Conservation of saproxylic beetles in a wooded pasture in northern Scania

Andreas Schmidt

Degree project 30 cr

Andreas Schmidt
andreas.schmidt.721@student.lu.se

Supervisor: Ola Olsson
ola.olsson@biol.lu.se

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Abstract

The area of wooded pasture in Europe has decreased drastically over the last centuries due to abandoned management. Herrevadskloster is a newly formed nature reserve in northern Scania with an unusually long continuity of being an open, grazed woodland containing large old trees. In this study, the reserve was studied to evaluate its potential to further the conservation of the redlisted saproxylic beetles; hermit beetle (*Osmoderma eremita*) and stag beetle (*Lucanus cervus*). Exhaustive surveys were carried out for both species to determine if they are still present within the reserve. Tree hollows were also surveyed within the reserve and its connectivity with other potential habitats for the two species was analyzed. In addition, a literature study was performed to analyze potential conservation efforts for the two species.

Neither hermit beetles, nor stag beetles, were found during the surveys indicating that they are no longer present. Eight hollows that could potentially be used by hermit beetles were found in the reserve. The connectivity analysis showed that even though there are several areas which could potentially be used by stag beetles in the area surrounding Herrevadskloster, these are not within dispersal distance of stag beetles. For hermit beetle, the potentially usable areas were fewer, smaller and out of reach of dispersing individuals. In spite of its isolation, the reserve could likely support a local population of stag beetles if a reintroduction were to be carried out.

Content

Introduction

The deciduous forests of southern Sweden is the habitat type that houses the largest number of threatened species in the country (Berg *et al.* 1994). Hannah *et al.* (1995) listed temperate broad leaf forests as the most disturbed biome worldwide and the total area of undisturbed, temperate broad leaf forests is very low (Hannah 1995). The extent of two important vegetation types for old deciduous trees, woodland and wooded pastures, have decreased significantly throughout Europe due to abandoned management (Kirby & Watkins 1998).

There has been much debate as to what the deciduous, primeval forests of Europe looked like. For a long time, the prevailing theory has been a closed climax forest where regeneration took place in gaps in the canopy, caused by dying and dead trees (Watt 1924; Watt 1925). One of the arguments for this theory was the observation that open land, when fenced off from grazing, would through succession become a closed forest (Watt 1919). More recently, the idea of a more open landscape, characterized by shrubs and large standards has been proposed (Vera 2000). Such a landscape would have formed a large, continuous, heterogenous landscape with a small-scale mosaic. In a continuous landscape with a long small-scale continuity there is little need for efficient dispersal. As could be expected according to this theory, several species of saproxylic beetles (beetles depending on dead or dying wood at some stage of their life) tend to have a poor dispersal ability or a reluctance to disperse (Harding & Rose 1986). This causes populations to become isolated and prevent them from colonizing new, suitable areas (Grove 2002). Many saproxylic insects have been shown to be highly sensitive to modern forestry and the lacking amounts of dead wood that it entails (Grove 2002). It has also been shown that saproxylic insects specialized on dead wood with long persistence, such as tree hollows, have a lower dispersal ability than saproxylic insects specialized on dead wood with shorter persistence, such as downed logs and branches (Nilsson & Baranowski 1997).

The study species

The hermit beetle (*Osmoderma* eremita) is a saproxylic beetle living in tree hollows. In order for a tree hollow to be usable by hermit beetles, it must contain an adequate amount of wood mold. Wood mold is created when specialized fungi break down either the cellulose or lignin of dead wood (Jansson *et al.* 2009). Over time, the resulting debris is complemented with the remains of insects, bird nests and dead leaves (Jansson *et al.* 2009, Ranius 2002). According to Ranius and Nilsson (1997) the species has a preference for both beech (*Fagus sylvatica*) and pedunculate oak (*Quercus robur*), but in Sweden oak seems to be the more commonly utilized species judging by the larger number of finds in and on oak trees (Antonsson 2001). This could, however, be due to the relative abundance of hollow trees of the various species, as Oleksa *et al.* (2007) found no preference for oak in Poland. In contrast, they found a clear preference for the more commonly occurring lime (*Tilia cordata*) and alder (*Alnus glutinosa*) that could not be explained by the relative abundance of tree species alone. Their explanation was that the beetle develops a preference for the species that is most locally common among hollow trees (Oleks *et al.* 2007). The dispersal rate of the hermit beetle is very low. Hedin *et al.* (2003) recorded a dispersal rate of 15%, meaning that 85% of the individuals never left their natal tree hollow. The majority of dispersals seem to be shorter than 50 m, even though single individuals in Sweden has been shown to disperse as far as 190 m (Hedin *et al.* 2003). A French study recorded one female that traveled nearly 700 m (Dubois & Vignon 2008). This dispersal was, however, not successful as the female died before reaching a suitable tree hollow (Dubois & Vignon 2008). The limited dispersal distance and reluctance to disperse means that beetles in individual trees form local populations with tree stands forming metapopulations (Ranius & Hedin 2001). This limited dispersal ability makes the hermit beetle particularly vulnerable to habitat fragmentation (Ranius 2000). Currently, the species is classified as near threatened (NT) in Sweden (ArtDatabanken 2015). The main distribution in the country is in the southeastern parts, in the counties of Östergötland, Småland

and Blekinge (Antonsson 2001). In Scania the distribution is limited to a handful of known locations (Antonsson 2001; ArtDatabanken 2017).

The stag beetle (*Lucanus cervus*) is also a saproxylic beetle, but unlike the hermit beetle, the larval development takes place in the ground where the larvae feeds on dead tree roots or the underside of fallen dead wood (Asp *et al. 2009*). The species can utilize most deciduous tree species but has most commonly been found on broad leaf species and especially oak (Harvey *et al.* 2011; Asp *et al.* 2009; Ehnström & Axelsson 2002). The species is currently listed as lest concern (LC) in Sweden but it is suspected that their numbers are decreasing (Ehnström 1999). The distribution in Sweden is weighted towards the southeastern part of the country and there are relatively few (< 20) known locations in Scania (ArtDatabanken 2017).

Pedunculate oak

Being something of a character species for wooded pastures, the pedunculate oak can be a prominent feature in open environments. The seedlings require large amounts of ambient light to survive and grow and adult trees are susceptible to shading from fast-growing, strong competitors such as Norway spruce (*Picea abies*) (Crow 1991; Kelly 2002; Vera 2000). However, despite this pronounced sensitivity to shade, seedlings are able to survive and even grow for quite some time in unfavorable light conditions, probably owing to the large nutrient reserve in the acorn (van Hees 1997; Brookes *et al.* 1980). Although, if the seedling is unable to over-top shading elements fast enough it will eventually die off (Kelly 2002).

Being a palatable species, pedunculate oak is often subjected to browsing, which can prove troublesome for regeneration (Vera 2000). That said, oaks can be quite tolerant to browsing. Mellanby (1968) noted that pedunculate oaks that had been grazed back several times by rabbits had successfully grown to heights of three to four meters. Even seedlings that were completely mown down annually by man survived for several years and grew vigorously (Mellanby 1968).

The study area

The nature reserve Herrevadskloster, situated in northern Scania, was created in 2011 to preserve pastures with old oaks (Johnmark & Fiskesjö 2011). The area covers 583 hectares and has a long continuity of being open and grazed and having large, old oak trees (Johnmark & Fiskesjö 2011). Neither stag beetle nor hermit beetle have been observed within the reserve for a long time, but sightings from the end of the nineteenth century suggests that both species have been present historically (Johnmark & Fiskesjö 2011). There is therefore a possibility that the long continuity of the wooded pastures at Herrevadskloster have permitted relict populations to persist. Today the area remains largely open. 276 hectares of the reserve is made up of wooded pastures grazed by cattle. These pastures are dominated by large oaks and beeches. On 118 hectares of this area the trees are more or less free standing while around 158 hectares consists of areas with a more varying density of trees. Some of these areas have a more closed tree cover, while others have only a sparse tree cover (Johnmark & Fiskesjö 2011).

Aims

The aims of this thesis are to evaluate the nature reserve Herrevadskloster as a potential habitat for stag beetle and hermit beetle. A thorough survey of stag beetle and hermit beetle have been carried out at the reserve in order to determine whether or not the species are still present. Recommendations for habitat improvement, assurance of temporal continuity and species reintroductions are made. In addition, an analysis of the connectivity of the reserve to other, suitable habitats is performed.

