UiT The Arctic University of Norway

Department of Arctic and Marine Biology

Reindeer husbandry challenges in winter in a wind power plant area - a study from an island in Troms county

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Foreword

When I first arrived in Tromsø 5 years ago, I was not planning to stay more than a year. Now 5 years later I am still here, and unsure if I ever want to leave. I started my education in Australia, but due to COVID-19, I had to leave that life behind and decided to pursue a degree in Biology at UiT in Tromsø. Each year has been different, some good and some not as good. But all the experiences have shaped me to who I am today.

I have met some wonderful people along the way that I am so grateful for. People I never would have met if I didn't move to Tromsø. Thank you for all the memories we have created together, if you know, you know! I look forward to sharing many more milestones with you in the future. I also want to thank my fellow master students. Thank you for countless walks, laughs, drinks, quizzes, mental breakdowns and motivating words. Cheers to us for getting through this journey together. A special thank you to my family and closest friends for always cheering me on and believing in me. You are always there when I need you, and I could not have made it without your love and support.

I would like to express my gratitude to my supervisors, Tove Aagnes Utsi, Gabriela Wagner and Diress Tsegaye Alemu for their time, guidance, support, and encouragements. You have provided me with valuable assistance throughout this entire process. I would like to give a special thank you to Dorvvošnjárgga Siida for their participation in this study. I am grateful for their time and for sharing valuable data and knowledge, and for their important contributions to this study.

Finally, I would like to leave you with a quote that resonates deeply with me: "This for everybody going through tough times. Believe me, been there, done that. But every day above ground is a great day, remember that." - Armando Christian Pérez

Abstract

The establishment of the Kvitfjell/Raudfjell Wind power plant (WPP) in a reindeer herding district has raised concerns about potential impacts on herded reindeer habitat use and herding practices. The wind power plant was constructed between October 2017 and December 2020. Two years prior to construction, a herding family moved to the area with a new reindeer herd and engaged in intensive herding activities to train the reindeer to navigate and utilize the best grazing sites. The herders provide supplementary feeding during winter feed shortages. The herders report that the WPP development has complicated winter herd management and intensified feeding crises.

To assess WPP effects on reindeer habitat use and herding practices, reindeer GPS (Global Positioning System) data from 2015 to 2024, alongside the herders experienced-based knowledge, was analysed. The data covers the period prior to construction (~2 years), the construction phase (~3 years), and the operational phase (4 years) of the WPP. The study covers 4 seasons based on herders' information (early winter, late winter, spring and summer). To identify reindeer habitat selection within year and season, a simple use vs. availability design was applied. Comparing locations used by reindeer to available locations in the study area, following the approach of Manly *et al*. (2002), before, during and after the WPP construction. Brownian bridge movement model (BBMM) was applied to estimate yearly seasonal home ranges. Semi-structured interviews were conducted, collecting data on the herders' observations and experience-based knowledge.

The GPS analyses revealed variable results, indicating possible aversion for habitats closer the WPP in late winter and spring some years and preference towards habitats closer to the WPP in early winter during and after the construction. Findings in spring potentially revealed a shift in calving grounds, affected by the construction and operational phase of the WPP. Documentation of the herders' experience indicates a significant increase in herding activities and supplementary feeding, influenced by the construction and operation of the WPP. The herders emphasized that the extra challenges imposed by the ice throw hazard from wind turbines have severely restricted their access to suitable winter pastures. The intense herding practices introduced by the herders to mitigate the effect of the WPP complicate our ability to isolate the WPP impact. Herding interventions may have obscured clear behavioral responses. However, the herders' traditional and experience-based knowledge provided crucial information needed to understand the underlying influences of our findings and contextualize the collected GPS data and gain clearer results of reindeer responses.

This study aims to enhance our understanding of renewable energy development in sensitive ecological regions and emphasize the importance of collaboration with local reindeer herders. By working with the herders, we can develop better strategies that effectively balance renewable energy constructions with the ecological and cultural values of reindeer husbandry. Future research must include herders and incorporate long-term, high-resolution GPS tracking, environmental variables, and behavioral monitoring, using accelerometers and video recordings to accurately assess the impacts of infrastructure development on reindeer habitat use and reindeer husbandry.

Keywords: *Avoidance · Behaviour · Distance interval · GPS data · Herders · Habitat use · Locked pastures · Preference · Reindeer · Summer range · Wind power plant (WPP) · Winter Range · Experience-based knowledge · Semi-structured interview.*

Abbrevations

a.s.l – Above Sea Level

BBMM – Brownian Bridge Movement Model

NVE – Norwegian Water Resources and Energy Directorate

ROS – Rain On Snow

RS – Resource selection

WPP - Wind power plants

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1 Introduction

Reindeer husbandry in Norway is a traditional practice of the Sámi people, the indigenous people of northern Fennoscandia. Reindeer husbandry in the northern Fennoscandia can be traced back to the 1500s and 1600s (Salmi, 2023) and remains a vital part of Sámi culture, history, and livelihood today (Williams, 2003). The Sámi hold the exclusive rights to engage in reindeer herding in Norway. The Reindeer Herding Act (2007) states that "individuals must be of Sámi descent and possess a familial connection to reindeer herding to hold rights to a reindeer mark. The reindeer brand, which is a unique cut made in the ear of the reindeer, serves as a means of identification and ownership". The relationship between herder and reindeer can be described as a well-functioning cooperation, where the herders' decision is highly dependent on reindeer behaviour (Skarin & Åhman, 2014). Traditional Sámi knowledge has been accumulated and passed down for generations. The knowledge has been adapted and refined to effectively understand and respond to specific climatic conditions, landscapes, and reindeer behaviour within changing ecosystems (Oskal *et al*., 2009). In other words, traditional knowledge and practices remain vital to understanding reindeer behaviour and the ecosystems they inhabit (Skarin & Åhman, 2014). Maintaining traditional reindeer herding practices and culture is crucial for the identity of the Sámi people.

Reindeer herders increasingly face pressure from climate change, predators and area conflicts (Hovelsrud *et al*., 2021).The increasing demand for renewable energy has resulted in expanded land use for wind power plants (WPP) (Skarin *et al*., 2018), leading to major conflicts between reindeer husbandry and the industry. Semi-domesticated reindeer (*Rangifer tarandus tarandus*), in this study referred to as herded reindeer, need large and varied grazing areas to effectively respond to seasonal shifts in resource distribution (Mårell & Edenius, 2006), making them vulnerable to fragmentation and disturbances (Eftestøl *et al*., 2021). The need for additional renewable energy sources is rooted in societal needs, however, one can debate that protecting ecosystem services and reindeer husbandry is an equally important societal need. The rising conflict between infrastructure developments and the preservation of reindeer husbandry and ecosystems, important for herding practices, increases. This underlines the need for a balanced approach in research that acknowledges both the need for energy development and the rights and traditions of reindeer husbandry.

1.1 Reindeer herding strategies

In Norway the Sámi reindeer herding areas are divided into grazing districts which are further organized into Siidas. The northern Sámi term describes a customary group that shares the work of reindeer herding within a designated area, working together for the benefit of its members (Horstkotte *et al*., 2022). The reindeer are commonly herded in a pastoral system, defined as a form of husbandry in which people move and track the animals to find suitable grazing grounds (McKune *et al*., 2015). According to Horstkotte *et al*. (2022) and Riseth *et al*. (2019) there are three main types of herding strategies in Norway: (1) Seasonal migrations between mountain or Atlantic coast summer pastures, to winter pastures in more continental inland. (2) A limited form by seasonal migration between inland mountain summer pastures and winter pastures by the Atlantic coast. (3) Year-round grazing, mainly on islands and pensinsula.

In Finnmark county, northern Norway, reindeer herders actively move the herd along the coast or islands, to inland winter pastures characterized by a continental climate, shallow snow and good access to forage (Horstkotte *et al*., 2022). However, over the years this has changed due to climate change increasing the frequency of rain-on-snow events (ROS). In contrast, coastal regions like in Troms county, northern Norway, reindeer herds exhibit migration patterns often involving shorter distances. The herds remain stationary with year-round herding practices on islands, benefiting from consistent all-year pastures (Horstkotte *et al*., 2022). Such coastal regions are known for providing rich summer grazing opportunities, while the winter pastures tend to be less accessible due to the oceanic climate with high variability in weather conditions, impacting the winter pastures (Horstkotte *et al*., 2022). The coastal winter pastures could be strongly influenced by heavy snow fall and ROS events (Cohen *et al.*, 2015). This often leads to locked pastures, resulting in increased herding intensity. This means that the reindeer need to be monitored more frequently to keep them from scattering and the herders guide them to suitable pastures. It also leads to the herders relying more on supplementary feeding to ensure sufficient access to nutrition. Locked pastures are referred to as “Goavvi” in northern Sámi. This term describes an extreme weather condition characterized by deep snow with ice layers on, or in the snow, causing impenetrable pastures (Mathiesen *et al*., 2023). An increase in ROS events in the future is expected, due to climate change (Cohen *et al*., 2015), heightening concerns among reindeer herders about the future of reindeer husbandry. Access to surrounding habitats that provide high-quality pastures is crucial during harsh winters (Serreze *et al*., 2021) and infrastructures can act as barriers and limit access to these alternative pastures.

1.2 Wind power plant effects on herded reindeer

The increasing demand for renewable energy has led to a substantial shift towards the establishment of renewable sources (Kaltenborn *et al.*, 2024). The Norwegian government is part of the green transition policy, aiming to reduce greenhouse gas emissions and transition to a low-carbon society (Ministry of Trade Industry and Fisheries, 2022). This goal is pursued through the development of green industry and renewable energy sources (Ministry of Trade Industry and Fisheries, 2022). According to the Norwegian Water Resources and Energy Directorate (NVE), there are currently 65 WPPs distributed across the country, with 42 ongoing licensing cases for additional developments (NVE, 2019). Several of these are proposed in regions used for reindeer husbandry.

The greatest impact on the reduction of uninterrupted nature in Norway is linked to renewable energy sources, particularly wind and hydropower (Miljødirektoratet, 2024). Alongside this development, there is a growing concern surrounding the alterations in the natural ecosystem of the areas where they are constructed, as they may pose unforeseen consequences for wildlife (Colman *et al*., 2013).

During the last decade there has been an increase in research on WPP developments effect on herded reindeer. Results vary, with some studies finding no clear avoidance behaviour, barrier effects or changes in habitat selection, in response to the WPPs (Colman *et al.*, 2013; Eftestøl *et al*., 2023; Tsegaye *et al*., 2017). However, results from Colman *et al*. (2013) indicated some local avoidance related to access roads leading to the WPP, during construction. Other studies found negative effects resulting from the WPPs (Skarin *et al*., 2015; Skarin *et al.,* 2018*)*. In both Skarin *et al*. (2015) and Skarin *et al.* (2018) findings indicated a decrease in use of habitats in proximity to the WPP during construction. Skarin and Åhman (2014) reviewed studies on the effects of human activity and infrastructure on semi-domesticated reindeer and discovered a common pattern. At the regional scale (migration or movement corridors used between seasonal ranges and feeding areas), research indicated that reindeer avoid infrastructure and human disturbances occurring several kilometers away. At a local scale (patch or feeding site used during hours or minutes), closer to human activities and infrastructures, studies did not find a significant reaction from the reindeer.

In recent years, conducting research on semi-domesticated reindeer, with a multidisciplinary approach, including the herders traditional knowledge and experienced-based-knowledge, have increased (Eftestøl et al., 2023; Sarkki et al., 2013; Skarin et al., 2015; Skarin et al., 2018). In Eftestøl *et al*. (2023) the herders experienced negative effects from the WPP, with the reindeer avoiding areas close to the WPP after construction, in summer. This led to an increase in herding activities to keep them grazing in the preferred summer range. In another study by Flydal *et al*. (2004), the Sámi reindeer pastoralists claimed that their herds were unable to calmly graze in habitats near the WPP, during autumn. There is a lack of studies focusing on the winter and spring season, often described as the most vulnerable periods for reindeer, when they are highly sensitive to disturbances (Dyer *et al*., 2001; Vistnes & Nellemann, 2001). There is a need for additional studies integrating local herders' observations and experience-based knowledge, when examining effects of energy developments on herded reindeer. By combining scientific and traditional knowledge systems, research can obtain a more holistic perspective on management, engaging the reindeer herding communities to share important knowledge, useful in the field of research (Eira *et al*., 2008). This form of collaboration can reveal underlying factors influencing reindeer movements, habitat use and behaviour, attributed to the herder's experience and knowledge of the animals and ecosystems they inhabit. Future research should have an additional focus on how the construction of wind power plants impacts herding practices. This will enhance our understanding of the effects of infrastructure developments on both herded reindeer and reindeer husbandry.

1.3 WINDMARK

This study was conducted in collaboration with the WINDMARK project by the Norwegian Institute of Bioeconomy Research (NIBIO). WINDMARK is an interdisciplinary initiative that aims to establish a framework for monitoring long-term effects and analyse cultural ecosystem services in the northern regions impacted by wind power plants (NIBIO). They aim to use the knowledge gained to inform policymakers about specific socio-ecological challenges and provide tools to reduce conflicts in the green transition. The results presented in this study are part of a work package focusing on the effects of WPP development on reindeer area use.

1.4 A relocated reindeer herd and construction of a wind power plant

In April 2015, a reindeer herding family (Dorvvošnjárgga Siida), relocated their reindeer herd to the southern part of Kvaløya, an island with a costal climate in Troms county, northern Norway. The herd originated from Finnmark county, where the reindeer had extensive seasonal migration routes. The reindeer had traditionally utilized inland areas for winter pastures and were moved to Reinøya, an island in Troms, by lorries and boats for calving and summer pastures. After relocation the Siida became a part of the reindeer herding district 14: Sállir/Kvaløya. The district consists of two independent Siidas and management of the herds are primarily carried out separately (Statsforvalteren, 2018). Two years after the relocation, in 2017, a WPP was constructed in the area on Kvitfjell and Raudfjell.

Dorvvošnjárgga Siida, uses the South part of the island as a year-round pasture, with small seasonal movements from the winter range to summer range. Upon arrival, the herders planned to utilize Kvitfjell and Raudfjell for both winter and spring pasture, as well as calving grounds. This was based on the areas' historical background and on-site inspections conducted by the herders (Herders personal comments; Statsforvalteren, 2018). The areas' elevation and windblown ridges made it the preferred area for winter grazing by the reindeer. (Norsk Miljøkraft Tromsø AS, 2007). Kvitfjell and Raudfjell is characterized by favorable wind conditions that blow snow away, preventing snow accumulation, keeping pastures accessible during heavy snowfall (Norsk Miljøkraft Tromsø AS, 2007). The northern part of the island is inaccessible during winter due to steep terrain and high avalanche risk (Herders personal comments). Both Kvitfjell and Raudfjell have traditionally served as preferred calving sites for reindeer in spring (Statsforvalteren, 2018). Consequently, Kvitfjell and Raudfjell are crucial areas for the reindeer during the winter and spring season.

