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The Effects of Human Disturbance on Ungulates on Multiuse Overpasses

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Abstract

The expanding road network and increasing traffic volumes impose a barrier between different wildlife habitats and populations. Wildlife-vehicle collisions are a factor that affects wildlife, human safety, and property. Road Wildlife crossing structures, such as overpasses and underpasses, are built to enable landscape connectivity, improve traffic safety, and mitigate the impact roads have on wildlife. Crossings structures include structures that are built only for wildlife use or for the use of both wildlife and humans. The latter are called multiuse overpasses.

Building large structures, like crossing structures, is expensive, therefore it is more cost-effective to build crossing structures suitable for both wildlife and humans. Human disturbance can influence the effectivity of crossing structures. Information about how human disturbance affects wildlife is needed to study the effectiveness of multiuse overpasses. In this thesis I evaluated the effects human disturbance have on ungulate multiuse overpass use. Using camera trap data from 9 multiuse overpasses located in southern Finland, I studied the effect of different human disturbances (non-motorized, motorized) on different ungulate species, and possible spatiotemporal avoidance.

The overpasses were located on highway 1 between Helsinki and Turku, on highway 7 between Loviisa and Vironlahti, and on highway 4 in Heinola. All overpasses had a landscaped side with vegetation and a gravel or dirt road. The camera traps were located in the middle of the overpass, approximately one meter above ground level. I considered one camera trap picture to be one individual crossing event, regardless of the number of animals in the picture.

During the monitoring period from December 2019 to May 2020, and November 2020, I detected 730 ungulate crossings, made by moose (*Alces alces*), white-tailed deer (*Odocoileus virginianus*), and roe deer (*Capreolus capreolus*). There were 4 707 crossings made by humans hiking, dog walking, cycling, driving a car, a motorbike, a snowmobile, a tractor, or a truck. While ungulates used the overpasses most active during the early evening, human activity peaked during the day. The results show that the time between non-motorized disturbance and an ungulate crossing was longer than the time between motorized disturbance and an ungulate crossing. The presence of spatiotemporal avoidance was evaluated by comparing time differences between crossing type pairs. I studied the possible spatiotemporal avoidance by calculating time differences between an ungulate crossing after an ungulate, and an ungulate crossing after a human. The reaction to human disturbance differed between the species, with only moose showing signs of spatiotemporal avoidance when comparing times between a moose crossing after a moose and a moose crossing after a human. Roe deer and white-tailed deer did not show signs of spatiotemporal avoidance.

An explanation for the results regarding spatiotemporal avoidance, can be linked to the differences in ungulates natural habitats when comparing moose, roe deer and white-tailed deer. Moose´s preferred habitat is large, forested areas, whereas roe deer and white-tailed deer occupy farmland, suburban areas, and areas in proximity to humans. The natural habitat of moose in itself results in minimal contact with humans.

The results of this thesis show that multiuse overpasses are to some extent successful, in working as a crossing structure for both ungulates and humans. The results regarding avoidance from moose, indicate that the effects of human-caused disturbance need to be considered with severity. Therefore, we cannot cling to the thought that multiuse overpasses would be sufficient for all species in every situation, but we need to be prepared to provide crossing structures for only wildlife use or limit the human use of crossing structures if needed.

Keywords

Wildlife structures, Multiuse overpasses, Ungulates, Human disturbance, Spatiotemporal avoidance

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Laajentuva tieverkosto ja kasvavat liikennemäärät aiheuttavat eläinten elinympäristöjen pirstaloitumista ja lisäävät tiestön estevaikutusta. Onnettomuudet liikenteen ja eläinten välillä ovat merkittäviä tekijöitä liikenneturvallisuudessa. Eläinten liikkumista varten rakennetut kulkureittirakenteet, kuten sillat ja alikulut, auttavat ylläpitämään elinympäristöjen kytkeytyvyyttä, parantavat liikenneturvallisuutta ja vähentävät tiestön vaikutuksia faunaan. Kulkureittirakenteet voivat olla rakenteita, jotka ovat rakennettu vain eläinten kulkua varten tai eläinten ja ihmisten yhteiskäyttöä varten. Eläinten ja ihmisten yhteiskäyttöä varten tarkoitettuja rakenteita kutsutaan vihersilloiksi.

Koska isojen kulkureittirakenteiden rakentaminen on kallista, on kustannustehokkaampaa rakentaa kulkureittejä, joita sekä eläimet, että ihmiset voivat käyttää. Ihmishäiriön epäillään vaikuttavan vihersiltojen tehokkuuteen, joten monikäyttörakenteiden toimivuuden arvioimiseksi on tärkeää saada tietoa siitä, miten ihmistoiminnasta aiheutuva häiriö vaikuttaa eläimiin. Tämän tutkimuksen tavoitteena on tutkia ihmishäiriön vaikutuksia hirvieläinten riistasiltojen käyttöön. Tutkin erilaisten ihmishäiriöiden (ei-moottoroitu, moottoroitu) vaikutuksia eri hirvieläinlajeihin sekä spatiotemporaalisen välttelyn läsnäoloa.

Tutkimuksessa riistakameroilla monitoroidut vihersillat sijaitsivat moottoriteiden varsilla Etelä-Suomessa. Kaksi siltaa sijaitsi Helsingin ja Turun välissä valtatiellä 1, seitsemän sijaitsi Loviisan ja Vironlahden välillä valtatiellä 7 ja yksi vihersilta oli valtatiellä neljä Heinolassa. Vihersillat olivat kaksi osaisia siten, että toinen puoli sillasta oli maisemoitu istutuksin ja toinen puoli oli soratietä. Riistakamerat sijaitsivat keskellä siltaa noin metrin korkeudella maan pinnasta. Kuva tulkittiin aina yhdeksi ylitykseksi riippumatta siitä, kuinka monta eläintä kuvassa oli.

Seurantajakso ajoittui joulukuusta 2019 toukokuuhun 2020 ja marraskuuhun 2020. Seurantajakson aikana riistakameran kuviin jäi 730 hirven (*Alces alces*), valkohäntäpeuran (*Odocoileus virginianus)* ja metsäkauriin (*Capreolus capreolus)* tekemää ylitystä. Ihmisten tekemiä ylityksiä kertyi 4707, ja ne tehtiin kävelijöiden, koiran ulkoilijoiden, pyöräilijöiden, autoilijoiden, moottoripyörien, traktorien, lumikelkkojen, tai kuorma-autojen toimesta. Hirvieläimet olivat aktiivisimmillaan alkuillasta, kun taas ihmisten aktiivisuus oli korkeimmillaan päivän aikana. Tutkimuksen tulokset osoittavat, että aika ei-moottoroidun häiriön ja hirvieläin ylityksen välissä oli pidempi, kuin aika moottoroidun ja hirvieläin ylityksen välissä. Spatiotemporaalisen välttelyn mahdollisuutta tutkittiin vertailemalla eri ylitysparien aikaeroja. Selvitin välttelyn mahdollisuutta laskemalla aikaerot hirvieläimen ylitettyä hirvieläimen jälkeen, ja hirvieläimen ylitettyä ihmisen jälkeen. Spatiotemporaalisen välttelyn kohdalla hirvieläinlajien reaktiot erosivat toisistaan. Hirvi oli lajeista ainoa, jonka kohdalla välttelyä voitiin todeta tapahtuvan. Metsäkauris ja valkohäntäpeura eivät näyttäneet merkkejä välttelystä.

Selityksenä spatiotemporaalisen välttelyn eriäviin tuloksiin voi olla hirvieläinten erilaiset elinympäristöt. Hirven elinympäristö koostuu suurista, metsäisistä alueista, kun taas metsäkauris ja valkohäntäpeura elävät kulttuurimaisemissa sekä ihmisten läheisyydessä.

Tutkimuksen tulokset osoittavat, että yhteiskäyttöön tarkoitetut vihersillat ovat jossain määrin onnistuneet toimimaan kulkureittirakenteena sekä eläimille, että ihmisille. Hirven osalta havaittu välttely kuitenkin osoitti, että ihmisen aiheuttamaan häiriöön tulee suhtautua vakavuudella. Tästä syystä ei pidä asennoitua siihen ajatukseen, että vihersillat olisivat riittävä ratkaisu kaikille lajeille kaikissa tilanteissa. Tarvittaessa on voitava rakentaa ja tarjota kulkureittejä vain eläinten käyttöön, tai ainakin rajoittaa ihmisten liikkumista kulkureiteillä.

Avainsanat
Vihersillat, Hirvieläimet, Ihmishäiriö

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CONTENTS

1. INTRODUCTION

1.1 BACKGROUND AND STUDY AIMS

In the recent modernized times, the road network has expanded, and traffic volumes have increased. Finland´s road network is constructed of over 450 000 kilometres of road, some 50 000 kilometres are paved roads (Finnish Transport Infrastructure Agency, 2018). The expanding road network and ever-increasing traffic volumes have dire effects on animal species. Forman and Alexander (1998) reviewed the major ecological effects of roads and concluded that road networks affect animal species in many different ways. Roads cause a barrier between different living environments and populations. The effects can be due to noise, light, fragmentation, and accidents. The most visible direct effects for humans happen when severe accidents, involving wildlife crossing roads, occur (Olsson, et al., 2008).