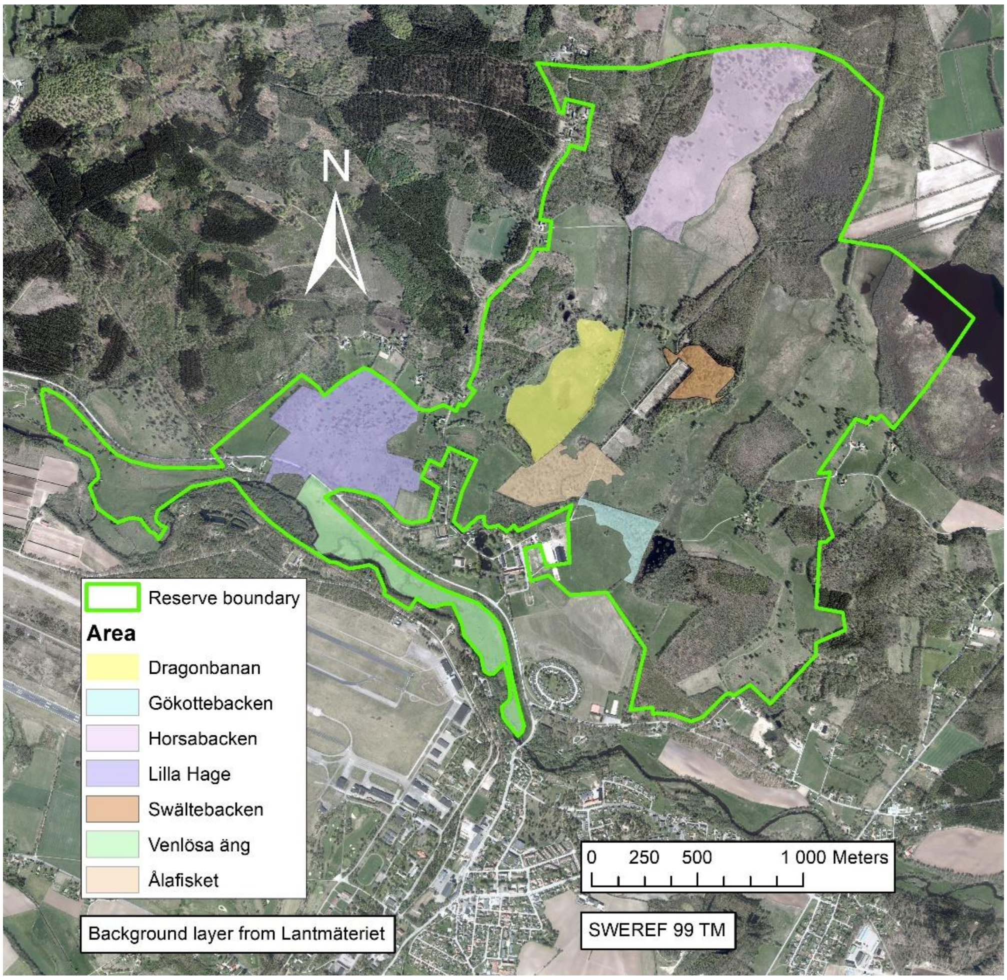

Figure 1. The studied areas of the reserve

Materials and methods

Stag beetle survey

Stag beetle surveys were carried out between the 4th of July and the 26th of July with a total of ten visits. The time of the first survey was determined by examining at what time of year stag beetles were most commonly reported in Scania to ArtPortalen. Due to unstable weather, several visits to the study area had to be postponed and several visits were made after the season peak, resulting in the relatively late first and last dates for the visits.

The transects were placed in accordance with available knowledge about the habitat preferences of the species. Elevation data with a spatial resolution of two meters created by Lantmäteriet was used to calculate the degree of slopes throughout the study area in ArcGIS (ESRI 2015). Slopes with an incline equal to or greater than four degrees were selected in accordance with the findings of Thomaes *et al.* (2010). Since the species has a preference for slopes with high sun exposure, slopes facing southeast, south and southwest were identified and extracted using the aspect tool and elevation data (Thomaes *et al.* 2010). In addition, a map of the soil types of the area created by the Geological survey of Sweden (SGU) was used to identify areas with sandy, well drained soils, which are preferred by the species (Thomaes *et al.* 2008; Thomaes *et al.* 2010). The assumption was made that the availability of broadleaf deadwood would be higher in areas with a higher density of large oaks and beeches. Therefore, GPS points from a previous survey of large trees and tree hollows in the area, carried out in 2008, were overlaid with the other layers. When placing the transects the highest priority was given to the presence of large oaks and beeches in open to relatively open areas. Areas where these overlapped with sun exposed slopes were prioritized. Five transects were placed throughout the reserve with lengths ranging from 201 to 2291 m. The transects were carried out on warm evenings with little to no wind and no precipitation, starting at 9 pm. The order in which the transects were carried out each evening was randomized using the random number generator in Microsoft Excel 2016. Each transect was carried out by walking at a consistent pace while looking for stag beetles in flight and examining the stems of oaks and beeches visually using a high-power head lamp. A net with a two-meter-long telescopic handle was used to assist in the catching of stag beetles.

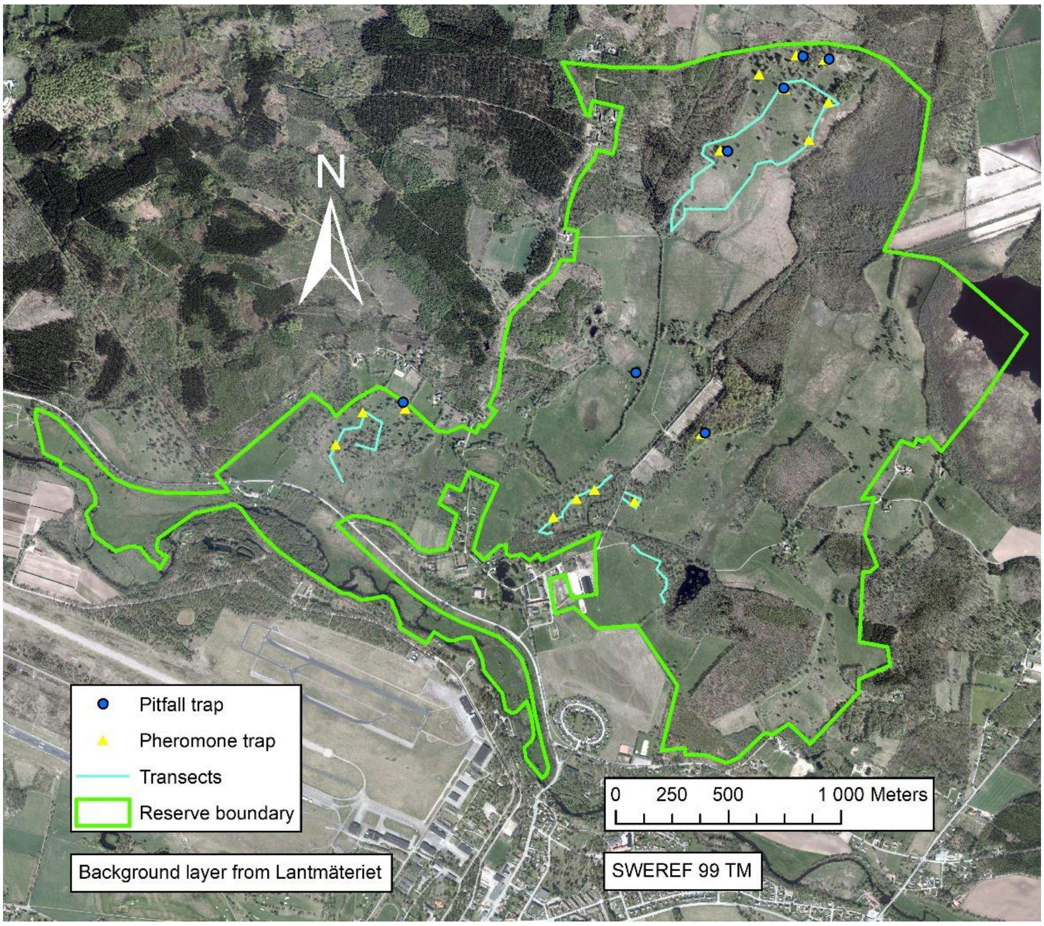

Figure 2. Locations of transects and pitfall- and pheromone traps.

Hermit beetle survey

The same GPS points, showing large trees and tree hollows in the area, that were used for the stag beetle survey, were used to identify trees with cavities. All tree cavities with an entrance diameter ≥ 15 cm were visited in the field and visually inspected. All cavities with an entrance diameter of 5-15 cm in trees with a diameter at breast height (dbh) > 100 cm were also included as these were assumed to have a higher likelihood of containing large amounts of wood mold. The basis for this assumption is that oaks with a dbh > 100 cm are more likely to contain tree cavities, likely due to more widespread heart rot (Ranius *et al* 2009). A widespread heart rot, where the hard, inner wood of the trunk is decomposed, should also enable large cavities to form within the tree, making the hollows of these trees more likely to contain large amounts of wood mold. Upon inspection, eight liters of wood mold was sampled from tree cavities containing sufficient amounts, as in Ranius (2002). The wood mold was sifted through a sieve with a grid diameter of three millimeters and searched for larvae, frass and fragments of imagines (fully formed adults). Pitfall traps were constructed from a 50 cl plastic cup with a smaller plastic cup insert. These were placed in inspected tree cavities which were deemed to be suitable for hermit beetles and which contained sufficient wood mold to conceal the trap so that the rim was flush with the surface of the wood mold (Fig. 3a). The main reasons for exclusion of hollows from the survey were hollows either being too open to sustain a micro climate, being too shallow to accommodate a pitfall trap or either the opening being too narrow, or the wood mold being too far from the opening to allow inspection and installation of traps.

15 cross-vein funnel traps of the type used by Svensson and Larsson (2008) were baited with a synthetic version of the male-released sex pheromone γ-decalactone and hung in oaks and beeches throughout the studied areas of the reserve (Fig. 3b). The dispensers consisted of 2 ml vials containing 400 µl of the pheromone which had been absorbed by a cotton dental roll. The vial was hung from the plastic cross above the funnel and were not refilled during the period of the study. Both pitfall traps and funnel traps were in place between the 15th of August and the 30th of August. During this period, they were checked for beetles every other day.

