

Effects of mining on reindeer habitat use and reindeer herding in Sodankylä, northern Finland

Alfred Colpaert

alfred.colpaert@uef.fi

University of Eastern Finland

Jouko Kumpula

Natural Resources Institute Finland

Augustine-Moses Gaavwase Gbagir

University of Eastern Finland

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Abstract

Reindeer herding in Finland is a traditional livelihood adapted to the northern Boreal and tundra environments. As reindeer roam freely, the activity depends on extensive pasture areas that are increasingly under pressure from competing land uses. The Central Lapland Greenstone Belt contains significant mineral resources, resulting in intensive mining exploration and development. The Kevitsa nickel–copper mine, established in 2012 within the Oraniemi reindeer herding district, has created substantial local impacts on reindeer pasture availability and herding practices.

This study examines how the Kevitsa mine affects reindeer habitat use and herding operations. Using GNSS collar data from 113 female reindeer collected between 2015 and 2020, combined with environmental and topographic datasets, resource selection functions (RSFs) were developed to quantify avoidance behaviour. Separate analyses were conducted for summer (May–July) and autumn (September–December). The optimal distance-decay parameters indicate significant avoidance during summer, with reduced pasture use extending up to approximately 1.8–1.9 km from the mine fence. Autumn avoidance was substantially weaker, limited to about 1.0 km, likely reflecting reduced sensitivity of female reindeer and calves and the attraction of high-quality autumn forage.

Overall, the mine eliminates about 15 km² of pastures within its fenced area and creates seasonal zones of reduced use around its perimeter. While these impacts cause significant local disruptions—such as blocked migration routes and the loss of a traditional corral—the broader Oraniemi district has maintained stable herd numbers. This is largely due to modern management practices, including supplementary winter feeding, which have largely decoupled herd size from natural pasture limitations. The findings highlight how mining infrastructure alters reindeer habitat use in a seasonally dependent manner while also demonstrating the adaptive capacity of contemporary Finnish reindeer herding.

Introduction

Reindeer herding has evolved over the centuries to become a unique economic and cultural trait of the European high north. It is well adapted to utilize the harsh environment of the Boreal Taiga and tundra. The Finnish reindeer (*Rangifer tarandus tarandus*) is a semi-domesticated form of the mountain reindeer. Although many adaptations have been made to optimize the herding system, reindeer still roam freely on northern pastures for most of the year. Finnish reindeer herding is regulated by the Finnish Reindeer Herding Law, which defines the reindeer herding area, the rights and obligations of the reindeer herders, and the way they organize in cooperative units. The reindeer herding area is divided into 54 herding districts, or co-operatives (Finnish: *palliskunta*). Herding co-operatives are district units which are responsible for organizing herding work and maintaining necessary reindeer infrastructure, like fences, huts and roundup corrals. Annually reindeer are gathered and rounded up into corrals, in summer for calf marking and in autumn to select animals for slaughter. The districts are also responsible for enforcing the maximum number of reindeer, which is set by the Ministry of Agriculture and Forestry. Reindeer are

privately owned, but graze freely on all public and private areas (except agricultural fields). All necessary labour is done collectively.

The area of a herding district is fixed, borders are often defined by natural barriers like rivers or lakes, and fences in other places. Therefore, all possible pasture areas are needed to maintain an economically viable herd. However, not all land within a district is pastureland, roads, built-up areas and other infrastructure reduce pastures, also forestry is often creating restraints on the usability of the area. It is therefore important to understand that high-quality pasture is in limited supply. This of course leads often to conflicts of interest between reindeer herding and competing forms of land-use, for example, wind power projects, power lines, tourism, forestry and resource extraction.