This study provides a unique research opportunity of a newly introduced reindeer herd, moved from learned migration grounds elsewhere to a new habitat with a different climate, coinciding with the construction of two adjacent WPPs shortly after herd arrival. It raises questions about how the reindeer adapt to their new environment, utilize the habitat, and which impact WPP development has on habitat use and the herders' practices.

The primary objectives of this thesis were to test 1) the effect of the construction and operational periods of the WPP on reindeer habitat use during early winter, late winter and spring, 2) potential avoidance of the WPP area during and after construction and 3) changes in herding practices in response to the WPP construction. Our first hypothesis is that the wind power plant affected reindeer habitat use during and after its construction, with reindeer preferring areas located further away from the WPP after construction. Our second hypothesis is that the herding practices were impacted by the construction of the WPP, resulting in an increased workload for herders, during and after the construction.

The study is based on a mixed method including GPS tracking of reindeer and semi-structured interviews with the reindeer herders over a nine-year study period (2015-2024), focusing on the early winter, late winter and spring season.

2 Study area

The study was conducted on the southwestern part of Kvaløya, an island with two adjacent WPPs (Kvitfjell and Raudfjell) in Troms county (Figure 1)Kvitfjell WPP is located at 566m above sea level (a.s.l) and the WPP on Raudfjell 542m a.s.l. The forest line ranges between 200-300 m a.s.l. The island is approximately 737 km², with the study area covering a total of 102 km².

2.1 Wind power plant

The construction of the WPP, started in October 2017. The concession period ended, and the WPP was officially opened on the 31st of December 2020. The two WPP consists of a total of 67 turbines (47 in Kvitfjell and 20 in Raudfjell), with a height of 85-m and a rotary diameter of 130 m. The total length of the supportive road network is approximately 45 km long, with a road width of approximately 4-5 m (NVE, 2017; Ruiter, 2022)

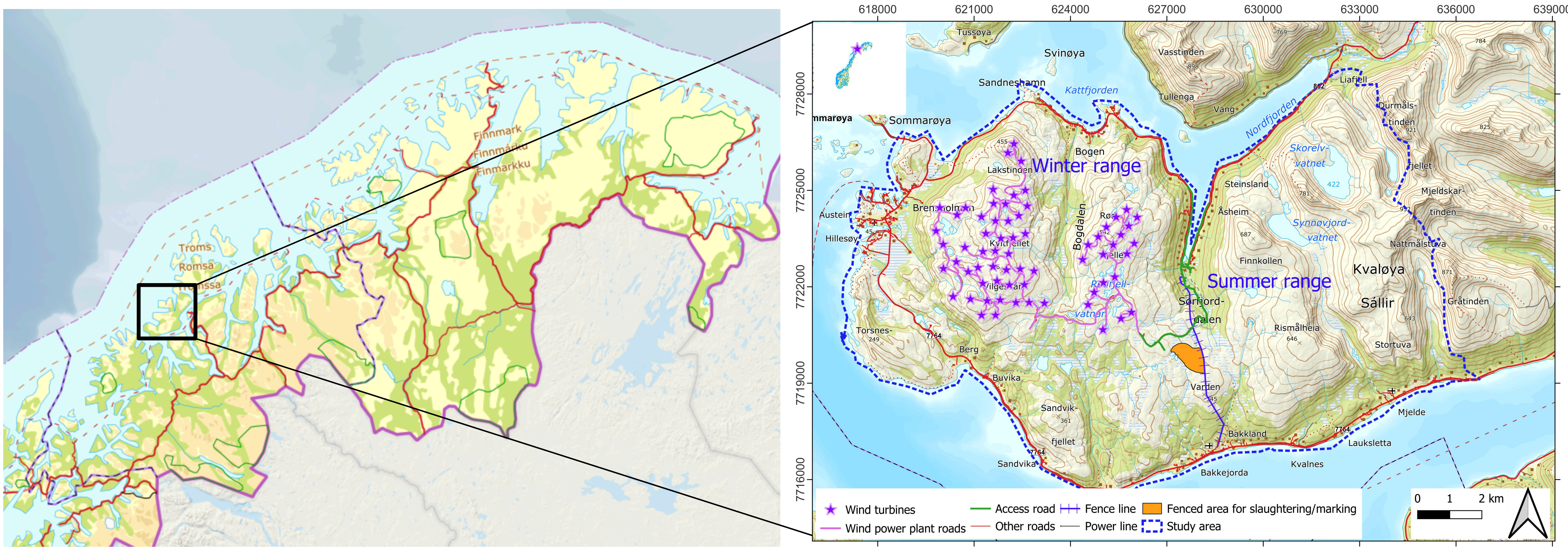

Figure 1: Map of Norway obtained from Kartverket (2025). The inset map showing the study area outlined by a dotted line. The area encompasses, the southwestern part of Kvaløya in Troms, Norway. The map shows the location of the two adjacent wind power plants on Kvitfjell and Raudfjell indicated by purple stars. Roads leading to the wind power plant and other roads are marked in solid lines. The corralling fence used for slaughter, vaccination and calf marking is marked in orange. Power line and fence line are represented on the map. Seasonal reindeer ranges are defined as winter range (Southside of Sørfjorddalen) and summer range (Northside of Sørfjorddalen).

2.2 Vegetation

The study area falls within the subarctic oceanic vegetation zone and is characterized by heathland vegetation, consisting mainly of heather, rushes, lichens and mosses (Norsk Miljøkraft AS, 2017). The area includes windblown ridges, typical for mountainous regions where the ground lacks, or only has a thin or unstable snow cover in winter (Norsk Miljøkraft Tromsø AS, 2007). The vegetation on Kvitfjell and Raudfjell is characterized by low species diversity due to soil with low pH, and the release of nutrient to plants is restricted (Norsk Miljøkraft AS, 2017; Norsk Miljøkraft Tromsø AS, 2007). The predominant species in the area are common vascular plants such as Three-leaved Rush (*Juncus trifidus*) and Alpine bearberry (*Arctostaphylos alpinus*). In the recently melted snow beds, Alpine ladye ferns (*Athyrium distentifolium*) and Mountain Sorrein (*Oxyria digyna*) are common. In the wind-sheltered parts, Matt grass (*Nardus stricta*) dominates (Fremstad, 1997; Norsk Miljøkraft Tromsø AS, 2007). The terrain is described as steep and rugged with exposed rock. The area is surrounded by small water bodies, peatlands and the bog vegetation is very homogeneous (Ruiter, 2022). See Appendix A, displaying a map of the study area and the areas vegetation types.

2.3 Climate

The island's climate is described as oceanic, with colder and frequently wet summers and mild winters (Norsk Miljøkraft AS, 2017; Norsk Miljøkraft Tromsø AS, 2007). The oceanic climate often makes winter pastures inaccessible due to deep snow, often combined with a hard crust, formed by changing temperatures and precipitation (Horstkotte *et al*., 2022). Climate change, characterized by milder winters and autumns, increases the issue of locked pastures on the island. Kvaløya has been identified as one of the most critical areas for reindeer winter grazing in Troms (Tromsø kommune, 2019). In contrast, the island's summer pasture is described as providing high-quality pastures and offering important areas for reindeer to cool down on warmer days (Tromsø kommune, 2019). The summer temperature is around 9 to 12 °C and the winter -2 to -9 °C (Meteorologisk institutt). It is predicted that temperatures in Tromsø will increase by 2–3°C by the year 2050 (Hanssen-Bauer *et al*., 2009). Potentially increasing the frequency of ROS events and locked pastures. The monthly average temperatures, in °Celsius, with standard deviations for the period from 2015 to 2024 can be found in Appendix B.

Table 1: Average temperatures (in °Celsius) recorded for each year and month from 2015-2024. Measurements were taken at the Kvaløysletta weather station (Meteorologisk institutt). The overall average represents the mean temperatures across all years.

Year	October	November	December	January	February	March	April	May
2015	4,1	1,5	-0,5	-3,7	-2,1	0,8	1,9	5,6
2016	4,5	0,1	0,1	-4,8	-2,3	-0,4	2,7	7,5
2017	4,3	0	-2,2	-1,7	-3	-1,7	-0,1	2,8
2018	3,4	3,4	-0,7	-4,1	-4,7	-5	1,5	7,7
2019	0,6	-1,9	-0,9	-4,6	-3,5	-3,3	2,3	4,8
2020	4,4	2,9	0	-1,7	-2	-2,2	-0,7	3,7
2021	3,4	0	-4,2	-3,6	-3,1	-1,6	0,7	3,9
2022	3,9	1,1	-2,6	-2,9	-4,1	0,6	0,8	5,8
2023	0,8	-2,2	-3,6	-1,5	-0,6	-4,7	2,5	5,1
2024	4,4	1,2	-2	-4,1	-2,6	-0,5	0,3	6,8
Total Mean	3,18	0,47	-2,03	-3,03	-2,95	-2,3	0,91	5,08

2.4 Seasonal pastures

Dorvvošnjárgga Siida used the south and north side of Sørfjorddalen at Kvaløya as their all year-pasture when they arrived in 2015 (Kilden, 2015). The area includes a fence extending from Sørfjorddalen over the mountain to Bakkejord/Bakklandelva. They also had a corralling fence for feeding in Bakkejord built in 2016 and used up until December 2018 (Statsforvalteren, 2018). In 2018, their current corralling fence was built at Sandhaugen. The main facility includes a grazing enclosure, pens, working fence, loading dock and a corridor leading to the road for animal transportation (Statsforvalteren, 2018).

During autumn, winter and spring, the area south of Sørfjorddalen was used. For spring pasture, Kvitfjell, Raudfjell and Bogdalen were the main areas. Calving primarily occurred in Kvitfjell and Raudfjell In summer, reindeer grazed in Kvitfjell, Raudfjell, Sandvika and areas on the northern side of Sørfjorddalen (Kilden, 2015; Statsforvalteren, 2018). Before construction, the main sites for supplementary feeding were in the mountains, Kvitfjell and Raudfjell.

3 Methods

The data included in this study are part of the WINDMARK project. This study incorporates both quantitative (GPS data) and qualitative data (Herders experiences). Both types of data were analysed separately to provide distinct insight, and combined, to enhance our understanding of the results and potential coinciding trends.

3.1 Interview and communication with the reindeer herders

Qualitative data were mainly collected through semi-structured interviews with the main herder, through the project group WINDMARK. Interviews started in 2015 and are ongoing. In total, four separate semi-structured interviews were used in this study, two of these were conducted in 2024 and 2025 in my presence. Semi-structured interviews include open-ended questions to which the subject can elaborate more on their thoughts and feelings, and the interviewer may ask additional questions (Young *et al.*, 2018). The technique highlights what the subject perceives as relevant and important. Further communication occurred during field work, often with several herders present simultaneously. Information from all interactions so far, applied in this study.

Using a similar approach as Eftestøl *et al*. (2023), the primary focus of the interview process was to map the herders' activities that could affect reindeer habitat use, including herding practices, corralling and feeding strategies. Secondly, our aim was to gain insight into the reindeer habitat, general movement patterns and responses to disturbances as experienced and understood by the herders. Finally, it was important to understand how the herders experienced the transition from herding in the area prior to, during and after the construction of the WPP. Throughout the analyses the herders were kept informed of the results, allowing for ongoing communication about trends in the data.

3.2 Reindeer GPS data

Data for reindeer movements were generated from GPS collared reindeer, using KVIKK collars for reindeer (OS ID / MSD Animal Health, 2025) and GPS senders (Findmy, 2025; Telespor AS, 2025) owned by both the herder and NIBIO. Collaring the reindeer was mostly carried out by the herders during calf marking and autumn slaughter when the reindeer are corralled in the fence. The WINDMARK project group assisted in the process, and I actively participated during fieldwork in October 2024. The collars with GPS senders were placed on different numbers of individuals and changed between reindeer over the years and across seasons, making it hard to control for when exactly the GPS senders were switched between reindeer. Challenges, including loss of signals, further complicated the ability to determine the proportion of the herd equipped with GPS senders. The collars with GPS sender were mainly placed on adult females known as good mothers and often act as leaders for the herd (Herders personal comments).

GPS data were retrieved from the manufacturer's online support sites Telespor AS (2025) and Findmy (2025) with permission from the herders. The extracted GPS data was saved as a CSV file and imported into Microsoft Excel version 16.77 (Microsoft Corporation, 2024) for preliminary processing. The GPS data set was uploaded into QGIS version 3.34.7-Prizren (QGIS Development Team, 2024). Reindeer exhibiting impacted behaviour and movements due to feeding, active herding, and corralling were identified through the analysis of GPS locations and conversations with the herder. Three feeding grounds were identified, and GPS locations from these areas were excluded. Individuals located near the feeding sites, as well as those in other localities, were not excluded. GPS data points from senders found in unusual locations were omitted. During calf marking and annual slaughtering, locations within the fenced areas were excluded, however, GPS locations from outside the fence were included. The GPS collars registered the animal's position at 8-hour intervals, however most of the GPS data had only 2 observations per day due to loss of signal. This resulted in irregular time stamps. In total 138 972 GPS positions were collected in the study area (including winter and summer ranges) and 119 126 GPS positions were used for the data analyses after cleaning (i.e. excluding fenced animals, feeding, etc.). The excluded GPS data represent about 14% of the total GPS locations in the study area.

3.3 Seasons

The GPS data cover the period from January 2016 until June 2024. The GPS data were sorted in Excel by year and divided into four seasons using Julian dates: Early winter (EW) started in October after slaughter and parasite treatment and ended January 31st. When there was no slaughter and parasite treatment EW started November 1st. Late winter (LW) started from the 1st of February and ended towards the end of April, when supplementary feeding stopped. When there was no feeding activity, late winter ended the 30th of April. Spring season (SP) followed the end of LW and ended before calf marking started (usually end of June or start of July). Spring and identification of the calving period was approached by calculating residence time. This refers to the increased time an animal spend in a certain location, often observed during calving, when females seek suitable, undisturbed areas for nurturing their young (Skjenneberg & Slagsvold, 1968). Residence time calculations were unclear, therefore information from the herders were used. The summer season (SU) started after calf marking or July 1st and ended before autumn slaughter and parasite treatment started. Sector diagrams displaying the proportion of total days collected for the separate seasons for 2015-2024 and within the separate years, can be seen in Figure 2 and Figure 3.