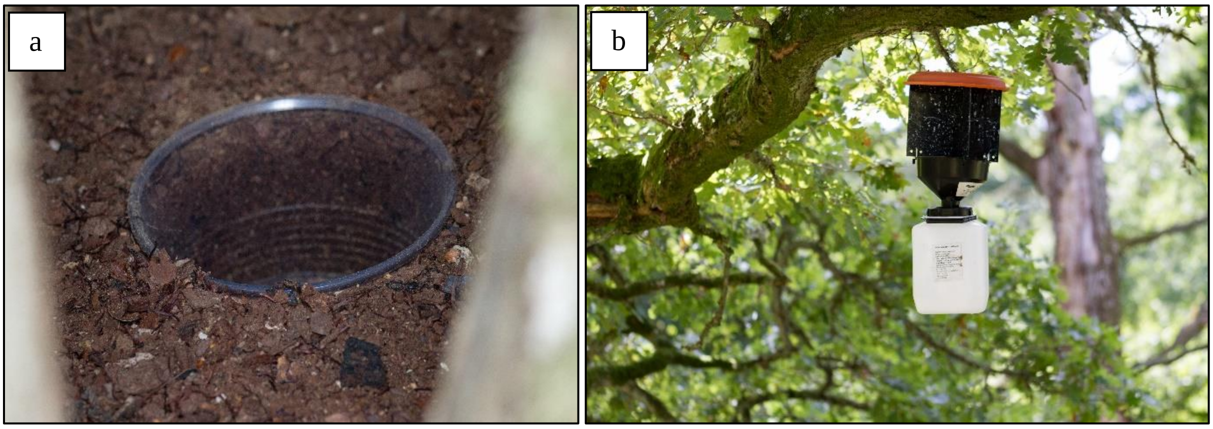

Figure 3.(a) Pitfall trap (b) Pheromone trap

Connectivity analyses

Two separate distance weighted density analyses for Scania were made for stag- and hermit beetles respectively using Matlab (version R2017a) (Hanski 1999). Input data for stag beetles were density of oak, presence of veteran trees, and half-open to open crown cover. The average dispersal distance was set at 500 m. For hermit beetles the input data were density of oaks with tree hollows of stage five and six (according to Levenskog 2008) in areas with half-open to open crown cover. For hermit beetles, the average dispersal distance was assumed to be 50 m.

Literature review

Relevant scientific literature was acquired through the search engines Google Scholar and Web of Science, using key words for the various topics. Relevant articles were in turn searched for cited literature.

Results

Field work

From the tree data 14 hollows were selected for field inspection (Table 1). Of these, seven were deemed suitable for pitfall traps, four of which are situated in Horsabacken, the biggest continuous wooded pasture in the area (Fig. 1). The remaining three are situated on Dragonbanan, in Lilla Hage and Swältebacken respectively. Of the inspected tree hollows, eight were deemed to be potentially usable habitat by hermit beetles (Fig. 4). Out of these, seven had at least one other suitable tree hollow within the longest recorded dispersal distance of hermit beetles in Sweden (190 m). One of the hollows was not evaluated as it could not be reached with the ladder since the tree was positioned on the top of a steep river bank and surrounded by dense vegetation.

No imagines of hermit beetle were detected during the survey and no tree hollows contained either larvae, frass or fragments of adults. The visual encounter survey revealed no presence of stag beetles. However, two individuals of the redlisted, saproxylic tanner beetle (*Prionus coriarius*) (NT) were encountered in the area of Ålafisket during the hermit beetle survey.

Table 1. Investigated tree hollows, showing tree species, positioning (height and cardinal direction), estimated amount of wood mold and whether a pitfall trap was installed. Reason for exclusion from trap survey refers to physical characteristics of the tree hollow itself (marked with N/A if not exluded). ID numbers for each hollow corresponds with ID on map in fig. 4.

ID	Area	Species	At ground level	Facing	Wood mold (L)	Trap	Reason for exclusion
1	Horsabacken	Beech	Yes	North	<10	No	Too open
2	Horsabacken	Beech	Yes	Northeast	>10	Yes	N/A
3	Horsabacken	Oak	No	North	>10	Yes	N/A
4	Horsabacken	Beech	No	West	<10	No	Too shallow
5	Horsabacken	Beech	No	North	>20	Yes	N/A
6	Horsabacken	Beech	No	East	>10	No	Too deep
7	Horsabacken	Oak	No	South	>10	Yes	N/A
8	Dragonbanan	Oak	Yes	West	>10	Yes	N/A
9	Swältebacken	Beech	Yes	South	>20	Yes	N/A
10	Lilla Hage	Apple	No	Southwest	<10	Yes	N/A
11	Lilla Hage	Oak	Yes	Northwest	>10	No	Too open
12	Lilla Hage	Apple	No	West	<10	No	Too narrow
13	Venlösa äng	Oak	Yes	West	<10	No	Too open
14	Venlösa äng	Oak	No	South	<10	No	Unreachable

A revisit to the study area at the end of October revealed that a fairly large area in the western part of Horsabacken was waterlogged.

The amount of natural grazing protection seems to vary greatly between the different areas of the reserve (personal observation). In Lilla Hage there is ample amounts of bramble (*Rubus fruticosus*) and in the northern part of Horsabaken the amount of bramble is locally very high. In Ålafisket it is very low with the exception of the easternmost part and in Gökottebacken there are negligible amounts.

The distance weighted density analysis for oaks within open to semi-open crown cover showed that there are several areas that contains potentially usable habitat for stag beetles (Fig. 5). For hollow oaks within open to semi-open crown cover the availability was much lower (Fig. 6 & Fig. 7.). Areas with high concentrations of hollow oaks also tend to be quite small and interspersed over long distances.

Literature review

Recruitment of trees

A large threat to many species of saproxylic beetles is the lack of a continuous availability of suitable habitat (Speight 1989). For many insect species, due to fragmentation, suitable habitat is only available in small patches, spread out in an uninhabitable matrix (Speight 1989; New 2009). Additionally, in many areas of high conservation value, the trees are of a similar age class, creating a gap in the temporal continuity (Harding & Rose 1986). This could have large consequences for species dependent on tree hollows, since this is a structure that starts to form in trees of old age. In oaks, hollows generally start to form around the age of 200 years (Key & Ball 1993; Ranius *et al.* 2009). A lack of rejuvenation of trees for a longer period of time could therefore cause an unbridgeable age gap, ultimately leading to local extinctions of saproxylic species decades or even centuries later.

Natural rejuvenation of oak is, to a large extent, dependent on dispersal by Eurasian jays (*Garrulus glandarius*) (Vera 2000; Kollmann & Schill 1996). These have a preference for caching in transitional vegetation in open habitats, such as brambles and shrubberies (Bossema 1979). Being planted in such an environment provides the oak seedling with good lighting conditions and protection from browsing (Callaway 1992; Rousset & Lepart 1999).

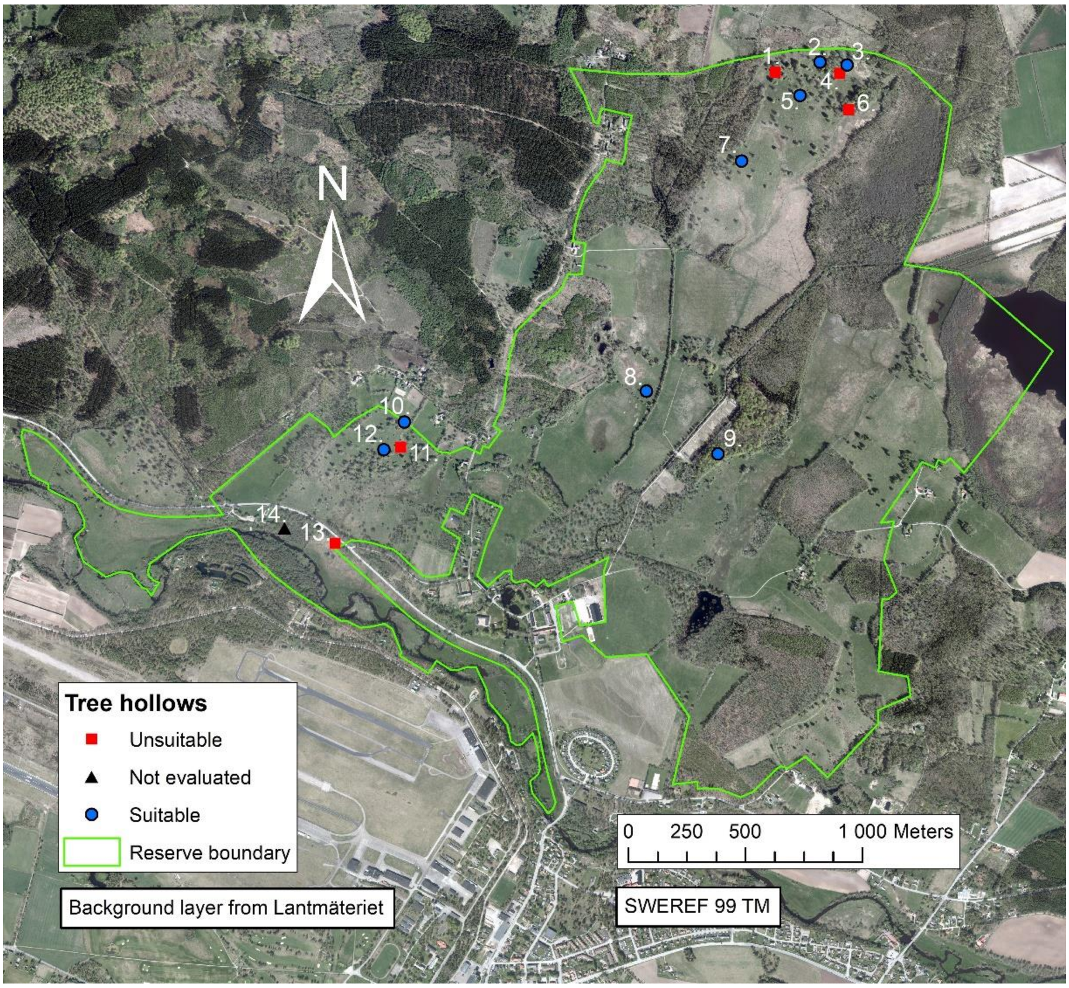

Figure 4. Distribution of surveyed tree hollows, classified as suitable or unsuitable for hermit beetles. Numbers correspond with ID in table 1.

