Wild boar rewilding in Border Park Kempen~Broek

An analysis of ecosystem services and disservices

Master's Thesis

Photo taken by ARK Natuurontwikkeling

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Abstract
Rewilding is an increasingly popular way of restoring ecosystems by maintaining or increasing biodiversity while reducing the impacts of human interventions through restoration of species and ecological processes. It is important to develop evidence-based arguments to support the wide-range impacts of rewilding. For the past 20 years, conservationists have worked on developing nature together with recreational areas within Border Park Kempen~Broek. One species that has returned to Kempen~Broek is the wild boar (*Sus scrofa*). This research aims to map the ecosystem services (rooting in natural habitat) and disservices (rooting in agricultural areas, wildlife-vehicle collisions and official damage reports) caused by the wild boar and investigate how these services and disservices are associated with natural and agricultural habitats. It also looks into how these services and disservices are spatially linked. Through collection of existing data as well as fieldwork, data on land use, rooting occurrence in natural habitat, vehicle collisions, agricultural damage claims and hunting numbers was collected. The results showed that there is no evidence for clustering of ecosystem services and disservices, and also no relationship with habitat type. The research did show a relationship between the occurrence of rooting in natural habitat and the distance from a forest edge. Rooting in natural habitat occurred more near a forest edge than away from a forest edge. This can be useful in the development of agricultural areas into natural areas, since rooting can break open grasslands and can contribute to the development of pioneer plant species. Furthermore, it is crucial to promote ecosystem services and mitigate ecosystem disservices. Creating an environment where disservices are minimized as much as possible allows for the further development of ecosystem services and the habitat as a whole.

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1. Introduction

1.1 Human-wildlife interactions

Halting environmental degradation and promoting restoration of natural habitats to ensure ecosystem services is high on the political agenda in Europe (Cerqueira et al., 2015). Rewilding is an increasingly popular way of restoring ecosystems by maintaining or increasing biodiversity while reducing the impacts of human interventions through restoration of species and ecological processes (Lorimer et al., 2015). It is important to develop evidence-based arguments to support the wide-range impacts of rewilding (Cerqueira et al, 2015). Rewilding and other restoration efforts result in increasing populations of certain wildlife species, including ungulates. This results in increasing interactions between humans and wildlife. Landscape characteristics have an effect on human-wildlife interactions and there is a need for a better understanding of the drivers behind those interactions (Morzillo et al., 2014). With the Netherlands being such a densely populated country, interactions are bound to arise between the various utilizers of available land. The restoration and development of natural areas promotes ecosystem services and flourishing of wildlife, but increasing wildlife populations may also come into conflict with infrastructure, agricultural areas and urban areas. One species that plays an important role in human-wildlife interactions in Europe is the wild boar (*Sus scrofa*) (Lombardini et al., 2017). Wild boar populations have rapidly increased over the last decades, and together with increasing human populations and intensification of agricultural activities, human-wild boar interactions have also escalated (Lombardini et al., 2017). Wild boar individuals can survive and thrive in habitats dominated by anthropogenic activities (Schley et al., 2008). It is, therefore, crucial to find a balance between ecosystem services and disservices provided and caused by the wild boar resulting from habitat restoration.

1.2 Ecosystem services and disservices

One important ecosystem service delivered by wild boar is that they contribute to natural disturbances through rooting, which can promote the species richness of natural areas and improve soil conditions (Kurstjens et al., 2003; Barrios-Garcia & Ballari, 2012). For example, rooting spots are beneficial for early-successional plants, like grasses or weeds, and provide food for other wildlife (Barrios-Garcia et al., 2012). Wild boar therefore fulfil a crucial role within existing ecosystems. Furthermore, wildlife species such as the wild boar can act as a stimulant for public recreation and tourism, which in turn stimulates the economic development of the area (Groot Bruinderink et al., 2011).

On the other hand, wild boar also bring about ecosystem disservices. One disservice is the disturbances caused by rooting in agricultural land. As wild boar have a diverse diet, any locally existing food is often exploited (Schley et al., 2008). Crop fields provide an extremely rich source of food with relatively minimal foraging efforts (Barrios-Garcia & Ballari, 2012). However, crop damage causes significant economic losses (Lombardini et al., 2017).

Another disservice is the risk of wildlife-vehicle collisions. Wildlife-vehicle collisions lead to challenges for wildlife management and conservation. This is especially the case in areas frequently visited by wildlife, where anthropogenic activities dominate (Neumann et al., 2012). Wildlife-vehicle collisions are of increasing concern as societal development accelerates

(Saint-Andrieux et al., 2020). The additional risks for human safety resulting from wildlife-vehicle collisions makes this interaction a socio-economic as well as a conservation issue (Saint-Andrieux et al., 2020). Infrastructure is present throughout most European landscapes and forms an integral part of our environment. Therefore, it is crucial to take infrastructure into account when studying wildlife conservation. Infrastructure mainly affects wildlife through mortality from wildlife-vehicle collisions, habitat loss and fragmentation, and noise, air and light pollution (Heigl et al., 2016).

1.3 Wild boar in Border Park Kempen~Broek

For the past 20 years, conservationists have worked on developing nature together with recreational areas within Border Park Kempen~Broek (ARK Natuurontwikkeling, n.d.), located along the boundary between The Netherlands and Belgium, encompassing North-Brabant, Limburg and Belgian Limburg. The main aim of conservation in this area is the restoration and reconnection of natural habitats, creating more possibilities for natural habitat use of the existing species. During World War II, this landscape was one of the last areas in the Netherlands, of what was once a marsh ecosystem, that was drained to increase food production (Jepson et al., 2018). The area has been characterized by agricultural activities since then. The area continues to be fragmented, as roads, canals and agricultural fields create barriers within the landscape. ARK Natuurontwikkeling and Natuurmonumenten, together with the municipalities and provincial governments, are working on the restoration of the area. The aim is to reconnect these fragmented landscapes in Kempen~Broek, through strategies like an ecoduct across highway A2 and wildlife-warning systems along roads (ARK Natuurontwikkeling, n.d.) and through developing former agricultural areas into more natural systems.

One species that has returned to Kempen~Broek is the wild boar (*Sus scrofa*). The wild boar is native to the Netherlands, but went extinct in 1826 due to overhunting (Van Tulden et al., 2020). In 1904, the wild boar was reintroduced as hunting animals for the Dutch Royal Family (Van Tulden et al., 2020). Officially, the wild boar may only occur in a few designated areas including *De Veluwe* and *Nationaal Park De Meinweg* (Natuurmonumenten, n.d.). Based on current policy, the wild boar should be restricted to these areas. However, due to migration from Belgium and Germany the wild boar is increasingly settling in areas outside of these officially appointed habitats (Natuurmonumenten, n.d.) across large parts along the eastern and southern borders of the Netherlands. Despite official regulations, North-Brabant and Limburg are increasingly tolerating the presence of the wild boar. This leads to debates, where parties emphasize either the positive or negative effects of the wild boar.

1.4 Research problem

There is a strong need for restoration of existing natural habitats. However, strategies for restoration and rewilding bring about both positive and negative effects in the form of ecosystem services and disservices. Currently, much of the debate is driven by perceptions of these positive and negative effects, but empirical data is often lacking. Increasing empirical data on both the services and disservices may allow for a more informed debate between opposing parties. It is important to gain a better understanding of the balance between these services and disservices. There is an increasing occurrence of landscapes that combine agricultural and conservation land uses, which are not strictly spatially separated. This creates a mosaic of landscapes. In such landscapes, it is crucial to understand how the spatial distribution of services and disservices are connected and how they link to the distribution of conservation and agricultural land uses. Although the wild boar is officially only allowed in a few locations, their populations have increased rapidly and the species has started to settle in other areas as well. The Border Park Kempen~Broek is a prime example of this wild boar comeback and of a mosaic landscape, where agricultural and conservation land uses co-occur. More knowledge on the distribution, habitat use and impacts of wild boar in the area is therefore desirable, since the wild boar is a relatively new species in the Kempen~Broek area.

Thus, this research aims to map the ecosystem services (rooting in natural habitat) and disservices (rooting in agricultural areas, wildlife-vehicle collisions and official damage reports) caused by the wild boar and investigate how these services and disservices are associated with natural and agricultural habitats. It also looks into how these services and disservices are spatially linked. To shape this research, the following overall research question has been formulated:

How does restoration of the natural habitat through rewilding affect the spatial distribution and extent of ecosystem services (rooting in natural habitat) and disservices (rooting in agricultural areas, wildlife-vehicle collisions and official damage reports) caused by the wild boar in Border Park Kempen~Broek?

To provide guidance throughout this research and to support the overall research question, the following sub-questions have been formed:

1. What are the different conservation and agricultural land use types within Border Park Kempen~Broek?
2. What is the spatial distribution of rooting locations and how is it linked to the different conservation and agricultural land use types?
3. What is the spatial and temporal distribution of wild boar vehicle collisions and how is it linked to the different conservation and agricultural land use types?
4. Can the distribution of agricultural areas (e.g., certain crop types like maize) and conservation habitats (e.g., grassland or deciduous forest) explain the spatial clustering patterns of services and disservices?
5. How do smaller-scale landscape characteristics (e.g., forest edges) influence the distribution of services and disservices?

Through answering the overall research question and sub-questions, the ecosystem services and disservices as a result of wild boar habitat use in Border Park Kempen~Broek will be analysed. Thus, this research is relevant for the future of the wild boar in Kempen~Broek, and for similar landscapes elsewhere in the Netherlands. It will also help understand how the distribution of land use types influences the balance of services and disservices by wild boar and how land use planning can mitigate ecosystem disservices while supporting the ecosystem services as well.

2. Theoretical Background

2.1 Diet and habitat preferences of the wild boar

Wild boar are one of the most widely distributed species in the world and use a wide range of habitats (Massei & Genov, 2004; Kim et al., 2019). Wild boar are fecund and capable of rapid reproduction (Barrios-Garcia & Ballari, 2012), leading to rapid population increase. In Europe, increases in wild boar populations are a result of socio-economic changes such as depopulation of rural areas, variation in dominant crop types, reintroduction of the species, lack of predators, hunting limitations, food availability and climatic changes (Leaper et al., 1999; Massei & Genov, 2004).

Wild boar are ungulates within the *Suidae* family and adult individuals can weigh between 35 and 230 kg (Leaper et al., 1999; Massei & Genov, 2004). The wild boar is primarily nocturnal (Johann et al., 2020). Wild boar habitat use is mainly linked to food availability, shelter and climatic conditions (Leaper et al., 1999). Wild boar prefer habitats with high-energy food sources that provide enough cover from predators and hunters (Massei & Genov, 2004). Wild boar occur in a variety of habitats, ranging from semiarid environments to tropical forests, mountain ranges and marshes (Massei et al., 2011). The species can exist in such a wide range of habitats due to their diverse diet, including leaves, roots, seeds, earthworms, insects and small mammals (Kim et al., 2019). They have a particular preference for the consumption of acorns and beech mast (Massei & Genov, 2004; Zeman et al., 2016). However, wild boar may also consume agricultural crops when energy-rich natural food is scarce (Massei & Genov, 2004). Wild boar prefer humid soils for rooting with high productivity and mainly deciduous forests (Kim et al, 2019). However, their habitat range can increase when food availability increases (Leaper et al., 1999). Wild boar also use open habitats such as heathland or grassland in search of food (Leaper et al., 1999).

During hot summer periods, the wild boar prefers to settle in shady areas because, due to lacking sweat glands, they need to cool down by wallowing and resting in cooler places (Leaper et al., 2019). These cooler places are often located in areas with dense vegetation. Cold and extreme winter weather has a negative impact on wild boar populations, whereas a warmer and more humid climate with higher development of beech and oak mast contributes to increasing wild boar populations (Bongi et al., 2017).

2.2 The effect of the wild boar on its habitat

As wild boar populations continue to grow across Europe due to their high rates of reproduction (Barrios-Garcia & Ballari, 2012), the wild boar has settled in many new habitats. This settlement in a new habitat results in new impacts. The increase in wild boar populations implies that the environmental and social impact of the species will also increase accordingly (Kim et al., 2019).

2.2.1 Effects on natural areas

Among the activities of the wild boar within its habitat, rooting has the most significant impact on soils, vegetation and ground-dwelling organisms (Bueno et al., 2009). While rooting, wild boar overturn the soil in search for food (Barrios-Garcia & Ballari, 2012). The scale of these rooting locations varies from a few square centimeters to hundreds of hectares (Bueno et al., 2009). Their rooting activity leads to open spots in the landscape, influencing the succession of existing plant species and creating space for pioneer species to flourish (Kurstjens et al., 2003). Rooting activities at an average depth of 5 to 15 centimeters mainly affect the species that are directly consumed by wild boar; however, may also affect species that are not eaten but of which the roots are left exposed (Massei & Genov, 2004). Where rooting activities are high and densely located, rooting can lead to a reduction of up to 80-95% of the vegetation cover and may result in the local extinction of individual plant species (Massei & Genov, 2004; Barrios-Garcia & Ballari, 2012).

Although rooting inherently disturbs vegetation cover, these disturbances also act as an opportunity for new development of biodiversity. In Sweden, rooting activities caused by wild boar increased plant species richness and abundance (Leaper et al., 1999; Massei & Genov, 2004). In Germany, the introduction of wild boar into young conifer plantations led to the removal of competitive vegetation, enhancing the regeneration and growth of the Norway Spruce (Leaper et al., 1999). In habitats where the vegetation is adapted to regular disturbances, the original plant cover can recover within 6 to 12 months after disturbance (Barrios-Garcia & Ballari, 2012). Rooting also accelerates decomposition of organic matter by incorporating forest litter into the soil and can positively affect nutrient cycling in the upper soil horizon (Massei & Genov, 2004). As a result, beech trees exhibited greater growth in areas with rooting in comparison to areas without rooting (Massei & Genov, 2004). Wirthner et al. (2012) found that rooting resulted in higher soil C and N concentrations and microbial biomass C, suggesting enhanced decomposition and faster turnover rates of carbon. Piattoni et al. (2012) suggest that wild boar may also play a role in spore dispersal of fungi, due to the consumption of fungi and their large movements throughout their habitat.

2.2.2 Effects on agricultural areas

Because of its broad diet, wild boar also consume agricultural crops and can thereby cause significant crop damage (Herrero et al., 2006; Schley et al., 2008; Thurfjell et al., 2009). The largest crop damage occurs as a result of consumption of the crop or through trampling (Schley et al., 2008). Higher risks of crop damage occur with an increasing presence of permanent crops (e.g. grassland, shrubland or orchards), a decreasing presence of urban areas, forests and shrublands and a smaller distance from sheltered areas, such as forest patches (Lombardini et al., 2017). Thurfjell et al. (2009) suggest that in fields with a smaller distance relative to escape cover, wild boar foraging behaviour in crop fields was more frequent. This is referred to as the forest edge effect. Thurfjell et al. (2009) also concluded that in areas with small crop fields, damage levels may be high everywhere in the field because all areas of a small field will be close to a forest edge providing escape cover. In areas with larger fields, the centers of these crop fields may be spared from damage. Additionally, crop damage is positively related to the abundance of wild boar in the area (Amici et al., 2012). Wild boar have a particular preference for maize and wheat, of which especially maize fields are damaged most (Schley & Roper, 2003; Herrero et al., 2006; Schley et al., 2008). This may not be solely due to preference of consumption, but also because maize plants provide cover due to their height (Schley et al., 2008).

2.2.3 Wildlife-vehicle collisions

Wildlife-vehicle collisions cause serious injuries for both animals and humans as well as property damage and they increase with traffic volume (Gren & Jägenbrand, 2017). One of the most direct negative impacts of roads on wildlife abundance is mortality, however roads also create barriers leading to habitat fragmentation (Heigl et al., 2016). Factors that play a role in wildlife-vehicle collisions include annual and seasonal variations in wildlife activity patterns, anthropogenic factors such as road and traffic density and type, wildlife fences and landscape fragmentation (Neumann et al., 2020).

Collisions with wild boar mainly occur during night time, which highlights the nocturnal character of the animal (Rodríguez-Morales et al., 2013; Kruuse et al., 2016). Also, during the night, visibility is lowest (Rodríguez-Morales et al., 2013; Thurfjell et al., 2015), enhancing the probability of collision. Furthermore, most accidents occur during the winter months, most likely as the result of a longer period of darkness and thus reduced visibility (Neumann et al., 2012; Rodríguez-Morales et al., 2013). Neumann et al. (2012) suggests that higher risk of collision during the winter is largely due to low light intensity and poor road conditions rather than to more wildlife crossings.

Wild boar cross roads to reach desired land covers, of which the rewards outweigh the risks of crossing a road (Thurfjell et al., 2015). Thurfjell et al. (2015) concluded that wild boar were more likely to cross roads to reach land covers providing crops than to reach land covers providing shelter. Moreover, collisions are most likely to occur in patchy, fragmented landscapes due to frequent movement between forest, open patches and cropland, which is especially the case for wild boar (Saint-Andrieux et al., 2020). Additionally, the frequency of wildlife-vehicle collisions is likely to increase over time due to expanding road networks, wildlife population growth and increasing traffic volumes (Seiler & Helldin, 2006; Neumann et al., 2012).

2.2.4 Disease spreading

Wild boar significantly contribute to the spreading of Classical and African swine fever among their own species and domestic pigs (O’Neill et al., 2020). The capacity of wild boar to spread diseases is further driven by increasing populations throughout Europe (Podgórski et al., 2018). Movements of animal hosts contribute to the transmission of pathogens between individuals and lead to spatial spread of disease and transmission from one population to another (Podgórski & Śmietanka, 2018). Swine fever first emerged in Europe in 1957 (O’Neill et al., 2020). In 1999, the disease was eradicated through strict control of infected or at-risk domestic pig populations (O’Neill et al., 2020). However, in June of 2007, the virus was once again reported in the Caucasus region of Georgia and has started to spread to neighbouring countries (De La Torre et al., 2015; Podgórski & Śmietanka, 2018). This brings concerns that wild boar populations throughout Europe can be infected and that the disease will spread further to domestic pigs (De La Torre et al., 2015), through for example human contact or infected feed. Swine fever is detrimental to wild boar and domestic pigs, as the virus causes acute haemorrhagic fever that becomes lethal about 8 to 20 days after infection (Podgórski & Śmietanka, 2018).

2.3 Current measures and strategies to mitigate conflicts

One measure to mitigate conflicts caused by wild boar is population control through hunting (Kurstjens et al., 2003). However, this is challenged by the fact that wild boar are very effective at staying away from hunters by reducing their movements and staying in habitats with sufficient cover (Thurfjell et al., 2013). Methods like hunting and trapping could lead to removal of healthy individuals or to adaptation of wild boar behaviour through becoming more active at night or increasing their habitat range to avoid hunters (European Food Safety Authority, 2014). Therefore, management efforts have shifted towards the protection of resources like cropland or livestock through the use of e.g. fences, in addition to hunting (Massei et al., 2011). Thus, farmers strive to minimize crop damage in their fields as much as possible through population control, but also through fencing, dissuasive feeding, scaring the wildlife or using repellents such as odour (Thurfjell et al., 2013). To mitigate wildlife-vehicle collisions, measures such as wildlife underpasses or wildlife overpasses can act as a way to create a safer road crossing environment (Glista et al., 2009). Glista et al. (2009) have concluded that the location of crossing structures is the most important factor predicting the effectiveness of these structures. Crossing structures should be placed within areas of suitable habitat, with minimal disturbances (Rodriguez et al., 1996).

