Faculty of Applied Ecology, Agricultural Sciences and Biotechnology

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Master thesis

Testing spatial overlap between humans and wild reindeer in summertime by using location-specific data

From Colourbox

Master in applied Ecology

6EV399

2022

Preface

This thesis is the final note of a five-year long study experience at Inland University. The study experience at Evenstad has been filled with good learning experiences and unforgettable moments with good friends and co-students.

To study at Evenstad has made it possible for me to learn about topics close to my heart, giving me an education where I get the opportunity to work with what I love. I grew up with hunting and outdoors. Spending time outdoors in beautiful landscapes and experiencing wildlife on close holds, is amazing. The interest in *Rangifer tarandus t.* grew as I moved to Evenstad. Because of its close distance to Rondane, it became an important part of the wildlife education. To see with own eyes how human encroachment negatively affect these animals was frightening, and it made me want to learn more.

I want to thank Vegard Gundersen and NINA (Norwegian Institute for Nature research) for an amazing opportunity in both a bachelor- and master-study. To work with the topic of wild reindeer and human disturbance have given me great knowledge. I have conceived a great deal of commitment to continuing the work of bettering the conditions for the last remaining parts of the wild mountain reindeer.

At last, I want to thank my supervisors, Vegard Gundersen & Kristin E. Mathiesen for incredible help during this thesis. To have supervisors with such broad knowledge have been so helpful. By responding in no-time, giving me valuable feedback, and lots of motivation, it has made this journey fun and exciting. I also want to thank the staff at the university, and finally my co-students at Evenstad for a great deal of good cooperation during these five years.

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Evenstad, May 2022

Abstract

Loss and fragmentation of habitat due to human activity is a worldwide issue. An increase in human growth has led to an increase in interactions between humans and wildlife populations, which entail changing migration patterns and habitat use of animals. Migrations are particularly associated with large animals moving long distances between seasonal habitats, which is typical for the wild mountain reindeer (Rangifer tarandus t.) located in the mountain areas of Southern Norway. An increased accessibility in the Norwegian mountain areas has led to an explosion of tourism and second-home developments the last 50 years. This caused high human activity within the reindeer ranges, resulting in human-made barriers, disturbance effects, and isolation of too small available habitats. An important part of today's reindeer management is to maintain the reindeer areas by monitoring human use and effects of mitigation measures. Methods such as use of automatic counters have been used to monitor human activity in vulnerable areas (e.g. Gundersen et al. 2019b). As GPS technology evolves, so do the GIS methods using location specific data. The purpose of this thesis was to use crowdsourced Strava data as a tool to monitor human use of Rondane reindeer range (RRR), and to test the disturbance effects of human activity (by Strava) on reindeer area-use during summer. Location data from Strava and GPS-tracking of reindeer from the summer of 2016 to 2019 were implemented and analyzed on three different levels.

Results showed clear indications of avoidance effects in Rondane South. Small scale distance- and count-analyzes showed a general avoidance of reindeer herds of buffered Strava segments. A medium-scale comparison of circular areas that include and not include GPS positions of reindeer herds indicate avoidance effects of reindeer caused by human activity. Finally, a large-scale comparison of Gudbrandsdalen on the west side and Østerdalen on the east side of the RS range showed that the Gudbrandsdalen area compromise high density of infrastructure, high intensity of human activity, adequate reindeer habitat, but far less GPS position than the Østerdalen area. Reindeer prefer areas in the Østerdalen area, where the infrastructure development and human activity rates are lower.

For future research, there is a need for more information about reindeer habitat quality in the preferred forest- and bog- habitats of RS. The use of crowdsourced Strava data is a relatively new method which in other studies shows promising representation of broad spatiotemporal patterns of human activity. However, an obvious weakness is that user groups like locals, hunters, fishermen, wilderness seekers, solitude and those that have activities outside designated recreational infrastructure, are less represented in the Strava dataset. Strava

represent an overview of the footprint that increased infrastructural facilitation in form of cabins, tourist centers and hiking trails has on the human activity rates within the reindeer areas. These results show promising results for future monitoring of human use and investigation of disturbance effects.

Sammendrag

Fragmentering og tap av habitat grunnet menneskelig aktivitet er et verdensomfattende problem. Menneskelig vekst øker mer og mer, noe som har ført til et større antall interaksjoner mellom folk og dyr. Dette påvirker områdebruk og trekkruter (migrasjon) hos dyr. Migrasjon er assosiert med sesongbasert forflytning mellom store områder, noe som er typisk for villreinen (Rangifer tarandus t.).

En økende tilgjengelighet i de norske fjellområdene har ført til en eksplosjon av hytter og friluftslivbasert reiseliv. Dette har gitt stor aktivitet i de norske villreinområdene, noe som har ført til negative effekter i form av unnvikelseseffekter og tap av habitat. En viktig del av dagens villreinforvaltning går på bevaring av leveområdene deres, ved å overvåke menneskelig aktivitet og se på effekter av kompenserende tiltak. Automatiske tellere har lenge blitt brukt for å beregne ferdselsintensiteter i utsatte områder. Etter hvert som teknologien utvikles, finnes stadig nye måter å gjøre dette på. Formålet med denne oppgaven var å finne ut om «crowdsourcet» Strava-data kan brukes som et verktøy for å overvåke ferdsel i Rondane villreinområde, og å teste forstyrrelseseffekter av Strava aktivitet på villreinens områdebruk om sommeren. Strava-data og GPS-data fra villrein fra sommeren 2016 til 2019 ble analysert på tre ulike nivåer.

Resultater viste klare unnvikelseseffekter i Rondane Sør. Lavskala-analysene viste generelt unnvikelse fra Strava-segmentene. Mediumskala analysen med en sammenligning av sirkulære områder med og uten GPS-posisjoner og stor-skala analysen av Gudbrandsdalen og Østerdalen hadde store likheter i resultatene, hvor hovedfunnene var at økt tilrettelegging med et høyere antall veier, stier og hytter gav økt ferdsel, som igjen viste unnvikelseseffekter av villrein. Villreinen prefererer lavereliggende områder i Østerdalen, hvor infrastrukturen er på et mye lavere nivå.

For framtidig forskning er det behov for mer detaljert kunnskap om habitatkvaliteten i de prefererte områdene i RS. Bruken av Strava-data er en relativt ny metode som viser svakheter som mangel på representativitet ved at brukergrupper som for eksempel jegere og fiskere er utelatt, samtidig som ferdsel i terreng utenfor infrastruktur blir feilregistrert. Likevel viser

resultatene godt hvilket fotavtrykk infrastrukturell tilrettelegging i form av hytter, turistsentre og stier, har på ferdselen i villreinområdet. Funnene fiser lovende resultater for videre bruk av Strava for framtidig overvåkning av menneskelig aktivitet og for undersøkelser av unnvikelseseffekter.

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1. Introduction

Habitat loss and fragmentation due to human activity is a worldwide issue for many species (Tucker et al., 2018). Animal movement, defined as migration and small-scale movement, is necessary for an ecosystem to function and for species to survive (Panzacchi et al., 2015). An increase in human growth and activity has led to an increase in interactions between humans and wildlife populations (Manor & Saltz, 2005). These interactions entail changing movement pattern and habitat use of animals. Fragmentation of habitats can lead to a reduction of population size and increase the risk of extinction (Fahrig, 1997).

Migrations are particularly associated with large animals moving long distances between seasonal habitats (Panzacchi et al., 2015). This phenomenon is typical for caribou and reindeers (*Rangifer tarandus*, hereafter called reindeer). They migrate throughout the year, as the seasons change, and food and other resources change with them (Punsvik & Frøstrup, 2016). The same corridors are used from year to year, often creating a regular movement pattern. Fragmentation of their ranges can affect these old historical routes (Panzacchi et al. 2013). Powerlines, hydropower reservoir, and main roads are examples of infrastructure that creates fragmentation and blockage or change of seasonal migration routes (Panzacchi et al., 2013; 2015; Strand et al., 2015b). Blockage of or barriers in large migration routes leads to reduction of available habitat, which results in limitation in food resources and less possibilities for adaptation to changing conditions and hiding/avoidance of predators. Fragmentation also leads to functional cascade effects like overgrazing in areas with less human impact (Nellemann et al., 2001), and because plants such as lichen, needs a long time for growth, food resources can be limited. Road development, both main and minor gravel roads, increase accessibility for people, and increase the human disturbance in important habitat for certain species (Panzacchi et al, 2013;2015; Flydal et al., 2019). As human activity in important habitats increase, it also results in disturbance on species foraging time and small-scale movement. Small-scale movement can be defined as an animal's daily search for food (Panzacchi et al., 2015). Typical responses to disturbance, are increased stress-levels and decreased feeding time (Punsvik & Frøstrup, 2016). Human activity might affect the small-scale movement of species at first, but when the activity intensity reaches a certain point, and lasts over longer periods of time, it might lead to barriers of larger migration routes (Panzacchi et al., 2015).

In Quebec Canada, wildlife researchers found that the reindeers (caribou) expanded their home ranges when the number of disturbances increased in some parts of their home range (Beauchesne et al., 2014). When the disturbance reached a top point, the home ranges decreased, showing that there is only a certain amount of disturbance the Caribou can handle before their home ranges contracts (Beauchesne et al., 2014). An encroachment of the home range could lead to ecological traps for the Caribou, because the risk of predation increases, and the availability of food resources decreases. Another species of reindeer that is extremely vulnerable to human activity and habitat fragmentation is the wild mountain reindeer (*Rangifer tarandus tarandus*) in Northern Europe, which you can only find "wild" in the mountain areas of Southern Norway (Punsvik & Frøstrup, 2016). All reindeer populations in Northern Norway, Sweden and Finland are semi-domesticated, apart from two small populations of wild forest reindeer (R. tarandus fennicus) in central Finland (Nieminen, 2013).

Today, there are 24 different wild reindeer areas in Southern Norway (Figure 1a). Before the industrial revolution, archaeological pitfalls indicate that there were 3-4 large and continuous ranges in southern Norway, and the reindeer moved freely to reach different seasonal resources (Andersen & Hustad, 2004). These four large main regions were Dovre-Rondane, Ottadalen (Reinheimen) & Jotunheimen, Hardangervidda – Setesdalen, and Østerdalsfjellene (Figure 1b). Heavy infrastructure development like railways, main roads, hydro-power development, second-home development, and tourist resorts in these areas have divided the original reindeer regions, preventing the herds from using the original large-scale migration routes from eastern continental winter habitat to western summer habitat (Skogland, 1986; Skogland & Grøvan, 1988).

During the last century, particular the last 50 years, recreational infrastructure, and tourist cabin development has increased significantly, especially in the fringe areas of the Norwegian wild reindeer ranges, leading to development of "soft infrastructure" as marked trails and ski tracks that crisscross the mountain areas (Panzacchi et al., 2015; Kaltenborn et al., 2014). Wild reindeer ranges are associated with national parks, which is very attractive for visitation for recreational purposes. This has led to increased human traffic in and out of reindeer ranges over the years, with seasonal variations throughout the year, with most traffic during summer (Gundersen et al., 2019; 2020). Human encroachment and disturbance within reindeer ranges can have double effects, both ceased migration corridors and avoidance effects of areas with high human activity for a certain amount of time (Punsvik & Frøstrup, 2016). Severe population effects of human disturbance causing habitat loss and isolation are lower reproduction rates and an increased mortality (Andersen & Hustad, 2004).

Another stress factor important to mention is how climate change can affect the reindeer and their home ranges. In addition to higher temperatures, climate changes can affect wind, precipitation- and humidity-patterns, and lead to a broader variation in weather condition (Tryland, 2018; Tyler et al., 2021). As the temperature rises, it could lead to an overlap in summer- and winter ranges, because the reindeers prefer higher altitudes during warmer periods (Heggberget et al., 2002). Reindeers are vulnerable to insects during summer season, and there is also an issue of increased amounts of insects at lower forest dominated altitudes. To avoid insect harassment, reindeers move to higher altitudes where the temperature is lower, the wind is stronger, and where they have access to snow beds and glaciers (Skarin et al., 2004). Human disturbances and human made barriers makes it more difficult for the reindeers to escape from insects (Vistnes et al., 2008). Fragmentation and human disturbances are important factors that caused denser populations which could affect the spread of diseases (Kjørstad et al., 2017; VKM, 2021). With the introduction of CWD (Chronic Wasting Disease) in the Norwegian reindeer ranges, there is an ongoing debate between managers and local stakeholders working to sustain connectivity in the reindeer areas, and other actors presenting further fragmentation as a way to stop the contamination (Mysterud et al., 2020). There is a lack of clear evidence for how reindeers would respond to these measures, and scientists "*urges for ideas on how to solve the tradeoff between genetic and demographic costs of fragmentation on one side and emerging pathogens on the other"* (Mysterud et al., 2020).

There is a lack of knowledge of how future stress factors as climate change will affect our ecosystems, and this limits the possibility to predict reindeer vulnerability and resilience towards external factors (Kjørstad et al., 2017), such as human encroachment, disturbance, and disease outbreaks. When talking about topics such as climate change and human disturbance, it leads up to questions about a reindeers' possibilities for adaption, resilience, and resistance. Adaptive capacity (adaption) is explained as the opportunity to adapt to environmental changes, based on genetic diversity and phenotypic plasticity (Kjørstad et al., 2017). Resilience is explained as the possibility to return to a normal state after a change, without changing their fundamental resource niche. Resistance is about being able to stand against changes through their general condition (Kjørstad et al., 2017). So, what about the reindeers? Numerous research projects have been investigating the possibility and ability of reindeers to adapt to climate change and human encroachment (Vistnes & Nellemann, 2007; Kjørstad et al., 2017; Gundersen et al., 2021c; Tyler et al., 2021). The main issue is that the reindeer herds are vulnerable to human disturbance and have less possibilities to adapt to both fast and slow changes in their environment. In addition, many of the reindeer ranges are presently too small and fragmented for seasonal migration between different preferred habitat conditions. To keep the remaining parts of the wild mountain reindeers sustainable, they need more space and access to larger areas, with the possibility to migrate between suitable habitats. These topics will be properly discussed during this paper.

Today, the use of location data from GPS-tracking systems gives lots of possibilities to analyze area-use of both reindeer and humans in the entire reindeer area, which gives an opportunity to study cumulative effects of human impact. These types of data can be sampled on the same GPS platform. GPS-collaring of reindeer has been a method to monitor habitat use in Norwegian wild populations since 2001 (Strand et al., 2005), including in all more than 500 individuals in seven ranges (Roaldsen et al., 2022). Since reindeer live in large herds it is necessary to monitor only few individuals within each range. Similarly, GPS units have been handing out to visitors in some of the wild reindeer ranges (Strand & Gundersen, 2019). This is often both an expensive and time-consuming sampling method. Instead, an alternative is to use aggregated crowdsourced location data. Over the last years a lot of applications where you can combine both exercise and geographical locations has been developed (Garmin, Huawei Health, Google fit etc.) (Barton, et al., 2021). This makes it possible for people to log their activity and share it with others via these apps, named crowdsourced data. One app that has become very popular among Norwegians, is the Strava App. (Barton et al., 2021). Originally, Strava was developed as an application for sports and exercise but today it includes outdoor recreational users. Even though there are biases in the population for those using Strava app or not (e.g. Lee & Sener, 2021), there are studies that presents estimations of the main pattern of human activity (hiking) within reindeer areas (Holtmoen 2021) and recreational areas (biking and hiking) (Venter et al., 2020;2021). This type of data gives new possibilities for spatiotemporal analysis in both large and remote areas (Holtmoen, 2021). Holtmoen compared Strava data to automatic counter data at Hardangervidda, both in the fringe areas and in remote areas of the wild reindeer range and found significant correlation during the summer season (Holtmoen, 2021). The purpose of this thesis is to follow up the study from Hardangervidda and to use crowdsourced Strava data as a tool to monitor human use of Rondane reindeer range (RRR), and to test the disturbance effects of human activity (by Strava) on reindeer area-use during summer. I will present both descriptive and comparative analyses on different scales, which are leading to following aims:

1. Present the spatial pattern and density of the reindeer herds in RRR during the summer of 2016-2019.

2. Estimate spatial patterns of and intensity of STRAVA users in RRR, both on and off designated recreational infrastructure, during the summer of 2016-2019.

3. Illustrate by four analyses the macroscopic impact of spatial distribution of Strava users on wild reindeer area use, using GPS-tracking positions collected in the same areas and periods.

4. Discuss management implication of the results and the possibility to use crowdsourced Strava-data in impact analyses of wild reindeer.

Figure 1a. Norwegian wild reindeer areas. There are 24 separate reindeer areas in the southern parts of Norway. (Villrein.no)

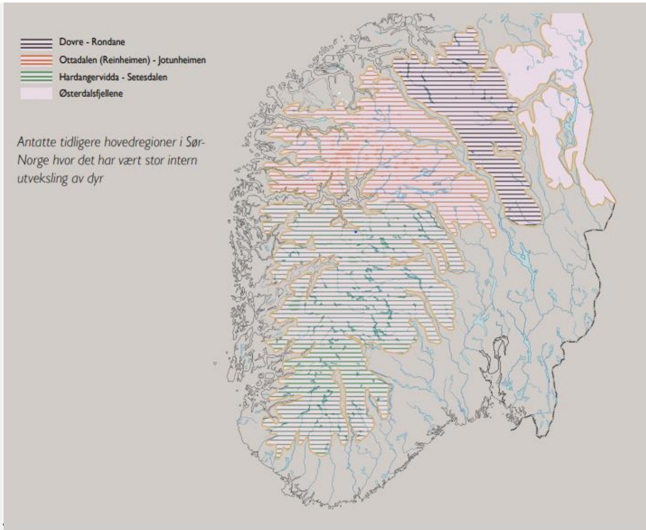

Figure 1b. The former wild reindeer areas. Four large main regions; Dovre-Rondane, Ottadalen - Jotunheimen, Hardangervidda - Setesdalen, Østerdalsfjellene (From Andersen & Hustad, 2004 p. 19)

2. Material & Methods

2.1 Study area of southern part of Rondane reindeer range

2.1.1. Rondane Reindeer Range

Rondane Reindeer Range (RRR) lies in Innlandet County, between Gudbrandsdalen and Østerdalen (Figure 2). The total size of RRR is approximately 5000 km^2 (Rolandsen et al., 2022), which is divided into Rondane North (RN) and Rondane South (RS). RRR consists of many protection areas. In the northern part you find Rondane and Dovre national parks (NP), several landscape protection areas, and nature reserves, and in the southern part many nature reserves which Hemmeldalen nature reserve is the largest (251 km^2) (Ryvarden, 2021). As a way to preserve habitats for reindeer, Rondane national park was established in 1962 as the first NP in Norway, with an expansion in 2003 (Forskrift om vern av Rondane Nasjonalpark, 2003).

