and a bottleneck effect where the most demanding saproxylic fauna gone extinct can be an explanation. The reason for why we find *E. ferrugineus* at these sites could be a result of better recolonization abilities compared to *O. eremita*.

The differences in biology between *O. eremita* and *E. ferrugineus* make them complement each other well as indicators. In a parallel analysis, the differences can be advantageous. *O. eremita* is likely detected close to its natal tree, and it is correlated to a high biodiversity. On the other hand, it appears to respond slowly to environmental changes and it is not the most demanding species. *E. ferrugineus* is a more demanding species, considerably higher up in an extinction hierarchy which makes it a broad umbrella species. Its mobile lifestyle makes it hard to determine where the beetle comes from and its supreme habitat requirements make it extremely rare. Only few localities would be worth saving if *E. ferrugineus* was the only species in consideration. The use of both species in parallel analyses will give a management hierarchy, where localities with both species should be considered the most prioritized to protect.

Implications for conservation

The large-scale responses of *E. ferrugineus* to tree densities reveal its demands for large unfragmented areas with high densities of giant trees. Judging from its present landscape distribution, *E. ferrugineus* appears to be very sensitive to a range of interconnected factors, including habitat fragmentation and isolation in too small tree stands without sufficient resources to sustain a population. As *E. ferrugineus* appears to be a more demanding species than *O. eremita*, localities where the former been found should be considered the most valuable, and should immediately be assigned the highest priority and the highest level of protection available. *E. ferrugineus* requires conservation on very large spatial scales to safeguard its survival, with strategic replacement trees designated already today in order to ensure a continuous resource supply. This is necessary as the regeneration dynamics of its habitat extend over centuries, whereas improper management could reduce the amount of available resources below sustainable levels within a few decades. The scale at which *E. ferrugineus* responds to tree densities and its distribution in the landscape leads me to conclude that there are five main populations of the beetle. Hallands väderö (HVO), an isolated island in the north and a region around Ringsjöarna (BSK, FUT, KLG) appears to be isolated populations. Övedskloster (OVK) at the east side of Vombsjön constitute a population more or less isolated from a large region in the south where the beetle been found at numerous sites. This region stretches from Torup (TRP) in the west to Örup (ORP) in the east, with a prominent population between Sjöbo and Ystad. Five sites: Torup (TRP), Sövdeborg (SDB), Snogeholm (SNH), Bellinga (BLL) and Örup (ORP) in this region have been classified to hold a local population and in between these, stray captures have been recorded at seven sites: Ekhagen (EKG), Eksholms naturreservat (EKH), Häckeberga (HCB), Fyledalen (FYL), Skogshejdan (SKH), Svartskylle (SVS), Krageholm (KRH) and Bjersjöholm (BJH). This indicates that there could be a metapopulation structure with varying exchange between localities, and a possibility for colonization of new habitats in between to occur. It should be noted that the long dispersal distances recorded for male *E. ferrugineus* does not seem to translate to high colonization ability. Studies over many areas of southern Sweden suggests female dispersal being much more limited (Larsson *et al.* unpublished). Immediate action should be taken to regenerate suitable habitats in between localities and to increase the connectivity between them in order to secure the survival of *E. ferrugineus* and other demanding species in this region. In regions as in the south of Skåne, where beetles are found at many sites, there is a possibility to connect resident populations to facilitate genetic exchange. Mapping of next generation of trees and preservation of these will increase contact between areas. Management efforts directed to recreate habitats for saproxylic fauna will be rewarding in this region as the chances for recolonization are high. Localities where *O. eremita* has been found alone are of great importance to solve regeneration problems and constitute strategic points from which to increase the amount of dead wood in the landscape. As proposed by Ranius (2002b) stands where *O. eremita* has been found have a potential to already sustain a rich saproxylic fauna, but could also constitute an even better habitat suitable for the most demanding species

within a reasonable time with the right management efforts. To increase the connectivity, a densification of patches or continuous corridors could be formed. The use of artificial wood mould in wooden boxes has been evaluated as a good way to create habitable patches and increase the connectivity (Jansson *et al.* 2009b).