The Central Lapland Greenstone Belt (CLGB) runs through central Lapland, about 200 km long (N-S) and 100 km wide E-W). The geology of the CLBG is extremely complex, showing signs of rifting and volcanism. It is characterized by the occurrence of many economically important ores, like gold, nickel, copper etc. This has resulted in intensive mineral exploration and mine development. Presently there is one functioning multi-ore mining operation (Kevitsa) in the Sodankylä commune, one dormant gold mine, and several mining projects in the process of Environmental Impact Assessment (EIA). Continuous exploration to locate additional ore deposits is also affecting pasture use. Mining sites need large areas for operation, ore extraction, processing and storage of waste-rock and sand, often in the order of ten to 20 square kilometres. It is evident that this creates problems for reindeer herders as a significant portion of the pasture area needs to be fenced off and cannot be utilized for many years, usually the lifetime of a mine is 20 to 40 years. Also, reindeer migration routes are blocked, causing the reindeer to change their yearly movement pattern, which in turn affects reindeer management and necessitating the relocation of herding infrastructure.

The Kevitsa mine

The Sodankylä Kevitsa nickel-copper ore mine was opened in 2012 by the Canadian First Quantum Minerals Ltd. The mine was sold in 2016 to the Swedish firm Boliden. The open pit mine is in continuous operation, copper and nickel concentrate is transported by truck to the harbours of Oulu and Kemi to be processed in the Boliden smelting plants in Harjavalta and Rönnskär. The mine is one of Finland's largest and is an important regional employer (516 employees in 2024) and a source of tax revenues. In 2024, the mine produced 9 849 000 tons of ore concentrate. The mining area is fenced in to prevent reindeer from entering, the total fenced area is 1465 hectares (14.65 km²) (Figs. 1 & 2).

The effects of infrastructure (windfarms, linear structures, mines) on mammals have been widely documented. Generally, herbivores are reported to avoid habitats close to infrastructure. This has been shown for both wild and semi-domesticated reindeer. Avoidance is a behavioural response triggered by visual, auditory, or scent-based cues from humans or human-made structures, whether perceived directly or through learned associations with infrastructure (Tyler et al. 2021).

The effect is typically described as a zone of influence, defined as the distance from infrastructure at which the effect on habitat selection diminishes to background levels (Boulanger et al. 2021). The extent of the zone of influence varies considerably between herds, seasons, and years, reflecting the interplay between habitat quality, forage availability, and the perceived level of disturbance (Vistnes & Nellemann 2008).

There are studies from mining activities in Norway and Canada (Eftestøl et al. 2019, Weir et al. 2007), where reindeer and caribou showed clear avoidance behaviour, but there are no detailed studies of the effects of mining operations on the behaviour of reindeer from Finland. Kumpula et al. (2007) and Anttonen et al. (2011) studied the effects of infrastructure on reindeer in Finland and reported disturbance distances of 2500 metres for population centres and 1500 metres for buildings and roads, no effects of forest roads were found. Reindeer pasture use and seasonal migration are well documented (Cavedon et al. 2022, Panchenko et al. 2024). The impact of infrastructure on migration and pasture use has been studied in Sweden, Norway and Canada (Cronwall 2026; Kite et al. 2024; Skarin & Åhman, 2014; Tyler et al. 2021; Vistnes et al. 2004; Vistnes & Nellemann, 2008). The effects of habituation on avoidance have been discussed for example by Reimers (2010).

The main research question of the study is how the Kevitsa mine affects reindeer pasture use. More specifically, the extent and seasonality of avoidance of a mining site by reindeer avoidance of the mining area. The second question is how reindeer herding has adapted to the mining operations.

Study area

The study area is the Oraniemi reindeer herding district which lies predominantly in the community of Sodankylä. The Oraniemi district has a gross surface area of 3 893 km². The maximum number of reindeer allowed is 6000, and the number of reindeer owners is 123 (2025). About 70% of the area is owned by the state, and 30% by private and other landowners. Our study focusses on the area around the Kevitsa mine.