Accidents can be prevented, and habitat areas connected by combining exclusion fences with the use of overpasses and underpasses (Clevenger, et al., 2001, Smith, et al., 2015, van der Ree, et al., 2015b, Huijser, et al., 2016). Crossing structures, such as overpasses and underpasses, are built for only human use (Rodrigues, et al., 1996, Bhardwaj, et al., 2020), for wildlife use (Mata, et al., 2005, Caldwell & Klip, 2019), or purposefully for the use of both wildlife and humans (van der Ree & van der Grift, 2015a, van der Grift, et al., 2021). Building crossing structures for both human and wildlife use is more cost-effective than building crossing structures separately for wildlife use and human use. Human disturbance is presumed to affect mainly large predator behaviour, but also ungulate behaviour, and wildlife activity on overpasses (Rodrigues, et al., 1997, Clevenger & Waltho, 2000, Ng, et al., 2004, Grilo, et al., 2008, Stankowich, 2008). Therefore it is important to study and determine the effect human disturbance have on the effectiveness of wildlife crossing structures.

In this study, I aimed to evaluate the effects of human disturbance on ungulates on multiuse overpasses. In the future, the results of this thesis can be used to help implement new strategies for maintaining habitat connectivity and minimizing ungulate-vehicle collisions.
The research questions are:

I. Do ungulates react differently to non-motorized human disturbance than to motorized human disturbance?

II. Is there spatiotemporal avoidance on multiuse overpasses between ungulates and humans?

The hypothesis for the research questions are:

I. Non-motorized human activities disturb ungulates more than motorized human activities.
II. Spatiotemporal avoidance exists between ungulates and humans on multiuse overpasses.

1.2 LITERATURE OVERVIEW

1.2.1 THE IMPACT OF THE ROAD NETWORK

The human population spreads in unhabituated areas with the help of the road network. Building, maintaining, and using roads can lead to habitat loss and lower the quality of an existing habitat (referred by Forman & Alexander, 1998, van der Ree, et al., 2015c). The road area and surrounding changes to vegetation can span from a meter to tens of meters in width, in disturbed habitat. The edge effect caused by a road, and sudden change in the otherwise continuous habitat, can cause changes in the microclimate and thus affect the species composition (Beckmann, et al., 2011). The edge effect can be beneficial for predators and invasive species (Laurance, 2004). A good example of a benefiting species is the little fire ant (*Wasmannia auropunctuta*) in African rainforests. It spreads through the logging roads and can cause blindness and mortality in native species (Laurance, et al., 2009).

Roads create gaps in the existing habitat, due to noise, light, pollution, vegetation clearing and disturbance, thus creating a barrier that obstructs the movement of wildlife (van der Ree, et al., 2015b). Road networks and traffic density create circumstances where populations are divided into smaller isolated subpopulations due to the barrier effect (referred by Forman & Alexander, 1998). A population is a group of individuals that reside in the same area at the same time and a subpopulation becomes after a population has been divided into smaller groups because of a barrier restricting movement (The Helsinki term bank for the arts and sciences, 2014). Isolated subpopulations of species that are rare, low-density and with a need for large home ranges (i.e., large carnivores) are at a greater risk of extinction because of the barrier effect (Grilo, et al., 2015). This is due to a need for large, connected land areas, for migratory movements for food and mates and to connect with other subpopulations for the exchange of genetic material to maintain a viable population (Beckmann, et al., 2011).

Noise pollution of passing traffic can be heard from hundreds of meters or even kilometres away. Traffic noise can be created by traffic on roads, by trains or by air traffic (Dominoni, et al., 2016, Silva Lucas, et al., 2017, Iglesias-Merchan, et al., 2018). Noise pollution affects wildlife in many ways. Studies show that captive ungulates´ heart rate increased in response to aircraft noise (Weisenberger, et al., 1996), Ovenbird (*Seiurus aurocapilla*) pairing success is reduced on noisy compressor sites (Habib, et al., 2007), traffic noise affects the bird clutch size negatively, due to females laying smaller clutches (Halfwerk, et al., 2010), and both birds and frogs alter their song and call in traffic noise (Summers, et al., 2011, Parris, et al., 2009).

Corlatti, et al., (2009) referred and stated that habitat loss and barrier effects affect not only the movement of the individual but also the movement of genes. A loss in gene flow will lead to inbreeding and weaker genetic diversity (Zachos, et al., 2006). Weaker genetic diversity is a contributing factor when dealing with the risk of extinction (Referred by Frankham, 2005). Reasons for extinction are a combination of habitat loss, overexploitation, demographic, environmental and genetic factors. A study conducted by Wilson, et al., (2015) show that moose residing near a major highway display a weak but notable genetic structure, this was not noted on moose residing in areas with no major highway. The authors also concluded that a man-made barrier can affect the genetic composition of a species.

Wildlife-vehicle collisions are a factor that affects wildlife, human safety, and property. Manneri (2002) estimated that the yearly road-induced animal mortality in Finland is 4,3 million birds, 0,2 million reptiles and over a million mammals and amphibians each. The estimated yearly road-induced mortality on paved roads in Europe is 194 million birds and 29 million mammals (Grilo, et al., 2020). Animal mortality in collisions does not only affect the individual in question, in some endangered species the impact of a deadly collision can affect the survival of the species (Beckmann, et al., 2011). Grilo, et al., (2020) stated that "Roads and traffic may provide the final push toward extinction for species already imperiled by other factors but could also be the beginning of the path toward extinction for relatively common species". For example, the endangered Florida Key deer (*Odocoileus virginianus clavium*), in its case over 50% of mortality is caused by deer-vehicle collisions (Parker, et al., 2011). A domestic example is the Finnish forest reindeer (*Rangifer tarandus fennicus*) which is an endangered species that is affected by traffic mortality. The Finnish forest reindeer population was approximately 2 800 individuals during spring 2022, of which 1.1% - 1.4% of the population die due to traffic every year (Karhula, 2021).

In 2020 alone there were over 14 000 reported ungulate-vehicle collisions (UVC) in Finland (Statistics Finland, 2021). Half of all the collisions were between white-tailed deer (*Odocoileus virginianus*) and cars. More than 5 000 collisions happened between roe deer (*Capreolus capreolus*) and cars, and there were approximately 1 500 collisions with moose (*Alces alces*) and cars (Liikenneturva, 2021). A study conducted by Niemi et al. (2015) shows that 76% of all ungulates, that have been a part of a traffic collision, die due to the accident. All UVCs are not reported, and the real amount is significantly higher than the reported amount (Almkvist, et al., 1980).

The Finnish Transport Infrastructure Agency (2018) stated that the total cost for moose-vehicle collisions in the year 2017 was 63.5 million euros. In 2020 there were three human fatalities due to UVCs, and 146 persons injured (Liikenneturva, 2021).

1.2.2 WILDLIFE CROSSING STRUCTURES

A wildlife crossing is an artificially built passage over or under a road or railway. Wildlife crossings are built for two important main purposes: preventing wildlife-vehicle accidents and connecting animal populations and habitats (Beckmann et al, 2011).

Beckmann et al. (2011) describe that wildlife crossings come in two different main categories: overpasses and underpasses. The shape, location, size, and construction materials depend on the intended target species. Underpasses are structures that permit wildlife to go under the road and are more common than overpasses (Smith, et al., 2015). Underpasses can be anything from small tunnels with water for amphibians and reptiles, to wildlife underpasses and viaducts for large and small mammals. Amphibian tunnels are built beneath the road surface in a series of multiple tunnels next to each other. Different amphibian species have different preferences in tunnels but prefer soil-based tunnels to concrete ones (Lesbarréres, et al., 2004). Amphibians are guided to the tunnels by fencing (Helldin &

Petrovan, 2019). Wildlife underpasses are constructions under roads or railways, that are built for the purpose of being used as crossing points. Wildlife underpasses vary in size and so does the intended target species (Gagnon, et al., 2011). Dry paths under road bridges have been proven to be a successful and cost-effective way of reducing traffic mortality in small and medium-sized vertebrates (Niemi, et al., 2014). Viaducts are often located in valleys or by rivers (Smith, et al., 2015). A viaduct consists of a high bridge that carries the road or railway over the obstacle. The large size of viaducts enables crossings for many different species. Non-wildlife underpasses can also substitute as a crossing structure for wildlife. Bhardwaj et al. (2020) found that non-wildlife underpasses can help to maintain wildlife connectivity. Their recommendation was to build the non-wildlife underpasses as big as possible to encourage ungulate use. The authors recorded moose and roe deer using the non-wildlife underpasses monitored in the study.

