

Sveriges lantbruksuniversitet Swedish University of Agricultural Sciences

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Longhorn beetles in lesser spotted woodpecker habitat

- A pheromone-based inventory of longhorn beetles in southern Sweden

Långhorningar i mindre hackspetthabitat

- En feromonbaserad inventering av långhorningar i södra Sverige

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Summary

The understanding of species' ecology and their trophic interactions, are crucial in the work of conservation. A population decline in a predatory species may be a result of a decline in their food source, a trophic level down. Then an understanding of why the predator's food source has declined is needed, to be able to pinpoint conservation actions. In Swedish forests one such trophic interaction is between dead wood, saproxylic insects and woodpeckers. Modern forestry of clear cuttings and monoculture plantations of coniferous trees, has changed many Swedish forests to be less diverse in tree species, age classes of trees, types of dead wood, denser and hence also deficits in dead deciduous wood. As a result, insects in Swedish forests have declined. Most longhorn beetle species (Cerambycidae) larvae are saproxylic and have different niches. Niches such as specific host trees, age classes of trees, types of wood and different succession stages of decomposed dead wood. Of the 118 species of longhorn beetles in Sweden, 46 were red listed in the 2020 Swedish red list evaluation. Lesser spotted woodpecker (Dryobates minor) is a small woodpecker preferring open broadleaf forests. Between 1975-1991 the Swedish population decreased by approximately 50% and today D. minor is classified as Near Threatened, according to the 2020 Swedish red list evaluation. Studies in southern Sweden have shown that the most important factor influencing reproduction success in *D. minor* is the prey density several weeks to months before breeding. During that time they feed on wood living insect larvae, mainly in dead thin twigs on living deciduous trees. Longhorn beetle larvae and pupae are probably the most important food source. In order to understand why D. minor is threatened, their food source has to be understood as well. In this study I used pheromone traps to monitor longhorn beetles in 34 areas between May-July, in the counties of Skåne, Blekinge, Småland and Västergötland in southern Sweden. Pheromone-based trapping is an effective method to monitor otherwise elusive species and in this study pheromone blends attracting mainly *Pyrrhidium sanguineum*, Phymatodes testaceus, Poecilium alni and Plagionotus arcuatus were used. The areas monitored in this study, had been inventoried 2019-2020 by "project lesser spotted woodpecker at Lund University", giving occurrence information about D. minor. In this study I found no differences in longhorn beetle abundance or longhorn beetle biodiversity between areas inhabited or uninhabited by D. minor. Hence, no evidence was found that D. minor habitat choice depend on the longhorn beetles studied. A strong positive association was, however, seen between P. sanguineum and P. alni and large dissimilarities between P. testaceus and P. alni as well as between P. sanguineum and Anaglyptus mysticus. These associations between the species could perhaps be used in future identification of indicator species. I also found a negative correlation between the biodiversity of longhorn beetles and increasing latitudes, but the factors affecting longhorn beetles are not clear. Lastly, several new localities with red listed species were found and my findings suggest that *P. sanguineum*, P. alni and perhaps also A. mysticus distributions are underestimated.

Popular scientific summary

In a forest ecosystem species are interacting and influencing each other. A predator such as a woodpecker eats wood living insects and depend on them for survival. Wood living insects on the other hand depend on the availability of suitable wood in the forest. So, if there is low availability of wood in a forest, few wood living insects will be abundant and hence few woodpeckers. Because of modern forestry of clear cuttings and often coniferous tree plantations, many forests contain fewer species of trees that also are in less diverse age classes. Wood living insect species depend on different tree species and different types of wood. This has led to a decrease in wood living insects in Sweden. There is also a deficit in dead wood (particularly deciduous) in southern Sweden and many of the wood living species, depend on dead wood, including most longhorn beetle species. 46 out of 118 species of longhorn beetles in Sweden are red listed, because of this forestry. Longhorn beetle larvae and pupae probably constitute the most important food source for the lesser spotted woodpecker. The lesser spotted woodpecker is a small woodpecker, preferring broadleaf forests, and they eat longhorn beetle larvae before their breeding season. During this time the overwintering larvae are important because of few other food options. The Swedish population of lesser spotted woodpecker had a large decline between the years 1975-1991 and is now threatened. To be able to understand why the lesser spotted woodpecker is threatened, we need to understand their food source. In this study I monitored longhorn beetles in southern Sweden during the summer of 2020. Areas that were monitored had been inventoried before, by searching for lesser spotted woodpecker. These areas and occurrence data of lesser spotted woodpecker were derived from "project lesser spotted woodpecker at Lund University". I used pheromone traps to collect certain species of longhorn beetles. Pheromones are intraspecific chemical signals, usually sexual attractants. Synthesized pheromones were used as lures in pheromone traps, making it possible to collect species that otherwise are hard to survey.

In this study I did not find more longhorn beetles or higher biodiversity of longhorn beetles in areas where lesser spotted woodpecker was present than where it was not present. Thereby, no evidence was found that *D. minor* habitat choice depend on the longhorn beetles studied. However, I did see some interesting patterns in the longhorn beetles captured, which could be used in the future when identifying indicator species. *Pyrrhidium sanguineum* and *Poecilium alni* had positive associations, whereas *Phymatodes testaceus* and *P. alni* as well as *P. sanguineum* and *Anaglyptus mysticus* had large dissimilarities. I also found a negative correlation between the biodiversity of longhorn beetles and increasing latitudes, but the factors affecting longhorn beetles are not clear. Lastly, several new localities with red listed species were found and my findings suggest that *P. sanguineum*, *P. alni* and perhaps also *A. mysticus* distributions are underestimated.

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Introduction

Forest ecosystems contain food webs where species at different trophic levels interact (Chapin III et al. 2012). An example of a simple trophic interaction could be the death of a tree, which then becomes a food source to saproxylic (wood dependent) insects and later those saproxylic insects get predated by woodpeckers (Dahlberg & Stokland 2004). Saproxylic insects will thereby be dependent on a continuation of dead wood and indirectly this will affect the woodpeckers as well (Aulen 1991; Nappi et al. 2015). In a natural forest, where there is a high diversity in tree species and age stages, there will also likely be much dead wood of different quality and thereby high biodiversity of wood living organisms as well (Dahlberg & Stokland 2004). Saproxylic insect species use different tree species, parts of the trees and succession stages of the wood as their host (Ehnström & Axelsson 2002). These host tree associations have evolved for a very long time, resulting in a specialization of saproxylic insect species to different trees. For example, coniferous and broadleaf trees have been separated for more than 300 million years and evolved different defenses against saproxylic insect species, which has resulted in that most saproxylic species either use coniferous trees or broadleaf trees as hosts and not both (Stokland et al. 2012). In Sweden there are approximately 3000 species of saproxylic insects, many of them associated to deciduous trees (Dahlberg & Stokland 2004). Deciduous forests in southern Sweden host many threatened forest species in the four groups: invertebrates, vertebrates, vascular plants and cryptogams. Especially habitats with old trees and oak forests harbor many threatened species in southern deciduous forests (Berg et al. 1994). Species of insects in Swedish forests have declined, mainly due to modern forestry of clear cuttings and monoculture plantations. Monoculture forests are less diverse in tree species, often age classes of trees and types of wood (Cronberg et al. 1986). In the south of Sweden, where it in the past existed more open meadows and deciduous forests, with sun exposed solitary tress having coarse wide branches, these beneficial habitats have now been replaced to a greater extent by dense shaded secondary forests or monocultures of coniferous trees (Lindhe et al. 2010). Spruce forests have since the early 20th century dominated the southern Sweden forests and have increased at a rather constant rate. Thus, the transition to dominated spruce forests actually began before modern forestry (1950s), which means that modern forestry is not solely responsible for the transition (Lindbladh et al. 2014). However, Lindbladh et al. (2014) suggest that the tree species composition and structures in southern forests in early 20th century, prior to modern forestry, were relatively heterogenous. According to Dahlberg and Stokland (2004) there is a deficit in coarse dead wood, especially deciduous, in Swedish forests. In the 1993 Swedish red list, saproxylic insects that were linked to oak trees of the genus *Quercus*, were highest both in total amount of species (37%) and in monophagous species (29%), according to Jonsell et al. (1998). A positive trend in increasing dead wood overall has been seen in Swedish forests the last 20 years, however, including dead deciduous wood. The reason for the increasing amount of dead wood is probably because of storms, although it should be highlighted that the forestry since mid 1990s has begun to actively save both snags and living trees, contributing to the increase of dead wood (SLU 2020).

Longhorn beetles

Longhorn beetles (Cerambycidae) is a diverse family in the order Coleoptera or beetles, with 35000 species all over the world (Ehnström & Holmer 2007). Most longhorn beetles are saproxylic (Jeppsson et al. 2010) and a majority of the species prefer old dead wood as larvae (Ehnström & Holmer 2007). Longhorn beetles contribute to the nutrient cycling and succession of wood in their ecosystems (Paine 2017), but there are also about 200 species which cause billions of dollars in economical losses to forestry, agriculture and horticulture (Monné et al. 2017). Some species are phloem feeders as larvae, which means they eat the sugary and protein rich substrate just below the bark (the secondary phloem). Others are wood feeders, living on nutrient poor but high-energy wood (Ulyshen 2018), or they could be both, but in different stages of their development (Ehnström & Holmer 2007). The inner wood contains cellulose, which is hard to digest, so most larvae feeding there depend on bacteria to digest cellulose to sugar and fungi to fixate protein in their intestine (Cronberg et al. 1986; Ulyshen 2018). There are some exceptions though, as for example the pest beetle *Hylotrupes bajalus*, which is able to produce the enzyme cellulase for digesting cellulose (Cronberg et al. 1986).

Females of adult longhorn beetles lay between 50-200 eggs in the wood, which then take about one to two weeks before hatching into larvae (Ehnström & Holmer 2007). Larvae of longhorn beetles often have soft white bodies and a hard head with strong mandibles to help them eat through the wood (Cronberg et al. 1986). Larvae of longhorn beetles in Sweden diapause during the winter and start eating in the spring when it is getting warmer. Some species need high temperatures before they complete their development and pupae (Ehnström & Holmer 2007). After 10-14 days the adult beetle emerges from the pupa and later digs itself out, and that is why the adult beetle also usually has large mandibles (Ehnström & Holmer 2007). The generation time from egg to adult takes about two years for most species. But Acanthocinus aedilis could emerge from the pupa after only a few months and in contrary Hylotrupes bajulus may take more than ten years before pupating (Ehnström & Holmer 2007). Adults of longhorn beetles are recognized by their often long antennas, which sometimes are even longer than their bodies. Males usually have longer antennas than females (Sandhall & Lindroth 1976; Ehnström & Holmer 2007). Some species are brightly colored (Lindhe et al. 2010) and typically slender, with long thin legs (Cronberg et al. 1994). Adults of longhorn beetles feed on sap, floral resources, foliage, conifer needles, tender bark or not at all, depending on species (Hanks 1999). Species which did not eat as adults in Hanks (1999) study, survived around four days as adults and other species that did eat, survived between 36-53 days. Ehnström and Holmer (2007), however, state that some non-feeding adult longhorn beetles live a couple of weeks and that there are feeding species that could survive as adults more than a year.

Status in Sweden

In Sweden there are 118 recorded species of longhorn beetles (exotic species excluded). During the last 200 years at least five species have gone extinct and some have become rarer, although most species exhibit relatively stable population trends (Jeppsson et al. 2010; Lindhe et al. 2010). The findings in Lindhe et al. (2010) contradict the Swedish red list, in which half of all species were considered as threatened. In the latest Swedish red list evaluation from 2020 there are 46 species red listed, four of them classified as Regionally Extinct (ArtDatabanken 2020). Some of those species that have become rarer depend on sun exposed dead wood of oak and forest fires (Ehnström & Holmer 2007; Lindhe et al. 2010).