The topography of the area is smooth, with numerous pine bogs and mires, most of the forest is in use for commercial logging. Agriculture is limited and focuses mainly on the production of hay for supplementary feeding of reindeer during winter. Several large bogs and mires are protected by the Natura 2000 network. The area has no tourist areas of importance.

The study area is about 100 kilometres above the Arctic Circle, south of the Sámi homeland area, inside the area specifically designated for reindeer herding (Fig. 3). The specifically for reindeer herding designated area is defined in the reindeer herding law and provides protection against competing land use. The climate is sub-Arctic, characterized by a short relatively warm summer and a long cold winter.

Methods and Materials

We have reindeer collar tracking information covering the entire Oraniemi district. The data consists of material collected by several projects and has been homogenized into one dataset covering the years 2015–2020. The reindeer tracking collars were obtained from Tracker Oy and deployed to reindeer by herders during the round-up periods. The collars were fitted to female reindeer, as these are the most valuable and the most susceptible to disturbances. The GNSS positions (Global Navigations Satellite System) were collected one per 24 hours and transferred by the GSM network to a server. It was assumed that the GSM-network coverage is complete for the whole research area. The total amount of collars varied from year to year, and it is assumed the collars were not fitted to the same animals. In total, the dataset contained 71,687 observations, from 113 collars (Fig. 3). We estimated from literature that the effects of the Kevitsa mine would not exceed 15 kilometres (Anttonen et al. 2011, Skarin 2014, Eftestøl, 2019). Therefore, we tested two buffers around the fence of the mine, 10 and 15 kilometres. We found little difference between results and used the 15-kilometre buffer for the analysis. As the years 2015, 2016 and 2017 had a limited number of observations these were excluded from further analysis. The fence around the mine was obtained from the topographic database from the National Land Survey of Finland (2020).

We used the reindeer pasture classification of the Finnish Natural Resources institute (Luke) (2018 data), the Corine dataset from 2022 of the National Environmental institute (SYKE), with a resolution of 25 metres., as well as digital elevation data (2 metre resolution DEM, slope and aspect) from the National Land Survey of Finland. All these data are in raster format. We also calculated the distance to the mine fence, (25 m raster), from which a distance decay value was calculated using Eq. 1. The distance raster used in the calculations was generated using the R raster package.

$$\text{decay} = \exp(-\text{dist} / \text{dd}) [1]$$

where dist is the Euclidean distance from distance grid cell to the fence around mine and dd is a set decay distance.

Methods

After Boyce et al. (2002) we developed resource selection functions (RSF) using satellite positioning collars and spatial habitat data. Specifically, we employed a logistic regression-based ‘used’ versus ‘available’ study design to estimate resource selection patterns at the habitat-level, e.g. the third-order selection (Johnson 1980). We used the R statistical software for all computations (R version 4.5.1, R Core Team 2025), and the terra (Hijmans et al. 2026) and raster (Hijmans 2025) geographical analysis packages. For modelling the behaviour of reindeer, we used adehabitatHR (Calenge 2024) software and generalized linear modelling (GLM) and linear mixed-effects model lme4 package (Bates et al. 2015).

Preliminary analyses revealed that there was a significant difference in behaviour between summer and autumn. Summer was defined as the calving period, (May, June and July), and autumn the period of pre-winter foraging (September, October, November. and December). Winter (January, February and March) was excluded from the analyses because reindeer are actively herded and supplementary fed in areas

distant from the mine. (Fig. 5). We tested different sets of GLM and mixed models, mixed models used year or animal id as random effect.

The 15 kilometres autumn buffer had 4269 observations and the summer buffer 3153 observations (years 2018, 2019 and 2020).

To model the avoidance behaviour of reindeer we use the distance to the mine fence expressed as a distance decay function, the same approach has been used by for example Skarin et al. (2015) and Eftestøl et al. (2019).