The administrative border of RRR is based on reindeer observations and habitat information (Jordhøy 2008). GPS- data have shown that reindeer herds possibly use some minor areas outside this border, in the southern parts of Rondane (Strand & Gundersen, 2019). RRR used to be a part of a larger region consisting of both Dovre and Rondane (Andersen & Hustad, 2004; Figure 1b). Due to fragmentation in form of main roads, cabin development areas and human traffic within the reindeer range, Rondane is divided into at least three quite isolated reindeer populations (Strand & Gundersen, 2019). There are two herds in RN, on each side of "Rondanemassivet", and one herd in RS, south of Fv 27. There is a fourth small population (approx. 100 individuals) at Finnsjøfjellet, which is a part of RRR for practical reasons, but this population originates most probably from Sølnkletten (Jordhøy, 2008; Rolandsen et al. 2022). RS is most suitable as a summer range, while RN has better winter habitats (Punsvik & Frøstrup, 2016). RN consist of alpine steep terrain, also areas above 2000 m.a.s.l., and has considerable amounts of lichen. In general, RS consists of more flat terrain with hills, forests and bogs compared to Rondane North. The management goal is to keep a sustainable Reindeer population, with a winter population on approximately 1600 individuals in the North area RN and 2300 individuals in RS (Villrein, n.d.).

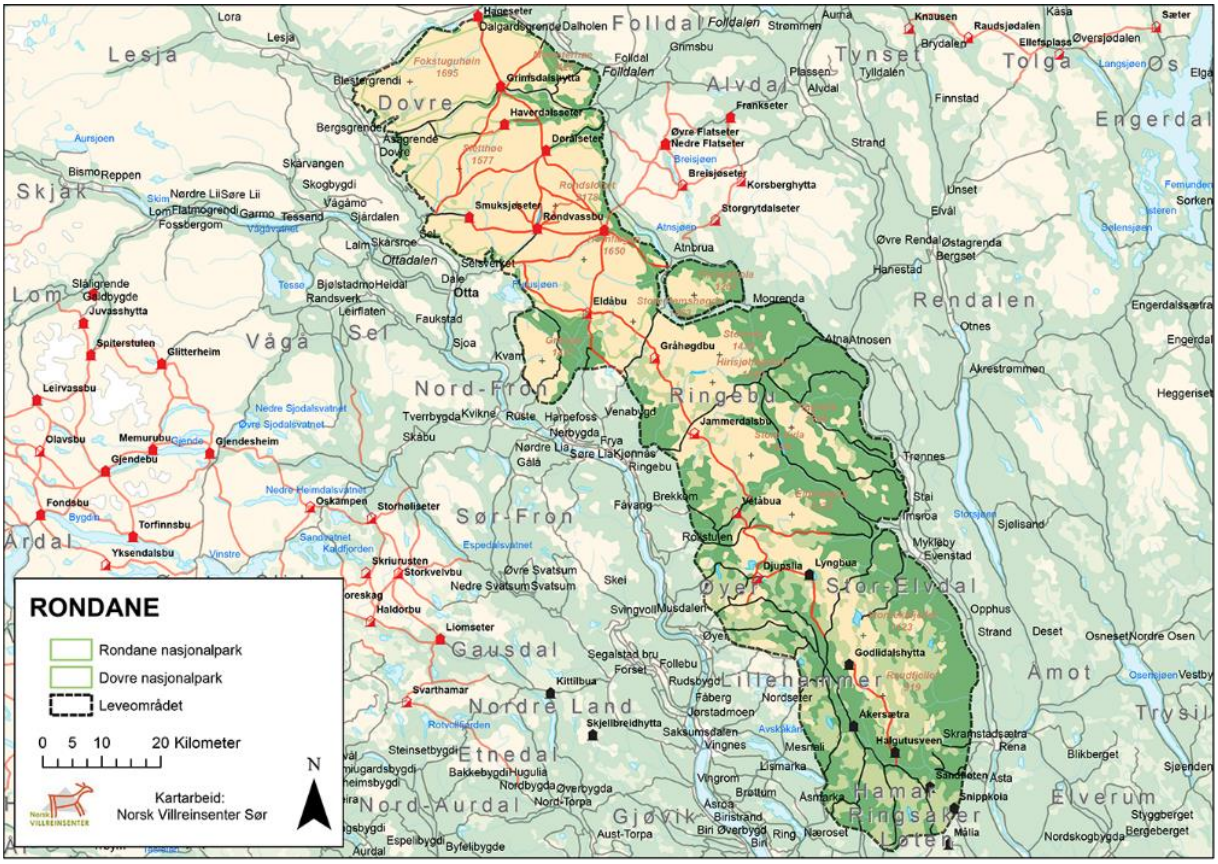

Figure 2. Rondane Wild Reindeer Range with Dovre up north, and Ringsaker down south (Villrein.no). Red lines show paths connecting tourist cabins (red and red-and-white squares). The black lines are roads.

2.1.2 Focus Area: Rondane South

The location of RS creates a high accessibility for people in general, and the geographical form of the area is long and narrow with easy visitor access from many entrances from the Gudbrandsdalen valley and some from the Østerdalen valley in the east. E6 through Gudbrandsdalen and Rv. 3 through Østerdalen are main highways between north and south in Norway, and RRR is available through these roads. Fv 27 Venabygdsfjellet, Friisvegen (Imsdalsvegen) and Birkebeinervegen are roads which cross over the reindeer area, from east to west. Construction of hotels, cabins, and resorts for tourists are developed in several places surrounding the fringe areas of the reindeer range. Venabygdsfjellet, Sjusjøen and Hafjell are examples of these types of establishments including large areas with second-home development. This infrastructure development has led to a dens network of gravel road in the fringe areas, and partly within the administrative border of the reindeer area. There are include in additional a dense network of hiking trails and groomed ski tracks associated with the second-home developed areas. Comprehensive second-home development the last decades and in addition an increasing trend of spending time outdoors in the Norwegian population, have caused and increasing use of RS, especially in the fringe zone. Several public cabins, managed by DNT and Fjellstyrene, are very popular pit-stops, and works as connection points for marked trails through the mountain area.

It is not only temporary inhabitants (tourists and cabin owners) that uses these areas. The mountain areas are also important for local inhabitants, with long traditions of hiking, husbandry, and hunting, in addition to subsistence activities like fishing, and berry picking. A general difference between visitors and locals, is that the locals more often use areas off recreational infrastructure, like off marked trails, while the visitors mostly often use existing recreational infrastructure (Strand et al., 2014; Gundersen et al., 2021b). Because the human area-use is so widespread, it overlaps with reindeer area-use, which has led to human – reindeer conflict in regards of complete and temporary barriers, in addition to reindeer avoiding important habitats (Strand et al., 2014, Strand & Gundersen, 2019a+b).

Due to high motorized traffic, the Fv 27 (County Road 27) functions as an almost complete barrier for the reindeer movement, and thus isolated the population north and south of the road (Strand et al., 2014; 2015b). The migration routes and calving areas in RS shows area use from north to south of the range (Figure 3). In general, the reindeer population prefer the areas in higher altitudes in Ringebufjellet during winter, but they are using these areas frequently during summer as well, depending on for instance temperature and insects (Jordhøy, 2008; Strand & Gundersen, 2019). Based on more than 10 years of GPS data (since 2009), these data showed that reindeer density is at its highest in the northern parts of Rondane South (Appendix 5), especially between Friisvegen and Fv 27 (Strand & Gundersen, 2019). This part of the reindeer area consists of open bog-, heather- and lichen areas in addition to mountain areas (Appendix 6). The reindeer area use during summer season will be thoroughly discussed in this thesis.

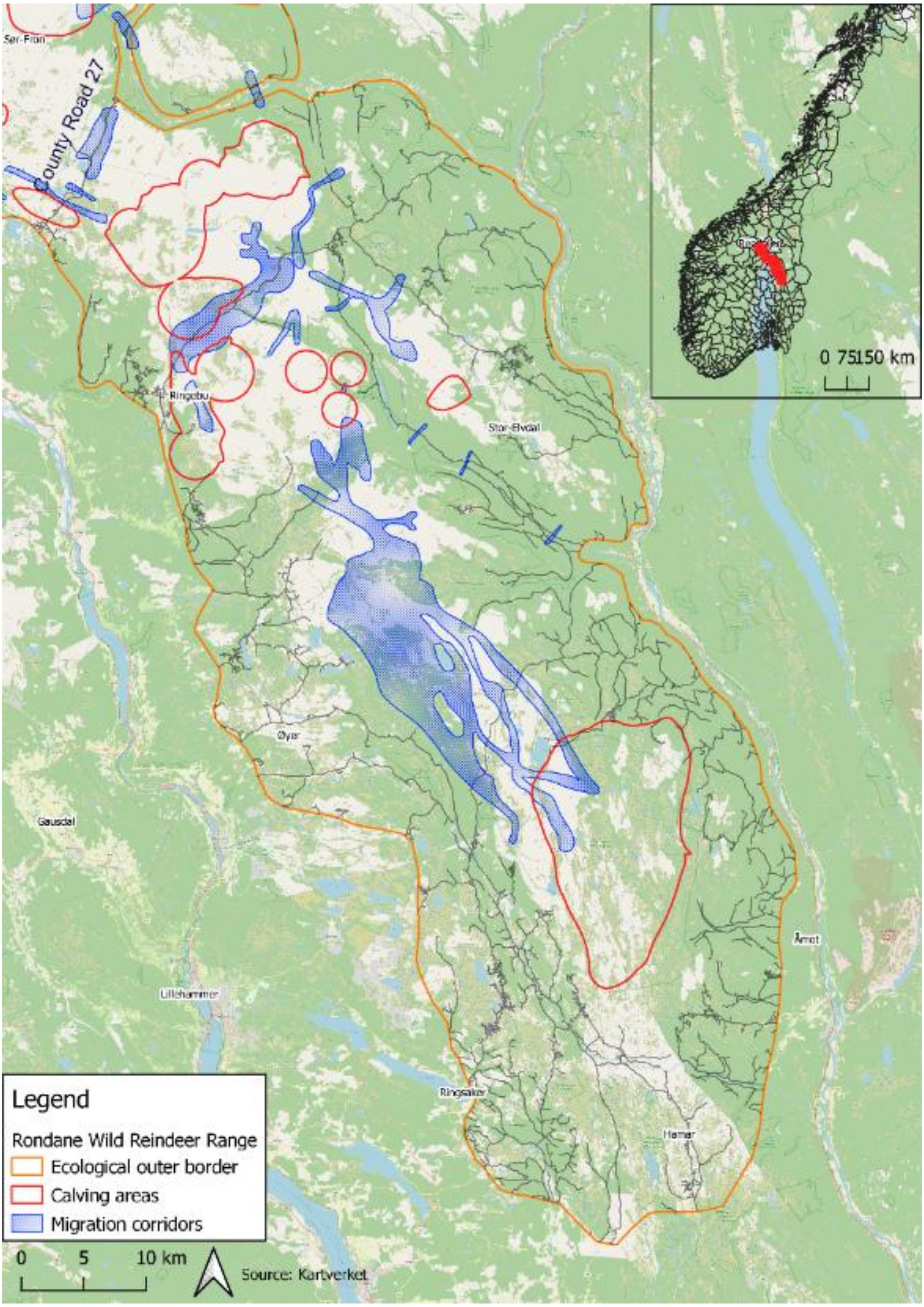

Figure 3. Rondane South Wild Reindeer Range, including migration routes (blue buffers) and calving areas (red circular areas).

2.2 Data retrieval

2.2.1 Reindeer activity data based on GPS-collars

Using GPS-collars, the Norwegian institute of Nature research monitored wild mountain reindeer in RRR, both north and south of the Fv 27, in the period from 2009 to up to date. Several individuals of **female** reindeer got monitored each year. These individuals with GPS-collars belong to a larger herd that include calves, but the data is not representing herds of male reindeer. I retrieved this data as a shapefile and used QGIS (Desktop 3.20.3) to find GPS-collars with locations in the study area in the period of 2009-2019. Because this thesis focuses on summer season, I proceeded with data from June to august of 2016 to 2019. These years were chosen because the Strava data available was limited to this time-period.

2.2.2 Human activity data based on Strava

To measure the amount of human activity in Rondane South, data from the Strava Application and Strava Metro dashboard was implemented in this study. Originally, athletes used this watch-compatible application to track their work-out sessions, but the user-crowd has expanded to include regular outdoor users (Barton et al., 2021). This smart-phone application gives people the opportunity to combine both exercise and geographical position information (Gundersen et al., 2021b). People can choose to register trips within the main categories running, bicycling, water- and winter activities. There is also an extensive list of other activities that can be logged but these are not available data. An online global heatmap visualizes where there are registered trips, graded from lower to higher intensity (Strava, n.d; Appendix 3).

I retrieved data that included shapefiles of Strava-activity from 2016 to March 2020 by using Strava Metro dashboard download function. By using data until March 2020, I avoid effects due to Covid-19 restrictions that was introduced 12th of March in Norway. Data from each summer season were chosen for further work. The datasets include information about activity types, activity- and athlete counts in both a yearly, monthly, and hourly perspective. The data is based on segments of trails and roads, and how much activity there are in each of those segments. Segments are built on numbers of registrations within the app in an exact area. A segment is sometimes just a part of a trail/road. The activity count may differ in different parts of the trail because people turn at different places, resulting in several segments along a road or trail.

2.3 Preparation of Strava data

2.3.1 Buffer zones:

The buffers are meant to function as a limit surrounding the Strava paths of which the area is of disturbance or not for the reindeers, based on when reindeers notice disturbance in average, and their escape distances (Reimers et al., 2010; Hagen et al., 2019; Gundersen et al., 2021a). I chose to work with the monthly data, because it gave the opportunity to choose a period to work with, without the data sets being too large. I ended up working with data from the summer seasons of 2016 to 2019 (June-August). Using QGIS, the 200-meter-buffer zones surrounding the Strava segments were calculated for each year. The buffers include the exact same information as the original strava-segments. The buffer layers were exported as xlsx-files for further work in Excel (Microsoft Corporation, 2020).

2.3.2 Daily athlete count and Strava Use Index (SUI):

I wanted to work with the average daily number of people in each of the segments. To do so, the monthly number of people were divided by days of the month. A consideration is that the number of people on a trail is higher in real life than in the app. Strava data is also connected to existing infrastructure (Venter et al., 2020), and large parts of RS are far from well developed areas. Other variables, such as weather, temperatures, and vacation periods, may also affect the amount of activity in RS. Based on these considerations, and knowledge from relevant studies using Strava data in Norway (Venter et al., 2020, 2021; Holtmoen 2021), I assumed that the Strava-data in RS is **3%** of the total amount of activity. Based on Strava being 3% of total assumed activity, *total assumed activity* per segment were calculated, which was used to create activity levels (Strava Use Indexes). Strava Use Index (SUI) is defined as the estimated number of persons using a particular path segment during a day. To show a broader specter of the variation of activity in the study area, I chose to have three SUIs:

Low (L-SUI): 0-15
Medium (M-SUI): 16-29
High (H-SUI): 30<

These indexes are based on previous research on how much activity on a path that's accepted before the reindeers avoid crossing the path, 0-15 persons per day seems to cause less problem for the reindeer, but the challenge for the herd to cross over the path increase a lot when the number of persons exceed 30 (Strand et al., 2014; Gundersen et al. 2019, 2020). Research in Rondane has shown that if the SUI increases to more than 30 people a day, the reindeers use areas far away from the paths, to avoid rapid crossing of the paths (Strand et al., 2014). Strand et al. (2015) also found that if the SUI is 3 to 30 people a day, the reindeers will either keep their distance or increase their movement speed, depending on if there are low or high densities of paths. These numbers are similar to the findings of Gundersen et al. (2020) at Hardangervidda, where reindeer herds started to avoid paths that are used by more than 10 to 15 persons per day. When a path is used by more than 30-50 people a day, reindeers avoided crossings.

2.4 Data analysis and statistics

2.4.1 Strava distribution

Total summarized number of SUI segments per year, in addition to the total number of segments each year, were calculated in Microsoft Excel. Descriptive diagrams were made to show the data distribution each year.

2.4.2 Analysis of the merged data from human use (Strava-data) and reindeer use (GPS-positions)

Files from the buffered Strava-data and GPS-positions of reindeer for each year were implemented for comparisons in this analysis. The dataset that was previously used for the Strava distribution got divided into separate years. A count-analysis (number of GPS reindeer positions) was run with the tool *"Count points in polygon"* in QGIS. The analysis was repeated for each year to avoid GPS-positions being counted in segments across years, but also to keep the opportunity of comparing the different years in later analysis sessions.

The Field calculator were used to calculate the size of the area occupied by Strava. Because the study area was clipped to the municipality borders, some areas north of County Road 27 was implemented in the study area. By using the same method as for the buffered Strava segments, the study area got a size of approximately 3000 km^2.