Two concepts that shape the debate on nature versus agriculture are land sharing and land sparing. Land sharing refers to the coexistence of agricultural and natural land through promoting agricultural practices with lower agricultural yields, while land sparing refers to raising yields on existing agricultural land to minimize the agricultural area needed and leave more land for natural areas (Baudron & Giller, 2014). Land sharing can be classified as extensive agriculture that is wildlife friendly and land sparing can be classified as intensive agriculture that is less wildlife friendly but also less extensive (Shackelford et al., 2015). These strategies, however, are not exclusive and generally it is assumed that a combination of the two strategies will lead to effective biodiversity conservation (Fischer et al., 2014). The balance and distribution of agricultural land and natural land and the related agricultural or conservation practices is thus crucial.

3. Hypotheses

Rooting locations: Based on the literature, it is expected that rooting locations will be present in (1) in grassland, heathland areas or deciduous forest and (2) in cropland areas, specifically in the vicinity of maize fields. Furthermore, based on the forest edge effect proposed by Thurfjell et al. (2009), it is expected that rooting occurrence is highest near a forest edge.

Effect of landscape features on rooting in agricultural areas: Based on the theory of forest edge effect proposed by Thurfjell et al. (2009), it is expected that the fields that are most affected by wild boar rooting are the fields located closest to a forest edge.

Wildlife-vehicle collisions: It is expected that the risk of wildlife-vehicle collisions increases (1) with wild boar rooting occurrence and (2) during the winter months and dark nights.

Spatial distribution of ecosystem services and disservices: It is expected that cropland located close to a forest edge will experience more disservices as rooting in cropland areas will be more frequent due to the nearby shelter of the forest. It is expected that ecosystem services will be highest in the natural habitats, especially grasslands.

4. Methodology

4.1 Study area

Border Park Kempen~Broek is situated partly in the Netherlands and partly in Belgium, and crosses the southern Dutch border. The area is part of the municipalities of Cranendonck, Nederweert and Weert in the Netherlands, and Bocholt, Bree, Kinrooi and Maaseik in Belgium. Kempen~Broek encompasses many forest areas, and aims to reconnect these areas (GrensPark Kempen~Broek, 2013). Historically, Kempen~Broek was a combination of marshlands and drier, more elevated areas. Human activities have led to exploitation of these marshlands for agriculture, while later these areas were left to develop naturally again. This has resulted in a wide-ranged mosaic landscape, with a combination of marshlands, dune fields, forests, heathlands and agricultural fields (GrensPark Kempen~Broek, 2013). Most commonly, agricultural fields can be subdivided into grassland, maize, asparagus and potatoes.

Kempen~Broek is home to many species, including ungulates such as red deer and wild boar. Wild boar settled in Kempen~Broek about 10 years ago. This development led to a rapid increase of damage claims in agricultural fields caused by rooting (personal communication, H. Stassen, March 9, 2021). As a result, Natuurmonumenten and the *Wild Beheer Eenheid* Grenskant have developed a strategy to manage the wild boar population in Kempen~Broek. Natuurmonumenten has appointed certain areas as ‘resting areas’, where wild boar are allowed to exist. Outside of these areas, hunters are allowed to shoot the animals. This creates a balance between species protection and species control to prevent damage to agricultural areas and wild boar-vehicle collisions. Currently, the number of individual wild boar is unknown, however there is data from hunters on how many boars get shot each year.

The study area is shown in figure 1 below. It is located between the city of Weert and the Belgian border.

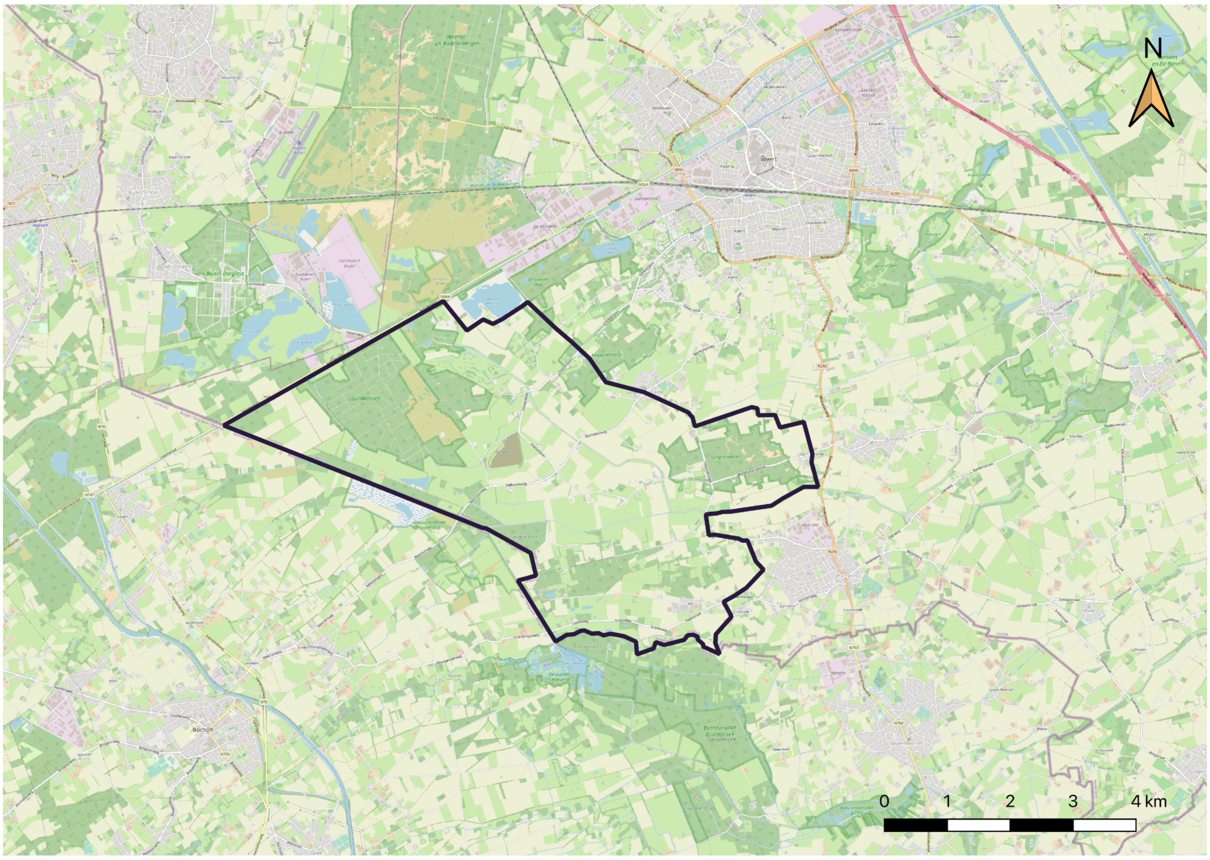

Figure 1: Study area within Border Park Kempen~Broek, between Weert and the Belgian border.

4.2 Data collection

4.2.1 Land-use map

The land-use map was generated based on existing data. I used the land-use map developed by Crombag (2021) (figure 2) as a basis. This map covers the natural areas of Kempen~Broek and maps the natural habitats only. Since the map by Crombag (2021) did not fully cover the study area of this research, I added natural habitats based on *Landgebruik Nederland (2019)* to fit the whole extent of the study area. I further developed this map by adding agricultural land uses. The land-use map was made for the area of Kempen~Broek on the Dutch side of the border only, following the outline of the previously selected study area. I extracted information on these agricultural habitats from existing GIS data layers from *Basisregistratie Percelen (2020)* (BRP) developed by Het Kadaster.

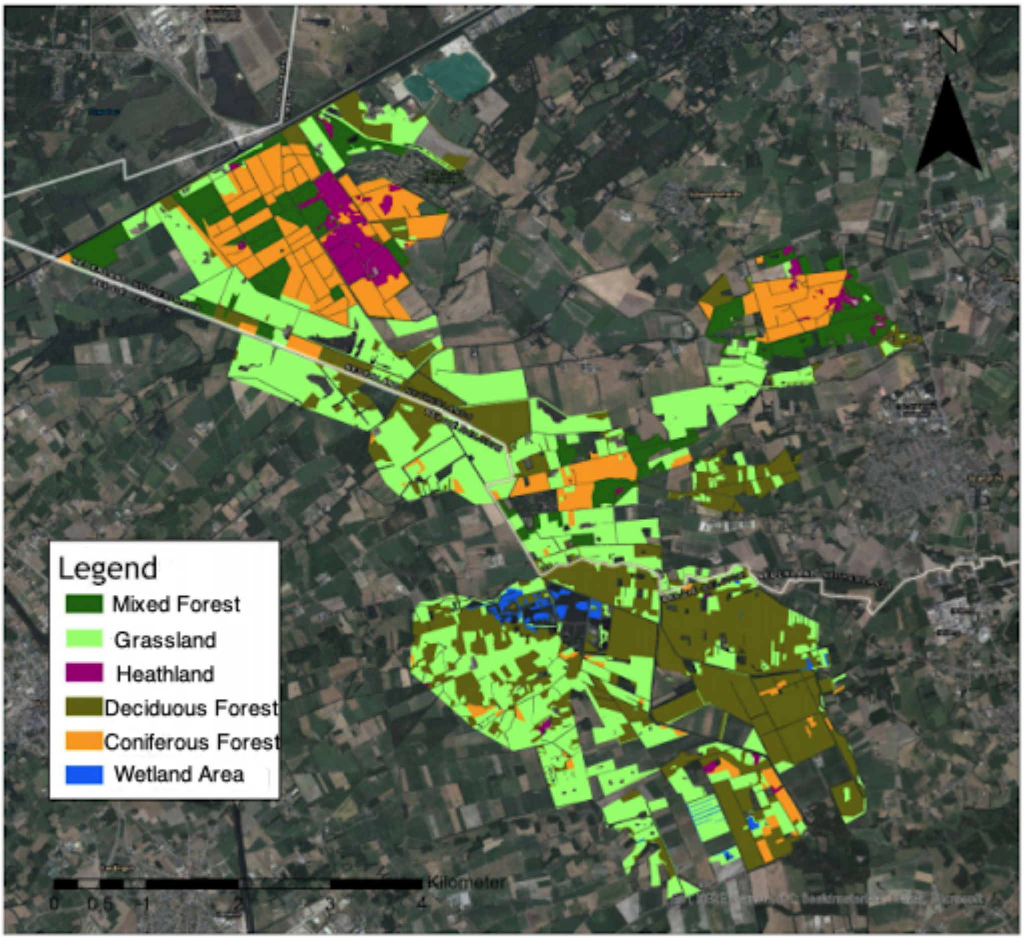

Figure 2: Land-use map of the studied research area in Kempen~Broek, adapted to English (Crombag, 2021).

4.2.2 Rooting locations

I mapped rooting locations during Spring (period April-May) 2021. According to Bueno et al. (2009), rooting provides the most reliable evidence of the presence of the wild boar. Rooting locations were mapped through conducting fieldwork. Rooting locations in natural areas as well as in agricultural areas were mapped on bike and walking transects. Before going out into the field, I set out these transects using GPS locations in QGIS3.10. The study area focused on part of an area of Kempen~Broek that falls under *Wild Beheer Eenheid* (WBE) Grenskant.

Bike transects

Bike transects were set out based on public trails and roads, as private areas are generally off limits. This was not a hindrance to the research, as the roads and trails networks in the area are rather dense. I cycled 59 transects in total, with a total length of 67.7 km and an average transect length of 1253.7 meters. I recorded where rooting locations were located and the density of these locations. The density was based on the percentage of rooting locations present per 50 meters on a transect. I visually inspected 5 meters on each side of a transect. This created grid cells of 50 by 10 meters on each transect. In addition to the rooting score, I also recorded the path type and a visibility score for each 50m segment on the bike transects.

The path types included:
1. Paved road for cars
2. Paved road for bikes
3. Sand road
4. Forest trail

The visibility score allowed me to correct for possible differences in visibility per habitat type. For example, visibility in a grassland habitat is much higher than in a forest habitat.

The visibility scores included:
1. Clear visibility, >100 meters on each side of the transect
2. >10 meters visibility on each side of the transect
3. <5 meters on each side of the transect

The rooting scores included:
1. No rooting
2. 1-10% of the 50-meter segment was rooted
3. 11-25% of the 50-meter segment was rooted
4. 26-50% of the 50-meter segment was rooted
5. 51-100% of the 50-meter segment was rooted

I also scored the main habitat types for each 50m segment on each transect using the habitats from the previously developed land-use map.

The habitat types included:
1. Mixed forest
2. Grassland (natural + agricultural)
3. Heathland
4. Deciduous forest
5. Coniferous forest
6. Maize
7. Mixed habitat
8. Privately owned land (including plots for houses)

According to these scores, a table was filled in per transect (table 1).

Table 1: Rooting locations per bike transect

Transect #				
Distance (m)	*Path type (1-4)*	*Visibility score (1-3)*	*Rooting score (1-5)*	*Habitat type (1-8)*
0				
50				
100				
etc.				

The setup of the bike transects is shown in figure 3 below.

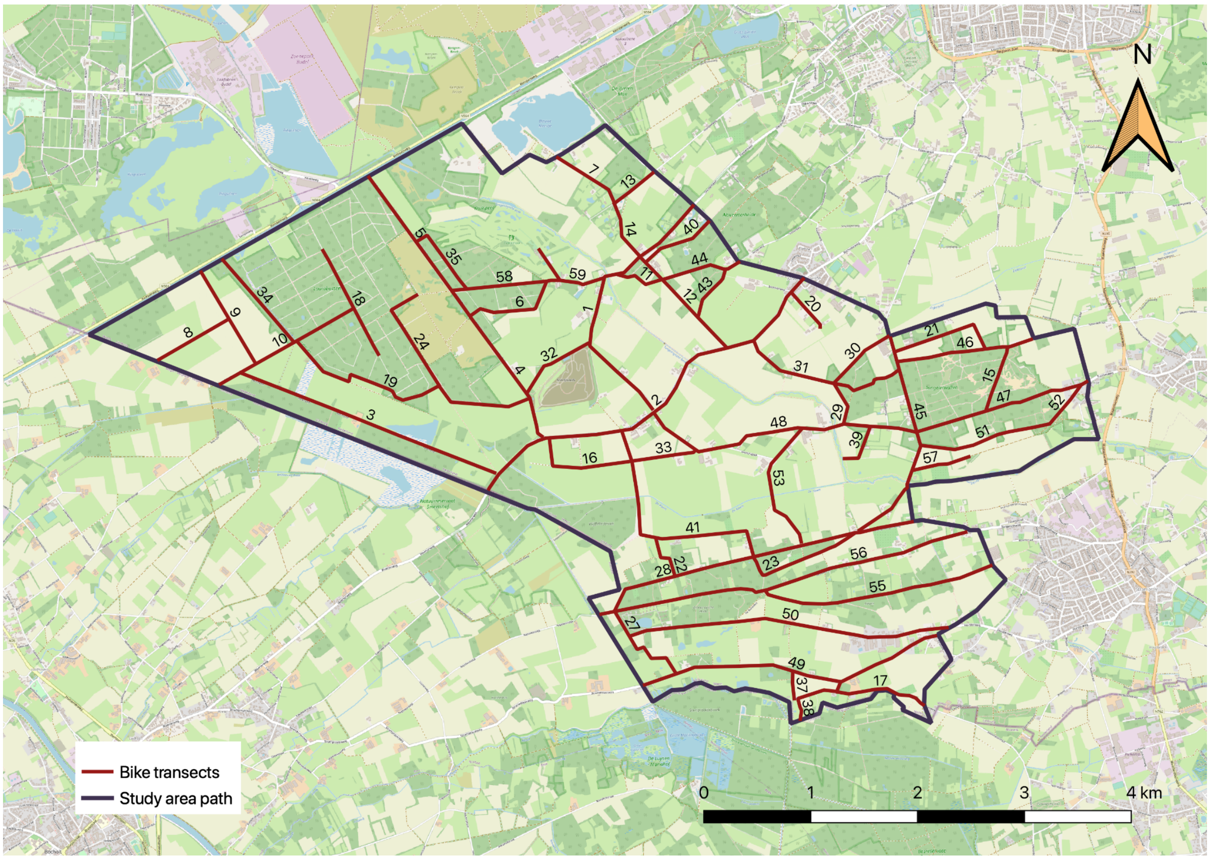

Figure 3: Setup of the bike transects placed within the study area.

Walking transects

In certain natural habitat types, foot transects were also set out away from existing trails and roads and on paths that were not accessible by bike. This was to avoid possible biases by only researching areas near public roads and trails that I could cycle on. The foot transects were set out based on the accessibility of an area. Certain areas within the study area were off limits due to concerns of trespassing and existing regulations. The foot transects were shorter than the bike transects, namely about 200 to 400 meters. This distance was based on the available space to lay down a transect. The total length was 8560 meters, with an average transect length of 305.7 meters. As with the bike transects, the density of rooting locations was based on the percentage of rooting locations present on a transect, 5 meters on each side of a transect. However, the grid cell size on a walking transect was smaller than on a bike transect. Transects were inspected every 10 meters, creating grid cells of 10 by 10 meters. On these transects, I specifically tested for smaller-scale landscape effects on rooting, such as the field and forest edge effects. On the foot transects, I recorded the following three variables: habitat type, visibility score and a rooting score.

The rooting scores were the same as for the bike transects:

1. No rooting
2. 1-10% of area is rooted
3. 11-25% of area is rooted
4. 26-50% of area is rooted
5. 51-100% of area is rooted

The visibility scores included:

1. Clear visibility, >100 meters on each side of the transect
2. >10 meters visibility on each side of the transect
3. <5 meters on each side of the transect

The habitat types included:

1. Mixed forest
2. Grassland (natural + agricultural)
3. Heathland
4. Deciduous forest
5. Coniferous forest
6. Maize
7. Mixed habitat

The habitat types again reflected the same as those on the developed land-use map and as used for the bike transects.

According to these scores, a table was filled in per transect (table 2).

Table 2: Rooting locations per walking transect

Transect #			
Distance (m)	*Habitat type (1-7)*	*Visibility score (1-3)*	*Rooting score (1-5)*
0			
10			
20			
30			
etc.			

The setup of the walking transects is shown in figure 4 below.