The optimal decay distance was tested using a plot of the AIC value (Akaike Information Criterion). Using a GLM function with a constant set of predictors, where the only changing parameter is the decay distance value. The decay value was divided into 20 steps varying between 10 to 200 metres for the autumn season, and 100 to 2000 metres for the summer season. These two separate seasons were defined by preliminary exploration of the data. We used a random selection of available reindeer locations of twice the number of used locations. Determining the optimal decay function value is dependent upon the set of random points for priming the model, we ran 20 iterations of the same setup, producing the best two values for calculating the distance decay function for autumn and summer.

In the next stage we tested various sets of explanatory variables for the final model. The analysis was performed separately for summer and autumn, the model was evaluated for the seasonal habitat using the 95% polygon of the Kernel Density Estimate raster. For the final model we used the variables giving the best model performance (Table 1).

Results

Distance decay value

To get the optimal decay distance, that is, the model with the lowest AIC value we used a fixed set of variables, with only the decay distance being changed. The GLM model used for this analysis is (R language notation):

```
Gmodel <- glm(Used ~ Forest + bogs + Water + d1 + scale(DEM) + scale(Slope) + scale(Aspect), data = rsf, family = "binomial")
```

where d1 is the decay distance for model n, we used 20 different values to fit the AIC curve to obtain the best decay distance.

The minimum AIC distance for the 15 kilometres buffer was 500 metres for the summer months, and for the autumn period 20 metres.

We tested two GLM models (10- and 15-kilometre buffer) and six mixed models, with random variables year, animal ID and year and ID, for both 10- and 15-kilometre buffers. Using the same parameters, DEM,

aspect, slope, forest, bogs and water there were only marginal difference in the results between the 10- and 15-kilometre buffers. There were also no substantial differences difference between the GLM and mixed-model approach. For the final analysis we decided to use the 15-kilometre buffer, and the general linear model (GLM). The models were run separately for summer (May, June and July) and autumn (September, October, November and December). The summer period had 2689 relocations and the autumn period 2831.

The final model used was (R language notation):

Table 1
Variables used in the GLM model, variable names as used in model.

Topographic variables	Environmental variables
DEM: Digital elevation in metres	decay: Decay distance calculated using equation [1]
Slope: Slope calculated from DEM, degree	Forest: Forest area from Corine database
Aspect: Aspect calculated from DEM, degree	Water: Water areas from Corine database
	bogs: Pine bogs and mires from the LUKE pasture classification

Table 2
Output of summer GLM model

Predictors	Estimate	Std. Error	z value	Pr(> z)	Significance
(Intercept)	-0.05363	0.06496	-0.826	0.409	
decay	-7.16191	1.31236	-5.457	4.84e-08	***
scale (Slope)	-0.27826	0.03401	-8.182	2.79e-16	***
scale (Aspect)	0.24656	0.02153	11.452	< 2e-16	***
scale (DEM)	0.13646	0.02492	5.476	4.35e-08	***
Forest	0.01264	0.05703	0.222	0.825	
Water	-2.70904	0.37794	-7.168	7.62e-13	***
bogs	0.36747	0.05551	6.620	3.60e-11	***
Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1					

Table 3
Output for autumn GLM model

Predictors	Estimate	Std. Error	z value	Pr(> z)	Significance
(Intercept)	0.09115	0.07377	1.236	0.217	
decay	-3.92080	0.52498	-7.469	8.11e-14	***
scale (Slope)	0.13769	0.02822	4.879	1.06e-06	***
scale (Aspect)	0.12037	0.02096	5.743	9.32e-09	***
scale (DEM)	-0.30079	0.02405	-12.505	2e-16	***
Forest	0.55645	0.07079	7.861	3.82e-15	***
Water	-3.64094	0.36017	-10.109	2e-16	***
bogs	-1.07180	0.05461	-19.628	2e-16	***
Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1					

Several approaches can be used to evaluate the performance of generalized linear models. In this study, we used classification accuracy and McFadden's pseudo-R². (MacFadden 1974).