After organizing the yearly data into one common file in excel, so that it included both *segments*, *mean daily activity count*, *SUI* and *year*, means and confidence intervals were calculated based on *N of segments* and *Std.Error*. I proceeded to R (R Development Core Team, 2020) and Rcmdr (Fox & Bouchet, 2020). Using a linear model, I ran a one-way ANOVA with *Year* as the explanatory variable, and *number of GPS points* as the response variable (lm (formula=N of GPS~Year)). In addition, a two-way ANOVA where *SUI* was added as an explanatory variable, were conducted (lm (formula=N of GPS~Year*SUI)).

A Distance analysis (*Distance to nearest hub (points)*) was conducted in QGIS to look at the difference in distance to segments of high, medium, or low SUI. The strava buffers from the previous analysis and the GPS-positions for Reindeer were implemented. The result layer included all the original information about the GPS-positions, in addition to *distance to the nearest segments*. The analysis was repeated each SUI. All files got exported and combined in Excel.

After organizing the raw data so that it included *distance to segment, intensity level* and *year,* means and confidence intervals (95%) was calculated using *N of points* and *Std.Error.* In R (Rcmdr), a two-way ANOVA were conducted with a linear model, using *Intensity* and *Year* as explanatory variable and *Distance to segment* as response variable (lm (formula=Distance ~ Intensity * Year)). Subsequently, a one-way ANOVA with *Intensity* as the explanatory variable was run (lm (formula = Distance ~ Intensity)).

2.5 Descriptive results of areas used and avoided by reindeer

The reindeer plots were run in a kernel density-analysis to get a visualization of where there are most registered GPS-positions in RS. To get a better understanding of why reindeers choose to use one area instead of another, and if the activity in RS, measured by the Strava data, can indicate a possibility of avoidance, I compared amounts of Strava segments, different road types, number of cabins and other establishments, and general habitat types within the study area.

Three categories of road types were implemented. *Main roads* are explained as developed roads for driving over further distances, while *smaller roads* are less developed, but still possible for driving. It can be for instance a road leading up to farmhouses. *Trails* are paths for hiking or bicycling in the terrain. For the variable of Buildings, I chose to use *cabins, farmhouses,* and *huts*. *Cabins* are second homes, mostly for temporary inhabitants. *Farmhouses* are farmer settlements located in the mountain areas for summer season farming, while *huts* are small, low-standard cabins, often located in the terrain. These are often used for hunting or resting during hiking trips. The habitat types included *cultivated areas, rivers, lakes, bogs, forest, quarries,* and *open mountain areas.* All this data was available via Geonorge.no.

All variables were implemented in QGIS for further preparation. Two methods were chosen (see below for further explanation). The first one was based on a selection of ten circular areas used (5 areas) and not used (5 areas) by reindeers, while the second method was based on a comparison of the western part (Gudbrandsdalen) and the eastern part (Østerdalen) of the whole

RS. I choose to compare two large areas (Gudbrandsdalen and Østerdalen), because there are comprehensive differences in the number of GPS-positions in these two areas, with far more GPS positions in the Østerdalen area. I wanted to see if there were any specific differences for the variables chosen between those areas that could explain this large-scale reindeer area use.

2.5.1 A comparison of selected circular areas avoided and not avoided by reindeers

Various locations with and without registered GPS-positions of reindeer were selected in QGIS, and separate layers for buffers with and without GPS-positions were made. I use circles with a 5 km radius as buffer area (Figure 4a), based on the assumption that reindeers use large areas in search of food within their daily movements. I selected the areas with no registered GPS-positions based on locations of old trapping systems, but also as a good representation of all areas that have no registered GPS-positions. The locations within areas with registered GPS-positions were chosen approximately in the center of the reindeer clusters. The layers containing roads, Strava-data, buildings, and habitat types were clipped to these buffers, and exported as xlsx-files for statistical preparation in excel.

The various categories of data were analyzed in excel. I combined the data from areas with GPS-positions with the data from areas with no registered GPS-positions and made comparison diagrams based on total numbers of data within each variable, within each area unit. *Strava segments*, *roads*, *buildings*, and *habitat types* got a diagram each.

2.5.2 A comparison of the Gudbrandsdalen and Østerdalen areas

Because results from QGIS indicate that Reindeers prefer Østerdalen and show avoidance towards Gudbrandsdalen, I decided to run a comparison of the same variables as the 5 km buffer comparison. Following the municipality borders, polygon layers for Gudbrandsdalen and Østerdalen were made (Figure 4b). The size of each area unit was calculated in the field calculator, and the area units was quite similar in size. Gudbrandsdalen is approximately 1538 km^2, and Østerdalen is approximately 1495 km^2. I followed the same procedures as for the previous method in regards of model-making in excel.

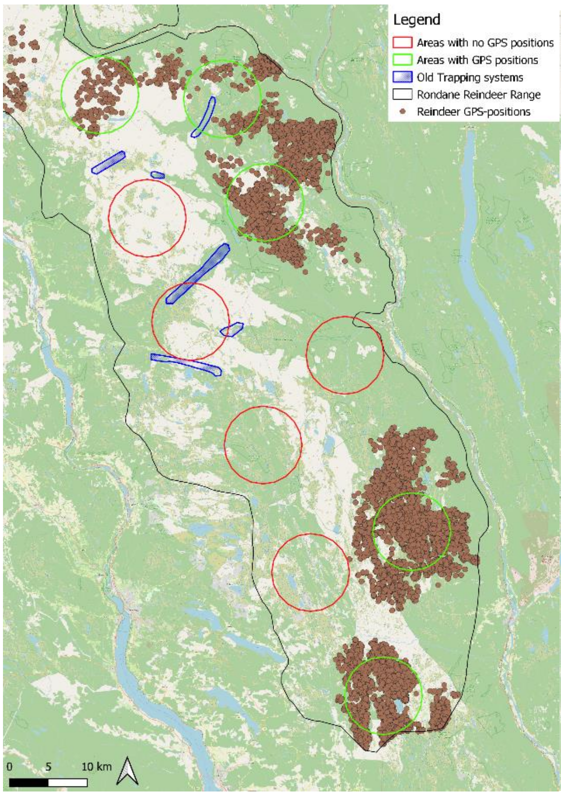

Figure 4a. Method 1 – 5 km Buffers of areas used and not used by reindeer in RS. Green circles area areas with GPS-positions of reindeer, while the red circles are areas without GPS-positions. Old trapping systems area marked as the blue buffered areas (The positions of the trapping systems are collected from Jordhøy et al., 2012).

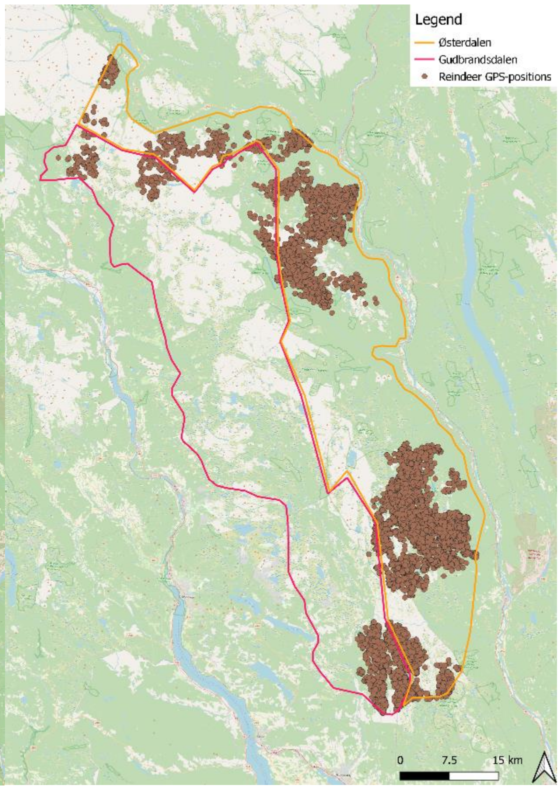

Figure 4b. Method 2 – The borders of Gudbrandsdalen (pink border on the east side) and Østerdalen (orange border on the west side). Gudbrandsdalen is approximately 1538 km^2, and Østerdalen is approximately 1496 km^2

3. Results

3.1 Descriptive presentation of the human and reindeer use of the RS area

3.1.1. Reindeer use of the area

I found that during the time-period for my study (summer 2016 – summer 2019) the GPS position density was highest in the southern part of RS, in addition to an area further north close by Løvåsvatnet (Figure 5). These areas have in common large tracks of forest and bogs, and less open mountain areas. The reindeer area use varies significantly from year to year in the study period (Figure 6). In 2016, the reindeer area use is concentrated in a small part up north, while the area-use in 2017 and 2018 are in the southern parts of RS. In 2019, the reindeer area use is more widespread, with locations both in the northern and southern parts of RS.

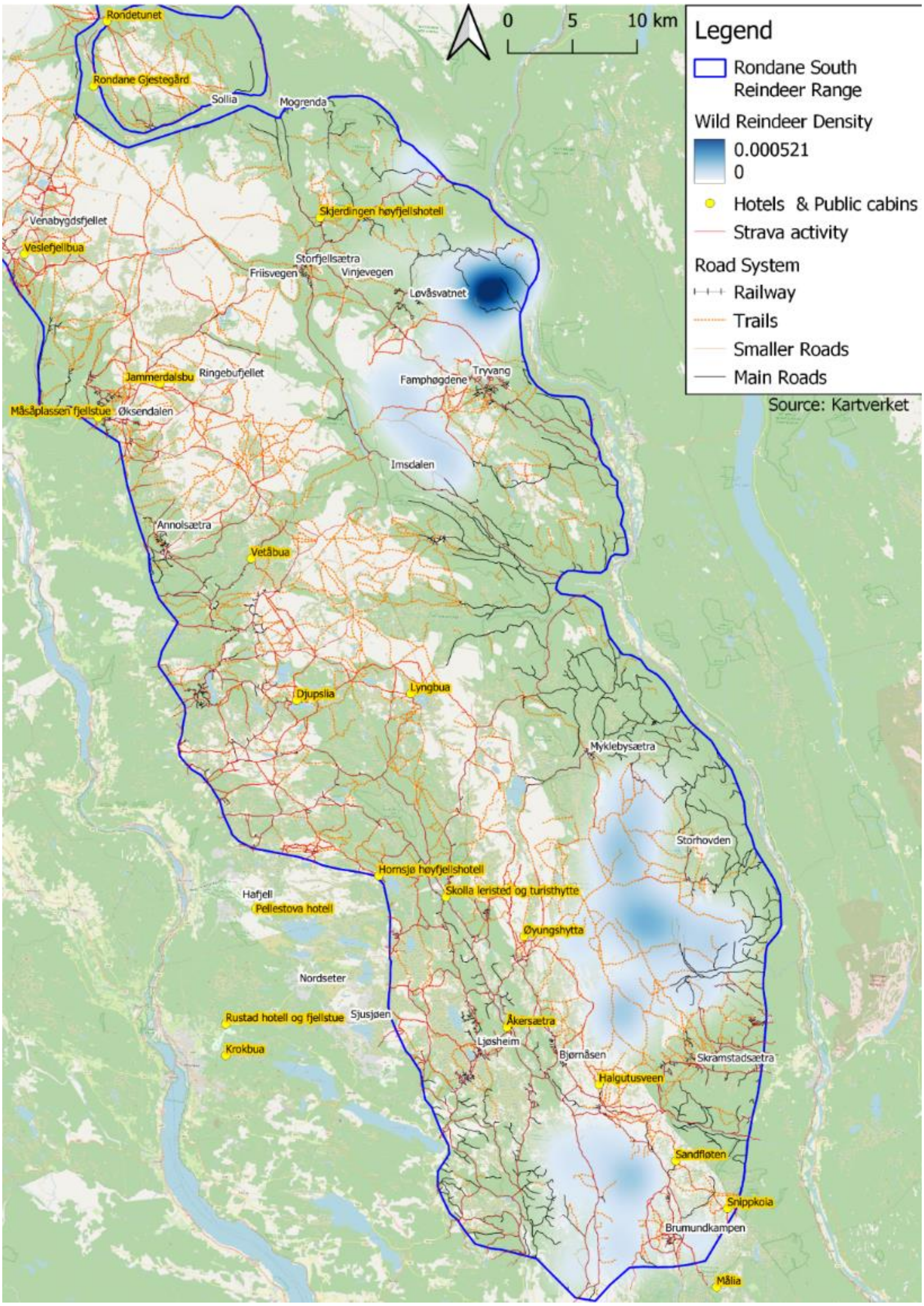

Figure 5. Reindeer- and human area use of Rondane South Wild Reindeer Range. Based on GPS-data during summer from 2016 to 2019. The blue spots show density of the reindeer, where darker blue means higher densities and lighter blue means lower densities. The yellow spots are hotels and public cabins inside and outside of the range.

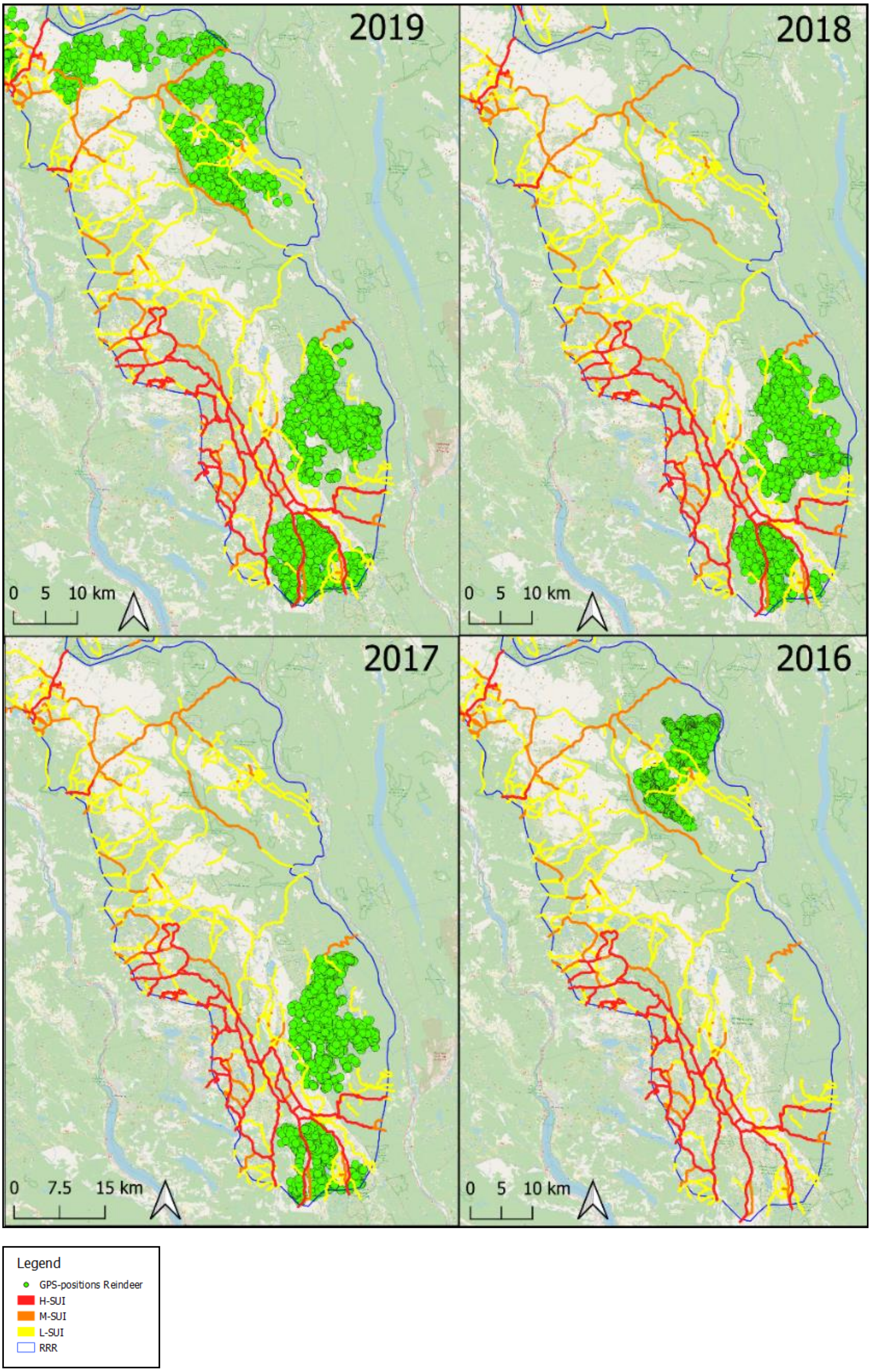

Figure 6. Variations in reindeer area use (green dots) in RS from 2016 to 2019, in relation to high (red), medium (orange), and low (yellow) SUI.

3.1.2. Human use of the area

The number of registered Strava-segments summertime in RS has increased from 2016 to 2019 (Figure 7). There is an increase of 38 % in registered segments in these four years. There are most segments with L-SUI, but the number of H-SUI and M-SUI have also increased during these summers (Figure 8, Table 1). An increase in registered segments as observed during these years, increased the spatial recreational use of RS (Appendix 1).

Table 1. Total number of segments within each SUI per year, and the total number of segments within each level.