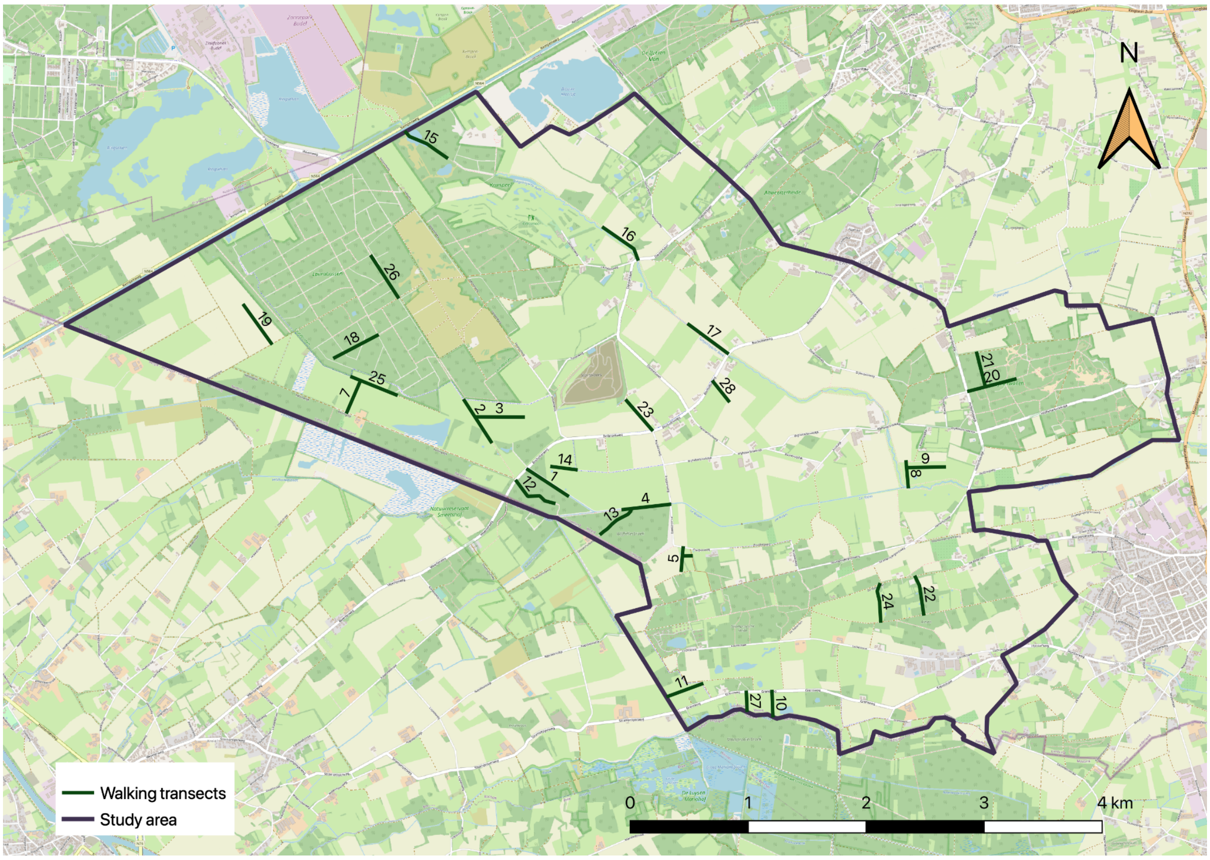

Figure 4: Setup of the walking transects placed within the study area.

4.2.4 Wild boar-vehicle collisions and additional data

Data on wild boar-vehicle collisions was provided by the *Faunabeheereenheid* (FBE) Limburg. The data was collected for the area that falls under WBE Grenskant and mapped in QGIS 3.10. This data corresponds to the period 2014-2021. I also obtained the data for damage claims in agricultural fields within the study area caused by wild boar and the wild boar hunting data for the same time period, including the total number of individual wild boar observed and shot and the corresponding locations. Due to the sensitivity of the subject, I am not allowed to include spatial information on the hunting locations in this thesis.

4.2.5 Mapping services and disservices

Using QGIS 3.10, I created maps of the land-use, rooting observations and percentages, wild boar-vehicle collisions, damage claims from rooting and the number of wild boar shot. These maps were combined to show the spatial distribution of all the variables studied in this research. This allowed me to investigate whether ecosystem services and disservices were spatially coupled or not.

Due to the fact that the fieldwork was conducted based on transects, and thus only covered selected areas within the study area, buffers were created in QGIS around the original transects. Each buffer covered an area of 300 meters around a transect. Using the "points in polygon" option in QGIS, I then determined how many observations of rooting, vehicle collisions, damage claims and hunted individuals were present within each buffer. From this it could be determined whether there was spatial clustering of the four variables.

A visibility of <5 meters on each side of a transect prohibited the method of mapping the rooting density. Therefore, measurement points where the visibility was <5 meters on each side of a transect were not taken into account in the data analysis. As transects were set out at varying lengths, the percentage of observed rooting was corrected for the length of the transect that it was observed on. This was done by dividing the average rooting percentage per transect (*AvP*), derived from the rooting scores, by the number of measurement points per transect (*Nmp*). This calculation is shown in equation 1.

$$\frac{AvP}{Nmp} \tag{1}$$

Measurement points were located every 50 meters on a bike transect and every 10 meters on a walking transect. The average rooting percentage at each measurement point was calculated by taking the average percentage linked to a rooting score. The average percentages per rooting score are shown in table 3 below.

Table 3: Average rooting percentage per rooting score

Rooting score	**Average rooting percentage per category**
1 (no rooting)	0%
2 (1-10%)	5.5%
3 (11-25%)	18%
4 (26-50%)	38%
5 (51-100%)	75.5%

Using the average rooting percentage per transect, observed rooting was linked to the habitat type in which the rooting was found. To simplify the analysis, the habitat type of each transect was selected based on the most dominantly occurring habitat type and agricultural grassland and natural grassland were categorized under one habitat type. Furthermore, as there was no rooting observed in agricultural land during the fieldwork, the term 'rooting' refers to rooting in natural habitats. This is thus categorized as an ecosystem service.

4.3 Statistical analyses

To analyse the spatial distribution of services and disservices, and to test for spatial coupling or clusters, I performed the following tests:

1. *Spatial clustering of rooting, vehicle collisions, agricultural damage claims and hunted individuals*

To test for spatial clustering between ecosystem services and disservices, I performed a Spearman Correlation Test between rooting and vehicle collisions, rooting and damage claims, and rooting and hunted individuals. I analysed the bike transects and walking transects separately.

2. *Spatial clustering of the four previously mentioned variables based on habitat type*

I performed a MANOVA with the habitat type as the independent variable and the rooting observations, damage claims and hunted individuals as dependent variables. The vehicle collisions were left out of the analysis because of the limited amount of data. I made a vector of the habitat type and a matrix of the three dependent variables. I then performed the MANOVA with the vector as the independent variable and the matrix as the dependent variable. I analysed the bike transects and walking transects separately.

3. *Density of rooting based on habitat type*

I first performed a two-way ANOVA to test the relationship between rooting, habitat type and transect type. This tested for the difference in effect of habitat type on rooting per transect type. I then performed a one-way ANOVA with habitat type as the independent variable and the average rooting percentages per transect as the dependent variable to test whether habitat type had an effect on the average rooting percentages per transect. For this test I analysed the bike transects and walking transects separately.

4. *Occurrence of vehicle collisions based on habitat type*

Due to the limited amount of data on vehicle collisions, a statistical test could not be performed for this criterion. The relationship was merely discussed in a descriptive manner.

5. *Occurrence of rooting on a bike transect compared to occurrence of rooting on a walking transect*

I tested if there was a difference in outcomes of rooting percentages between the methodologies for the bike transects and walking transects. I performed a Spearman Correlation to test this.

6. *Time of day of vehicle collisions*

Due to the limited amount of data, a statistical test could not be performed for this criterion. The relationship was merely discussed in a descriptive manner.

7. *Seasonality of vehicle collisions*

Due to the limited amount of data, a statistical test could not be performed for this criterion. The relationship was merely discussed in a descriptive manner. The data of vehicle collisions were given per month and were then categorized per season.

8. *Distance of rooting from a forest edge*

I tested for the forest edge effect in relation to the occurrence of rooting, with the distance from a forest edge as the independent variable and the occurrence of rooting as the dependent variable. The distance from a forest edge was derived in QGIS using the plugin NNJoin. NNJoin calculates the distance of a point to the nearest edge of a polygon. By combining all forest habitat groups into one simplified forest habitat type, and making this a shapefile of polygons, the distance of rooting points to the nearest forest edge could be calculated. To simplify the analysis, the measured distances were combined into categories: “within 50m”, “within 100m”, etc.

9. *Distance of agricultural damage claims from a forest edge*

I tested for the forest edge effect in relation to the occurrence of damage claims by performing a one-way ANOVA with the distance from a forest edge as the independent variable and the occurrence of damage claims as the dependent variable. The methodology for the distance between damage claims from a forest edge is the same as the methodology for the distance between the rooting points and a forest edge. To simplify the analysis, the measured distances were combined into categories: “within 50m”, “within 100m”, etc.

All tests were analysed based on a 95% confidence interval in RStudio, thus with an alpha value of 0.05.

5. Results

5.1 Land use maps

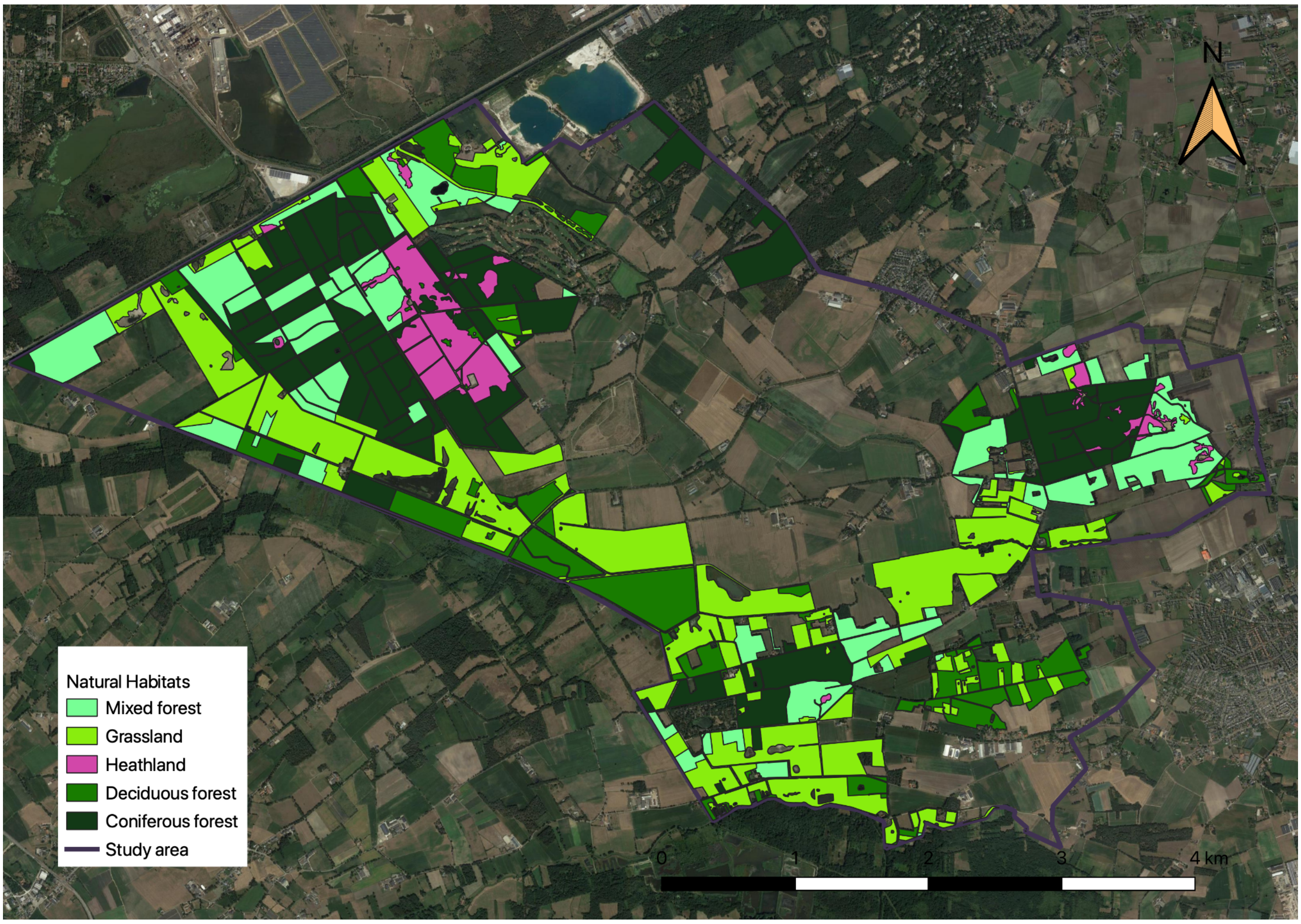

Figure 5: Natural habitats within the study area.

Figure 5 shows the natural habitats within the study area. This map was slightly modified to fit the study area from the map developed by Crombag (2021). What can be seen is that there are clearly defined forest habitats, which are connected through grassland areas. The most occurring forest habitat is coniferous forest, followed by mixed forest. There are also some areas of heathland.

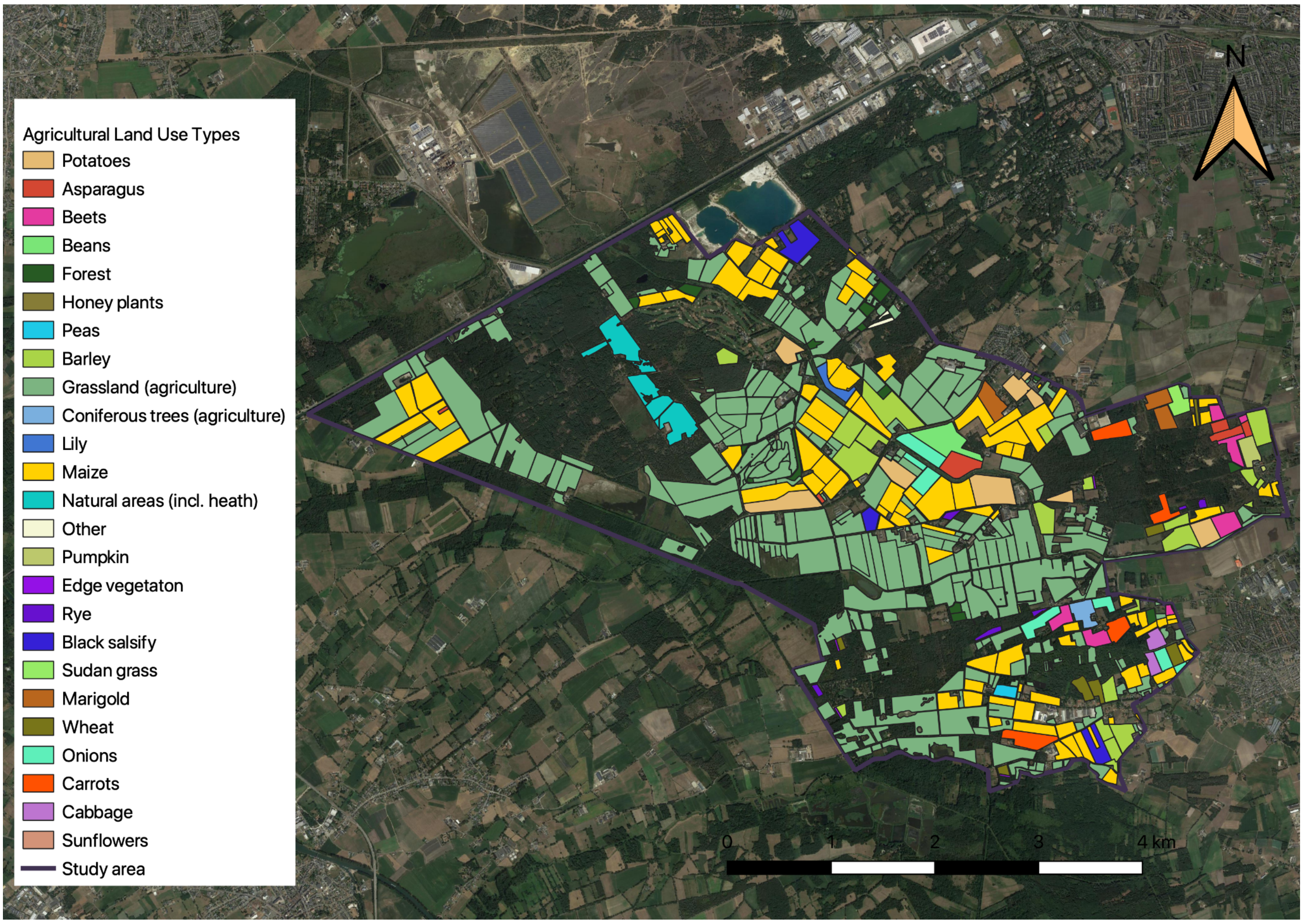

Figure 6: Agricultural land use types within the study area.

Figure 6 shows the agricultural land use types within the study area. What can be seen is that most of the agricultural land is grassland. Maize is also a widely grown crop within the study area. It is noticeable, when comparing the natural habitats with the agricultural land uses, that grassland overlaps in some areas.

5.2 Rooting locations and percentages

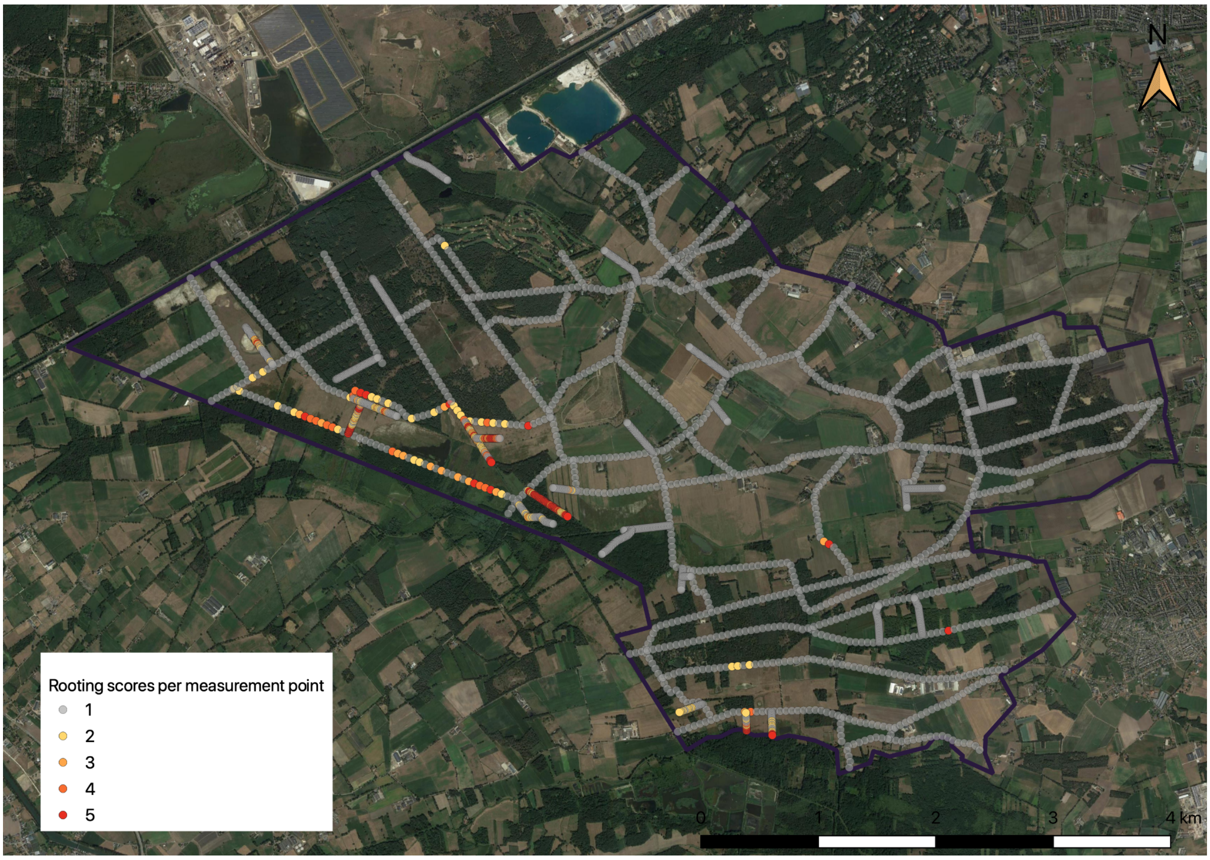

Figure 7: The observed rooting scores per measurement point.