For comparison we ran the same GLM model with a randomly generated set of coordinates for 100 random animals. We used the outcome as reference for our results. The result of the random test was a value 0.5090677, indicating a true random binomial distribution. The MapFadden Pseudo R² value was 0.000701104, indicates that the model has virtually no explanatory power.

Summer GLM model

Although all independent variables are significant, the intercept is only significant for the summer model (Table 2). The distance decay variable has a significant negative estimate, indicating reindeer effectively avoid the mining area. The sign of DEM is positive in the summer model, as reindeer use the higher areas for refuge against insect harassment. The Slope variable has a negative sign for the summer model, indicating reindeer avoiding steep slopes, e.g. favouring pine bogs and mires, or flat hill tops which are by virtue near horizontal. The Aspect variable probably has only marginal explanatory value. The Forest variable has no significance in the summer model, e.g. it has no special status in habitat choice. The bog variable scores significantly as it is one of the major habitats favoured by reindeer in early summer, as these are excellent pastures. A GLM model without the topographic variables showed similar trends, but the accuracy was slightly less than the model with both topographic and environmental variables (58%).

For the summer season the GLM model gives a goodness of fit of 0.6061986 (61%). The Pseudo R² of the summer GLM model has a value of 0.05358081, indicating a lower level, but still significant performance of the model. MacFadden suggested values of 0.2–0.4 for excellent model performance.

Autumn GLM model

All the independent variables in the autumn GLM model are significant (Table 3). However, the distance decay estimate is less steep than in summer. The elevation (DEM) is slightly negative, indicating higher areas are not important during autumn. Forest has a clear positive attraction as here most of the autumn forage is situated (grasses, herbs and mushrooms). Bogs and mires are clearly avoided, as these have no forage value during autumn.

The autumn period gives a value of 0.6578852 for the GLM fit (66%). The MacFadden Pseudo R² of the autumn GLM model is 0.1049821, which indicates the model has fair predictive power. The model without topographical variables scores only marginally lower, indicating that the topographic variables have little explanatory value.

By plotting the models against the distance to the fence of the mine we observe a clear avoidance behaviour during the summer, Fig. 4 shows a distance of 1898 metres, this being the distance where the mine no longer affects the pasture use of reindeer. Closer to the mine the avoidance behaviour gets increasingly stronger. This fits well with the known fact that female reindeer with calves tend to favour quiet and secluded areas to protect their offspring. On the other hand, this behaviour is much less evident during the autumn, in this time, although calves still follow their mother, the reaction to mining operations is reduced and attraction of the good autumn pastures around the Kevitsa mine outweighs the disturbance factor. Figure 4 shows clearly that the avoidance is limited, pasture use probability reduced only to 0.4, and avoidance distance of 1139 metres. This indicates a limited negative effect of mining related disturbance in autumn. This is confirmed by field observations of reindeer foraging near the fence of the mine in September 2023. The Kevitsa area was previously an important autumn grazing pasture, and one abandoned reindeer corral is just north of the mine fence, this corral has been unusable after the mine started in 2012 but still is a clear reminder of the importance of this area for reindeer herding.

Discussion

We analysed reindeer behaviour related to the Kevitsa mine in a 15-kilometre zone around the site. Reindeer did avoid the mining site during the early summer. The avoidance reaction was less evident during the autumn season, and reindeer continued to use the area to some extent the area up to the fence around the mine. This seasonal behaviour was modelled using two RSF-functions (Fig. 6). The models agree with our knowledge of reindeer pasture use, they are attracted to bogs and mires in the early and mid-summer as these provide good grazing of soft green vegetation. Forest is less favoured during summer. Pine bogs and mires area negatively correlated with autumn habitat selection, indicating a shift of pasture use towards forest for foraging on herbs and mushrooms to fatten up before winter.

