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Monitoring anthropogenic activity in the Hardangervidda wild reindeer range

Possible applications of crowdsourced Strava-data in remote settings

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Preface

This master thesis (60ECTS) was written as the final thesis of the study-program Masters in Biology at University of Tromsø (UiT), faculty of Biosciences, Fisheries and Economics, department of Arctic and Marine Biology. My supervisors has been Audun Stien (UiT) and Vegard Gundersen (NINA, dep. Lillehammer).

Maps showing habitat suitability for wild reindeer on Hardangervidda in summer used in this thesis, was created by Manuela Panzacchi and Bram Van Moorter for NINA's project Renewable Reindeer (RenewableReindeer (nina.no)) and will be published in an upcoming report (Tema-rapport) for NINA in 2021 (Panzacchi et.al., 2021, in press). Methods, analyses and results are previously published in Panzacchi et.al., 2015a. NINA had the main idea for this thesis and has contributed with the material for my analyses such as raw data from automatic counters, Strava-data and GPS-data from GPS-collared wild reindeer.

Abstract

Seen in light of the increasing interest of nature-based tourism and recreational outdoor activities in Norway the last decades (Reimers, Eftestøl & Colman, 2003; Haukeland, Grue & Veisten, 2010), spatiotemporal information on human activity in remote areas and knowledge about how this activity may affect wildlife and nature is a crucial part of a knowledge-based management (Gundersen et.al., 2011, p.14; Gundersen, Strand & Punsvik, 2016, p.166). Hardangervidda is the largest national park in mainland Norway and is also home to the largest population of wild mountain reindeer (*Rangifer tarandus tarandus*), a specie of international responsibility in management and conservation and recently added to the Norwegian red list (Kjørstad et.al., 2017, p.26; Artsdatabanken, 2021). In this thesis, I calibrated crowdsourced data from the Strava-app with visitor data from automatic counters from 2016-2019, to identify spatiotemporal activity patterns in Hardangervidda area (inside and outside the national park) and to evaluate the use of Strava as a methodological approach for monitoring visitor traffic in remote areas. The spatiotemporal patterns on human activity in summer in the period 2016-2019 derived from Strava-data was presented in combination with a habitat suitability map for wild mountain reindeer and GPS-positions from GPS-collared wild reindeer during the same period, to discuss potential conflict-areas regarding human – wild reindeer interferences on Hardangervidda. Because there is a lack of knowledge about how automatic counters work in remote settings in wintertime, counter accuracy was tested by comparing measures between two automatic counters in the exact same location at specific trail-segments during winter 2018.

My results showed that the relationship between Strava-data and data from automatic counters was consistent during summer season (July-Sept.), while data from winter season (March and April) showed no consistent pattern between the two measures. The relationship between the two measures of human activity was assumed to be related to the number of observations from Strava, as there were considerably more observations during summer than winter. The results showed that the consistency between the counter-pairs across all locations was $\rho_{c} = 0.82$ and $r > 0.7$ for 15 of the counter-pairs, indicating high counting accuracy for automatic counters also in remote settings in wintertime. Observations of human activity from Strava showed more observations outside the national park than inside the national park, in all years and all months. The seasonal variation in Strava-observations showed a distinct peak during summer (July-August), and lower numbers for the remaining months. There was an increase in Strava-observations over the study years both inside and outside the national park, however, this increase is assumed to be related to an increased use of the Strava-app and cannot be concluded to be evidence for increased human activity on Hardangervidda. The main emphasis of the Strava-data was in the surrounding edge zone and in relation to the marked trails and public tourist cabins in the Hardangervidda area.

Using Strava-data as a single monitoring method is not recommended, as there are challenges concerning representability and reliability in the dataset (Barton, Gundersen & Venter, p.36). This is especially evident for the off-trail recreational use, were my results suggest that this type of activity is rarely detected by Strava. However, Strava-data does provide large amounts of spatiotemporal data on human activity, and my results complement results from previous studies that Strava-data has potential as a valuable supplement to describe the main use pattern in an area and can increase data from other monitoring systems. The marked trails, especially the coherent routes south-north and east-west may function as a barrier for the wild reindeer population, preventing them to use suitable summer-pastures in the northern and western part of the range, with consequence of very high density of reindeer in a limited area in the south-east. An increased level of visitors on Hardangervidda with higher frequency of human activity on the marked trails may lead to long-term disturbance effects for the wild reindeer population, like habitat alteration, avoidance of large areas of suitable habitats and potential cascade-effects like increased grazing-pressure in certain areas (Andersen & Hustad, 2004, p.40; Gundersen & Singsaas, 2020, in press). Further studies on visitors' impact on the wild reindeer population on Hardangervidda should be carried out to achieve a sustainable human use of this area and to secure the wild reindeer populations' livelihoods and sustainable population dynamics.

Keywords: wild reindeer, Hardangervidda, Strava, automatic counters, visitor data, anthropogenic disturbance effects

Acknowledgements

I’m proud to have accomplished my goal to finally hand in my master thesis in Biology and hopefully call myself a biologist! I’ve always been grateful for what nature can provide me and I hope this will give me the opportunity to give something back.

First of all, a big thanks goes to my patient and skilled supervisors at University in Tromsø, Audun Stien, and at NINA dep. Lillehammer, Vegard Gundersen. Thank you for always being helpful (often at short notice), helping with statistics, references and other priceless advices and guidance on the way!

Thank you for the loving support from my family: Mom, Dad and Mats. You have provided me the basics for loving the outdoors and caring for nature. Your strong engagement to wild reindeer and nature conservation has inspired me and given me even more motivation to finish my studies in the fields of biology. Thank you for supporting me no matter what.

This year, a lot of time has been spent at home in my tiny apartment with Sondre. Thank you for your patience, support, advices and love in ups and downs and for all our adventures together!

Hilde, thank you for your advices during the writing process!

Lastly, thanks to my friends for taking my mind off my thesis and into nature and the mountains when that was necessary!

Vilde Grøthe Holtmoen, Universitetet i Tromsø, 31.05.2021

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1.0 Introduction

All over the world, the extent of tourism, public recreational activities and other anthropogenic activities in remote areas are increasing (Reimers, Eftestøl & Colman, 2003; Haukeland, Grue & Veisten, 2010) and even the most considerate hiker is in the position to unintentionally disturb wildlife (Leung & Marion, 2000, p.23). Both direct impacts like habitat alteration and indirect impacts like reduced population health and fitness, are common forms in which recreational activities may interfere with wildlife (Leung & Marion, 2000, p.24).

For an adaptive knowledge-based management of wildlife areas it is important to have scientific data and systematic knowledge about anthropogenic activities in these areas (Gundersen et.al., 2011, p.14; Gundersen, Strand & Punsvik, 2016, p.166). This includes information on the type of activity, its volume and spatiotemporal distribution, as well as knowledge about impacts on wildlife from human presence and the human-wildlife interactions (Gundersen, Strand & Punsvik, 2016, p.166). With the twofold aims to give visitors satisfied nature experiences and to protect conservation values from human impact, collecting and analyzing data on visitor use is an important component of management and planning in protected areas around the world (Wardell & Moore, 2004, p.5; Kajala et.al, 2007 p.11; Gundersen et.al., 2021b, p.4).

The area of Hardangervidda in Southern Norway holds the largest population of wild mountain reindeer *(Rangifer tarandus tarandus)* in Norway and it is considered an international obligation to protect and manage this population in a sustainable way (Kjørstad et.al, 2017, p.26). Recently, wild mountain reindeer was added to the Norwegian red list of endangered species (2021), with the status as near endangered. The reason for this was partly due to habitat-fragmentation caused by anthropogenic disturbances, hereunder tourism and recreational activities in reindeer habitats (Artsdatabanken, 2021). As infrastructure development (Flydal et.al., 2019) in general, as well as recreational outdoor activities and tourism have increased in the area the last decades (Reimers, Eftestøl & Colman, 2003; Haukeland, Grue & Veisten, 2010; Gundersen et.al, 2021), it is necessary to act in such a way that humans and reindeer can continue to coexist in mountain landscapes, as they have done for thousands of years (Røed et.al., 2014).

The importance of gathering and monitoring visitor use and analyze spatiotemporal patterns of use, must be seen in relation to the societal and social development during the last century as people have more leisure time and participate in different recreational activities with increased specializing, as well as an increased focus on public health (Odden, 2008; SSB, 2021). Before the start of 20th century, recreational activities in remote areas were not very common, and activities like hiking and cross-country skiing in remote areas are relatively new concepts (Gundersen, Strand & Punsvik, 2016, p.163).

Quantitative data on visitors use of national parks and protected areas was scarce up until 2000 but have increased the last two decades (Kajala et.al., 2007; Pettebone, Newman & Lawson, 2010; Haukeland, Grue & Veistad, 2010; Gundersen et.al., 2021b). Several methods have been developed for collecting data on spatiotemporal visitor use and the volume of users, e.g. systematic movement observations, surveys using questionnaires, automatic counters, aerial photography, quantification based on permits and methods using secondary data like road fee (Wardell & Moore, 2004, p.13). However, many of these methods for collecting precise data on visitor use are challenging due to high costs with respect to personnel-hours and technical equipment.

Over the last years, automatic counters have received recognition for their ability to estimate visitor numbers at observation points (Pettebone, Newman & Lawson, 2010). However, automatic counters are most frequently used in urban settings and temperate areas, and are less tested in remote alpine settings (Andersen et.al, 2013). Since raw data from automatic counters can be inaccurate in terms of visitor use due to e.g. counter errors (Pettebone, Newman & Lawson, 2010; Andersen et.al., 2013) it may be necessary to calibrate the data and to combine several measures of human activity (triangulation) to obtain high-resolution and precise estimates on human activity. Some studies (Watson et.al, 2000; Bates et.al., 2006) have calibrated automatic counter data with visual observations or manual counts and found strong correlations between the two counting methods (in Pettebone, Newman & Lawson, 2010). This calibration method is, however, highly time-consuming, and may not be feasible for large-scale projects running over several years (Pettebone, Newman & Lawson, 2010).

In recent years, new potential data sources have appeared as people increasingly use apps that log their physical activity and activity routes (Barton, Gundersen & Venter, 2021, p.22). Strava is one of the most common apps for logging and documenting physical exercise and hiking routes using GPS-watches and smartphones. Up until recent years, the app has been mostly used by athletes for exercise purposes (running and biking), but today also include people who engage in other types of outdoor recreational activities, like long-distance hiking and cross country skiing (Barton, Gundersen & Venter, 2021, p.23). The app has a growing potential as a monitoring tool for human activity-patterns as its use increases (e.g. Venter et.al., 2020), and Strava gained millions of users worldwide since the launch in 2009 (strava.com., n.d., a; runnersworld.com, 2020). In Norway Strava has registered 175.000 runners and 95.000 bikers (2020) (Venter et.al, 2020) and this data is currently the most comprehensive source of data on activity patterns in Norway (Vistad et.al, 2019, p.16). Due to the high spatial resolution and high number of users, the GPS-data from the Strava can give a picture of the geographical distribution of area-use on a large scale (Barton, Gundersen & Venter, 2021, p.22; Vistad et.al, 2019, p.16).

Previous studies has shown that Strava has the potential for revealing patterns on activity, travels and sustainable tourism, as well as support research in public health and sustainable and effective urban planning (Sun & Mobasheri, 2017, p.2, Barton, Gundersen & Venter, 2021, p.22), see e.g. Selala & Musakwa (2016), Jestico, Nelson, and Winters (2016), Sun (2017), Lee & Sener (2018), Hochmair, Bardin & Ahmouda (2019), Hong, McArthur & Stewart (2020), Camacho-Torregrosa et.al (2021). In a feature called Strava Metro, the GPS-data is aggregated and summarized in statistics and geographical mapping (strava.com, n.d., b), providing an accessible crowdsourced dataset for researchers and others in need of such information. As Lee & Sener (2021) points out:

> *"The plausible reason for the popularity of Strava Metro-offering data is its readiness and preparedness in a format that is useable for spatial and statistical analysis, with a rich coverage in time and space yet relatively reasonable price"* (Lee & Sener, 2021, p.29).

The method of calibrating Strava-data by data from automatic counters is currently not widely used, but may have potential to increase precision of data on visitor use also in remote areas (Barton, Gundersen & Venter., 2021, p.22).The same method was used by Venter et.al (2020; 2021 in press) for mapping outdoor recreational activity during the Covid-19 lockdown in Oslo in spring 2020, in addition to studies regarding infrastructure analyzes and bicycle patterns in urban areas (see e.g. Boss et.al, 2018; CDOT, 2018).