GPS data collected during the early winter season were categorized under a specific year, even though it spans over two calendar years. For example, GPS data from late 2016 (October-December) through January 2017 (1-31 January) is classified as belonging to the year 2016. For this analysis, GPS data for the early winter season in 2017 were excluded from the analysis due to missing data. Late winter and spring data from 2015 were omitted from the analysis due to a lack of sufficient data. GPS data for summer 2024 were not obtained at the start of this study. The number of GPS collared individuals equipped with GPS senders for each year in each season varied between 5-71 individuals. The summary of GPS collared individuals and number of GPS locations for each year in each season can be found in Appendix C.

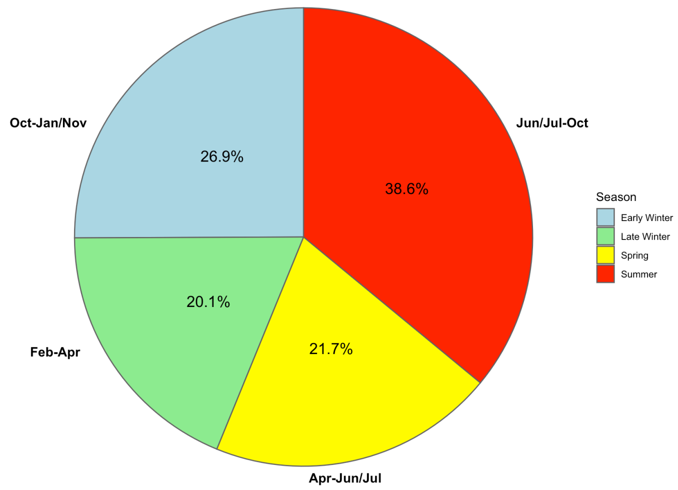

Figure 2: Sector diagram displaying the proportion of total days collected for the seasons, early winter, (Oct-Jan/Nov), late winter (Feb-Apr), spring (Apr-Jun/Jul), and summer (Jun/Jul-Oct), for the whole study period 2015-2024.

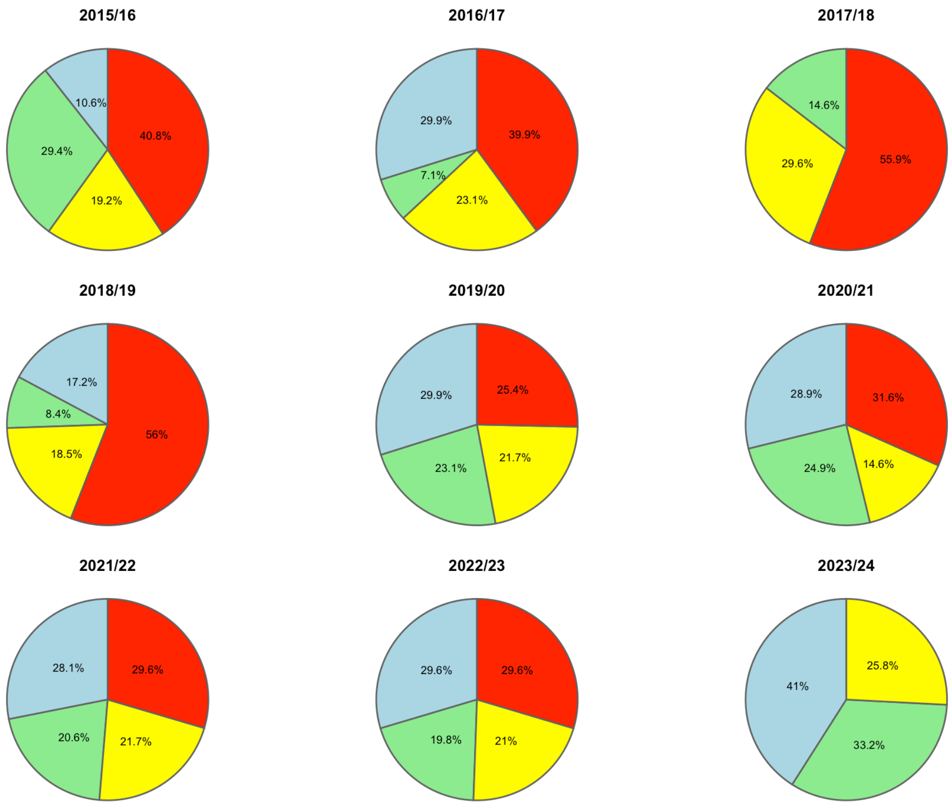

Figure 3: Sector diagram displaying the proportion of days collected for early winter, late winter, spring and summer for each year 2015 to 2024. Each diagram illustrates the percentage of days based on the total number of days for the specific year. GPS data for early winter 2017 was omitted and GPS data for summer 2024 were not collected at the beginning of the study.

3.4 GPS data

To investigate habitat use and potential WPP avoidance of reindeer two approaches were employed: (1) comparison of distance intervals to proportion of individuals and GPS locations for each year in each season, and (2) estimating yearly seasonal population home ranges for each year and season.

3.4.1 Comparison of distance intervals

For the first approach, distance intervals around the WPP were created in QGIS (QGIS Development Team, 2024). The distance intervals 0-1 km and 1-5 km were compared, containing 45 and 55 % of the winter range, respectively. This was done to evaluate how the WPP may influence the reindeer habitat utilization, movement patterns and home range in areas around the WPP. Various distance intervals were tested but gave unclear results. The comparison was therefore limited to two distance intervals: 0-1 km and 1-5 km. All GPS points falling within the distinct distance intervals were extracted and separated for each year and within seasons. The expected number of individuals was calculated using the proportion of the area and the total number of individuals for that particular interval. The proportion test was calculated by the observed proportion of individuals within the distance interval compared to the expected proportion. This statistical method assesses whether there is a significant difference between the observed and expected frequencies, indicating potential avoidance of reindeer towards the WPP, by selecting locations farther away. The confidence interval (CI) was calculated using the prop.test () function in RStudio version 2023.12.0+369 (R Core Team, 2023) using the package "RVAideMemoire" (Maxime HERVE, 2023), "chisquare" (Gianmarco Alberti, 2024) and "chisq.posthoc.test" (Ebbert, 2019). Results contained the lower and upper limits of the 95% confidence interval. A CI = 0.5 indicated that observed proportions were not significantly different from the expected proportion, labeled as "E" for "expected" in Table 2. CI < 0.5 indicated a significantly lower observed proportion than expected, labeled as "L" for "lower". A CI > 0.5 suggested that the observed proportion was significantly greater than expected, labeled as "M" for "more" than expected.

For the reindeer GPS count, a simple selection ratio test was conducted in RStudio (R Core Team, 2023) within the two distance intervals, 0-1 km and 1-5 km, following Manly's selectivity measure (selection ratio = used/available). Preference/avoidance was tested and the differences between selection ratios were computed for the two-distance intervals for each year in each season (Manly *et al*., 2002). Selection ratio of 1 indicated that reindeer used the distance interval in proportion to its availability, meaning there were no preference or avoidance. A selection ratio > 1 indicated positive selection for the distance interval, i.e. the distance was used more than expected based on the available area. Higher values suggest a stronger preference. Selection ratios < 1 indicated avoidance of the distance interval, with the distance interval used less than expected based on the available area. Lower values indicate stronger avoidance. The R-script for the analysis can be found in Appendix D.

3.4.2 Estimating yearly seasonal home ranges

For the second approach, the Brownian bridge movement model (BBMM) were used, to estimate yearly seasonal home ranges, using the GPS locations, location error, distance between locations, and time interval, to estimate how likely an animal is to be found in different areas (grid cells) around their path (Horne *et al*., 2007). Helpful in identifying the reindeer habitat selection, important habitats and migration paths (Fischer *et al*., 2013). A population-level BBMM was employed due to the nature of the GPS dataset, which included long tracking intervals, missing fixes, and irregular time gaps. These limitations reduced the temporal resolution and continuity required for reliable individual-level BBMM estimation (Horne *et al*., 2007). Herding practices in our study area influenced reindeer to move in groups, thereby limiting the independence of individual movement trajectories. To ensure data accuracy, double counting of individuals and GPS location recorded < 5 times, were removed from the data set. The BBMM analysis and maps were generated in RStudio (R Core Team, 2023). List of packages used in the analysis can be found in Appendix E.

Time periods between the successive GPS fixes were set to 12 hours. This means that the model estimated animal movements between two consecutive locations (fixes) within a 12-hour timeframe. The parameter location error was set to 20 meters, accounting for possible inaccuracies often present in GPS location recordings. Probability contours of 25%, 50%, and 95% were generated to represent different utilization distributions. The 25% contour identified the core area of use, the 50% contour represented the areas with a 50% probability of use, and the 95% probability contour indicated areas less intensively used, encompassing the reindeer general movement patterns. These contours illustrate the reindeer spatial use at varying intensities, providing insight into home range, habitat use and movement patterns

4 Results

4.1 Seasonal pastures after WPP construction

According to personal comments from the herders in 2025, they describe the following uses of pastures after the WPP construction. The Siida utilizes pastures on the south side of Sørfjorddalen during early winter, late winter and spring, defined as the winter range (Figure 1).The lower lying areas, Torsnesaksla, Buvika, Sandvika and Brensholmen serves as the main pastures. Kvitfjell and Raudfjell are used when accessible. In spring, the main calving areas are in Bogdalen and parts of Buvika and Torsnesaksla. After the annual calf marking, the reindeer move to the north side of Sørrfjorddalen. The north side is used as summer pastures until late autumn, defined as the summer range (Figure 1). After the autumn slaughter and parasite treatment in the corralling fence, the reindeer remain in the winter range. The fence from Sørfjorddalen to Bakkejord/Bakklandelva does not completely separate the reindeer from the winter and summer ranges. In winter the fence is often covered by snow, allowing reindeer to cross to the northern side. In summer, the fence is occasionally left open with reindeer moving to the southside. During and after construction the main area for supplementary feeding has been Torsnesaksla.

4.2 Reindeer habitat use and behaviour experienced by the herders

The herders reported a high level of conflicts during the construction phase regarding winter grazing accessibility impacted by the presence of the WPP. This has led to challenges for the herders, as it directly hindered their ability to find suitable grazing and manage the reindeer.

Upon arrival on Kvaløya, the herders decided to get the reindeer used to a limited section of the island in order to maintain better herd control. In the initial years focus was on using the southern part of the island, as a year-round pasture, with good success. The herders initially kept the reindeer on the southwestern side of the study area for the first winter and two summer seasons, which is now used as their winter range. Gradually, the reindeer moved northeast in summer, and this is now their primary summer range. In November 2016 the herders kept the reindeer in a grazing enclosure on the east side (Bakkejord), for a three-month period to maintain control over the herd and prevent it from dispersing. When the reindeer were released from the enclosure, they were fed and herded in Kvitfjell and Raudfjell, for the rest of the winter and spring season. The herders did the same in 2017 and 2018 up until December. This was mainly due to the beginning of the construction phase of the WPP in 2017, making Kvitfjell and Raudfjell less accessible. The following years, reindeer were not kept in the enclosure.

Describing the grazing conditions in Kvitfjell and Raudfjell before construction the herder stated that, "*The grazing was really good in the area during the summer. The winter pasture was limited; however, it was the only accessible and the best one available*." He explained that the area constituted good winter pastures, because favorable wind conditions helped keep the pastures accessible during heavy snowfall by blowing the snow away. In October 2017 the construction phase of the WPP began, leading to the need for new herding strategies and adaptations towards the changes in habitat structure and pasture availability.

> *"In the beginning at Kvaløya, I fed the reindeer in the mountains in a way I am not able to any longer, because of the wind power plant. I had full control over the herd, and I used the minimal amount of supplementary feed needed. I had complete control over the herd"*

The herders experienced a shift in habitat use by the reindeer, due to the WPP development, both during and after construction. They reported that reindeer used larger parts of the island in winter, spring and summer before the construction, compared to during and after construction. During and after construction the reindeer use Kvitfjell and Raudfjell less, mainly using the lowland areas on the southwestern side. However, if the climate is harsh, heavy snow fall and ROS events occur, the reindeer tend to scatter in areas closer to the WPP, described as the only area with accessible winter pastures by the herders. The herders also reported that the reindeer do not graze and ruminate peacefully in proximity to the WPP, hence, leading to more supplementary feeding and herding. Peaceful grazing is characterized by the animals having the time and ability to lie down and ruminate effectively (Herders personal comments).

> *"The reindeer are constantly moving, and I perceive them as stressed and disturbed. They cannot graze peacefully and effectively."*

The herder further emphasized that: "*Before construction of the WPP the winter range was also used by the reindeer in summer. During construction the reindeer gradually moved Northeast in the summer".* He reports that the summer range is not suitable for winter and spring grazing, due to steep terrain and risk of avalanches. After construction the herders report that as summer approaches and greener pastures emerges, the reindeer quickly move away from the WPP area in spring, pushing towards the summer range. He noted, "*There are great grazing conditions in the WPP area during summer, and they used to graze there, calmly, all year, before the construction. Now they instantly leave when alternative pastures are available*". The herders had to intensify their management efforts to keep the herd gathered within the winter range, until conditions allowed the reindeer to safely move to the summer range.

Describing the reindeer grazing behaviour in the summer season, the reindeer exhibit a calmer behaviour, with access to high-quality pastures. The herder believes that the reindeer' inability to graze peacefully in the WPP area may be connected to the visibility and noise from the turbines. He compares the sound from turbines to barking dogs. He suggests that it prevents the reindeer from lying down and effectively digest their food.