Our results show a distinct difference between the summer and autumn avoidance. The summer zone of influence, with diminished usage is noticeable up to 1900 metres from the fence around the mining area. The autumn avoidance behaviour is less pronounced, with a zone of influence with a moderate reduction

of pasture use is 1150 metres (Fig. 4). The 1900 metres zone of influence (from fence) during summer fits very well with observations from Norway (Eftestøl et al. 2019), which reported a zone of influence of 1500 metres. Weir et al. (2007) reported a reduction of caribou within a four-kilometre buffer from the centre of the mine. In our case the zone of influence extended about two kilometres from the fence. This summer avoidance is explained by the fact that female reindeer favour secluded areas for calving and nursing their calves. The observation of limited avoidance during the autumn period can be explained by the fact that calves need less protection, and reindeer are attracted to the good autumn pastures close to the mine fence.

The impact of the Kevitsa mine is first of all the loss of nearly 15 square kilometres of pasture within the fenced area. The avoidance reaction of reindeer has introduced an extra zone of approximately 1900 metres during summer and 1150 metres during autumn. The avoidance behaviour within the 1900-meter zone is not an exact area, grazing within the zone will occur, but decreases in intensity towards the fence. During autumn the 1150 metres zone is much less well defined, and the avoidance effect is weaker. Besides the actual mine, also the access road to the mine affects reindeer herding. The local landscape has changed drastically since 2012, what was once a predominantly a wilderness herding district had to adapt to a new situation, which has caused changes in reindeer migration routes and herding management (Fig. 1). One nearby roundup corral had to be abandoned, as it became impossible to try to move reindeer to this area and use this corral for roundups.

On the scale of the entire Oraniemi herding district the situation has been less severe. The area covered by the mine and the surrounding disturbance area covers about one percent of the total area of the herding area. From statistics since the 1960 the mine had no visible effects on the number of reindeer, or the amounts of reindeer slaughtered. This is because reindeer numbers have become less dependent on natural winter pastures, grazing conditions and weather events than earlier. The present number of reindeer can be supported by offering supplementary forage (mostly hay) to reindeer during the critical winter season (Fig- 7).

However, some repeated hard winters for reindeer during recent years have also shown that difficult weather and grazing conditions can still considerably affect the number of reindeer and productivity of herds as well as profitability of reindeer herding livelihood (Pekkarinen et al. 2022; Kumpula et al. 2024). Also, increasing losses of reindeer to predation, although not directly related to mining, have a negative effect on reindeer herding (Pekkarinen et al. 2020; Rasmus et al. 2020). However, we can still conclude that present management practices (calf slaughter, parasite treatment, mechanisation and supplementary feeding) have allowed the Oraniemi herding district to adapt relatively well to the ongoing changes in the present reindeer herding environment.

Reindeer management in the Oraniemi district has been able to adapt and adjust to the situation caused by the creation of the Kevitsa mine. On the other hand, it is clear that on the local level the Kevitsa mine has caused and still causes considerable disturbances and changes for pasture areas and their use to those herders who have historically used the Kevitsa area and surrounding pastures. This disturbance

process in the herding environment and the resulting changes in the herding system have evidently also increased both the costs and workload in reindeer herding (Pekkarinen et al. 2015).

Declarations

Conflict of Interest

The authors declare no competing interests.

Ethics, Consent to Participate, and Consent to Publish declarations

not applicable.

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Author Contribution

AC: Conceptualization, study design, methodology, GIS analysis, writing original draft.

JK: interpretation of results, writing and review. AG: Statistical analysis, graphics, review and editing.

All authors reviewed the final text.

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Data Availability

GNSS collar data are not publicly available due to ownership restrictions but are available from the corresponding author upon reasonable request.