In this thesis, I will combine automatic counter-data and Strava-data from Hardangervidda from summer and winter 2016-2019 to evaluate their relationship and consistency, and further discuss the potential of Strava data for monitoring spatiotemporal human activity in large-scale, remote areas such as Hardangervidda. Further, I will descriptively present the spatiotemporal human use patterns at Hardangervidda in summer as suggested by Strava-data, and evaluate the overlap between human activities and GPS-positions of wild reindeer herds from the same period, to highlight and discuss potential disturbance on the wild reindeer population in Hardangervidda. Because the core area for the wild reindeer population in Hardangervidda is mainly within the national park, my results on human activity patterns will be distinguished between inside and outside the national park. Finally, the counting accuracy of automatic counters in remote areas during wintertime is tested, as there were lacking knowledge about this in existing literature.

2.0 Background

2.1 Wild mountain reindeer (*Rangifer tarandus tarandus*)

Norway is home to the largest wild mountain reindeer population in Europe (*Rangifer tarandus tarandus*) and it is considered a national and international obligation to manage and protect this species in a sustainable manner (Kjørstad et.al, 2017, p.26). As it once ran freely across the European continent over 10’000 years ago, the wild reindeer population is today fragmented and distributed into 24 sub-populations in Southern Norway (Panzacchi et.al, 2015a; villrein.no, n.d. a) (*Fig.1*), mainly as an effect of human interference in their habitat such as roads, railroads, dams and other human infrastructure developments (Nilsen & Strand, 2017). The largest herd is found at Hardangervidda, which has gone through substantial fluctuations in population numbers the last 50 years, due to periods with over-harvesting and hunting bans (Strand, Bevanger & Falldorf, 2006, p.24; Reimers et.al, 2010, Gundersen et.al., 2021 b, p.24). According to the management plan the herd should have a size of appr. 12’000 individuals during winter season, which makes up about one third of the total population of wild mountain reindeer in Norway (Bjerketvedt et.al, 2014; Kjørstad et.al, 2017, p.89; villrein.no, n.d. b).

Hardangervidda is also the last place where the wild mountain reindeer still has kept relative intact patterns of seasonal migrations (Mossing & Heggenes, 2010, p.20), even though Hardangervidda was previously part of a much larger continuous habitat for wild reindeer (Punsvik, Vaa & Lund, 2016, p.229). Today, the main migration corridors in north to the Nordfjella range and the two Setesdal ranges (Ryfylke and Austhei) in the south has ceased, and the same have the migration corridors in the east like Norefjell-Reinsjøfjell, Brattefjell-Vindeggen and to Blefjell in the south (Punsvik, Vaa & Lund, 2016, p. 230; Kjørstad et.al., 2017). Wild reindeer has little inter-specific competition from other ungulates, and possible predators like golden eagle (*Aguila chrysaetos*) and wolverine *(Gulo gulo*) are merely present and do not make up a threat to the population (Panzacchi et.al, 2015a). Hunting is thus left as the main mortality factor and together with abundance of important forage resources, limits population size (Panzacchi et.al, 2015a). The wild reindeer population is today managed by recreational hunting with an aim to increase health and fitness of the animals and recover grazing areas (Strand, Bevanger & Faldorf, 2006, p.3; Strand et.al., 2012; Bjerketvedt et.al, 2014).

Figure 1*: Map of the 24 management areas in Norway for Rangifer tarandus tarandus (from villrein.no, n.d.).*

Figure 2*: Wild mountain reindeer herd in winter (Mossing, 2021).*

2.1.1 Wild reindeer area use on Hardangervidda.

Wild mountain reindeer are adapted to a life in the high mountains. The nomadic way of life is one of this species' main characteristics and they are dependent on large areas for making seasonal migrations (Strand, Bevanger & Faldorf, 2006, p.3). The wild reindeer's migration route follows a cyclic pattern between calving-areas, summer-pastures and winter-pastures (Fylkestingene i Telemark, Vestland & Viken, 2020, p.11; Gundersen et.al, 2021b). Usually the migration route is stable but can change and modulate in response to climatic factors, vegetation, topography and anthropogenic activities (Mossing & Heggenes, 2010, p.19; Panzacchi et.al., 2013; Fylkestingene i Telemark, Vestland & Viken, 2020, p.11).

Wild mountain reindeer lives in herds (*Fig.2*) with up to several hundred individuals and the area they seek must therefore have sufficient forage to feed the entire herd (Andersen & Hustad, 2004, p.23). Finding high-quality nutritional forage is crucial for surviving the long and harsh winter, as well as for growth and reproduction (Kjørstad et.al, 2017, p.66). Western parts of Hardangervidda were previously commonly used as summer-pastures, whereas in recent years, more of the central and south-eastern parts of Hardangervidda are used in summer (Fylkestingene i Telemark, Vestland & Viken, 2020, p.11). Important winter pasture areas are found in the eastern parts of Hardangervidda; here the landscape is mostly flat, and the snow-cover is thin which makes the lichens easily accessible (Jordhøy & Strand, 2009, p.3). In recent years, the most important calving areas have been in Telemark, between Songa and Møsvatn, whereas before 2001, it was in Veigdalen in Hordaland (Fylkestingene i Telemark, Vestland & Viken, 2020, p.11).

Since 2001, it has been possible to follow the movements of some of the large reindeer herds in Hardangervidda. From 2001 – today, NINA (Norwegian Institute for Nature Research) have marked over 100 individuals with GPS-collars in Hardangervidda (Gundersen, et.al., 2021, p.40). This dataset of GPS-positions gives valuable information on habitat use and changes in the use of historical migration routes and have provided several analyses on how infrastructure and other anthropogenic activity affect wild reindeer (Strand et.al., 2015a, p.3; Fylkestingene I Telemark, Vestland & Viken, 2020, p.11) (Panzacchi et.al., 2013; Panzacchi, Van Moorter & Strand, 2013; Panzacchi et.al., 2015a; Panzacchi et.al., 2015b).

2.1.2 Wild reindeer responses to human activities.

Humans are considered predators and a natural threat by wild reindeer (Røed et.al, 2014). Because they are shy by nature and have particularly well-developed senses of smell, sight and hearing, they can assess risks, including humans, from great distances (Reimers & Colman, 2006). A large number of visitors visits Hardangervidda during summer and winter, and the network of trails between different tourist cabins makes up the main hiking-routes on Hardangervidda today. Studies show that appr. 81 % of visitors keep to these marked trails on Hardangervidda (Gundersen, Strand & Punsvik, 2016, p.163; Selvaag et al. 2018, p.42) and due to this high level of traffic, it is a natural response that wild reindeer avoid and keep a distance to marked trails as well as cabins and other infrastructure used by humans (Nellemann et.al., 2000; Gundersen et.al., 2019).

The effect hikers have on wild reindeer is connected to the access to refuge-areas in addition to the density and intensity of the use of the trails (Gundersen, Strand & Punsvik, 2016, p.163; Gundersen et.al., 2019; Gundersen et.al., 2021b, p.52). Human disturbances on wild reindeer is often categorized as either *short-term local disturbances* that trigger acute stress and flight behavior, or *regional long-term disturbances* that can lead to avoidance of an area and demographic and genetic consequences at population level (Gundersen, Strand & Punsvik, 2016, p.160; Gundersen & Singsaas, 2020, in press). Physiologically, stress means that the animal is constantly prepared to face a threat (Gundersen, Strand & Punsvik, 2016, p.160). Disturbances from e.g. insect harassments or anthropogenic activity can lead to e.g. decreased search-time for pastures (Reimers & Colman, 2006; Skarin et.al., 2014; Holand & Punsvik, 2016, p.15) and wild reindeer may reduce their use of habitats in areas with frequent encounters.

2.1.3 Infrastructure, habitat-fragmentation and barrier effects

Wild reindeer behavior and genetics may to a large extent have remained the same for thousands of years (Røed et.al., 2014) while human society have gone through substantial changes (Punsvik & Frøstrup, 2016, p.9). Today reindeer must cope with disturbances from diverse anthropogenic activities and infrastructures. What once was a continuous, remote mountain habitat of summer and winter grazing land and calving areas, is today fragmented by road-networks, railways, dams and powerlines, construction works, private and public huts, marked summer trails and pooled winter tracks (Jordhøy & Strand, 2009; Panzacchi et.al., 2015a). As a response to these changes in landscape, reindeer modulate their movements and the patterns they have followed for centuries may be interrupted (Panzacchi et.al., 2013). Such habitat-fragmentation is globally considered one of the main causes for loss of biological diversity, and is especially striking for wild reindeer (Iuell, 2016, p.239) as they are dependent on large areas for migration. This kind of infrastructure requires large areas and may generate so-called "barrier-effects" for the reindeer, which in turn can eventually lead to a reduction in the flow of genes between population, as well as affecting the access to and pressure on suitable forage habitats (Jordhøy & Strand, 2008, p.33; Røed et al. 2014; Flydal et.al., 2019). As the national park is regulated by law, human constructions and developments inside the national park is highly restricted. However, the surrounding edge zone of Hardangervidda has a high level of anthropogenic interventions and activity, especially related to the "second-home" development in areas like Geilo, Rauland, Garen-Maurseth, Røldal and Veggli. Several studies have documented large avoidance effects for reindeer in these areas (Kjørstad et.al., 2017; Gundersen et.al., 2021b).

The main roads surrounding the national park are other examples of physical barriers. Highway Rv7 in the north separates the wild reindeer range of Hardangervidda, preventing the reindeer to migrate across these areas (Bevanger et.al, 2005, p.13) which is historically known as an important migration-route (Strand, Bevanger & Faldorf, 2006, p.26). Also, highway E134 in the south creates a barrier for the reindeer from migrating between the areas of Hardangervidda and Setesdal (Strand et.al, 2015, p.51). Another example is that the herd in Setesdal-Austhei must cross a main road when migrating from winter pastures in north to calving areas in south (Panzacchi, van Moorter & Strand, 2013, p.15). Developing tunnels e.g. along E134 and introducing winter-closing e.g. Rv7 is existing management measures to protect reindeer's migration routes, and an important political agenda in Norway today (see Strand et al. 2015).

3.0 Methods

3.1 Study area: Hardangervidda national park

Hardangervidda national park was established in 1981 and covers an area of 3422 km^2 (Bjerketvedt et.al, 2014, p.58). The national park lies within the total mountain plateau area of Hardangervidda and the reindeer management unit, covering 8130 km^2 (Gundersen, et.al, 2020). Most of Hardangervidda lies within the alpine zone, hence above the tree-line with an average altitude between 1000-1300 m.a.s.l. (Mossing & Heggenes, 2010, p.16) and this is also reflected in nature-types, plants and vegetation present. Grass heaths and dwarf shrubs dominate in the low alpine zone, while higher up lichens, bogs, mosses, gravel and rocks dominate the fauna (Melvold & Skaugen, 2018, p.8). The landscape on Hardangervidda also follows a topographic gradient from east to west, where the areas in the east are mainly dominated by lichens and gradually less lichen-dominated towards the west (Strand, Bevanger & Faldorf, 2006, p.26). The geological landscape varies from flat tundra landscape in the east, to mountain-ranges reaching up to 1700 m.a.s.l. in the south and west (Melvold & Skaugen, 2018, p.8) (*Fig.4*). One of the main reasons for the development of a national park in this area was to protect its unique wildlife and landscape – and hereunder protect the wild reindeer population (Fylkesmannen i Telemark, Buskerud & Hordaland, 2011, p.11). The park is protected and regulated by Norwegian law including specific regulation rules (Naturmangfoldloven, 2009; Forskrift om Hardangervidda nasjonalpark, 1981).