Vera (2000) suggest that protection from grazing provided by shrubs is what enabled establishment and rejuvenation of oak in prehistoric times. Even though this mechanism is driven by the caching behavior of jays, it should be possible to locally increase the rejuvenation rates of oak by manually planting acorns and seedlings in shrubberies. Field experiments performed by Jensen *et al.* (2012), where seedlings of pedunculate- and sessile oak were planted in naturally occurring shrubberies, showed that the shrubberies provided protection against browsing by roe deer (*Capreolus capreolus*) and moose (*Alces alces*). Seedlings planted in shrubberies experienced both a lower browsing intensity and a lower risk of being browsed altogether (Jensen *et al.* 2012). This is in accordance with the hypothesis of associational resistance, where palatable plants experience a lower grazing pressure by growing next to unpalatable or inedible plants (Olff *et al.* 1999). Both browsing intensity and risk of browsing did however increase markedly as the oak seedlings over-topped the shrub canopy (Jensen *et al.* 2012). The negative effect of over-topping the shrub canopy was also demonstrated by Gómez *et al.* (2001) on scots pine (*Pinus sylvestris*). However, they found that the negative effect of over-topping was absent when the sapling was completely surrounded by shrubs, which served as a mechanical barrier against grazing animals (domestic goats (*Capra hircus*), Spanish ibex (*Capra pyrenaica*) and domestic sheep (*Ovis aries*)). Kuiters and Slim (2002) showed that bramble played an essential facilitating role in the regeneration of browse-sensitive species such as pedunculate oak on abandoned arable lands grazed by horses. Practically all successful rejuvenation of pedunculate oak in their study area occurred within bramble thickets (Kuiters & Slim 2003).

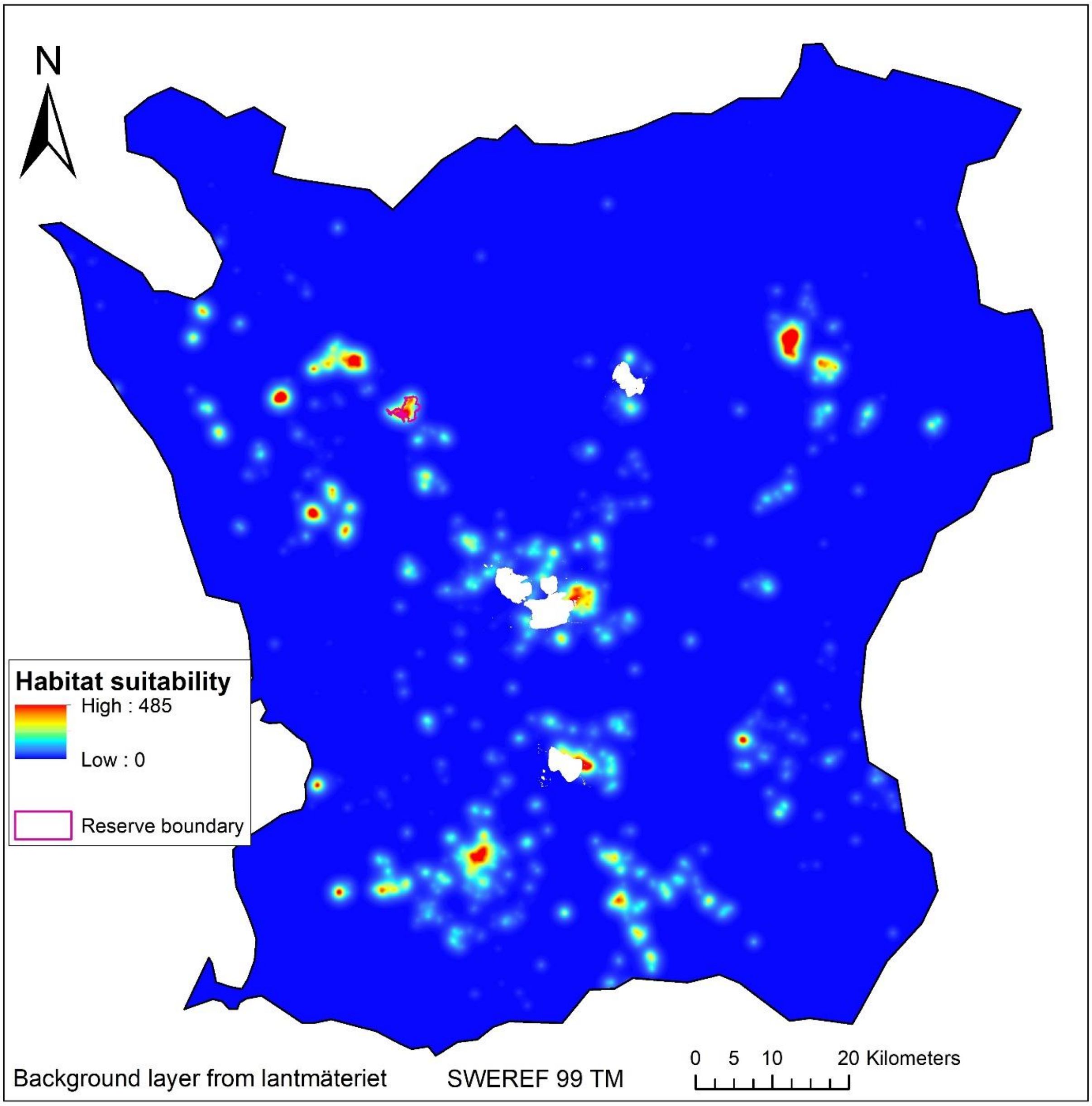

Figure 5. Habitat suitability for stag beetle in Scania determined by distance weighted density of large oaks in semi-open to open areas. Numbers indicate the number of suitable trees within a 500 m distance of the center of each pixel.

Similar results were acquired by Williams *et al.* (2006) for the recruitment of *Quercus douglasii* and *Q. lobata*, though in their study, no acorns germinated successfully in the center of the thickets due to high levels of seed predation from small vertebrates.

Coarse woody material (also called "coarse woody debris", hereafter referred to as CWM), such as logs and large branches, could potentially also be utilized as mechanical barriers against grazing. Morgan (1991) found that larger seedlings of beech and oak in New Forest, southern England, were located mainly in thickets of holly (*Ilex aquifolium*), as had previously been described by Rackham (2003), but also around CWM such as fallen branches and logs. The association with CWM was stronger for the less shade tolerant seedlings of oak than those of beech, likely due to the lower light availability in the holly thickets making CWM a more suitable compromise between light availability and protection against grazers (Morgan 1991).

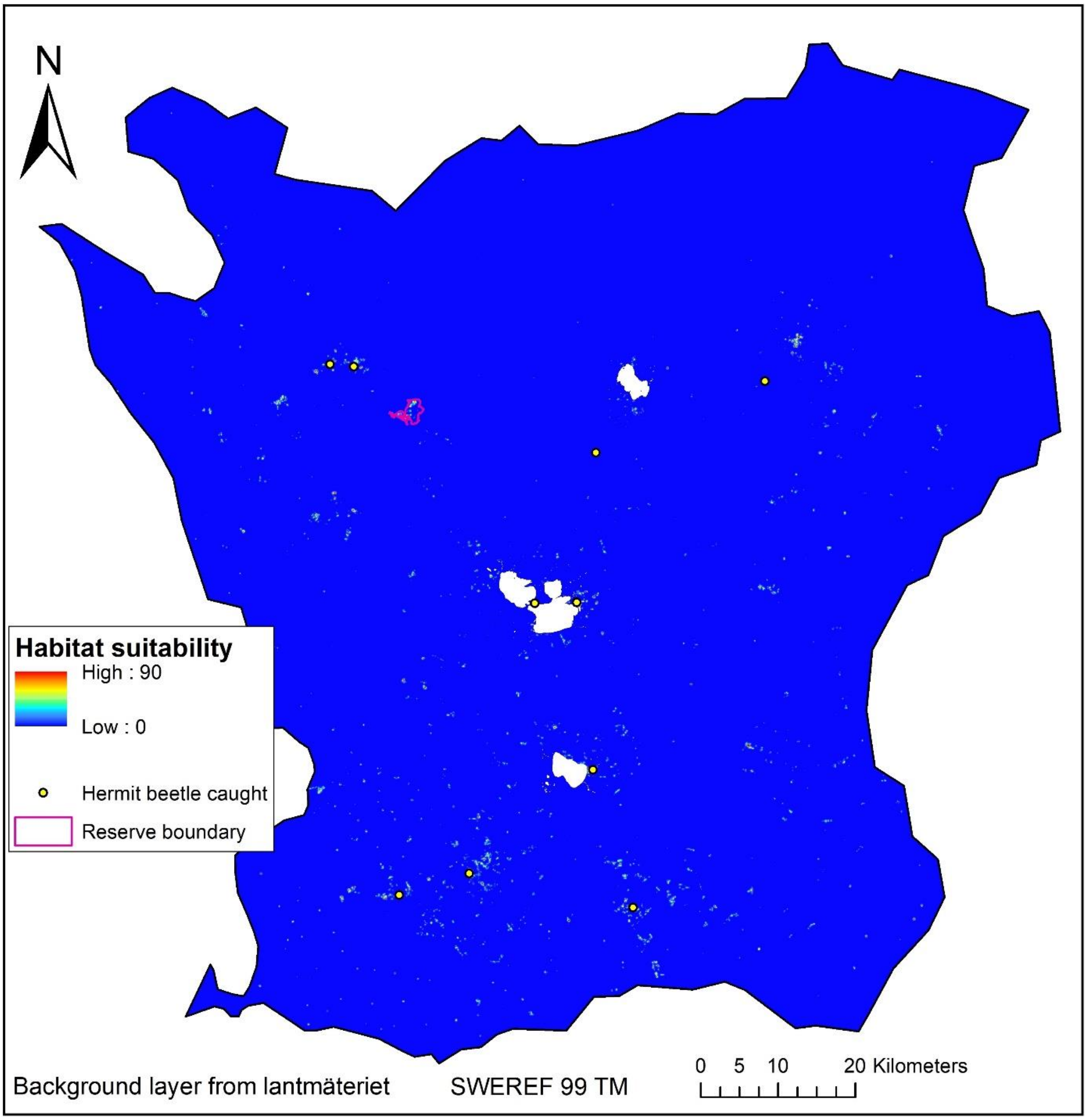

Figure 6. Habitat suitability for hermit beetle in Scania determined by distance weighted density of oaks with tree hollows of stage 5 and 6 in semi-open to open areas. Numbers indicate the number of suitable trees within a 50 m distance of the center of each pixel. Yellow dots indicate locations where hermit beetles have been caught in pheromone traps.