Overpasses are structures that permit wildlife to go above the road (Beckmann, et al., 2011). Overpasses include canopy crossings and glider poles for species moving on higher ground, landscape bridges that span for more than 100 meters, and multiuse overpasses (Smith, et al., 2015, Linden, et al., 2020). Canopy bridges consist of rope, net or pole that are suspended over the road. Canopy crossings are used by arboreal and scansorial species, such as opossum (*Didelphimorphia*), koalas (*Phascolarctos cinereus*), monkeys (*Simiiformes*), and lizards (*Lacertilia*) (Soanes & van der Ree, 2015, Donaldson & Cunneyworth, 2015). Glider poles are for some species to jump and glide over the road. Glider poles are used for example by Carolina northern flying squirrel (*Glaucomys sabrinus coloratus*) (Kelly, et al., 2013). Landscape bridges cater to many different species due to the continuous habitat over the road. The review by Corlatti et al. (2009) defined wildlife overpasses as “bridge-like structures of whatever size, designed for use by fauna or, at the most, for dual-use by farm vehicles and wildlife, and planted with grass, shrubs, or trees”. Wildlife is guided onto the wildlife overpass with fencing. A multiuse overpass is a structure that serves as a crossing for both animals and humans (van der Grift, et al., 2012). Multiuse overpasses are divided into two halves. One half of the overpass is paved with gravel for human use and the second half has vegetation, for example, trees and shrubs. Multiuse overpasses are widely used in Europe, North America, Canada, and parts of Asia as well (Asari, et al, 2020, Beckmann et al, 2011, Myslajek et al, 2020). In this thesis, I will be dealing only with multiuse overpasses.

Studies about human co-use on wildlife crossing structures from around the world show a variety of species using structures also used by humans (van der Ree & van der Grift, 2015c). Large predators like black bear (*Ursus americanus*), grizzly bear (*Ursus arctos horribilis*), cougar (*Puma concolor*), bobcat (*Lynx rufus*), and wolf (*Canis lupus*) in Canada (Clevenger & Waltho, 2005, Warnock-Juteau, et al., 2022), badger (*Meles mele*s),, and genet (*Genetta*) in Portugal (Grilo, et al., 2008), coyotes (*Canis latrans*) in the United States (Ng, et al., 2004), reptiles (*Reptilia*), vertebrates (*Vertebrata*) (Mata, et al., 2005), and wildcats (*Felis silvestris*) in Spain (Rodrigues, et al., 1997).

A monitoring project commissioned by the Finnish Transport Infrastructure Agency and conducted by Niemi (2021), studied the animal movements on ten multiuse overpasses in Southern Finland. The results of this monitoring project show that at least 11 different wildlife species crossed the overpasses. These species included: mountain hare (*Lepus timidu*s), European hare (*Lepus europaeus*), red fox (*Vulpes vulpes*), European badger, raccoon dog (*Nyctereutes procyonoides*), moose, white-tailed deer, roe deer, wild boar (*Sus scrofa*), Eurasian lynx (*Lynx lynx*) and brown bear (*Ursus arctos*).

Wildlife crossing structures need to be built in a way that decreases the effects of traffic, encourages wildlife to cross and guides wildlife onto the structures (Smith, et al., 2015). This can be achieved by landscaping the structures with planting vegetation as a guide and shelter. Ungulate use of wildlife structures is greatly affected by the structural factors of the overpasses, such as length and width (Clevenger & Waltho, 2000). Wildlife can avoid crossing structures with visual barriers that are possible hiding places for predators (Gagnon, et al., 2011). The location of the wildlife crossing structures is said to be one of the most determining factors of its functionality (Clevenger & Waltho, 2000, Rodrigues, et al., 1996). Suitable locations for wildlife structures are such that there is minimal human disturbance, and close proximity to suitable habitats for wildlife (Rodrigues, et al., 1996).

Building wildlife crossing structures is a costly matter. The total cost of a wildlife bridge depends on the bridge design, location, and substrate. The Swedish Transport Administration has estimated the price of building a square meter of a bridge can cost up to 2 000 € (Seiler, et al., 2016). For a 20-meter-wide bridge across a 60-meter-wide highway, the total amount would be approximately 2.4 million euros. Due to the high costs of building wildlife overpasses, it is more cost-beneficial to build multiuse overpasses that serve as a means of movement for both animals and humans (van der Ree & van der Grift, 2015c).

Exclusion fencing is a cost-effective and efficient way to reduce ungulate-vehicle collisions (Beckmann, et al., 2011). Wildlife crossing structures are often paired with exclusion fences to reduce the barrier effect by guiding the animals to the crossing structures. High fencing along the highway can prevent animals from going on the road and guide them to crossing structures (Dodd Jr, et al., 2004, Huijser, et al., 2016).

In the Handbook of Road Ecology, van der Ree et al. (2015) states that fencing along roads is primarily used to hinder animals from moving on the road, thus minimizing the risk of a wildlife-vehicle collision. While fencing is an effective prevention of accidents it can pose as a barrier to movement (Jaeger & Fahrig, 2004). Fencing can also attribute to mortality in ungulates as a result of entanglement (Greenfield, et al., 2021). Fencing as a barrier effect can cause some local extinctions of migratory species and fragmented habitats. The pairing of fences and wildlife crossings is necessary, due to the barrier effect. The location of fencing and crossing structures should be based on known wildlife habitats and movement, also rates of wildlife-vehicle collision should be taken into account (van der Ree, et al., 2015a).

The end of the fence problem occurs when short fences are built, and wildlife can follow the fence to its end and cross over the road there (Bellis & Graves, 1971). This creates dangerous situations for wildlife and humans. The aforementioned authors recommend that to avoid the problem it is best to build long continuous stretches of fencing, instead of short sections. The end of the fence problem can be avoided by guiding wildlife to crossings by fencing. Studies have shown that fencing combined with wildlife crossing structures can reduce ungulate-vehicle collisions by 80 % (Clevenger, et al., 2001).

1.2.3 HUMAN USE AND DISTURBANCE ON WILDLIFE CROSSING STRUCTURES

Human disturbance on multiuse overpasses can come in the shape of a hiker, rider, cyclist, car, or other motor vehicle. Clevenger & Waltho (2000) states that human activities can have a negative effect on wildlife crossings. The results of the monitoring project by Niemi (2021) show that there is a wide variation in the ways humans use crossing structures. This includes riding snowmobiles, riding horses, dog walkers and hikers, excavators and tractors, dog teams pulling ATVs, and cars and motorbikes. The use can happen in groups of people or singular persons.

The review by Stankowich (2008) shows that ungulates are more disturbed by a human on foot than by a cyclist, horseback rider, or a driving car. This may be the cause of associating a human by foot with hunting activities. Hunting is thought to be the reason why animals perceive humans off-trail as more dangerous than humans on a trail. A human off-trail is deemed to be more likely to chase or hunt, than a human on a trail (Taylor & Knight, 2003, Neumann, et al., 2011). Miller et al. (2001) studied wildlife's responses to pedestrians and dogs and found that animals can adapt and habituate to human activities that occur frequently and are predictable. Activities that happen on the same trail at similar times day after day, have a smaller area of influence and flush distance, than activities that happen in unexpected places. The study also showed that deer are more affected by a pedestrian with a dog than only a pedestrian. The authors pondered that this may be due to dogs' capability to hunt and prey on deer, throughout history.

The majority of the human use of crossing structures happens during the day. Many animals that use the crossing structures are more active during the night. The differences in active hours between humans and animals may enable the co-use of multiuse overpasses (van der Ree & van der Grift, 2015c). A study about wildlife overpass co-use conducted in the Netherlands by van der Grift et al (2021), showed that roe deer crossed the overpass three hours later on days with a high amount of human use. A study by Wevers et al (2020) shows that in a high human disturbance area, wild boars are more active during the night and in darkness to try to avoid interactions with humans. Roe deer on the other hand did not display a change in active hours due to human interactions. Roe deer activity overlapped with humans 40% and wild boar overlapped only 17%.

Clevenger & Waltho (2000) showed that the use of the crossing structures of large predators are negatively affected by human presence and distance to the nearest settlement. This statement was furthermore corroborated by Caldwell & Klip (2019) stating that coyotes, mountain lions and bobcats present temporal or spatial avoidance in underpasses due to human activities. Human use had a smaller significance in ungulate crossing rates.

As previously stated, human usage of crossing structures affects wildlife negatively (Clevenger & Waltho, 2000, Stankowich, 2008). Therefore, recommendations for building a co-use overpass are shunned upon, due to the assumption that wildlife does not use crossings that are used also by humans. Recent studies have shown promising results of human and wildlife co-use on crossing structures (Asari, et al., 2020, van der Grift, et al., 2021). Building and maintaining wildlife crossing structures is expensive, hence building a crossing structure that is suitable for both human and wildlife use is a more cost-efficient solution (van der Ree & van der Grift, 2015c)

2. MATERIAL AND METHODS

2.1 UNGULATES IN SOUTHERN FINLAND

Ungulate species in southern Finland include moose, white-tailed deer, roe deer, fallow deer (*Dama dama*) and wild boar (*Sus scrofa*). This study will focus on the movements of moose, white-tailed deer, and roe deer. Wild boar and fallow deer are excluded from this study, due to the lack of data.