As spring arrives and the calving season begins, the herder reflects on how the WPP area used to be the preferred calving grounds. He explains, *"Before construction Kvitfjell and Raudfjell served as the traditional calving ground for the reindeer; however, this area has significantly diminished now."* According to the herders, the calving area have shifted from Kvitfjell and Raudfjell to Bogdalen, and lower lying habitats after construction (see Figure 4)

> *"The reindeer no longer use the mountain as they used to, and the calving areas have diminished considerably."*

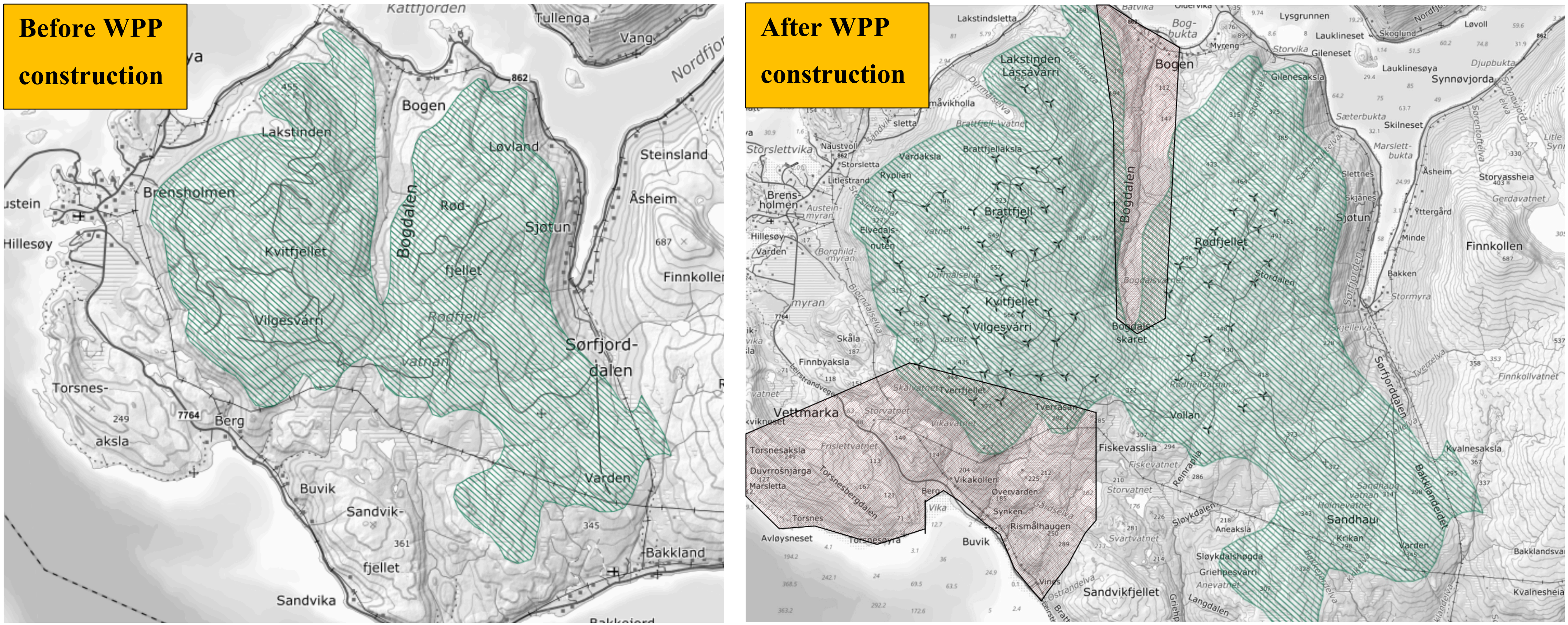

Figure 4: Comparison of the calving areas before and after WPP construction. The left map shows the winter range, and the calving area used before construction in green by Kilden (2015). The right map illustrates the herders' description of calving areas used by the reindeer after construction, marked in red.

4.2.1 WPP constructions impact on herding practices

The construction of the WPP has increased herders' workload primarily in two ways. First, the ice throw hazard from the turbines limiting access to winter pastures, forcing the herders to actively monitor and herd the reindeer away from the WPP area, rather than allowing it to range freely. The herders also underlined how the risk of death if they enter the area and get hit by ice thrown from the turbines, make it impossible for them to use the area. This has significantly increased their workload and imposed a major psychological load on the herders.

Second, there is an increased need for supplementary feeding during the early winter, late winter, and spring season due to the restricted access to available pastures in Kvitfjell and Raudfjell. After construction, the herders' supplementary feeding is best described as “fullfeeding”. According to the herders, 'fullfeeding' refers to the practice of providing reindeer with nearly all their food through supplementary feeding, with natural pasture feed only making up a small part of their diet in winter. The herders feed the reindeer from approximately mid-November to far out in May, providing about 1.5–2 kg of feed per reindeer per day. The increased reliance on supplementary feeding of the reindeer is to prevent the reindeer from starving in periods with locked pastures and due to the lack of available pastures. The herder explains how the coastal climate and heavy snow falls in the area is one of the main contributing factors for supplementary feeding, “*There are no optimal winter grazing areas, and even without the WPP I would still engage in some form of feeding - preferably in the mountains rather than along the road.*” The herder emphasizes that in the absence of the WPP the reindeer would utilize the available pastures better and he would not have to feed them as much. This would reduce the workload and economic burden of winter feeding.

> *“I would probably manage with feeding them 25% of what I currently do during the winter season, if the wind turbines were not present.”*

The supplementary feeding increases expenses for fuel and equipment used to lift, transport, distribute and store the feed. Distribution of supplementary feed also involves several steps that are both time-consuming and physically demanding. The process begins with gathering and herding the reindeer to the feeding site. The supplementary feed packaged can weigh up to 800kg and is loaded onto sleds designed for feed transportation. Proper distribution is crucial, and the feed must be introduced gradually, ensuring that the reindeer adjust to it over time. Overfeeding can lead to digestive issues and in severe cases death. The herders in our study described how they distribute feed in specific patterns to reduce the risk of contamination by reindeer feces. Finally, any remaining fodder must be stored in dry environments to maintain its quality for future use.

> *"I do not advocate for feeding. If I could avoid it, I would - it's a terrible job. I don't want to rely on supplementary feed or tourism. I want to do what I love: herd reindeer."*

- When using a grazing plan where reindeer can meet part of their feed needs through grazing, approximately 650 grams of concentrate feed per reindeer per day is calculated.
- 0.65 kg of concentrate feed at 4.20 NOK/kg equals 2.73 NOK per reindeer per day.

Figure 5: Calculation of supplementary feeding cost for reindeer by Eilertsen and Winje (2017).

The herder explained how the construction and operational phase following the WPP, imposed additional issues with an increased number of reindeer in the lowland pastures. Since they are unable to use and feed the reindeer in the mountains, they actively herd them away from the WPP area and feed them in the lowlands. This led to more reindeer along the roads and increased the risk of losing reindeer in traffic collisions, hence more worries for the herders, and increased workload monitoring the reindeer frequently. Another adaptation to the WPP is the time of herding. Before construction, the herder could tend to the animals every third day without worrying about losing control. After construction, he reports that there are rarely any days where it goes longer than 7 hours without checking on the reindeer. The herders are also concerned that increased herd density and supplementary feeding due to limited pastures may heighten the risk of disease transmission.

The reindeer herders' key experiences of the WPP effects on reindeer habitat use and behaviour in the areas before, during, and after the construction:

(1) The reindeer are forced to seek pastures closer to the WPP during harsh weather causing locked pastures in the lower lying areas.

(2) Increased stress to the reindeer when they graze closer to the WPP compared to when they graze farther away, leading to concerns about reindeer well-being and grazing effectiveness.

(3) Diminished calving grounds, with reindeer more concentrated in Bogdalen after construction, compared to before construction, when calving took place in Kvitfjell and Raudfjell.

(4) Before WPP construction the herd could graze in Kvitfjell and Raudfjell year-round. After WPP construction the reindeer press towards the summer range as soon as pastures starts greening in spring.

(5) Decreased reindeer habitat use on Kvitfjell and Raudfjell, and loss of winter pasture during and after construction, due to ice throw hazard making the areas inaccessible.

Main impacts of the WPP construction on the reindeer herders' practices:

(1) Increased herding activities during and after the construction. Increased monitoring of the reindeer and need for supplementary feeding during early winter, late winter, and spring.

(2) Increased safety risk for humans and reindeer, resulting from ice throw hazard from wind turbines, imposing a psychological load on the herders. It also led to extra work keeping the reindeer gathered to prevent them from dispersing and entering the WPP area.

(3) The herders are unable to feed the reindeer in the mountains and need to feed them in the lower lying habitats, causing the reindeer to move closer to roads. Increasing the risk and worry that reindeer will be killed in traffic.

(4) Increased herd density and supplementary feeding potentially increasing the risk of disease transmission.

4.3 GPS data

4.3.1 Comparison of distance intervals

Examining the results comparing the proportion of GPS marked individuals within the distance intervals 0-1 km and the 1-5 km from the wind turbines, the data for early winter and spring seasons (all years), indicated that the observed number of individuals generally aligned with the expected number (see Table 2). The 95% confidence interval, for the observed proportion, contained 0.5 for all years, indicating no significant deviation from the expected proportions, denoted as "E". However, during the late winter season of 2017 and 2018, the observed number of individuals within the 0-1 km interval was below the expected proportion, suggesting avoidance of areas closer to the WPP area. See Appendix D for the R-script from the proportion test.

Table 2: Comparison of the proportion of GPS marked individuals within 0-1 km and the rest of the study area, using the chi-square test. The size of the area was used to calculate the expected number relative to the observed numbers. The total area cover of the study area was 102 km², representing 45 and 55 % of the 0-1km and 1-5km, respectively.

Season	Year	0-1 km			1-5 km		
		Observed individuals	Proportion	95% CI	Observed individuals	Proportion	95% CI
Early winter	2015/16	10	0.357 (E)	(0.193,0.559)	30	0.577 (E)	(0.433,0.710)
	2016/17	35	0.467 (E)	(0.352, 0.585)	55	0.524 (E)	(0.425,0.621)
	2017/18	NA	NA	NA	NA	NA	NA
	2018/19	37	0.552 (E)	(0.426,0.672)	31	0.524 (E)	(0.425,0.621)
	2019/20	103	0.450 (E)	(0.385,0.517)	179	0.449 (E)	(0.331,0.573)
	2020/21	48	0.462 (E)	(0.364,0.562)	77	0.534 (E)	(0.479,0.589)
	2021/22	114	0.498 (E)	(0.431,0.564)	144	0.527 (E)	(0.443, 0.610)
	2022/23	48	0.490 (E)	(0.389, 0.592)	64	0.502 (E)	(0.443, 0.561)
	2023/24	107	0.455 (E)	(0.322, 0.593)	191	0.537 (E)	(0.483,0.589)

Late winter	2016	25	0.455 (E)	(0.322,0.593)	42	0.531 (E)	(0.417,0.644)
	2017	9	0.243 (L)	(0.124,0.416)	53	0.609 (E)	(0.498,0.710)
	2018	35	0.389 (L)	(0.290,0.498)	87	0.565 (E)	(0.483,0.644)
	2019	28	0.4 (E)	(0.287,0.524)	65	0.560 (E)	(0.465,0.651)
	2020	36	0.429 (E)	(0.323,0.541)	72	0.545 (E)	(0.457,0.632)
	2021	50	0.510 (E)	(0.408,0.612)	58	0.492 (E)	(0.399,0.585)
	2022	7	0.5 (E)	(0.268,0.732)	9	0.5 (E)	(0.290, 0.710)
	2023	26	0.481 (E)	(0.345,0.620)	37	0.514 (E)	(0.394,0.632)
	2024	136	0.456 (E)	(0.399,0.515)	226	0.531 (E)	(0.482,0.579)
Spring	2016	36	0.439 (E)	(0.331,0.553)	66	0.541 (E)	(0.449,0.631)
	2017	34	0.486 (E)	(0.366,0.607)	47	0.511 (E)	(0.405,0.616)
	2018	61	0.473 (E)	(0.385,0.562)	91	0.517 (E)	(0.441,0.592)
	2019	73	0.493 (E)	(0.411,0.576)	95	0.505 (E)	(0.432,0.579)
	2020	63	0.5 (E)	(0.414,0.586)	79	0.5 (E)	(0.423, 0.577)

2021	21	0.477 (E)	(0.327,0.631)	30	0.517 (E)	(0.383, 0.649)
2022	45	0.455 (E)	(0.355,0.557)	76	0.531 (E)	(0.446, 0.615)
2023	34	0.479 (E)	(0.360,0.600)	48	0.516 (E)	(0.411, 0.620)
2024	100	0.546 (E)	(0.471,0.620)	85	0.455 (E)	(0.382, 0.529)

The observed values were calculated by multiplying the total observed values by the proportion of the area by the size of the distance intervals. The letters in parenthesis in the body of the table indicate whether the observed value was as expected (E), significantly less (L) or more (M) than expected. If the 95 % confidence interval for the observed proportion contains 0.5, it suggests a non-significant difference from the expected proportion, this is labelled as "E".

Analysis of the comparison of GPS locations within 0-1 km and 1-5 km distance of the WPP, using availability design (Manly et al., 2002), revealed variable results (see Figure 6). In early winter of 2016/17, 2018/19, 2020/21, and 2022/23, results indicated a preference for the 0-1 km interval, indicated by the selection ratios (SR) being > 1. Conversely, in 2015/16 and 2023/24, with SR < 1, indicating a preference towards the 1-5 km and avoidance to the 0-1 km interval. In 2019/20, the SR approximated 1, indicating no clear preference or avoidance.

In late winter of 2016 through 2021, 2023 and 2024, the SR was consistently < 1 within the 0-1 km interval, and > 1 within the 1-5 km interval. In spring 2016 and 2021 results indicated no clear preference or avoidance. However, in 2017, 2018, 2020, 2023 and 2024 the results showed a higher-than-expected number of GPS locations within the 0-1 km interval, and fewer in the 1-5 km interval, indicating a potential preference towards the 0-1km interval. Conversely, in 2019 and 2022, fewer GPS locations were found within the 0-1 km interval, with an increase in the 1-5 km interval. See Appendix E for the table of the selection ratio tests. It is important to note that the total number of GPS locations varied greatly between years and within seasons. See Appendix C for the total number of GPS counts for years and seasons.