CWM may protect oak seedlings directly as mechanical barriers, but it is also likely that there is an indirect effect enabling the establishment of scrub, shrubberies and brambles, since brambles can establish very quickly (van Uytvanck *et al.* 2008). The death and subsequent fall of a tree opens up a habitat patch for light demanding, fast growing plants such as bramble, further facilitated by the mechanical protection of the branches and trunk of the dead tree (Vera 2000). The resulting vegetation is of the type which is favored by jays for the caching of acorns (Bossema 1979). Provided that there is a population of Eurasian jays present, this will likely lead to the emergence of oak seedlings, facilitated by the associational resistance of the bramble thicket (Vera 2000). Eventually, the seedlings will overtop the bramble, which will ultimately die off due to shading from the branches of the oak as it matures (Vera 2000). As the brambles die off, the lack of the mechanical protection of the thicket should reenable grazing of the area as the CWM decomposes, preventing the establishment of seedlings of potential competitors to the oak.

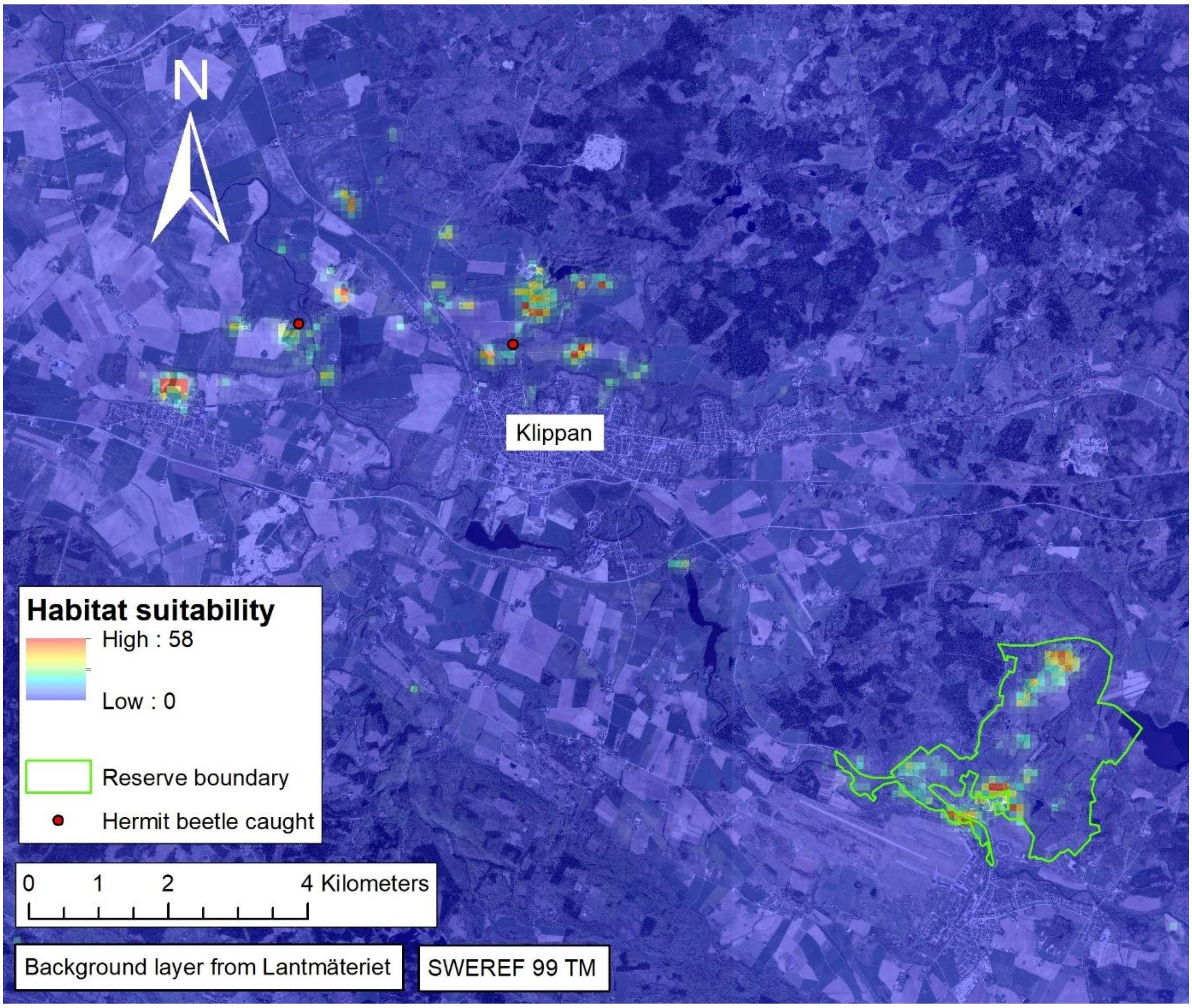

Figure 7. Habitat suitability for hermit beetle in and around Herrevadskloster determined by distance weighted density of oaks with tree hollows of stage 5 and 6 in semi-open to open areas. Numbers indicate the number of suitable trees within a 50 m distance of the center of each pixel. Red dots indicate locations where hermit beetles have been caught in pheromone traps.

The use of naturally occurring vegetation and/or CWM for the rejuvenation of trees has several benefits over rejuvenation within constructed grazing exclosures. Firstly, it is more cost effective, since there is no cost of building materials and labor for construction and maintenance. Secondly it allows for a more natural look of the reserve, increasing its recreational value. That said, grazing exclosures offer a complete protection against browsing of large herbivores (Jensen *et al.* 2012). A total of 140 grazing exclosures constructed from steel mesh were erected in the reserve in 2015 within Horsabacken, Ålafisket and Gökottebacken (as well as other areas which were not included in this study) (Tove Hultberg, pers. comm.). Whithin these, some 2 500 seedlings of pedunculate oaks were planted. The seedlings had been grown from acorns collected within the reserve. Saplings are now present in all exclosures, although in some exclosures the number of living saplings is only one or two and some saplings appear to have been damaged through grazing, possibly by field voles (*Microtus agrestis*) (personal observation). During the autumn of 2017, an additional 2 500 seedlings of the same origin were planted within the reserve (Tove Hultberg, pers. comm.). The majority of these were planted within the existing grazing exclosures, but some of them were planted within hawthorn (*Crataegus sp.*) and within the shelter of CWM to utilize natural grazing protection. In addition, 600 seedlings were planted in 8 new grazing exclosures, constructed either by steel mesh or by cleared thorny bushes (Tove Hultberg, pers. comm.).

Veteranisation

The idea behind veteranisation is that relatively young, healthy trees are damaged in order to induce heart rot, ultimately creating features associated with much older trees (Read 2000; Carey & Sanderson 1981). Several methods of veteranisation have been tested throughout the years. A common way of damaging trees is through the removal of branches. Natural breakage of branches, resulting in jagged branch ends yields better results for regrowth than the straight cut of a chainsaw (Finch 1993). To imitate this artificially, several methods for the breaking of branches have been employed, including breakage through winching and the use of explosives. Neither is recommended today, however, since winching often resulted in root damage or uprooting and the results of explosives were too unpredictable (Finch 1993: Fay 2004). A more successful method for creating jagged branch ends is through the use of coronet cuts. A chainsaw is used to make several incisions so that the end resembles a coronet (Fay 2003).

A more direct approach is routing, where a hole is made in the trunk using a drill or chainsaw. Trials with routing carried out on red maple (*Acer rubrum*), red oak (*Quercus rubra*) and white oak (*Quercus alba*) showed negligible mortality of trees due to structural damage and all affected trees were small and exposed to strong winds (Carey & Sanderson 1981). In the study, a large proportion of the hollows formed by routing became waterfilled and the authors recommended careful selection of the point of routing to ensure that a minimum of runoff from rain enters the hollow (Carey & Sanderson 1981).

Veteranisation is a relatively new management form, and as a result there is a general lack of long time data on the effects of various treatments. A predecessor to veteranisation is pollarding. Although developed as a farming technique rather than a method for nature conservation, pollarding could prove to be useful for conservation. Ancient pollards tend to develop hollows at the top of the bole, as opposed to ancient trees which have never been pollarded, which tend to develop hollows further down on the bole (Fay 2004). This is useful since hermit beetles seem to prefer hollows situated high up on the trunk (Hedin & Mellbrand 2003). In addition, pollarding prolongs the life of the individual trees (Kirby 1992; Lonsdale 1993). Pollarding also introduces heart rot to the tree at an earlier stage in its life through the continued damage, likely causing hollows to form earlier (Kirby 1992). The mortality and response of the tree to pollarding varies widely with tree age and species. Beech is notoriously sensitive to pollarding, especially older trees (Coleman 1993; Mitchell 1989). Much like old beeches, old oaks also have a high mortality following pollarding (Mitchell 1989).

Tree management

The sensitivity of mature oaks to shading highlights the importance of maintaining an open environment around veteran trees of this species (Vera 2000). To some extent, the shaded environment beneath the canopy will repress the growth of competitors beneath the canopy of mature trees (Grime 2001). Some species, such as beech, will however grow in these conditions, ultimately competing with the mature oak, shortening its life span (Vera 2000; Grime 2001). As an oak becomes over-mature, the outermost branches die off in what is called crown retrenchment (Read 2000). This increases the available amount of light beneath the canopy, facilitating the growth of competing trees. Should grazers be unsuccessful in the removal of competitors at this point it might be necessary to remove these manually to ensure longevity of over-mature and ancient trees. If the grazing pressure has varied over time, the canopy cover may have closed, with trees having become established in close proximity to ancient trees. In such cases it is imperative that cutting of trees is carried out around trees of high conservation value to reduce shading (Read 2000). This should be carried out in steps over the course of several years as it has been shown that old oaks may die from rapid changes in microclimate caused by a sudden opening of the canopy (Read 2000).