As was described before, monoculture forests are less diverse in tree species, often age classes of trees and types of wood (Cronberg et al. 1986). This is a problem for the various wood living longhorn beetle specialists which have different niches, as for example regarding tree species, age classes of trees, types of wood (living, injured, stressed, dead snag, downed dead wood, roots), different succession stages of decomposed dead wood (Cronberg et al. 1986; Hanks 1999; Ulyshen 2018). Also denser forests could be a problem as ³/₄ of the Swedish species of longhorn beetles are believed to benefit from sun exposure (Lindhe et al. 2010). Another threat to many species of longhorn beetles is the increasing extraction of wood that earlier was left behind, but now is used in the making of biofuel. The extraction of dead wood gives adult beetles less reproduction sites, but also kills larvae that have not pupated (Ehnström & Holmer 2007; Lindhe et al. 2010). In the case of fuel piles containing oak, Hedin et al. (2008) proved them to be ecological traps and the highest density of both species and individuals was found in sun-exposed parts of the piles.

Pheromones

Longhorn beetles, just as most other insects, depend heavily on chemical cues from their environment in their search for mates, food and oviposition sites. Attracting cues could for example be volatiles from plants (food to adults or hosts for larvae) or sex pheromones (Allison et al. 2004). Pheromones are intraspecific chemical signals: volatiles released by individuals of a certain species which cause a reaction in other individuals of the same species (Karlsson & Luscher 1959). Pheromones have multiple uses in organisms and differ between taxa (Nandagopal et al. 2008). Longhorn beetle species in the sub families Lamiinae, Cerambycinae and Spondylidinae are known to use male produced sex- aggregation pheromones (Hanks & Millar 2016). Sex- aggregation pheromones are released by only one sex, but attract both sexes, because of sexual motives (Cardé 2014). Species of the sub families Lepturinae and Prioninae are known to use sex pheromones (Hanks & Millar 2016), which are released by one sex and attract the other sex (Cardé 2014). In the last two decades, identification of pheromone volatiles in longhorn beetles has increased rapidly and there are now pheromones recognized in more than 100 species (Hanks & Millar 2016). After pheromones have been recognized and field tested, they sometimes can be synthesized and used as lures in pheromone baited traps for collecting longhorn beetles (Molander et al. 2019a). Therefore elusive species such as species living in the canopy, small populations or rare species, could effectively be monitored using pheromone baited trapping methods targeting specific species (Hanks & Millar 2016; Larsson 2016). Often the same compounds in pheromones are used by several species of longhorn beetles, making it possible to monitor several species with a single blend (Hanks et al. 2018; Molander et al. 2019a).

Lesser spotted woodpecker

Lesser spotted woodpecker (Dryobates minor), hereafter called D. minor, is a small (14-15 cm, 20-25 g) black and white woodpecker, preferring open broadleaf forests (Cramp 1985; Ulfstrand et al. 2001). Males and females are sexually dimorphic, males having a red crown, which females lack (Cramp 1985). They are distributed in the palearctic region and occur all over Sweden (ArtDatabanken 2019). In south of Sweden, Wiktander et al. (2001a) tracked their home range mean size to 742 ha in winter and 102 ha in late spring, which is remarkable considering their small body size. When they nested, their home range mean size decreased to only 43 ha, which Wiktander et al. (2001a) thought could be explained by high travel costs when feeding nestlings and because of more available food in situ. D. minor are biparental and generally monogamous, with few exceptions. When they are established in their breeding area they also get very territorial (Wiktander et al. 2000). At least 40 ha forest dominated by deciduous trees, in an area of maximum 200 ha, seems to be their habitat requirement (Wiktander et al. 2001a). In Wiktanders et al. (1992) study, nemoral deciduous forests (mainly oak, but also beech, lime, ash, maple, elm, hornbeam) and riparian deciduous forests (deciduous forests on wet land) had a positive association with the occurrence of D. minor and mixed coniferous/deciduous forests had a negative association. Between the years 1975-1991 the Swedish population of *D. minor* decreased by approximately 50% (Nilsson et al. 1992). Since then, it seems that the population has stabilized and perhaps even increased (Green et al. 2020). However, D. minor was still classified as Near Threatened in the Swedish 2020 red list evaluation (ArtDatabanken 2020). The reason for the decline in the past decades is probably due to the modern forestry, removing of dead wood and higher densities of coniferous forests (Ulfstrand et al. 2001). It should be noted that different sorts of dead wood probably are of different importance for *D. minor*. Smith (2007) for example, did not see any positive effects in *D. minor* when dead wood increased in a study in England, but he saw a strong selection for snags. He thought that the type of dead wood which increased (mainly dead wood on the ground and larger limbs), was not the right kind of dead wood to benefit D. minor. Lohmus et al. (2010) were confirming the lesser importance of downed dead wood for D. minor in their study in Estonia. But because of their small weak beak, they still need rotten wood when foraging in winter and when excavating nesting holes (Cramp 1985; Ulfstrand et al. 2001; Kosinski & Kempa 2007). New nesting holes are excavated in the spring (Wiktander et al. 2000) and in Wiktanders et al. (2001b) study, the first clutch was laid between May 1-30. In Olssons et al. (1992) study, the Swedish population of D. minor preferred forests rich in snags. They discuss that it could be because of the use of snags as a food source and as nests. But they also had an alternative theory, that forests with many snags also have a lot of dead wood on living trees.

Olsson et al. (1999) studied foraging behavior and reproduction success in a population of *D. minor* in southern Sweden. Their result indicated that the most important factor influencing reproduction success was the prey density several weeks to months before breeding. During fall, winter and spring, they feed on wood living insect larvae, mainly in dead thin twigs on living deciduous trees, but also to some extent in thicker branches and snags (Olsson 1998; Olsson et al. 1999; Smith 2007). Wiktander et al. (1994) noted that when feeding nestlings in late May and June, only 15% of the food was wood living insects whereas 77% was surface

living arthropods (8% unknown). In Smith's (2007) study the median diameter of twigs when foraging was 2 cm and ranging between 1-10 cm, at a mean height of 16.69 m in the trees and in Olsson (1998) the most foraged twigs were 1-5 cm in diameter. Charman et al. (2012a) also confirmed the preference of twigs and saw a clear preference for oak trees when foraging, but preference for trees will probably differ between forest stands and years (Olsson et al. 2001). Olsson et al. (1999) discuss that to understand why *D. minor* have decreased, the understanding of their primary prey's (wood living insect larvae) demands, must increase. In Charmans et al. (2012b) study on the cause of the low breeding success in the *D. minor* in England, they concluded that limited food availability in the breeding season probably is the cause and that studies on the pre-breeding and breeding food sources are crucial for the developing of action plans. Woodpeckers are known to eat longhorn beetle larvae and especially in the winter they are of most importance (Ehnström & Holmer 2007). *D. minor* is no exception (Cramp 1985), as their most important food source probably is larvae and pupae of longhorn beetles (Olsson 1998).

Aim

D. minor prefer broadleaf forests and longhorn beetles living there could be the most important food source, during the most important time of the year (pre-breeding season), regarding reproductive success in *D. minor*. Thereby it is possible that *D. minor* habitat choice in breeding season depend on the abundance of longhorn beetles dependent on broadleaf trees. To be able to implement effective conservation actions for *D. minor*, it will be important to know more about how their food source influences their habitat choice. My first aim in this study was therefore to investigate if presence of *D. minor* in an area could be predicted by the abundance of four longhorn beetle species dependent on broadleaf trees, *Pyrrhidium sanguineum, Phymatodes testaceus, Poecilium alni* and *Plagionatus arcuatus*. That was done by using pheromone traps, targeting those four species. The pheromone traps also randomly capture other longhorn beetles and possibly also by attracting other species to certain compounds in the pheromones. Thereby, I also investigated if there was a difference in the biodiversity of longhorn beetles between areas inhabited and not inhabited by *D. minor*.

To protect all threatened species is not economically feasible. Thereby it is essential to direct conservation actions at areas where you protect as many threatened species as possible (biodiversity hotspots), with as low costs as possible (Myers et al. 2000). One way to cost-effectively identify such hotspot areas is to monitor indicator species with pheromone traps, providing important information about the areas without having to monitor all species (Andersson et al. 2014). Knowledge about species interactions are needed to be able to use indicator species. My second aim was therefore to see if there are any positive or negative associations between the longhorn beetle species in this study.

Knowledge about species distribution and geographical differences are also important to pinpoint where conservation actions are needed and why. Therefore, my third aim was to investigate if there are any differences between the biodiversity of longhorn beetles in different geographic regions and also to contribute to further knowledge about species distributions.

Material and methods

In the summer of 2020 (May-July), I collected longhorn beetles in Skåne, Blekinge, Småland and Västergötland in southern Sweden, by means of pheromone traps. Pheromone traps were placed in 34 areas in the end of April and baited with pheromone lures to attract adult longhorn beetles. Collection of captured beetles was then made in intervals of two to three weeks and baited with new lures at the same time.

Pheromone traps, blends and procedure

I used the trap design as described in Molander (2019). The traps contained two cross panels 20×25 cm (Nordic Plastics Group AB, Trelleborg, Sweden), which were treated with a blend of 1:1 tap water and Fluon (Sigma-Aldrich, St. Louis, Missouri, USA) to get a slippery surface. Treating traps with Fluon has been shown to increase the efficiency when capturing longhorn beetles (Graham et al. 2010; Graham & Poland 2012). Beneath the panels is a Fluon treated funnel, 20 cm in diameter at the inlet and a slope of 45 degrees (Hall Miba, Alvesta, Sweden) leading caught beetles to a one-liter plastic jar (Corning Life Science, Stockholm, Sweden) containing 0,25 l propylene glycol, so that captured beetles are trapped and preserved. To prevent rain water getting into the jar a brown roof with a diameter of 28 cm (Soparco, Chaingy, France), was placed on top of the trap. Traps were then tied approximately 1,5 m up onto a bent iron reinforcement bar, which was stuck into the ground (figure 1). Lures were tied on the cross panel, facing south-east. Lures, i.e. different blends of pheromones listed below, were used and filled into polyethylene 5.5×6.5 cm $\times 40$ μ m



Figure 1: A pheromone trap. Photo: Patrik Celander

Grippie zip-lock bag (Grippie Light Nr-02, b.n.t. Scandinavia AB, Arlöv, Sweden). Those zip bags were tied onto the cross panels which allowed the compounds to slowly transpire trough the zip bag, giving it a longer attracting period. The pheromone blend that was used in the first period April 4-May 2 until May 17-20, was a 12,5:50 blend of 2-methyl-1-butanol and 3-hydroxy-2-hexanone, similar to a well working pheromone to lure *P. sanguineum*, *P. alni* and *P. testaceus*, described in Molander et al. (2019a). The second period May 17-20 until June 4-8, a 10:12,5:50 blend of 3-hydroxy-2-decanone, 2-methyl-1-butanol and 3-hydroxy-2-hexanone was used. Targeting species when using this blend was the same as above, but also a later active species *P. arcuatus* which is drawn to a similar blend (Imrei et al. 2019). The same blend as in the second period was used in the third and last period June 4-8 until July 1-5. The last period was the longest (4 weeks) because there was no immediate need to collect the beetles when the trapping season was over. One exception was however made, taking down traps at location MH135 June 22 due to the desire of the landowner, giving those traps a 15 day final period. That still corresponds to the period when traps are most attractive (Eriksson et al. unpublished data). In all blends the pheromones were diluted with isopropanol

until a total volume of 1 ml per lure was aliquoted in eppendorf tubes. Tubes were then stored cold in a fridge before field usage. The grippie zip bags were filled with the blend first when arriving at the trap site. When collecting trapped beetles, I poured the trap jar with glycol through a tea filter into a different jar, filtering out beetles. The same glycol was then reused during the whole field season. All samples with beetles were brought to SLU laboratory in Alnarp, where I used a stereo microscope and Ehnström & Holmer (2007) to determine the species and count all longhorn beetles. All longhorn beetles were then stored in falcon tubes containing 95% ethanol.