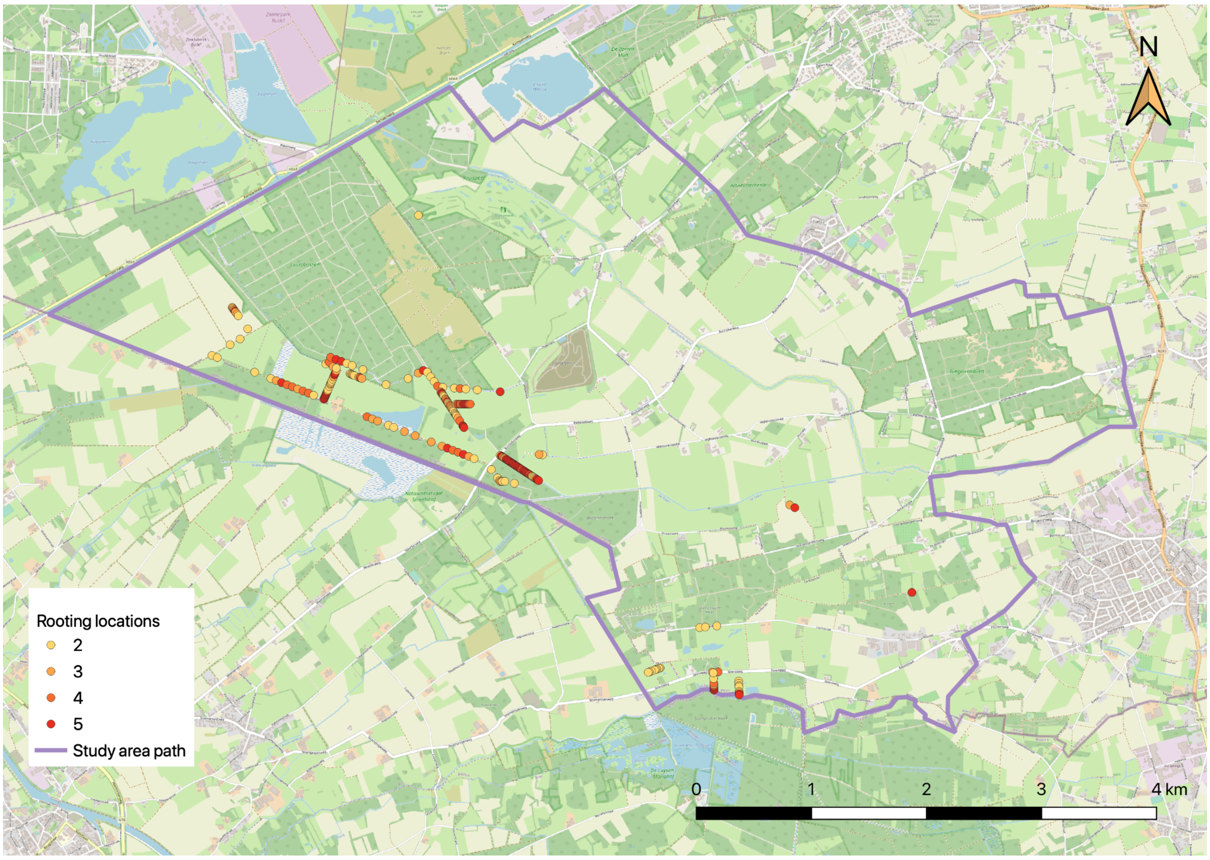

Figure 8: The measurement points at which rooting was found.

Figures 7 and 8 show the outcomes of the conducted fieldwork. The dots in figure 8 show the points at which rooting was found. The yellow dots show a low density of rooting while the red points show the highest density of rooting that was found. It can be seen that most rooting is found near the Belgian border and the Bocholterweg. Some rooting was also found near the Belgian border in the south-eastern part of the study area. Very little rooting was found in the agricultural parts of the study area.

5.3 Additional variables

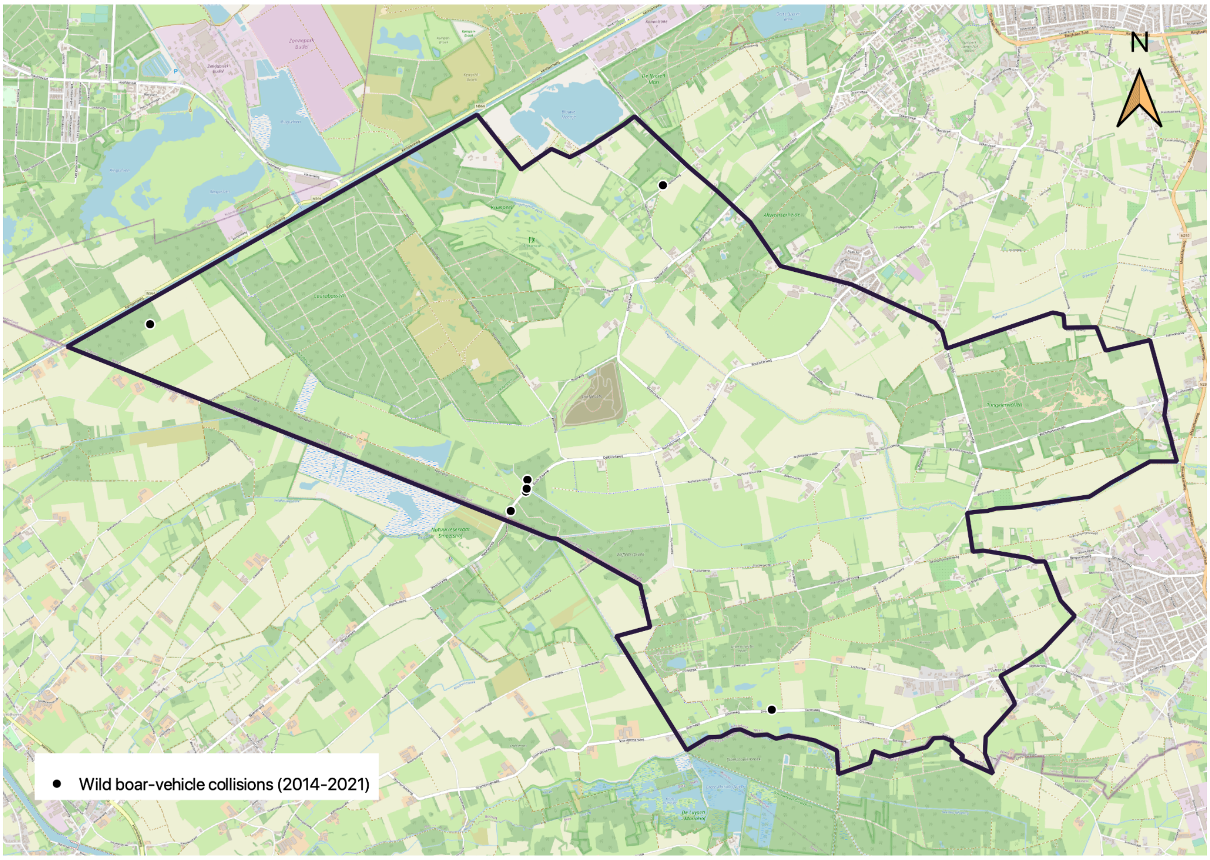

Figure 9: The locations of wild boar-vehicle collisions for the period 2014-2021.

Figure 9 shows the wild boar-vehicle collisions that occurred within the study area between 2014 and 2021. From a total of 7 collisions, 4 of them occurred on the Bocholterweg near the Belgian border. This is also where the current wildlife warning system is located. The overall number of vehicle collisions that have occurred within the study area is relatively low and averaged at about 1 per year.

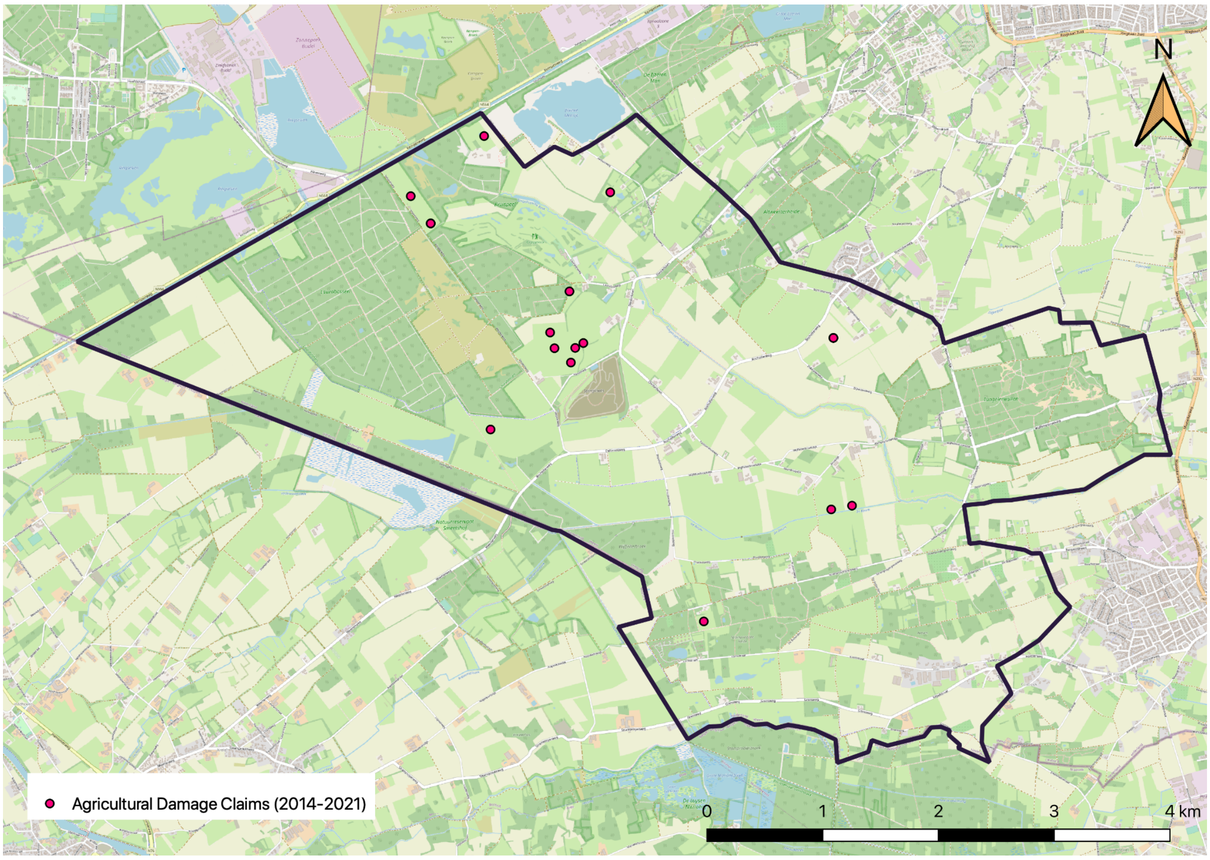

Figure 10: The agricultural damage claims for the period 2014-2021.

Figure 10 shows the reported damage claims in agricultural areas caused by the wild boar between 2014-2021. When comparing this map to the land use map, it can be seen that most damage claims are reported in agricultural grasslands.

Although the locations of hunted individuals were also included in the analysis, a map of this cannot be shown in this thesis due to the sensitivity of the matter. This follows the data-sharing agreement by the FBE.

5.4 Statistical Analyses

This section describes the outcomes of the various statistical analyses conducted in this research.

1. Spatial clustering of rooting, vehicle collisions, agricultural damage claims and hunted individuals

<u>Bike transects:</u>

Between rooting and vehicle collisions:

```
        Spearman's rank correlation rho

data:  spatial_biketransects$NUMPOINTS_rooting and spatial_biketransects$NUMPOINT_vehiclecollisi
ons
S = 529.22, p-value = 0.01806
alternative hypothesis: true rho is not equal to 0
sample estimates:
      rho
0.5357697
```

Between rooting and damage claims:

```
        Spearman's rank correlation rho

data:  spatial_biketransects$NUMPOINTS_rooting and spatial_biketransects$NUMPOINT_damageclaims
S = 1571, p-value = 0.1105
alternative hypothesis: true rho is not equal to 0
sample estimates:
       rho
-0.3780806
```

Between rooting and hunted individuals:

```
        Spearman's rank correlation rho

data:  spatial_biketransects$NUMPOINTS_rooting and spatial_biketransects$NUMPOINT_hunted
S = 1026.7, p-value = 0.6856
alternative hypothesis: true rho is not equal to 0
sample estimates:
       rho
0.09937904
```

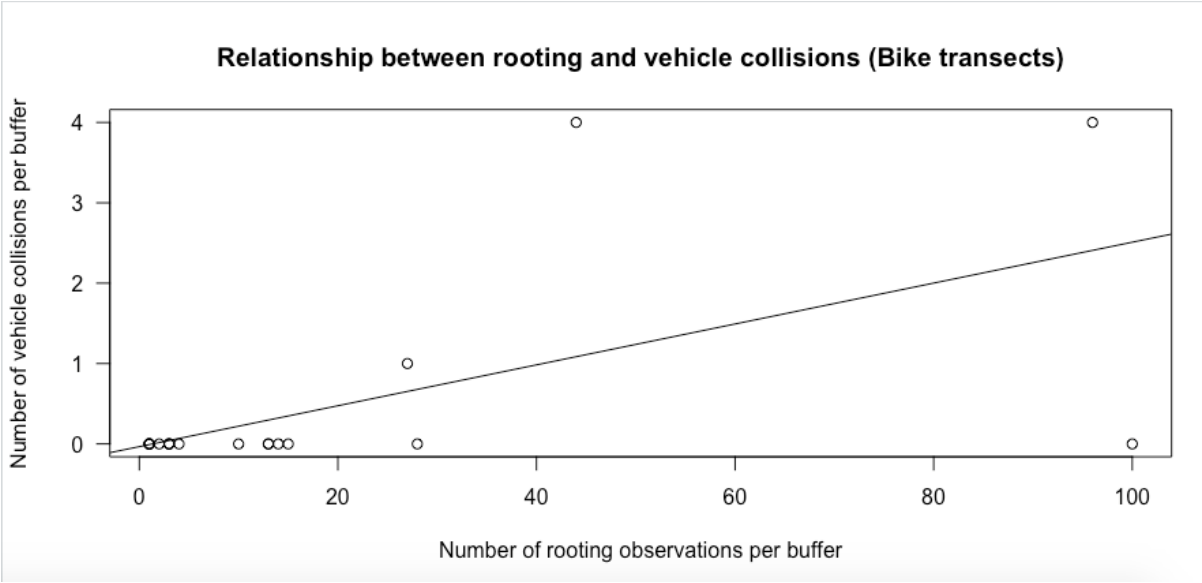

Figure 11: The relationship between the occurrence of rooting and vehicle collisions (bike transects).

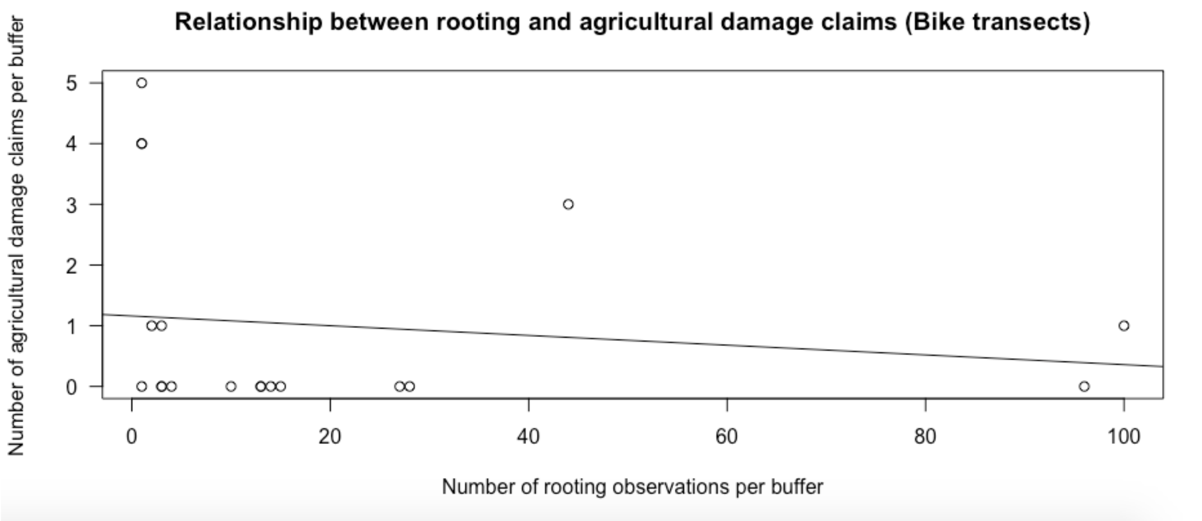

FIgure 12: The relationship between the occurrence of rooting and agricultural damage claims (bike transects).

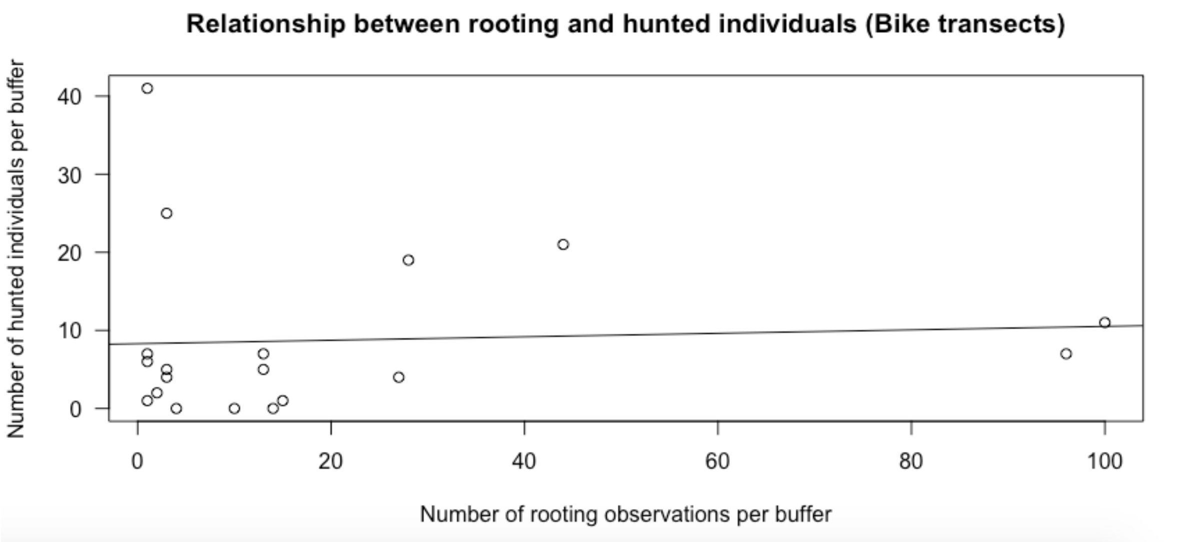

Figure 13: The relationship between the occurrence of rooting and hunted individuals (bike transects).