Trees that are likely to split due to excessive end-loading could be good candidates for retrenchment pruning (Fay 2003). This is when the outermost branches of a tree are pruned, leaving the thicker branches untouched, but greatly reducing the weight of the branches (Fay 2003). The technique mimics the natural dieback of branches that occurs in mature trees and may prolong the life of individual trees (Fay 2016).

Wood mold boxes

One proposed way of bridging age gaps in stands with old hollow trees is the use of wood mold boxes. The boxes are constructed out of wood and are filled with materials that mimic the natural contents of a tree hollow. Trials with wood mold boxes have been carried out in Östergötland by Jansson *et al.* (2009) with promising results. They found that 70% of the species found in local tree hollows had colonized the boxes within a three-year period (Jansson 2009). In that study, the boxes were not successfully colonized by hermit beetle. There was however one individual found in one of the boxes, indicating that the species could be attracted to the boxes (Jansson 2009). In a follow-up study, four individuals were caught in the boxes using eclector traps, indicating that the species had indeed colonized some of the boxes (Carlsson *et al.* 2016). At this point the boxes had been in position for ten years and it is likely that the late colonization is simply due to the slow rate of dispersal of the species, with a low percentage of adults leaving their natal tree hollow (Ranius & Hedin 2001). Carlsson *et al.* (2016) hypothesize that the artificial wood mold in the boxes become increasingly similar to the wood mold of natural tree hollows over time, something that was indicated by a shift in species composition from generalist saproxylic species and species associated with bird nests towards species specialized on wood hollows (Carlsson *et al.* 2016). This indicates that the boxes could potentially be utilized to a high extent by hermit beetles, provided that the construction holds up for an adequate amount of time. It is, however, also possible that the small number of documented colonizations could be due to unsuitable conditions in the wood mold boxes, meaning that the numbers of hermit beetles that hatch in the boxes will remain low even if the artificial wood mold is given more time to mature. Here, longer time series are needed to evaluate the potential of using wood mold boxes to relatively quickly increase the habitat availability for hermit beetles and bridge age gaps between old hollow trees. In the trials in Östergötland, the authors also tried various additions to the wood mold in an attempt to improve nutrient- and microhabitat conditions in the boxes. They found that over the course of 4 years, the addition of a dead hen to the wood mold had a positive effect on the number of individuals of species of hollow-oak specialists (Jansson *et al.* 2009). This effect did not, however, persist after the initial 4 years. Seeing as only one hermit beetle was observed in the boxes during this period, it is possible that the addition of a dead hen has no positive effect on the presence of hermit beetles.

Considering the limited dispersal ability of hermit beetles, it is important that wood mold boxes are not placed too far from suitable tree cavities. Since few dispersing individuals travel further than 50 m, ideally, no box should be placed much further than that from other wood mold boxes or tree hollows to enable sufficient amounts of beetles to reach the boxes for a successful colonization (Hedin *et al.* 2003; Svensson *et al.* 2011). However, Carlsson *et al.* (2016) noticed that boxes placed on trees with existing suitable tree hollows attracted fewer individuals, possibly due to the boxes having to "compete" with the natural tree hollows for dispersing individuals. Therefore, boxes should be placed some distance from existing tree hollows in order to maximize their benefit. Further, since the hermit beetle's usage of host-trees is consistent with metapopulation dynamics, it should be advantageous to concentrate the boxes to a smaller area, rather than spacing them out over a larger one (Ranius 2000).

Jansson *et al.* (2009) noted that the substrate in their wood mold boxes decreased with 15-30% over the course of three years, indicating that boxes will need to be refilled regularly. The microhabitat of the boxes will likely be more constant if refilling is done regularly in small quantities, rather than more rarely and in larger quantities, especially in smaller boxes. The larger boxes (approximately 1,000 L) which will be used in Herrevadskloster should be less affected by this. A more frequent refilling should also mimic natural conditions more closely, since in a tree hollow, new material is constantly added through the decomposition of the inner walls of the tree trunk. The importance of this is unknown, but it is possible that hermit beetles as well as other species would benefit from this.

Relocation and reintroduction

Relocation, although being a widely used practice in conservation work, has seen very little use in the conservation of invertebrates (Drag & Cizek 2015). Most recorded reintroductions of invertebrates have been of lepidopteran species, although examples of reintroduction of species from other orders of insects exist as well (New 2009). A German translocation project for field crickets (*Gryllus campestris*) succeeded in establishing a new population in a nature reserve, registering substantial population increases over a five-year period following the introduction (Hochkirch *et al.* 2007). Introductions have also been carried out with beetles. In 1990, a pilot reintroduction effort was started in the United States for the endangered American burying beetle (*Nicrophorus americanus*) (Amaral *et al.* 1997). Initially, 25 captive-raised individuals were released on Penikese Island in Massachusetts, with re-occurring, annual releases for the subsequent three years. A total of 211 individuals were released over the years. Breeding success rates were high (as high as 97% in one year), and progeny were observed six years after the first release, indicating that the population might persist (Amaral *et al.* 1997). The apparent success of this reintroduction is probably largely due to meticulous planning and continued efforts. Prior to release, food availability, competition, availability of predators and soil preferences were studied. Beetles were released in pairs along with carrion to stimulate breeding and potential competitors of the same genus were translocated from the area to reduce competition (Amaral *et al.* 1997). A much less thorough, but equally successful example was presented by Drag and Cizek in 2015. A clandestine translocation of ten adults of the endangered great Capricorn beetle (*Cerambyx cerdo*), carried out illegally in 1987 in the Czech Republic, led to the successful establishment of what appears to be a viable population, 174 km from the source population (Drag & Cizek 2015). After the introduction, the species was not seen for eight years, except for one dead imago which could possibly be one of the released animals. Ten years after the introduction, two oaks showed signs of being inhabited by larvae and today over 30 oaks at the site are inhabited by the species (Drag & Cizek 2015).

Discussion

Field work

There is a possibility that the survey did not cover all suitable tree hollows in the reserve. However, due to the extensive nature of the tree survey used as background data, it is unlikely that a substantial number of tree hollows were missed. Further, due to the low percentage of the tree hollows in the reserve that supports a microclimate suitable for hermit beetles, it is even more unlikely that any potentially missed tree hollows would be suitable for hermit beetles. It could be argued that the minimum requirement of eight liters of wood mold for a tree hollow is too strict. However, it has been shown that hermit beetles are more frequent in larger wood hollows which contain more wood mold and simulations indicate that carrying capacity and extinction risk is proportional to the amount of wood mold (Ranius & Nilsson 1997; Ranius 2000; Hedin & Mellbrand 2003; Ranius 2007). A larger amount of wood mold likely also creates a more favorable micro-climate (Ranius & Nilsson 1997). Further, a small hollow with tiny amounts of wood mold is most likely a relatively young habitat patch, meaning that it would need to have been colonized recently. If there is indeed a population of hermit beetles within the reserve and this survey simply failed to detect it, then due to its isolation, it is most likely a relict population of relatively few individuals. The likelihood of such a population of a species with a very limited dispersal rate to colonize a newly formed habitat patch would be negligible.

Since the larvae of hermit beetle feed on the harder rotten wood at the border between the softer and harder wood in tree hollows, they are easily missed when sampling wood mold for sifting (Palm

1953). The high production and relatively slow decomposition of frass should, however, mean that even if the larvae themselves are overlooked, their presence is still noticed (Ranius & Nilsson 1997; Antonsson 1999). Further, the large amount of wood mold sampled in each tree hollow makes it unlikely that frass and fragments of imagines would be missed.

Due to technical and administrative difficulties, both the pitfall traps and the pheromone traps were not put in place until after the peak in the flight season of the hermit beetle. Although imagines may appear as late as the beginning of September, this is unusual, and the activity drops off towards the end of August, meaning that the detectability is lower at that time. This may of course have had a negative effect on the chances of detecting a remnant population.

The strong influence of weather conditions on stag beetles' tendency to swarm likely causes their detectability to fluctuate over shorter time periods (Rink & Sinsch 2007; Asp *et al.* 2009). Since the weather conditions fluctuated greatly during the study period it is possible that at times the detectability was rather low. This should, however, have been largely counteracted by the relatively high number of visits during the period of the survey. The summer temperatures were unusually low and the weather unstable which may have caused a delay in the swarming. Other finds of adult stag beetles from Scania at the time of the survey suggests, however, that this was not the case.

The long development time of the larvae means that in small populations there may be no adults emerging during a certain year (Ehnström 1999). It is therefore possible that there is a small relict population in Herrevadskloster and that no imagines emerged during the year of the survey. The complete exclusion of this possibility would require recurring yearly surveys for up to six years, which is the maximum length of larval development that has been reported (Harvey *et al.* 2011). Even though the presence of a relict population cannot be excluded, for the purposes of this thesis, it will be assumed that the species is locally extinct.

Literature review

Relocation and reintroduction of hermit beetle

In the cases of species reintroductions presented in this thesis, the areas in which the species were introduced featured an appropriate habitat. New (2009) stated that, when it comes to insects, an areas suitability for the reintroduction of a species can often only be determined with certainty in hindsight. That said, it is vital that an areas suitability is thoroughly examined prior to a reintroduction attempt, especially if the species in question is rare.