	2016	**2017**	**2018**	**2019**	**Total**
H-SUI	381	326	425	411	1543
M-SUI	227	307	433	432	1399
L-SUI	1263	1354	1727	1733	6077

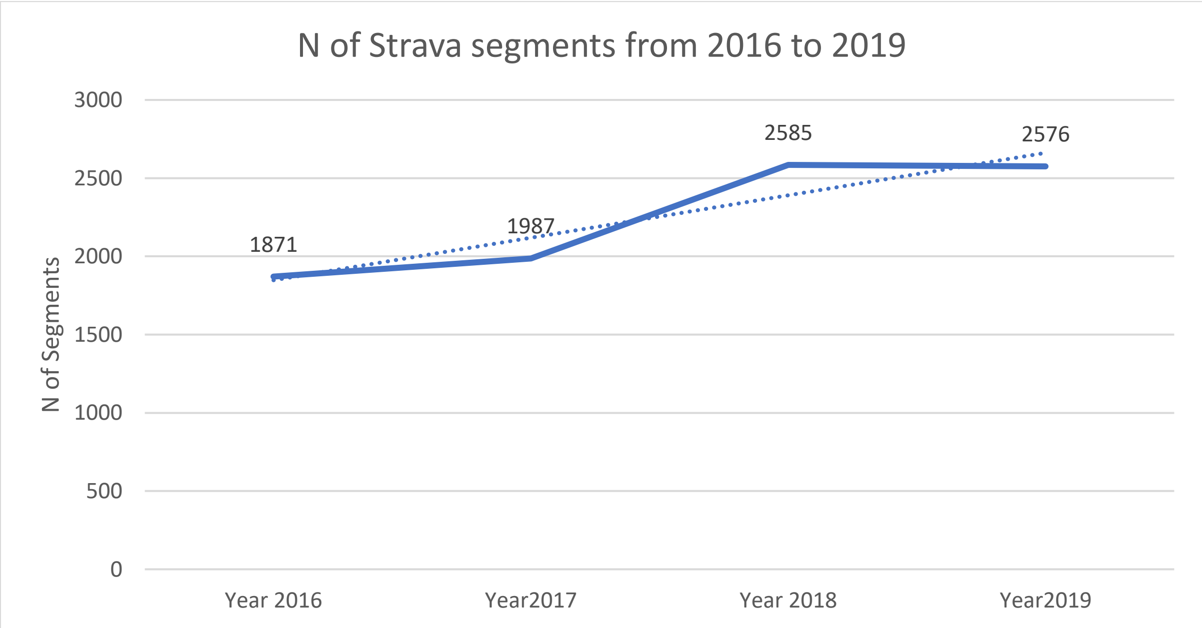

Figure 7. Total number of Strava segments each year, showing an increased spatial recreational use of RS.

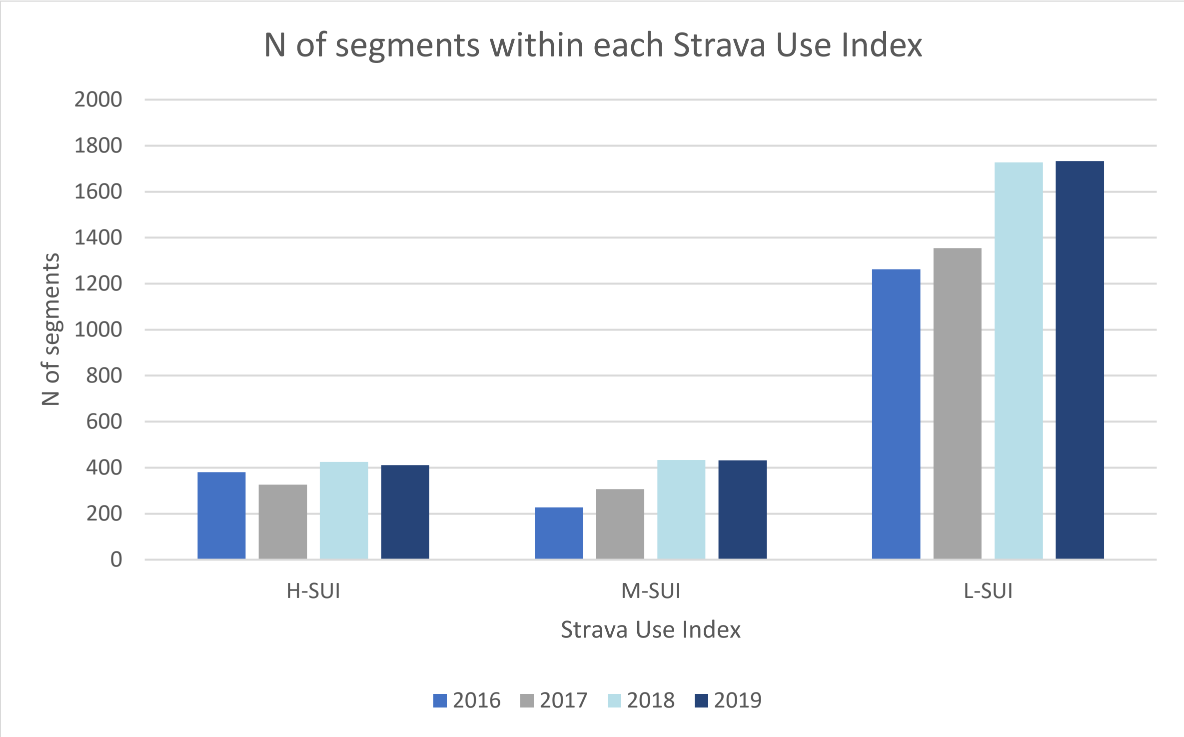

Figure 8. Total number of Strava segments each year within each SUI. The Strava use Indexes are based on the Assumed daily athlete count, with boundary values based on previous research of path avoidance by Rangifer tarandus t. Boundary values: L-SUI: 0-15; M-SUI: 16-29; H-SUI; 30+.

3.2 Habitat use of reindeer: Comparative analyses at three different scales

3.2.1 Small scale analyses of the Strava segments

3.2.1.1. Count analyses of reindeer positions inside and outside the Strava segments buffer zone

My results show that very few of the total N of GPS-positions of reindeer herds are registered within the 200m buffer along all Strava segments in RS (Table 2). I found no statistical differences between the number of GPS-positions within the different SUIs in the period 2016 to 2019 ($F_{11.57}=1.44$, $p=0.148$, $R2=0.002$) (Figure 9), meaning that they are similar low for all segments. When comparing the difference in number of GPS-positions each year within the buffer area, the mean number of GPS-positions was significant higher in 2019 than any other year ($p=0.0369$, Figure 10). However, the ANOVA model comparing number of segments from 2016 to 2019 is not significant ($F_{3.57}=3.018$, $p=0.028$, $R2=0.001$). There was a broader distribution of GPS-positions in 2019 than any other year (Figure 6).

Table 2. Total number of GPS-positions within areas of H-SUI, M-SUI, and L-SUI each year in addition to the total number of GPS-positions in the Study area.

	High	**Medium**	**Low**	**Total N of GPS-points**
2016	0	0	20	4276
2017	3	0	10	2726
2018	5	0	11	2819
2019	1	31	109	7083

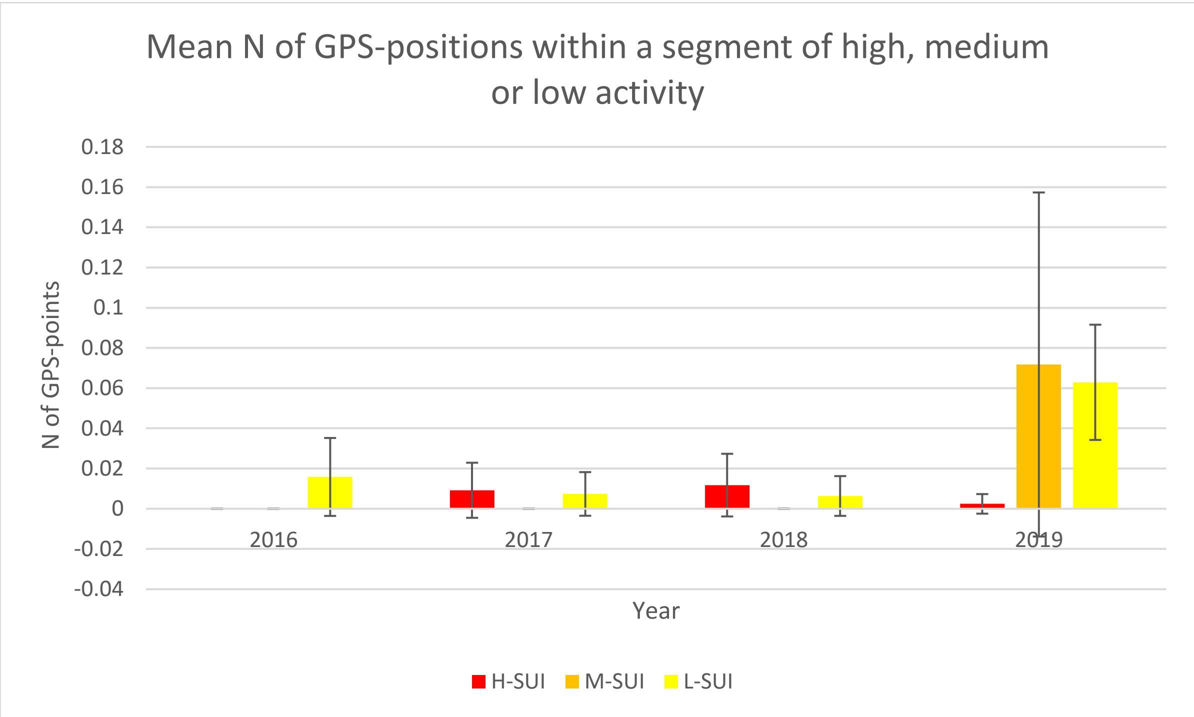

Figure 9. Mean number of GPS-positions (±2SE) within a segment, compared by year and SUI. The colors are like the colors of each SUI on the maps.

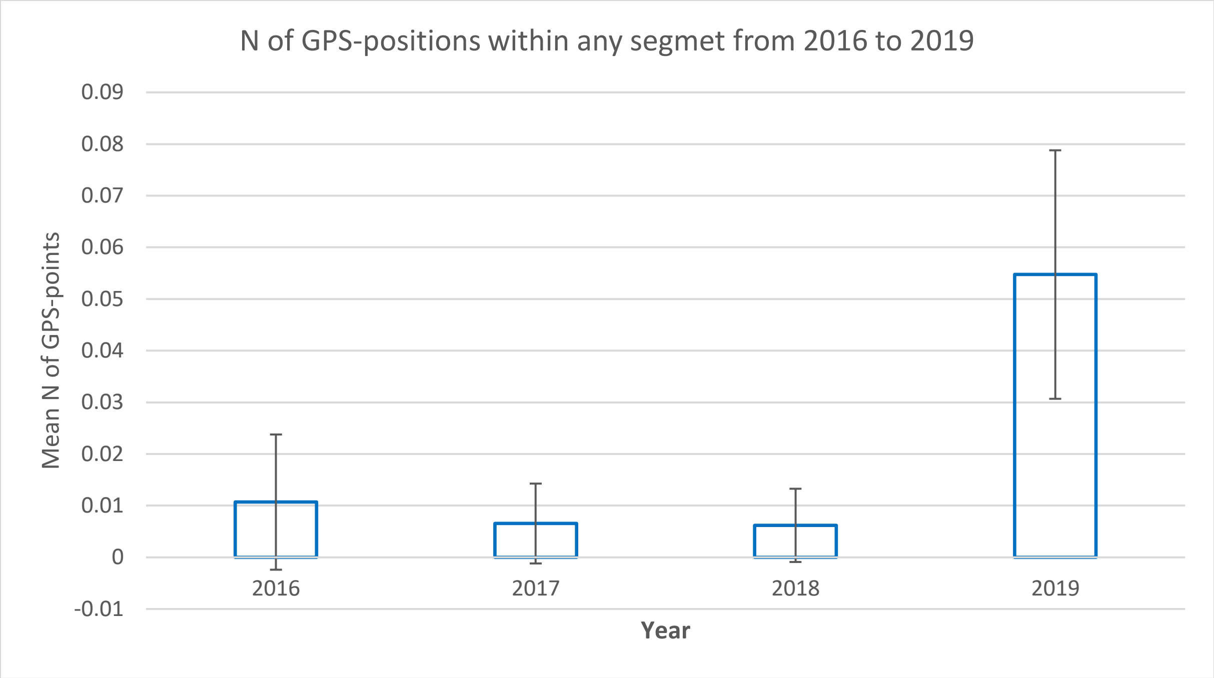

Figure 10. Mean number of GPS-positions (±2SE) within a segment compared by years.

3.2.1.2. Distance Analysis to the nearest Strava segment

The distance from the GPS-positions to the nearest SUI segment with L-SUI, M-SUI and H-SUI varied significantly between years ($F_{11.507}$= 1.214e+04, p<0.001, R^2=0.72) (Figure 11, Table 3). The mean distance to nearest segment varied from approximately 12 000 meters in 2016 to 5000 and 6000 meters the following years. In 2016 the distance to H-SUI was in average more than 25 000 meters, approximately three times as long as the following three years. In 2016, the GPS-collared reindeers were in areas far away from H-SUI, compared to any other year (Figure 6).

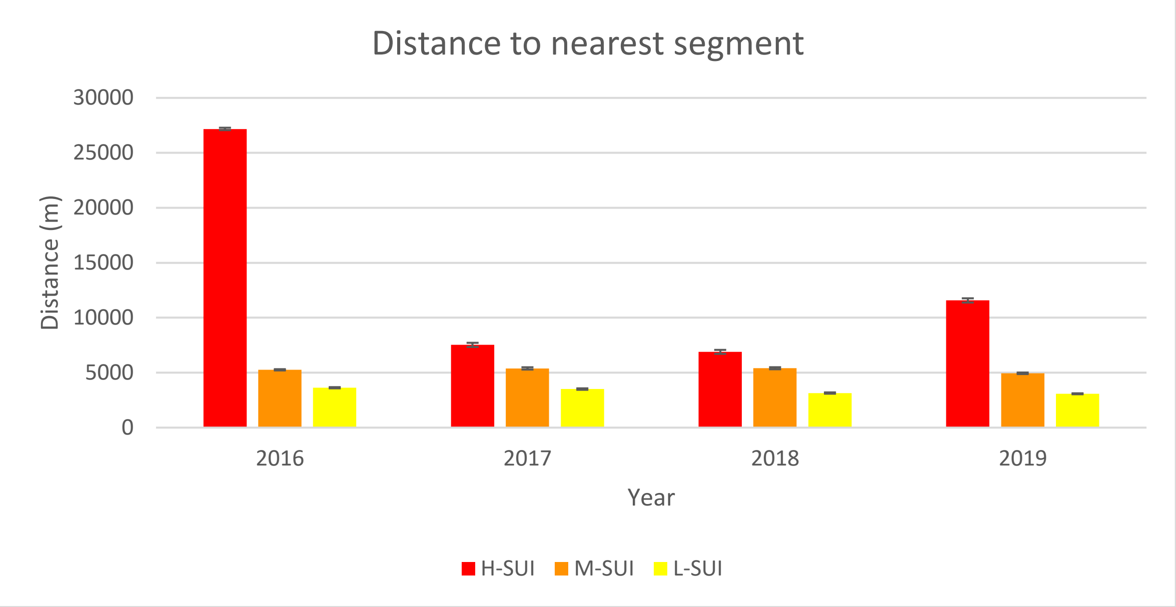

Figure 11. Mean distance (±2SE) to nearest segment within each SUI per year. The color of each category matches the color gradings of Strava segments in the maps.

Table 3. Linear model (Rcmdr) of the Distance analysis. Comparison of distance to nearest segment by activity level (SUII) and year.

Call: lm(formula = Distance..m. ~ Activity.level * Year, data = Distance)					
Coefficients:	**Estimate**	**Std. Error**	**t value**	**Pr(>|t|)**	**Significance**
(Intercept)	27175.02	61.59	441.2	<2e-16	***
Activity.level[T.low]	-23545.8	87.11	-270.3	<2e-16	***
Activity.level[T.med]	-21915.47	87.11	-251.6	<2e-16	***
Year[T.2017]	-19646.55	98.71	-199	<2e-16	***
Year[T.2018]	-20280.94	97.71	-207.6	<2e-16	***
Year[T.2019]	-15600.28	78	-200	<2e-16	***
Activity.level[T.low]:Year[T.2017]	19524.59	139.6	139.9	<2e-16	***
Activity.level[T.med]:Year[T.2017]	19774.6	139.6	141.7	<2e-16	***
Activity.level[T.low]:Year[T.2018]	19797.7	138.19	143.3	<2e-16	***
Activity.level[T.med]:Year[T.2018]	20423.89	138.19	147.8	<2e-16	***
Activity.level[T.low]:Year[T.2019]	15050.65	110.31	136.4	<2e-16	***
Activity.level[T.med]:Year[T.2019]	15283.87	110.31	138.6	<2e-16	***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1					
Residual standard error: 4028 on 50700 degrees of freedom					
Multiple R-squared: 0.7248, **Adjusted R-squared**: 0.7247					
F-statistic: 1.214e+04 on 11 and 50700 DF, **p-value**: < 2.2e-16					

3.2.2. Medium scale analyses of circular areas used and not used by reindeer

The habitat characteristics that are most widespread in all the different areas, are bogs, forest areas, lakes, and open areas (Figure 12). The areas used by reindeer consists of more lakes, bogs, and forest habit than those not used by reindeers. The areas not used by reindeers have more open mountain areas than areas used by reindeer.

Cabins are the most widespread building type in areas no matter being used or avoided by reindeers (Figure 13). There are more of every building type in areas avoided by reindeer, but the biggest difference is in the number of cabins, where areas avoided by reindeers have a larger number of cabins.

Trails and main roads are more common than smaller roads within the areas studied (Figure 14). There are more of every road type within the areas that's avoided by reindeers.

There are most low-level segments within the areas (Figure 15). Areas avoided by reindeer have more segments of H-SUI and L-SUI, while the areas used by reindeers have more M-SUI segments than areas avoided by reindeers.