Targeted species in this study

Four species were selected as targets in this study. They all belong to the family of longhorn beetles (Cerambycidae) and have oak as host (Ehnström & Holmer 2007).

Pyrrhidium sanguineum (Rödhjon; figure 2), is 6-15 mm long with relatively short black antennas and legs. The elytra (forewings) are brown red and covered with blood red setae (bristles). The larvae are white, 15 mm long, and have a one to two year developing time before pupating. The adult beetle starts to get active in the end of April-beginning of May (Ehnström & Holmer 2007). Host trees for larvae are deciduous trees, where they live underneath the bark. In Sweden recent dead branches and stems of oak seem to be preferred as hosts (Ehnström & Holmer 2007). The distribution of P. sanguineum in Sweden seems to have shifted eastward since the mid of 20th century and the population probably increased during the same time (Lindhe et al. 2010). Most of the latest findings are in Skåne, Blekinge, eastern Småland and Öland (Ehnström & Holmer 2007). In the Swedish red list it went from being classified as Near Threatened (ArtDatabanken 2015) to Least Concern (ArtDatabanken 2020). The main threat to the population is the extraction of logging residues before larvae have been pupating and left the wood (Ehnström & Holmer 2007). This has been shown in the Hedin et al. (2008) study, where *P. sanguineum* was one of the most abundant species in the fuel pile wood containing a large portion of oak.

Poecilium alni (Kvistspegelbock; figure 3) is 4-7 mm long, black and red brown with patches of white setae. The larva is white, 7 mm long and have one year of development. Their host is deciduous trees, preferably recent dead thin twigs (1-2 cm) of oak, on both dead and living trees. The larvae pupate in the end of April/beginning of May (Ehnström & Holmer 2007). During the last 200 years its distribution in Sweden seems to have expanded, with a probable increase in population size during the early 20th century (Lindhe et al. 2010). Its distribution in Sweden goes from southern Skåne to Södermanland and is as *P. sanguineum* threatened by the chipping of wood



Figure 2: An individual of Pyrrhidium sanguineum. Photo: Patrik Celander



Figure 3: An individual of Poecilium alni. *Photo: Patrik Celander*

(Ehnström & Holmer 2007). In the 2020 Swedish red list evaluation, it was classified as Least Concern (ArtDatabanken 2020).

Phymatodes testaceus (Vedspegelbock; figure 4) is 6-18 mm long, often with red yellow legs and blue elytra, but the elytra could also be yellow brown. The larva is white and 15 mm long. They have a two-year developing time and pupae in May. This species prefers dead dry bark of oak or beech, but could also be found in other deciduous trees (Ehnström & Holmer 2007). In the late 20th century the distribution of *P. testaceus* in southern Sweden probably expanded inlands and the population increased (Lindhe et al. 2010). *P. testaceus* is most common in southern Sweden, but could be found up to northern Uppland (Ehnström & Holmer 2007). According to Ehnström and Holmer (2007) there is no apparent threat to the Swedish population of *P. testaceus* and it was classified as Least Concern in the 2020 Swedish red list evaluation (ArtDatabanken 2020).

Plagionotus arcuatus (Smalbandad ekbarkbock; figure 5) is 8-20 mm long and has red yellow legs and antennas. The elytra are black with yellow bands across, giving it a wasp looking appearance. The larva could be up to 29 mm long and have a development time of two years. After the larva pupae in spring the adult beetle is active in late May to the end of July. Mainly oak is used as a host to the larvae and they prefer recent dead wood of thicker branches or stems (Ehnström & Holmer 2007). During the last 200 years the Swedish population seems to have increased, but the distribution remained the same (Lindhe et al. 2010). The distribution in Sweden of P. arcuatus ranges from Skåne to northern Uppland and the largest threat is also to this species the using of residue products after clear cuttings (Ehnström & Holmer 2007). In Hedins et al. (2008) study, P. arcuatus was one of the most abundant species in the fuel pile, containing a large portion of oak. P. arcuatus was evaluated and classified as Least Concern in the 2020 Swedish red list evaluation (ArtDatabanken 2020).



Figure 4: An individual of Phymatodes testaceus. Photo: Patrik Celander



Figure 5: An individual of Plagionotus arcuatus. Photo: Patrik Celander

Localities

34 areas in Skåne, Blekinge, Småland and Västergötland were chosen for monitoring of longhorn beetles (figure 6). Each area was a square of 2 km² and had been derived from "project lesser spotted woodpecker at Lund University" (Olsson & Kost, ongoing from 2018). Following is a description on how their areas were chosen, cited from Carsten Kost (pers. com. 2020-06-28) "The survey sites are a combination of previously surveyed (1985-1988) and newly placed (2019-2020) sites. Previously surveyed sites were placed by volunteers and researchers where the species was known to occur or assumed to occur based on available habitat. For the newly placed sites we used land-use and height data (Naturvårdsverket 2018) to create a habitat suitability model for the D. minor in Sweden. Different combinations of forest types and feature height on a raster grid of Sweden (Resolution: $10 \times 10 \text{ m}$) got values assigned that reflect their importance for the species according to prior ecological knowledge (Olsson et al. 1992; Wiktander et al. 1992). Feature height data (in the case of forest patches representing the canopy height) was used as a proxy for forest age. The highest values were assigned to old-growth hardwood forest, the lowest to young mixed forest. Coniferous forest types and non-forest land use types got a value of zero. The values were then summed within a circle of 200 ha around each pixel and visualized as a heatmap. This heatmap was used to find local maxima of habitat suitability for D. *minor* around which new survey squares were placed. The choice of the grander area within which a local maximum was searched for was based on proximity to volunteers that had no prior survey site close to them".



Figure 6: A map showing the areas monitored as black squares. Squares are not proportional. Map created in QGIS version 3.10.3-A Coruña, using layer from Nationella marktäckedata 2018 basskikt, Naturvårdsverket. Version 1.0 2019-03-12.

I reduced and picked out areas/squares from (Olsson & Kost unpublished data 2020), using QGIS version 3.10.3-A Coruña and google maps to reach some more criteria: At least 10 ha of broadleaf forest in the areas/squares was recommended by Ola Olsson (pers. com 2020) and that data was derived from National land cover database (Naturvårdsverket 2018), no urban environment in the areas, not in a national park or military area, roads available and oak trees present. In each square/area I then chose two sites where the traps were placed. Those sites were chosen based on distance from each other, oak trees present and sun exposure. Qgis, with layer from National land cover database (Naturvårdsverket 2018) and google maps was used to locate suitable sites and a field visit to make the final decision. The two sites picked in each square had a mean distance of 860 m from each other according to google maps measuring tool. On each site I put up three pheromone traps with a mean distance of 23 m from each other. The distance between each trap on a site was measured by counting steps and was then converted into meters. In total 204 traps (34 areas \times 2 sites within \times 3 traps per site) were put up. Complementary information described below were noted on the sites. Sun exposure was estimated on each trap location in a scale 0-5, with help of a template: 0= No sun exposure, 1= Complete canopy cover, as in a dense forest, 2= High amounts of canopy cover, as in a small glade with little sun exposure, 3= Small amount of canopy cover, as in a open glade with much sun exposure. 4= Very small amounts of canopy cover, as in an edge zone between a field and a forest, 5= No canopy cover, as on a field. In certain places levels were upgraded when for example an open glade at third criteria was close to an edge zone and

with sun exposure from side, giving it sun exposure more similar to criteria four than three. Also the amount of dead deciduous wood, around the traps in relation to the other field sites was estimated at scale 1-3. 1= Low , 2= Medium, 3= High. And lastly, I measured the basal area of oak, by counting oak trees around the traps using a relascope. Errors listed below were noted during the study, but all were judged as minor, because of my large data set and replicates. During the last period vegetation around 14 traps had grown up to the level of the panels, perhaps influencing capturing efficiency. However, because I did not notice any problems with the vegetation growing too high, when emptying the first or second time, it seems unlikely that inflight was a problem during the beginning of the last period. Also the later part of the last period is probably less important, because of lacking pheromone in the bait. So it seems unlikely that this error would affect the result noticeably. A few jars were also found on the ground during the study, three after the first period, two after the second period and four after the last period. These errors were also judged as minor.

Dryobates minor occurrence

D. minor occurrence data from 2019-2020, was derived from Olsson & Kost (unpublished data 2020). The occurrence of D. minor in their study is decided, by doing inventories in those squares/areas described in the section above, between March-April 2019-2021, with the help of the public. To classify an area as inhabited by D. minor, at least one of the following criteria must be met: 1, a contact with a calmly foraging individual for at least 15 minutes. 2, seeing an individual excavating a nesting hole. 3, a shorter contact with an individual, in at least two different occasions. 4, a contact with individuals of both sexes in either the same occasion or different occasions. 5, presence of a new nesting hole in the square. Each square/area gets classified as presence of D. minor or no presence. All areas that have been monitored in my study, have been inventoried 2019 or 2020, or both, except area MHX3 and MH144. In no areas where D. minor had been inventoried both 2019 and 2020, did the presence change. Area MHX3 was after consulting with Carsten Kost, classified as uninhabited by D. minor. Because MHX3 has a lot of bird registrations on (Swedish species observation system 2020) within years 2016-2020, but no registrations of D. minor during the nesting season March-May, it seems unlikely that the area is inhabited. MH144 was classified as inhabited of D. minor, because of four registrations in (Swedish species observation system 2020) of D. minor in that area, by three different persons at different dates, between March-April in 2019 and 2020. So MH144 is fulfilling criteria 3 above. My goal was to monitor 50/50 inhabited/uninhabited areas by D. minor. Out of 34 areas, 18 were inhabited by D. minor and 16 uninhabited (appendix 1).

Analysis

Longhorn beetle species and individuals from the first, second and third emptying were summed for each of the 204 traps. Traps that had been found on the ground got the mean value of the other traps on their trap site, unless it contained more individuals than the other traps. The mean value of individuals from each species and trap was calculated for each area/square or each trap site, depending on analyses. Shannon diversity index was calculated for all longhorn beetles collected in each area/square and used to compare the biodiversity of longhorn beetles. In some analyses the sum of all longhorn beetles species mean, except *P*.

sanguineum, *P. arcuatus*, *P. alni* and *P. testaceus* was used and is referred to as "other longhorn beetles". For all statistical analyzes except the PCoA (principal coordinates analysis), SPSS (IBM SPSS statistics version 26) was used. The PCoA was conducted in R (R version 3.6.1).

Dryobates minor relation to longhorn beetles

A logistic regression was conducted with presence of *D. minor* as dependent variable and *P. sanguineum*, *P. testaceus*, *P. alni*, *P. arcuatus* and geographic regions as independent variables, with geographic regions as categorical independent variable. This to test if the abundance of my four target species could predict the presence of *D. minor*, with the geographic regions in consideration. Areas were divided in four different geographic regions, which were based on latitude and clustering to other traps nearby, starting with geographic region 1 furthest down in the south and than counted northwards (appendix 1). A t-test was also conducted, looking for differences in Shannon diversity index between areas inhabited with *D. minor* and uninhabited. A PCoA with Bray-Curtis dissimilarity was then made, to see if there was any difference in species compositions, taking all longhorn beetles into account, in areas where *D. minor* was present or not.

Relations between longhorn beetles

A Spearman rank correlation was conducted on *P. sanguineum*, *P. testaceus*, *P. alni* and *P. arcuatus*, looking for correlations between the species. The same PCoA as described above was also used to see between which species that have the longest distances (i.e. most dissimilarity) in the analysis. Those species with longest distance in the PCoA, are species that rarely are found together in an area.