With the present availability of suitable tree hollows in Herrevadskloster, it is unlikely that a reintroduction of hermit beetle would be successful. Even if a population could be established in a few of the current trees, the small number of usable trees and the isolation from other metapopulations would make the newly established metapopulation vulnerable to stochastic events. It has been showed that the extinction risk of hermit beetle metapopulations is negatively correlated with the number of hollow trees at the stand level (Ranius 2007). The amount of suitable hollow trees required within a stand to create a metapopulation with a high persistence does, however, seem to be relatively low. According to simulations, for a stand with more than 10 hollow trees, the extinction risk is close to 0% over a 200-year period (Ranius 2007). Several of the hollows in the reserve, while being potentially usable by hermit beetle, are suboptimal. The hollow in Swältebacken, which likely contains the largest amount of wood mold, is situated in a beech forest with a closed canopy. This means that there is virtually no direct sunshine on the tree trunk at all, leading to a cooler microclimate and a closed canopy has been shown to negatively affect the occurrence of hermit beetles (Ranius & Nilsson 1997). Additionally, the entrance to the tree hollow is situated at ground level. Hedin and Mellbrand (2003) found that height above ground of the entrance of tree hollows correlated positively with the occurrence of hermit beetles. The authors hypothesized that this is due to two reasons; firstly, a hollow situated close to the ground is more accessible to predators such as Carabids, Staphylinids as well as vertebrates such as badgers, shrews and mice. Secondly, the microclimate is likely more variable, with fluctuations in humidity and temperature, since the tree hollow is not insulated from the ground (Hedin & Mellbrand 2003). Ranius and Nilsson (1997) found that hermit beetles occurred more frequently in tree hollows with south- and west facing openings, likely due to a warmer and more stable microclimate. Only three of the hollows classified as usable are facing these cardinal directions (west, south and southwest respectively). The most limiting factor in Herrevadskloster is the limited number of hollow trees and the relatively long distances between them. Even though most potentially usable tree hollows have another usable tree hollow within dispersal distance most of them only have one or two hollows within dispersal distance, meaning that if the trees were successfully colonized by hermit beetles, there would be very little genetic exchange between the individual populations (Hedin *et al.* 2003). If the availability of suitable tree hollows should increase in the future, the possibility for a reintroduction of the species should be re-evaluated.

The distance weighted density analysis for hollow trees in open to semi-open environments (Fig. 6) showed that the number of usable habitat for hermit beetles is quite low and that these are interspersed with long distances between patches. It is possible that the analysis is too pessimistic with regards to the frequency of long-distance dispersal of the species. The results of the analysis are, however, consistent with the trapping data from Mattias Larsson (pers. comm.) and the analysis indicate that the closest major suitable habitat to Herrevadskloster is just north of Klippan, where beetles have previously been caught.

Relocation and reintroduction of stag beetle

Reintroductions should not be carried out unless the original cause of extinction has been addressed (IUCN 1987). Unfortunately, due to the lack of historical records regarding the presence of stag beetles after the end of the nineteenth century, it is impossible to draw any certain conclusions as to when and why the local population died out. When reviewing the history of the area with its long continuity of large old broad leaf trees and grazing, it is puzzling that a population of stag beetles would die out there. In most places, the trees are interspersed so that the ground around the base of the trees is sun exposed, providing a warmer microclimate for the larvae. Further, the area is fairly big with a surface area of 118 hectares of open wooded pasture and an additional 158 hectares in need of some form of restoration. The suitable areas within the reserve are close enough to each other for male stag beetles to maintain geneflow between patches and only Horsabacken is out of reach for dispersing females from other areas (Rink and Sinsch 2007). The soil in the area is sandy and well drained, providing good conditions for larval development. In spite of this, the western part of Horsabacken was waterlogged during the revisit to the study area in October. For some time prior to the revisit, there had been heavy rains, meaning that the area is possibly only waterlogged in unusually wet years. If waterlogging during the wetter months is a more commonly occurring event, however, it would make the western part of Horsabacken completely unsuitable for larval development. Since this is based on a single observation it might be that this is a rare incident. However, even rarely occurring events of waterlogging could have large negative effects on a population of stag beetles since it would likely kill of a large number of larvae. That said, the northern part of Horsabacken, as well as Ålafisket, should still be a suitable habitat.

A population could die out for several reasons, such as habitat degradation, habitat fragmentation, isolation and predation. The main predators of adult stag beetles are corvids followed by fox (*Vulpes vulpes*), both of which are present in the area (personal observation) (Harvey *et al.* 2011). As for the larvae, the main predators are wild boar (*Sus scrofa*) and badger (*Meles meles*) (Harvey *et al.* 2011). Since wild boar was extinct in Sweden at the time when the population likely died out, this leaves only badger as a known, major predator on larvae. Predation by native species alone is likely not the cause of the extinction, although it might have been a contributing factor. Habitat fragmentation has likely had a negative effect on the population, considering that wooded pastures is a habitat type that has become increasingly rare over the last century (Kirby & Watkins 1998). The subsequent isolation may have played a part in the extinction, but isolation alone is unlikely to be the cause. Inbreeding depression mainly affects small, already vulnerable populations and an absence of immigration due to isolation is mainly detrimental if the population is already doing poorly (Shaffer 1981; Lande 1998). Even though isolation is probably a real threat facing several, if not most, populations of stag beetle in Scania, I argue that it is unlikely to cause local extinction of viable populations. Hodgson *et al.* (2011) proposed that the positive effects of connectivity on population size and growth rate are much smaller than those of habitat size and quality. This is mainly due to the fact that both the size and quality of a habitat directly influences carrying capacity and growth rate, thereby increasing population viability, while connectivity does not necessarily increase population viability Hodgson *et al.* (2011). Isolation may however have detrimental effects on populations already suffering from habitat loss or habitat deterioration.

The distance weighted density analysis located several areas in Scania which could potentially be usable by stag beetles (Fig. 5). Although several of these are located in the area surrounding Herrevadskloster, they are not within dispersal distance of the reserve. It should be noted that the analysis did not consider veteran trees of other deciduous species, such as beech, which could potentially provide deadwood for larval development. The choice to only include oak in the analysis was made as most finds of stag beetle in Sweden have been on oak and it is reported as the most important host species in Europe (Harvey *et al.* 2011). The survey of veteran trees which was used as background data for the analysis is not a complete survey of the entirety of Scania. Rather, areas which could contain veteran trees were selected from aerial footage and subsequently surveyed. Therefore, there may be potentially usable habitats that have been overlooked in the analysis, even though these are unlikely to be larger continuous areas.

It is difficult to evaluate the amount of subterranean dead wood. The large amount of old oaks and beeches should however provide substantial amounts of dead roots. Many oaks within the reserve have old, visible injuries at the base of the trunk, likely from gnawing of horses which were grazing in the reserve during the period when it was used by the army (Fig. 8) (Johnmark & Fiskesjö 2011). This is especially true for the larger area known as Horsabacken. These injuries show exposed rotting wood. The rot from these areas have most likely spread underground to create ample amounts of subterranean deadwood.

Substantial amounts of tanner beetles have been caught with pheromone traps within the reserve, indicating that there is a local population (Mattias Larsson, pers. comm.). This gives some further indication that the area could be suitable for stag beetle, since their ecology is quite similar. Like the stag beetle, the larval development of the tanner beetle takes place underground where the larvae feed on deadwood (Duffy 1946). It should, however, be mentioned that the tanner beetle can utilize a wider range of tree species for food and occasionally even utilize wood of coniferous tree species (Duffy 1946). As mentioned earlier, stag beetles have been found to utilize most deciduous tree species, but in Sweden this appears to be uncommon. Potentially, tanner beetles could therefore have access to more oviposition sites in the area than stag beetles would. This should, however, not have a pronounced effect since the dominant tree species within the reserve are oak and beech, which both are preferred host species of stag beetle (Harvey *et al.* 2011). On the other hand, a less discriminating preference for host species should be more beneficial in a fragmented landscape, since it could enable tanner beetles to disperse through areas which would serve as boundaries for stag beetles due to their higher demands on host species. It should also be mentioned that the tanner beetle may have a greater dispersal ability than stag beetle since it has been shown that males of tanner beetle can disperse nearly 3 km (Larsson 2017). The dispersal ability of females is

Figure 8. Deadwood at the base of a veteran oak in Horsabacken, likely caused by the gnawing of horses.

unknown, but if it is similar to that of males the species would likely be less vulnerable to habitat fragmentation than stag beetle (Larsson 2017). The limited expansion of tanner beetle populations to neighboring, suitable habitats suggests, however, that this is not the case (Sarac 2016; Mattias Larsson, pers. comm.).

Since it is impossible to determine what caused the extinction of the previous population there is a risk that the conditions responsible remains the same. The conditions in the reserve does however seem favorable. As mentioned earlier, it is difficult to conclude with certainty that a habitat is suitable for reintroduction and to some extent it is a form of trial and error. For that reason, it is important that the collection of individuals for translocation does not increase the vulnerability of the source population. To ensure this, it is vital that continuous monitoring is carried out at the source population to ensure that it is stable before any collection is initiated. Since the larvae are located underground, locating and collecting a sufficient amount for a successful reintroduction would require a tremendous effort and would likely also damage the subterranean dead wood. In addition, translocation of larvae, rather than imagines, is likely ill-advised since more individuals would need to be collected to compensate for mortality before maturity. Since it would be difficult to ensure that wild caught larvae are of the same age, there is a notable risk that the larvae, once translocated, would emerge from their pupae in different years. This would entail that the effective number of individuals available for mating in a certain year would be lower than if all the translocated individuals had been of the same age, causing an Allee effect with subsequent low reproduction rates. Instead, I propose the relocation of imagines. It is likely that microclimate has an effect on the individual development time, meaning that even if imagines are translocated, there is a possibility that the pupae of the F1 generation will hatch in different years. To compensate for this, imagines should be translocated in several consecutive years. This will also make sure that imagines are present in all years which is important since it should decrease the impact of poor weather in individual years. It will also compensate for mortality and potentially low initial reproductive rates. It is often desirable to acquire individuals for translocation from a donor population situated closely to the reintroduction area. In case of local adaptations, collecting specimens for introduction in the vicinity should be more likely to result in well adapted individuals. Therefore, it is always advisable to collect individuals from the nearest stable population.