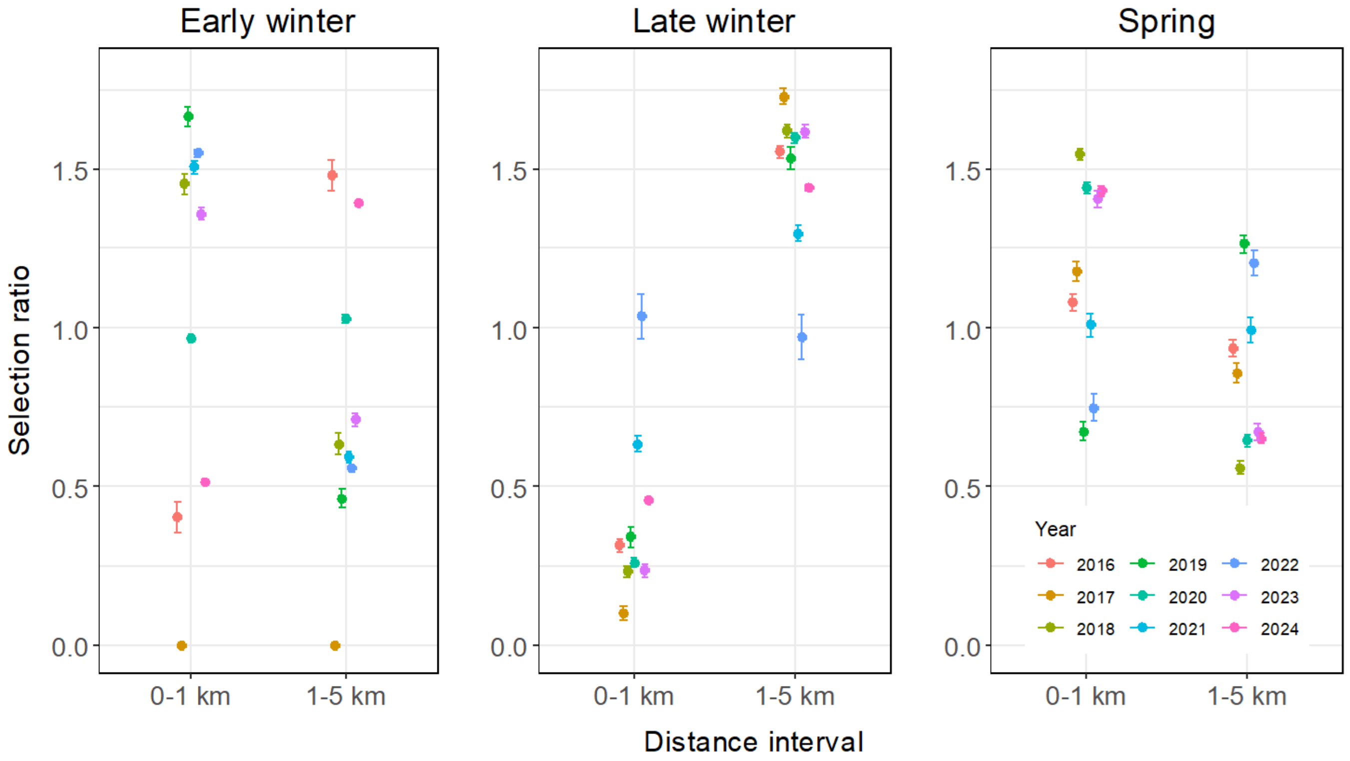

Figure 6: Comparison of the GPS locations within 0-1 km and 1-5 km distance intervals from the wind power plants in the study area using availability design (Manly et al., 2002). The size of the area was used to calculate the expected number relative to the observed. An error-bar plot displays the results for early winter, late winter and spring for the years 2016-2024. The x-axis shows the two distance intervals (0-1 km and 1-5 km). The y-axis indicates the selection ratio, representing a measure of preference related to the distance. Selection ratio of 1 indicates that reindeer use the distance interval in proportion to its availability, meaning there is no preference or avoidance. A selection ratio greater than 1 indicates positive selection for that distance interval, with reindeer using it more than expected based on the available area. Higher values suggest a stronger preference. A Selection Ratio less than 1 indicates avoidance of that distance interval, with reindeer using it less than expected based on the available area. Lower values indicate stronger avoidance

4.3.2 Estimating yearly seasonal home ranges

The Brownian Bridge movement model maps (BBMM maps), displaying the reindeer home ranges, indicate yearly and seasonal variation (Figure 7-10). The 25% (purple) and 50% (yellow) probability contours showing the most used areas within the study area. During the first years of the early winter season, results show no large variation, probably due to insufficient data. The early winter season 2020/21, 2021/22 and 2022/23 home ranges (Figure 7) indicate that reindeer used mainly areas surrounding the WPP. Their general movement pattern shown by the 95% (orange) probability contour, indicated areas less intensively used by reindeer in both lowland habitats and areas in proximity to the WPP. Conversely, in 2023/24 (Figure 10) reindeer general movement pattern was in the lowlands. During late winter (Figure 8) the most used areas are fairly similar across all years, with the lowlands, specifically Torsnesaksla and Brensholmen being used. Areas in proximity to the WPP are not used during late winter.

In spring, large-scale habitat use before and after the construction period varied. Home ranges for the before construction period (2015-2017) and during construction (2017-2020) and 2021, are similar, with the reindeer mainly using habitats near Torsnesaksla. Two years after the wind turbines started operating, in 2022, 23 & 24 larger parts northward on the island, within the winter range, were generally used (Figure 10). The core area of use these years were concise, with the reindeer concentrated in Bogdalen. In spring 2024, the reindeer general movement pattern covered large parts of the winter range (Figure 10). See Appendix F for the BBMM for the summer season.

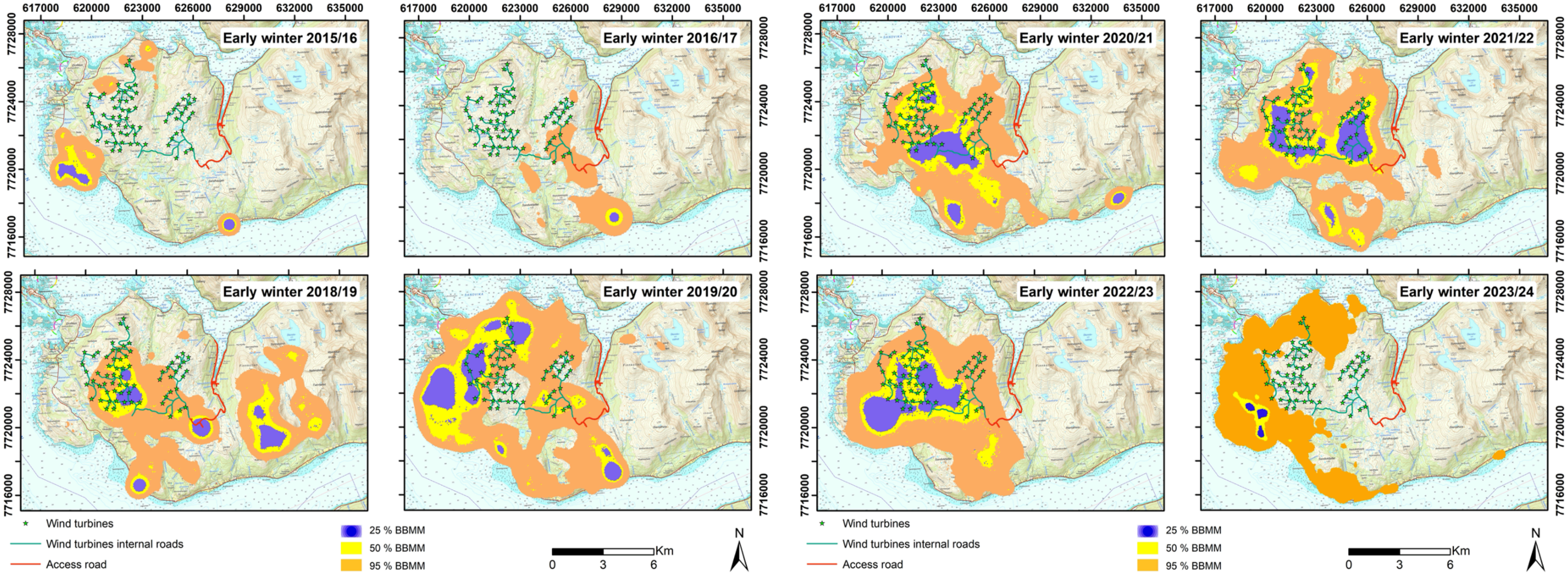

Figure 7: Yearly seasonal home ranges (BBMM) for early winter. The map shows the study area, including wind turbines, internal roads and access roads. The colored areas represents the home range at different utilization distribution levels: 25% (purple) indicates the core area used by reindeer, 50% (yellow) represent a broader area with a high probability of use, and 95% (orange) showing the general movement pattern and the areas less intensively used. The maps display results from early winter 2015/16 through early winter 2023/24.

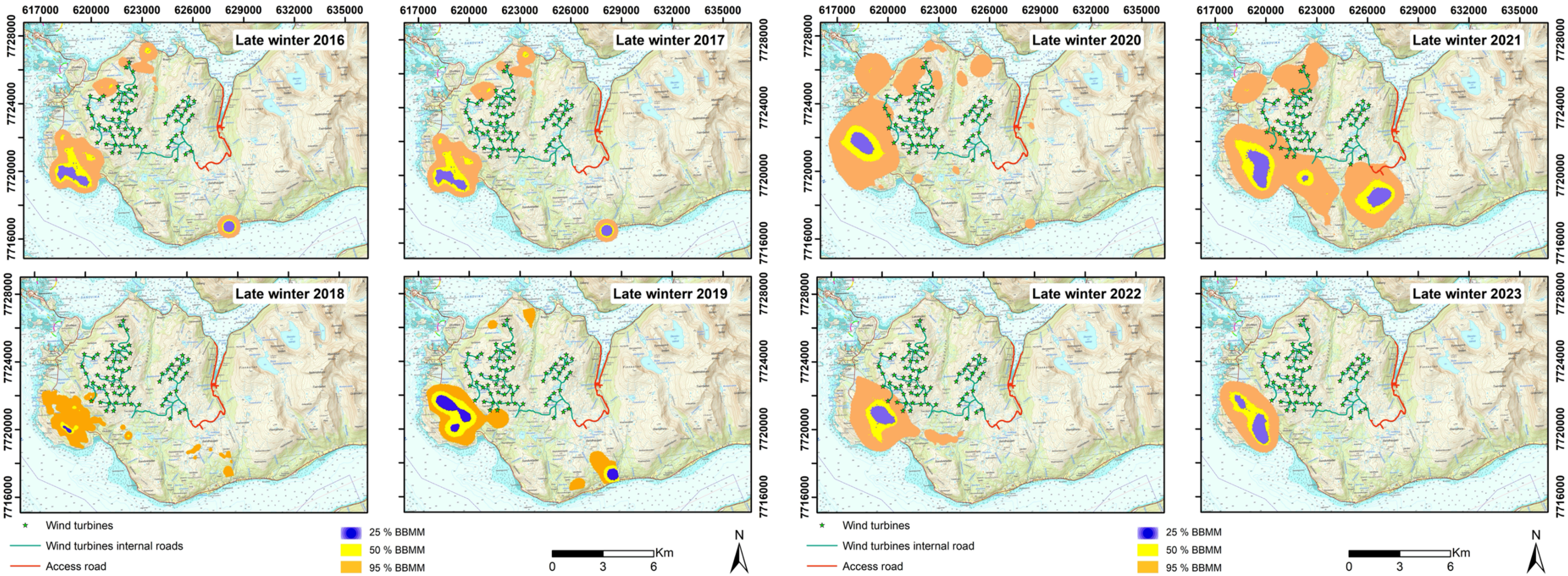

Figure 8: Yearly seasonal home ranges (BBMM) for late winter. The map shows the study area, including wind turbines, internal roads and access roads. The colored areas represents the home range at different utilization distribution levels: 25% (purple) indicates the core area used by reindeer, 50% (yellow) represent a broader area with a high probability of use, and 95% (orange) showing the general movement pattern and areas less intensively used. The maps display results from early winter 2016 through early winter 2023.

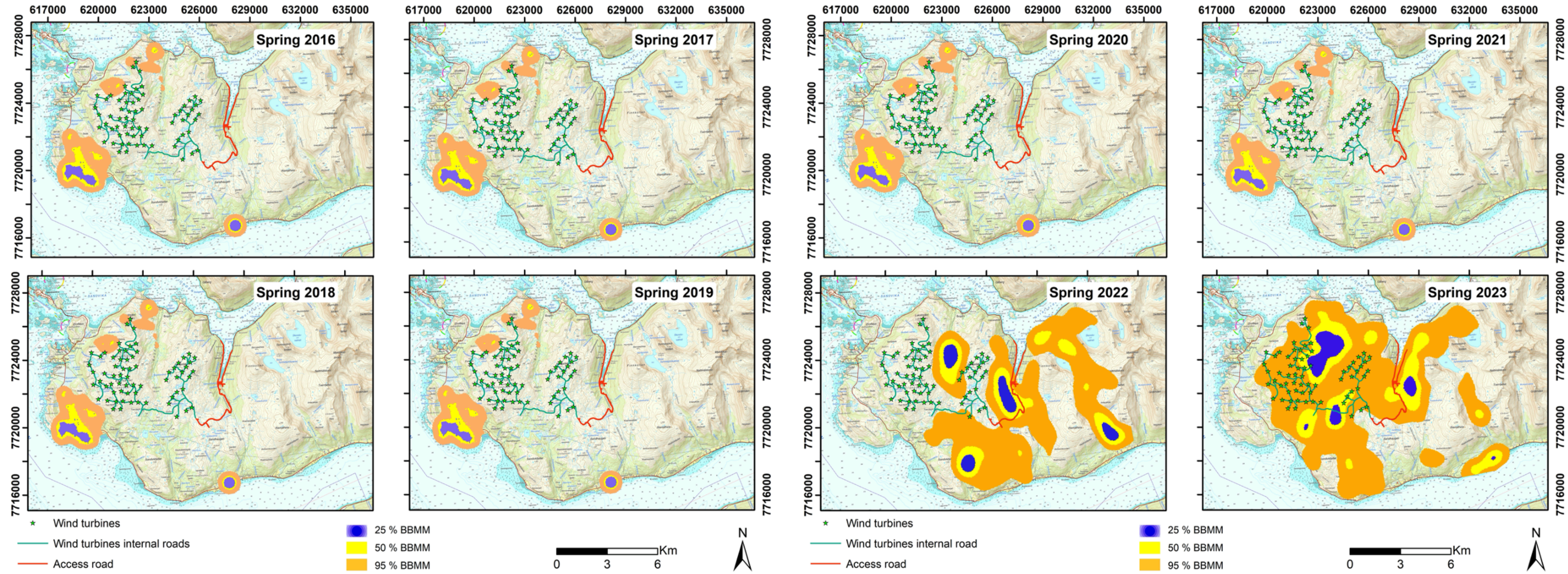

Figure 9: Yearly seasonal home ranges (BBMM) for spring. The map shows the study area, including wind turbines, internal roads and access roads. The colored areas represents the home range at different utilization distribution levels: 25% (purple) indicates the core area used by reindeer, 50% (yellow) represent a broader area with a high probability of use, and 95% (orange) showing the general movement pattern and areas less intensively used. The maps display results from early winter 2016 through early winter 2023.