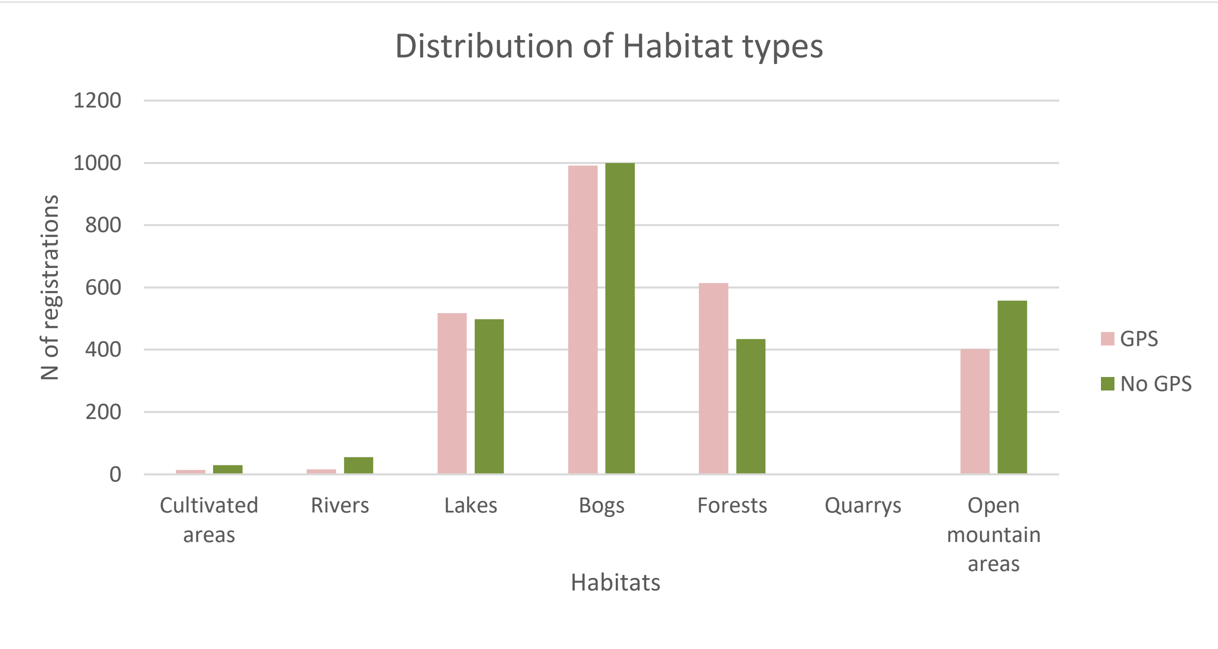

Figure 12. General distribution of habitat types within 5km circular buffers of selected areas used and avoided by reindeer. The areas are based on areas with and without GPS-positions in RS (Figure 7).

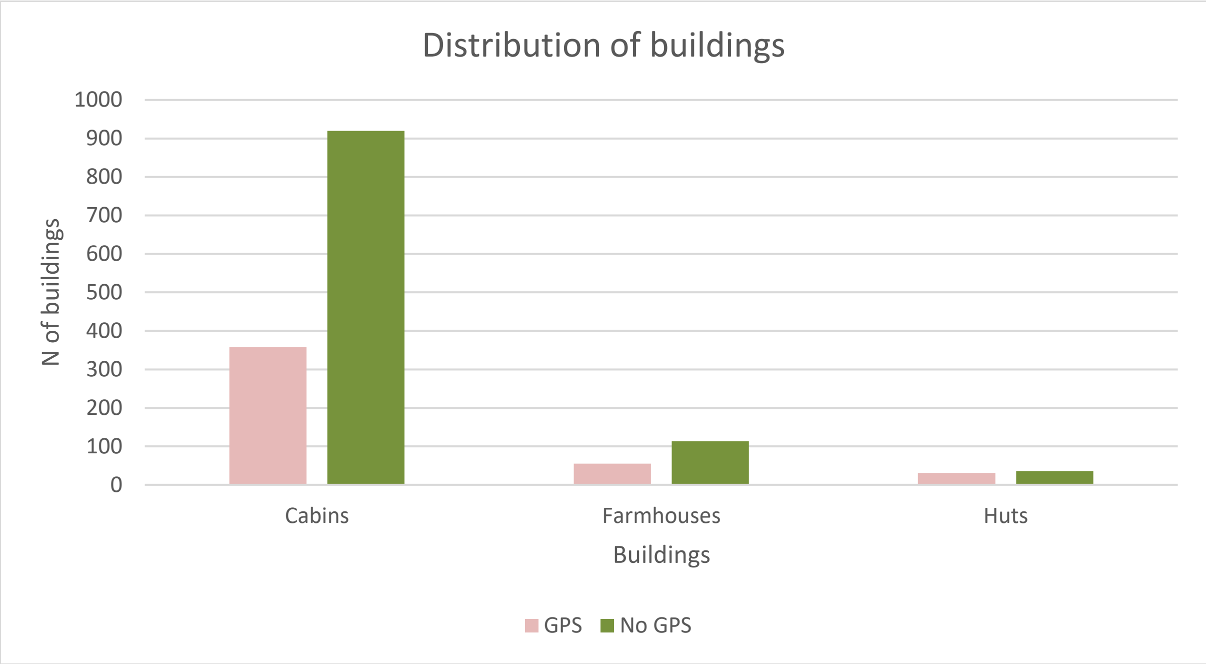

Figure 13. Number of cabins, farmhouses, and huts in circular areas with and without GPS-positions of reindeer.

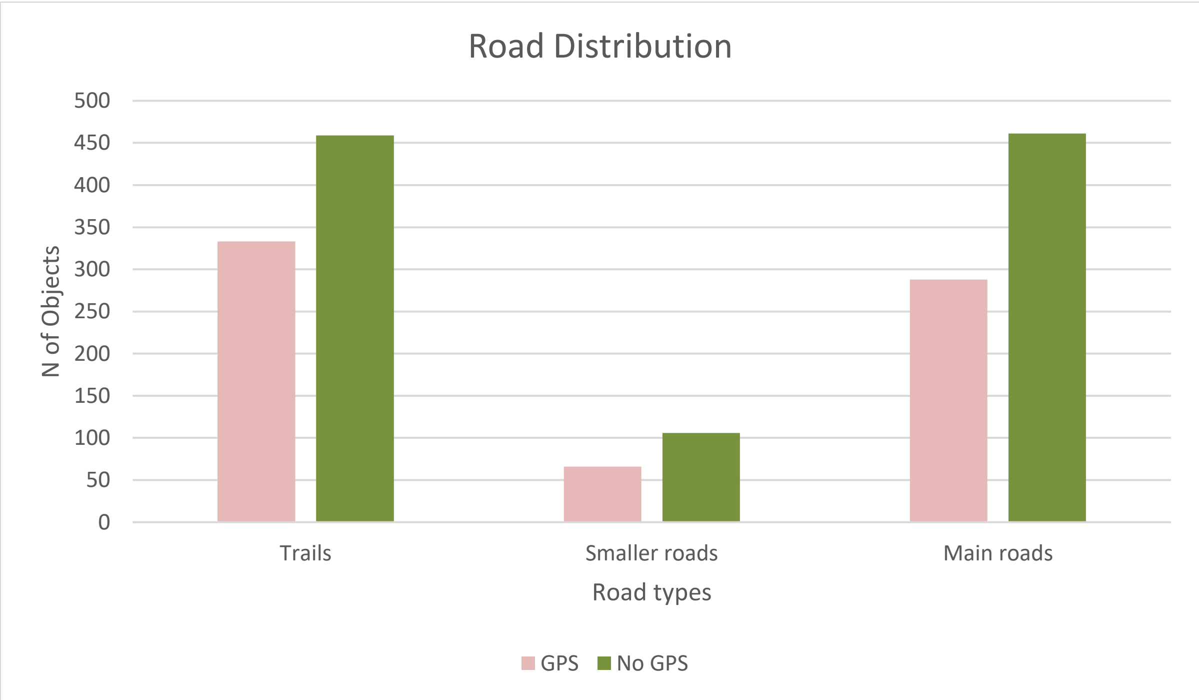

Figure 14. Number of main roads, smaller roads, and trails in circular areas with and without GPS-positions of wild reindeer.

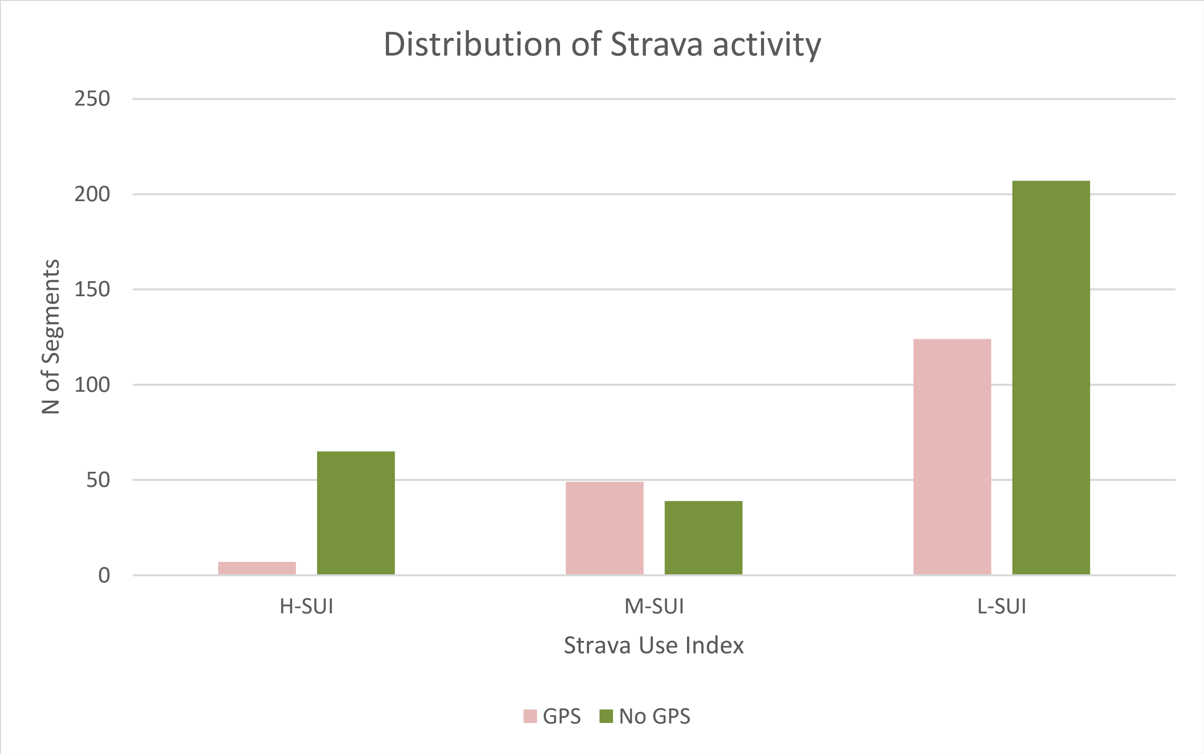

Figure 15. Difference in number of H-SUI, M-SUI, and L-SUI of Strava segments, within circular areas used and avoided by reindeer. The data used for this analysis are based on 5 km buffers of selected areas with and without GPS-positions in RS.

3.2.3. Large scale analyses of the Gudbrandsdalen and Østerdalen areas

Almost all GPS-positions of reindeer are registered in Østerdalen, while there are very few registered in Gudbrandsdalen (Figure 16). The areas surrounding the prehistorical trapping systems are also completely avoided by the reindeers during summer season, except from Imsdalsvola far north and east in the RS area. Visual inspection on the map in Figure 16 showed that there are much more registered Strava-segments within each SUI in Gudbrandsdalen area compared to the Østerdalen area. I had a closer look at older GPS-material and found that areas in the northern part of RS that have not been used in my study period the last four years, have been used by reindeer herds from 2013 to 2015 (Appendix 2). In the far southern parts, the area use has been similar between years in the same period.

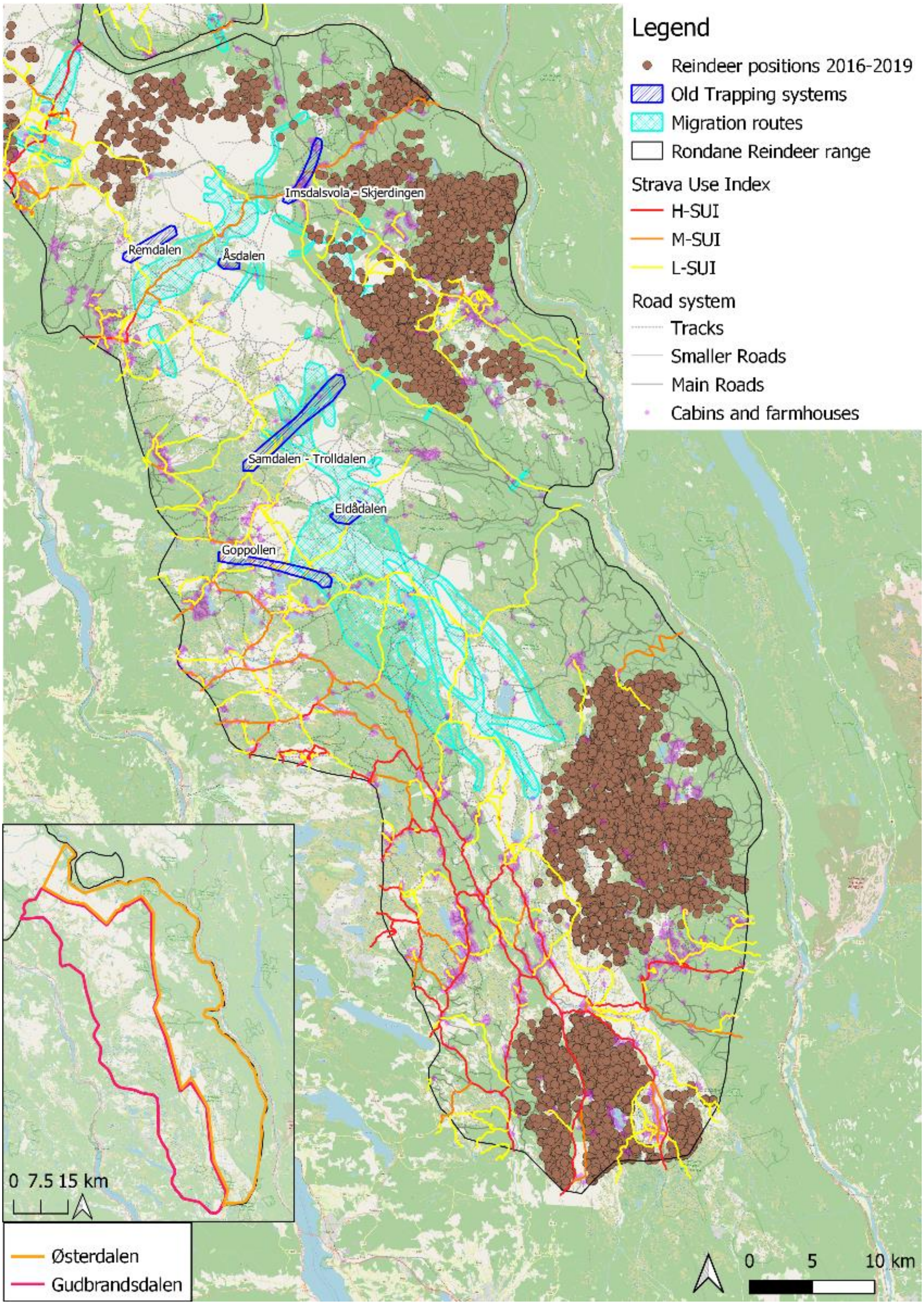

Figure 16. Area-use in Rondane South, including migration routes and old trapping systems. GPS-positions are presented as brown dots, while the migration routes are turquois buffers. The old trapping systems are marked as blue buffers. Strava segments of H-SUI (red), M-SUI (orange) and L-SUI (yellow) are also presented.

The number of registered Strava segments of L-SUI, M-SUI and H-SUI are all higher in Gudbrandsdalen than in Østerdalen (Figure 17). There are approximately three times more registered SUI segments in Gudbrandsdalen than Østerdalen. These results show far more recreational activity in Gudbrandsdalen than in Østerdalen.

The distribution of habitat types is quite similar in Gudbrandsdalen and Østerdalen, except from a larger amount of open mountain areas in Gudbrandsdalen (Figure 18), a habitat type that is preferred by reindeer. Gudbrandsdalen also has a higher amount of both lake- and forest areas, but the difference is not that considerable.

Of all the building types, the cabins have the highest number within both areas. The number of cabins and farmhouses is higher in Gudbrandsdalen than Østerdalen (Figure 19). The number of huts is higher in Østerdalen.

The amount of infrastructure development including both trails and main roads are much higher in Gudbrandsdalen than in Østerdalen (Figure 20), but the number of smaller roads is at a similar low level.