Since wild boar are now present in the reserve (personal observation), there is a risk that they may predate heavily upon stag beetle larvae that are more easily reached, e.g. those feeding on smaller pieces of half-buried dead wood. Therefore, hunting within the reserve might be beneficial, especially before a viable population of stag beetles has been established, and protective hunting of wild boar is currently ongoing in the reserve. Continuous monitoring should be carried out following the reintroduction to evaluate its result in the form of presence and rate of increase. In addition to detecting the possible need for intervention, continuous monitoring also provides valuable information for future reintroductions, especially if the reintroduction should prove to be unsuccessful.

Recruitment of trees

Since there is already a sizable amount of bramble at Horsabacken and Lilla Hage, these should provide opportunities for the establishment and growth of seedling and sapling oaks. Indeed, several sapling oaks are already emerging from these brambles and in Lilla Hage a substantial amount of these are already above the browsing limit (Fig. 9). CWM should be allowed to remain to a large extent to promote rejuvenation. Should excessive amounts of CWM accumulate, some amount should be moved from grazed areas to promote grazing and to maintain an open landscape. This is especially important for CWM created by the removal of young competing trees in close proximity to large, old oaks, as failure to do so could result in old trees of high conservation value dying prematurely due to competition from young trees emerging from the natural grazing protection.

Veteranisation and tree management

In order to acquire a more complete understanding of the effects of the different veteranisation treatments on substrate quality and tree survivability, longer time series are needed. Unfortunately, the lack of replacement trees in many locations means that there is little time to await further results. Therefore, since clear results for several of the possible management actions will not be available for several decades, it may be necessary to take actions before these results are in. Due to this uncertainty it is important that no trees that already possess features of value to conservation are subjected to veteranisation. This is especially important if there are few trees in that specific age class, as the loss of a single tree could then reduce the availability of ancient trees in the future. For that reason, suitable candidates for veteranisation are young or mature trees in areas with sufficient recruitment of new trees. If veteranisation is carried out it is important that the methods and results are documented,


Figure 9. Rejuvenation of oak in patches of bramble in Lilla Hage.

regardless of the outcome, as there is a general lack of knowledge concerning the long-term effects of veteranisation.

A disadvantage of pollarding is that it requires recurring repollarding on a more or less regular basis. As a result, if a large number of trees are pollarded it could become a costly management technique. Neglected pollards are prone to splitting and the repollarding of a long-neglected pollard of oak or beech has a high risk of killing the tree as it is an extensive procedure (Read 2000; Mitchell 1989). Therefore, if the decision to create new pollards is taken, it is important that the management is continued, as initiation and later abandonment of management may do more harm in the long run than no management at all.

Wood mold boxes

Even though there currently seems to be no hermit beetles in the reserve, the addition of wood mold boxes could benefit several other saproxylic species, especially species that specialize on tree hollows. Any saproxylic species that are currently present likely have a greater dispersal ability than hermit beetles and therefore it may seem excessive to base the positioning of the boxes on the dispersal ability of hermit beetles. However, since an exhaustive survey of saproxylic invertebrates has not been carried out in the area, tailoring the conservation measures to a more demanding species should ensure that the measures taken are adequate for other, relatively demanding species that may be present (Appendix Fig 10). An alternative would be to have more interspaced boxes in order to cover a greater part of the reserve. Even though this likely offers less possibilities for the movement of species with limited dispersal, placing the boxes over a larger area could increase the chances of them being discovered by dispersing individuals. In addition, covering a greater area could offer a convenient opportunity to perform a survey of saproxylic species. Subsequent inspection of the boxes following their installation could give valuable information on the occurrence of species. This data could then be used to target efforts, such as the further addition of wood mold boxes, at areas where rare or threatened species occur. Even with a more interspersed placement of boxes, the focus should still be on the areas with the highest availability of natural tree hollows, since this increases the likelihood of colonization by species that are already present in the reserve. In addition to the dispersal abilities of saproxylic species, the positioning of wood mold boxes requires some practical considerations. It is important that the installation of the boxes does not cause any undue degradation of other objects of conservation interest, such as damage to sensitive flora due to transportation of the boxes with heavy machinery. To prevent the boxes from being tipped over by grazing cattle, the boxes should be anchored to nearby trees with steel bands. In order to create a warmer microclimate, the boxes should also be positioned so that sun exposure is maximized without significantly decreasing the sun exposure of the trunk of the nearby tree. Even though the trials with wood mold boxes in Östergötland showed no significant long-term effects of the addition of dead birds, there is a possibility that additional nutrient in the form of dead birds has a positive effect, but that one hen is insufficient for a longer period of time. It would therefore be beneficial to study this further, ideally by adding new dead birds continually since this should mimic natural conditions more closely, where addition probably occurs sporadically in the form of individual dead chicks and failed broods. In addition, it should provide a more stable nutrient level.

Conclusions

There does not seem to be any remnant populations of hermit beetle and stag beetle at Herrevadskloster. Based on the limited number of suitable tree hollows and the isolation from other metapopulations, a reintroduction of hermit beetles would not be appropriate as the reserve is currently not capable of sustaining a viable metapopulation. The reserve should, however, be able to support a population of stag beetles, owing to the suitable soil type, the openness of the tree cover and availability of subterranean dead wood. Therefore, a carefully executed reintroduction could be successful, provided that a suitable donor population can be found. Currently the amount of rejuvenation of oak varies throughout the reserve and in most areas, it is quite low. The exception is the area Lilla Hage, likely due to the large amount of bramble. In the other areas the amount of bramble is generally quite low which could explain the low amount of rejuvenation. The grazing exclosures should however alleviate this to some extent, especially with the recent addition of more seedlings. To minimize age gaps, efforts should be taken to ensure longevity of current and future veteran trees in the reserve. As a part of this, if funding is available, it would be beneficial with retrenchment pruning as well as pollarding. It could also prove beneficial to perform trials with veteranisation to speed up the formation of veteran tree features.

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Appendix

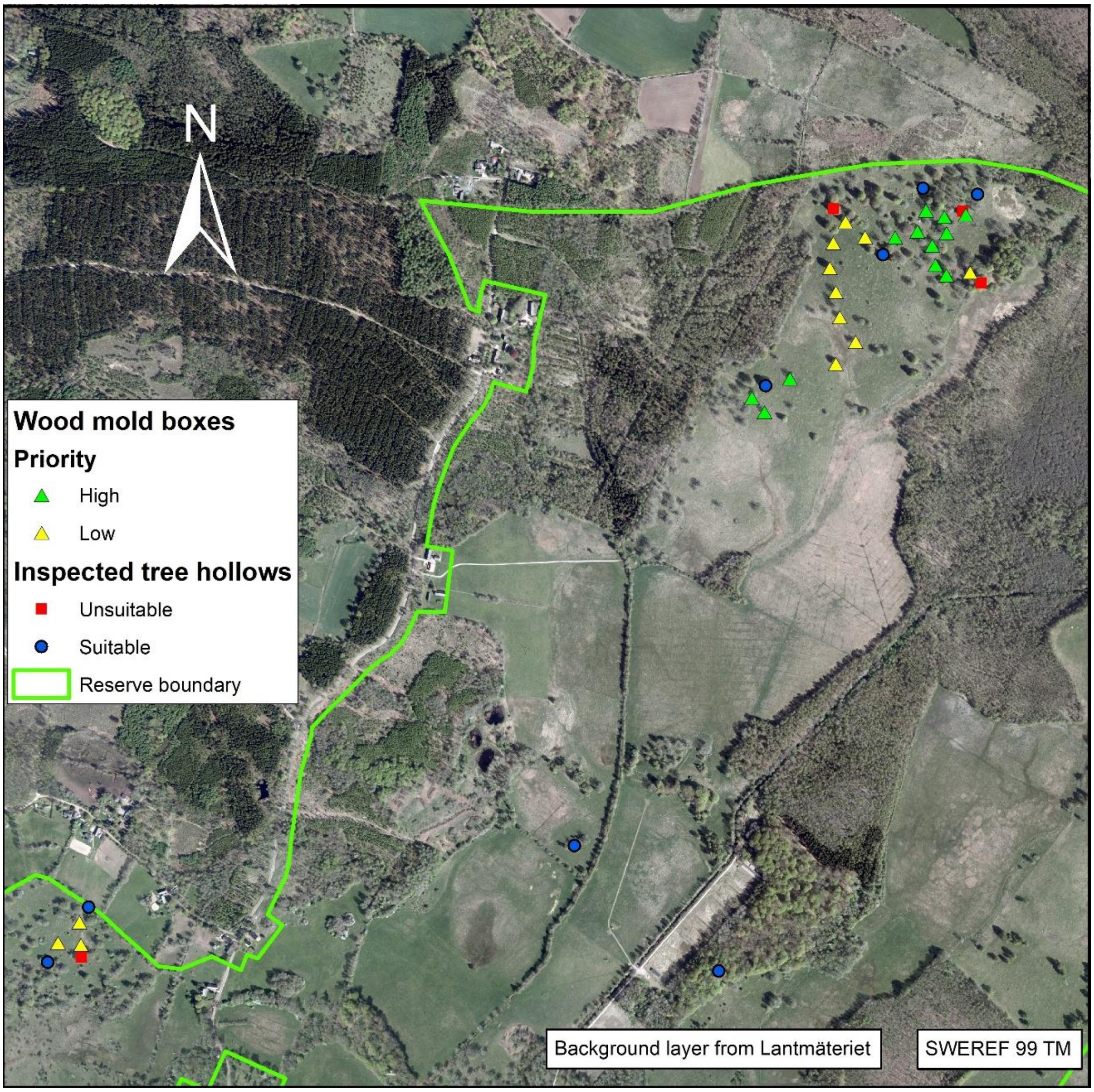

Figure 10. Suggested distribution of wood mold boxes with an interval suitable for the dispersal of hermit beetles. Boxes are classified according to priority and tree hollows according to suitability for hermit beetles.