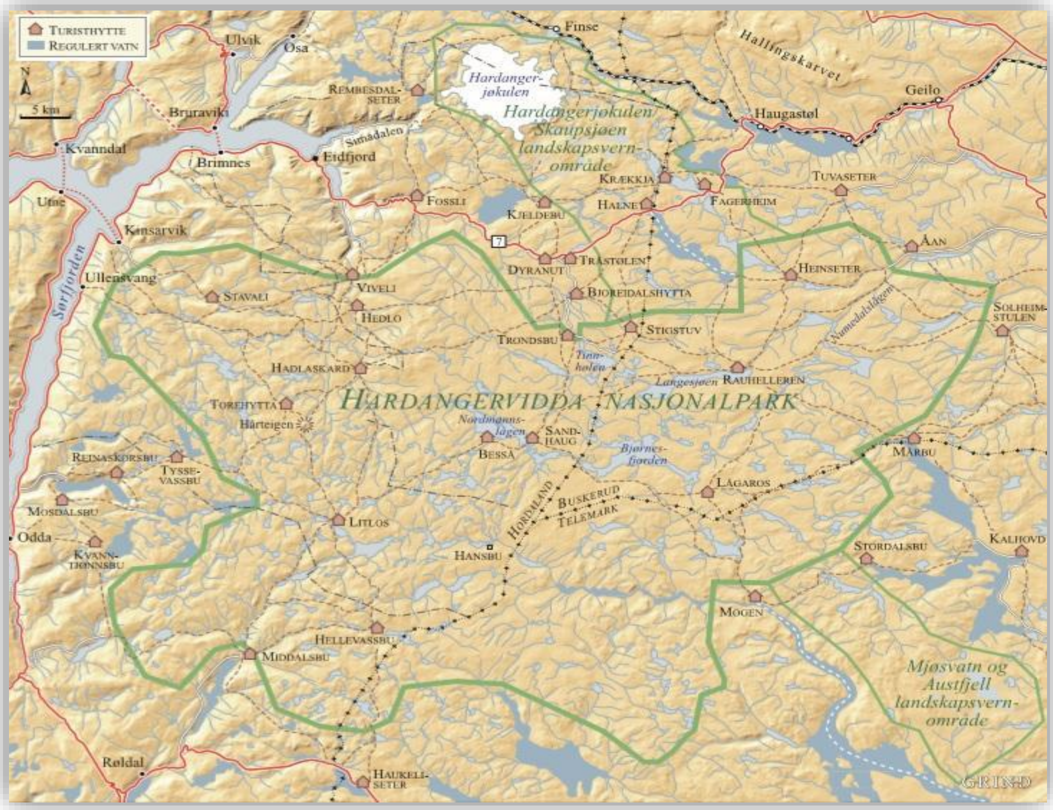


Figure 3: *The area of Hardangervidda with boarders (green line) of the national park (grind.no, n.d.)*

Figure 4 a and b: *The landscape in Hardangervidda varies from east to the west. The western part of Hardangervidda (upper picture) is dominated by high mountain-ranges and rocks, and the vegetation is scarce with bogs, mosses and lichens. The landscape in the eastern parts of Hardangervidda (lower picture) is a flat tundra landscape, and the vegetation include shrubs and grasses. Both pictures are from appr. 1100 m.a.s.l. (both pictures by Vilde Holtmoen, 2020 and 2018).*

Activities on Hardangervidda

Residents from surrounding municipalities have been using Hardangervidda for centuries; mainly for the purpose of subsistence harvesting (hunt, fish, berries etc.) or agriculture (herding and outfield harvesting) (Flemsæter et.al., 2018). There exist comprehensive written sources that describe different types of traditional use of Hardangervidda, and this knowledge can often be characterized as local, descriptive and not systematic (Selvaag et.al., 2020). Hardangervidda was also an important traffic route, connecting east and west. During the 1900's, people started to use the area for recreational activities and the right to roam (Allemannsretten) - the act that gives the public access to roam and camp freely in nature (with some obligations) – is strongly rooted in the Norwegian outdoor tradition (Gundersen, Strand & Punsvik, 2016, p.168; Fylkestingene i Telemark, Vestland & Viken, 2020, p.8). This act makes Hardangervidda available for everyone who wants to visit (Friluftsloven, 1957). Besides from local and private cabins in the national park, and many second-home areas in the fringe of the park, the Norwegian Tourist Association (DNT) owns 21 public tourist cabins on Hardangervidda available for everyone. In all, 9 of these are organized with staff and the rest are self-service cabins (Reimers et.al, 2010; dntoslo.no, n.d.). The cabins are connected in a network of marked summer-trails and winter-tracks, and they are spread over most of Hardangervidda, except for the south-central part that have no cabins or marked trails (*Fig.5*).

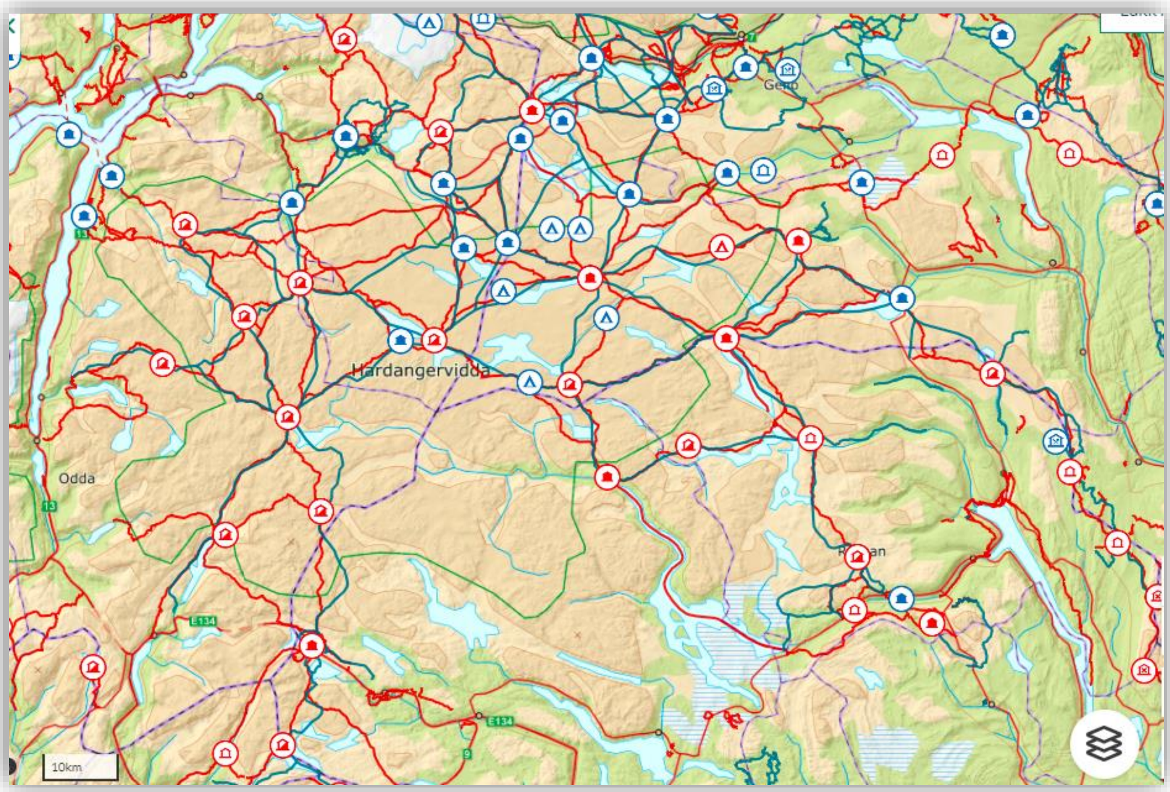


Figure 5: *Map of Hardangervidda with the network of public cabins (cabin-symbols), summer-trails (red lines) and winter-trails (blue lines). Most of the cabins are owned and organized by DNT. (Screenshot from ut.no).*

Most of the staffed DNT-cabins at Hardangervidda is only open during parts of the year, and the main season in winter/spring is during March and April, with a peak in Easter, and main summer season is from July-September (Gundersen et.al., 2020).

The combination of a well-arranged infrastructure with marked trails and tourist cabins in an otherwise remote area make Hardangervidda an attractive destination for foreign and long-travelled national visitors, which also make up the largest user-group on Hardangervidda (Gundersen, Strand & Punsvik, 2016, p.162; Gundersen et.al., 2021a, p.48,51). Studies show that locals are usually well known in the area, and do not necessarily follow the marked trails, while long-travelled tourists have a somewhat different pattern of activity – usually following marked trails and make use of facilities available, like the DNT-cabins (Gundersen, Strand & Punsvik, 2016, p.162; Gundersen et.al., 2021b, p.27). Hiking, cross-country skiing, hunting and fishing are the most common activities on Hardangervidda today, but there are also other activities that have shown its presence in the last decades as the modern development of outdoor life introduces new and specialized activities (Strand, Bevanger & Faldorf, 2006, p.43; Odden, 2008; Strand et.al, 2010, p.11; Selvaag et.al., 2018, p.30; Gundersen et.al., 2021b, p.54). Examples are cross-country skiing that is separated to a diversity of ski activities like freeride, randonnée, kiting, skating etc., and similar specializing has been seen for bicycling (Odden, 2008).

This modernization of outdoor recreational activities could conflict the perception of traditional outdoor recreation (friluftsliv) and has the potential of giving new disturbance regimes for wildlife and nature conservation on Hardangervidda (Gundersen, Strand & Punsvik, 2016, p.162; Gundersen et.al., 2021a, p.9). One example of this is ski-kiting (see e.g. Lilleeng et.al., 2007). A commercial tourism-market involves economic interests (Haukeland, Grue & Veisten, 2010; Strand et. al, 2010, p.12) and may demand further need for facilities and infrastructure such as access roads, marked trails, accommodation opportunities and other services, compared to the traditional outdoor activities (Haysmith & Hunt, 1995, p. 205).

An example of this is the 14 km hike to Trolltunga, situated just in the fringe-zone of Hardangervidda National Park. Trolltunga has grown to be a tremendous tourist-attraction the last decade, with an increase from 800 visitors in 2010 to 80.000 visitors in 2016 (Fjelltveit, 2016) and there has been an increasing number of guiding companies offering diverse adventures in the area. How these new trends of outdoor activities are affecting the wild reindeer population on Hardangervidda are poorly understood and should be an object for further studies. It is however, enshrined in the Nature Diversity Act §9 that management authorities of national parks should first of all protect natural values, and when the effect of human activity on wild reindeer is yet not known, they should give wild reindeer first priority (Naturmangfoldloven, 2009, §9; Gundersen, Strand & Punsvik, 2016, p.162).

3.2 Spatiotemporal Data of Visitor Use: Strava and Automatic Counters.

Strava

NINA has purchased the rights for handling of raw-data material from 2016-2022 (Vistad et.al, 2019, p.16; Barton, Gundersen & Venter, 2021) and the dataset for this thesis contain information from 2016-2019. Strava-data were handled using QGIS version 3.4.11; a free GIS-software program made for visualizing and handling of spatial data. The dataset from Strava used in this thesis was spatially structured in such a way that the area of Hardangervidda was divided into 132288 hexagonal pixels (350m sides) with their unique ID. Each pixel covered an area of 0.075km^2 (measured in QGIS). In the raw dataset, the number of observations of users inside a pixel was aggregated at a monthly scale (Gundersen et.al, 2021a, p.20). Furthermore, the number of observations within each pixel was recorded using 5 as the measurement unit, i.e. 0-4 observations was recorded as 0, 5-9 observations was recorded as 5 etc.

The spatiotemporal aggregation of the data and course measurement unit was implemented to reduce infringement on Strava-users privacy. Users of Strava are informed in the privacy policy that Strava sell aggregated information for purposes like science, and it is not gathered any personal information about the individual Strava-users others than their GPS-positions within a pixel (strava.com, n.d., c). Strava-data were organized in summer-seasons (July-September, 2016-2018) and winter-seasons (March and April, 2017-2019) in QGIS and the spatiotemporal information from the attribute tables was exported as txt-files for each year and each season. The Strava-dataset included hiking and running as activities in summer (not e.g. biking), and skiing as activity in winter.

Automatic Counters

NINA has been collecting data on human activity along trails using automatic counters in the period 2016-2019 (Gundersen et.al., 2020, 2021a). Two main types of automatic counters were used: the EcoCounter and TrafX. Both types of counters work by an infrared sensor that has a reach of 4 meters. The sensor registers the body heat of the person that passes – this creates an amplitude that is recognized by the counter, and the counter register the presence of a person (Vistad et.al, 2019, p.13). The EcoCounter send information directly to a database using the mobile phone network, while the TrafX must be collected and downloaded manually (Vistad, et.al, 2019, p.12). For automatic counters, there are less issues concerning privacy as the counts usually do not collect any personal information and cannot be traced back to the individual persons.

The number of counters used, dates for installation and retrieval of the automatic counters are presented in Table 1. Site locations were changed between years, but the counters were always located close to the marked trails on Hardangervidda to increase the probability of counting users of the trails (*Fig.6*). Each counter was assumed to represent a trail-segment, defined as the distance between two trail junctions. The data from the automatic counters contain information on the location of the counter and daily counts. The datasets for all the counters were first inspected using Excel. Extreme outliers, as indicated by sudden bursts of observations 10-fold higher than nearby dates were deleted, in addition to counters that had obvious technical errors (e.g. no counts during the entire period in a frequently used trail). The counter data were then summarized as the average number of observations per day per month.