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Appendix

Localities surveyed in this thesis and four unsurveyed localities potentially housing *O. eremita*. Initials for the person who published the most recent compilation of finds of each beetle and the year is specified in the previous column (Glenn Svensson, Kjell Antonsson, Mikael Molander, Sven G Nilsson)

Abbreviation	Locality	Municipality	Year	Coordinate (RT90_25gonV)		Number of traps used	Used in landscape analysis?	Finds of <i>Osmoderma eremita</i>			Finds of <i>Elater ferrugineus</i>				
				X	Y			2010-2011	Previous		2010-2011		Previous		
									Year	Publisher	Capture/day	Classified	Year	Publisher	
ALN	Alnarpsparken	Burlöv	2011	1328323	6172628	1	Yes	0	0	0	0,000	0	0	0	0
BAB	Balsberget	Kristianstad	2011	1400718	6220500	1	Yes	0	0	0	0,000	0	0	0	0
BLL	Bellinga	Tomelilla	2010	1367565	6157400	2	Yes	Present	1998	KA	1,8235	Local pop.	0	0	0
BSB	Benestads backar	Tomelilla	2011	1379830	6156680	1	Yes	0	0	0	0,000	0	0	0	0
BJH	Bergsjöhölm	Ystad	2010/2011	1372051	6149615	1	Yes	0	0	0	0,0588	Stray capture	0	0	0
BBJ	Billebjer	Lund	2011	1343582	6175926	1	Yes	0	0	0	0,0000	0	0	0	0
BJG	Bjarsgård	Klippan	2010/2011	1333847	6227993	4	Yes	Present	0	0	0,0000	0	0	0	0
BIL	Bjarsjölagård	Sjöbo	2011	1367895	6179549	1	Yes	0	0	0	0,0000	0	0	0	0
BRG	Borgen	Svalöv	2011	1315464	6208427	1	No	0	0	0	0,0000	0	0	0	0
BOB	Borstbäcken	Lund	2011	1360323	6178893	1	Yes	0	0	0	0,9099	Stray capture	0	0	0
BSK	Bosjöklöster	Höör	2010	1356399	6196590	1	Yes/No	Present	2003	KA	2,2222	Local pop.	0	0	0
BKG	Bäckaskog	Kristianstad	2011	1409317	6218745	1	Yes	0	0	0	0,0000	0	0	0	0
BRK	Böringe klöster	Svedala	2011	1342941	6156069	1	Yes	0	0	0	0,0000	0	0	0	0
CLL	Charlottenlund	Ystad	2011	1366258	6146377	1	Yes	0	0	0	0,0000	0	0	0	0
CHR	Christinelunds ädellövskog	Helsingborg	2011	1301579	6227338	1	Yes	0	0	0	0,0000	0	0	0	0
DAS	Dalby Söderskog	Lund	2011	1344542	6174367	1	Yes	0	0	0	0,0000	0	0	0	0
DRM	Drakamöllan	Simrishamn	2011	1394977	6182188	1	Yes	0	0	0	0,0000	0	0	0	0
DUV	Duveke	Svalöv	2011	1327870	6208113	1	Yes	0	0	0	0,0000	0	0	0	0
EKG	Ekhagen	Svedala	2010	1338408	6159045	3	Yes	Present	1998	JB	0,0294	Stray capture	0	0	0
EKH	Eksholms naturreservat	Lund	2011	1342433	6161209	1	Yes	0	0	0	0,0294	Stray capture	0	0	0
ESP	Esperd	Tomelilla	-	1381995	6165625	-	No	-	1860	KA	-	-	-	-	-
ERU	Everöds utmark	Tomelilla	2011	1382483	6194641	1	Yes	0	0	0	0,0000	0	0	0	0
FRH	Fairyhill, ONO, 500m	Höör	-	1351500	6199675	-	No	-	2003	KA	-	-	-	-	-