Walking transects:

Rooting and vehicle collisions:

```
        Spearman's rank correlation rho

data:  spatial_walkingtransects$NUMPOINTS_rooting and spatial_walkingtransects$NUMPOINT_vehiclec
ollisions
S = 210.61, p-value = 0.1515
alternative hypothesis: true rho is not equal to 0
sample estimates:
      rho
0.4214104
```

Rooting and damage claims:

```
        Spearman's rank correlation rho

data:  spatial_walkingtransects$NUMPOINTS_rooting and spatial_walkingtransects$NUMPOINT_damagecl
aims
S = 176.56, p-value = 0.07174
alternative hypothesis: true rho is not equal to 0
sample estimates:
     rho
0.514949
```

Rooting and hunted individuals:

```
        Spearman's rank correlation rho

data:  spatial_walkingtransects$NUMPOINTS_rooting and spatial_walkingtransects$NUMPOINT_hunted
S = 233.29, p-value = 0.2282
alternative hypothesis: true rho is not equal to 0
sample estimates:
     rho
0.359082
```

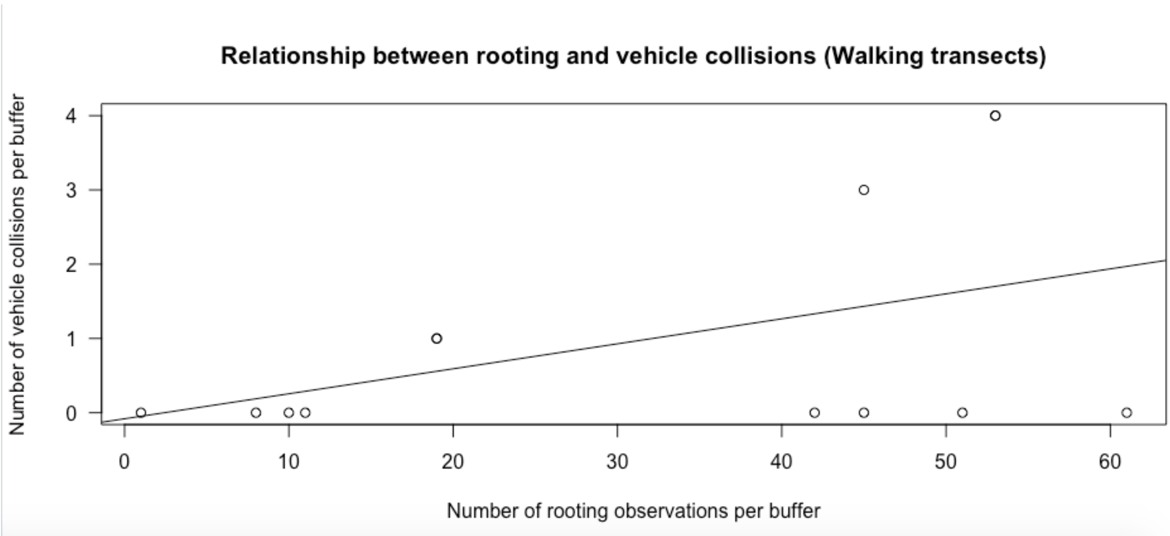

Figure 14: The relationship between the occurrence of rooting and vehicle collisions (walking transects).

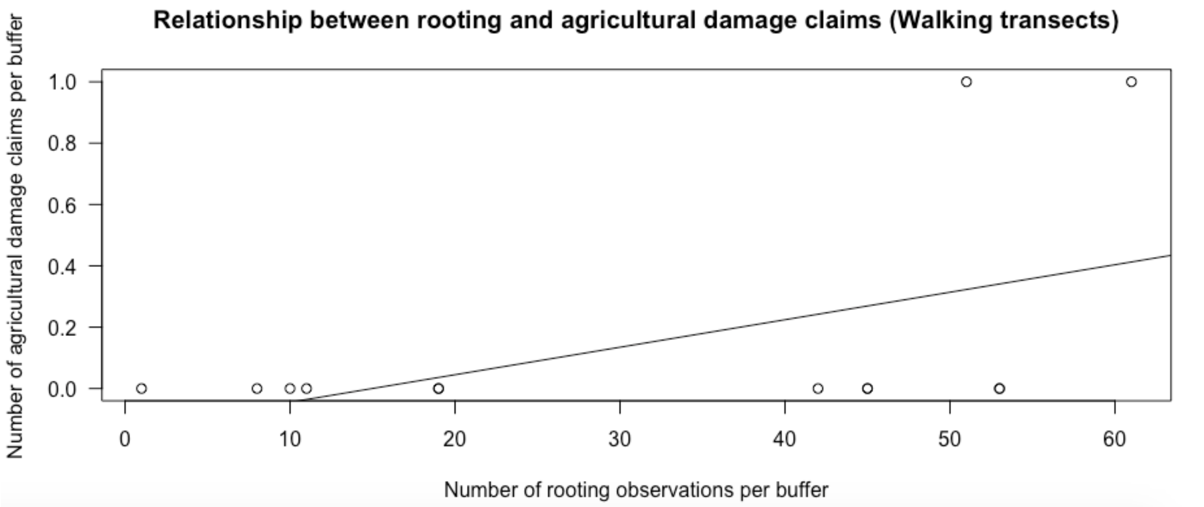

Figure 15: The relationship between the occurrence of rooting and agricultural damage claims (walking transects).

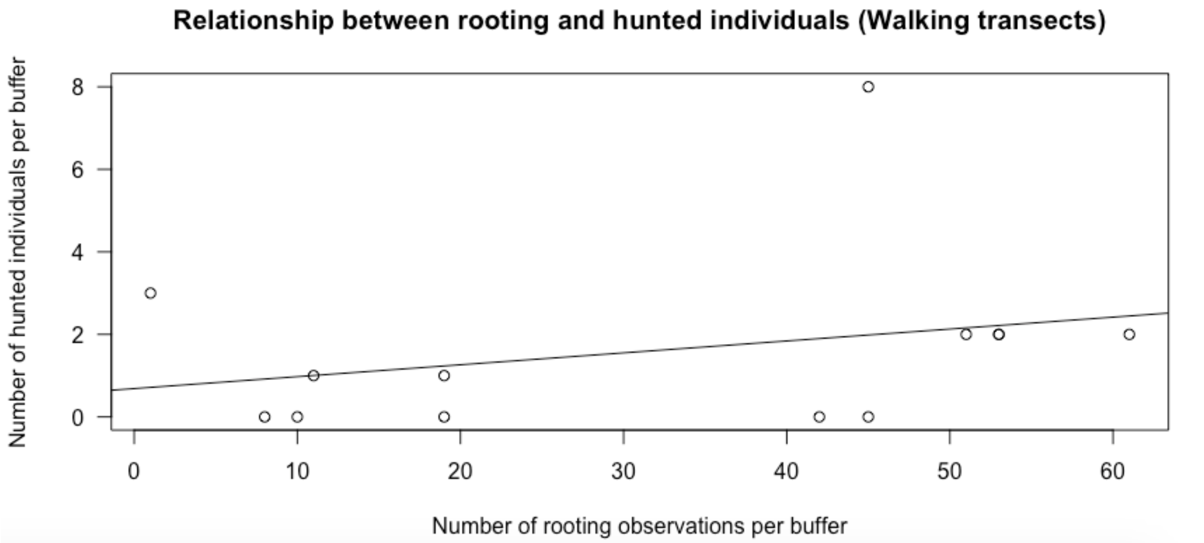

Figure 16: The relationship between the occurrence of rooting and hunted individuals (walking transects).

Figures 11-16 show the relationships between the ecosystem services and disservices on both the bike and walking transects. The Spearman Correlation Tests mostly resulted in a p-value greater than 0.05. This means that for most of the tests, there was no correlation found between any of the two variables. The only test that returned with a p-value lower than 0.05 was the correlation between rooting and vehicle collisions on a bike transect. Due to the limited occurrence of vehicle collisions within the study area, this result may not be representative. It can be seen from the Spearman's rho values as well as the plots that most variables have a positive relationship. This means that if one variable increases, the other increases accordingly. However, this relationship cannot be statistically supported. The only negative relationship is between rooting and agricultural damage claims on the bike transects.

2. Spatial clustering of the four previously mentioned variables based on habitat type

```
> summary(MANOVAspatialclustering_habitatBIKE)
          Df  Pillai approx F num Df den Df Pr(>F)
Hbike      1 0.14508  0.84848      3     15 0.4887
Residuals 17
```

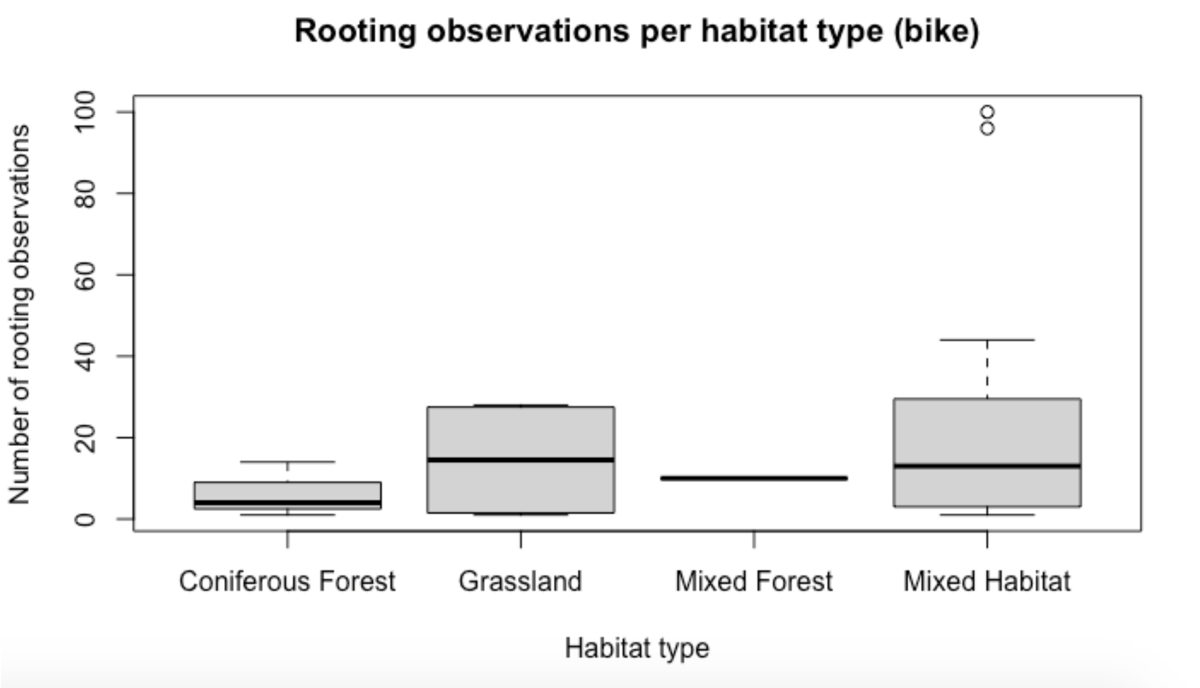

Figure 17: The number of rooting observations per habitat type (bike transects).

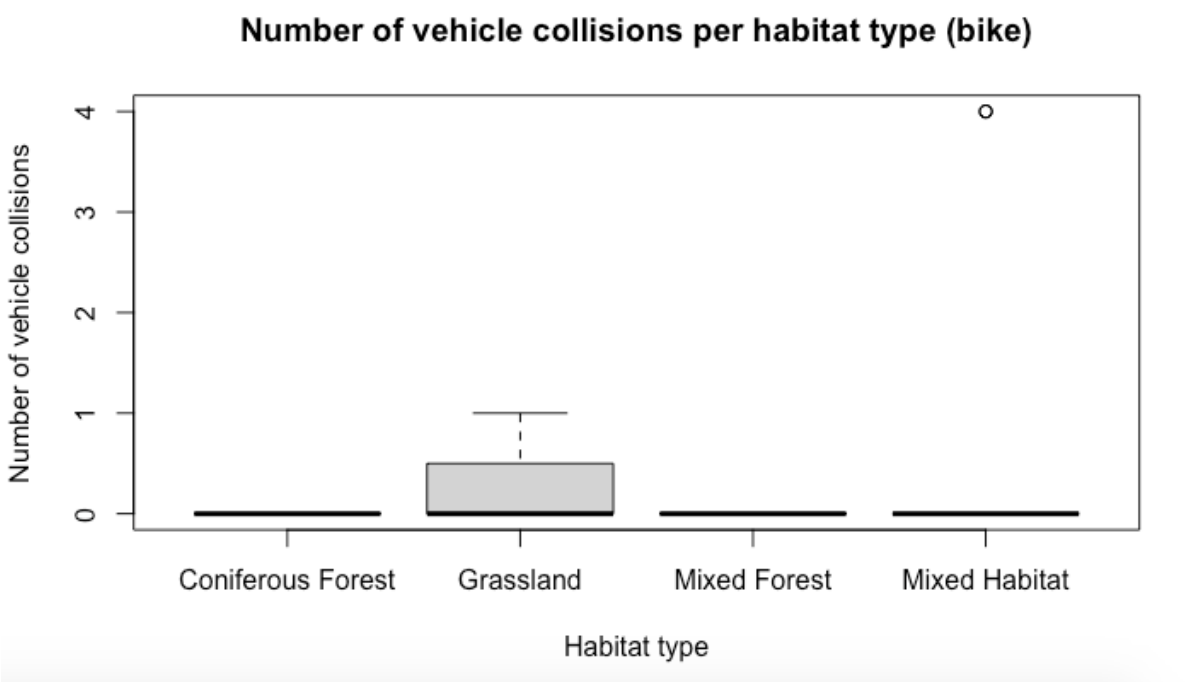

Figure 18: The number of vehicle collisions per habitat type (bike transects).

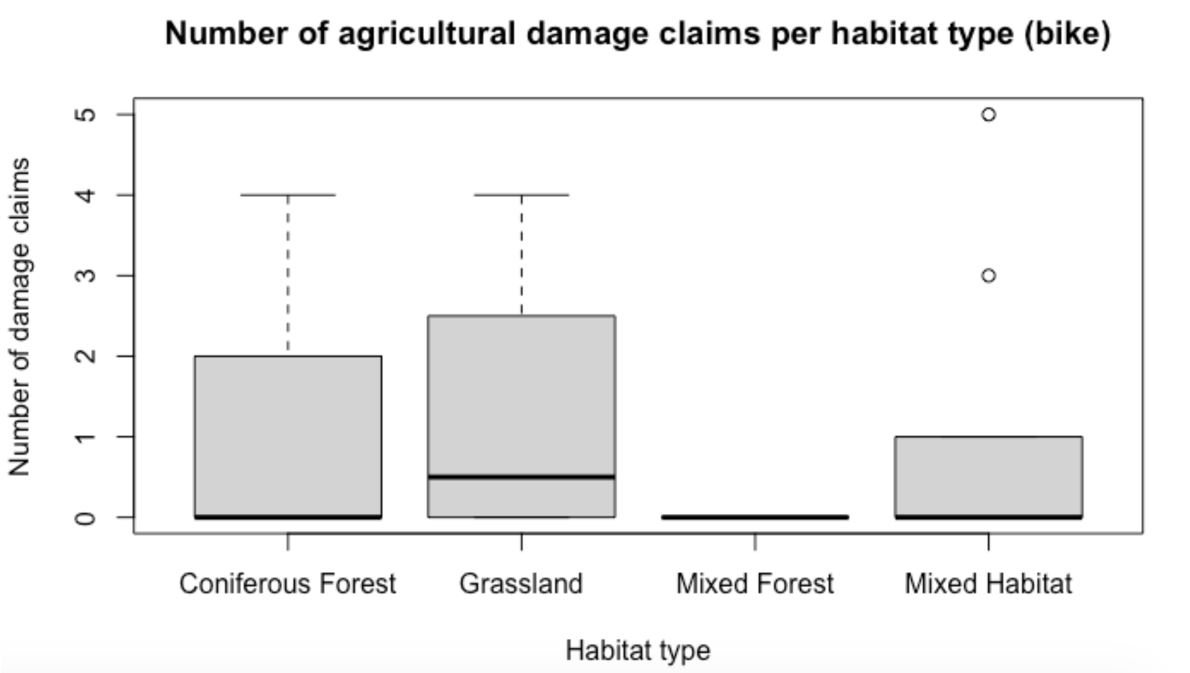

Figure 19: The number of agricultural damage claims per habitat type (bike transects).