Table 1: *Number of automatic counters and dates for set out and retrieval for each year and season.*

	Summer 2016	***Summer 2017***	***Summer 2018***	***Winter 2017***	***Winter 2018***	***Winter 2019***
Number of counters	***20***	***65***	***55***	***14***	***47***	***17***
Date out	***08.07.16***	***30.06.17***	***30.06.18***	***07.03.17***	***27.02.18***	***05.03.19***
Date in	***12.10.16***	***02.10.17***	***02.10.17***	***17.04.17***	***28.04.18***	***23.04.19***

In winter 2018, 18 pairs of counters were placed along various trail-segments over Hardangervidda to evaluate the consistency of the counts obtained from the automatic counters.

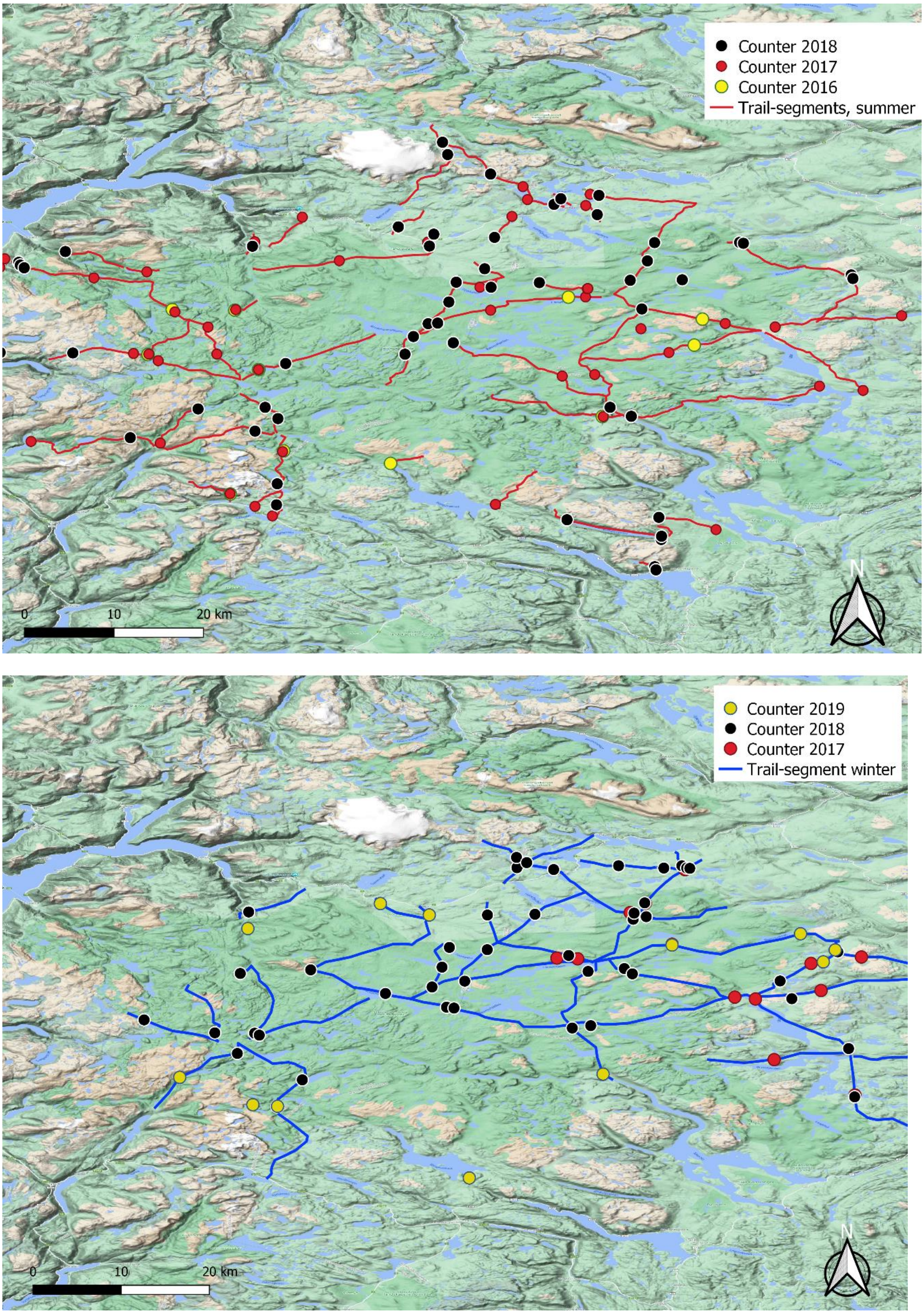


Figure 6 a and b*: Map of Hardangervidda with position of counters in summer seasons 2016-2018 (**a,** above) and the associated trails segments, and position of counters in winter seasons 2017-2019 (**b,** below) and the associated trails segments.*

Visitor – wild reindeer interactions in summer

To visualize areas with potential visitor-reindeer interactions in summer, a habitat suitability map for wild reindeer in summer was combined with Strava-data and GPS-data from marked wild reindeer from the same period in QGIS. Google terrain was used as background-layer. The habitat suitability maps by Panzacchi et.al. (2021, in press), are based on regression models for wild reindeer habitat use in summer that includes several environmental variables (topography, terrain, vegetation etc.) and various kinds of human infrastructure (Panzacchi et.al., 2015a; Gundersen et.al., 2021b, p.41; Panzacchi, et.al., 2021, in press). A vector layer with GPS-positions from all available marked wild reindeer from summer 2016-2019 (June-September, collected by NINA) was added on top of the habitat-suitability map. Finally, a layer with the aggregated Strava-observations from summer seasons (June-September) 2016-2019 was added on top where the number of visitors were categorized in different colors to identify the most used hiking-trails and analyze where the traffic is highest with implications for wild reindeer migration. The aim was to highlight frequently used areas by humans and to see if this could interfere with wild reindeer movements during the same period.

3.3 Data preparation and statistical analyses

Statistical analyses were carried out in R-studio. R-studio is a free software program for scientific research including statistical analyses (rstudio.com, n.d.). The package "ggplot2" version 3.3.3 (Wickham, 2016) was used for all the plots. The package "cccrm" version 2.0.1 (Carrasco & Martinez, 2020) was used for calculating the concordance correlation coefficient. The package "RColorBrewer" (Neuwirth, 2014) was used for adding color-pallets to the scatterplots. The package "ggpubr" (Kassambara, 2020) was used to combine several plots and the package "scales" (Wickham & Seidel, 2020) was used to set right scale in the plots.

Relationship between Strava-data and counter-data

Strava-data and counter-data were combined using the Strava data from the pixel the automatic counter data was located within to create a summarized file containing information from both Strava and the automatic counters. Strava-data was measured as the aggregated number of observations within one pixel for each month, while the counter-data was measured as the average daily count for each month. A linear regression model (lm) was fitted to the data from each of the months separately, with the Strava-counts as response variable, year and the automatic counter data as predictor variables. In 2017 and 2018, a counter was located in the popular site "Trolltunga". Observations associated with this site were much higher in summer months than all other sites, for both Strava-data and counter-data. Therefore, for July, August and September, analyses were done both with and without this site included in the dataset to evaluate to what degree results depended on this outlier. In 2016, there was no counter located at the Trolltunga-site, and the Trolltunga-site did not have substantially higher observations than other sites in March and April. The two datasets were plotted in a scatter plot with regression lines and confidence intervals for each summer and winter month, showing the yearly variation on the relationship between Strava-data and counter-data, using ggplot and the function geom_smooth.

Seasonal and annual patterns of activity from Strava-data

Strava-data included observations from the edge zone surrounding Hardangervidda national park, an area that have high densities of private cabins as well as some public cabins and ski-resorts (e.g. Dyranut, Haukelisæter, Halne, Rauland, Maurset, Veggli and Geilo). This area is likely to have another use than the central parts of the national park and the edge zone is also probably more used by locals. The datasets with monthly counts of activity within each pixel was therefore analyzed by grouping pixels within and outside the national park to investigate into the temporal variation in the Strava-observations. Two plots were made on *the sum of Strava-observations across all pixels*, distinguished between inside and outside the national park.

Counter consistency

To evaluate how consistent observations of humans passing was between counters in the winter, the daily counts for the 18 counter-pairs were plotted in R-studio, using ggplot with different colors for each counter-pair and the concordance correlation coefficient (ρ_c) across pairs was calculated, using the cccvc-function in R. The concordance correlation coefficient assesses agreement between two continuous datasets and takes a value between -1 (perfect disagreement), 0 (no agreement) and 1 (perfect agreement) (Carrasco & Jover, 2004). In addition, the Pearson correlation coefficient, *r*, for each counter-pair was calculated in Excel, and a histogram of the distribution of *r*-values was made in R-studio.

4.0 Results

4.1 Relationship between Strava-data and counter-data

Summer-season (July-September): There was a significant, positive relationship between activity-counts obtained by Strava and activity counts from automatic counters in summer (July, August and September) (*Tab.2-3, Fig.7*). The positive linear relationship between Strava-data and counter-data is consistent and increasing over the study years with increasing values for both intercept and slopes from 2016-2018. These findings were not affected by neither inclusion nor exclusion of the Trolltunga-site, except for September that showed a weaker positive association ($R^2 = 0.40$) when the Trolltunga site was excluded (*Tab.2*). The results also show that the number of Strava-observations increases over the study-years, independently of data from automatic counters as there is an increase in both slope and intercept in the regression equations over the study-years (*Tab.2*).

Winter-season (March-April): For March and April the results indicate no consistent positive relationship between activity counts obtained by Strava and activity counts from automatic counters (*Fig.8, Tab.2-3)*, with no consistent increase in slope or intercept. These months had little variation and low maximum observation numbers compared to the summer months (< 20 Strava-observations at maximum for all pixels, compared to > 500 Strava-observations at maximum in some pixels in summer). An exception is the results for March 2018 and April 2019 that showed a positive relationship. The results were significant for April (p-value < 0.0005), but not for March (p-value > 0.05).

Data from the automatic counters were measured as the average daily count for each month while Strava was summarized as the aggregated number of observations per month within one pixel. It is possible to obtain a crude estimate of the relationship between the estimates from Strava and the automatic counters by taking the estimates of the slope in Table 3 and divide this by number of days in the month. This would suggest that there is an increase in the proportion of observations in Strava in relation to observations by automatic counters, going from ≈ 0.1 % in 2016, ≈ 0.7% in 2017 and ≈ 0.9 % in 2018.

Table 2: *Adjusted R-squared and p-values from ANOVA tests of variance in Strava activity counts being explained by activity counts from automatic counters in the same pixel and same month, year fitted as a factor and the interaction between counter-data and year. ns = p > 0.05, * = p < 0.05, ** = p < 0.005 and *** = p < 0.0005. Parameter estimates of the regression models are given in Table 3.*
 # output-values from the linear models where the Trolltunga-site is excluded.