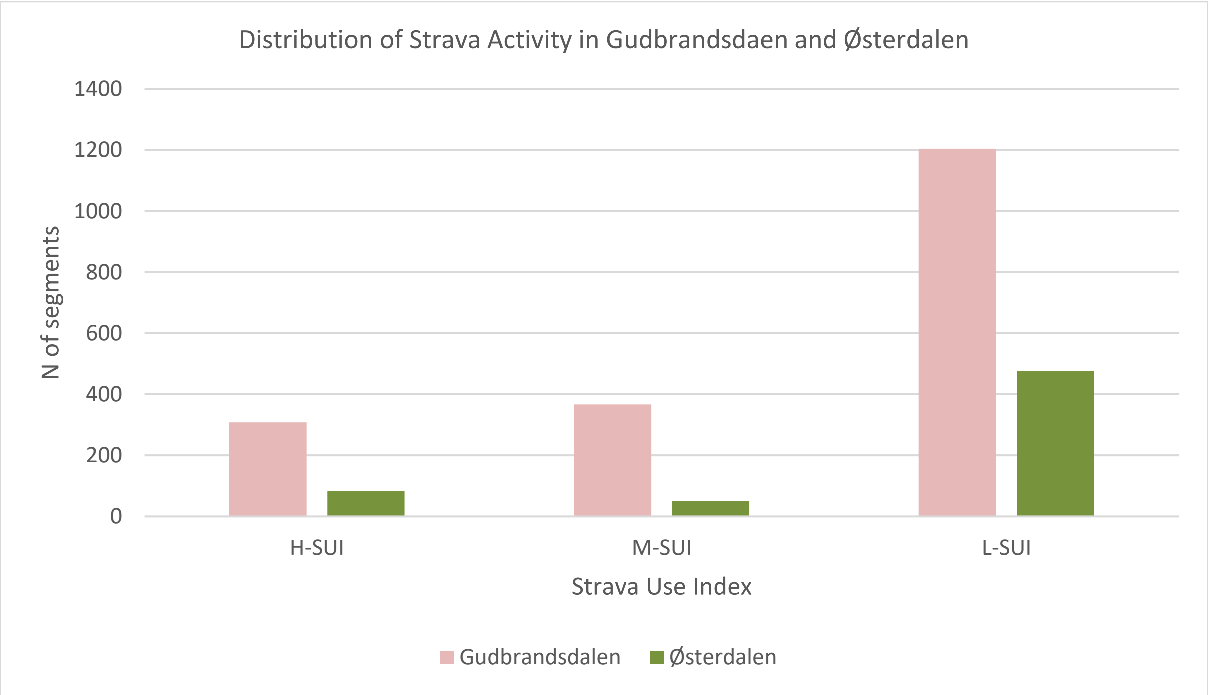

Figure 17. Difference in distribution of H-SUI, M-SUI, and L-SUI of Strava segments in Gudbrandsdalen and Østerdalen. There are more registered segments of each SUI in Gudbrandsdalen than Østerdalen.

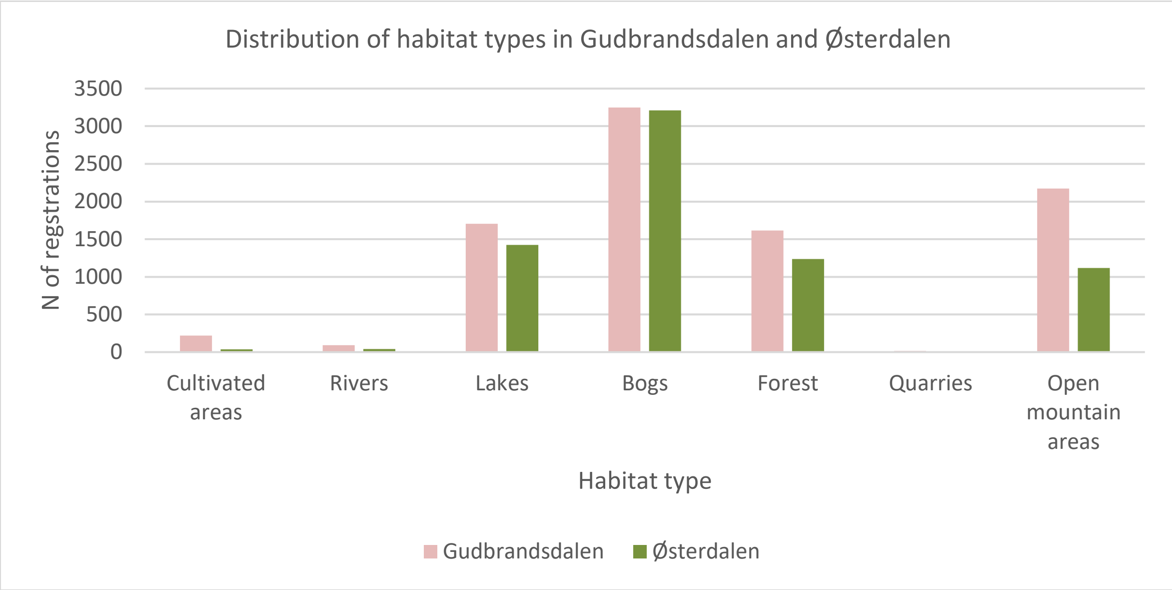

Figure 18. Distribution of habitat types in Gudbrandsdalen and Østerdalen. The distribution is quite similar in both places, except from a higher amount of open mountain areas in Gudbrandsdalen than in Østerdalen.

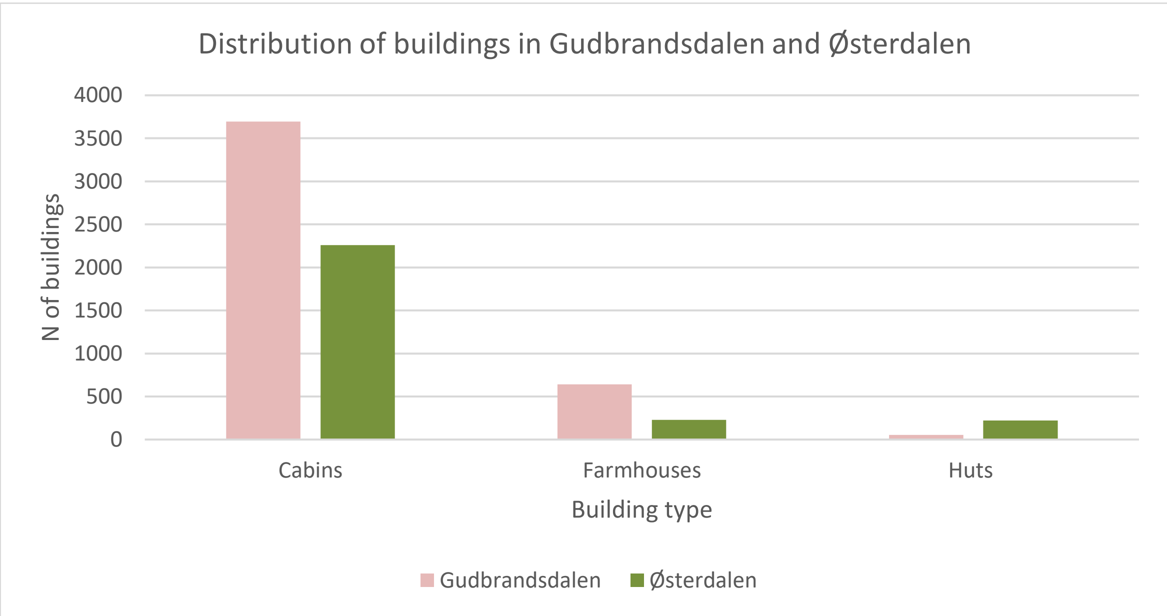

Figure 19. A comparison of building distribution in Gudbrandsdalen and Østerdalen. There are more cabins and farmhouses in Gudbrandsdalen, while there are more huts in Østerdalen.

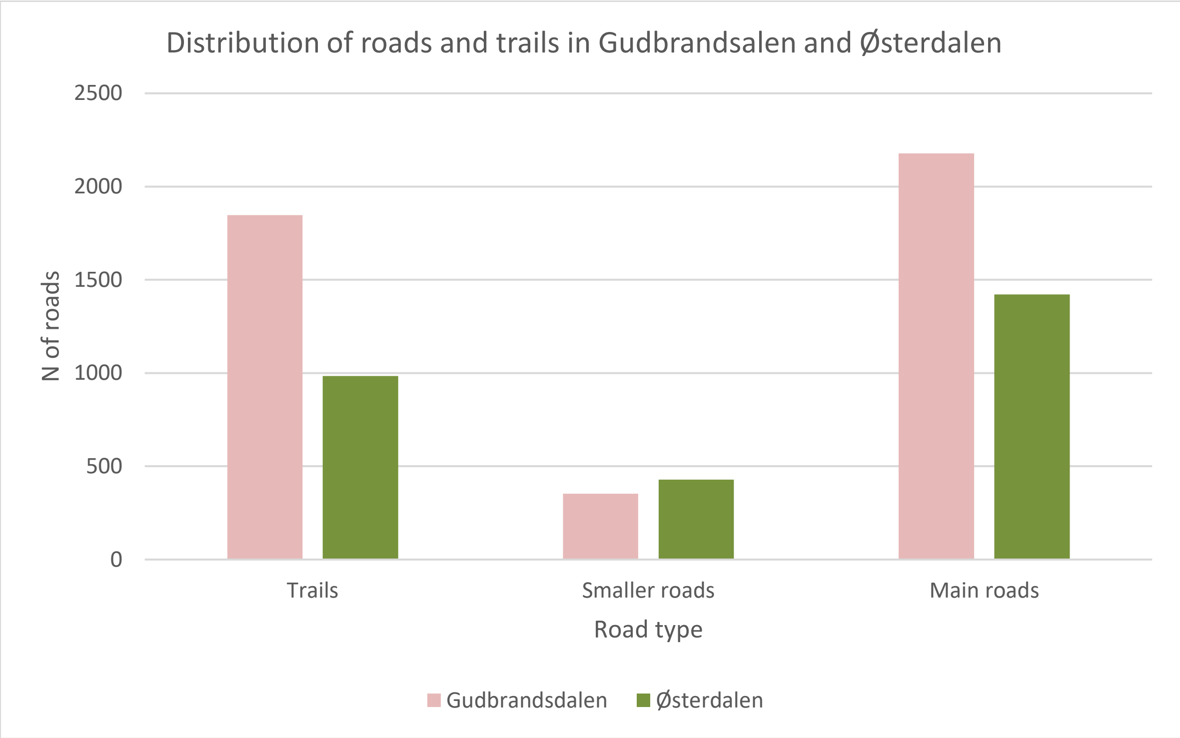

Figure 20. A comparison of road distribution in Gudbrandsdalen and Østerdalen. There are more trails and main roads in Gudbrandsdalen, while the number of smaller roads is quite similar.

4. Discussion

4.1 Wild reindeer herds avoid areas with human activity

The main purpose of this thesis was to use crowdsourced Strava data as a tool to monitor spatiotemporal human use of RRR, and to test the disturbance effects of human activity on reindeer area use during summer based on the Strava data. The results from the comparative analyses on three different levels shows clear reindeer avoidance in areas where there is medium and high level of infrastructural facilitation and Strava activity. Both the count-analysis and distance analysis showed a general avoidance towards the Strava-segments. The result showed an incredibly small number of reindeer GPS-positions within the buffered segments, which, except from somewhat higher number in 2019, did not vary much between years. The analyses of the mean distance to nearest segment, showed that it varied from 12 000 meters in 2016 to 5000 and 6000 meters the following years. However, all these distances are considered to be very long distances regarding the limited size and shape of the reindeer range. The large distance in 2016 is explained by a much more concentrated area use by the reindeer herds in the Fampen area in north-east, far away from areas with high densities of Strava segments. This is especially true for the H-SUI, defined as the most intensively used Strava segments. However, the reason for less GPS positions further south in RS in 2016 is more due to lack of GPS collared reindeer than true area uses this year. Most probably there where reindeer herds further south that where not GPS-collared.

The comparison of circular areas that are used and avoided by reindeer in the medium-scale analysis and the large-scale comparison of Gudbrandsdalen and Østerdalen, showed both similar results in form of strong reindeer avoidance towards infrastructural facilitation and Strava activity. The comparison of Gudbrandsdalen and Østerdalen area showed that the reindeer area use was skewed to the east Østerdalen side of RS, an area with far less infrastructure and Strava activity. However, both these large-scale areas consist of quite similar habitat conditions of mountain conifer and deciduous forest and bogs, which are preferred areas for the reindeer herds in RS (Strand & Gundersen, 2019). Interestingly, there is much more open mountain areas in the Gudbrandsdalen area than Østerdalen, but still Gudbrandsdalen is less used by the reindeer during summer. RS represent in this way a special case of reindeer area-use in Norway, together with Setesdal-Austhei reindeer range far south in Norway, in the way that they preferred mainly lower elevations forests and bogs during summer (Roaldsen et al. 2022). There is less knowledge about what kind of resources the reindeer preferred in forest dominated areas, regarding grazing resources and how they cope with insects and need for cool environment during hot summer days (Strand & Gundersen 2019). The results showed that there are much more cabins, trails, large roads, and farmhouses in the Gudbrandsdalen area than Østerdalen, and in circular areas without GPS-positions. What makes Østerdalen differ from Gudbrandsdalen, is that there are much less developed second-home areas in Østerdalen compared to for instance Venabygdsfjellet, Hafjell, Nordseter and Sjusjøen along Gudbrandsdalen. There is infrastructure in form of many roads in the fringe areas of Østerdalen as well, in addition to areas with low-standard cabins from the 1970s, such as in Fampen, Myklebysætra and Øyungen. These areas are less developed by recreational infrastructure (Brænd 2020). Higher facilitation, in form of modern high-standard cabins (including electricity and water/wastewater) and tourist resorts, enables high human activity in the fringe zone of the reindeer range (Strand et al., 2014; Håland & Flydal, 2021). Results from the circular areas showed that there are more M-SUI segments in circular areas used by reindeers. The findings of the higher quantity of smaller roads in Østerdalen, corresponds with the most attractive areas for the reindeer. Smaller roads have less human traffic than larger roads and marked trails. There are much more Strava segments (all SUIs) in the Gudbrandsdalen area than in Østerdalen. The large-scale areas are of an equivalent size, and have quite similar content of nature types, so this reinforces the likelihood that it is the development of infrastructure and human activity that caused the observed reindeer avoidance. There seems to be consensus in the literature of overall avoidance effects for wild and semi-domestic reindeer populations (e.g. Panzacchi et al., 2013; 2015; Flydal et al., 2019; Gundersen et al., 2019; 2020; 2022), and that is discussed further here.

These results add up to previous studies of avoidance effects on reindeers. Vistnes et al. (2004) found area avoidance of reindeers up to 2.5 km from roads and hiking trails. The GPS-collaring program in Rondane from 2009-2014 showed a clear avoidance and barrier effects of paths with high amount of activity (Strand et al., 2014; Gundersen et al., 2019). In this study the level of human activity were derived from automatic counters. With 3-30 people on a path during a day, the analyses showed that the reindeers cross the path more than expected but would keep distance to the paths with increasing amount of people. If there were more than 30 people a day on a path, there were challenging for the reindeer herds to cross over the path and surrounding areas along the path were avoided. Equivalent results for path crossing are identified from the Hardangervidda reindeer range (Gundersen et al., 2020). The results from comparative analyses on different scale points in the same direction which led to a conclusion that there are strong avoidance effects among wild reindeer caused by human activity in the RS area. Overall simple categories of nature types depicting habitat quality was quite similar in these analyses. There is a clear indication that high density of both heavy infrastructure and recreational infrastructure in the Gudbrandsdalen area has led to tremendous increase in the human use, which has caused large-scaled avoidance effects by the reindeer herds.

When conducting impact analyses, both habitat quality and natural barriers are crucial factors which affects the results. Habitat selection models calculates a species preferred areas within a unit, based on main explaining factors as movement patterns, grazing opportunities, predator-avoidance, and other natural conditions such as water bodies and elevation (Northrup et al., 2022). It would be preferable to have more knowledge on habitat quality in the areas preferred by reindeer in RS. Because reindeer area-use in RS differs a lot compared with pure mountainous reindeer ranges, such as Hardangervidda or even Rondane North, the knowledge and research for habitat quality in these areas cannot easily be transferred to RS. It is worth mentioning the OneImpact-model that use (among other analyses) habitat selection analyses (Panzacchi, van Moorter & Veiberg, 2020) and try to calculate and estimate the cumulative effect of both natural and human-made factors that is affecting reindeer area use and migration within home ranges (Gundersen et al., 2021a). This model is based on GPS positions from seven large reindeer ranges (included Rondane) as well as approximately 250-300 GIS layers describing the habitat quality and the permeability of the landscape for the reindeer herds. The results are estimations of each factor`s contribution to the model, and the most important habitat quality factors that the model visualizing preferred habitat for reindeer in Rondane is based on data from all these other ranges. In other words, the habitat selection model does not consider that the peculiar area use in RS is not compatible with area use in other reindeer areas with typical mountain habitat. There is a need of more research to understand the habitat quality of RS.

The areas in the most southern lower parts of RS seems to be used by reindeer despite there being a dense network of both M-SUI and H-SUI in the surrounding areas. This area use might be interpreted as the eastern part of RS consisting of important habitat for the reindeers (Strand & Gundersen, 2019). This may also explain why there were more M-SUI segments in areas used by reindeer in the circular analysis. Herds may have different responses to human disturbance, depending on for instance population structures based on female-male ratios, calves in the herd, size of the herd, overall population density and habitat availability (Panzacchi et al., 2013; Flydal, 2019). The reindeer area use is often consisted within a small, concentrated area during summer, and this could be interpreted as a behavior to avoid human disturbance, or it is simple preferred habitat characteristics in these concentrated often conifer dominated areas. During tourist seasons in July and August before the hunting period, reindeer have previously shown to have more concentrated space use (Gundersen et al., 2019). There is some variation in reindeer area use from 2016 to 2019 which could be a response to human activity within the range. The reindeer area-use in 2016 might be concentrated or limited because of the GPS-collaring program that got finalized in 2014/2015 (Strand et al., 2014), resulting in a period of a lower number of GPS-collared individuals in 2015/2016. Gundersen et al. (2019) also found that reindeer's main strategy when being disturbed is to move to areas of low human trail use or to areas with low trail density, so called refuge areas. These are similar results to my findings, where the area use is quite concentrated in the study period, apart from 2019.