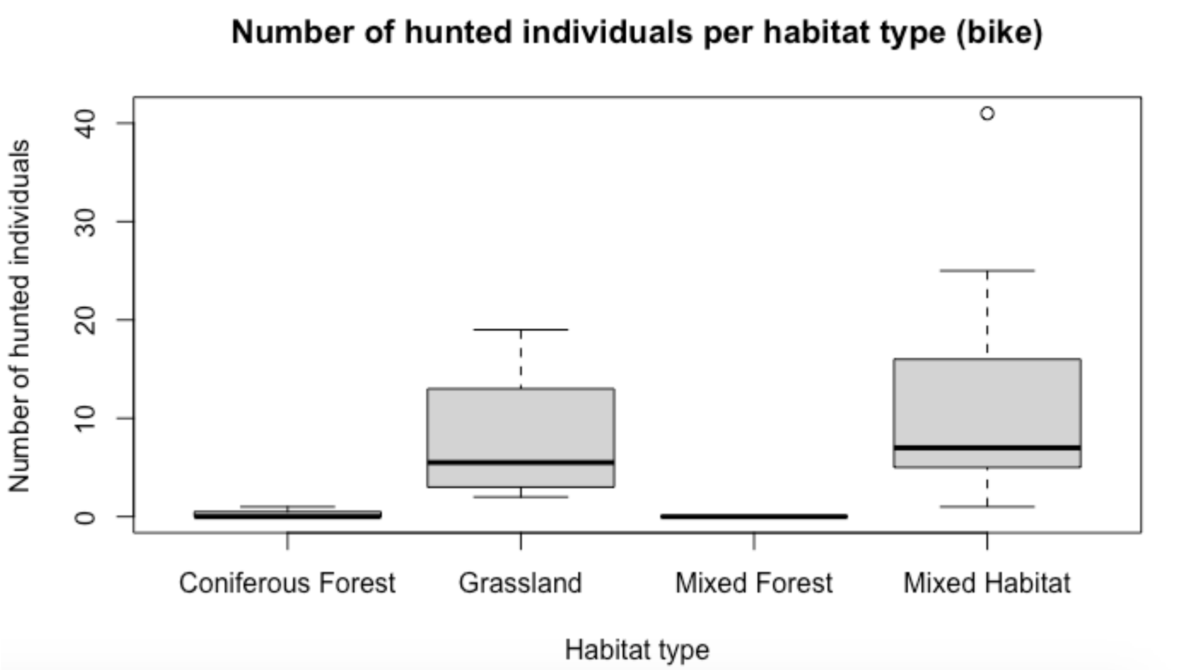

Figure 20: The number of hunted individuals per habitat type (bike transects).

```
> summary(MANOVAspatialclustering_habitatWALKING)
          Df   Pillai approx F num Df den Df Pr(>F)
Hwalking   1 0.086134  0.28276      3      9 0.8367
Residuals 11
```

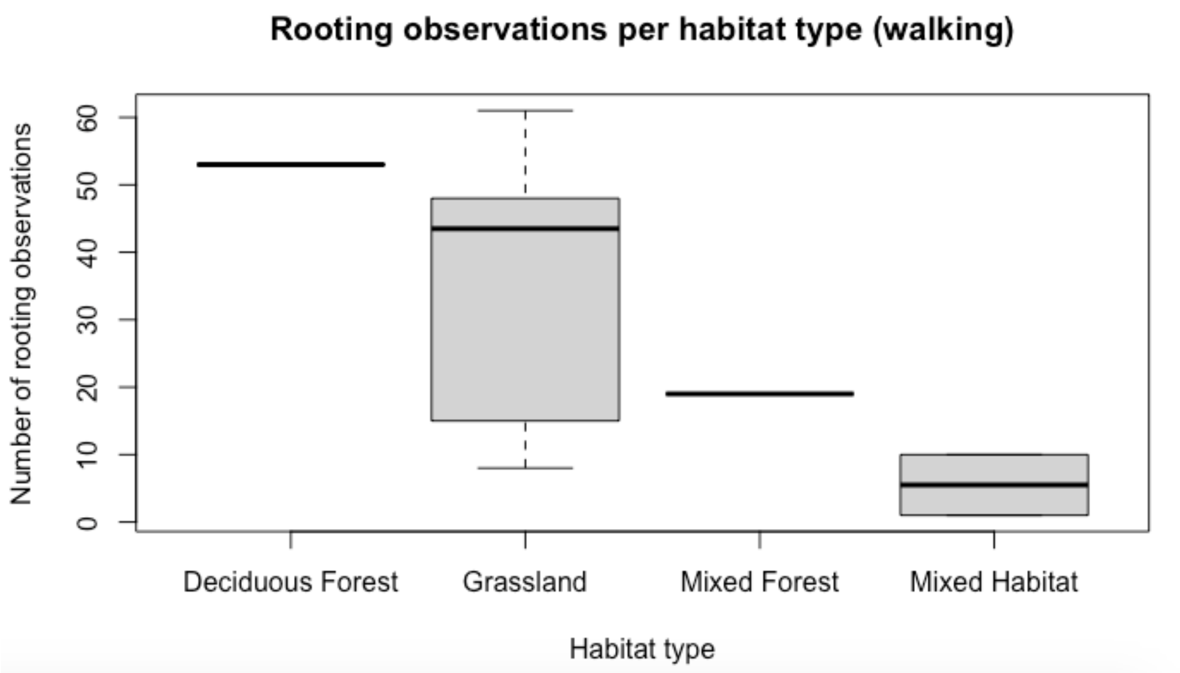

Figure 21: The number of rooting observations per habitat type (walking transects).

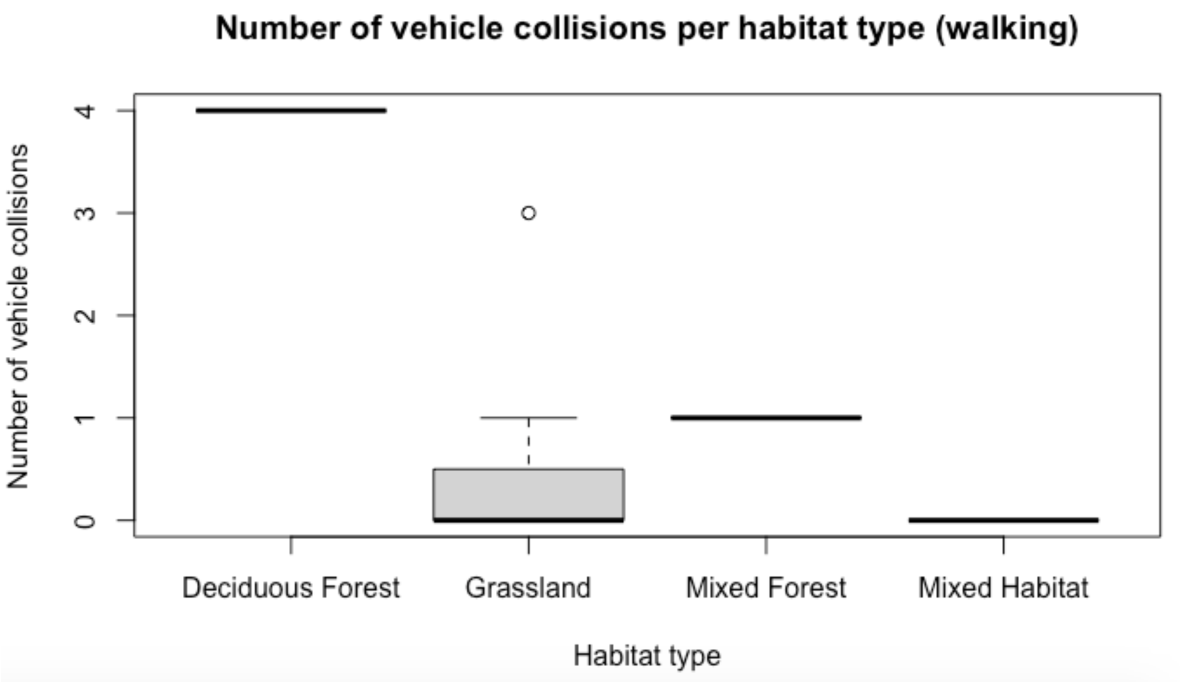

Figure 22: The number of vehicle collisions per habitat type (walking transects).

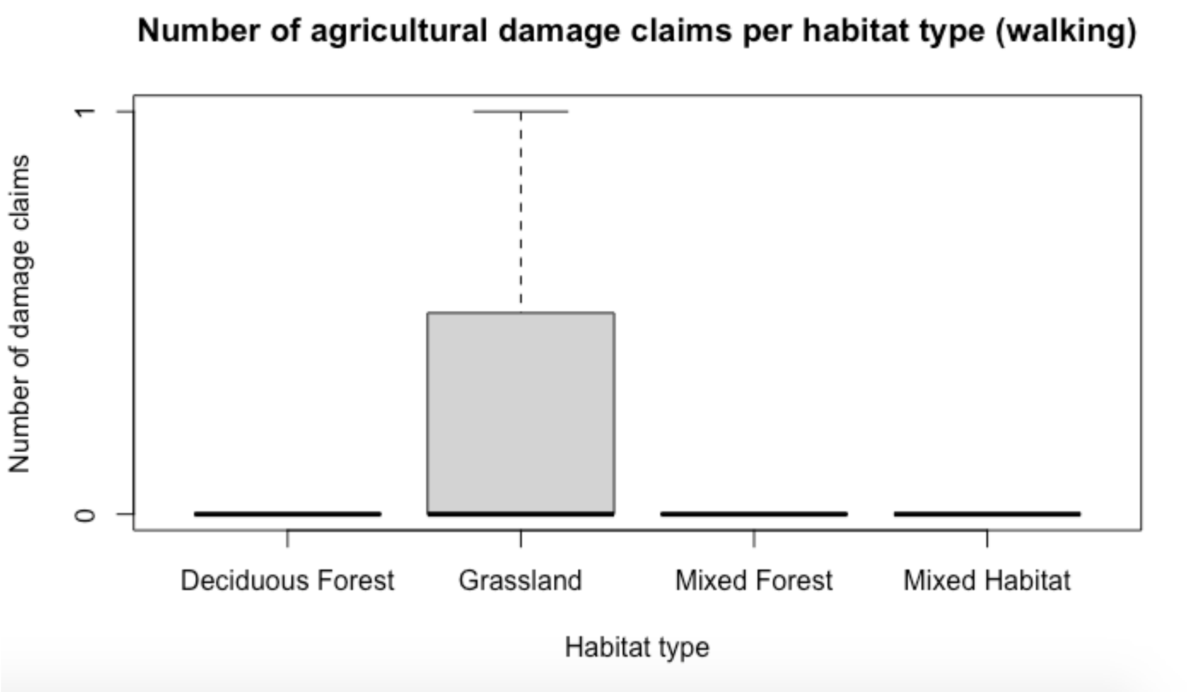

Figure 23: The number of agricultural damage claims per habitat type (walking transects).

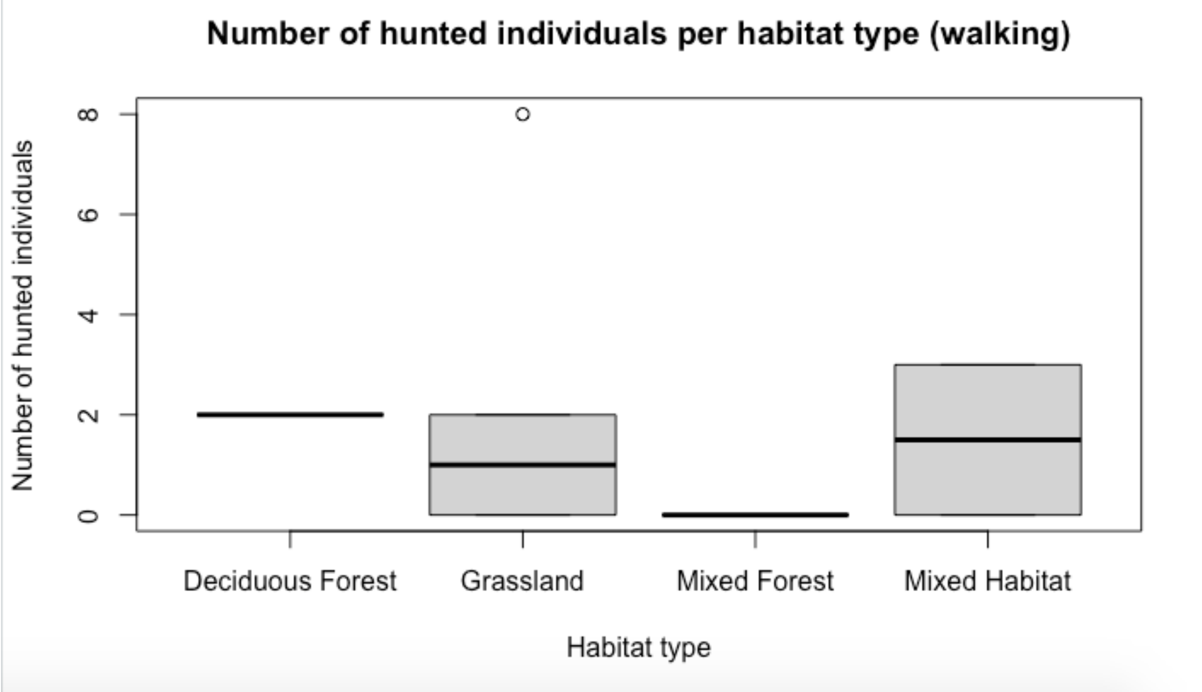

Figure 24: The number of hunted individuals per habitat type (walking transects).

Figures 17-24 show the relationships between ecosystem services, disservices and habitat type. Both MANOVA were not statistically significant. Therefore, habitat type does not have a significant influence on the presence of rooting observations, damage claims and hunted individuals.

3. Density of rooting based on habitat type

I performed a two-way ANOVA where rooting on both transect types was analysed as the dependent variable and habitat type and transect type were independent variables. This tested for the relationship between rooting and habitat type, rooting and transect type and habitat type by transect type.

```
> summary(Rooting_habitat_both.aov)
                                  Df Sum Sq Mean Sq F value  Pr(>F)   
Habitattype_bothF                  6  160.4   26.73   3.330 0.00601 **
Transecttype_both                  1   57.4   57.40   7.152 0.00929 **
Habitattype_bothF:Transecttype_both  3   71.7   23.91   2.980 0.03710 * 
Residuals                         71  569.8    8.03                   
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

All three parameters were statistically significant. This means that when combining the rooting percentages for both transect types, habitat type does have an effect on the presence of rooting but the effect of habitat depends on transect type. In other words, the variation in amount of rooting between habitat types was different for the bike transects than for the walking transects. Therefore, the transect types should be analysed separately.

To test for differences between transect type methodology, the rooting percentages were analysed per transect type.

```
	Spearman's rank correlation rho

data:  Rooting_biketransect and Rooting_walkingtransect
S = 1951.1, p-value = 0.01244
alternative hypothesis: true rho is not equal to 0
sample estimates:
      rho 
0.4660243 
```

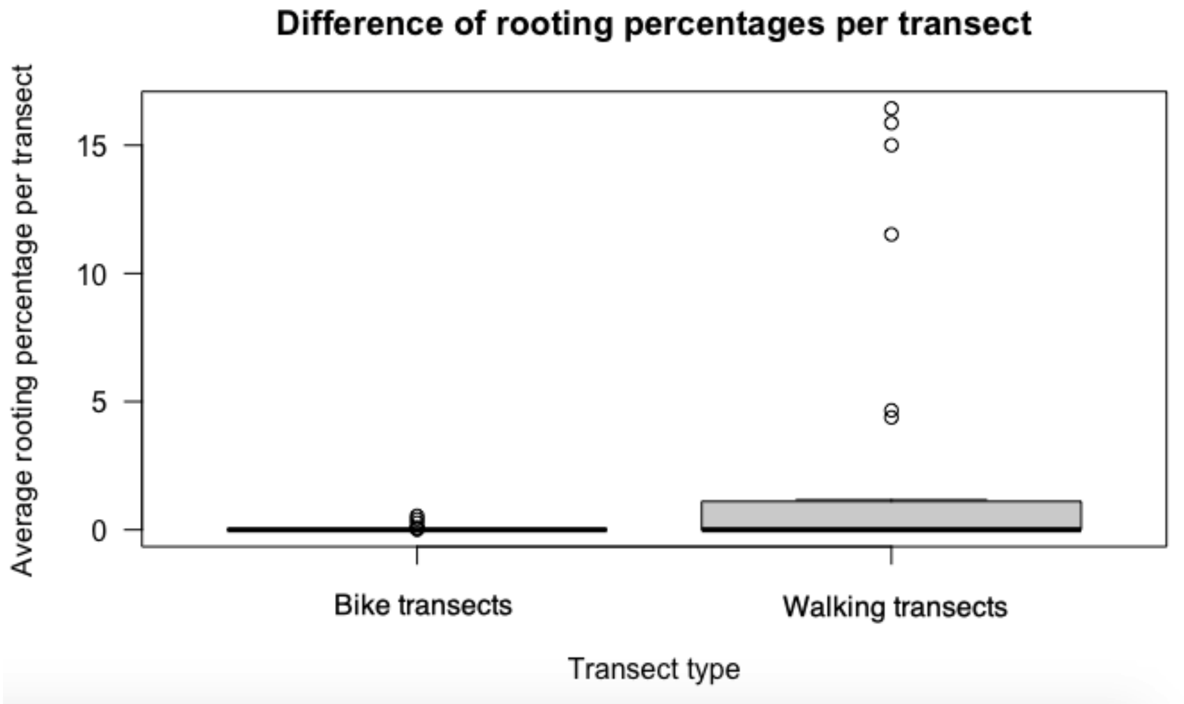

Figure 25: The difference of rooting percentages per transect type.

Figure 25 shows the differences in rooting percentages per transect type, with bike transects on the left and walking transects on the right. The test came out as statistically significant, with a positive rho value. Thus, it can be concluded that the percentages of rooting per transect for the walking transects are significantly higher than for the bike transects.

Analysing the transect types separately:

```
> summary(Rooting_habitat_bike.aov)
                  Df Sum Sq  Mean Sq F value Pr(>F)
Habitattype_bikeF  4 0.0085 0.002121   0.208  0.933
Residuals         49 0.4989 0.010183
```

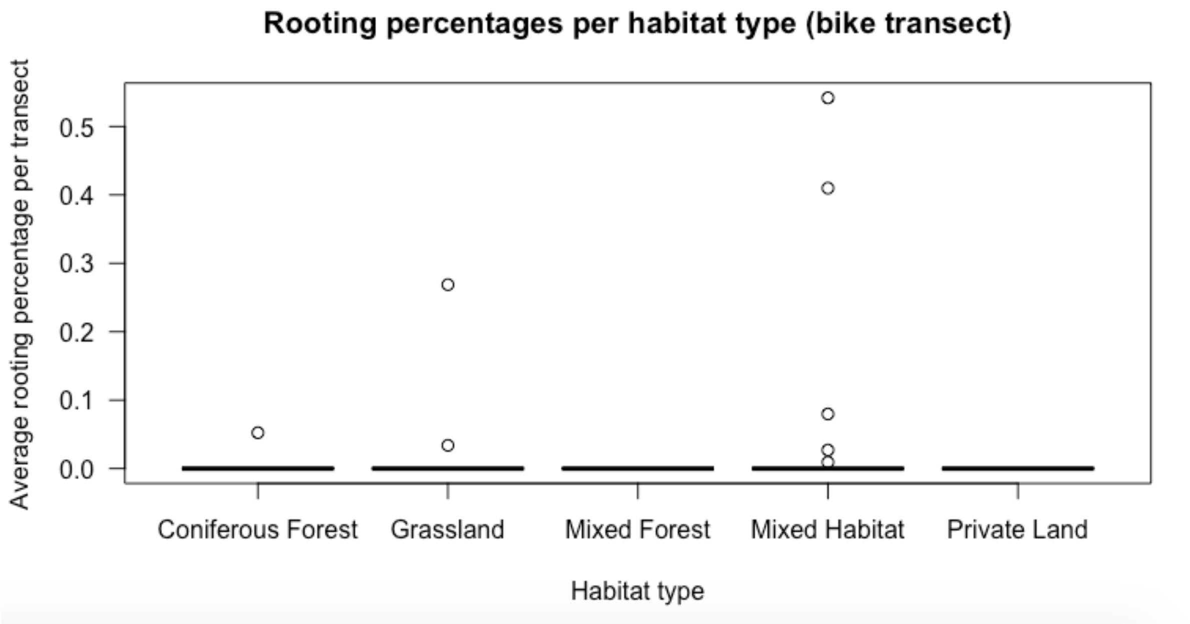

Figure 26: The percentages of rooting per habitat type (bike transects).