	Adjusted R-squared	*counter*	*year*	*counter : year*
July	*0.96*	***	***	***
August	*0.97*	***	***	***
September	*0.86*	***	*	***
March	*0.52*	***	*ns*	*ns*
April	*0.33*	*	*	***
July#	*0.81*	***	***	***
August#	*0.76*	***	***	***
September#	*0.40*	***	*	***

Table 3: *Regression equations for the yearly variation in Strava data (y) as a function of the average number of observations per day the same month observed by the automatic counters (x), with calculated standard error (SE) Regression lines are shown in Fig.7 and 8. * regression equations where the Trolltunga-site is excluded.*

	July	*August*	*September*	*March*	*April*
y (2016)	***4.53*** *(±3.22)* ***+ 0.05x*** *(±0.04)*	***2.45*** *(±2.48)* ***+ 0.04x*** *(±0.05)*	***- 0.43*** *(±2.35)* ***+ 0.05x*** *(±0.1)*		
y (2017)	***5.04*** *(±1.65)* ***+ 0.24x*** *(±0.01)*	***3.12*** *(±1.24)* ***+ 0.19x*** *(±0.01)*	***1.85*** *(±1.22)* ***+ 0.20x*** *(±0.01)*	***- 0.73*** *(±1.0)* ***+ 0.22x*** *(±0.09)*	***1.93*** *(±0.73)* ***- 0.01x*** *(±0.01)*
y (2018)	***7.76*** *(±1.86)* ***+ 0.29x*** *(±0.01)*	***7.14*** *(±1.3)* ***+ 0.30x*** *(±0.01)*	***2.78*** *(±1.25)* ***+ 0.28x*** *(±0.01)*	***- 0.21*** *(±0.44)* ***+ 0.08x*** *(±0.01)*	***0.16*** *(±0.42)* ***- 0.01x*** *(±0.02)*
y (2019)	*No data*	*No data*	*No data*	***1.18*** *(±1.02)* ***- 0.02x*** *(±0.06)*	***- 0.35*** *(±0.75)* ***+ 0.09x*** *(±0.02)*
y (2016)*	***4.53*** *(±3.14)* ***+ 0.05x*** *(±0.04)*	***2.45*** *(±2.46)* ***+ 0.04x*** *(±0.05)*	***-0.43*** *(±2.33)* ***+ 0.05x*** *(±0.10)*		
y (2017)*	***7.37*** *(±1.97)* ***+ 0.17x*** *(±0.04)*	***4.82*** *(±1.56)* ***+ 0.13x*** *(±0.03)*	***0.69*** *(±1.54)* ***+ 0.29x*** *(±0.07)*		
y (2018)*	***9.84*** *(±2.05)* ***+ 0.26x*** *(±0.02)*	***7.66*** *(±1.49)* ***+ 0.28x*** *(±0.02)*	***1.68*** *(±1.44)* ***+ 0.38x*** *(±0.07)*		

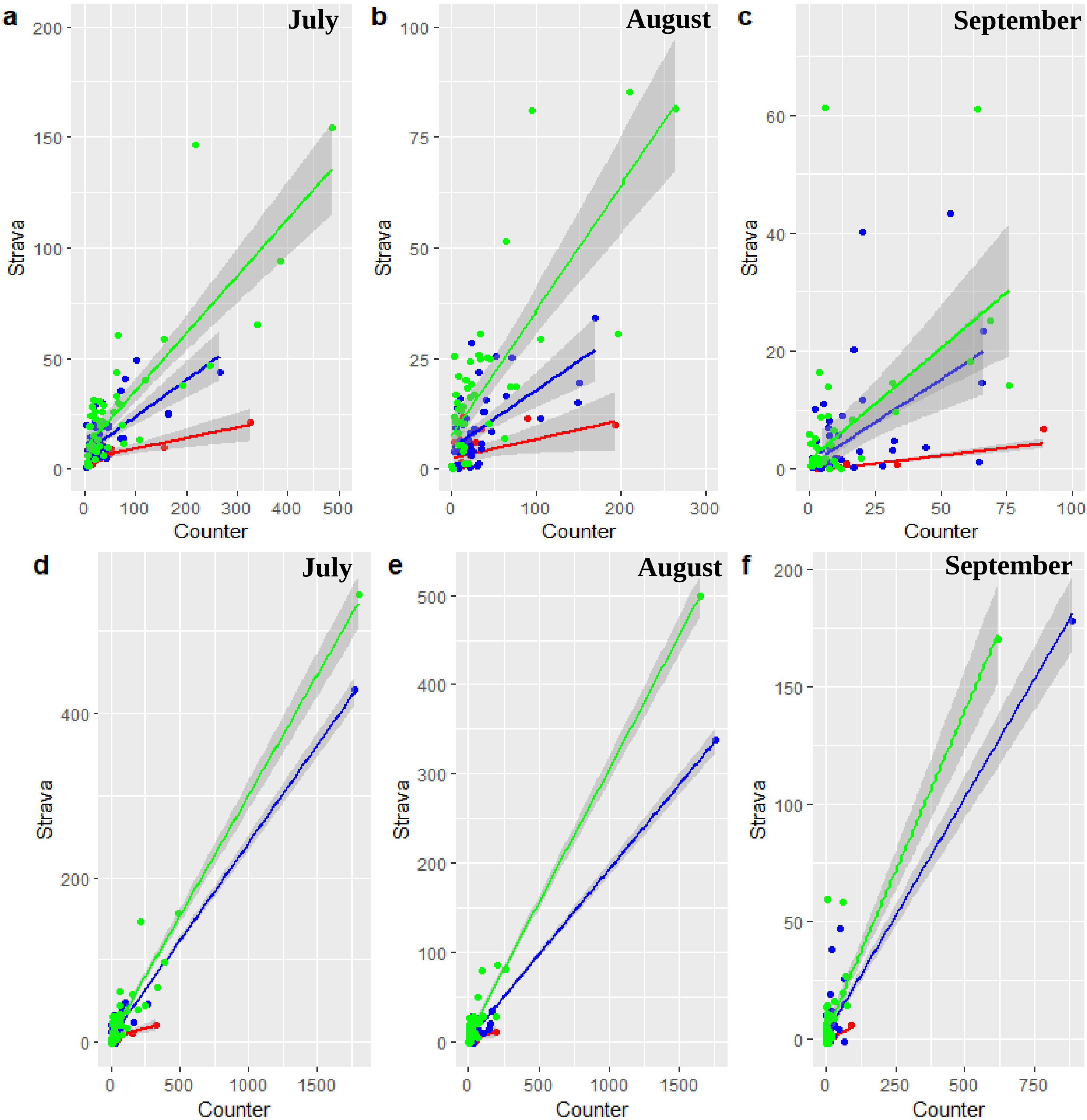


Figure 7 a - f: *Plot with regression lines for summer months and the yearly variation on the relationship between Strava-data and counter-data for summer months (July, August, September) from 2016-2018. Red = 2016, blue = 2017, green = 2018. Confidence intervals in shaded dark grey around regression line. a-c is with "Trolltunga" excluded; d-f is with "Trolltunga" included. Strava is measured as aggregated number over one month, while counter is measured as average daily number over the same month.*

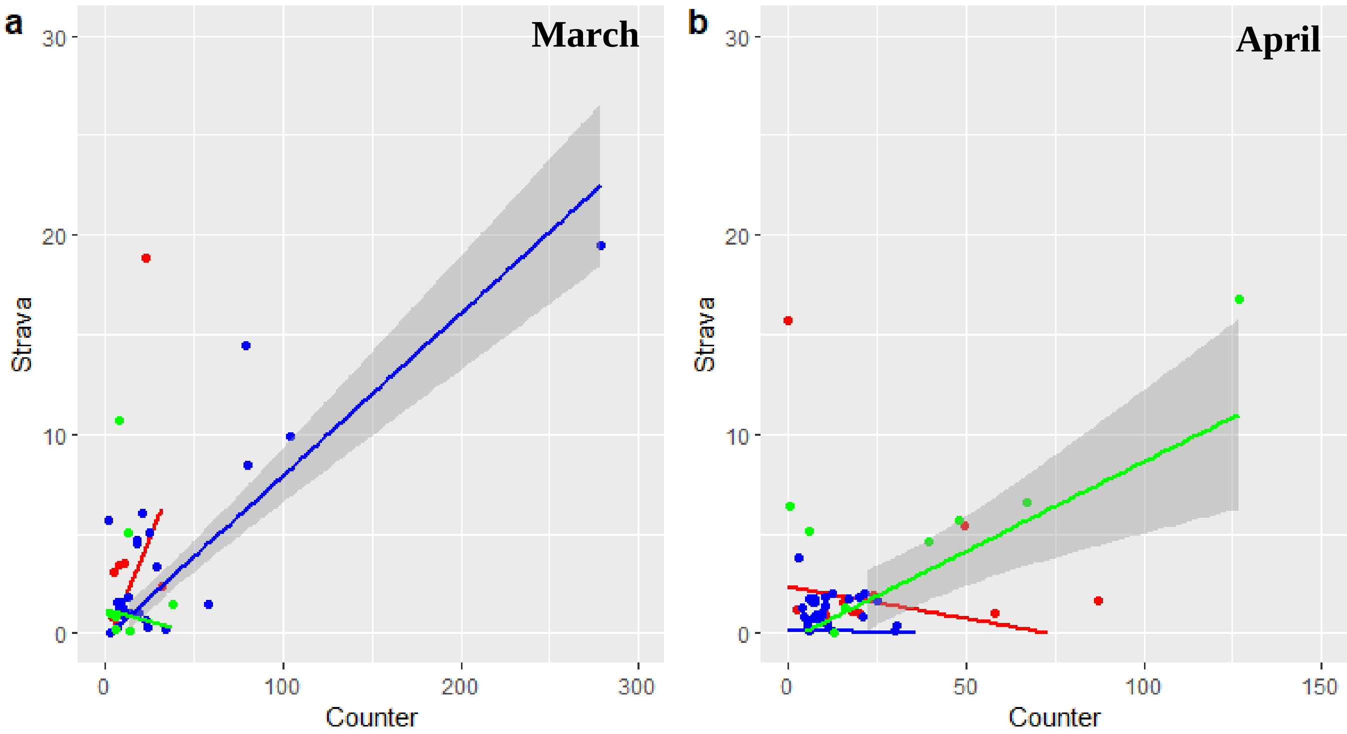


Figure 8 a and b: *Plot with regression lines for winter months and the yearly variation on the relationship between Strava-data and counter-data for winter months (a=March, b=April) from 2017-2019. Red = 2017, blue = 2018, green = 2019. Confidence intervals in shaded dark grey around the regression lines. Strava is measured as aggregated number over one month, while counter is measured as average daily number over the same month.*

4.2 Consistency in counter observations

When two counters were placed exactly at the same trail segment, the counter-pairs typically showed strong correlations in daily observations with $r > 0.7$ for 15 of the counter-pairs (*Fig.9*). The exception was two pairs with low correlation ($r = 0.24$) and one pair with no correlation ($r = 0$). The datasets from these three counter-pairs were inspected to see if there would be any specific reason for the low correlations, like extremely high values (10-fold or higher) for one of the counters, but this was not found. The concordance correlation coefficient across all counter pairs was high, with $\rho_c = 0.82$ (*Fig.10*).

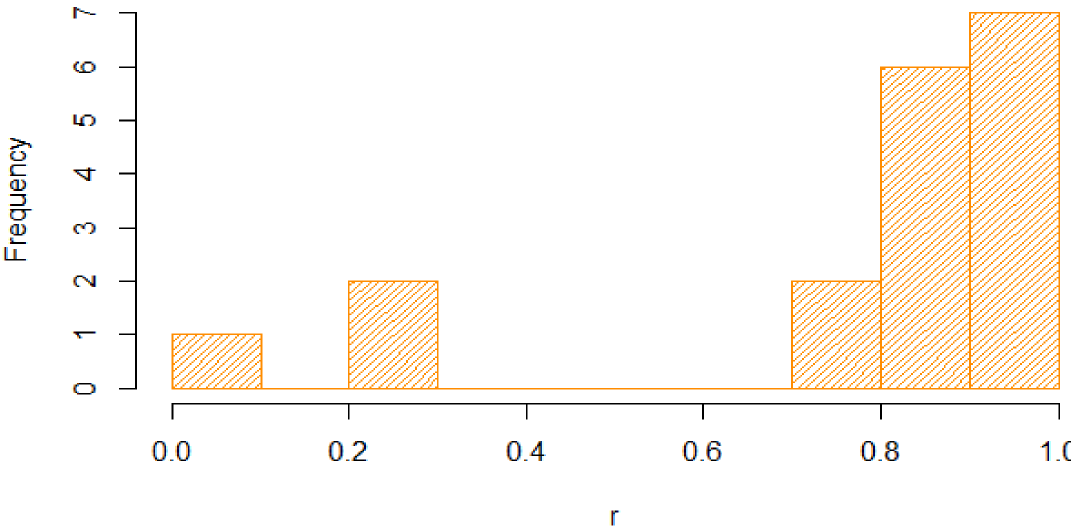


Figure 9: *Histogram of the r – distribution from the double counters in winter 2018.*