The Finnish moose population was estimated to be in 2019 approximately 87 200 individuals (Natural Resources Institute Finland, 2020). The moose population is spread across the whole of Finland. In the western parts of this thesis research area after the hunting season 2021, the moose density was at its highest, with more than four moose per a thousand hectares, while in the eastern parts of the research area the density is 3,5 moose/1 000 hectares (Natural Resources Institute Finland). Moose is a partially migratory species, which means that individuals migrate between summer and winter pastures in search of better foraging. Singh et al. (2012) suggests that some of the factors that affect individuals' migrational tendencies include age, snow conditions and road density. The distance the moose, monitored in the lastly mentioned study, made varied from 3 to 217 kilometres. Moose are most active during dusk, dawn, and night (Almkvist, et al., 1980).

White-tailed deer were introduced to Finland at the beginning of the 20th century. It habituates the southern and central parts of Finland. White-tailed deer has a growing population of approximately 125 000 individuals, in 2020 (Aikio & Pusenius, 2021). In the southwestern parts of the research area, the density of white-tailed deer was 30 deer/1 000 hectares during the winter of 2020 - 2021. White-tailed deer migrate seasonally between different pastures. Mature deer stay faithful to their seasonal home ranges (Grund, et al., 2002). Many deer species, including white-tailed deer and roe deer, are at their highest peak of activity during dusk and dawn (Aschoff, 1966).

Roe deer is the smallest deer species in Finland. It is spread in all of Finland, but the population is most dense in the southern and southwestern parts of Finland (The Finnish Wildlife Agency). The roe deer population is estimated to be at minimum 80 000 individuals (winter 2021) (Matala, et al., 2021). Roe deer bucks are exceptionally territorial. Roe deer form herds for the winter, to efficiently find foraging and detect possible predators. During spring the roebucks find their territories and start defending them. Young roe bucks without territories can migrate on large areas, of hundreds of hectares, but older roe deer are faithful to their home ranges and territories (Metsästäjäin Keskusjärjestö, 2007).

Moose, white-tailed deer and roe deer are game animals in Finland. Moose and white-tailed deer hunting are regulated with licenses, whereas with roe deer hunting reporting the catch to authorities is mandatory (The Finnish Wildlife Agency, 2022). Many hunters, landowners and hunting clubs establish winter feeding stations for animals. The feeding ensures the survival of the animals during the winter, and reduces damage to forestry, agriculture and traffic (The Finnish Wildlife Agency, 2022).

2.2 STUDY AREA

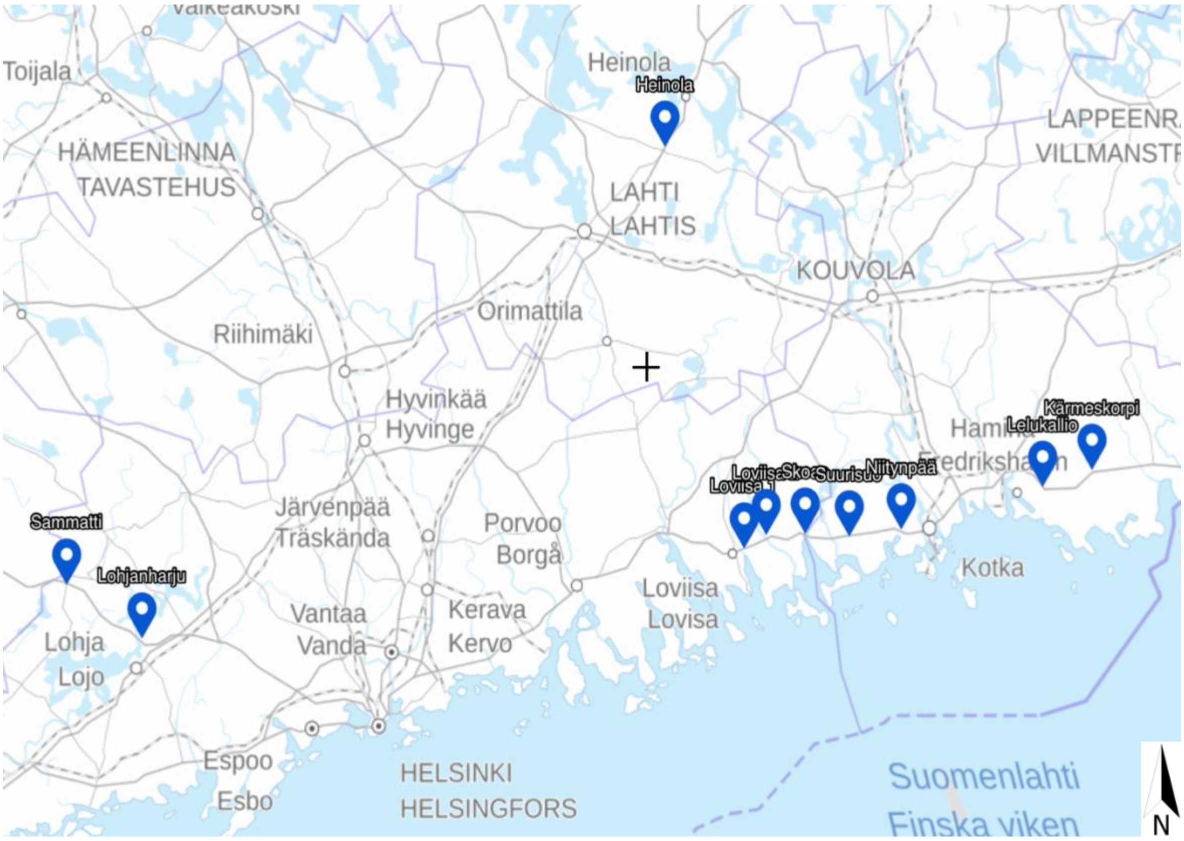
The data was obtained from a monitoring project done for the Finnish Transport Infrastructure Agency. The overpasses chosen for this study were located along three different highways in southern Finland. Seven of the overpasses were on highway 7, from Loviisa to Vironlahti. Two of the overpasses were on highway 1, from Helsinki to Turku, and one overpass was located in Heinola on highway 4 (Picture 1). One overpass called Skoas on highway 7 was left out of this study due to local objection to the camera covering the whole overpass. The camera was placed so that it filmed only the terrain part of the overpass, and therefore the data obtained from Skoas was not comparable with the rest of the data. Seven of the nine studied overpasses were frequently used by motorized activity, whereas two of the overpasses had more limited access to motorized vehicles and were predominantly only used by non-motorized human activities. For further information about the multiuse overpasses see Appendices 1.

Within the area of Uusimaa, there are 272 kilometres of road with exclusion fencing (Soosalu, et al., 2019). All overpasses researched in this thesis were on highways with fencing. The highways had two lanes going in either direction. Only two of the overpasses were on areas where the highways underneath have lighting. The traffic volumes on highway 7 were approximately 9 000 cars per day. Whereas under Lohjanharju on highway 1 the traffic volume was 25 000 cars, and under Sammatti on highway 1 the traffic volume was

12 000. On highway 4 the traffic volume was approximately 18 000 cars per day (Finnish Transport Infrastructure Agency, 2021).

The landscape surrounding the areas to the overpasses differs in the eastern and western parts of the study area (Appendix 2). The surrounding area to the western overpasses consists of fields and large connected forest areas. The two overpasses along highway 1 are older than the overpasses on highway 7. This affects the level of vegetation on the overpass. The older overpasses in western Finland are well landscaped into the surrounding nature and provide vegetation as a shelter for animals. The vegetation is continuous over the overpasses and obstructs the line of sight for the animals, but the animals do not have to go in the open.
In the eastern parts of the study area, the surroundings of the overpasses consist mostly of large, connected forest areas. Highway 7 follows the shores of The Baltic Sea. The smallest distance between an overpass and the sea is 4 kilometres. A powerline has been built and is currently under construction next to highway 7. The powerline causes a permanent, 100 meters wide, clear-cut area next to overpasses Loviisa1, Loviisa2, Lelukallio, and Kärmekorventie on highway 7. All overpasses on highway 7 have been built in the year 2014 and after. This causes the vegetation on the overpasses to be very young and does not provide much cover. Without landscaping, vegetation animals must move in the open to cross the overpass. The surrounding nature of the overpass on highway 4 consists of forest, field, and human settlement. The overpass on highway 4 has landscaping vegetation, but the vegetation is so dense it is impenetrable for animals.

The climate type in Finland is intermediate climate and the vegetation zone is boreal zone. The mean average temperature in southern Finland in 2020 was 8.7 degrees Celsius (Ilmatieteen Laitos, 2021). Winter 2019/2020 when the gathering of the data took place, was unusual regarding snow coverage. The snow coverage lasted in southern Finland for only four days, and it was the least snowy winter since 1911 with only 3 centimetres of snow (Ilmatieteen Laitos, 2020).