Longhorn beetles in different geographic regions

I wanted to test if there are any differences between the geographic regions in longhorn beetle biodiversity and abundance. A One-way ANOVA test was conducted to test if there was any difference in the Shannon diversity index between the four different geographic regions and a post hoc test to see between which regions there was a difference. Also a Kruskall-Wallis test was made to see if there was any difference in the abundance of *P. sanguineum*, *P. testaceus*, *P. alni* and *P. arcuatus* between the four different geographic regions and a pairwise comparison with Bonferroni correction for multiple tests, to see between which regions there were differences. To test if longhorn beetle biodiversity index with latitude as independent variable. Because I suspected that with increasing latitudes there is also a decrease in broadleaf forest, I therefore also conducted a multiple regression on Shannon diversity index with latitude and broadleaf forest as independent variables. Because there was a negative correlation between increasing latitudes and the amount of broadleaf forest in my areas, also multicollinearity was tested for.

Trap sites relation to the area

To test if sites that I have selected actually are representing longhorn beetle populations in their area, I did a Spearman rank correlation test. The mean value of all longhorn beetles captured in their trap site was correlated with the other trap site in the same area.

Factors on the sites

Spearman rank correlations was made to see if there was any correlation in the amount of dead wood, sun exposure and living oak tress on the sites, with the abundance of *P*. *sanguineum*, *P. testaceus*, *P. alni*, *P. arcuatus* and "other longhorn beetles".

Species distribution

The Swedish species observation systems (2020) was used to analyze if red listed species caught in new areas as compared to the years 1900-2020. An area was noted as a new locality, if there were no registered individuals in that cohesive forest area. If the area was very isolated as for example several tens of kilometers away from earlier findings or with a large town in between, I highlighted those with bold text. My target species *P. sanguineum*, *P. testaceus*, *P. alni* and *P. arcuatus* were analyzed on a larger scale in municipal regions at Swedish species observation system (2020) within the years 1900-2020. A region was listed as a new locality if there were no registered individuals of the species in the municipal region.

Results

Catch statistics

In total 35 species and 9953 individuals of longhorn beetles were collected. The areas with highest species richness were MH233 in southeastern Småland and MH305 in central Skåne, with 14 species of longhorn beetles each (appendix 1). The four most abundant species were as expected, the target species *P. sanguineum*, *P. testaceus*, *P. alni* and *P. arcuatus* (table 1). Other captured species worth mentioning are: *Anaglyptus mysticus*, red listed as Near Threatened (NT), *Cerambyx scopolii* (NT), *Anoplodera sexguttata* (NT), *Stictoleptura scutellata* Vulnerable (VU), *Lucanus cervus* Least Concern (LC) and *Gnorimus nobilis* (NT), the two latter not longhorn beetles though (ArtDatabanken 2020). See (appendix 2) for full inventory list.

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P. sanguineum	P. testaceus	P. alni	P. arcuatus	Rhagium mordax	A. mysticus	Clytus arietis	Total Cerambycidae					
4792 ind	1451 ind	2711 ind	316 ind	223 ind	147 ind	132 ind	9953 ind					
34/34 areas	33/34 areas	28/34 areas	33/34 areas	31/34 areas	13/34 areas	25/34 areas						

Table 1: The sum from all three emptying of the seven most abundant species and the total collected individuals of longhorn beetles. The lower row shows in how many areas the species was found.

Dryobates minor relation to longhorn beetles

There were no significant differences in log-likelihood between baseline- and new model (P> 0.05), when predicting *D. minor* presence with *P. sanguineum*, *P. testaceus*, *P. alni*, *P. arcuatus* and geographic regions as independent variables, with geographic regions as a

categorical independent variable. The t-test showed no differences in Shannon diversity index between areas inhabited with *D. minor* and uninhabited (P > 0.05; figure 7). As seen in the PCoA (figure 8), there are no clear dissimilarities in species compositions between areas inhabited or uninhabited by *D. minor* either.



Figure 7: A bar plot with error bars, showing the mean Shannon diversity index of the longhorn beetles in areas inhabited and uninhabited by Dryobates minor.



Figure 8: PCoA (principal coordinates analysis) with Bray-Curtis dissimilarity. Areas inhabited by D. minor are colored in blue and areas not inhabited are colored as green.

Relations between longhorn beetles

P. sanguineum and *P. alni* were the only species that showed a positive correlation between each other (P=0.003, $R^2=0.218$, N=34; figure 9). According to the PCoA (figure 8), *P. sanguineum* seems to have much dissimilarity to *A. mysticus* and *Stenurella melanura*. *P. testaceus* and *P. alni* also seems to have high dissimilarity. *A. mysticus* was found in 13 areas with 147 individuals, *Stenurella melanura* was however only found in 7 areas with 18 individuals.



Figure 9: A scatter plot showing a positive correlation between the mean number of individuals per area in P. sanguineum and P. alni (P = 0.003, $R^2 = 0.218$, N = 34).

Longhorn beetles in different geographic regions

The One-way ANOVA showed that Shannon diversity index was different between the four regions (P< 0.000, df regions= 3, F regions= 12.572, df error= 30). There was a difference between region 1-2 (P=0.001), 1-3 (P=0.006), 1-4 (P< 0.000), region 1 with higher Shannon diversity index. The Kruskall-Wallis test showed that there was a difference between the four geographic regions in the abundance of *P. alni* as well (P= 0.04). When comparing *P. alni* abundance between regions pairwise, region 2 and 4 was different (P=0.037), with region 4 having a lower mean. No significant difference in the abundance of *P. sanguineum*, *P. testaceus* and *P. arcuatus* was shown between the geographic regions. Shannon diversity index had a negative correlation with latitudes (P< 0.000, R²= 0.445, B= -2.737E-6; figure 10). However, in the multiple regression with both latitude and broadleaf forest as independent variables, the amount of broadleaf forest did not have a strong impact on Shannon diversity index and latitude, with R² = 0.448 from this multiple regression, it is obvious that broadleaf forest is not an important variable in this analysis (R² = 0.448, adjusted R²⁼ 0.413, ANOVA P< 0.000, Latitude P< 0.000, Latitude B= -2.830E-6, Broadleaf forest P= 0.661,



Broadleaf forest B= -0.001). There was no multicollinearity between latitudes and broadleaf forest (Tolerance= 0.871, VIF= 1.149).

Figure 10: A scatter plot showing a negative correlation in Shannon diversity index with increasing latitude in the areas (P < 0.000, $R^2 = 0.445$, B = -2.737E-6).

Trap sites relation to the area

The spearman rank correlation showed that the mean value of all longhorn beetles caught in their trap site were correlated to the other trap site in the same area (P< 0.000, R^2 = 0.380, N=34).

Factors on the sites

Spearman rank correlations showed that there was a positive correlation on the amount of dead deciduous wood and abundance of *P. testaceus* (P< 0.000, R²= 0.104, N= 68). *P. sanguineum*, *P. alni*, *P. arcuatus* and "other longhorn beetles" on the other hand did not correlate. 13 sites were rated with a low amount of dead deciduous wood, 18 sites with medium amount and 37 sites with a high amount of dead deciduous wood. There was also a correlation in *P. arcuatus* (P= 0.005, R²= 0.103, N= 68), *P. alni* (P= 0.002, R²= 0.054, N= 68) and "other longhorn beetles" (P< 0.000, R²= 0.193, N= 68) with increasing sun exposure. *P. sanguineum* and *P. testaceus* did not show any correlation though. No sites were rated as 0 sun exposure; one site was rated as 1; six sites were rated as 2; 21 sites were rated as 3; 40 sites were rated as 4 and no sites were rated as 5. A correlation with living oak trees was only seen in *P. testaceus* (P= 0.002, R²= 0.071, N= 68).

Species distribution

Three of the red listed species that were captured were found in new areas when comparing to (Swedish species observation system 2020). Note that old inventories that have not been registered in the Swedish species observation system are not taken into account. Bolded areas

are highlighted because they are more isolated from earlier findings and coordinates to areas can be found in (appendix 2). *A. sexguttata*, first time seen in the area MH233 since 1995 (2km away). *S. scutellata* first time seen in the area **MH305**. *A. mysticus* first time seen in the area **MH227**, **MH239**, **MH305**, **MH4**, **MH7** MH54, MH55 and also first time seen since 1993 in MH1, MH3. Of my target species, *P. sanguineum* was found for the first time in the municipal region of Borås, Jönköping, Kungälv, Sölvesborg, Tranemo, Ulricehamn, Vara, Värnamo, Ystad and Sjöbo. There were also only one registration of the species in the municipal region of Eslöv (2015) and Lerum (2017). *P. alni* was found for the first time in the municipal region of Borås, Eslöv, Lerum, Osby, Sölvesborg, Ulricehamn and Vara. Only one registration of the species has been registered in the municipal region of Alvesta (1996), Kungälv (1973), Ljungby (1984) and Värnamo (2008). *P. testaceus* was found for the first time since 1940 in the municipal region of Osby and there was only one registration of the species in Ulricehamn from 2008. Lastly, *P. arcuatus* was found for the first time in the municipal region of Ulricehamn and there was only one registration of the species in Vara from 1979.

Discussion

The presence of *D. minor* in an area could not be predicted by the abundance of *P. sanguineum*, *P. testaceus*, *P. alni* or *P. arcuatus* in this study. Neither was there any difference in longhorn beetle biodiversity between inhabited and uninhabited areas by *D. minor*. A positive association between different species of longhorn beetles was only seen in *P. sanguineum* and *P. alni*. But large dissimilarities could be seen between *P. sanguineum* and *A. mysticus* as well as between *P. testaceus* and *P. alni*. There were differences between geographic regions in longhorn beetle biodiversity and with increasing latitudes the longhorn beetle biodiversity decreased. Several new localities with red listed species were found and the distribution of *P. sanguineum*, *P. alni* and perhaps *A. mysticus* seems to be underestimated.

Dryobates minor relation to longhorn beetles

This study did not find any indication of a higher abundance in longhorn beetles at areas inhabited with *D. minor*. Neither the specific target species (*P. sanguineum*, *P. testaceus*, *P. alni*, *P. arcuatus*) or general diversity as defined by Shannon diversity index indicated a difference between areas inhabited or uninhabited by *D. minor*. Nor could any differences in species composition be distinguished. Thereby may the food availability of longhorn beetles not be a limiting factor to *D. minor* in southern Sweden. There could be several reasons for this result, I list six hypotheses below.

1. Neither food availability nor habitat availability is a problem. Some other factor is keeping the population low and the choice of breeding area is randomized, because all areas in the study are of equal quality.

2. Food availability is perhaps not an issue, but nesting availability is. For example, suitable snags for nesting could be a limiting factor and not available in all areas. Olsson et al. (1992)

saw a clear preference for forests rich in snags. Pakkala et al. (2019) found that only 3.6% of the nesting cavities excavated by *D. minor* were reused. The 106 cavities in Pakkalas et al. (2019) study had a median life span of six years and 82 of the cavity losses was due to natural causes, with trees fallen/broken as the most common cause (53/82). So the life span of suitable snags could be low and then a fast rate of newly appropriate snags is needed to sustain *D. minor* with nesting possibilities. However, areas in this study have been selected in part by age and it seems unlikely that differences in snags would be that high between areas, influencing habitat choice.

3. Nest predation could keep *D. minor* away from certain areas. Smith and Smith (2020) studied the reason to the decline in nest survival and productivity of *D. minor* in Britain and discussed if the increasing population of great spotted woodpecker could be the reason to the decline, due to nest predation. Smith and Smith (2020) could however not find evidence of great spotted woodpecker being the reason to the decline and concluded that probably a mismatch with food availability in spring leads to starvation in Britain populations. Charmans et al. (2012b) also did not find great spotted woodpecker nest predation in Britain being a major problem. Nest predation by great spotted woodpecker is thereby known, but poorly studied for other conceivable species. Overall, nest predation does not seem to be a major problem and I find it unlikely that it is influencing the habitat choice substantially.