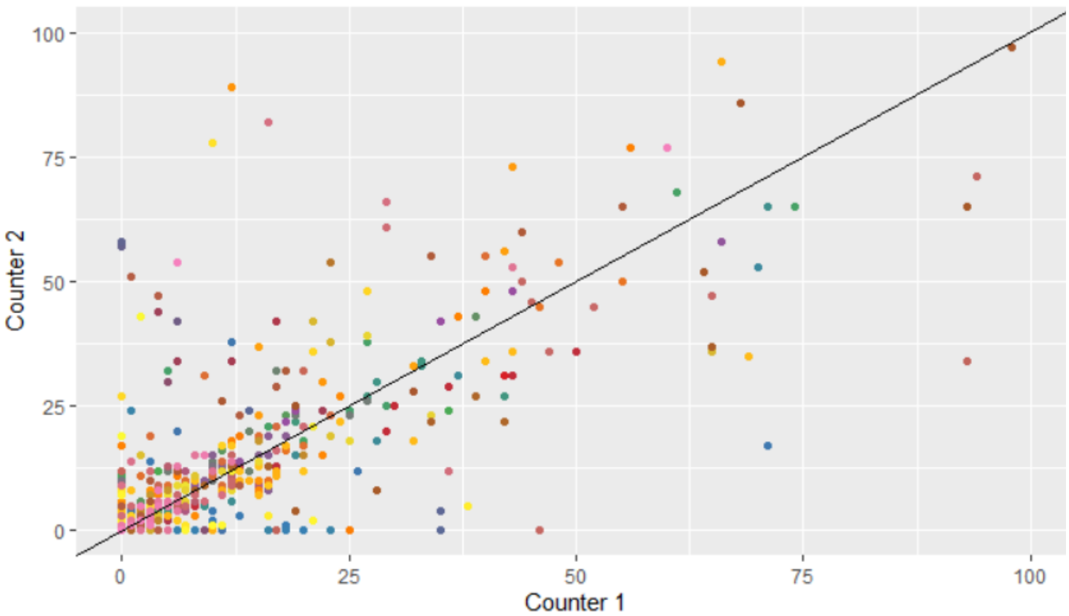


Figure 10*: Counter consistency between two counters placed along the same trail-segment during the period 28^{th} of February to 28^{th} of April 2018. Each color represents a pair of counters with daily observations. In total there were 18 pairs of counters.*

4.3 Seasonal and annual patterns of activity inside and outside the national park based on Strava data.

Inside the national park: during the year, the highest numbers of Strava-observations were in summer months, with a peak in July. The rest of the year, Strava suggested little activity inside the National park, except for a smaller increase in March-April and September (*Fig.11a*). There was an increase in Strava-observations across years for all months except for October – December, which had very low numbers of observations over all four years. In March-April there seemed to be some variation between years and the pattern corresponded with the timing of Easter, which is a main ski-holiday period in Norway. There were more observations in March 2018 when Easter was in March, and more observations in April in 2017 and 2019, when Easter was in April.

Outside the national park: outside the national park there were in general higher numbers (than inside the national park) of Strava-observations for all months. However, the seasonal patterns were similar as inside the national park, with peak activity in July-August (*Fig.11b*) and more observations in March 2018 and April 2017/19. There was also an increase in Strava-observations across years for all months, with some variation between years in March and April.

The main difference in the seasonal activity inside and outside the national park was higher levels of activity outside the national park both in spring (March-April-May) and in autumn (September-October). July had the highest peak for all years, both inside and outside the national park. The sum of observations across all pixels has increased from 16350 observations inside the national park in 2016 to 91025 observations in 2019 (*Fig.11a*). Outside national park, the number has increased from 57005 observations in 2016 to 211975 observations in 2019 (*Fig.11b*).

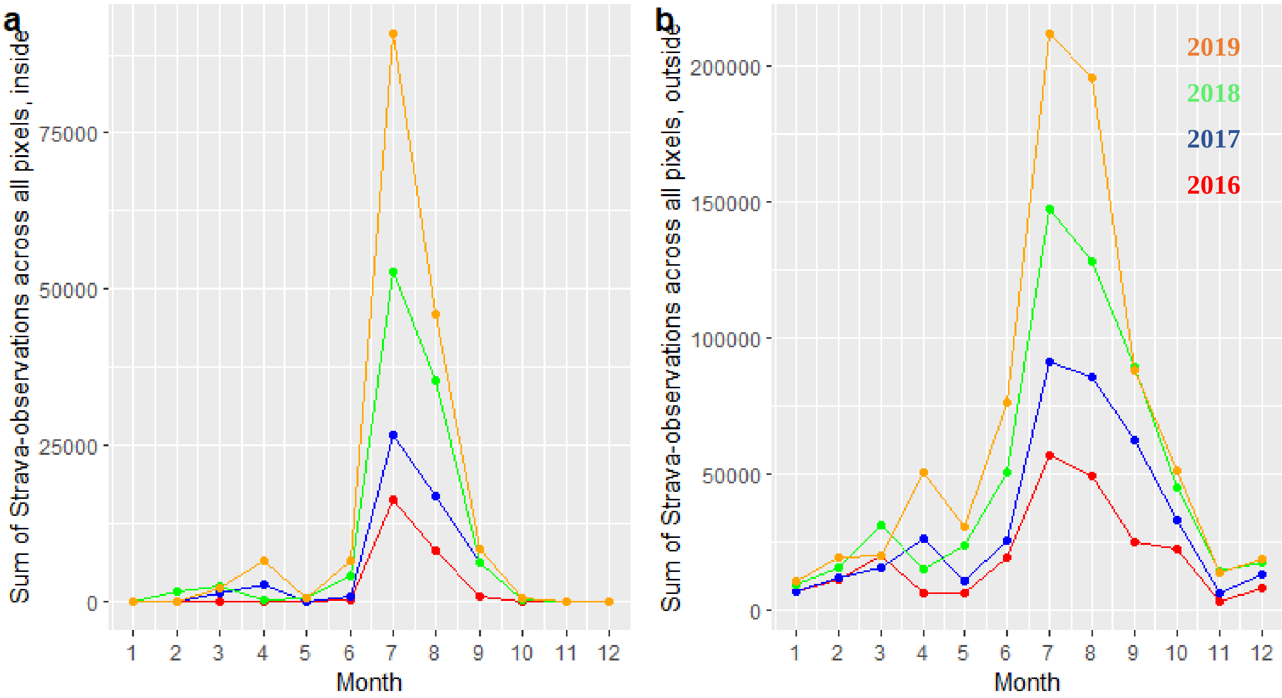


Figure 11 a and b: *Seasonal and annual variation on the aggregated monthly number of all Strava-observations across all pixels inside (a) and outside (b) the national park.*

4.4 Visitor – wild reindeer interactions during summer

The habitat suitability map in figure 12 indicates that the most preferred summer areas for wild reindeer are found in the south and central parts of Hardangervidda, in addition there are some smaller areas in the east and north-west. The GPS-data (Fig.13) from wild reindeer also show that they mainly use the central and southern parts during summer, in addition to some activity seen further east and north in the national park. Most of the wild reindeer are found within the national park boarders, with little expansion outside the edge zone. One exception is in the south, where there is reindeer activity not far from the main road (E134). As this is GPS-data from 2016-2019, it indicates that wild reindeer returns to approximately the same areas in summer over several years. In comparison, the aggregated Strava-data on human activity show high activity in the edge-zones of Hardangervidda, with particularly dense activity related to popular private second-home areas (Fig.13). The human activity inside the national park is almost exclusively kept to certain marked trails and public tourist cabins (Fig.5). The activity crossing the inner parts of the national park is normally between 5-100 observations per pixel, but some selected routes between popular tourist cabins have up to 200 observations per pixel. These routes do not cross the central areas where the wild reindeer is mostly located, but follow routes close-by, like the coherent routes north-south and east-west.

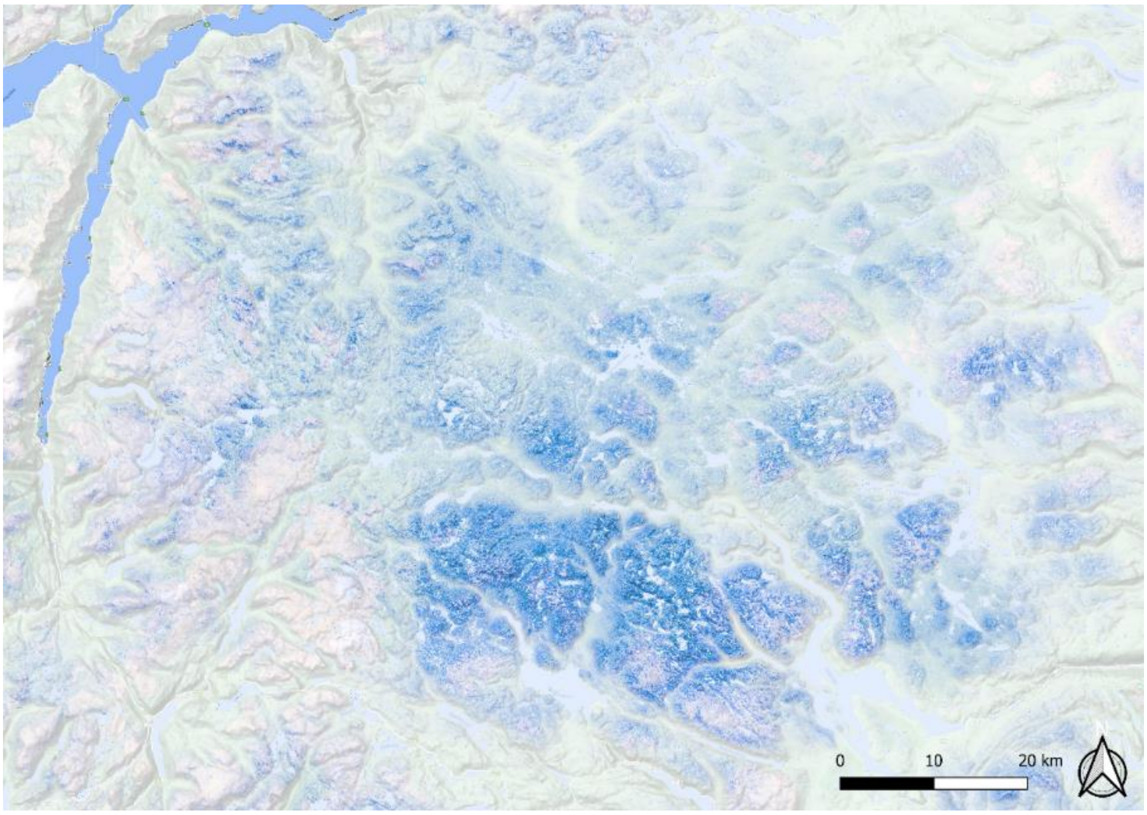
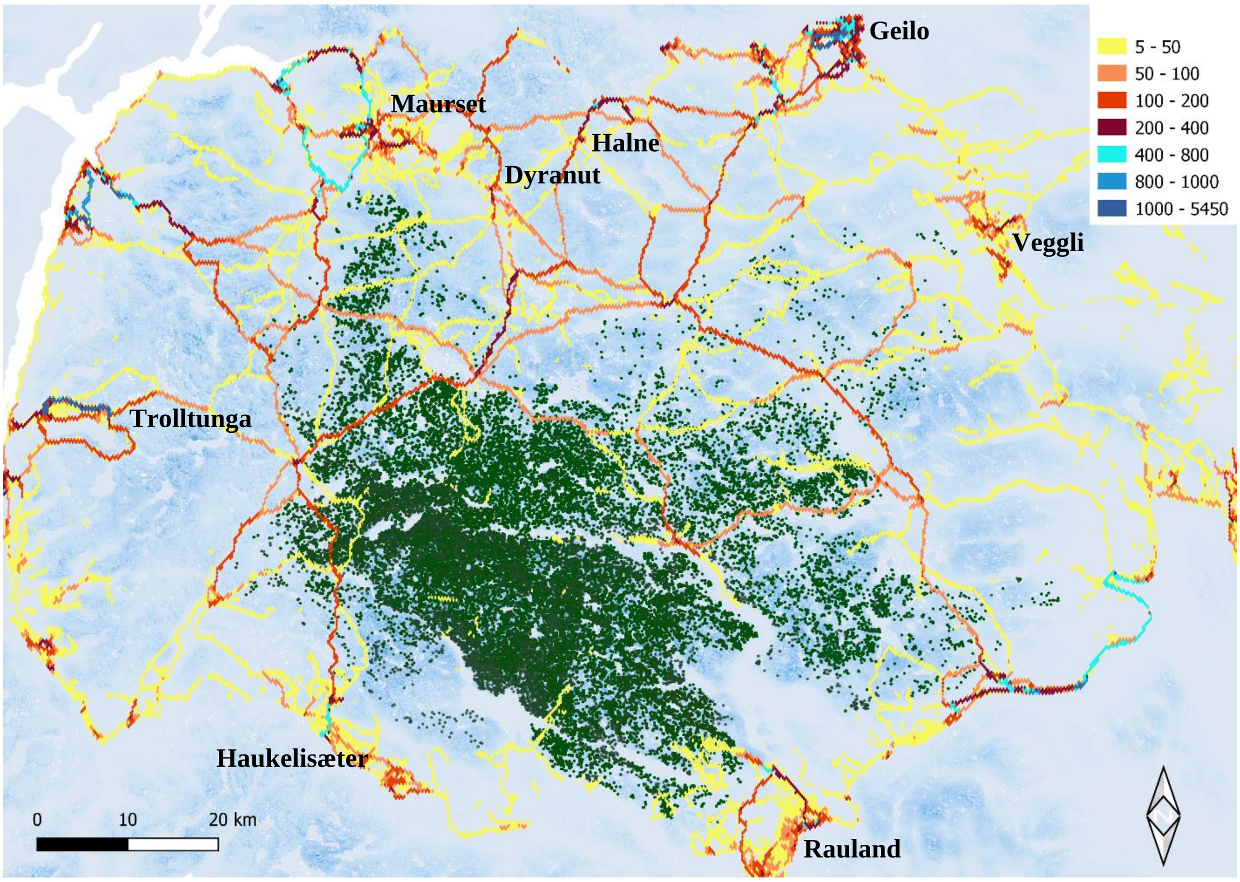