```
> summary(Rooting_habitat_walking.aov)
                   Df Sum Sq Mean Sq F value Pr(>F)
Habitattype_walkingF  5  169.8   33.96   1.312  0.295
Residuals          22  569.3   25.88
```

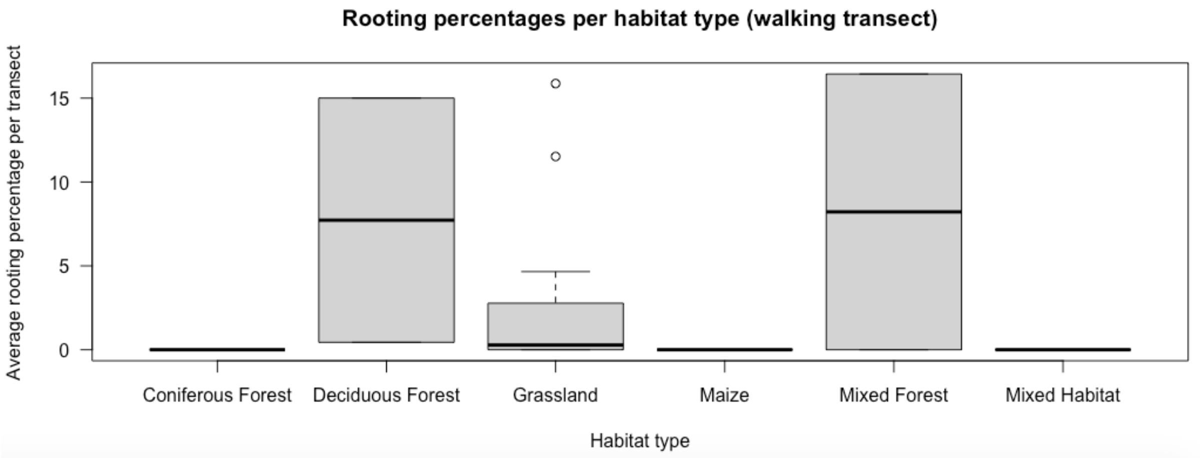

Figure 27: The percentages of rooting per habitat type (walking transects).

Figures 26 and 27 show the average percentages of rooting per habitat type. Both tests came out as non-significant. Thus, it cannot be concluded that habitat type has an influence on the rooting percentage per transect. What can be seen when looking at the data, is that for the bike transects most transects with rooting are found in a mixed habitat (score 7) and for the walking transects most transects with rooting are found in a grassland habitat (score 2). This can also be seen when comparing the rooting map with the natural habitat and land use maps.

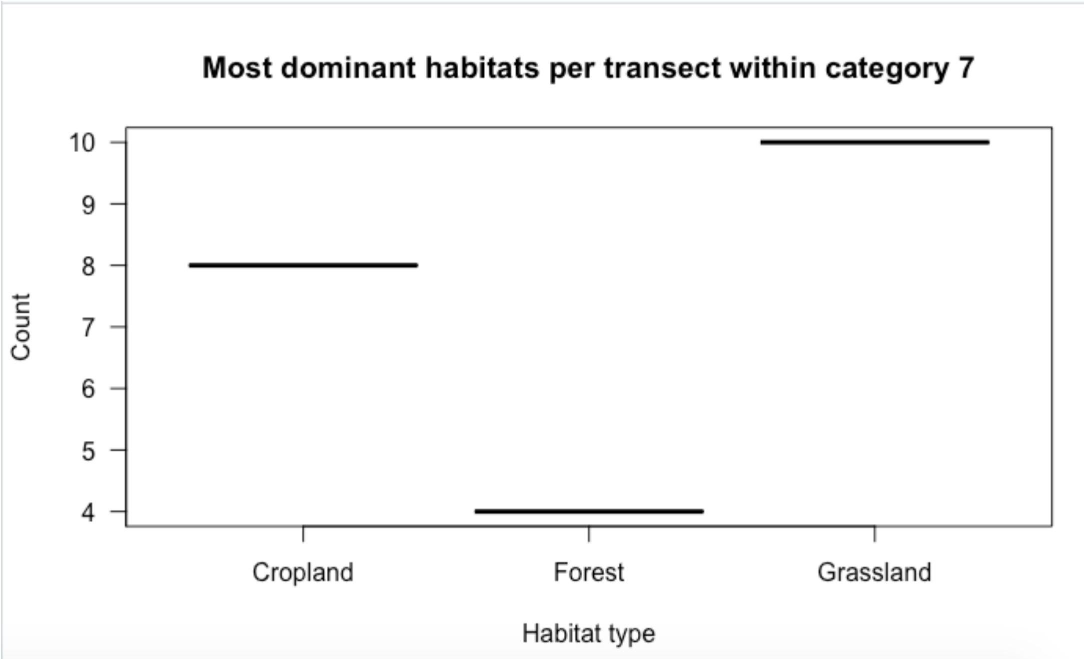

Figure 28: The most dominant habitat per transect within the category 7 “mixed habitat” (bike transects).

Figure 28 shows the most dominant habitats within the habitat type “mixed habitat”, which only occurred on the bike transects. On the bike transects, most rooting occurred on transects with the category 7 “Mixed Habitat”. Analysis shows that within category 7, grassland habitat is most dominant.

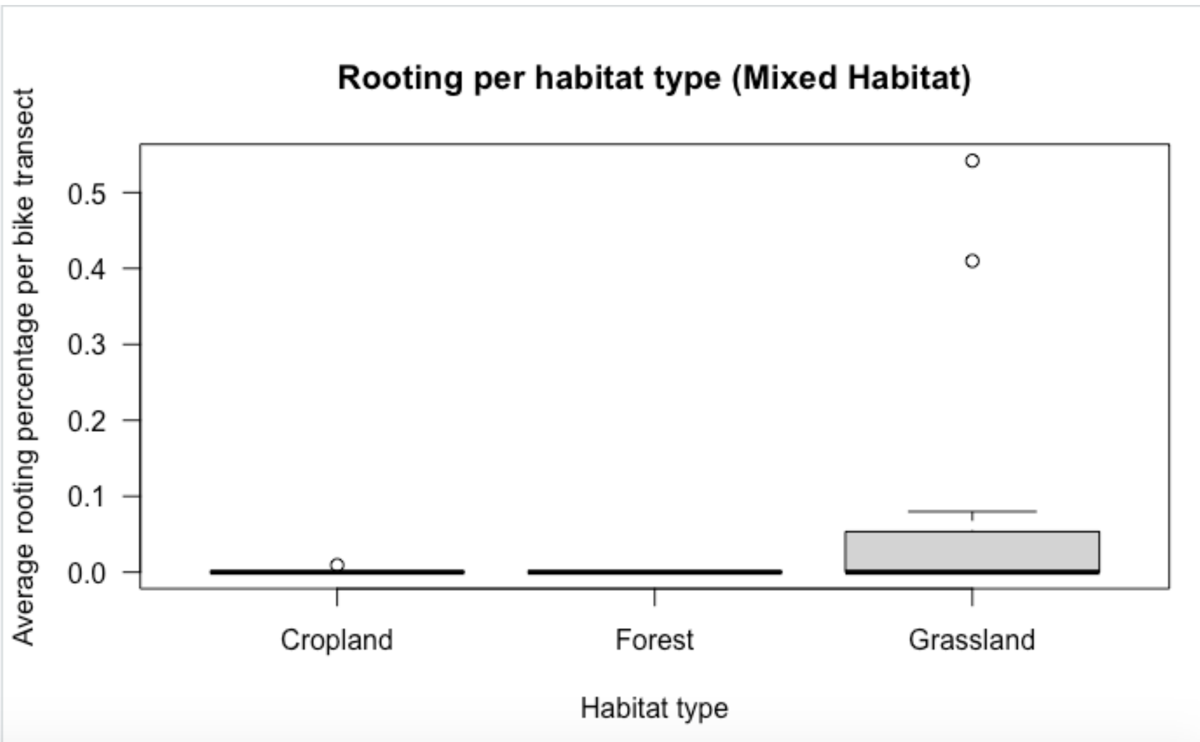

Figure 29: The rooting percentages per habitat type within the “mixed habitat” (bike transects).

Figure 29 shows the rooting percentages per habitat type, within the category “mixed habitat”. This matches the outcome of the walking transects, where rooting was mostly found in grassland habitats.

4. Occurrence of vehicle collisions based on habitat type

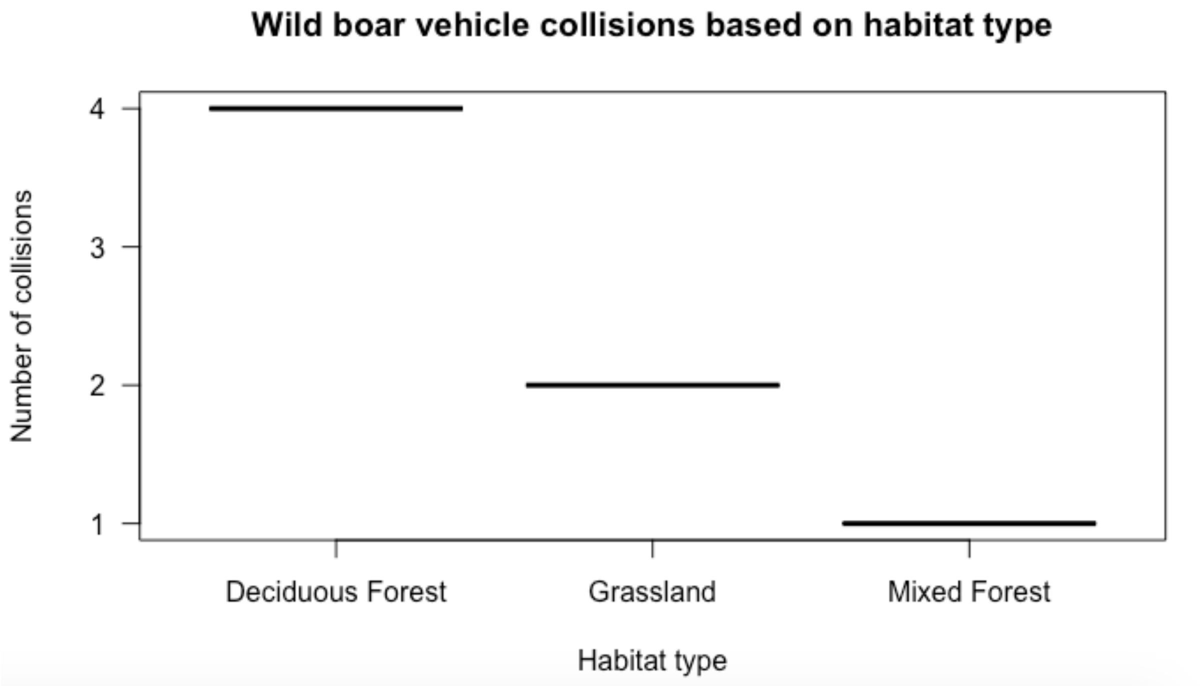

Figure 30: The number of wild boar-vehicle collisions per habitat type.

Figure 30 shows the number of wild boar-vehicle collisions per habitat type. Due to the limited amount of data, it was not possible to conduct a statistical analysis. Four out of seven vehicle collisions occurred in habitat type 4 “deciduous forest”. This can be seen in the plot.

5. Time of day of vehicle collisions

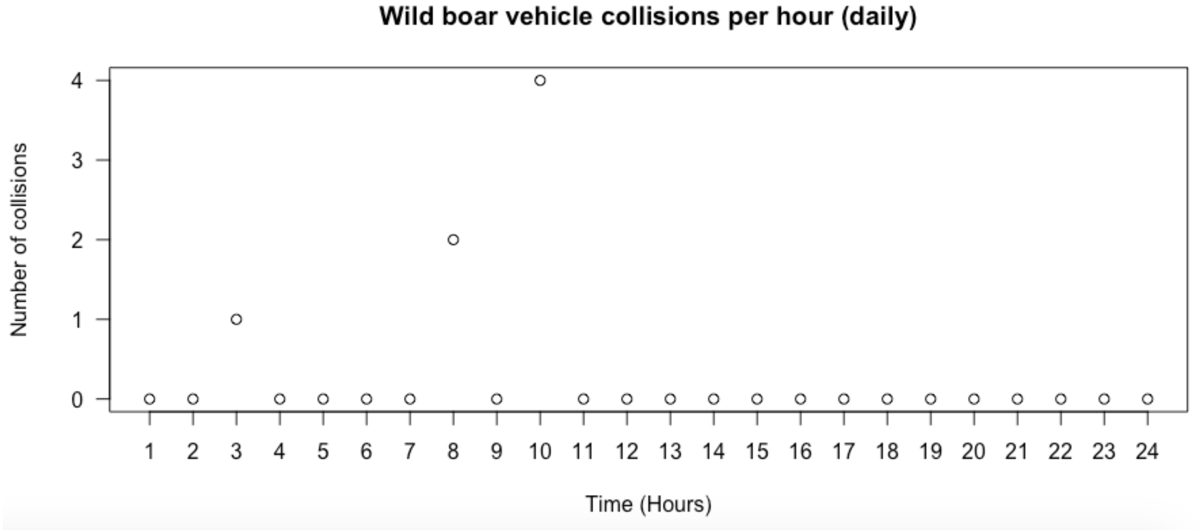

Figure 31: The number of wild boar-vehicle collisions based on the time of occurrence.

Figure 31 shows the number of wild boar-vehicle collisions per time of occurrence. It was not possible to perform a statistical analysis due to the limited data available, as only 7 collisions occurred within the study area in the period 2014-2021. All vehicle collisions occurred during the night or (early) morning, with most collisions occurring at 10:00.

6. Seasonality of vehicle collisions

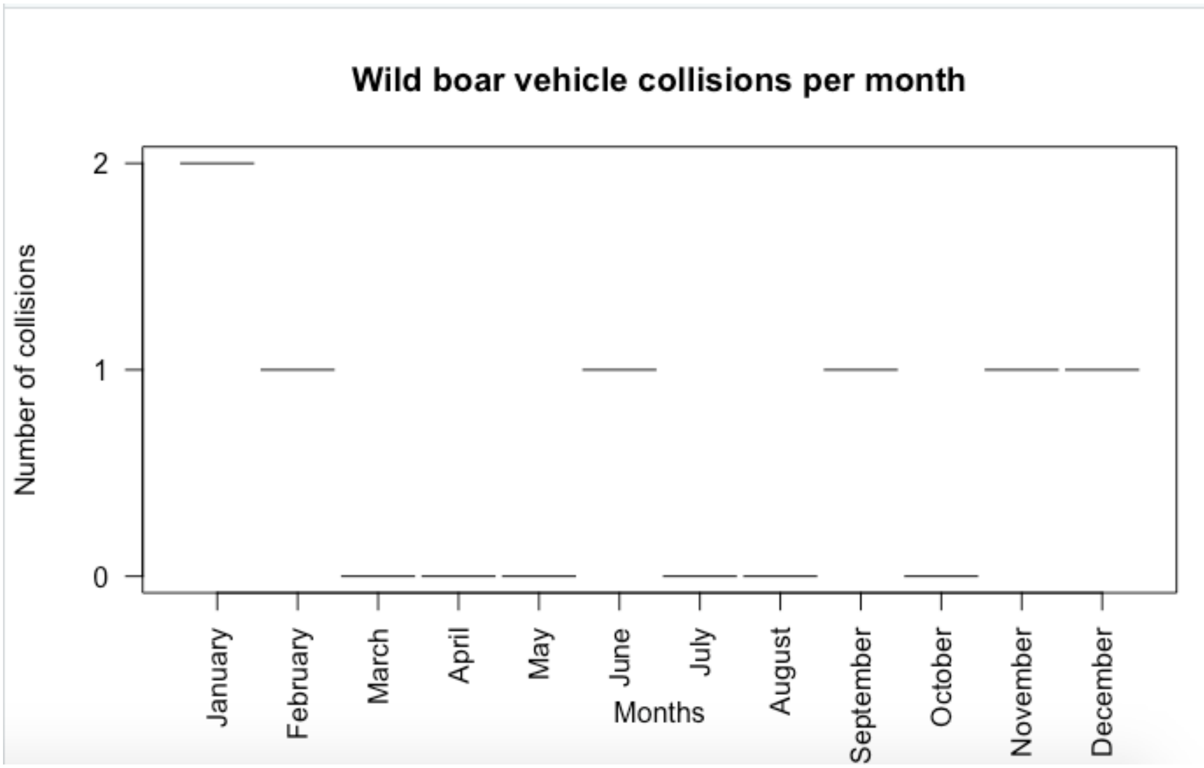

Figure 32: The number of wild boar-vehicle collisions per month.

Figure 32 shows the number of wild boar-vehicle collisions per month. Most vehicle collisions occurred in the autumn and winter months, but the number of collisions was too low to conduct a statistical analysis.

7. Distance of rooting from a forest edge

```
> summary(Rooting_forestedge.aov)
                Df Sum Sq Mean Sq F value Pr(>F)
Distance_rooting  1   9723    9723   11.99 0.0258 *
Residuals         4   3244     811
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

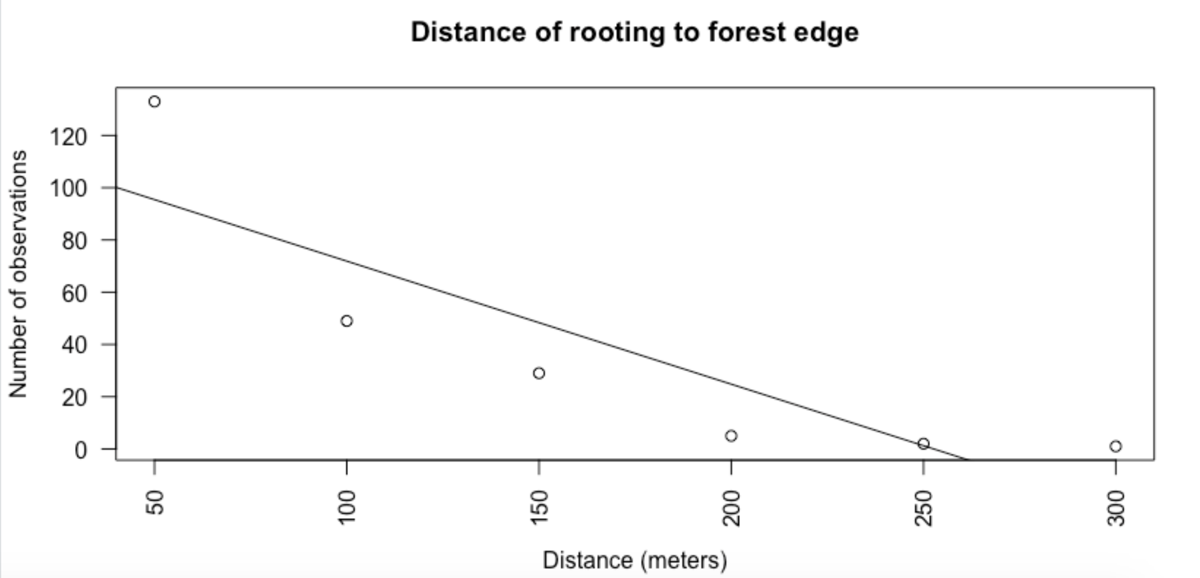

Figure 33: The number of rooting observations per distance from a forest edge.

Figure 33 shows the number of rooting observations per distance from a forest edge. The results for the test were statistically significant. Thus, it can be concluded that the forest edge effect is significant for the occurrence of rooting: there are more occurrences of rooting near a forest edge than away from a forest edge.