4. There could actually be a higher abundance of longhorn beetles in inhabited areas at winter, but *D. minor* is such an effective predator in the spring that less adult longhorn beetles hatches and evens up the differences between the areas. Other species of woodpeckers are known to be effective predators, as when regulating spruce bark beetles for example (Fayt et al. 2005). Evidence for this hypothesis is lacking, however.

5. Food availability during pre-breeding season is perhaps not a problem, but later during the nestling- and fledging period there could be limited food resources. Reproduction success in D. minor has been shown to decrease with later breeding (Wiktander et al. 2001b; Rossmanith et al. 2007). Clutch size and hence numbers of fledglings were lower when later breeding in both studies, but also body mass of nestlings were lower in Rossmanith et al. (2007). The conclusion by Rossmanith et al. (2007) was because of the shift from surface dwelling larvae of mainly caterpillars in early breeders, to wood dwelling larvae in later breeders. Surface dwelling larvae are easier to catch and are hence probably more energy efficient for the woodpecker when foraging (Rossmanith et al. 2007). Wiktander et al. (2001b) speculated in that because the first time period in a nestling's life probably is the most vulnerable to temperature, the timing of caterpillars could be of importance so that one parent could stay and care for the nestlings instead of both foraging and hence get higher reproduction success. To summarize, the timing of caterpillars probably is important for reproduction success and with that in consideration, habitat choice could depend on other insects instead of longhorn beetles. However, both Olsson et al. (1999) and Wiktander et al. (2001b) thought that wood living insects pre-breeding are most important for reproduction success.

6. Food availability is a limiting factor during spring, but perhaps other food sources influence the choice of breeding habitat equal to those longhorn beetles studied. Olsson et al. (2001) studied *D. minor* foraging preference for different tree species. What Olsson et al. (2001) concluded was that preference for trees shifted between years and was influenced by the fluctuations in *Argyresthia goedartella* larvae. It is a species of lepidoptera that has alder and birch as hosts and when alder blooming occurred it influenced the preference for the trees. There was a significant difference in the number of larvae available between years of alder blooming and years with no blooming. The densities of *A. goedartella* did however not explain the preference for alder trees between territories (Olsson et al. 2001). To summarize, *A. goedartella* was influencing *D. minor*'s choice of trees when foraging, but what is important to my result, is that Olsson et al. (2001) did not see any preference for alder trees between territories. Hence, I do not think it is likely that *A. goedartella* alone is the food source that influences habitat choice, but further studies including *A. goedartella* and other insects may be desirable.

If I would have to speculate in the most likely hypothesis, possibly hypothesis 1, that there are some other unknown factors that keeping the *D. minor* population low, or 6, that other food sources influence their choice of breeding habitat equally to those longhorn beetle species studied, seems most likely. The first hypothesis is based on that there are knowledge gaps in the understanding of why *D. minor* is threatened and that there could be several unknown factors responsible. It is a broad hypothesis, however, that involves many possible factors and is not very helpful for further studies. The sixth hypothesis still support the current knowledge and what this study was based on (Olsson et al. 1999), but indicate that those species captured were not representative for the total food source in the areas. Perhaps my target longhorn beetle species were not representative and it would have been necessary to include other insect groups as well. The randomly caught species of longhorn beetles were perhaps not representative either, as all traps were placed on the ground in sun exposed areas, which probably catch species with certain niches. However, these are just my own speculations.

Relations between longhorn beetles

The abundance of *P. sanguineum* and *P. alni* correlated, which means that they often occur in the same areas in correlated ratios. *P. sanguineum* was more common than *P. alni*, 34/34 areas versus 28/34 areas. Both species are benefiting from newly dead wood of oak, *P. sanguineum* prefer 5-15 cm in diameter branches while *P. alni* prefer 1-2 cm twigs (Ehnström & Axelsson 2002). *P. sanguineum* could be rich in numbers where there is a continuity over years in newly dead wood and in cutting areas where branches have been left behind (Ehnström & Holmer 2007). *P. alni* is often rich in numbers in thinning areas where twigs have been left behind as well (Ehnström & Axelsson 2002). Molander (2019) found that *P. sanguineum* and *P. alni* correlated with each other in his locations in Skåne, but not in eastern Småland. To summarize, they seem to benefit from the same kind of habitat, without being competitors and correlations between them have been shown in Molander (2019), which supports my result. Perhaps one of the species could be used as an indicator species for the other one in the future.

In the PCoA there were large dissimilarities between *P. sanguineum* and *A. mysticus*, indicating different ecology of the species. A. mysticus larvae lives in thick branches and stems of hard dead dry wood of several different deciduous trees. They are known to thrive in broadleaf forests with old common hazel and in old fruit tree plantations (Ehnström & Axelsson 2002). They are also a local species (Ehnström & Holmer 2007), meaning that they are common in certain areas and rare in others, which this study support when only found in 13/34 areas. This result should although be interpreted with caution, because A. mysticus was not a target species even though they might have been attracted to the 3-hydroxy-2-hexanone compound, which is one of the compounds released by males of A. mysticus (Molander et al. 2019b). P. sanguineum has previously been considered a local species as well (Ehnström & Holmer 2007), but more findings of the species have upgraded it from Near Threatened (ArtDatabanken 2015) to Least Concern in the Swedish red list (ArtDatabanken 2020). For example, Molander (2019) found the species common in southeast- and southwest Sweden. In my study P. sanguineum was the most common species found in all areas, which supports the latest years' findings of it being more common than previously thought. To summarize, the indication of *P. sanguineum* and *A. mysticus* having large dissimilarities and not occurring in same areas are supported by their known ecology.

Also in the PCoA there were indications of large dissimilarities between *P. testaceus* and *P. alni*. Both species benefit from oak forest, but *P. testaceus* is known to be a generalist species, which also benefits from the European beech (Ehnström & Holmer 2007) and it was indeed caught in 33/34 areas. *P. alni* was, as mentioned before, only found in 28/34 areas and also had a significant difference in abundance between the different geographic regions. Molander (2019) saw weak positive association of *P. alni* and oak volume at a landscape scale. *P. testaceus* on the other hand did not show any association with oak volume in landscape scale. Molander (2019) did neither see a correlation between the species in Skåne and eastern Småland. A hypothesis could be that *P. testaceus* is a generalist, thriving where specialists as maybe *P. alni* have difficulties. To summarize, I think there are indications that there are strong dissimilarities between them, which affects their cooccurrence. Species showing large dissimilarities to each other is not appropriate as indicator species to each other and when monitored, they should still be targeted individually.

Longhorn beetles in different geographic regions

The biodiversity of longhorn beetles as measured by Shannon diversity index was different between the geographic regions. These differences I thought perhaps could be explained by increasing latitudes, which influence the amount of broadleaf forest in the areas and hence the biodiversity of longhorn beetles. When doing a multiple regression, the biodiversity of longhorn beetles had a significant negative correlation to increasing latitude, but the amount of broadleaf forest in the areas was not having a strong impact. This means that there are some other factors affecting biodiversity in longhorn beetles, when latitudes increase, than the amount of broadleaf forest. However, I only analyzed broadleaf forest inside the areas/squares and perhaps if looking at larger scales it could show other results. It is also important to know that geographic region four, which is the northernmost region, is located on the west coast. Region three has next highest latitudes and is located in the inland, versus region one and two which are located in the south and south-east Sweden. Because of that shift from south, southeast to the inland and then to the west coast with increasing latitudes, there could probably be other factors more linked to that shift in longitude than latitude. My results however, match the result in Väisänen and Heliövaara (1994), where they looked at geographical diversity in four insects groups in northern Europe, including longhorn beetles. They did not find any patterns of diversity in relation to longitude, but they did see a negative association with increasing latitude in each insect group. To summarize, there are geographical differences in longhorn beetle biodiversity that could be explained by a negative association to latitudes, but the factors affecting longhorn beetles are not clear.

Trap sites relation to the area

Because it would be too time consuming to place traps all over an area of 2 km² when having 34 areas, I chose to pick out two sites in each area with three traps at each site. If sites correlate to the other sites in the same area, it means that the samples in each area are homogenous. If samples on different sites in areas are homogenous, then there is a high probability that if you only would have chosen one site to sample in an area, you would still get data representing that area. There was a clear correlation between the sites in my study, indicating that my data are representing the true population of the longhorn beetles studied in the areas at this given time. This result also shows that my criteria when choosing sites worked.

Factors on the sites

The amount of dead deciduous wood around the sites correlated positive with the abundance of *P. testaceus*. This could perhaps be explained by odors from the dead wood that makes more individuals of *P. testaceus* drawn to the site. Or is the dead wood on the site representing dead wood in a larger area, so that there are actually more individuals hatching, because of more available hosts. The question is then why there was no correlation in the rest of the longhorn beetles, which also benefit from dead wood. The tree species of the dead wood and type was not noted and different sites had different species of trees. With that in consideration, it is not too daring to think that the longhorn beetle species with the highest chance of seeing a correlation with unknown dead deciduous wood would be a generalist species which has the highest amount of host species in this broadleaf habitat. Of the four target species in this study, that would probably be *P. testaceus* (Ehnström & Holmer 2007), which could explain the result. Although one should not exclude the factor that there is a certain amount of uncertainty when estimating the amount of dead wood, which could affect the result.

Higher amount of sun exposure had a positive correlation on the capturing of *P. alni*, *P. arcuatus* and "other longhorn beetles". Whereas no correlation was seen in *P. sanguineum* and *P. testaceus*. This result matches Molander (2019) where *P. alni* and *P. arcuatus* preferred sun exposed edges, *P. testaceus* preferred interior stands with less sun exposure and *P. sanguineum* did not show any preference. *P sanguineum* is generally active early in the season, before bud burst in most trees and especially oak, which could explain its indifference to normally shady habitats. Regarding the positive correlation in sun exposure with "other

longhorn beetles", it is not a surprising result either, as ³/₄ of all longhorn beetle species in Sweden are believed to benefit from sun exposure (Lindhe et al. 2010).

Species distribution

Three of the red listed species caught were found in new areas, when comparing to Swedish species observation system (2020) within years 1900-2020. *A. mysticus* was interestingly found in several new areas and perhaps could be more common than previously thought. Of my four target species, *P. sanguineum* and *P. alni* were found for the first time in many municipal regions. These two species would be of interest for further studies and perhaps mapping their true distribution more accurately. *P. arcuatus* and *P. testaceus* distribution seem to be more correctly mapped. Findings in new areas are most likely not due to a rapid expanding distribution of the species, but rather because of lacking sampling in the areas and perhaps because some species are more elusive. It should also be noted that I only analyzed registrations in Swedish species not registered.

Conclusions

This study could not predict the presence of *D. minor* in an area by the abundance of *P. sanguineum*, *P. testaceus*, *P. alni* or *P. arcuatus*. Nor was it any difference in longhorn beetle biodiversity, between inhabited and uninhabited areas by *D. minor*. Thereby, no indications were found that *D. minor* habitat choice depend on the longhorn beetles studied. A stronger positive association was seen between *P. sanguineum* and *P. alni*, which also was strengthen by their ecology and Molanders (2019) result. Large dissimilarities, were seen between *P. testaceus* and *P. alni* as well as between *P. sanguineum* and *A. mysticus*, which also could be explained by their ecology. These association between the species could perhaps be used in the future to identify indicator species. Geographical differences were shown in longhorn beetle biodiversity and could be explained by a negative association to increasing latitudes, but the factors affecting longhorn beetles are not clear. Lastly, I found new areas with red listed species and the distribution of *P. sanguineum*, *P. alni* and perhaps *A. mysticus* seems to be underestimated, with several new locality findings in this study, giving opportunities for others to investigate their distribution and abundance further.