Figure 12: *Habitat suitability map for wild mountain reindeer in summer. Blue areas are the most preferred habitats while lighter colors are less preferred habitat (Panzacchi et.al., 2021, in press).*



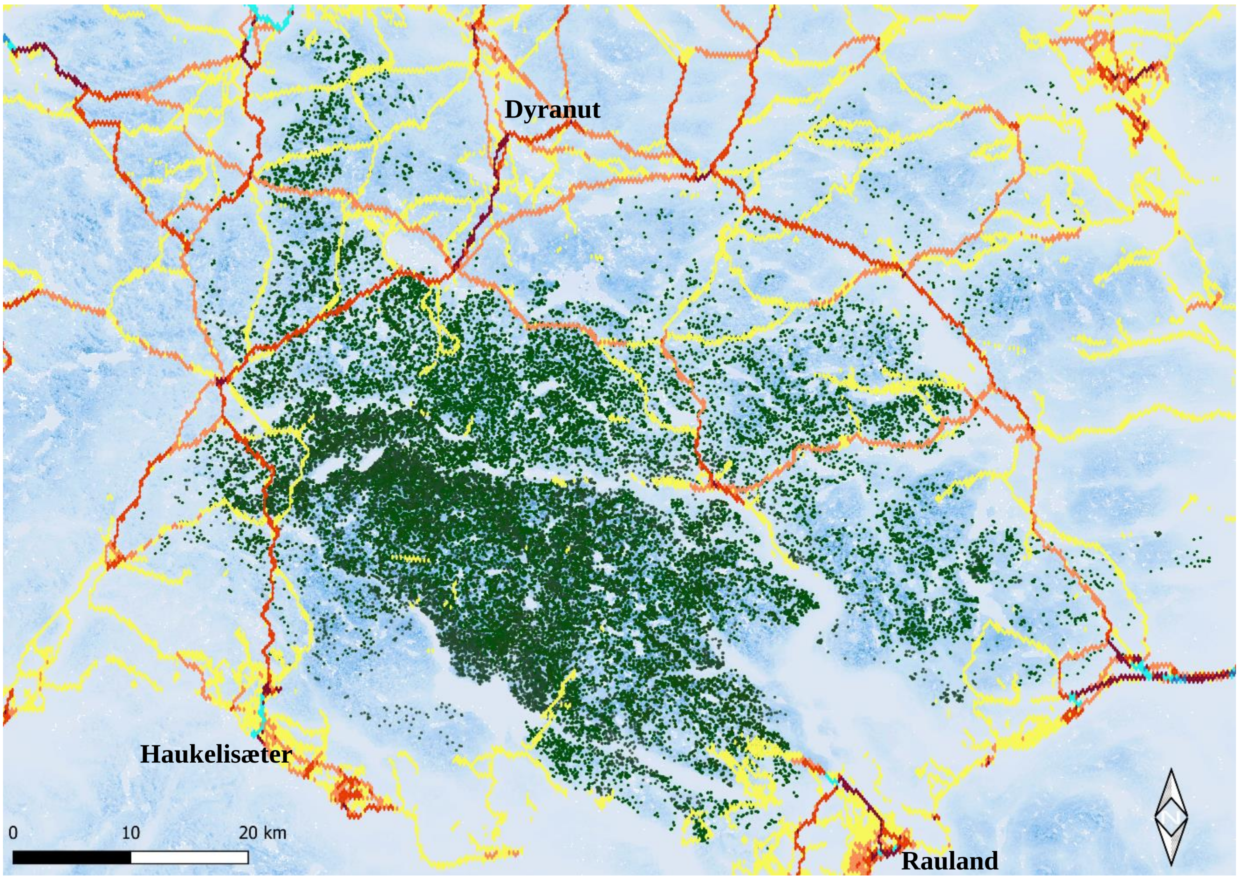


Figure 13 a and b: *Overview map of Hardangervidda (above) and central parts of Hardangervidda (lower), including the habitat suitability map for wild reindeer (Panzacchi et.al., 2021, in press), aggregated Strava-data from summer months (June-September) 2016-2019 where the numbers of observations within one pixel are categorized in different colors, and the GPS-positions from marked reindeer during the same period (dark green dots). Names from areas (e.g. cabin-areas in the edge zone) with high density of observations are added to the map*

5.0 Discussion

The main findings in this thesis was a positive relationship between Strava-data and automatic counter data in the summer season (July-September) (*Fig.7*). For winter season (March-April), no consistent relationship was found between the two monitoring measures (*Fig.8*). The pairs of automatic counters showed an overall high correlation in remote settings in wintertime, with $\rho_c = 0.82$ (*Fig.10*). The annual and seasonal pattern of activity as measured by Strava-data showed a peak in the number of observations across all pixels in summer months, and the number of observations across pixels increased over the study-years from 2016-2019 (*Fig.11*). The aggregated data from Strava from summer months 2016-2019 (*Fig.13*) revealed an activity pattern with the highest observation numbers in the edge zone of Hardangervidda, as well as high activity related to the marked trails on Hardangervidda. In the following, these findings will be evaluated and discussed in relation to similar studies.

The relationship between Strava-data and automatic counter data.

My results indicate that the measures on human activity is consistent between the automatic counters and Strava data during summer, whereas the relationship in winter (March and April) is inconsistent. There were substantial seasonal variations in the number of Strava-observations (observations within each pixel) during the year and this seasonal variation in observations may affect the relationship between Strava-data and automatic counter-data. Data from summer months (July-September) had high numbers of Strava-observations (> 500 observations at max in one pixel for some locations) and there was a corresponding positive relationship between the Strava-data and counter-data. The estimates were significant with p-value < 0.0005. In March and April there was lower number of Strava-observations (< 20 observations at max in all pixels) and this allow measurement error to cause a larger part of the observed variability. The low number of observations is a likely explanation for why the estimates for March are not significant (p-value < 0.05), as a low number of observations does not represent the data very well. Accordingly, March 2018 and April 2019 were exceptions with more Strava-observations and also evidence for a positive relationship between Strava-data and automatic counter-data. The higher number of observations these months was associated with the Eastern holidays that was in March 2018 and in April 2019.

My findings are promising because, as far as I have detected in existing literature, no previous studies have validated Strava as an indicator of spatiotemporal human activity in this kind of remote settings. As mentioned, my results suggest that the number of observations is a determinator for how useful the Strava-data represent an actual use of a given trail. In the following I will discuss my findings with similar studies, however, with the limitations that these have been carried out in more urban settings.

Similar results with high correlation between Strava and automatic counters were found by Venter et.al (2020) when examining recreational use of green space areas in the capital city of Oslo during Covid-19 lockdown in 2020. Their results revealed a similar strong positive relationship (R^2 of 0.8) between Strava-data and automatic counters. Boss et.al (2018) examined spatial patterns in bicycle ridership and found linear patterns of associations between Strava-data and counter-data with R^2 ranging from 0.76 to 0.96. Lee & Sener (2021) made a literature review on the usage of Strava for monitoring bicycle activity where they examined different methods used for testing the representativeness of the Strava-data. Many of these studies also demonstrated correlations with field-observations, and they concluded Strava as a useful supplement to other monitoring methods for increasing reliability and representativeness (Lee & Sener, 2021). Similarly, Colorado Department of Transportation (CDOT) compared data from bicycle counters and Strava in the state of Colorado. They used linear regression and found R^2-values ranging from 0.66 to 0.997, indicating strong positive relationships (CDOT, 2018). As such, my results from the summer months fit well with the findings from a range of studies showing strong agreement between Strava estimates of human activity and data obtained by automatic counters.

Furthermore, CDOT also evaluated the representativeness of Strava-data in relation to the total statewide bicycle population (CDOT, 2018). Their results showed that users of Strava represented between 3-30 % (depending on location) of the bicycle population in the study area, and they concluded that in spite of high representation some locations, Strava was potentially misrepresentative to the behavior of the general bicycle population (CDOT, 2018). In the case of the data from Hardangervidda – the proportion of observations in Strava in relation to observations by automatic counters was 0.9 % in 2018, suggesting that the population of Strava-users is small and thus makes Strava data potentially unrepresentative for the total population of visitors on Hardangervidda (Gundersen et.al, 2021a, p.21). Similar conclusion was also made by Lee & Sener

(2021), that recommends cross-use of Strava data to calibrate and achieving accurate estimates of the total visitor numbers.

Results show that Strava-values increases independently of counter-data in summer months 2016-2018. The proportion of observation in Strava seen in relation to observations from the automatic counter has increased from 0.1 % in 2016 to 0.9 % in 2018, indicating an increased use of the Strava-app in Hardangervidda area over the study years. How the usage of Strava will change over the next years is difficult to forecast, as it is connected to both developments in terms of technology and social user trends - and the lifetime and popularity of an app is hard to predict. However, assuming that the use of the Strava-app will continue to increase over the next years, it has obviously, a potential to work as a solid data base on human activity and perhaps also become more representative for the target population of all kinds of visitors in remote areas.

Automatic counter accuracy in remote areas in winter

The overall correlation between the double counters in 2018 was $\rho_{c\,=}$ 0.82, suggesting that counter accuracy is high in remote areas during winter. However, although the automatic counters have the potential to provide large amounts of precise data, there are also some pitfalls regarding technical and quantitative errors, e.g. two persons walking beside each other may be counted as one, and if a person stops within the range of the counter it may be counted multiple times (Pettebone, Newman & Lawson, 2010). Andersen et.al (2013) tested automatic counters' accuracy and highlighted four factors that affected counter error rates: air temperature, distance to the sensor, visitor clothing and visitor volume. When used in areas such as Hardangervidda, these factors are highly relevant, especially regarding temperature and clothing. Vistad et.al (2019) mention that in summer conditions the normal margin of error for automatic counters is ± 5%, but when temperature drops below -10˚C, this margin increases to ±10% (Vistad et.al, 2019, p.13). In addition, people using insulating clothing, such as down-jackets, will reduce body-heat perceived by the sensor and it may fail to detect the person (Andersen et.al, 2013).

Another factor could be problems with fog, snow, and ice in front of the sensor, however, the sensor should work despite such conditions (Vistad et.al, 2019, p.13). Temperatures at Hardangervidda drop below -10˚C during March and April and it is likely that people also use thick winter clothing.

Considering these factors, it may indicate that the data from the automatic counters during winter may be somewhat inaccurate. As such, despite the high overall correlation between the counter pairs, it is not known if both counters may have the same quantitative error. Some outliers in the dataset is easily detected via visual inspection (like a ten-fold increase in the neighboring numbers) while smaller, systematic counter errors are harder to reveal (Pettebone, Newman & Lawson, 2010). Systematic counter errors can be an additional factor explaining the non-consistent relationship between Strava-data and automatic counter data in March and April. If e.g. the observation-numbers from the automatic counters are significantly higher than the true number of visitors, then this will affect the correlation between Strava-data and counter-data, because data from Strava were low during these months.

The potential of Strava for monitoring visitors in remote areas.

Even though crowdsourced data like Strava provides large amounts of data and can be an effective tool in outdoor recreational research, working with this type of data can be challenging especially regarding reliability, validity and representability (Barton, Gundersen & Venter, p.36). Strava-data show demographic skewness in the population and are also skewed with respect to activity in time and space and type of activity (Barton, Gundersen & Venter, 2021, p.53). This is why it is important to calibrate Strava against other types of data. Hence, some important factors must be considered when interpreting Strava-data exclusively. The Strava data suggest main *patterns* of activity in time and space. The number of Strava-observations within one pixel (sum of observations in one pixel per month) can be misleadingly interpreted as the number of individual visitors using this area in one month, however this is not necessarily the case. It is more likely that a person who log their activity with Strava during a hike or exercise will be registered within several pixels, following a route or trail. The number of observations within one pixel may be due to the same person visiting the same area (pixel) several times in the same month, e.g. a person that follows a specific trail once a week will account for 4 of the observations within one pixel. A person walking back and forth on a trail during a day will also be registered twice. As such, an increase in the observation number within one pixel over years or months may be due to the same person who has increased their activity-frequency. That being said, when considering human activity as an impact factor for wildlife, a person constitutes the same influence regardless of whether it is the same person or not.