Picture 1. The location of the camera trap monitored multiuse overpasses in the study area. Overpass Skoas seen on the map was excluded from the study due to data not being comparable. (Maanmittauslaitos Karttapaikka, downloaded 4/2021)

2.3 CAMERA MONITORING

The research was conducted as a camera trap monitoring. Many synonyms are being used in the scientific world for the term camera trap, some of these are trail camera, wildlife camera and remote camera (Meek, et al., 2014). In this study, I will be using the term camera trap. The cameras chosen for the research were Uovision UM785-3G. The chosen settings for the camera traps took three still picture bursts, with a one-minute time delay in between bursts. The one-minute delay reduced the number of pictures taken from the same activity. The Passive Infrared motion sensor (PIR) had a trigger speed of 0.6 seconds. The manufacturer promised recognition distance was from 16 to 18 meters. In practical use, it was noted that the camera traps recognition distance is longer than promised. The Uovision UM785-3G camera traps were paired with Elisa data subscriptions that make remote controlling and adjustments possible.

The camera traps were protected from the elements with plastic covers. Batteries and lead-acid batteries were used as a power supply. The camera traps were horizontally situated in the middle of the overpass at approximately one meter above ground level and fastened with cable ties to the surrounding fence. The camera traps had a clear view over the width of the overpass. The camera traps were fastened to the centre of the overpass so that they recorded every moving object that went over the overpass. The centre of the overpass was chosen as the optimal placement for the camera traps because most of the overpasses had a sand trackpad in the middle, and thus it was clear of vegetation. Due to there being minimal amount of vegetation in front of the camera traps, there was no need for cutting down trees and shrubs before the monitoring started. Some random branches or hay were cut during the monitoring to minimize empty pictures due to wind. Placing the camera traps in the centre made it more likely that the camera traps pictured only animals crossing the overpass and not turning around and going back.

The gathering of the camera trap data started in September 2019 and was meant to last until September 2020. Due to technical issues with the cameras, the gathering period was extended until the end of November 2020. In this thesis, I will be analyzing data only from the time periods December 2019 to May 2020, and November 2020. Due to pictures caused by wind moving the vegetation and technical issues with memory cards, the data was not consistent for the whole monitoring period (Niemi, 2021). The chosen time periods for this thesis are from when the camera traps worked around the clock and an excessive number of empty pictures were not created. Daylight savings wasn´t taken into account, because the camera traps changed the time automatically. During the monitoring time, the batteries and memory cards of the cameras were being controlled and exchanged for new ones every three months or when needed. The pictures were transported from memory cards to an external hard drive.

2.4 PICTURE PROCESSING

The pictures captured by the camera traps were manually gone through and all empty pictures without human or animal activity were deleted. The original number of pictures, for the whole one-year monitoring period, was approximately 100 000 pictures. Empty pictures occurred due to greenery moving in the wind or a drastic change in light conditions. The remainder of the pictures were brought to an open software Digikam 7.2.0. In Digikam the pictures were manually tagged, one by one, with tags suitable for the picture (Appendix 3). The tags were thought out together with my supervisor. These tags included information about the species, weather, human disturbance, snow coverage, the direction of movement and speed of movement. All pictures with animals moving across the multiuse overpass were tagged. Because the number of pictures of other wildlife was relatively small, I decided to focus this thesis on ungulates. In some cases, the specific species for ungulates could not be identified, mostly due to poor lighting in the camera trap pictures. These ungulates were tagged as unidentified ungulates. The pictures also include other metadata, such as the location of the camera traps and the time when the picture was taken. From Digikam the data was exported to Excel using an Exif tool. After the data was processed, all images picturing humans were destroyed, for confidentiality reasons.

2.5 STATISTICAL ANALYSIS

For the statistical analysis, I had to establish the sequence of events and calculate the time differences between events. One event being one independent crossing captured on a camera trap image, excluding the number of animals in the picture. Before the time differences were possible to be calculated, columns for previous activity needed to be added. One event is a crossing detected and timestamped by the camera traps. I used R (Version 4.1.2) (R Core Team 2020) and RStudio (Version 2021.09.1) and a code provided and made by Knufinke (Knufinke, 2021). I also used the overlap package in R (Ridout & Linkie, 2009) to help with the statistical analysis.

I calculated the crossing rate by using Excel (Version 16.59). Crossing rate in this thesis means crossings per monitoring day/overpass. I calculated the crossing rates for all ungulate species separately. I also used Excel to make the graphs and figures for this thesis.

To evaluate the difference between crossing type-pairs, time to previous activity, I tested the differences between crossing type-pairs; moose-moose vs. human-moose, roe deer-roe deer vs. human-roe deer and white-tailed deer-white-tailed deer vs. human-white-tailed deer. Due to the majority of crossings being done by white-tailed deer, I also compared sequences of human-white-tailed deer vs ungulate-ungulate, on two of the most active overpasses Lohjanharju and Sammatti. I used the Mann Whitney *U* test to compare the differences in time to previous activity. The Mann-Whitney *U* test compares differences between two independent groups, without assuming that values are normally distributed (Laerd Statistics, 2021). Niedballa et al. (2019) have proven it to be an alternative but effective method to detect spatiotemporal avoidance. Spatiotemporal avoidance happens when a species is avoiding a location after the attendance of another species. For this test, I used RStudio as well.

The null hypothesis for the Mann-Whitney *U*-test is: *An ungulate follows its conspecific crossing the overpass after the same time as it follows a human crossing the overpass.*
In this thesis, I used the significance level p-value of 0.05. If the p-value is below 0.05 the null hypothesis is rejected, and the conclusion is made that there is a significant difference in the crossing times between two crossing pairs.

3. RESULTS

I detected 730 independent ungulate crossings during the 7-month long study period. I considered independent crossings to be one crossing event captured on a camera trap image, the number of animals was not taken into account. On the 9 overpasses in this study, the number of ungulate crossings detected ranged from 5 - 392 (0.7 - 54.0% of detected crossings on overpasses). There were 4 707 crossings made by humans. The number of human crossings ranged from 43 – 1 419 (0.9 - 30.0% of detected human crossings on overpasses). I classified 15.0% of the total amount of crossings to be by ungulates (ungulates/humans). Other wildlife was not considered in percentage calculations. Of the total amount of ungulate crossings, 55.0% were done by white-tailed deer, 15.0% by roe deer, 11.0% by moose and 19.0% by unidentified ungulates. The crossing rate for white-tailed deer was on average 0.19 crossings and ranged from 0.00 - 2.90 (N=396) crossings per day per overpass. The average crossing rate for moose was 0.04 crossings and ranged from 0.00 - 1.10 (N=83) crossings per day per overpass. For roe deer, the average was 0.05 and it ranged from 0.00 - 1.30 (N=107) crossings per day per overpass. For mean crossing rate/day/overpass see appendix 4. Unidentified ungulates were not considered when calculating crossing rates.

3.1 DAILY PATTERNS OF OVERPASS USAGE

The temporal patterns were established by looking at the number of crossings per hour of the day. Ungulates use of the multiuse overpasses was most active during the early evening (Figure 2a). This time coincides with the winter months' dusk. Humans were most active before noon (Figure 2b). Figure 2c shows the time of motorized and non-motorized crossings separately. There was a decline in ungulate activity during human peak hours between 10.00 and 11.00 o´clock.

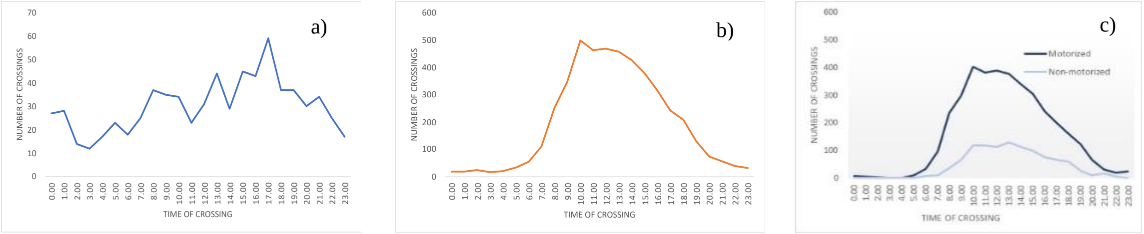


Figure 2. Time of crossings per hour during the 7-month long monitoring period on all multiuse overpasses of a) Ungulates (N=730 crossings), b) humans (4707 crossings), and c) time of motorized and non-motorized crossings.