Reference list

- Allison, J.D., Borden, J.H, & Seybold, S.J. (2004). A review of the chemical ecology of the Cerambycidae (Coleoptera). *Chemoecology*, vol. 14 (3-4), pp. 123-150. DOI: 10.1007/s00049-004-0277-1.
- Andersson, K., Bergman, K.O., Andersson, F., Hedenström, E., Jansson, N., Burman, J., Winde, I., Larsson, M.C, & Milberg, P. (2014). High-accuracy sampling of saproxylic diversity indicators at regional scales with pheromones: The case of *Elater ferrugineus* (Coleoptera, Elateridae). *Biological Conservation*, vol. 171, pp. 156-166. DOI: 10.1016/j.biocon.2014.01.007.

ArtDatabanken. (2019). *Dendrocopos minor*- Mindre hackspett. Available at: https://artfakta.se/artbestamning/taxon/100048 (2020-03-25).

ArtDatabanken. (2015). Rödlistade arter i Sverige 2015. Uppsala: ArtDatabanken SLU.

ArtDatabanken. (2020). Rödlistade arter i Sverige 2020. Uppsala: ArtDatabanken SLU.

- Aulen, G. (1991). Increasing insect abundance by killing deciduous trees: a method of improving the food situation for endangered woodpeckers. *Holarctic Ecology*, vol. 14 (1), pp. 68-80.
- Berg, A., Ehnström, B., Gustafsson, I., Hallingbäck, T., Jonsell, M, & Weslien, J. (1994). Threatened Plant, Animal, and Fungus Species in Swedish Forests: Distribution and Habitat Associations. *Conservation Biology*, vol. 8 (3), pp. 718-731. DOI: 10.1046/j.1523-1739.1994.08030718.x.
- Cardé, R.T. (2014). Defining Attraction and Aggregation Pheromones: Teleological Versus Functional Perspectives. *Journal of Chemical Ecology*, vol. 40 (6), pp. 519-520. DOI: 10.1007/s10886-014-0465-610.1007/s10886-014-0465-6.
- Chapin III, F.S., Matson, P.A, & Vitousek, P.M. (2012). *Principles of Terrestrial Ecosystem Ecology. Second edition.* New York: Springer.
- Charman, E.C., Smith, K.W., Dillon, I.A., Dodd, S., Gruar, D.J., Cristinacce, A., Grice, P.V,
 & Gregory, R.D. (2012b). Drivers of low breeding success in the Lesser Spotted
 Woodpecker *Dendrocopos minor* in England: testing hypotheses for the decline.
 Bird Study, vol. 59 (3), pp. 255-265. DOI: 10.1080/00063657.2012.662941.
- Charman, E.C., Smith, K.W., Dodd, S., Gruar, D.J, & Dillon, I.A. (2012a). Pre-breeding foraging and nest site habitat selection by Lesser Spotted Woodpeckers *Dendrocopos minor* in mature woodland blocks in England. *Ornis Fennica*, vol. 89 (3), pp. 182-196.
- Cramp, S (ed). (1985). Handbook of the Birds of Europe, the Middle East and North Africa. The Birds of the Western Palearctic. Volume IV-Terns to woodpeckers. Oxford: Oxford University Press.
- Cronberg, N., Svensson, M., Pröjts, J., Wikars, L.O., Sandström, J., Persson, K, & Johansson, T. (1986). *Knuffa för insekter. Del 2- om insekternas ekologi och evolution*. Stockholm: Fältbiologerna.
- Cronberg, N., Elmfors, A., Persson, K., Sandström, J., Svensson, M, & Wikars, L.O. (1994). *Insekter. Om insektsgrupperna och deras utseende*. Stockholm: Fältbiologerna.
- Dahlberg, A, & Stokland, J.N. (2004). *Vedlevande arters krav på substrat*. Skogsstyrelsen: Report 7.
- Ehnström, B, & Axelsson, R. (2002). *Insektsgnag i bark och ved*. Uppsala: ArtDatabanken SLU.
- Ehnström, B, & Holmer, M. (2007). *Nationalnyckeln till Sveriges flora och fauna*. *Skalbaggar: Långhorningar. Coleoptera: Cerambycidae*. Uppsala: ArtDatabanken SLU.

- Fayt, P., Machmer, M.M, & Steeger, C. (2005). Regulation of spruce bark beetles by woodpeckers—a literature review. *Forest Ecology and Management*, vol. 206 (1–3), pp. 1-14. DOI: 10.1016/j.foreco.2004.10.054.
- Green, M., Haas, F, & Lindström, Å. (2020). Monitoring population changes of birds in Sweden. Annual report for 2019. Department of Biology, Lund University. Available at: http://www.fageltaxering.lu.se/sites/default/files/files/Rapporter/arsrapportfor2019 kf.pdf (2020-03-25).
- Graham, E.E., Mitchell, R.F., Reagel, P.F., Barbour, J.D., Millar, J.G, & Hanks, L.M. (2010). Treating Panel Traps With a Fluoropolymer Enhances Their Efficiency in Capturing Cerambycid Beetles. *Journal of Economic Entomology*, vol. 103 (3), pp. 641-647. DOI: 10.1603/EC10013.
- Graham, E.E, & Poland, T.M. (2012). Efficacy of Fluon Conditioning for Capturing Cerambycid Beetles in Different Trap Designs and Persistence on Panel Traps Over Time. *Journal of Economic Entomology*, vol. 105 (2), pp. 395-401. DOI: 10.1603/EC11432.
- Hanks, L.M. (1999). Influence of the larval host plant on reproductive strategies of cerambycid beetles. *Annual Review of Entomology*, vol. 44, pp. 483-505. DOI: 10.1146/annurev.ento.44.1.483.
- Hanks, L.M, & Millar, J.G. (2016). Sex and Aggregation-Sex Pheromones of Cerambycid Beetles: Basic Science and Practical Applications. *Journal of Chemical Ecology*, vol. 42 (7), pp. 631-654. DOI: 10.1007/s10886-016-0733-8.
- Hanks, L.M., Mongold-Diers, J.A., Atkinson, T.H., Fierke, M.K., Ginzel, M.D., Graham, E.E., Poland, T.M., Richards, A.B., Richardson, M.L, & Millar, J.G. (2018).
 Blends of Pheromones, With and Without Host Plant Volatiles, Can Attract Multiple Species of Cerambycid Beetles Simultaneously. *Journal of Economic Entomology*, vol. 111 (2), pp. 716-724. DOI: 10.1093/jee/tox373.
- Hedin, J., Isacsson, G., Jonsell, M, & Komonen, A. (2008). Forest fuel piles as ecological traps for saproxylic beetles in oak. *Scandinavian Journal of Forest Research*, vol. 23 (4), pp. 348-357. DOI: 10.1080/02827580802269991.
- Imrei, Z., Molander, M.A., Winde, I.B., Lohonyai, Z., Csonka, E.B., Fail, J., Hanks, L.M., Zou, Y.F, & Millar, J.G. (2019). Identification of the aggregation-sex pheromone of *Plagionotus arcuatus ssp. arcuatus* (Coleoptera: Cerambycidae) from two geographically separated European populations. *Science of Nature*, vol. 106 (5-6), pp. 18. DOI: 10.1007/s00114-019-1612-2.
- Jeppsson, T., Lindhe, A., G\u00e4rdenfors, U, & Forslund, P. (2010). The use of historical collections to estimate population trends: A case study using Swedish longhorn beetles (Coleoptera: Cerambycidae). *Biological Conservation*, vol. 143 (9), pp. 1940-1950. DOI: 10.1016/j.biocon.2010.04.015.

- Jonsell, M., Weslien, J, & Ehnström, B. (1998). Substrate requirements of red-listed saproxylic invertebrates in Sweden. *Biodiversity and Conservation*, vol. 7 (6), pp. 749-764. DOI: 10.1023/A:1008888319031.
- Karlsson, P, & Luscher, M. (1959). 'Pheromones': a New Term for a Class of Biologically Active Substances. *Nature*, vol. 183 (4653), pp. 55-56. DOI. 10.1038/183055a0.
- Kosinski, Z, & Kempa, M. (2007). Density, distribution and nest-sites of woodpeckers *picidae*, in a managed forest of Western Poland. *Polish Journal of Ecology*, vol. 55 (3), pp. 519-533.
- Larsson, M.C. (2016). Pheromones and Other Semiochemicals for Monitoring Rare and Endangered Species. *Journal of Chemical Ecology*, vol. 42 (9), pp. 853-868. DOI: 10.1007/s10886-016-0753-4.
- Lindbladh, M., Axelsson, A.L., Hultberg, T., Brunet, J, & Felton, A. (2014). From broadleaves to spruce - the borealization of southern Sweden. *Scandinavian Journal of Forest Research*, vol. 29 (7), pp. 686-696. DOI: 10.1080/02827581.2014.960893.
- Lindhe, A., Jeppsson, T, & Ehnström, B. (2010). Longhorn beetles in Sweden changes in distribution and abundance over the last two hundred years. *Entomologisk Tidskrift*, vol. 131 (4), pp. 241-512.
- Lohmus, A., Kinks, M, & Soon, M. (2010). The Importance of Dead-Wood Supply for Woodpeckers in Estonia. *Baltic Forestry*, vol. 16 (1), pp. 76-86.
- Molander, M.A. (2019). A pheromone-based toolbox of longhorn beetles (Cerambycidae) for monitoring biodiversity in ephemeral deadwood substrates of oak. Diss. Alnarp: Swedish University of Agricultural Sciences.
- Molander, M.A., Eriksson, B., Winde, I.B., Zou, Y.F., Millar, J.G, & Larsson, M.C. (2019b). The aggregation-sex pheromones of the cerambycid beetles *Anaglyptus mysticus* and *Xylotrechus antilope ssp. antilope:* new model species for insect conservation through pheromone-based monitoring. *Chemoecology*, vol. 29 (3), pp. 111-124. DOI: 10.1007/s00049-019-00281-5.
- Molander, M.A., Winde, I.B., Burman, J., Nyabuga, F.N., Lindblom, T.U.T., Hanks, L.M., Millar, J.G, & Larsson, M.C. (2019a). Common Cerambycid Pheromone Components as Attractants for Longhorn Beetles (Cerambycidae) Breeding in Ephemeral Oak Substrates in Northern Europe. *Journal of Chemical Ecology*, vol. 45 (7), pp. 537-548. DOI: 10.1007/s10886-019-01082-4.
- Monné, M.L., Monné, M.A, & Wang, Q. (2017). General morphology, Classification, and Biology of Cerambycidae. In Wang, Q (ed.). *Cerambycidae of the world: Biology and management*. Boca Raton: CRC Press/Taylor & Francis.
- Myers, N., Mittermeier, R.A., Mittermeier, C.G., da Fonseca, G.A.B, & Kent, J. (2000). Biodiversity hotspots for conservation priorities. *Nature*, vol. 403 (6772), pp. 853-858. DOI: 10.1038/35002501.
- Nandagopal, V., Prakash, A, & Rao, J. (2008). Know the pheromones: Basics and its application. *Journal of Biopesticides*, vol. 1 (2), pp. 210-215.