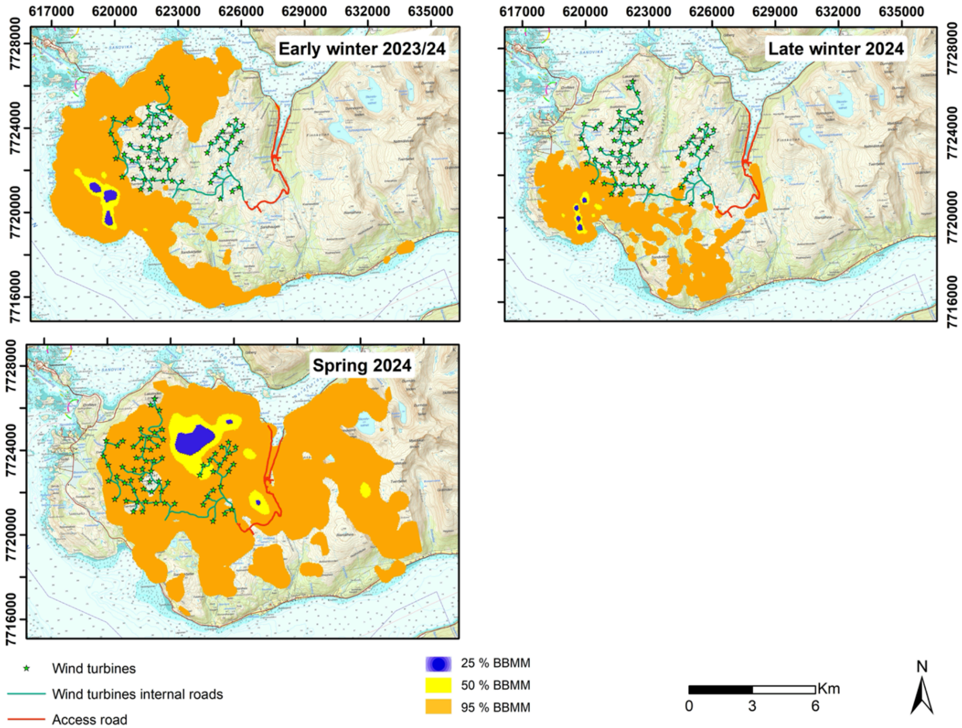

Figure 10: Yearly seasonal home ranges (BBMM) for early winter, late winter and spring for 2023-2024. The map shows the study area, including wind turbines, internal roads and access roads. The colored areas represents the home range at different utilization distribution levels: 25% (purple) indicates the core area used by reindeer, 50% (yellow) represent a broader area with a high probability of use, and 95% (orange) showing the general movement pattern and areas less intensively used..

5 Discussion

5.1 Reindeer habitat use - combination of GPS data and herders experience

The analysis of GPS data and semi-structured interviews indicated some coinciding trends. The GPS data showed both preference and avoidance of the WPP. The home range distribution of reindeer varied across years and seasons, with indications that in some years reindeer utilized areas closer to the WPP, while in others they used areas further away. The selection ratios (see Figure 6) indicated that reindeer generally avoided areas near the WPP, mainly during late winter and spring in some years.

The herders experienced reduced use of habitats adjacent to the WPP across all three seasons (early winter, late winter, spring), during favorable weather conditions but observed increased use during harsh conditions, such as heavy snowfall and ROS events, when pastures in the lower regions were inaccessible. However, the herders pointed out that the animals were not peacefully grazing and ruminating in the WPP area in the operational phase, in line with what herders reported in Flydal *et al.* (2004). This led to an increase in supplementary feeding and more intensive herding practices for the herders in our study. Reindeer require time for undisturbed or "peaceful" grazing and rumination, to get enough nutrients and energy, which again affects the reindeer survival and reproduction (Skarin & Åhman, 2014). Rumination time refers to the digestion process of regurgitation, re-mastication, salivation and swallowing of ingesta and returning the material to the rumen (Paudyal, 2021; Soriani et al., 2013). Rumination time has been studied as an indicator for health and reproduction in ruminating animals (Paudyal, 2021; Paudyal *et al.*, 2018; Reith & Hoy, 2012; Soriani *et al.*, 2013; Soriani *et al.*, 2012) and has linked reduced rumination time to an increase in stress and diseases in cattle (Hansen *et al.*, 2003; Soriani *et al.*, 2012). Analysis of GPS locations alone cannot determine how grazing and rumination behaviour in reindeer may be influenced by the WPP. The GPS data do not explain how the animals ruminate, graze or why they stay in one area or move away from another. Visual observation is a common method for monitoring rumination and grazing behaviour (Schirmann *et al.*, 2009), emphasizing the importance of collaboration with herders whom observe the reindeer closely. To further improve monitoring accuracy, I argue that future studies should incorporate accelerometer data and video technology. In a study by Rautiainen *et al*. (2022) tri-axial accelerometer data and video recordings of reindeer are used to document fine-scale foraging patterns and behaviour. The study demonstrates how video recordings helped train machine learning models to identify and classify behaviors such as grazing, browsing, inactivity, walking, and trotting based on the accelerometer signals. This method can improve data accuracy and prove to be an important tool when examining reindeer behaviour and habitat choices potentially affected by extreme weather events, changes in habitat structure, and land fragmentations due to infrastructure developments.

The comparison of the proportion of GPS marked individuals within the distance intervals indicated that the observed number of reindeer within the 0-1 km and 1-5 km intervals in early winter, late winter, and spring generally matched the expected proportion (see Table 2). Results from the simple selection ratio test indicated preference for habitats in the 0-1km distance interval in early winter for several years (Figure 6). Home range distribution during the construction period for early winter 2018-2021 and in the operational phase 2021-2023, findings indicated that areas closer to the WPP were the most used habitats (Figure 7). This could potentially indicate that the reindeer preferred habitats closer to the WPP in early winter. These results contradict our first hypothesis, which proposed that reindeer would prefer areas further away from the WPP after its construction. A similar behaviour and spatial use close to WPP by reindeer was reported by Tsegaye *et al*. (2017), in an area important for the herds winter grazing. Their data collection was based on direct observations and GPS-data, they did not include information from the local herders. In our study the reindeer herders' observation and knowledge were included.

The herders explained that the preference observed in early winter (Figure 7) is not a result of the reindeer preferring habitats near the WPP, but a response to climatic conditions, causing locked pastures in the lower lying habitats, and the lack of alternative pastures. The higher elevations, favorable wind conditions, and drier climate provide crucial foraging opportunities in Kvitfjell and Raudfjell, when other habitats are inaccessible (Herders personal comments). The herders observed that during harsh weather conditions lower lying pastures became 'glue-like', creating inaccessible pastures. The early winter of 2022 and 2023 was exemplified, "*The snow conditions created locked pastures, and the reindeer were forced to spread widely across the wind power plant area to find suitable grazing. We were unable to keep control of the herd"*. When weather conditions led to locked pastures in the lower regions it potentially forced the reindeer to use habitats closer to the WPP, since it encompassed the only accessible pastures, made so by favorable wind conditions and low snow cover. This could be an explanatory factor for why results for early winter indicate a preference for areas closer to the WPP. This emphasizes the importance of including herders' knowledge to contextualize GPS data and reveal underlying factors, potentially influencing the GPS data. Additionally, it underlines the highly complex nature of reindeer habitat use, which is strongly affected by environmental conditions. As a result, drawing definitive conclusions, confirming or disproving our hypothesis proves to be difficult. Gill *et al*. (2001) discuss how animals in areas affected by human disturbances and infrastructure may avoid these disturbances by utilizing nearby alternative habitats. In contrast, where no suitable alternative habitat is nearby, animals are forced to use the available habitat despite the disturbances. The area in our study lacks alternative winter pastures and when the lowland pasture is impenetrable, reindeer are potentially forced to use habitats closer to the WPP, despite the disturbance.

The herders reported that after the construction of the WPP, as summer pastures started greening in spring, the reindeer began to move away from the winter range and push toward the summer range. This behaviour may indicate avoidance of the WPP, as the reindeer were observed by the herders, moving to alternative habitats as soon as they became more available. In our study, the summer season was not analysed, making it impossible to draw clear conclusion on potential shifts in habitat use from spring to summer. Further research should be conducted, investigating the sudden shift from the winter to summer ranges in spring, incorporating field observations, vegetation data on the onset of summer pastures, in combination with GPS tracking.

Results from the selection ratio (SR) were variable with reindeer showing a preference for habitats within the 0-1 km interval some years, but not others. Particularly in late winter, when SR consistently measured < 1, indicating avoidance for habitats in the 0-1 km distance interval (Figure 6) and preference for habitats further away. This is similar to results in Skarin *et al*. (2018), where reindeer decreased their preference towards habitats surrounding the wind power plant during construction and operational phase compared to before construction. Similar effects were reported in Skarin *et al*. (2015). Our results, indicating avoidance in late winter, were affected by the herders actively trying to keep the reindeer away from the WPP area to (1) avoid ice throw hazard to herders and reindeer (2) keep the herd together to spend less time searching single animals spread in a large and inaccessible terrain and (3) mitigate the negative impacts of reduced pastures and grazing peace. The active herding measure to mitigate for the impact of the WPP may have obscured clear behavioral responses and mitigated WPP impacts.

A limitation to our study is the lack of information on which specific areas were affected in the construction phase, since not all roads, turbines and infrastructure for the WPP were built simultaneously. Detailed documentation of the construction timeline and affected areas would improve our understanding of reindeer habitat use and responses. Combining this with daily movement tracking and visualisation, focusing on specific days or weeks where construction activities occur for example blasting, can potentially reveal clearer effects than analysing only monthly or yearly data. This requires cooperation with the WPP developers to know when construction activities occur. This type of fine-scale data can improve research and potentially identify clearer effects of WPP development on reindeer.

In early and late winter 2023-24 the home range distribution indicates that the reindeer stayed further away from habitats closer to the WPP, using the lower lying habitats (Figure 10). The variabilities between years and seasons makes it challenging to interpret reindeer responses to the WPP and to draw definitive inferences about the validity of our hypothesis. Colman *et al.* (2017), state that changes in avoidance for habitats near the WPP can make it difficult to determine if habitat use is due to avoidance of the WPP or natural variations. Potential effects of infrastructures on reindeer on a spatial and temporal scale, are dependent on a variety of factors potentially obscuring and limiting results (Flydal *et al.*, 2019), including changes in population dynamics, seasonal variations, predation, climate fluctuations, other disturbances, and the randomness of animal movement. Accounting for all influencing factors is challenging due to the complexity of ecological interactions (Flydal et al., 2019). This study acknowledges these limitations and uncertainties. The herders emphasized that reindeer habitat choices are highly influenced by weather fluctuations. In our study no environmental variables known to influence reindeer habitat use such as elevation, vegetation cover, temperature, and precipitation (Skarin, 2006, 2007; Tablado et al., 2014) were included in the data analysis. I recommend incorporating such variables in future research to provide a more comprehensive understanding of the drivers behind reindeer habitat choices.

In spring the reindeer home ranges were mainly in the lowland regions before and during construction and closer to the WPP after construction (Figure 9). In Skarin *et al*. (2015) the reindeer were closer to the WPP area before construction and further away during construction in the calving and post-calving period. Their results indicated avoidance of habitats closer to the WPP. Similar to our study, Skarin *et al*. (2015) used the Brownian Bridge Movement Model (BBMM) to assess reindeer home ranges and movement corridors. Unlike our approach, Skarin et al. (2015) applied resource selection functions (RSFs) which included environmental variables such as vegetation type, forest height, elevation, ruggedness, and slope. Including these variables in habitat selection models provides a more comprehensive understanding of reindeer habitat preferences and helps interpret their responses to environmental disturbances. This approach can also help identify critical habitats and potential areas of conflict. Insufficient data from years prior to the WPP construction in our study, limits our ability to compare habitat use before to the during and after construction period.

The home range selection for spring revealed an increased concentration of reindeer in Bogdalen near the WPP, a year after construction, coinciding with the herders' experience (Figure 9 and Figure 4). The herders indicated that Kvitfjell and Raudfjell were the preferred calving grounds before construction. This is supported by maps from Kilden (2015) of reindeer seasonal pastures before construction (Figure 4). The herders reported that that the calving grounds diminished after construction and calving is now concentrated in Bogdalen (Figure 4). The herders suggest that this might be an adaptive response by reindeer to reduce effects from noise and shadowing from turbines, potentially disturbing the females. In Skarin *et al*. (2018) they reported that reindeer preferred areas where the turbines were out of sight to avoid turbine noise, which may facilitate better predator detection and communication between females and their calves. Herders in Eftestøl *et al.* (2023) reported a decrease in reindeer use of ridges visible from wind turbines following construction and that the effect was stronger in weather conditions of high visibility. Future research should investigate the potential effects of the visibility and noise of WPPs on reindeer choice of calving sites and habitat selection. During calving the females and their calves are more vulnerable to disturbances, thus, it is important that they have access to undisturbed areas (Dyer *et a*l., 2001; Pinard *et al*., 2012; Vistnes & Nellemann, 2001). The herders explain that Bogdalen is not an ideal area for calving , as females prefer firm ground for giving birth, and Bogdalen mainly consist of wetlands (Herders personal comments). As a mitigation measure, the herders suggest that the turbine operations could be temporarily stopped during calving. This would allow reindeer to give birth peacefully in the most suitable areas.

Several studies on infrastructure effect on reindeer have been done sampling GPS data over a relatively short time period, fewer than 5 years (Anttonen *et al.*, 2011; Flydal *et al*., 2004; Flydal *et al*., 2009). Eftestøl *et al.* (2023) emphasize that independent of negative stimuli, reindeer may simply choose to graze farther away from the wind power plant one year, and therefore it is important to conduct studies on habitat use over several years and scales. In our study nine years of GPS data alongside direct observations and experienced based knowledge from the herders were collected, similar to the approach of Eftestøl *et al*. (2023) and Skarin *et al*. (2015). However, there is a significant gap in research integrating both herders' knowledge and observations with reindeer GPS data. The herder in our study emphasized that observing the reindeer movement daily in combination with GPS data can more accurately detect patterns and provide a more detailed picture on what happens in the WPP area. *"There is not only one reason for their movements, but it is a combination of weather, behaviour, infrastructures and other influences".*

Our findings show that reindeer habitat use is influenced by the WPP construction. The herders' reported that due to the WPP the reindeer no longer have access to winter pastures and are instead utilizing lower-lying habitats for grazing. This can also be seen in the GPS data with reindeer in late winter not using areas in proximity to the WPP. The herders also reported that once alternative habitats became available in spring, reindeer tended to move away from the winter range toward the summer range. As mentioned, this pattern requires further analysis to better understand the underlying factors influencing these movements. Based on herders' information and collected data it was confirmed that reindeer utilized areas like Kvitfjell and Raudfjell in spring for calving before construction. After construction the GPS data showed a concentration of reindeer in Bogdalen during spring, which aligns with the herders' reports. This change in habitat use indicate that the WPP has influenced reindeer habitat use after construction. Future studies must prioritize both quantitative and qualitative data to provide a comprehensive understanding of the effects of WPP development on herded reindeer. Documentation of both findings, even when results appear contradictory, is vital for establishing a solid knowledge base for further research. Tsegaye *et al*. (2017) emphasize that quantitative GPS-data analyses on their own, may be insufficient for documenting large-scaled effects of infrastructure on reindeer. In this study, both scientifically collected GPS data and traditional and experience-based knowledge are equally weighted data sources for knowledge creation. This provides a stronger foundation for distinguishing between the effects of the WPP, herding activities and natural fluctuations.

5.2 Herding practices and impact of wind power plant

The herders' information indicates that herding practices have changed since the construction of the WPP, resulting in increased workload, which supports our initial hypothesis. The herders monitor the reindeer multiple times a day as opposed to checking on them every other day prior to construction. Winter pasture availability has decreased, while workload and supplementary feeding have increased, due to 1) ice throw hazard and 2) climatic conditions.