The reindeer tolerance, or lack of tolerance, to human activity on paths has been studied in several of the Norwegian reindeer areas (Vistnes & Nellemann, 2007; Strand et al., 2012; 2013; 2014; 2015a+b; 2019; Wold et al., 2012; Gundersen et al., 2021). In RN, the traffic from Mysusæter and Høvringen into "Rondanemassivet" and Rondvassbu, has created a complete barrier for the reindeers, within Rondane National Park, and segregated the reindeer population in two (Strand & Gundersen, 2019; Strand et al., 2014). Fv. 27 further south in the area, also functions as a barrier for the reindeers, which is why RS and RN are managed as two different populations (Rolandsen et al., 2022). On Hardangervidda, recent studies showed that human activity and infrastructure had a significant effect on reindeer area use of potential functional areas and important migration routes during both summer and winter season (Gundersen et al., 2021). The human disturbance resulted in area avoidance and barrier effects precenting functional area use, and this is the main parameter for a recent evaluation of the ten main reindeer ranges in Norway (Roaldsen et al., 2022). Barriers and avoidance effects are what the Norwegian environmental management bodies wants to avoid within the Norwegian reindeer areas, however, because recreational activities and tourism are a particularly important part of the Norwegian society and culture as well as important for the local economy, it creates difficulties to prioritize between reindeer and leisure habitats in the mountain. In the next part, management implications based on the main results presented above will be presented.

4.2 Management implications

The fringe location along Gudbrandsdalen, that is intensively developed of infrastructure and in combination of a long and narrow formation of RS, have led to high accessibility for people into the wild reindeer ranges from this side (Villrein, n.d.). Outdoor activities and tourism is an important part of the local economy and municipality's income (Harland & Flydal, 2021), and local economy is one of the main management goals in the regional plan for wild reindeer in Rondane (Oppland Fylkeskommune, 2013). Outdoor recreation is an important part of Norwegian outdoor life ,culture and traditions, and caused positive effects on human health and well-being. From a management perspective, it is important to identify the disturbance effects of cabins and other kind of heavy infrastructure development have on the reindeer herds (Kjørstad et al., 2017; Håland & Flydal, 2021). Results presented in my thesis showed that Gudbrandsdalen area is much more developed of heavy infrastructure and recreational activities, and that in sum leaves a larger footprint on the reindeer area, than the less developed areas in Østerdalen. This has most probably caused large-scaled avoidance effects for the reindeer herds in the Gudbrandsdalen part. The Norwegian Environment Agency established a "Environmental quality standard" for wild reindeer in Norway in 2017 (Kjørstad et al., 2017). An expert group assigned to this quality standard has during 2021-2022 classified different focal areas regarding area avoidance in the RS area, but very few areas are included in the western Gudbrandsdalen part (Rolandsen et al., 2022). As results in my thesis indicate strong avoidance effects along the Gudbrandsdalen side, despite similar abundance of coarse categories of nature types, one could be critical to the decision in the quality norm report (Rolandsen et al., 2022). The methodology for classification compares the reindeer use the last ten years with what is expected in a 50-year period, in a period where most of the second-home development taken place. The reindeer area use in RS has increased during this period, but one must consider that a reason for an increased area use in RS is because of an increase in reindeer population size (Strand et al., 2015). In the 1960-1970s, the population was at approx. 60 individuals (Jordhøy, 2008), while today there are about 2000 individuals in this area. Consequently, the reindeer area use is more widespread than it was 50 years back. It is then a paradox that increase reindeer area use is taken part in a period with comprehensive increase in human use of the RS area.

The regional management plan for Rondane wild reindeer range (Oppland Fylkeskommune, 2013) have divided RRR into three different management zones, where sone 1 is the border of *the national reindeer area*, while sone 2 is a buffer sone between sone 1 and sone 3. Sone 3 is the development area. In theory, ecological buffer zones (sone 2) are "protected zones establisher around sensitive areas to lessen the impacts of human activity and land disturbance" (TNC, 2015. p.1). In the regional plan, "development areas in the fringe sone" are within the *biological border*, allowing some kind of tourist- and cabin development in those areas (Singsaas & Gundersen, 2021). The high amounts of infrastructural facilitation in

Gudbrandsdalen and the large footprint of human activity within the reindeer range shows the effect of the development area in and outside sone 3. Because of short distance from the development areas in the valley, and large roads to summer houses and second-home areas, and short distance to the border of the reindeer area on the west side, this might be an explanation of why the activity patterns from Strava is so dense and widespread in those areas. The *biological border (administrative border)*, the *border of the home range* decided in the management plan, and the *border of the national reindeer area* are all at different places (Oppland Fylkeskommune, 2013 p. 46), which might cause some planning and management confusion. In the development of the regional management plan, the Ministry of Environment states that for areas to be included in *the national reindeer area,* it would have a quality which could ensure a sustainable reindeer population (Singsaas & Gundersen, 2021). That would also include absence of human disturbance on the reindeer population. The area use in RS differs from herds in RN and most other reindeer ranges, in which the reindeer used to seek to higher altitudes during summer (Strand & Gundersen, 2019). Because the reindeer area use during summer is more centered to the lower forest- and bog-areas on the east side of RS, these areas could be categorized as refuge summer habitats. It would be optimal if these areas were included in the *national reindeer area*, resulting in a stricter area management, including restrictions regarding infrastructure. A zoning like the one suggested in Singsaas & Gundersen (2021) and Gundersen et al. (2021a+b), with *wilderness areas, backcountry areas* and *entrance areas,* could help to keep the area management in today's buffer zones to conserve the reindeer habitats. The main issue in today's reindeer ranges is that the reindeers don't have enough space to cope with future challenges as density dependent diseases, climate change and increase human activity in the mountain areas. By including the summer refuge areas in the RS area one can prevent future increasing disturbance effects in those areas. It is also important to ensure that the human activity pressure from the west side does not increase further into the range, for example that el-bikes increase the range for the bicyclist.

To improve the conditions for wild reindeer, several mitigation measures have been implemented in the Rondane range, such as removal and remarking of hiking trails and removal of public tourist cabins (Nellemann et al., 2010; Fjelle, 2020). In Rondane, the tourist cabin Breitjønnbu was relocated in the 1990s in fringe of the reindeer range (Today: Jammerdalsbu), and in 2021 Gråhøgdbu was also relocated (Today: Veslefjellbua) in the fringe zone to improve the conditions and enable habitat that was used by reindeers before the trails and cabins existed (NINA, 2021). Trail markings have also been removed on several places, such as Mysusæter

– Bjørnhollia through Musvolddalen, and Remdalsbua – Breitjønnet (Fjelle, 2020). When making these adjustments, it is important to monitor how these measurements affect reindeer use of the areas. Since the point of removal and remarking is to decrease the human pressure, it is necessary to find out if the human use changes regarding visitor volume and spatiotemporal pattern of use in the area. Management implication and the use of mitigation tools to manage people in a way that reduce the conflict with wild reindeer is an important frame for my thesis, despite that it does not test effects of mitigation tools for wild reindeer. I suggest a broader use of communication tools in the fringe zones of RS to influence a reindeer friendly behavior, by using information plates and educational attractions. I also suggest implementing questionnaire surveys in RS, where one could focus on what recreational users know about the reindeer situation, and what they would prefer to experience and do of activities in the area. This could give advice to facilitation in the fringe zone in a way that channels the tourists towards less vulnerable reindeer areas.

4.3 Methodological considerations

4.3.1 Evaluation of usage Strava

There was an increase in registered Strava segments from 2016 to 2019, which indicates increased spatial area use in RS (37.68%). Even though these results only show difference in registered segments, they also indicate that the user group has increased. Previous research has indicated a 6-8% increase of Strava users each year (Venter et al., 2020; 2021). In a very large and remote area of Hardangervidda wild reindeer range (approx. 10 000 km^2), a study identifies a significant correlation between Strava data and automatic counter (approx. 60 units) during summer season in 2017 and 2018 (Holtmoen, 2021: Figure 7 a-f). I assume that an increase of Strava users in RS is a combination of an increase in popularity of using the Strava App., and of an increasing general trend of recreational activity in the mountain areas the last decade. Of the three SUIs, there were most registrations within L-SUI, while the numbers were lower for both M- and H-SUI. Based on this one can assume that if there were more infrastructure further into the range, there would be a higher amount of M- or H-SUI segments. When doing impact analysis in reindeer ranges, one must consider that large parts of the range are remote areas with less recreational infrastructure and larger parts of the area only have unmarked paths. A lot of unmarked paths that are registered in map-databases appear that have no registered Strava data (Appendix 6). The Strava data is connected to OSMs (Open Street Maps), and data registered by the Strava app gets connected to linear features (infrastructure) in the OSM (Thorsen et al., 2022). If there are no linear features registered in the OSM, on the exact place an app user is walking, the data connects to the closest linear feature available in the OSM. This would make it challenging to map activity rates in refuge areas for reindeers that is often located in the areas far from any recreational infrastructure. Thus, the amount of human activity in the remote areas of the range is more inaccurate than the activity in the fringe areas with a dense recreational infrastructure network. With the available Strava data downloaded from the dashboard, it is not possible to separate registrations of the same user to get an accurate individual count due to the Strava Privacy policies (Strava, 2021). These policies also affect the individual count as a minimum of three different users within a certain time and place must use the app for it to be considered in the Strava database (Venter et al., 2020; 2021).

It must be taken into consideration that the usage of Strava data in disturbance studies in reindeer areas is a relatively new method, and that there are some weaknesses to this approach. By relying on only Strava when doing impact analysis of human disturbance, it would not be representative for all human activity in the study area. It leaves out information about usage of activities where the majorities of the users are not using the Strava app, for example activities such as subsistence harvesting like berry-picking, hunting, and fishing, as well as wilderness and adventure seekers and for human traditional use like herding and agricultural activities related to summer farms. A suggestion for later research in this matter would be to interpret a more rapid use of questionnaire surveys for all these user groups to identify their space use. When doing impact analysis, it would have been optimal if Strava location data not had to be associated by mapped infrastructure (OSM), so that one could get more accurate results for dispersed use in remote areas. Even though there are some disadvantages to this using Strava data, it still shows promising results. Crowdsourced data gives an opportunity to describe the main human activity patterns in RS, and to identify the effects of soft and heavy infrastructure development on both human activity pattern and reindeer use. This method is promising because it enables the possibility to measure what effect old or new establishments of infrastructure will have in an area, by connecting the Strava activity rates to the infrastructure. For instance, could Strava data be used to test effects of removal or remarking of trails, or removal of open cabins. Mitigation tools and manipulation of infrastructure in the landscape is important in today's area management. Former research has proved that reindeers respond negatively to linear structures in the landscape (Jordhøy et al., 2002), however, it is mainly the human activity intensity on these structures that is important for wildlife disturbance. In such cases Strava have advantages as it present comprehensive data in large scale landscapes, like for example reindeer ranges. A road with low human activity has a less negative effect than a similar road (size, physical attributes) with high intensity of use. Crowdsourced Strava-data gives a broad picture of human activity within a chosen area in a more efficient way than with the usage of for instance automatic counters that is measuring a single point. By using crowdsourced data, researchers can download and use large datasets in urban and rural settings and over large areas in a cost-effective way. One could imply that these types of data give a better and more efficient result over a larger study area than with the usage of for example automatic counters in fixed point. In combination, counters could be used to calibrate the Strava data and this has been done in both urban and remote landscape settings (Holtmoen 2021; Venter et al. 2020). The Strava data is stored within a server system and free for everyone to download on the Strava Metro dashboard. The user group tends to increase every year, and an increase in response rate will increase the representativity and give a more accurate activity pattern within the study areas. This is especially true as the demography of the Strava-users better fits with the demography (etc. age, gander, activity) of the recreational users (Barton et al., 2020). With studies showing obvious positive correlations between user volume of automatic counters at fixed points and Strava segments (Venter et al., 2020; Holtmoen, 2021; Gundersen et al., 2021), I suppose the use of crowdsourced data will be more relevant for research and management purposes in the wild reindeer ranges the years to come.

4.3.2 Other considerations

There are certain choices and decisions made during the study that will influence the outcome of the analyses, for example available GPS data on reindeer. It is common that larger reindeer herds during winter is divided into smaller herds in summertime. Consequently, and because of limited numbers of individuals that have been GPS collared, there may be larger areas used by the reindeer that have not been mapped. There are different number of GPS collared individuals each year (Appendix 4), and coincidences can determine whether a herd is mapped or not. Additionally, all GPS collared reindeer in the RS area are female individuals, and GPS collaring of male reindeer would most probably have caused a more diverse result, especially the use of fringe area in the RS. However, a goal for the reindeer GPS collaring project in the RS area is that the data obtained must be quite representative (Strand et al., 2014).

I used *total athlete count* (people count) within each segment to calculate *assumed total activity*. The assumed total activity was used to create Strava Use Indexes of high, medium, and low. Therefore, it was natural to use the number of registered segments within every SUI for the presentation of the Strava data from 2016 to 2019. I could have used total athlete count each year or within each segment, but as the SUIs are based on the athlete count, that was not necessary. The *assumed total activity* was calculated, based on Strava being 3% of the total amount of activity in the study area. Because this definition is based on earlier studies (e.g. Venter et al., 2020) and an assumption of transferable context, one must consider that there could be more or less activity in certain areas in RS. I thought that by using a higher percentage, it could have overestimated the results, giving a higher inaccuracy in the results, but for later studies, with the popularity of Strava increasing, and with the assumption that the Strava user base increases by 6 % each year one can assume that a higher percentage is necessary (see Venter et al., 2020).

A 200 m buffer was chosen for the Strava segments. Previous research on information about the flight initiation distance and escape distance of reindeer have done tests in flat and open terrain in Rondane, where results showed initiation distance of more than 300 meters (Reimers et al., 2012; Kjørstad et al., 2017; Gundersen et al., 2022). As discussed earlier, RS differ from other reindeer ranges, by containing large forest dominated areas, which could function as refuge areas for reindeer herds in summertime. Despite that vigilance distance in Rondane north area is together with the Snøhetta, Knutshø and Sølnkletten wild reindeer ranges, the longest in Norway, this is measured in open flat landscapes (Reimers et al., 2010). There are no studies that have tested vigilance distance in forests, but it is obvious that this distance is much shorter within forest dominated landscapes.

Regarding the comparative analyses, such as the count analysis, where the goal was to compare the difference in number of reindeer plots between two areas, the size of these areas is an important factor. In this matter, the areas that is occupied by SUI-buffers, will be a lot smaller than the total available area in the study area. It is natural that the area outside of the buffers would consist of more reindeer plots due to a larger area. It is important to mention that the meaning of this count analysis was to see if there was a reindeer avoidance towards Strava areas. Because a 200 m buffer around each segment was implemented, the count analysis was a good method to find out whether reindeer were located within the areas of human activity or not. Another approach would have been to measure number of plots per area unit. With such approach one could divide the study area into different area units (polygons) of the same size, giving them a value of either H-, M- or L-SUI, and then compare number of plots. But because this is time consuming, and because the medium-scale and large-scale comparison are the main part of the results, I chose to conduct the count-analysis together with the distance analysis.

5.Conclusion

The purpose of this thesis was to present crowdsourced Strava data as a tool to monitor human use of RRR, and to test the disturbance effects of human Strava activity on reindeer area use during summer.

My findings leave clear indications of reindeer avoidance toward areas with high and medium human activity in RS. Small scale analyses showed in general longer distance to any Strava segment, and very few registered GPS positions of herds points within the Strava buffers of human activity. Medium scale analyses of circular areas with and without GPS-positions and a large-scale comparison of Gudbrandsdalen and Østerdalen clearly showed that higher amount of infrastructure development in form of roads, trails and cabins led to increased human Strava activity and consequently, avoidance effects on reindeer. Reindeers prefer the Østerdalen area, where there is much lesser soft and heavy infrastructure development. Based on these results management authorities should emphasis the forest areas of RS as vulnerable refuge areas for reindeer during summer and ensuring a more restrictive infrastructure development strategy for the future. Overall, there is lack of knowledge of habitat quality in RS, which needs to be a high priority for future research.

There are up to date very few studies using Strava data in nature impact and wildlife disturbance studies. Strava data has obvious biases in form of representativity of the general population of recreational users, in volume users, spatiotemporal distribution and type of activity that are represented in the data. However, as indicated in the discussion, the spatiotemporal distribution as used in my thesis seem to be quite representative with exception the most remote areas where there are few visitors that are not using Strava. The crowdsourced Strava data has given me an opportunity to see what footprint infrastructural facilitation leaves within a reindeer area, and how the human activity patterns are connected within a larger area. My results leave promising results for future work with Strava as a method for monitoring of human use and investigating of disturbance effects on wild reindeer.