3.2 THE EFFECTS OF HUMAN DISTURBANCE ON UNGULATES

I calculated the time (hour and minutes) between non-motorized human activity (hikers, dog walkers, cyclists, and horse riders) or motorized human activity (cars, ATVs, tractors, motorcycles, and trucks) and ungulate crossings and found that time between events with non-motorized activity was longer than with motorized activity (Figure 3). When all overpasses were taken into account, white-tailed deer crossed the overpass approximately 12 hours after a non-motorized human activity (0h 18min - 43h 6min) and 6 hours after a motorized human activity (0h 1min - 45h 12min). Roe deer crossed the overpass 22 hours after non-motorized human activity (0h 12min - 119h 7min) and 6 hours after motorized human activity (0h 1min - 39h 43min). Moose went over the overpass 19 hours after non-motorized activity (0h 11min - 59h 18min) and 7 hours after motorized activity (0h 2min - 26h 43min).

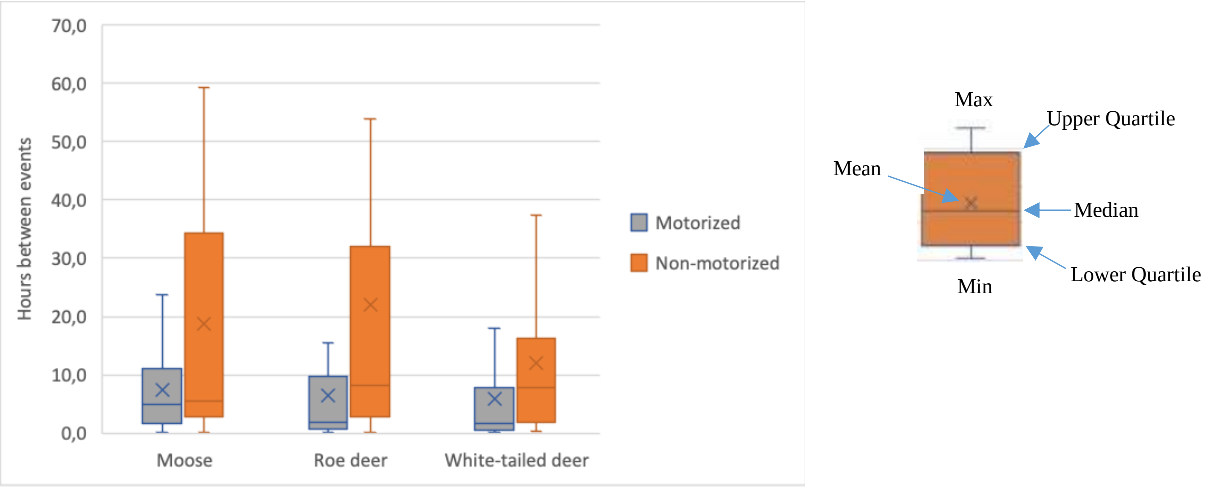


Figure 3. The boxplot describes the time between events after motorized and non-motorized human disturbance on ungulates on all overpasses.

I looked closer at the white-tailed deer crossings at two overpasses with the most white-tailed deer crossings, Lohjanharju and Sammatti. First, I excluded the overpass Lohjanharju, where human crossings were only occasional, and looked only at crossings on other overpasses. I found that the time between white-tailed deer crossings after non-motorized activity was 8h 7min and crossings after motorized activity 5h 6min (Figure 4a). After that I looked at the crossings only on overpass Lohjanharju, the time between non-motorized activity and a white-tailed deer crossing was 19h 42min and between motorized activity and a crossing, it was 23h 12min (Figure 4b). Lastly, when looking only at the crossings on overpass Sammatti, with the most human and white-tailed deer activity, the time between non-motorized and white-tailed deer crossings was 7h 7min and between motorized and white-tailed deer crossing it was 4h 8min (Figure 4c).

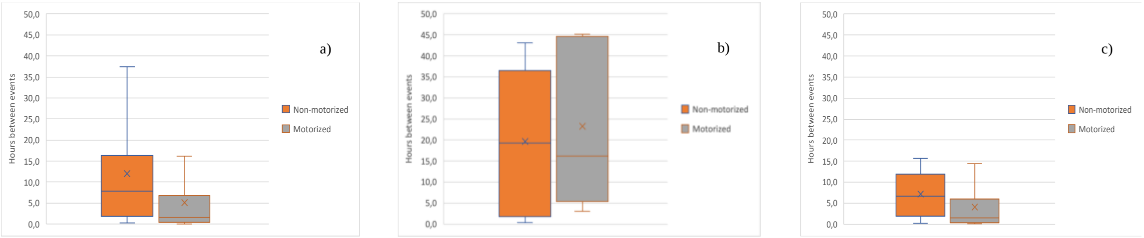


Figure 4. Boxplots describing the time between events after motorized and non-motorized human disturbance on white-tailed deer on a) all overpasses, excluding Lohjanharju, b) only on overpass Lohjanharju, and c) only on overpass Sammatti.

3.3 CROSSING TIMES

I aimed to recognize possible spatiotemporal avoidance by testing if in example a moose followed a moose faster than a moose followed a human. On average a moose followed its conspecific after 4h 38min and a human after 9h 51min. A roe deer followed a roe deer on average after 11h 12min and a human after 10h 36min. A white-tailed deer followed a white-tailed deer on average after 8h 4min and a human after 6h 46min. On overpass Lohjanharju a white-tailed deer followed on average an ungulate after 10h 54min and a human after 21h 4min. On overpass Sammatti a white-tailed deer followed an ungulate on average after 3h 18min and after a human 4h 24min. From the tested crossing pairs only moose crossing after a moose, and white-tailed deer crossing after a white-tailed deer on overpass Lohjanharju, showed a statistically significant enough difference that the null hypothesis was rejected

(Table 1). The other crossing pairs did not show a significant difference between crossing times.

Table 1. A table representing the results of the Mann-Whitney *U*-test – Crossing pairs. N1 being the number of ungulate-ungulate crossings and N2 being the number of human-ungulate crossings. The *U* represents the difference between the two ranks. The smaller the *U*-value is the more improbable it is to have occurred at random (Hole, 2011).

Crossing pairs	**Difference in crossing times**	**p-value**	***U***	**N1**	**N2**	**Interpretation of result**
Moose - moose (N1), human - moose (N2)	Yes	0,011	380,5	24	50	There is a significant difference between the crossing times of a moose crossing after a moose and a moose crossing after a human
Roe deer - roe deer (N1), human - roe deer (N2)	No	0,6	733	35	45	No significant difference between the crossing times of a roe deer crossing after a roe deer or a roe deer crossing after a human
White-tailed deer - white-tailed deer (N1), human - white-tailed deer (N2)	No	0,461	13035	190	144	No significant difference between the crossing times of a white-tailed deer crossing after a white-tailed deer or a white-tailed deer crossing after a human
Lohjanharju human - white-tailed deer (N1), white-tailed deer - white-tailed deer (N2)	Yes	0,029	440	13	108	There is a significant difference between the crossing times of a white-tailed deer crossing after a white-tailed deer and a white-tailed deer crossing after a human
Sammatti human - white-tailed deer (N1), white-tailed deer - white-tailed deer (N2)	No	0,766	4164	111	77	No significant difference between the crossing times of a white-tailed deer crossing after a white-tailed deer or a white-tailed deer crossing after a human

4. DISCUSSION

4.1 DAILY PATTERN OF MOVEMENTS

As the data obtained during the monitoring period for this thesis showed, there were notable differences in the number of crossings on the multiuse overpasses. Reasons for the varying number of crossings could have been because of the differences in ungulate densities. The ungulate densities were higher in the western parts of the research area, where also the overpasses with the higher number of crossings resided. Another influencing factor could have been the state of the vegetation on the overpasses. On the more used overpasses, the shielding vegetation was older and more shielding, than on the overpasses that were not as frequently used.

The results of this thesis suggest that there was a difference in how ungulates react to human activity. Ungulates crossed the overpasses later after a non-motorized human activity. This confirms the first research question hypothesis, which states that non-motorized human activity disturbs ungulates more than motorized activity. The longer avoidance period can be based on associating humans by foot with hunting (Stankowich, 2008). A case study in Sweden by Neumann et al. (2011) showed that GPS-collared moose fled the disturbed area and had higher movement rates and diurnal activity rates for some hours, after being disturbed by off-trail hiking or snowmobiling. Non-motorized activity and motorized activity took place approximately at the same time periods during the day (Figure 2c). This suggests that the difference between crossing times after a non-motorized and motorized activity is not dependent on these activities happening at different times. For example, if non-motorized human activity happens during the day when ungulates are least active and resting (Almkvist, et al., 1980, Aschoff, 1966), and motorized activity continue even in the evening when the ungulates are more active.