A definition for "good grazing" by Sámi reindeer herders is outlined by (Inga, 2007) as "an area that may be grazed under a variety of climatic conditions, but also as a place where reindeer can access enough forage without disturbance (guohtun ráfi, "grazing peace", Northern Sámi)". What constitutes a "good pasture" varies considerably from year to year, depending on the quality of the forage and climatic conditions (Sara, 2009). In our study, access to the "good pasture" has been severely restricted. The ice throw hazard from the turbines in the winter season makes it too dangerous for herders and reindeer to enter the areas. As a result, the areas no longer fulfill the criteria for "good grazing", as outlined by Inga (2007), since the reindeer are unable to access the necessary forage without disturbance or danger. The herders need to keep the herd gathered to prevent them from dispersing in the WPP area, due to the danger of ice throw, intensifying their workload. In Eftestøl *et al*. (2023) herders also reported an increase in herding activities following the construction of a WPP. They had to actively herd the reindeer frequently to keep them grazing in the preferred summer ranges, as the animals tried pushing away from the area, influenced by the WPP. The herders in Eftestøl *et al*. (2023) stated that the reindeer general movement patterns changed after the construction of a WPP and the reindeer actively avoided areas near the turbines. Holand *et al*. (2024) emphasize that the ability of reindeer to select good forage within seasonal pastures is central for reindeer herding and crucial for the reindeer ability to survive and reproduce. The prior impact assessments for the construction of the WPP on Kvitfjell and

Raudfjell underestimated potential impacts associated with ice throw from turbines. The report by Norsk Miljøkraft Tromsø AS (2007) prior to construction concluded that the impact of ice throw was considered none to minimal. It stated that the likelihood of people being in the area during weather conditions that could cause ice throw was very low. The report did not take the presence of reindeer and herders into consideration. Prior to the WPP construction the area was used as all-year pasture for reindeer, with Raudfjell and Kvitfjell encompassing the only suitable winter pasture (Herders personal comments; Kilden, 2015). The area is now the Siidas main pasture grounds in early winter, late winter, and spring. The herders propose a stop in the WPP operations for at least one week to facilitate herd gathering in winter. They plan to herd and feed the reindeer in the lowlands from November/December to May (Herders personal comments). The area lacks alternative winter pastures, and they need additional support to manage the extended periods of restricted access to winter pastures. They propose that extra assistance with herding, feeding, and fence maintenance in certain periods would be beneficial and wages could be provided to support this labor (Herders personal comments).

As a measure to maintain herd productivity, mitigate for disturbances and ensure herd health, supplementary feeding of reindeer is a common response in reindeer husbandry. After the construction of the WPP, the herders reported a significant increase in supplementary feeding, which in turn heightened their workload. The herders described it as “fullfeeding”, providing reindeer with nearly all their food through supplementary feeding, with natural pasture feed making up a small part of their diet in winter. Prior to the construction, they partially relied on supplementary feeding in combination with natural pastures. Some economical models show that reindeer herding based on natural pastures in an undisturbed environment is generally more profitable than reindeer herding based on supplementary feeding (Holand *et al*., 2024). The findings of Kumpula (2001) indicated that for optimal body condition and to satisfy reindeer energy need, during winter, access to natural pastures is important. Another study on wild-reindeer showed that resource limitation in winter can delay mean time of calving (Skogland, 1983). This underlines the importance of access to resources such as natural winter pastures for reindeer, as it can affect their reproductive success and health. Kumpula (2001) emphasizes that keeping reindeer at high densities in reduced areas may hinder pasture recovery, potentially heightening the risk for long-term dependency on supplementary feed. The increase of supplementary feeding is a result of fragmented pastures, reduced quantity and quality of pasture, and increased human activity (Anttonen *et al*., 2011). If the WPP were not present, the herders stated that reindeer would be able to utilize the pastures in Kvitfjell and Raudfjell better, which would subsequently reduce the herders' workload associated with supplementary feeding during winter. In Holand *et al*. (2024), several points are raised by other herders regarding supplementary feeding 1) sustainable reindeer herding should rely on natural pastures, 2) Supplementary feeding should not act as substitute for traditional grazing pastures, 3) reindeer can become too domesticated and less vigilant to predators. Generated with assistance from OpenAI (2025). Supplementary feeding is physically hard and a time-consuming job. It increases the physical strain on the herders and the expenses for fuel and wear and tear on equipment like snowmobiles and sleds (Eilertsen & Winje, 2017). The herders in our study emphasized the need for financial support, as extensive supplementary feeding is a result of the WPP construction making winter pastures inaccessible. The herders suggest creating storage areas for the feed to reduce the workload and improve the ease of feeding distribution. Another suggestion is locally produced feed to make supplementary feeding more sustainable and accessible (Herders personal comments).

The herders in our study also worry about an increase in infectious and stress-related diseases, since the reduced winter pasture and available grazing areas have forced the reindeer in closer contact, increasing the risk of disease transmission. In a study by Tryland *et al*. (2019) they studied a disease outbreak among corralled and supplementary fed reindeer. Results indicated that supplementary feeding and corralling, increasing animal-to-animal contact, stress, and poor hygienic conditions, facilitate the transmission of pathogens such as Orf virus and *Fusobacterium necrophorum*. The research highlights that environmental changes, such as pasture fragmentation and climate change, influence the emergence and spread of infectious diseases in reindeer (Tryland *et a*l., 2019). This underlines the importance of area flexibility for reindeer and reindeer husbandry. In our study, the reindeer lacks alternative winter pastures, and the WPP and the increased frequency of climate events, "Goavvi" causing locked pasture, force the herders to keep the reindeer at high densities and supplementary feed. Area flexibility could decrease potential disease outbreaks and provide better foraging opportunities, important for reindeer and reindeer husbandry. In Horstkotte *et al*. (2022) they interviewed reindeer herders that underlined the importance of spatial and temporal mobility, to minimize negative effects of locked pastures. The herders in our study suggest that halting the WPP operation in periods of extreme weather conditions and vulnerability in winter and during calving could facilitate better area flexibility (Herders personal comments). This could thus provide reindeer with better foraging opportunities and improve their welfare.

In summary, the findings support the second hypothesis that the construction of the WPP has impacted herding practices both during and after the construction. The WPP construction has led to the herders having to engage in more active herding in early winter, late winter and spring to prevent reindeer from dispersing into the WPP area due to ice throw hazard from turbines. The underestimated impact of ice throw has proven particularly problematic, as it limits access to vital winter pastures and makes it difficult to gather the herd. It increases the psychological toll on the herders, as they risk their lives if they enter the WPP area. They also reported a significant increase in reliance on supplementary feeding as a response to the reduced accessibility of natural winter pastures. The reliance on supplementary feeding due to habitat fragmentation and restricted access to natural winter pastures raises concerns about sustainability, increased workload, and potential health risks for the reindeer. Addressing these challenges requires collaborative efforts, including practical mitigation measures such as halting the WPP operation in periods of extra vulnerability during winter and calving. There is a need for additional financial support and ongoing dialogue with herders to better accommodate their needs. Moving forward, integrating herders' insights into planning and policy decisions is essential for maintaining reindeer herding's sustainability in the face of ongoing development and environmental changes.

6 Limitations

While this study provides valuable insights into potential effects of WPP development on reindeer habitat use and related herding practices, it is important to acknowledge limitations that may influence the interpretation of the findings. The GPS data collected prior to WPP construction were limited or insufficient and GPS data for the early winter 2017 were insufficient and omitted from the analysis. This made it challenging to establish clear inferences for reindeer habitat use and potential impacts during and after construction compared to the before construction period. The before construction phase is usually not assessed by GPS over several years in the run up of a licensing process/impact assessment. I argue that mapping and documenting reindeer seasonal movements, movement corridors and pastures, in addition to, herding practices influencing movement, such as feeding, across reindeer herding districts would strengthen baseline data. This could provide clearer insights into potential effects of WPP developments on reindeer and their habitat use. Our study did not incorporate environmental variables, and I suggest that future research would benefit from incorporating such variables to provide a better understanding of the drivers behind reindeer responses.

The GPS data in the study are highly influenced by herding activities and supplementary feeding, potentially mitigating the effects of the WPP on reindeer responses and may have obscured results. Other limitations in the GPS data were missing fixes and long tracking intervals, sometimes only 2 or 1 per day. Reducing temporal resolution and irregular time gaps that reduce the temporal resolution and continuity required for reliable individual-level BBMM estimations. GPS data alone cannot reflect the daily challenges faced by the reindeer herders. While the GPS locations during the construction phase depict that reindeer used the entire WPP area, the herder’s day-to-day assessment shows a different picture, one that can only be captured through their observations. The GPS data do not provide any information regarding herding efforts. This is information only obtained through communication with reindeer herders.

7 Conclusion

The data basis in our study makes it unsuitable to draw clear conclusions on the before-during-after construction effect of the WPP on reindeer habitat use. The findings show variable habitat use patterns across seasons and years, indicating that reindeer potentially preferred areas near the WPP in early winter during and after construction. The herders reported that the preference was not a result of the reindeer preferring the habitats, but a response to climatic conditions causing locked pastures in the lower lying areas and the lack of alternative winter pastures. This forced the reindeer to disperse in the WPP area, encompassing the only suitable winter pastures. The herders reported that the reindeer were stressed and did not graze and ruminate peacefully in the WPP area. Further research should include field observations, video recording and accelerometer data to document fine-scale foraging patterns and behaviour. I also recommend that future studies include high temporal resolution GPS data as discussed by Flydal *et al*. (2019). This is to better distinguish between natural variations and effects of infrastructure on herded reindeer.

In late winter and spring some years, results from the home range distribution and selection ratios indicated avoidance towards areas closer to the WPP. The WPP construction restricted access to winter pastures in Kvitfjell and Raudfjell due to ice throw hazard. The ice throw hazard made it too dangerous for both herders and reindeer to enter the WPP area. Therefore, the herders actively tried to keep the herd away from the area in winter, to mitigate the WPP effects. In spring, home range selection and herders' information indicated that Kvitfjell and Raudfjell, formerly used as calving sites, decreased in use after the construction. Instead, the reindeer have become more concentrated in Bogdalen, indicating a shift in calving areas, potentially to reduce noise and shadowing from turbines. The herders emphasize the need for temporary halts in the wind power plants during critical periods like winter and calving to minimize disturbances and improve animal welfare.

The herders' information indicated an impact on herding practices during and after the WPP construction. They had to increase their herding efforts, monitoring the reindeer frequently and supplementary feeding them substantially more than prior to construction. This was mainly as a result of the restricted access to winter pastures caused by the ice throw hazard and increased frequency of climatic conditions causing locked pastures. The intense herding interventions complicate our ability to isolate the WPP impact. This may have mitigated the effect of the WPP and potentially obscured clear behavioral responses. While our results cannot be used to make clear inferences about the effect of the WPP on habitat use, it highlights the complexity of ecological system, influenced by multiple variables and intricate relationships. Our study underscores the need for a multifaceted approach in research, to address complex responses in reindeer and potential effects of infrastructure development. Future research must engage in early and transparent communication with reindeer herders and give them platforms to document their insights and experiences. The traditional and experience-based knowledge from the herders in our study provided crucial information needed to contextualize the GPS data. This enhanced our understanding of the reindeer habitat use and the impact of the WPP construction on both the reindeer and the herding practices.

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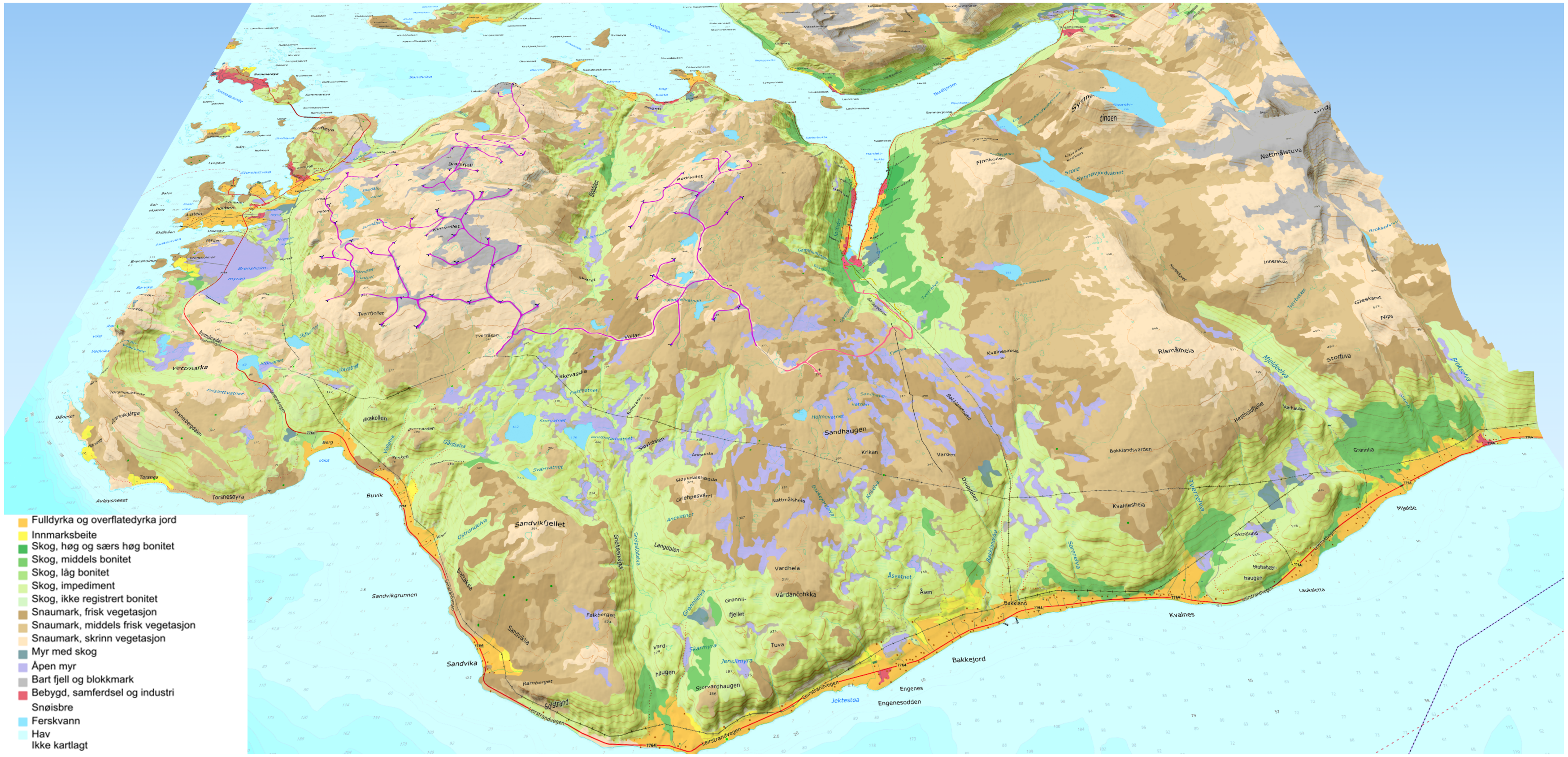
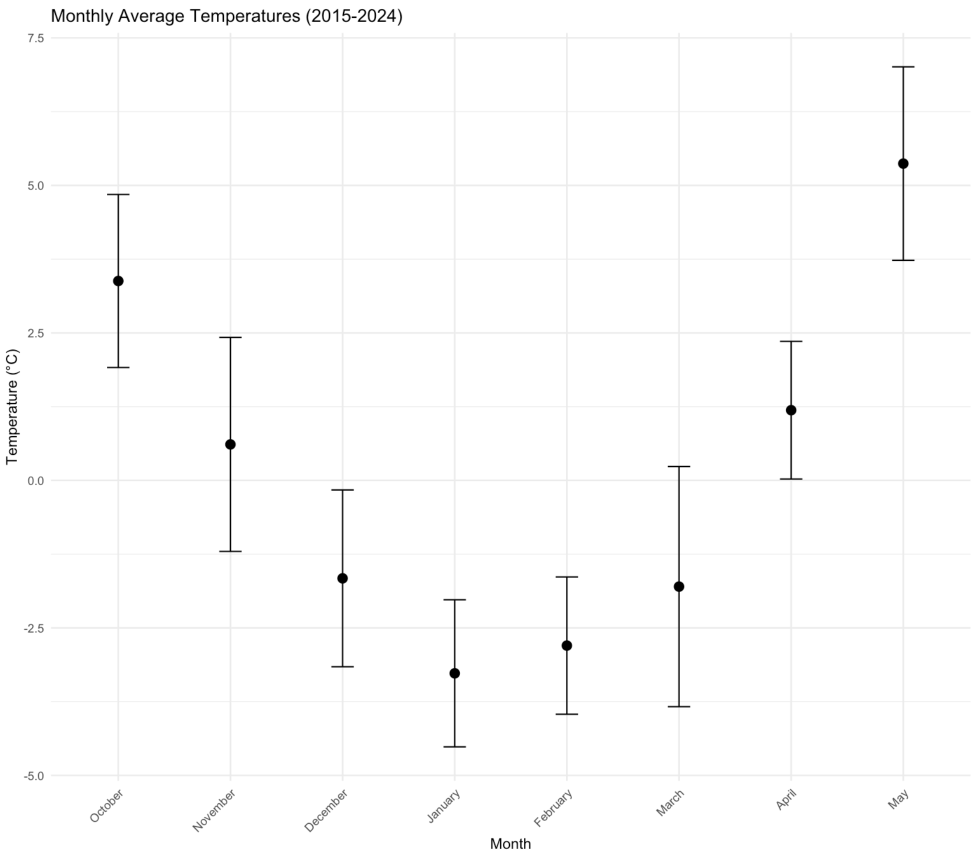
Appendix A: Vegetation map