- Nappi, A., Drapeau, P, & Leduc, A. (2015). How important is dead wood for woodpeckers foraging in eastern North American boreal forests? *Forest Ecology and Management*, vol. 346, pp. 10-21. DOI: 10.1016/j.foreco.2015.02.028.
- Naturvårdsverket. (2018). *Nationella marktäckedata 2018 basskikt*. Version 1.0 2019-03-12. Available at: https://www.naturvardsverket.se/Sa-mar-miljon/Kartor/Nationella-Marktackedata-NMD/.
- Nilsson, S.G., Olsson, O., Svensson, S, & Wiktander, U. (1992). Population trends and fluctuations in Swedish woodpeckers. *Ornis Svecica*, vol. 2 (1), pp. 13–21.
- Olsson. O. (1998). Through the eyes of a woodpecker: understanding habitat selection, territory quality and reproductive decisions from individual behavior. Diss. Lund: Lund University.
- Olsson, O., Nilsson, I.N., Nilsson, S.G., Pettersson, B., Stagen, A, & Wiktander, U. (1992). Habitat preferences of the lesser spotted woodpecker *Dendrocopos minor*. *Ornis Fennica*, vol. 69 (3), pp. 119-125.
- Olsson, O., Wiktander, U., Holmgren, N.M.A, & Nilsson, S.G. (1999). Gaining ecological information about Bayesian foragers through their behaviour. II. A field test with woodpeckers. *Oikos*, vol. 87 (2), pp. 264-276. DOI: 10.2307/3546741.
- Olsson, O., Wiktander, U., Malmqvist, A, & Nilsson, S.G. (2001). Variability of patch type preferences in relation to resource availability and breeding success in a bird. *Oecologia*, vol. 127 (3), pp. 435-443. DOI: 10.1007/s004420000596.
- Pakkala, T., Tiainen, J., Piha, M, & Kouki, J. (2019). Hole life: survival patterns and reuse of cavities made by the Lesser Spotted Woodpecker *Dendrocopos minor*. *Ardea*, vol. 107 (2), pp. 173-181. DOI: 10.5253/arde.v107i2.a4.
- Paine, T.D. (2017). Natural Enemies and Biological Control of Cerambycid pests. General morphology, Classification, and Biology of Cerambycidae. In Wang, Q (ed.). *Cerambycidae of the world: Biology and management*. Boca Raton: CRC Press/Taylor & Francis.
- Rossmanith, E., Hontsch, K., Blaum, N, & Jeltsch, F. (2007). Reproductive success and nestling diet in the Lesser Spotted Woodpecker (*Picoides minor*): the early bird gets the caterpillar. *Journal of Ornithology*, vol. 148 (3), pp. 323-332. DOI: 10.1007/s10336-007-0134-4.
- Sandhall, Å, & Lindroth, C.H. (1976). *Skalbaggar. Naturguide i färg om skalbaggarnas utseende, utveckling, levnadsätt och beteenden.* Västerås: ICA bokförlag.
- SLU. (2020). Forest statistics 2020/Skogsdata 2020. Aktuella uppgifter om de svenska skogarna från Riksskogstaxeringen. Department of Forest Resource Management, SLU Umeå. Available at: https://www.slu.se/globalassets/ew/org/centrb/rt/dokument/skogsdata/skogsdata_2 020_webb.pdf (2020-09-24).
- Smith, K.W. (2007). The utilization of dead wood resources by woodpeckers in Britain. *Ibis*, vol. 149, pp. 183-192. DOI: 10.1111/j.1474-919X.2007.00738.x.

- Smith, K.W, & Smith, L. (2020). Long-term trends in the nest survival and productivity of the Lesser Spotted Woodpecker *Dryobates minor* in Britain. *Bird Study*, vol. 67 (1), pp. 109-118. DOI: 10.1080/00063657.2020.1780195.
- Stokland, J.N., Siitonen, J, & Jonsson, B.G. (2012). *Biodiversity in Dead Wood, Ecology, Biodiversity and Conservation*. Cambridge: Cambridge University Press.
- Swedish Species Observation System. (2020). List of records of *Pyrrhidium sanguineum*, *Poecilium alni*, *Phymatodes testaceus*, *Plagionotus arcuatus*, *Anaglyptus mysticus*, *Anoplodera sexguttata*, *Stictoleptura scutellata* 1900-2020, *D. minor* 2016-2020. Available at: https://www.artportalen.se/.
- Ulfstrand, S., Kukka, J., Ebenhard, T., Lindholm, A., Malmhagen, B., Jännes, H., Koskimies, P., Lokki, J, & Nikander, P.J. (2001). *Djur i Sveriges natur: fåglar*. Malmö: Bertmarks förlag.
- Ulyshen, M.D. (2018). *Saproxylic insects. Diversity, Ecology and Conservation*. Springer: Zoological Monographs 1.
- Väisänen, R, & Heliövaara, K. (1994). Hot-spots of insect diversity in northern Europe. *Annales Zoologici Fennici*, vol. 31 (1), pp. 71-81.
- Wiktander, U., Nilsson, I.N., Nilsson, S.G., Olsson, O., Pettersson, B, & Stagen, A. (1992). Occurrence of the Lesser Spotted Woodpecker *Dendrocopos minor* in relation to area of deciduous forest. *Ornis Fennica*, vol. 69 (3), pp. 113-118.
- Wiktander, U., Nilsson, S.G., Olsson, O, & Stagen, A. (1994). Breeding success of a Lesser Spotted Woodpecker *Dendrocopos minor* population. *IBIS*, vol. 136 (3), pp. 318-322. DOI: 10.1111/j.1474-919X.1994.tb01101.x.
- Wiktander, U., Olsson, O, & Nilsson, S.G. (2000). Parental care and social mating system in the Lesser Spotted Woodpecker *Dendrocopos minor*. *Journal of Avian Biology*, vol. 31 (4), pp. 447-456. DOI: 10.1034/j.1600-048X.2000.310003.x.
- Wiktander, U., Olsson, O, & Nilsson, S.G. (2001b). Annual and seasonal reproductive trends in the Lesser Spotted Woodpecker *Dendrocopos minor*. *IBIS*, vol. 143 (1), pp. 72-82. DOI: 10.1111/j.1474-919X.2001.tb04171.x.
- Wiktander, U., Olsson, O, & Nilsson, S.G. (2001a). Seasonal variation in home-range size, and habitat area requirement of the lesser spotted woodpecker (*Dendrocopos minor*) in southern Sweden. *Biological Conservation*, vol. 100 (3), pp. 387-395. DOI: 10.1016/S0006-3207(01)00045-3.

Appendices

Appendix 1: A table showing all areas monitored and if Dryobates minor occur in the area. Geographic region is the region, to which an area belongs, region 1 is furthest down in Skåne and with increasing number, latitudes also increases. Species richness is the number of longhorn beetle species that was found in that area. Shannon diversity index is the biodiversity index of longhorn beetles in the area.

Area	D. minor occurrence	Geographic region	Species richness	Shannon diversity index
MH1	No	1	7	1,64
MH133	Yes	3	7	1,45
MH134	Yes	3	7	1,09
MH135	Yes	3	4	0,56
MH143	Yes	3	11	1,47
MH144	Yes	4	8	0,96
MH171	No	4	4	0,52
MH172	Yes	4	8	1,40
MH173	Yes	4	10	1,03
MH2	Yes	1	13	1,86
MH207	Yes	2	9	1,31
MH227	No	2	5	0,92
MH229	Yes	2	10	0,86
MH231	No	2	5	1,42
MH233	No	2	14	1,19
MH234	No	2	9	1,12
MH239	No	2	11	1,32
MH262	Yes	4	8	0,81
MH3	Yes	1	10	1,86
MH305	No	1	14	1,18
MH4	Yes	2	8	1,17
MH54	No	1	8	1,41
MH55	Yes	1	11	1,89
MH7	Yes	2	13	1,06
MH72	Yes	4	8	0,71
MH73	Yes	4	12	0,97
MH75	No	4	8	0,44
MH78	No	4	5	1,03
MH79	No	4	5	1,41
MH8	Yes	2	6	1,22
MH9	No	3	12	1,08
MHX1	No	1	10	1,61
MHX3	No	1	13	1,83
MHX4	No	1	11	1,90

Appendix 2: Tables showing longhorn beetle species and the summed number of individuals collected on each site during the monitoring period (in the last table also Lucanus cervus and Gnorimus nobilis is reported). In the first table the coordinates for each site are presented in the coordinate system WGS 84.

Trap site	Coordinates WGS 84	Pyrrhidium sanguineum	Phymatodes testaceus	Poecilium alni	Plagionotus arcuatus	Rhagium mordax	Rhagium inquisitor	Gaurotes virginea	Grammoptera ruficornis	Pogonocherus hispidus	Anaglyptus mysticus
MH1.1	55.517194 13.739484	11	3	0	1	3	0	0	0	0	16
MH1.2	55.523956 13.734464	7	2	0	2	2	0	0	0	0	1
MH133.1	56.990115 14.087663	18	4	4	2	0	0	0	0	0	0
MH133.2	56.981364 14.075801	15	3	12	2	8	0	0	0	1	0
MH134.1	56.808489 14.017971	52	9	6	2	2	0	0	0	0	0
MH134.2	56.812190 14.002844	54	8	4	3	8	0	0	0	0	0
MH135.1	56.934117 14.063942	0	0	0	1	0	0	0	0	0	0
MH135.2	56.937397 14.050109	5	0	52	2	0	0	0	0	1	0
MH143.1	56.963390 14.319824	38	2	2	9	2	2	0	0	0	0
MH143.2	56.960487 14.306351	46	56	12	4	7	0	0	0	0	0
MH144.1	57.821962 14.137151	1	22	0	8	3	0	0	1	0	0
MH144.2	57.833264 14.148195	0	45	0	8	3	0	0	0	0	0
MH171.1	57.683892 13.039698	8	23	0	11	0	0	0	0	0	0
MH171.2	57.689008 13.037952	4	127	0	0	0	0	0	0	0	0
MH172.1	57.708586 13.135040	10	41	1	3	4	0	0	0	0	0
MH172.2	57.714377 13.140209	8	0	0	8	2	0	0	0	0	0
MH173.1	58.146539 13.139991	6	1	80	6	0	0	0	0	0	0
MH173.2	58.143990 13.130154	1	4	3	0	0	1	0	0	0	0
MH2.1	55.571625 13.754286	20	13	6	0	4	0	0	0	0	10
MH2.2	55.578613 13.758518	37	23	5	2	4	1	0	0	0	14
MH207.1	56.353345 14.007193	77	1	148	24	4	0	0	0	0	0
MH207.2	56.348076 14.003795	107	43	0	2	0	0	0	0	1	0

MH227.1	56.031259	1	0	12	0	1	0	0	0	0	10
	14.619485							-		-	
MH227.2	56.030460	3	94	0	0	2	0	0	0	0	8
	E6 270E11	250	0	80	2	E	0	0	0	0	0
WIE229.1	14.518582	250	ŏ	80	2	5	0	0	0	0	0
MH229.2	56.376412	257	11	699	13	2	0	0	0	0	0
	14.527418	207		000	10	-	Ū	C	U	U	0
MH231.1	56.029280	17	12	14	2	16	0	0	0	0	0
	14.692384										
MH231.2	56.025427	16	14	7	0	0	0	0	0	0	0
	14.703828										
MH233.1	56.335736	72	23	327	21	3	1	0	0	0	0
	14.824949										
MH233.2	56.339240	74	9	27	0	4	0	0	0	0	0
	14.837763										
MH234.1	56.370252	110	47	19	0	10	0	0	0	0	0
	14.980074										
MH234.2	56.367684	181	32	77	5	1	1	0	0	0	0
	14.995107										
MH239.1	56.304397	105	4	17	1	1	0	0	0	0	4
	14.644898										
MH239.2	56.296236	92	17	71	8	10	0	0	0	0	6
	14.645828										
MH262.1	57.882033	311	201	20	3	1	0	1	0	0	0
	11.884061										
MH262.2	57.887158	229	54	3	0	0	0	0	0	0	0
	11.864977										
MH3.1	55.544250	8	9	1	2	0	0	0	0	0	13
	13.706750										
MH3.2	55.544353	9	1	0	1	2	0	0	0	0	4
	13.709542										
MH305.1	55.832799	235	1	183	3	11	0	0	0	0	0
	13.391345										
MH305.2	55.836846	347	82	39	8	32	1	0	0	0	1
	13.402922										
MH4.1	56.085957	42	2	63	4	0	0	0	0	0	2
	13.946124										
MH4.2	56.083922	18	1	0	0	2	0	0	0	0	0
	13.960604										
MH54.1	55.862515	12	10	6	5	2	0	0	0	0	7
	13.996812										
MH54.2	55.859973	56	0	5	4	1	0	0	0	0	1
	14.015698										
MH55.1	55.561222	26	12	7	6	7	1	0	0	0	2
	13.675417	+	+	 				-		-	
MH55.2	55.572972	9	0	14	2	0	0	0	0	0	5
	13.689389										
MH7.1	56.211098	87	5	201	4	2	0	0	0	0	4
	13.911057							<u> </u>		<u> </u>	