White-tailed deer had the shortest time between non-motorized activity and a crossing event. Of the three ungulate species researched in this thesis, white-tailed deer had the most crossings. Because of the number of crossings, I looked at white-tailed deer events more closely. On Sammatti, the overpass with the most human and the most white-tailed deer activity, the time between a non-motorized activity and a white-tailed deer crossing was the shortest (7 hours). The density of the white-tailed deer population is at its´ highest in the area of the overpass in question. The reason for the shorter avoidance period can be due to white-tailed deer adapting and habituating to frequent and predictable human activity (Miller, et al., 2001). In addition to taking a closer look at the overpass Sammatti between white-tailed deer and non-motorized human activity, I also looked at the overpass Lohjanharju, with the longest time in between these events in question (21h 4min). The population density was similar to each other in the places of these two overpasses (Aikio & Pusenius, 2021), but can vary even in short distances due to the surrounding habitat and area. The most likely reason for the longer avoidance time lies in the frequency of human activities. Lohjanharju was rarely used by humans and thus the time in between events grew longer.

Niedballa et al. (2019) concluded that the U-test I used in my thesis is an alternative but suitable way for testing spatiotemporal avoidance from camera trap data. The results of the test indicate that there is some spatiotemporal avoidance on moose, and white-tailed deer on the overpass Lohjanharju, with the longest avoidance times. These results partially confirm the second research question hypothesis, which stated that spatiotemporal avoidance exists among ungulates on overpasses. However, the results from overpass Lohjanharju are not necessarily due to white-tailed deer avoiding crossing soon after human activity, rather than the result of a low frequency of human activity on the overpass. The results regarding moose avoiding overpasses after human crossings are not surprising when considering the species' natural habitat. Moose's preferred habitat is large, forested areas (Hundertmark, 2015), whereas roe deer and white-tailed deer occupy farmland, suburban areas, and areas in close proximity to humans (Gallina & Lopez Arevalo, 2015, Lovari, et al., 2015). The natural habitat of moose in itself results in minimal contact with humans. Special features in crossing amounts can falsify the results regarding spatiotemporal avoidance. On an overpass with a high abundance of ungulate crossing, there might be some animals that have adapted to human activity and use the overpass without avoidance, being responsible for a large number of crossing events. On the other hand, a low number of crossings can prevent the accurate assumption of the activity patterns by giving individual events unequal weight (Niedballa, et al., 2019). Therefore, it is important to also view the data as a whole and not only focus on special cases such as Lohjanharju and Sammatti. Even though I could not determine human avoidance for the other ungulate species, it does not mean there isn´t any. It means it could not be found with the methods I used in my thesis.

The crossing rates for ungulates vary in studies. Gagnon et al. (2005) studied wildlife use of underpasses and found that elks crossing rate at the underpasses was on average 0.35 crossings/day, and white-tailed deer's crossing rate was on average 0.4, whereas sika deer crossing overpasses ranged from 0.25 - 1.56 crossings per month (Asari, et al., 2020). Roe deer crossing overpasses ranged from 0.7 - 2.4 crossings/day (Myslajek, et al., 2020). Crossing rates help to compare structures located in the same area, but in addition, wildlife density is an influencing factor. The differences in crossing rates can be caused by different population sizes and densities and can also vary from species' willingness to use wildlife crossing structures. The crossing rate can differ due to the location and age of the structure. If the structure is poorly located, or located on wildlife's migrational routes, the frequency of use is not as high as it is if located on routes wildlife use daily.

The multiuse overpasses in my research area varied in age. The oldest ones were 15 years old during the monitoring period and the youngest one was only two years. Due to the age differences of the overpasses also the vegetation coverage varied. The older overpasses had continuous vegetation on the terrain part of the overpass when some of the newer ones were completely bare due to saplings and plantings not surviving. The age of the overpass can influence the number of ungulate crossings on overpasses, and therefore also affect the crossing rate.

Myslajek, et al. (2020) found additional evidence to support the hypothesis that wildlife needs time to acclimate to wildlife crossings. During their monitoring period, the number of animal crossings on the overpasses increased with time. The vegetation coverage can be an influencing factor when considering wildlife acclimating to crossing structures. Seidler, et al. (2018) stated that after years of wildlife using the same migration routes, that cross the road surface, it takes time for wildlife to adapt to man-made crossing structures. The lower number of crossings on the eastern overpasses in this study could be partially due to this reason, that animals have not yet adapted and habituated to the new overpasses. The knowledge of wildlife habituating to crossing structures with time is beneficial when considering building wildlife crossing structures. Building crossing structures is very costly, but also cost-effective if the use is suitable for both wildlife and humans. As previous studies show, wildlife acclimate to using the overpasses with time.

4.2 KEY LIMITATIONS OF THE STUDY AND FURTHER CONSIDERATIONS

In this study, I identified some of the limitations to be associated with the monitoring setup of the overpasses. One limitation was the setup being only one camera in the centre of the overpass. During the planning of the research setup, the intention was to have three cameras on each overpass, one at each end and one in the middle. Unfortunately, due to the structure of the overpasses, that was not possible. With the camera traps at the ends of the overpass, it would have been possible to determine the number of factual crossings and approaching ungulates. Only having data from one camera trap means, that the data might include ungulates that have turned around after being pictured by the camera. The camera trap in the centre of the overpass captured only those animals that passed the camera and not the ones that approached the overpass and turned around. The number of approaches could tell us if the number of crossing ungulates accounts for a large or a small amount of the potentially crossing individuals see Clevenger, 2011. Bhardwaj et al. (2020) used reference sand beds, in addition to the sand bed in the wildlife passage, to document the animal presence in the vicinity of the passage. The authors found that in 4 passages out of 33 roe deer was present but didn't cross the passage, and out of 23 passages, moose was present but used only 12 of them. A study conducted on Rocky Mountain elks´ (*Cervus elaphus nelsoni*) underpass crossings in the USA, show that during summer 81% of the approaching elks approached and crossed the underpass, and during winter the amount was only 58% (Dodd, et al., 2007). In addition to the one camera per overpass having its downfalls, I had no way of defining real empty pictures taken by the camera traps due to, for example, wind, and "empty" pictures that an animal had set of but not gotten captured in the picture. It also remains a mystery what happened during the one-minute delay in between the picture bursts. The one camera trap setup also affected the data loss due to camera malfunctions. With more than one camera per overpass, there would likely always be at least one working camera trap to collect data.

For this thesis, I chose data from only the months with no technical issues. Due to the limitations of my data, I could not study the effects of human disturbance on seasonal and migrational movements on ungulates overpass use. It would be important to study how the migration from winter to summer pastures affects the migrating moose. For the survival of the population, it would be important that migrating individuals could get through the bottleneck a crossing poses, rather than individuals going back and forth on the overpass daily. In addition, it would be necessary to study how the rutting season impacts how wildlife reacts to human use on overpasses.

Another source of error could be in the tagging of the camera trap images. The tagging was manually made only by me, so humane errors in determining the correct species are possible. Having a second person to control the tagged images could minimize the possibility of errors.

Of the total number of ungulate crossings captured during the monitoring period, 19% were classified as unidentified ungulates. In this thesis, the reason for the unidentified ungulates was poor lighting in the images and a greater distance to the camera trap. Because of the use of the passive infrared sensor in the camera traps, the farther the moving object is, the greater the probability of missing an event is (Tourani, et al., 2020). For further studies, I would suggest a camera trap on both sides of the width of the overpass.

In addition to avoiding humans and human activity on crossing structures, ungulates could be avoiding predators (Martinig, et al., 2020). I had no evidence of predation happening on or near the overpasses. Predation and predators can impact ungulates´ willingness to use the overpasses. There was no indication that predators affected ungulates crossing the overpasses in this study. During the monitoring period from December 2019 to December 2020, one bear crossing and 23 lynx crossings were detected on the overpasses in this thesis (Niemi, 2021).

For further research of human disturbance on ungulates on multiuse overpasses, it would be beneficial to also look into temporal segregation, in addition to spatiotemporal avoidance. Temporal segregation occurs when a species changes its´ activity patterns because of the presence of another species (Niedballa, et al., 2019). It would be beneficial to study temporal segregation and spatiotemporal avoidance together. I would also suggest a different camera setup, with multiple cameras, to be used in future studies.

5. CONCLUSIONS

This thesis aimed to study if human disturbance affects ungulates on multiuse overpasses, and do ungulates react differently to non-motorized human disturbance than to motorized human disturbance. I found that the time between a non-motorized disturbance and an ungulate was longer than motorized disturbance and an ungulate. Results also indicate that moose and white-tailed deer on some overpasses avoid the structures after human use. The results didn´t show evidence of avoidance on roe deer and white-tailed deer on other overpasses, however, this does not indisputably determine that there is no avoidance, it was just not found with the methods I used in this thesis.

The results of my thesis show that multiuse overpasses are to some extent successful, in working as a crossing structure for both humans and ungulates. The results regarding avoidance from moose, indicate that the effects of human-caused disturbance need to be considered with severity and that also other species than large predators (Clevenger & Waltho, 2000, Caldwell & Klip, 2019), can be susceptible to human disturbance. Therefore, we cannot cling to the thought that multiuse overpasses would be sufficient for all species in every situation, but we need to be prepared to provide crossing structures for only wildlife use or limit the human use of crossing structures if needed.

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7. APPENDICES

Appendix 1.