8. Distance of agricultural damage claims from a forest edge

```
> summary(Damageclaims_forestedge.aov)
               Df Sum Sq Mean Sq F value Pr(>F)
Distance_damage  1  12.89  12.893   2.483  0.176
Residuals        5  25.96   5.193
```

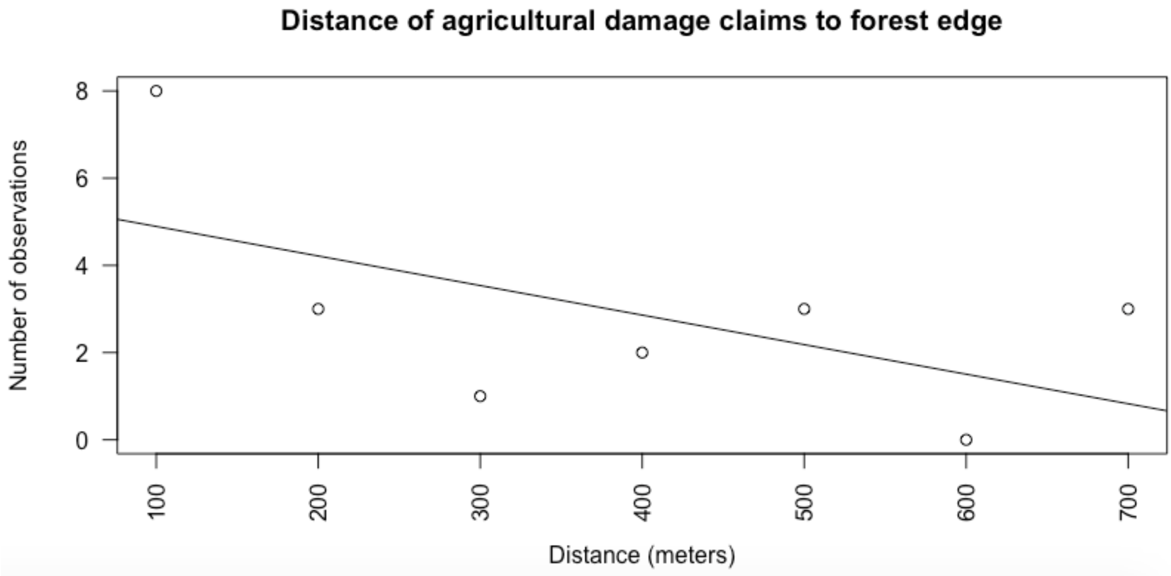

Figure 34: The number of agricultural damage claims per distance from a forest edge.

Figure 34 shows the number of agricultural damage claims per distance from a forest edge. The results of the test were not statistically significant. Thus, it can be concluded that the forest edge effect is not significant for the damage claims. However, the regression line does show that damage claims are higher near a forest edge, but this is merely descriptive.

6. Discussion

Although most of the statistical tests conducted during this research were not statistically significant, three tests did come back significant. One clear result is that habitat type had a different effect on the bike transects than on the walking transects. This means that when analysing the effect of habitat type on rooting, the bike transects and walking transects were analysed separately and should not be combined. Furthermore, another clear result was the effect of the 'forest edge effect' on rooting. This means that rooting was more frequent near a forest edge than further away from a forest edge. Lastly, rooting occurrence was significantly higher on the walking transects than on the bike transects.

Other results were not statistically significant and can therefore only be discussed in a descriptive manner. One result is that rooting was most often found in grassland areas, mostly in natural habitats. No rooting was found in agricultural areas. The most common habitats found within the study area were forest, grassland and croplands such as maize. Furthermore, most vehicle collisions occurred near the Belgian border on the Bocholterweg. However, the number of occurred collisions was too low to effectively analyse.

6.1 Interpretation of results per sub-question

To provide guidance, the results are discussed per sub-question. The main research question of this research was: *How does restoration of the natural habitat through rewilding affect the spatial distribution and extent of ecosystem services (rooting in natural habitat) and disservices (rooting in agricultural areas and wildlife-vehicle collisions) caused by the wild boar in Border Park Kempen~Broek?*

1. What are the different conservation and agricultural land use types within Border Park Kempen~Broek?

For the natural areas it was found that there were clear forest areas, mostly coniferous forest and mixed forest. Between the forest areas, there were areas of grassland which connect the forest areas. There were also some areas of heathland. For agricultural areas, the most occurring land use type was grassland. Maize was also a widely grown crop within the study area. Natural and agricultural grassland overlap in certain areas. This may be due to the fact that the focus of the area has shifted overtime, where agricultural areas are slowly developing into natural areas (GrensPark Kempen~Broek, 2013).

2. What is the spatial distribution of rooting locations and how is it linked to the different conservation and agricultural land use types?

The hypothesis was that rooting would be present in grassland or heathland areas, and in cropland areas, specifically in the vicinity of maize fields. Rooting was indeed found in grassland areas, however not in heathland areas. Rooting in cropland areas was based on the agricultural damage claims. All damage claims were found in agricultural grasslands. There was no relationship found between maize fields and the presence of rooting. The clearest relationship was found between the occurrence of rooting and the presence of grasslands. Most rooting as well as most damage claims were found in grassland areas. However, it is important to take into account that habitat types had varying numbers of transects in them, with some habitat types having even only one transect. Therefore, the results of the ANOVA should be interpreted with much caution. It cannot be concluded for certain what the effect of habitat was on rooting, since the tests were not statistically significant and transect sample sizes varied among habitat types. Therefore, the results could only be analysed in a descriptive manner.

The highest occurrence of rooting was found at the southern part of the study area, near the Belgian border. It can be seen that rooting was very dense in areas near the Bocholterweg. When comparing the rooting map to the natural habitat and land use map, it could be seen that most rooting occurs in grassland areas. When analysing the bike transects and walking transect separately, the result was not statistically significant and therefore habitat did not have a clear effect on the occurrence of rooting. However, from the plots it could be seen that rooting tended to occur most in habitat types 2 (grassland) and 7 (mixed habitat). Mixed habitat occurred mostly on bike transects, since these were much longer than the walking transects. Therefore, the probability of a bike transect crossing multiple habitat types was higher than for a walking transect. After analysing the occurrence of rooting per habitat type per transect within the mixed habitat type, it was concluded that grassland had the highest percentage of rooting. This outcome matches the existing literature. Leaper et al., (1999) have concluded that wild boar prefer open habitats such as grasslands for rooting. Morelle et al., (2015) concluded that wild boar prefer grassland rooting and tend to remember suitable rooting spots in the vicinity of resting spots. This implies that wild boar have a tendency to return to the same spots for rooting if previous food searches in that area have been successful. This could explain why the rooting maps in this research showed such a concentrated area of rooting, especially in the grasslands near the Belgian border.

The results from the fieldwork showed that no rooting was found in agricultural areas. This could be a consequence of the timing of the research. The fieldwork was conducted in the spring, the period in which farmers have already ploughed their fields. This may have caused rooting damage to disappear from the cropland, as it has been restored by the farmer. Conducting the fieldwork in, for example, the winter period before the fields are ploughed may bring about different results. Furthermore, cropland is mostly privately owned land and therefore I was not able to conduct research within the croplands. This may have caused me to miss certain rooting spots, as it was not possible to enter the fields and analyse them closely.

For the bike transects most transects with rooting were found in a mixed habitat (score 7) and for the walking transects most transects with rooting were found in a grassland habitat (score 2). This may be due to the fact that bike transects were much longer, and thus the probability of crossing multiple habitats on one transects was higher than with the walking transect. The walking transects were much shorter and thus the probability of crossing multiple habitats was much lower.

Analysing the methodology: bike transects versus walking transects

When analysing the difference between rooting on a bike transect and a walking transect, the result was statistically significant. This means that the rooting percentages on a walking transect were significantly higher than on a bike transect. This may be due to the fact that walking transects were studied at a slower speed than the bike transects, and thus rooting could be noticed better on a walking transect. Furthermore, walking transects were not set out on roads or bike paths and thus the probability of finding rooting was higher. A road might scare an animal away from it, and thus the probability of rooting to occur next to a road could have been lower. Walking transects were also set out more in natural habitats. Therefore, the probability of rooting to occur may be higher since natural habitats are better suitable for an animal to find food, however wild boar may also very often root next to paths. Additionally, it is important to notice that the y-axes of average rooting percentages on the bike transects were much lower than on a walking transect. This is most likely due to the high number of 0's on the bike transect, causing the average rooting percentages per transect to be very low. Additionally, it is important to notice that the y-axes of average rooting percentages on the bike transects are much lower than on a walking transect. This is most likely due to the high number of 0's on the bike transect, causing the average rooting percentages per transect to be very low.

3. What is the spatial and temporal distribution of wild boar vehicle collisions and how is it linked to the different conservation and agricultural land use types?

The hypothesis was that vehicle collisions would increase with wild boar rooting density and during the winter months and dark nights. There was no significant relationship found between rooting and vehicle collisions. Therefore, it cannot be concluded that a higher rooting density led to a higher probability of collisions, although the test did show a positive relationship. However, the number of vehicle collisions that have occurred in the study area was too low to effectively analyse the outcome of this. Therefore, this test is not reliable and clear conclusions cannot be drawn from it.

Within the study area, there were a total of 7 vehicle collisions in the period 2014-2021. 4 out of those 7 occurred at the same location on the Bocholterweg. All accidents occurred either at night or in the morning and most of them occurred in the autumn or winter months, which matches the hypothesis. Although the data in this research were not suitable for statistical analysis, there is a clear pattern visible in the results. Most vehicle collisions occurred near deciduous forests. There was no relationship found between habitat type and the occurrence of vehicle collisions due to lack of data.

The pattern that all collisions occurred in the night or early morning and that most collisions occurred in the autumn or winter months matches the existing literature. Rodríguez-Morales et al., (2013) concluded that almost all wild boar-vehicle collisions occurred during the night. This is also the period during which visibility for both the driver and the animal are lowest. Rodríguez-Morales et al., (2013) also concluded that most collisions occurred during the autumn and winter months of October, November, December and January. This matches with the data of this research, since 5 out of total 7 collisions occurred in November, December, January and February.

4. Can the distribution of agricultural areas (e.g., certain crop types like maize) and conservation habitats (e.g., grassland or deciduous forest) explain the spatial clustering patterns of services and disservices?

Although none of the analyses were statistically significant, the plots for spatial clustering between rooting, vehicle collisions, agricultural damage claims and hunted individuals did show that almost all variables had a positive relationship. However, this effect is merely a descriptive relationship and could not be supported with statistical evidence. The only negative relationship was found on the bike transects between rooting and the agricultural damage claims. This implies that there was no clear clustering between rooting and damage claims when analysing the bike transects. However, this result is also merely descriptive since no relationship resulted in a statistically significant outcome. Amici et al., (2012) concluded that damage in crop fields was higher with a higher abundance of wild boar. However, when assuming wild boar rooting as a proxy for wild boar abundance, there is no clear relationship that agricultural damage increases with rooting. This is most likely because other landscape factors also influence wild boar behaviour. For example, certain barriers like roads, streams or fences can prohibit a wild boar from reaching a crop field. Therefore, the extent of wild boar damage in crop fields are dependent on more factors than just wild boar abundance. Schley & Roper (2003), Herrero et al., (2006) and Schley et al., (2008) all concluded that damage in agricultural areas was highest in maize fields. The results of this research cannot support this statement since all agricultural damage claims were reported in grasslands and none in maize fields. What is interesting is that there is no clear clustering of services and disservices in the study area. This may be due to the fact that natural areas are clearly separated from agricultural areas, which can be seen by looking at the land use map. This separation could be the reason that ecosystem services and disservices are not spatially coupled: rooting in natural habitat (ecosystem service) occurred in a different part of the study area than the damage claims, vehicle collisions and hunted individuals.

When analysing the effect of habitat type on spatial clustering, the result was also not statistically significant. Although, from the plots it can be seen that all variables were present in habitat type 2, grassland. This may be due to the fact that grassland was widely present throughout the study area, and thus the probability of a variable to occur in grassland was rather high, and that wild boar have a preference for grasslands (Leaper et al., 1999). However, the boxplots show that several habitat types most likely only had one transect in them. This can be seen in the box plots where habitat types only showed a line in the plot. This means that the sample size and the resulting variance was highly unequal between groups. Therefore, the method of using a MANOVA analysis may not be a suitable method to conduct this analysis.

5. How do smaller-scale landscape characteristics (e.g., forest edges) influence the distribution of services and disservices?

When analysing the distance of rooting from a forest edge, the result was statistically significant. This means that there is a clear relationship between rooting and forest edges: rooting is highest near a forest edge and decreases with distance away from a forest edge. When looking at the plot, it can be seen that the relationship even resembles an exponential relationship. Lombardini et al., (2017) concluded that permanent landscapes, such as grasslands, have a higher probability for rooting to occur, most likely in combination with an absence of urban areas and a smaller distance from sheltered areas. The statistical analysis and maps support this conclusion, since rooting occurred mostly in natural areas, away from urban areas, and close to a forest edge. Furthermore, Morelle et al., (2015) concluded that grassland rooting occurs in the vicinity of resting spots. Since wild boar tend to search for cover in for example forest areas, rooting near forest areas occurs frequently.

When analysing the distance of agricultural damage claims from a forest edge, the result was not statistically significant. However, when looking at the plot it can be seen that there is a somewhat negative relationship between the two variables. The trendline showed that the damage claims decrease with distance away from a forest edge. This matches the hypothesis that the fields most affected by rooting are closest to a forest edge. Although the result is merely a descriptive relationship, it matches the conclusion made by Thurfjell et al. (2009) who suggested that in agricultural fields with a smaller distance relative to escape cover, wild boar foraging behaviour was more frequent.

6.2 Critical analysis of the research as a whole

Although this research was aimed to be as correct as possible, there are some points to reconsider. One is that the fieldwork period of this research took place in the months of April and May. This may lead to biases or inconsistencies in the presence of rooting caused by wild boar. It is possible that if the fieldwork research was carried out in a different period of the year, results would vary. Bratton et al., (1982) studied temporal patterns of wild boar rooting and concluded that rooting was less intensive during the spring and early summer. Therefore, carrying out the same method of fieldwork in another period of the year, for example in the winter when rooting was more intense (Bratton et al., 1982), may cause the presence and density of rooting to be more intense. Furthermore, it is important to take the observer bias into account. As there was only one observer within this research it does not directly cause a bias, however if another observer carries out the same methodology it may bring about inconsistencies. Additionally, due to time constraints there was a set maximum to the amount of transect that could be set out. Consequently, there could be areas of rooting that were not covered by the transects because they only cover certain parts of the study area.

The study area in this research encompasses both natural habitats as well as agricultural areas. Although the research aimed at mapping the presence of rooting in both landscapes, there are some biases caused by the different types of land use management. For example, in natural areas it was possible to observe and map both older rooting spots as well as more recent rooting spots. In agricultural areas, cropland gets ploughed and managed every year, causing rooting to no longer be visible. Farmers also aim at keeping animals out of their fields. Thus, the probability of a wild boar rooting in cropland was much lower than the probability of rooting in natural habitats. Furthermore, croplands are generally private land not open to the public. Therefore, mapping the occurrence of rooting in cropland was not possible based on the method of observation. To substitute this, the agricultural damage claims of rooting damage caused by wild boar was included in this research. However, this may also bring inconsistencies since it is only reported in cropland and it may be the case that not every event of damage is reported.

Rooting of wild boar is merely an indication of where they find their food, since rooting is a method of searching for food. Therefore, wild boar may be present in areas other than the areas where rooting was present. This is also noticeable when looking at the locations at which individuals were hunted, which occurred in areas where no rooting was found. Another aspect that may explain the difference between the spatial distribution of rooting and hunted individuals is the resting zones within the area. Hunting is not allowed in resting zones, and rooting is most likely present within these zones. However, there is no clear map of where these resting zones are located. It can be assumed that these resting zones are placed in natural habitats, and thus the presence of rooting is an ecosystem service within these resting areas.

Wild boar-vehicle collisions were analysed as a disservice as a result of the presence of wild boar. However, vehicle collisions are dependent on more than just the presence of wild boar. Variables like road density, busyness, time of day, seasonality and barriers influence the probability of collisions to occur. This research assumed a spatial clustering of variables, where the presence of wild boar increases the probability of collision. However, it is crucial to also take other variables into account to conclude the full relationship between wild boar and vehicle collisions. Although it was not possible to effectively analyse the vehicle collisions within this research due to a very low sample size. Therefore, conclusions regarding this part of the research should be analysed with care as there is no clear statistical evidence to support any of the results.

Lastly, figure 14 shows that there were agricultural damage claims that occurred in deciduous forest. Although, when looking at figure 5 and figure 10, it shows that damage claims occurred solely in grassland. This misalignment is due to the methodology that appointed one dominant habitat type per transect. Therefore, damage claims occurred in buffers from transects that had deciduous forest as the dominant habitat type. However, the use of buffers around transects was necessary to compare the ecosystem services and disservices on and around a transect.

6.3 Possibilities for future research

Although this research was aimed to be as complete as possible, further research is necessary to fully understand the effects of wild boar within Border Park Kempen~Broek as well as the interactions between ecosystem services and disservices brought about by the wild boar. Firstly, new research could build upon this research by studying more transects in the study area to get an even better representation of the locations and densities of wild boar rooting. Additionally, the same methodology could be carried out in other areas in Kempen~Broek, including the Belgian part of the park, or other existing natural areas with similar characteristics to Kempen~Broek. Furthermore, to get a better understanding of the ecosystem services brought about by the wild boar, the effect of rooting on the natural habitat should be researched. Although this research conducted a literature review on the ecosystem services of the wild boar, the effects of wild boar rooting on natural areas were not directly studied. This is an important aspect of research for nature conservation, as wild boar can have a significant effect on vegetation development within the ecosystem. Research should also be conducted on the effect of wild boar behaviour on other animal species, as well as the interactions between species to understand the relationship of wild boar to neighbouring species. Lastly, Border Park Kempen~Broek has developed resting zones for wild boar, in which the animals cannot be hunted. After attempting to find a map of these resting zones, it became clear that a map had not yet been developed. To study the patterns of wild boar behaviour, in combination with hunting strategies, it is important to develop a clear overview of where these resting zones are located and what the effects are of the presence of these zones.

7. Conclusions

The aim of this research was to map the ecosystem services (rooting in natural habitat) and disservices (rooting in agricultural areas, wildlife-vehicle collisions and official damage reports) caused by the wild boar and investigate how these services and disservices were associated with natural and agricultural habitats. It also looked into how these services and disservices were spatially linked. The main research question was:

How does restoration of the natural habitat through rewilding affect the spatial distribution and extent of ecosystem services (rooting in natural habitat) and disservices (rooting in agricultural areas, wildlife-vehicle collisions and official damage reports) caused by the wild boar in Border Park Kempen~Broek?

The results show that there was no clustering of ecosystem services and disservices in the study area of this research. There was also no relationship found between services, disservices and habitat type. This may be due the clear separation between natural habitat and agricultural habitat, as well as the created 'resting zones' for the wild boar. The only clear relationship that was found was between observed rooting in natural habitat and forest edges, referred to as the forest edge effect. From this it can be concluded that rooting in natural habitat occurred more near a forest edge than away from a forest edge, which matched the existing literature. Therefore, it is more likely that open habitats near a forest edge will be rooted. This can be useful in the development of agricultural areas into natural areas, since rooting can break open grasslands and can contribute to the development of pioneer plant species. This result could also be applied to other natural areas, with similar characteristics to Kempen~Broek, where the shift towards a more natural habitat still needs to occur.

Although this research could not conclude the presence of spatial clustering of ecosystem services and disservices, the maps still showed that services and disservices occurred throughout the study area. It is crucial that ecosystem services are promoted and the ecosystem disservices are mitigated. Creating an environment where disservices are minimized as much as possible allows for the further development of ecosystem services and the habitat as a whole. The wildlife warning system located at the Bocholterweg is a prime example of this. Renewing this system in such a way that it functions effectively minimizes the disservices of wild boar-vehicle collisions and creates a safer environment for wildlife as well as the road users. In combination with the further development of natural habitats, this creates an environment for wildlife species and vegetation to flourish.

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