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Figures

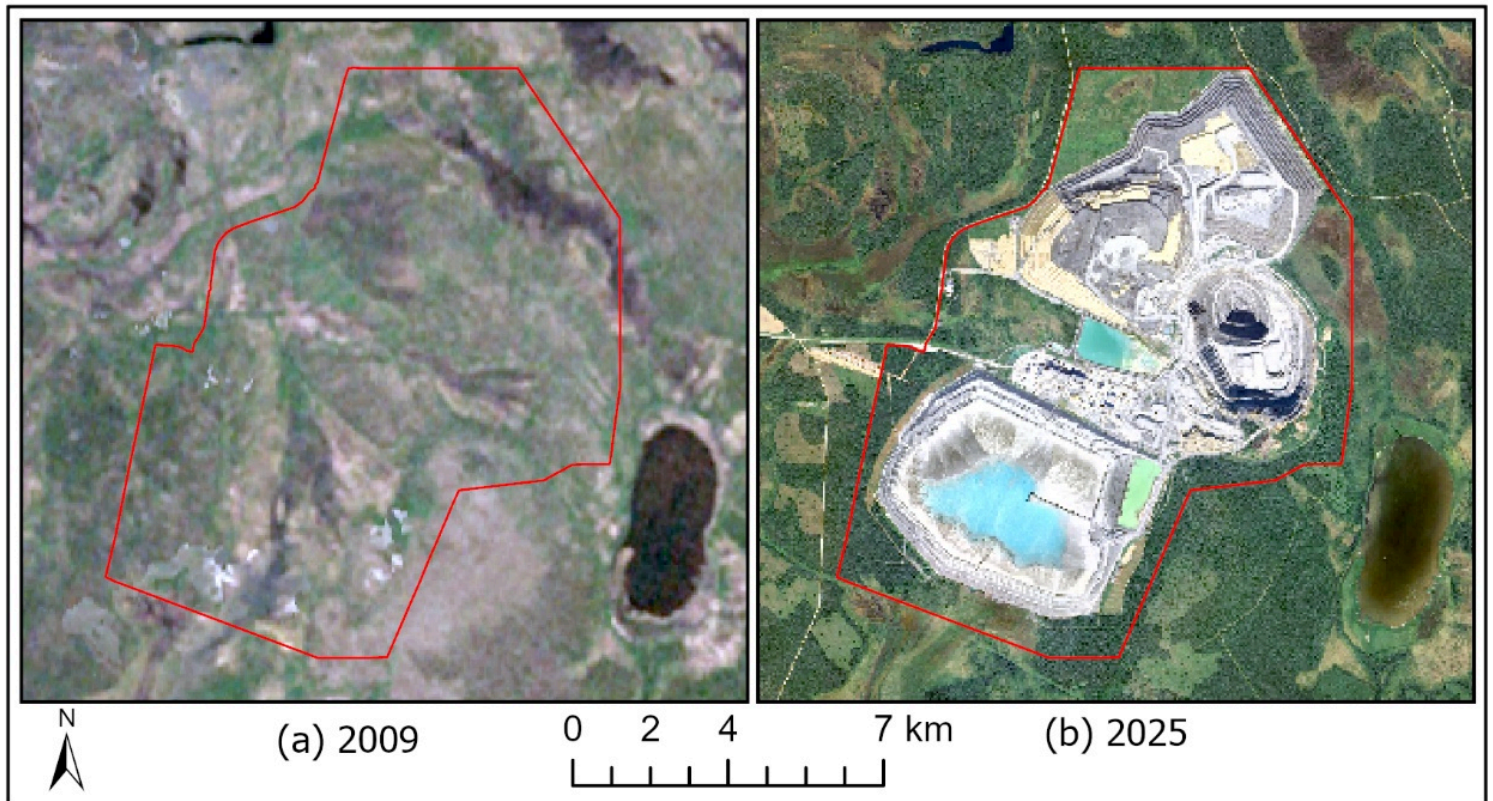


Figure 1

The Kevitsa site before and after the establishment of the mine (Images: Google Earth 2026)).



Figure 2

Aerial image of The Kevitsa mine, and waste rock tailings, photo: Alfred Colpaert 15/9/2023.