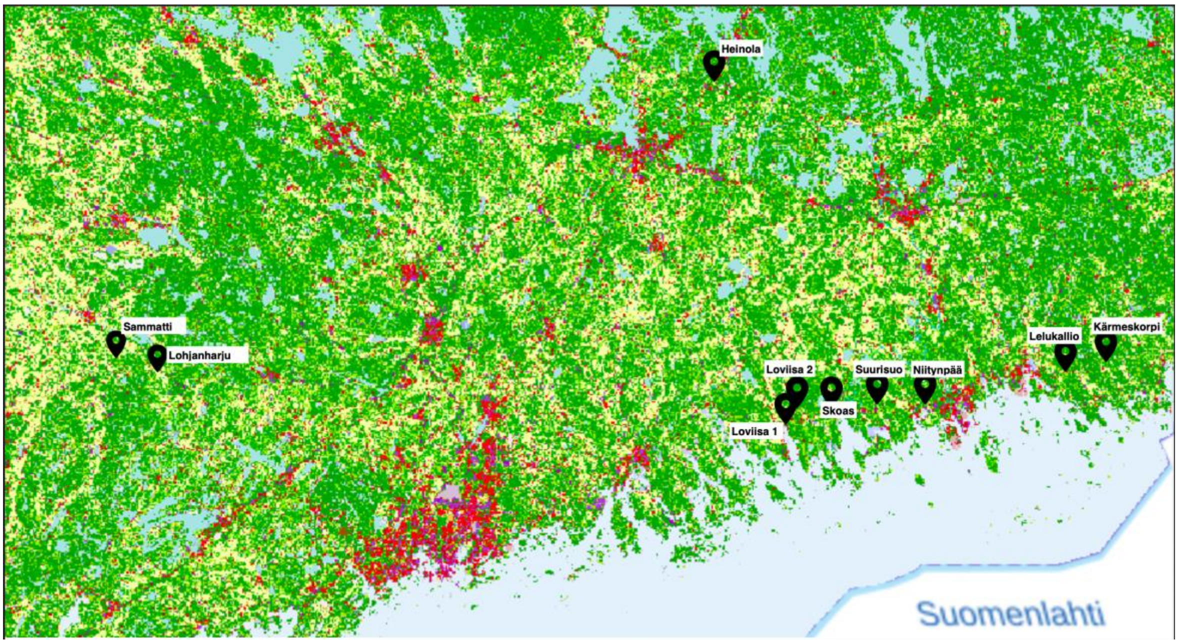
Table. Characteristics of the multiuse overpasses.

Name Completion year	Highway	Width (m)	Length (m)	Distance to vegetation north (m)	Distance to vegetation south (m)	Remarks
Sammatti 2008	1	24	60	0	0	The overpass is divided into two sections. One section is an actively used gravel road, and the second section is landscaped with trees and vegetation for animal use. Both entrances are connected to the surrounding vegetation.
Lohjanharju 2005	1	32	30	0	0	Very well landscaped overpass, that has a rarely used gravel road. The overpass is overgrown by young pine trees. Both entrances are connected to the surrounding vegetation.
Loviisa 1 2014	7	27	61	80	30	Open overpass, with a crossing gravel road. The landscaped section is on higher ground than the gravel road. Saplings are growing on the landscaped section, and in the future, the

						overpass will be more landscaped.
Loviisa 2 2014	7	27	81	20	10	Open overpass, with a crossing gravel road. The landscaped section has some shrubs and pine saplings. Next to the gravel road is a railing. Animals can choose to move in between the fencing and the railing.
Suurisuo 2014	7	24	52	20	30	Open overpass, with a crossing gravel road. Landscaping has been done by planting different tree saplings and using big rocks to give protection.
Niitynpää 2014	7	63	62	30	20	Well landscaped overpass, with a crossing gravel road. The landscaping vegetation consists of pines and birch. Next to the fencing is s railing.

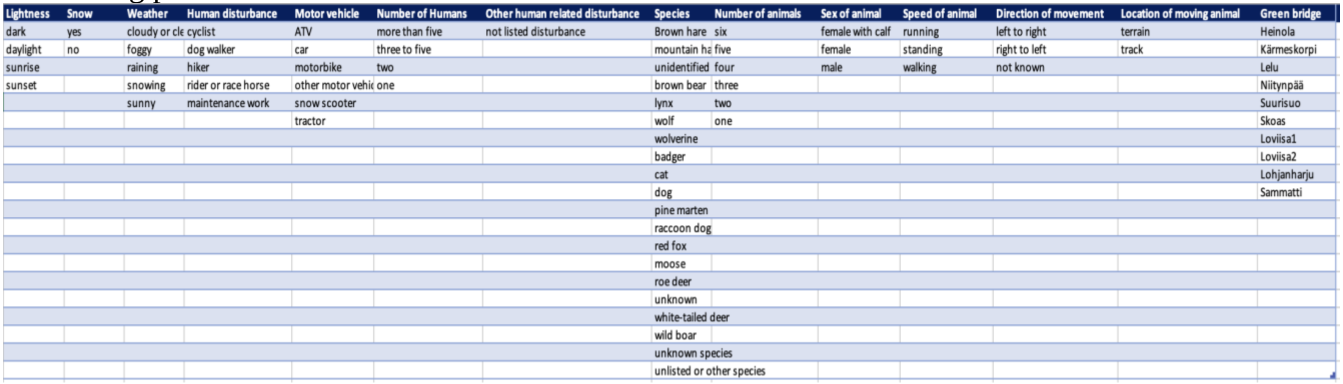
Lelukallio 2016	7, 170	28	100	70	60	Long overpass, with a crossing gravel road. The overpass has been landscaped with some saplings. Both entrances are open and do not have any protecting vegetation for the animals.
Kärmekorventie 2018	7	25	60	10	70	Open overpass, with an actively used crossing gravel road. Some landscaping trees. The overpass is on the same level as the surrounding area, so animals have a direct view of sight over it.
Heinola 2005	4	10	77	0	0	An overpass with two sections. Dense young pine trees as one section, and a path with a straight drop to the highway as a second section. Both entrances are connected with the surrounding vegetation.

Appendix 2. Corine-data map of land use in the research area, showing the location of the multiuse overpasses. Overpass Skoas was left out of this study. The red colour indicates infrastructure, the green colour represents different forests and the yellow colour indicates field and agricultural areas.



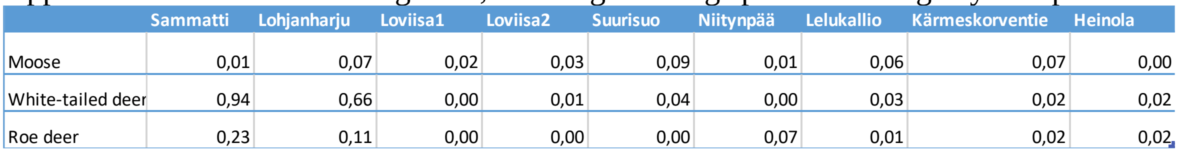
Corine-data map of land use, Suomen ympäristökeskus. Loaded 18.11.2021.
Lähde: SYKE (lähtöaineistot Suomen metsäkeskus, Metsähallitus, LUKE, MML, Hansen/UMD/Google/USGS/NASA)

Appendix 3. Tags used in Digicam, to describe the camera trap pictures taken during the monitoring period for this thesis.



Lightness	Snow	Weather	Human disturbance	Motor vehicle	Number of Humans	Other human related disturbance	Species	Number of animals	Sex of animal	Speed of animal	Direction of movement	Location of moving animal	Green bridge
dark	yes	cloudy or cle	cyclist	ATV	more than five	not listed disturbance	Brown hare	six	female with calf	running	left to right	terrain	Heinola
daylight	no	foggy	dog walker	car	three to five		mountain ha	five	female	standing	right to left	track	Kärmeskorpi
sunrise		raining	hiker	motorbike	two		unidentified	four	male	walking	not known		Lelu
sunset		snowing	rider or race horse	other motor vehic	one		brown bear	three					Niitynpää
		sunny	maintenance work	snow scooter			lynx	two					Suurisuo
				tractor			wolf	one					Skoas
							wolverine						Loviisa1
							badger						Loviisa2
							cat						Lohjanharju
							dog						Sammatti
							pine marten						
							raccoon dog						
							red fox						
							moose						
							roe deer						
							unknown						
							white-tailed deer						
							wild boar						
							unknown species						
							unlisted or other species						

Appendix 4. The mean crossing rates, meaning crossings per monitoring day/overpass.



	Sammatti	Lohjanharju	Loviisa1	Loviisa2	Suurisuo	Niitynpää	Lelukallio	Kärmeskorventie	Heinola
Moose	0,01	0,07	0,02	0,03	0,09	0,01	0,06	0,07	0,00
White-tailed deer	0,94	0,66	0,00	0,01	0,04	0,00	0,03	0,02	0,02
Roe deer	0,23	0,11	0,00	0,00	0,00	0,07	0,01	0,02	0,02