My results indicate that Strava data increases across years in summer independently of the counter-data. This suggests that the increase in activity observed in Strava-data over the years is at least partly due to more people using the Strava-app. It is likely to believe that the app has increased in popularity the last years, in line with the growing focus on physical activity and health benefits from outdoor recreational activity and exercise (SSB, 2021). Furthermore, Barton, Gundersen & Venter (2021) states that Strava has widened their user-group from almost exclusively athletes to embrace "regular" people with other activity patterns. In addition, Strava does not only log your activity, it also allows one to discover new routes all over the work and share ones activity with friends and the public, which also makes it a social network (strava.com, n.d., a). Only in 2020, Strava grew by 2 million users each month – worldwide. (strava.com, 2020).

However, a study from Gundersen et.al. (2021a) states that also the overall traffic on Hardangervidda *has* increased over the last years, based on combined data from automatic counters, Strava, questionnaires and accommodation statistics from DNT-cabins. Same study separated visitors of Hardangervidda into three categories depending on what geographical area they use: those who are on a day-trip (using mostly the edge zone of the national park), those who travels over several days on marked trails and those who travels over several days in unmarked terrain (Gundersen et.al, 2021a, p.72). They found that especially the day-based traffic in the edge zone of the national park had increased significantly in recent years (Gundersen et.al., 2021a, p.22).

Based on Strava-data in this thesis, there is a higher number of observations outside than inside the national park. These observations are especially associated with the popular second-home areas e.g. Geilo, Rauland, Garen-Maurseth and the tourist cabins along the surrounding main-roads E134 and Rv7, like Dyranut, Halne and Haukelisæter (*Fig.11,13)*. Another general trend according to Strava data is that most of the observations inside the national park follows the network of marked trails and public cabins organized by DNT. These findings may support that many of those using Strava may belong to the first two categories of visitors from the Gundersen et.al. (2021a) report; the daytrip users and those who follow marked trails over several days, and that the last category (those who travel over several days in unmarked terrain) is underrepresented in the Strava-data. This means that the human activities in unmarked terrain may be harder to detect and monitor, as it is not detected by neither Strava nor the automatic counters. This activity that is not dependent on infrastructure is usually related to local use of private cabins and activities like berry picking, hunting and fishing, off-piste skiing, biking and kiting (Gundersen et.al., 2021b, p.64; Gundersen & Singsaas, 2020, in press). This activity is often found between main recreational infrastructure (see e.g. Selvaag et al., 2020) and may be of importance in wild reindeer interactions, as it is less predictable and stable than the activity that follows a specific pattern on the marked trails. My results indicate that this off-trail user-group of visitors is not, or to a very little extent, covered with data from the Strava app. Another possible explanation for the reduced Strava-observations inside the national park may be that there is reduced possibilities for charging smartphones and GPS-watches in remote areas.

Potential human - wild reindeer interferences in summer

The seasonal migration between summer-pastures, winter-pastures and calving areas makes wild reindeer dependent on large areas and particularly vulnerable to habitat fragmentation (Nilsen & Strand, 2017, p.4). Studies from Rondane, Snøhetta and Nordfjella showed that wild reindeers habitat use is affected by visitor traffic in the area (Nilsen & Strand, 2017, p.19). The response of wild reindeer to visitor traffic on marked trails depends on the intensity of the use of the trail (Gundersen, Strand & Punsvik, 2016, p.163; Gundersen et.al., 2020). Already at low intensities of human activity, the animals are disturbed and increase movement rates. At high intensity, the trails may work as a complete barrier to reindeer movement in that the animals choose not to cross (Nilsen & Strand, 2017, p.19; Gundersen, Strand & Punsvik, 2016, p.163; Gundersen et.al., 2020).

After calves are born in May, it is important that the animals rest and recover after a long and harsh winter, and they seek for suitable summer pastures (Reimers, 1997). To be able to gain sufficient fat-layers before winter it is important for the reindeer to be tranquil during summer-feeding, as an increase in stress-levels and disturbances increases daily movements and energy-demands, which in turn may lead to reduced energy-reserves (Bjerketvedt, 1981; Reimers, 1997). The most suitable summer areas for wild reindeer are in the south and central parts of Hardangervidda, in addition to some smaller areas in the east and north-west (*Fig.12*). GPS-data show that the wild reindeers also make use of this areas in the central and southern parts of Hardangervidda (*Fig.13*). They do not seem to move towards the outer edges, with an exception in south, where there are some movements not far from the main road, which works as a physical barrier for migration towards areas further south (see e.g. Strand et.al. 2006; 2015a). In general, the edge zone around Hardangervidda has a high level of infrastructure development like private and public cabins and roads, which makes wild reindeer avoid this area (Gundersen et.al., 2021b, p.51). The wild reindeer do not seem to prefer the suitable areas in north-west, areas that historically (before 2001) were commonly used for calving and summer-pasture (Fylkestingene i Telemark, Vestland & Viken, 2020, p.11).

As these GPS-position points are data from the period of four years (2016-2019), it indicates that wild reindeer return to approximately the same area each summer. This was also found by Strand, Bevanger & Faldorf (2006) in a study on reindeers' area use on Hardangervidda, showing that reindeer tend to return to the same summer-areas in southern/central parts of Hardangervidda over several years, where the yearly estimates of area use in summer overlaps with up to 80 %. In contrast, same study showed that winter area use is much more extensive, and animals are spread over larger areas (Strand, Bevanger & Faldorf, 2006, p. 42).

The Strava-data on human activity (*Fig.13)* may suggest that areas with high concentration of wild reindeer activity have little *direct* interference from human activity. A reason may be that no marked trails or tourist cabins are found in this area (*Fig.5*). In the surrounding area, however, there is a high number of public trails and cabins, with a corresponding high level of activity and there are some areas where the public trails may interfere with wild reindeer movements. Example of this is be the coherent trails crossing the national park from south-north and east-west. We know that wild reindeer tend to keep away from marked trails and cabins and that the intensity of the use of the trails is connected to the reindeers' response (Strand et.al., 2015b, p.3; Gundersen, Strand & Punsvik, 2016, p.163; Gundersen et.al., 2021b, p.52; Nellemann et.al., 2000). Seen in relation to the results found in Snøhetta, Rondane and Nordfjella (Nilsen & Strand, 2017) the human activity in this area may potentially cause barrier-effects for the wild reindeer, keeping them in these central parts and south-eastern parts of Hardangervidda and preventing them from searching for other grazing areas in summer.

We know that anthropogenic activities can make wild reindeer change and modulate their movements (Mossing & Heggenes, 2010; Nilsen & Strand, 2017; Fylkestingene I Telemark, Vestland & Viken, 2020; Gundersen et.al., 2020) and that the number of visitors using the trail may be a factor contributing to reindeer habitat alteration (Gundersen et.al., 2019; 2020). If the density on the use of the trails increases in the future, the wild reindeers' response may change from short-term disturbances like general stress and increased movements in the area to long-term disturbance responses (complete avoidance of the area) (Gundersen, Strand & Punsvik, 2016, p.160; Gundersen & Singsaas, 2020, in press). This in turn could potentially lead to cascade effects such as that the animals have to settle for fewer and perhaps less suitable areas for summer-grazing, and an increased grazing-pressure in certain areas – which consequently may affect population dynamics (Andersen & Hustad, 2004, p.40; Nilsen & Strand, 2017, p.23).

Furthermore, some studies show that wild reindeer show different tolerance behavior towards human activity, depending on to what extent and frequency the animals are faced with human encounters, and to the type of activity conducted. Reimers et.al (2010) compared flight-responses when a human was approaching the herd by foot in two different areas: Blefjell and Hardangervidda. They found that the herd in Blefjell, which has a high level of human activity, showed decreased flight-response compared to the herd in Hardangervidda (Reimers et.al, 2010). Lilleeng et.al. in 2007, measured the fright- and flight-distance provoked by snow-kiters compared with cross-country skiers and hikers. The study concluded that wild reindeer showed an earlier and stronger behavioral reaction to snow-kiters compared to hikers and skiers, possibly explained by that snow-kiters make up a larger area (Lilleeng et.al, 2007). These kind of studies shows that flight- and fright-responses also may be dependent on the activity conducted (see also Reimers et.al., 2010).

Measures for protecting the wild reindeer population on Hardangervidda

Norway has an international obligation to protect the wild reindeer (Kjørstad et.al., 2017) and seen in relation to the trends of increasing recreational outdoor use (Reimers, Eftestøl & Colman, 2003; Gundersen et.al., 2021a)**,** protection of this species is utterly important. Controlling human activities in remote areas is highly challenging, if not impossible, and go against the perception of Norwegian outdoor culture and the right to roam (Allemannsretten) (Gundersen, Strand & Punsvik, 2016, p.168). However, assuming many people use the facilitated trails and tourist cabins in the area, there may be possibilities for the management authorities to control the majority of the activity away from critical wild reindeer areas (Gundersen, Strand & Punsvik, 2016, p.169.) Also DNT (Norwegian Tourist Association), which is the largest association with interests in Hardangervidda, has a certain responsibility to contribute to a sustainable wild reindeer management with regards to placement of marked trails and tourist cabins (Gundersen, et.al., 2021a, p.11; dnt.no, n.d.). Changing or moving certain trails in conflict areas so that the interference in wild reindeer range is kept as low as possible is an example of possible management measures. One example on this was in Rondane in 1996/97, where The Norwegian Tourist Association (DNT) removed signposts from certain trails in critical areas and established new trails that reduced interference with wild reindeer, and also conveyed information about wild reindeer precautions to their members (Evensen, 1998 in Kajala, 2007, p.141). Fjelle (2020) documented that the use of these removed trails has reduced visitor volume to very low numbers in all the cases.

DNT also have chosen to partly or completely close some of their tourist cabins, or moved them to other locations (dnt.no, n.d). One example is Gråhøgdbu in Rondane, that was removed from a location in the core area for wild reindeer to the outer fringe of their range (Kleiven, 2019). Another measure may be to change standard from staffed to self-employed cabins (Evensen, 1998, p.151). These are examples of measures that can contribute to controlling the majority of tourists in wild reindeer habitat. In general, before planning new establishments of infrastructure or buildings within and outside the national park, a thorough impact assessment should be conducted with close regards to wild mountain reindeer and nature conservation. Furthermore, Gundersen et.al. (2021b) points out that reducing development in the edge zone, reducing the level of motorized activity and dispensations for e.g. building of cabins as important management measures to reduce the impact on the wild reindeer population (Gundersen et.al., 2021b, p.64).

6.0 Conclusion

Working with crowdsourced data like Strava is complex, due to large amounts of data on visitor movements in time and space, and the potential biased group of people using this app. The results while interpreting this type of data should be seen as trends and tendencies and one should be careful before making firm conclusions based on Strava-data exclusively (Barton, Gundersen & Venter, 2021, p.36). Due to the skewness in the population of people using Strava, using Strava-data as a single measure on human activity is not recommended. However, my results complement the results from previous studies that have found a positive relationship between Strava-data and automatic counter data. It also suggests that Strava-data has potential as a valuable supplement to and can increase accuracy of other types of data on human activity, also in remote areas. Furthermore, more people have started using the Strava-app over the study years, and if its user-group widens and become more representative for the target population, it can be an even more valuable type of data on human activity in the future. Based on my results, it also seems like the number of observations can be an indicator of how useful the data is, which should be considered when using this type of data in the future.

We already know that humans interfere with wild reindeer and have done so for a very long time. An increased level of human activity inside the national park is predicted to affect the wild reindeer population to a large extend, causing effects like habitat avoidance, habitat alteration and general stress. Wild reindeer avoid particularly the edge zone of the national park due to high level of human interventions and activity, and consequently to protect and increase the habitat quality of the core area as refugees areas for the wild reindeer population is even more important. Further studies on visitors' impact on the wild reindeer population should be carried out to achieve a sustainable human use of Hardangervidda area, as well as further development of management mitigation measures to secure the welfare of the wild reindeer population.

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