FSK	Forsakar	Simrishamn	2011	1391047	6190281	1	No	0	0	0	0,0000	0	0	0	0
FUT	Fulltofta	Sjöbo	2010	1361817	6196645	6	Yes	Present	2001	KA	0,0256	Stray capture	0	0	0
FYL	Fyledalen	Tomelilla	2011	1376400	6161928	1	Yes	0	0	0	0,0385	Stray capture	0	0	0
FSD	Fågelsångsdalen	Lund	2011	1344391	6179055	1	Yes	0	0	0	0,0000	0	0	0	0
GGG	Gyllebosjön	Simrishamn	2011	1398561	6164715	1	Yes	0	0	0	0,0000	0	0	0	0
HVO	Hallands väderö	Båstad	2010	1300340	6261335	10	No	Present	2002	KA	4,2000	Local pop.	2006	GS	GS
HSK	Hanaskog	Kristianstad	2011	1394599	6227323	1	Yes	0	1998	KA	0,0000	0	0	0	0
HVK	Herrevads klöster	Klippan	2011	1340549	6221134	1	Yes	0	1855	KA	0,0000	0	0	0	0
HJR	Hjularöd	Sjöbo	2011	1359098	6180686	1	Yes	0	0	0	0,0606	Stray capture	0	0	0
HVD	Hovdala	Hässleholm	2011	1369785	6221430	1	Yes	0	0	0	0,0000	0	0	0	0
HCB	Häckebärga	Lund	2010/2011	1349414	6160502	7	Yes	Present	1951/1998	KA	0,0588	Stray capture	0	0	0
KLI	Klingavälsån	Lund	2011	1356951	6169854	1	Yes	0	0	0	0,0294	Stray capture	0	0	0
KLK	Klinta gård	Eslöv	2011	1356258	6193864	1	Yes	0	0	0	0,1875	Stray capture	0	0	0
KLK	Kläveröd	Klippan	2011	1336676	6215170	1	Yes	0	0	0	0,0000	0	0	0	0
KNT	Knutstorp	Svalöv	2010	1333261	6209007	1	Yes	0	0	0	0,0000	0	0	0	0
KRH	Krageholm	Ystad	2010/2011	1370276	6153055	1	Yes	0	0	0	0,2941	Stray capture	0	0	0
KRI	Kristinehov	Simrishamn	2011	1384259	6177820	1	Yes	0	0	0	0,0000	0	0	0	0
KRV	Kronovall	Tomelilla	2011	1388557	6168313	1	Yes	0	0	0	0,0000	0	0	0	0
KBR	Kullaberg	Höganäs	2011	1297012	6243494	1	Yes	0	0	0	0,0000	0	0	0	0
KSR	Kvarsum	Hörby	2011	1365300	6204510	1	Yes	0	0	0	0,0000	0	0	0	0
KVK	Kvidinge k:a	Klippan	2011	1328505	6227131	1	Yes	0	0	0	0,0000	0	0	0	0
LUB	Linnebjär	Lund	2011	1342766	6180962	1	Yes	0	0	0	0,0000	0	0	0	0
LUS	Låstumasåsen	Simrishamn	2011	1393332	6162021	1	Yes	0	0	0	0,0000	0	0	0	0
LYB	Lyby stubbskottång	Hörby	2011	1362210	6192527	1	Yes	0	0	0	0,0000	0	0	0	0
MGL	Maglö ekar	Kristianstad	2011	1364513	6215991	1	Yes	Present	0	0	0,0000	0	0	0	0
MSH	Malthesholm	Kristianstad	2011	1386436	6198323	1	Yes	0	0	0	0,0000	0	0	0	0
MLK	Mölleröds kungsgård	Hässleholm	2011	1369662	6227904	1	Yes	0	1998	KA	0,0000	0	0	0	0
ORG	Orups gård	Eslöv	2011	1355222	6190180	1	Yes	0	0	0	0,0000	0	0	0	0
OVH	Ovesholm	Kristianstad	2011	1387403	6209379	1	Yes	0	0	0	0,0000	0	0	0	0
PRS	Prästaskogen	Lund	2011	1348882	6175258	1	Yes	0	0	0	0,0000	0	0	0	0
PSK	Pålsjöskog	Helsingborg	2011	1305733	6220221	1	No	0	0	0	0,0000	0	0	0	0
RAV	Ravlanda skjutfält	Simrishamn	2011	1398729	6178404	1	Yes	0	0	0	0,0000	0	0	0	0