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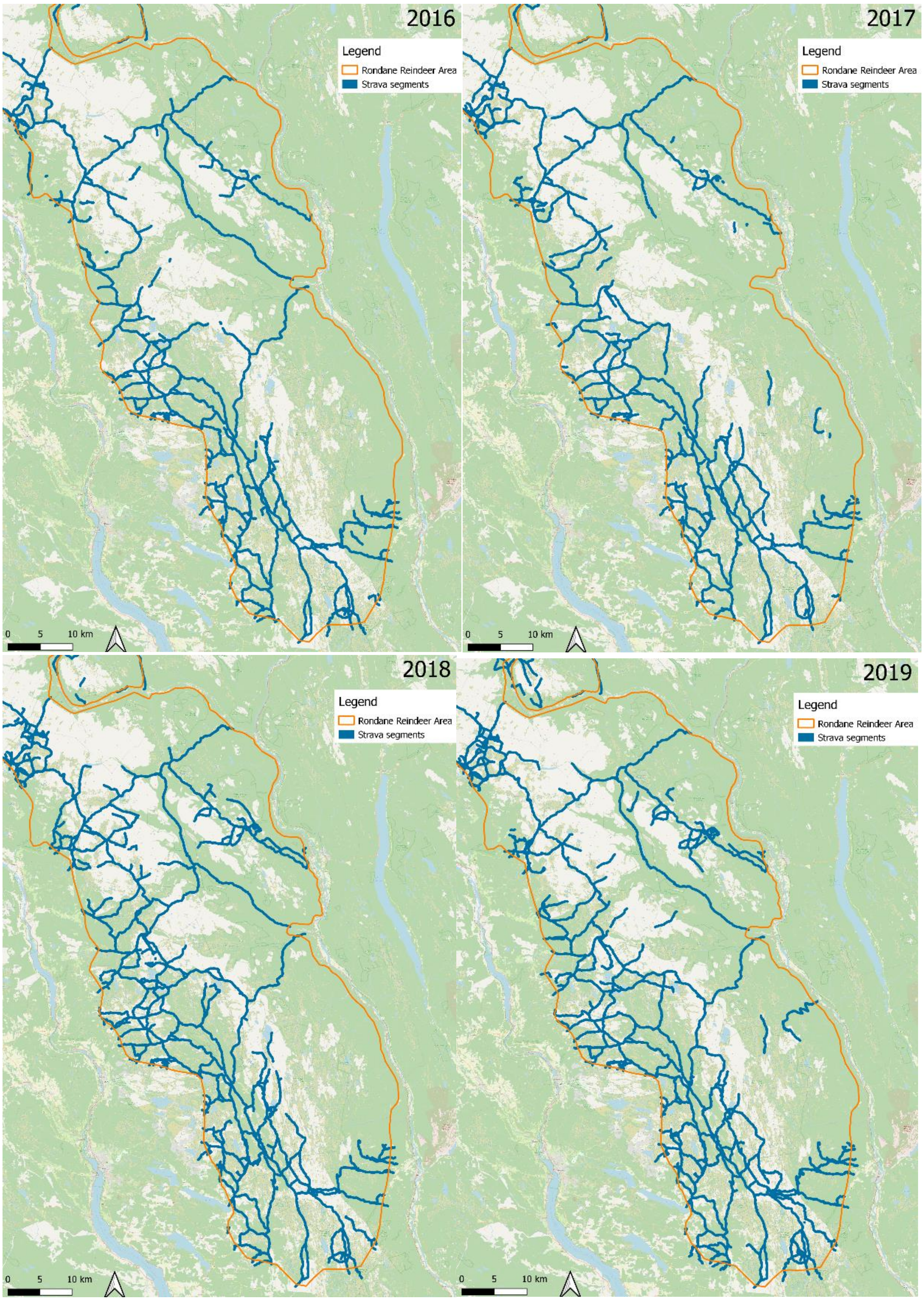
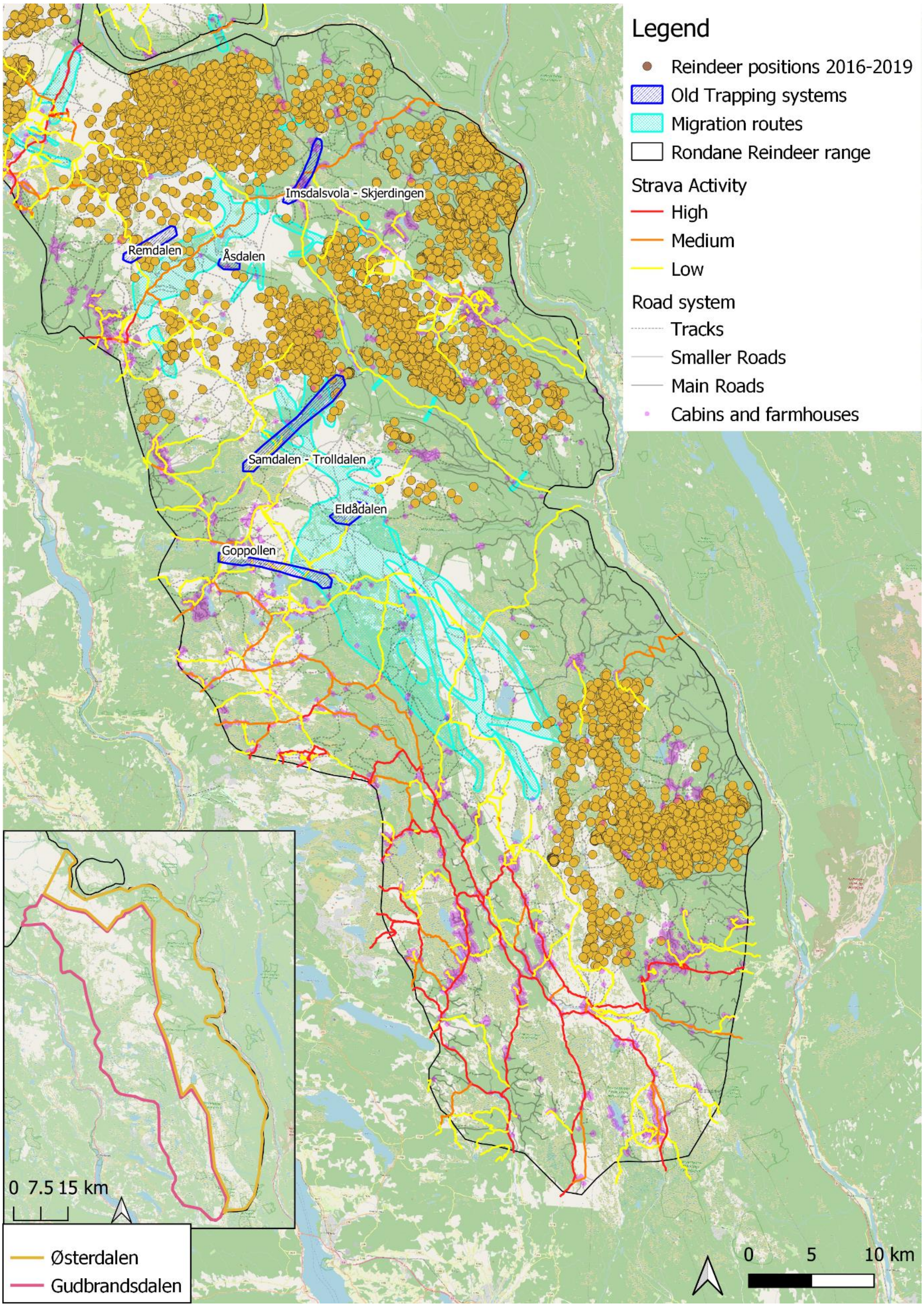
Appendix

Appendix 1 – Evolvement in registered Strava segments 2016-2019



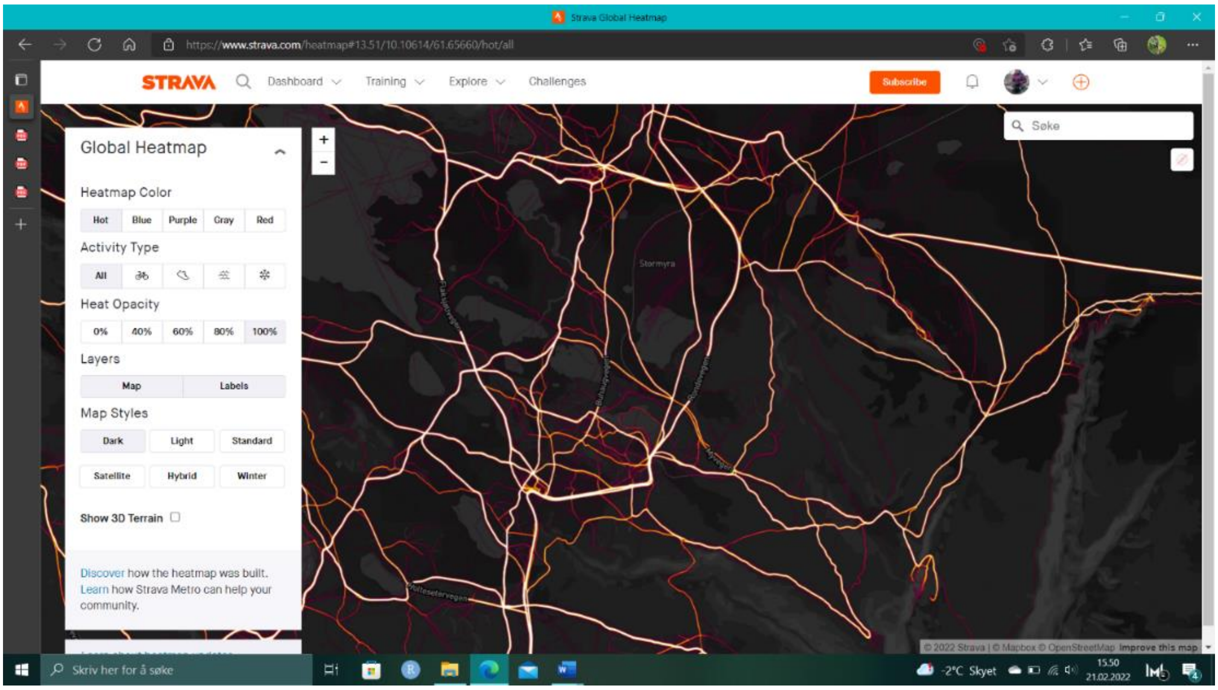
Appendix 1. Registered Strava segments from summer of 2016 to summer of 2019.

Appendix 2 – Distribution of GPS-positions 2013-2015



Appendix 2. Distribution of reindeer positions from 2013 to 2015 within Rondane South. GPS-positions are marked as dark yellow dots. Migration routes are the turquois buffers, and the old trapping systems are the dark blue buffers. Strava segments of H-SUI (red), M-SUI (orange) and L-SUI (yellow) are presented.

Appendix 3 – Strava Heatmap



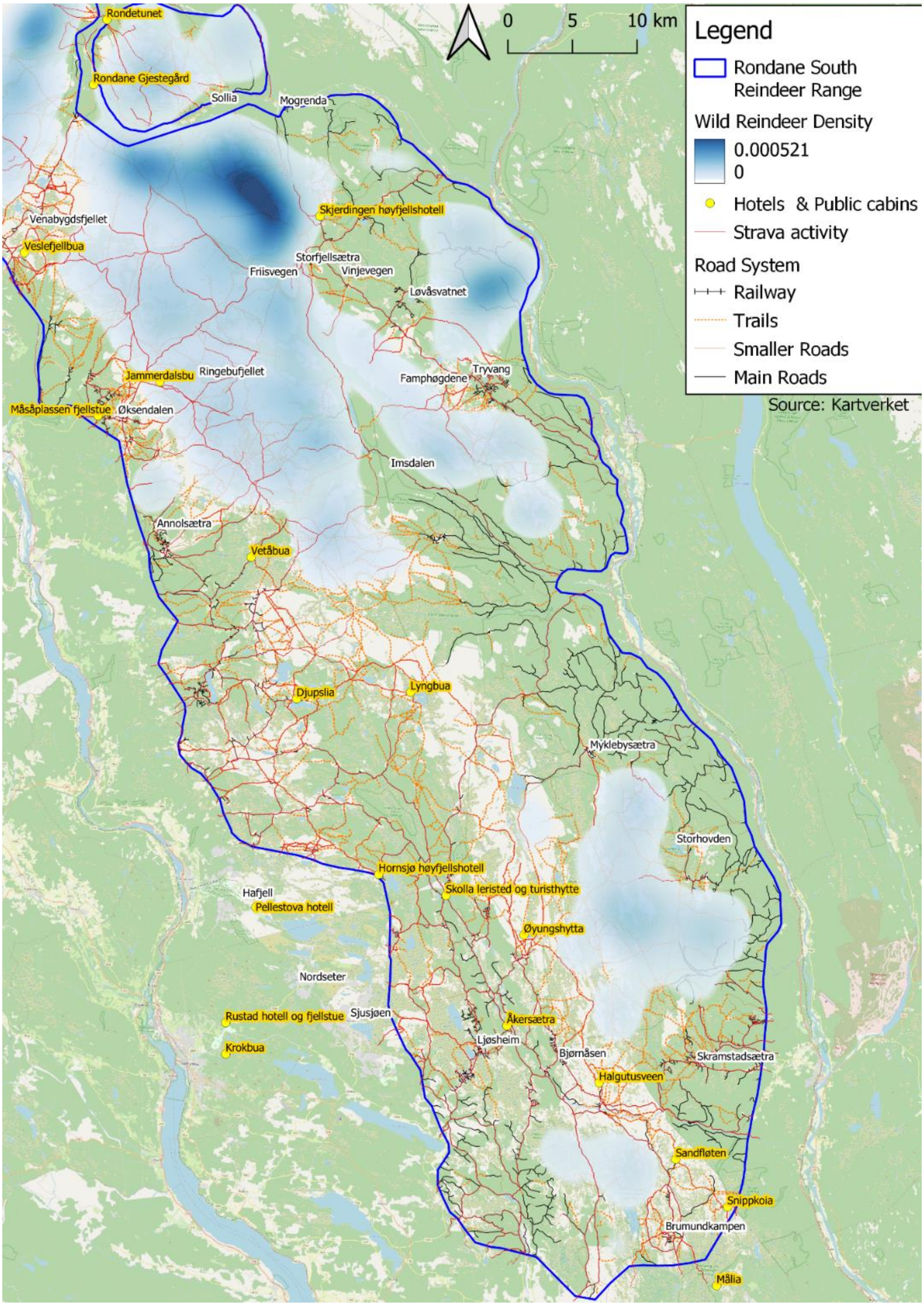
Appendix 3. Strava Global Heatmap. Warmer colors mean higher SUI, while cold colors indicate lower SUI.

Appendix 4 – Number of GPS-collared individuals from 2010 to 2019.

	GPS-collars in Rondane South
2010	11
2011	4
2012	12
2013	8
2014	4
2015	4
2016	**3**
2017	**6**
2018	**4**
2019	**8**

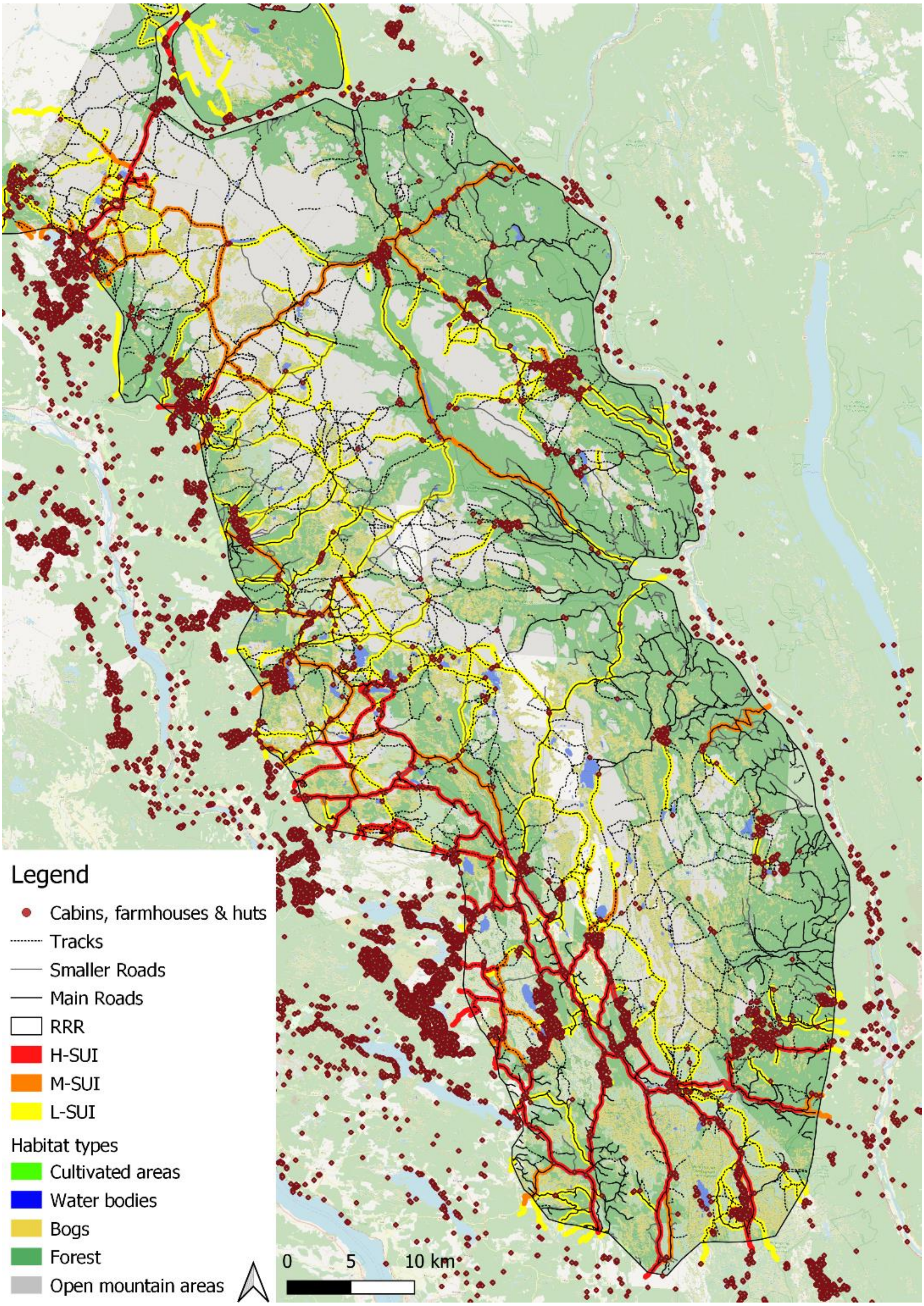
Appendix 4. Total number of marked individuals in Rondane South from 2010 to 2019, showing a big variation between years.

Appendix 5 – Density of Reindeers 2010-2019



Appendix 5. Reindeer- and Human area use of Rondane South based on 10 years of GPS-data (2010-2019). The blue fields show the density, where darker blue means higher densities and lighter blue means lower densities.

Appendix 6 – Habitat types and infrastructure



Appendix 6. General habitat types within Rondane South in addition to infrastructural facilitation and Strava segments of H-SUI (red), M-SUI (orange), and L-SUI (yellow). Cabins, farmhouses, and huts are marked in burgundy. Roads are black lines, smaller roads are grey lines, while tracks (trails) have dotted lines.