	56 200060	50	0	124	2	4	0	2	0	0	4
MH7.2	56.209968	58	8	134	3	4	0	2	0	0	1
MH72 1	57 749837	129	4	17	0	1	0	0	0	0	0
101172.1	12.225841	125		- /	Ũ	-	Ū	Ũ	Ū	Ū	0
MH72.2	57.746184	218	36	11	2	3	2	0	0	0	0
	12.218090										
MH73.1	57.835638	171	7	121	3	0	0	0	0	1	0
	12.390282										
MH73.2	57.830370	195	23	22	4	2	0	0	0	1	0
	12.378385										
MH75.1	57.567248	141	0	0	4	2	0	0	0	0	0
	13.362466										
MH75.2	57.569258	295	9	0	32	0	0	0	0	0	0
	13.355984										
MH78.1	57.644888	33	83	0	4	2	0	0	0	0	0
	13.051302										
MH78.2	57.639715	19	1	0	9	2	0	0	0	0	0
	13.048051										
MH79.1	57.660729	7	16	5	9	0	0	0	0	0	0
	13.399538										
MH79.2	57.667637	4	3	5	1	1	0	0	0	0	0
	13.394212										
MH8.1	56.155350	14	2	0	0	1	0	0	0	0	0
	13.680880										
MH8.2	56.147933	13	2	5	1	7	0	0	0	0	0
	13.665952										
MH9.1	56.824921	133	21	10	15	8	0	0	0	1	0
	14.523006										
MH9.2	56.820202	179	52	3	6	2	0	0	0	0	0
	14.514398										
MHX1.1	55.701522	19	17	95	11	4	0	0	0	0	4
	13.596546										
MHX1.2	55.704859	11	19	22	6	2	1	0	0	0	6
	13.585594										
MHX3.1	55.576401	28	36	10	3	3	0	0	0	0	12
	13.408591										
MHX3.2	55.572429	15	6	24	6	0	0	0	0	0	2
	13.398731										
MHX4.1	55.556950	13	4	0	3	5	1	0	0	0	7
	13.816614										
MHX4.2	55.563508	5	23	0	0	3	0	0	0	0	7
	13.824114										

Trap site	Clytus arietis	Oxymirus cursor	Saperda scalaris	Stenurella melanura	Pogonocherus fasiculatus	Tetropium castaneum	Callidium violaceum	Judolia sexmaculata	Molorchus minor	Xylotrechus rusticus	Pogonocherus hispidulus	Anastrangalia sanguinolenta	Ruptela maculata
MH1.1	0	0	0	5	0	0	0	0	0	0	0	0	0
MH1.2	0	1	0	1	0	0	0	0	0	0	0	0	0
MH133.1	0	0	0	0	0	0	0	0	0	0	0	0	0
MH133.2	0	0	0	0	0	0	0	0	1	0	0	0	0
MH134.1	2	0	0	0	0	0	0	0	0	1	0	0	0
MH134.2	2	0	0	0	0	0	0	0	0	0	0	0	0
MH135.1	0	0	0	0	0	0	0	0	0	0	0	0	0
MH135.2	0	0	0	0	0	0	0	0	0	0	0	0	0
MH143.1	0	1	0	0	0	0	0	0	0	1	0	0	0
MH143.2	1	0	1	0	0	0	0	0	0	2	0	0	0
MH144.1	1	1	0	0	0	0	0	0	0	0	0	0	0
MH144.2	0	0	0	0	0	0	0	0	0	0	0	0	0
MH171.1	1	0	0	0	0	0	0	0	0	0	0	0	0
MH171.2	0	0	0	0	0	0	0	0	0	0	0	0	0
MH172.1	2	1	1	0	0	0	0	0	0	0	0	0	0
MH172.2	0	0	0	0	0	0	0	0	0	0	0	0	0
MH173.1	0	0	0	0	1	0	0	0	0	3	0	0	0
MH173.2	0	1	1	0	0	0	0	0	0	0	0	0	0
MH2.1	13	0	1	2	0	0	0	0	0	0	0	2	0
MH2.2	2	0	0	2	0	0	0	0	0	0	0	0	0
MH207.1	1	0	0	0	0	0	0	0	0	6	0	0	0
MH207.2	1	0	1	0	0	0	0	0	0	1	0	0	0
MH227.1	0	0	0	0	0	0	0	0	0	0	0	0	0
MH227.2	0	0	0	0	0	0	0	0	0	0	0	0	0
MH229.1	1	0	0	0	0	0	0	0	0	0	0	0	0
MH229.2	3	1	0	0	0	0	0	1	0	2	0	0	0
MH231.1	0	0	0	0	0	0	0	0	0	0	0	0	0
MH231.2	0	0	0	0	0	0	0	0	0	0	0	0	0
MH233.1	3	0	0	0	0	10	1	2	0	2	0	0	0
MH233.2	1	0	1	0	0	0	0	0	0	1	0	0	0
MH234.1	0	1	1	0	0	0	0	0	0	1	0	0	0
MH234.2	0	2	0	0	0	0	0	0	0	0	0	0	0
MH239.1	1	0	0	0	0	0	0	0	0	0	0	0	0
MH239.2	8	0	2	0	0	0	0	0	0	0	0	0	0
MH262.1	2	0	0	0	0	0	0	0	0	0	0	0	0
MH262.2	1	0	0	0	0	1	0	0	0	0	0	0	0
MH3.1	10	0	1	1	0	0	0	0	0	0	0	0	0
MH3.2	5	0	1	1	0	0	0	0	0	0	0	0	0
MH305.1	0	0	2	2	0	0	0	0	0	0	0	1	0
MH305.2	10	0	1	0	0	0	0	0	0	0	0	0	0
MH4.1	3	0	0	0	0	0	0	0	0	2	0	0	0
MH4.2	0	0	0	0	0	0	0	0	0	0	0	0	0
MH54.1	4	0	1	0	0	0	0	0	0	0	0	0	0
MH54.2	0	0	1	0	0	0	0	0	0	0	0	0	0
MH55.1	4	0	0	2	0	0	0	0	0	0	0	1	0

MH55.2	1	0	0	0	0	0	0	0	0	0	0	0	0
MH7.1	0	1	0	0	0	0	0	0	0	1	0	1	0
MH7.2	1	2	0	0	0	0	0	0	0	7	0	1	0
MH72.1	0	0	1	0	0	0	0	0	0	0	0	0	0
MH72.2	2	0	1	0	0	0	0	0	0	0	0	0	0
MH73.1	4	0	0	1	0	0	0	0	0	1	0	0	0
MH73.2	0	1	0	0	0	0	0	0	0	0	1	0	0
MH75.1	1	1	1	0	0	0	0	0	0	0	0	0	0
MH75.2	0	0	0	0	0	0	0	0	0	1	0	0	0
MH78.1	0	0	0	0	0	0	0	0	0	0	0	0	0
MH78.2	0	0	0	0	0	0	0	1	0	0	0	0	0
MH79.1	0	0	0	0	0	0	0	0	0	0	0	0	0
MH79.2	0	0	0	0	0	0	0	0	0	0	0	0	0
MH8.1	0	0	0	0	0	0	0	0	0	0	0	0	0
MH8.2	2	0	0	0	0	0	0	0	0	0	0	0	0
MH9.1	3	3	0	0	0	1	0	0	0	0	0	0	0
MH9.2	3	0	0	0	0	0	0	0	0	3	0	0	0
MHX1.1	4	3	0	0	0	0	0	0	0	0	0	0	0
MHX1.2	8	4	0	0	0	0	0	0	0	0	0	0	1
MHX3.1	3	0	2	0	0	0	0	0	0	0	0	0	0
MHX3.2	3	0	0	1	1	0	0	0	0	0	0	0	0
MHX4.1	14	2	0	0	0	0	0	0	0	0	0	0	1
MHX4.2	1	0	0	0	0	0	0	0	0	0	0	0	0

Trap site														
				ata	onia	шп			is is	~		a		
	х <i>ү</i> с і	tola	na olor	i asci	vad	ra atar	sns	suro	ptui corn	dera ata	8 8	ptu ita	S	sn
	amt poll	nost via	ster. acic	turc idrif	udo Ia	phy. bell	sndo	nocc rida	tole culia	oplo gutt	mui atur	tole tellc	anu	orim oilis
	Cer sco	Ste. dut	Alo tab	dnb dəq	Pse liviù	Gla um	Leid net	Ste. me.	Stic ma	And sex	Ase stri	Stic scu	cer cer	Gne
MH1.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MH1.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MH133.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MH133.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MH134.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MH134.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MH135.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MH135.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MH143.1	0	0	0	0	0	0	0	0	1	0	0	0	0	0
MH143.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MH144.1	0	0	0	1	0	0	0	0	0	0	0	0	0	0
MH144.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MH171.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MH171.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MH172.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MH172.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MH173.1	0	0	0	0	0	0	0	0	1	0	0	0	0	0
MH173.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MH2.1	0	0	1	0	0	0	0	0	0	0	0	0	0	0
MH2.2	0	0	0	0	1	0	0	0	0	0	0	0	2	0
MH207.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MH207.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MH227.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MH227.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MH229.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MH229.2	0	0	0	0	0	0	1	0	0	0	0	0	0	0
MH231.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MH231.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MH233.1	0	0	0	0	0	0	0	0	0	0	1	0	0	0
MH233.2	0	0	0	0	0	0	0	0	0	1	0	0	0	0
MH234.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MH234.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MH239.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MH239.2	0	1	2	0	0	0	1	0	0	0	0	0	0	0
MH262.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MH262.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MH3.1	0	0	1	0	0	0	0	0	0	0	0	0	0	0
MH3.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MH305.1	0	0	0	2	0	0	0	0	0	0	0	0	0	0
MH305.2	0	0	0	1	0	0	1	0	0	0	0	1	0	0
MH4.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MH4.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MH54.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MH54.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MH55.1	0	0	0	1	0	0	0	0	0	0	0	0	0	0
MH55.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MH7.1	0	0	0	0	0	0	0	1	0	0	0	0	0	0

MH7.2	0	0	0	0	0	0	0	0	1	0	0	0	0	0
MH72.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MH72.2	0	0	0	0	0	0	0	0	0	0	0	0	0	1
MH73.1	0	0	0	0	0	0	0	0	1	0	0	0	0	0
MH73.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MH75.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MH75.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MH78.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MH78.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MH79.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MH79.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MH8.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MH8.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MH9.1	0	0	0	0	0	0	0	1	1	0	0	0	0	0
MH9.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MHX1.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MHX1.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MHX3.1	0	0	0	1	0	1	1	0	0	0	0	0	0	0
MHX3.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MHX4.1	2	0	0	0	0	0	0	0	0	0	0	0	0	0
MHX4.2	0	1	0	0	0	0	0	0	0	0	0	0	0	0