RSD	Rosendal	Helsingborg	2010	1314724	6222342	1	Yes	0	0	0	0,0000	0	0	0	0
RSL	Rosenlund	Helsingborg	2011	1315847	6219228	1	Yes	0	0	0	0,0000	0	0	0	0
RVS	Rävstads golfbana	Svedala	2011	1344280	6160730	1	Yes	0	0	0	0,0000	0	0	0	0
SKH	Skogshejdan	Sjöbo	2011	1375657	6160007	1	Yes	0	0	0	0,1667	Stray capture	0	0	0
SKB	Skönabäck	Skurup	2011	1356089	6159049	1	Yes	0	0	0	0,0000	0	0	0	0
SNH	Snogeholm	Sjöbo	2010/2011	1367485	6160985	8	Yes	0	0	0	1,0526	Local pop.	0	0	0
SPR	Spannarp	Helsingborg	2011	1318901	6233154	1	Yes	0	0	0	0,0000	0	0	0	0
SPK	Sporrakulla	Kristianstad	2011	1403114	6241035	1	Yes	0	0	0	0,0000	0	0	0	0
STL	St. Lars	Lund	2011	1335174	6175734	1	Yes	0	0	0	0,0000	0	0	0	0
STH	Stenshuvud	Höganäs	2011	1403209	6170579	1	Yes	0	1997	KA	0,0000	0	0	0	0
SVB	Svabesholm	Simrishamn	2011	1402113	6170985	1	Yes	0	0	0	0,0000	0	0	0	0
SVN	Svaneholm	Trelleborg	2011	1352679	6154990	1	Yes	0	0	0	0,0000	0	0	0	0
SVS	Svartskylle	Ystad	2011	1373420	6158756	1	Yes	0	0	0	0,3889	Stray capture	0	0	0
SVK	Svedberga kulle	Helsingborg	2011	1307297	6230799	1	Yes	0	0	0	0,0000	0	0	0	0
SDA	Söderåsen	Klippan	2011	1339524	6214230	2	Yes	0	0	0	0,0000	0	1882	SGN	SGN
SBT	Sörbytorp	Kristianstad	2011	1386516	6224973	1	No	Present	1998	KA	0,0000	0	0	0	0
SDB	Sövdeborg	Sjöbo	2010/2011	1367450	6162987	10	Yes	0	0	0	0,8462	Local pop.	2001	MM	MM
TMK	Tomarps kungsgård	Klippan	2010	1330607	6227994	3	Yes	Present	2002	0	0,0000	0	0	0	0
TSP	Torsebro	Kristianstad	2011	1395454	6221153	1	Yes	0	1996	KA	0,0000	0	0	0	0
TRP	Torup	Svedala	2010	1336249	6163287	1	Yes	0	1988	KA	0,8068	Local pop.	0	0	0
TRO	Trolle Ljungby	Kristianstad	-	1410555	6211555	-	No	-	1881	KA	-	-	-	-	-
TRH	Trolleholm	Svalöv	2011	1340894	6201136	1	Yes	0	0	0	0,0000	0	0	0	0
TRN	Trollenas	Eslöv	2011	1339414	6196032	1	Yes	0	0	0	0,0000	0	0	0	0
TRL	Töringelund	Svedala	2011	1331184	6158998	1	Yes	0	0	0	0,0000	0	0	0	0
UDP	Uddarp	Kristianstad	2011	1389990	6210885	1	Yes	0	0	0	0,0000	0	0	0	0
VNS	Vanås	Kristianstad	2011	1390823	6230208	1	Yes	0	1998	KA	0,0000	0	0	0	0
VDB	Vedelsbäck, Stehag	Höör	-	1349155	6200155	-	No	-	1897	KA	-	-	-	-	-
VGH	Vegehalm	Angelholm	2010	1314252	6234955	3	Yes	0	0	0	0,0000	0	0	0	0
VRK	Verkaån	Simrishamn	2011	1390186	6178489	1	Yes	0	0	0	0,0000	0	0	0	0
VAG	Örtofta	Lund	2011	1339436	6187053	1	Yes	0	0	0	0,0000	0	0	0	0
ORP	Örup	Tomelilla	2010/2011	1381702	6155874	8	Yes	0	1936	KA	1,3636	Local pop.	1981	SGN	SGN
OVK	Övedsklöster	Sjöbo	2010/2011	1363692	6177174	14	Yes	Present	1998	KA	0,8158	Local pop.	2001	MM	MM

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