Appendix A: Vegetation map of the southern part of Kvaløya in Tromsø. Obtained with permission from Diress Tsegaye Alemu.

Appendix B: Temperature data



Appendix B: Monthly average temperatures for October-May for 2015-2024. The data illustrates the seasonal variation, with lower temperatures during winter months (December, January) and higher temperatures in spring (April, May). The confidence intervals also indicate the uncertainty or variability in the temperature estimates for each month. The temperature data is collected from Meteorologisk institutt

Appendix C: Individual count and GPS count

Appendix C: Summary of GPS collared individuals and number of GPS counts for each year in each season.

Season	Year	Individuals	GPScount
Early winter	2015/16	15	244
	2016/17	18	945
	2017/18	NA	NA
	2018/19	25	1324
	2019/20	57	5378
	2020/21	26	2533
	2021/22	61	6616
	2022/23	24	2039
	2023/24	60	12290
	Sub total	286	31369
Late winter	2016	18	1265
	2017	17	330
	2018	31	1074
	2019	24	437
	2020	35	1661
	2021	26	1321
	2022	5	190
	2023	19	956
	2024	72	8038

	Sub total	247	15272
Spring	2016	18	1408
	2017	17	986
	2018	31	2614
	2019	49	1388
	2020	33	3027
	2021	11	711
	2022	33	895
	2023	18	1632
	2024	54	5147
	Sub total	264	17808
Summer	2016	17	1335
	2017	17	1593
	2018	30	4370
	2019	44	12223
	2020	43	3319
	2021	71	17731
	2022	44	2726
	2023	63	11470
	2024	NA	NA
	Sub total	329	54767

Appendix D: Proportion test R-script

proportion test

```
library(RVAideMemoire)
```

```
*** Package RVAideMemoire v 0.9-83-7 ***
```

```
library(chisquare)
library(chisq.posthoc.test)

##-------------------------- WINDMARK Observed vs expected values

# Ewinter 2015 Observed values and expected values for the individual counts
observed_Ewinter_2015 <-57
expected_Ewinter_2015 <-40

# Chi-square test for "Ewinter_2015"
(chi_square_Ewinter_2015 <- chisq.test(c(observed_Ewinter_2015, expected_Ewinter_2015)))
```

```

	Chi-squared test for given probabilities

data:  c(observed_Ewinter_2015, expected_Ewinter_2015)
X-squared = 2.9794, df = 1, p-value = 0.08433
```

```
#Now, let's interpret the results:
# Chi-square test statistic and p-value
(statistic_Ewinter_2015 <- chi_square_Ewinter_2015$statistic)
```

```
X-squared
 2.979381
```

```
(p_value_Ewinter_2015 <- chi_square_Ewinter_2015$p.value)
```

```
[1] 0.0843315
```

```
# Interpretation Ewinter 2015
if (p_value_Ewinter_2015 < 0.05) {
  cat("There is a significant difference between observed and expected frequencies for 'bare'.\n")
} else {
  cat("There is no significant difference between observed and expected frequencies for 'bare'.\n")
}
```

```
There is no significant difference between observed and expected frequencies for 'bare'.
```

```
# Observed proportion
(observed_prop_Ewinter_2015 <- observed_Ewinter_2015 / sum(c(observed_Ewinter_2015, expected_Ewinter_2015)))
```

```
[1] 0.5876289
```

```
#0.2159091 is the proportion value

# Confidence interval for the observed proportion
(conf_interval_Ewinter_2015 <- prop.test(observed_Ewinter_2015, sum(c(observed_Ewinter_2015, expected_Ewinter_2015)),
  conf.level = 0.95)$conf.int)
```

```
[1] 0.4830295 0.6852076
attr(,"conf.level")
[1] 0.95
```

Appendix D: R-script from the conducted proportion test.

Appendix E: BBMM packages

Library ("adehabitatLT") (Calenge *et al.*, 2023)

Library(“BBMM”)(Nielson *et al.*, 2013)

Library (“Lattice”) (Sarkar, 2008)

Library (“raster”) (Hijmans, 2024)

Library ("splines") (R Core Team, 2024)

Library (“survival”) (Therneau & Grambsch, 2000)

Library (“terra”) (Hijmans, 2024)

Appendix F: Selection ratio table

Appendix E: Compassion of the GPS locations within 0-1 km and 1-5 km distance intervals from the wind power plants in the study area using availablity design (Manly et al., 2002).The size of the area was used to calculate the expected number relative to the observed.

Season	Year	0-1 km			1-5 km		
		Observed GPS locations	Selection ratio	95% CI	Observed GPS locations	Selection ratio	95% CI
Early winter	2015/16	44	0.403 (-)	(0.355, 0.452)	200	1.482 (+)	(1.434, 1.531)
	2016/17	510	1.453 (+)	(1.420, 1.487)	275	0.634 (-)	(0.600, 0.667)
	2018/19	620	1.665 (+)	(1.635, 1.695)	213	0.462 (-)	(0.433, 0.492)
	2019/20	2176	0.965 (±)	(0.951, 0.979)	2869	1.028 (±)	(1.015, 1.042)
	2020/21	1594	1.505 (+)	(1.486, 1.523)	776	0.592 (-)	(0.573, 0.611)

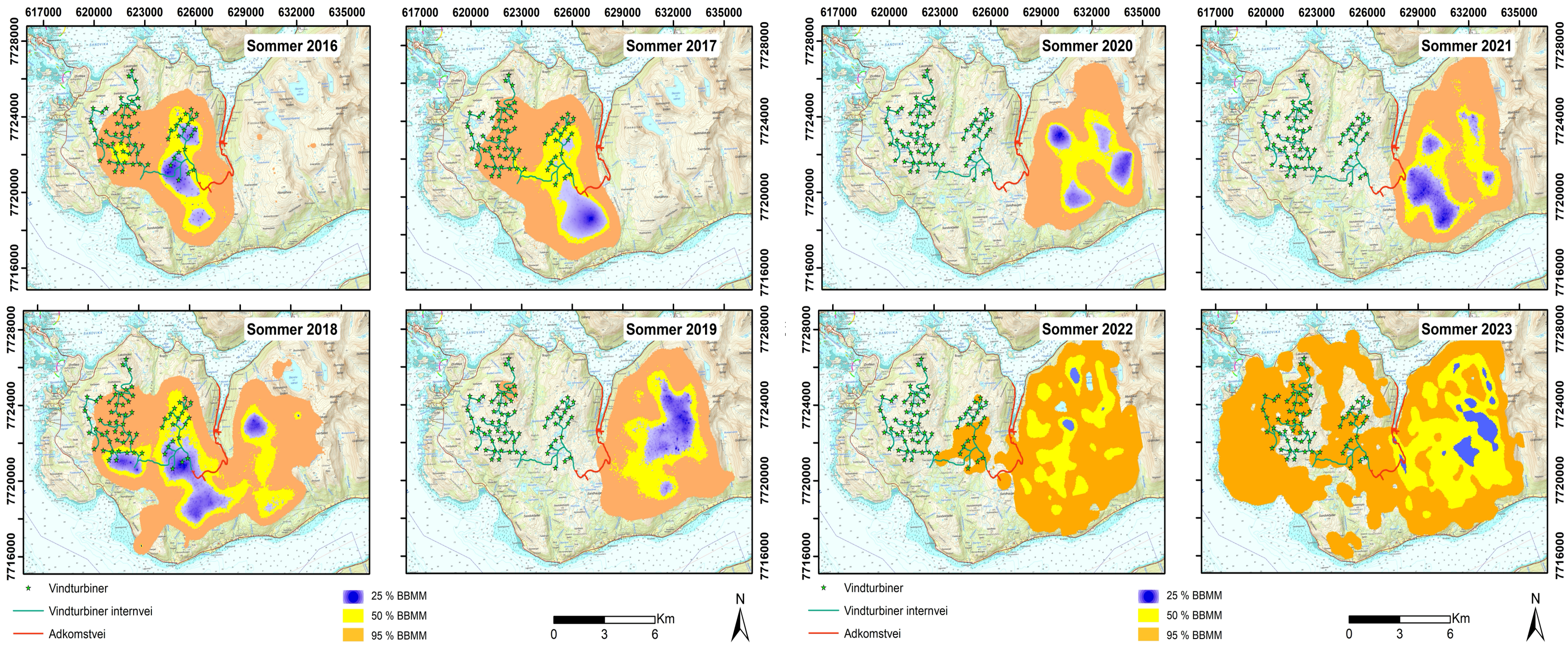
	2021/22	4442	1.549 (+)	(1.538, 1.561)	1971	0.556 (-)	(0.545, 0.567)
	2022/23	1237	1.359 (+)	(1.338, 1.380)	799	0.710 (-)	(0.688, 0.731)
	2023/2024	2822	0.515 (-)	(0.507, 0.522)	9442	1.392 (+)	(1.385, 1.400)
Late winter	2016	166	0.315 (-)	(0.295, 0.335)	1014	1.554 (+)	(1.534, 1.574)
	2017	14	0.100 (-)	(0.077, 0.123)	300	1.728 (+)	(1.705, 1.751)
	2018	111	0.234 (-)	(0.215, 0.252)	951	1.619 (+)	(1.601, 1.638)
	2019	65	0.341 (-)	(0.306, 0.375)	362	1.533 (+)	(1.499, 1.567)

	2020	190	0.260 (-)	(0.245, 0.276)	1442	1.598 (+)	(1.582, 1.613)
	2021	373	0.633 (-)	(0.608, 0.657)	946	1.297 (+)	(1.273, 1.321)
	2022	88	1.036 (±)	(0.965, 1.107)	102	0.971 (±)	(0.900, 1.042)
	2023	101	0.236 (-)	(0.217, 0.256)	855	1.617 (+)	(1.598, 1.637)
	2024	1598	0.457 (-)	(0.448, 0.466)	6229	1.439 (+)	(1.430, 1.448)
Spring	2016	666	1.080 (±)	(1.053, 1.106)	714	0.936 (±)	(0.909, 0.962)
	2017	519	1.177 (+)	(1.146, 1.209)	467	0.857 (-)	(0.825, 0.888)

2018	1804	1.544 (+)	(1.527, 1.562)	809	0.560 (-)	(0.542, 0.578)
2019	320	0.673 (-)	(0.646, 0.701)	743	1.264 (+)	(1.236, 1.292)
2020	1708	1.441 (+)	(1.423, 1,459)	944	0.644 (-)	(0.625, 0.662)
2021	304	1.009 (±)	(0.971, 1.047)	370	0.993 (±)	(0.955, 1.030)
2022	175	0.749 (-)	(0.708, 0.789)	348	1.203 (+)	(1.163, 1.244)
2023	749	1.406 (+)	(1.378, 1.433)	443	0.672 (-)	(0.645, 0.700)
2024	2381	1.431 (+)	(1.416, 1.447)	1340	0.651 (-)	(0.636, 0.667)

Selection ratio of 1 indicates that reindeer use the distance interval in proportion to its availability, meaning there is no preference or avoidance. A ***selection ratio greater than 1*** *indicates positive selection for that distance interval, with reindeer using this distance more than expected based on the available area; higher values suggest a stronger preference. A* ***Selection Ratio less than 1*** *indicates avoidance of that distance interval, with reindeer using this distance less than expected based on the available area; lower values indicate stronger avoidance.*

Appendix G: BBMM summer



Appendix F: Yearly seasonal home ranges (BBMM) for Summer. The map shows the study area, including wind turbines, internal roads and access roads. The colored areas represents the home range at different utilization distribution levels: 25% (purple) indicates the core area used by reindeer, 50% (yellow) represent a broader area with a high probability of use, and 95% (orange) showing the general movement pattern, including locations with a high probability of use. The maps display results from early winter 2016 through early winter 2023.