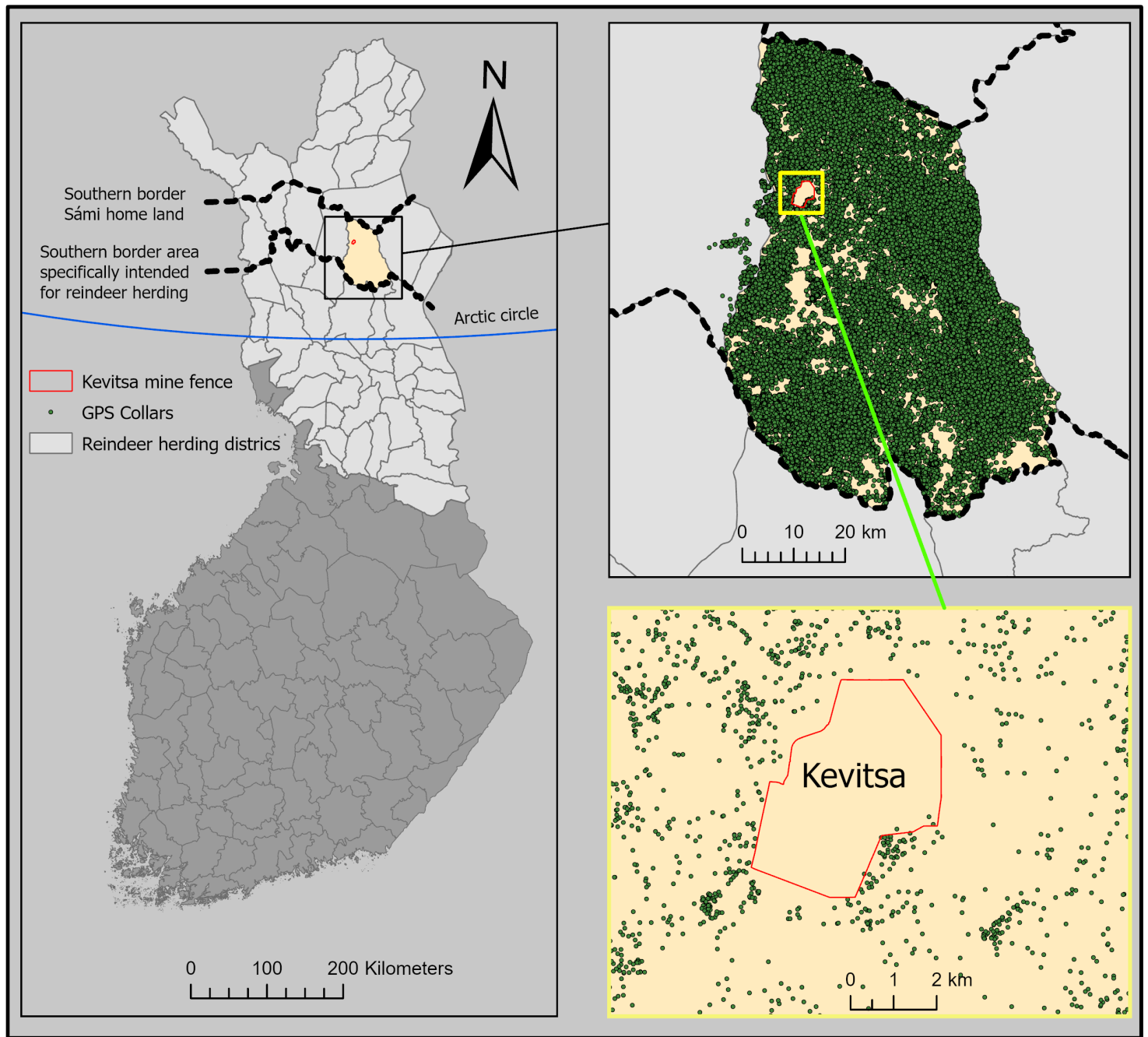


Figure 3

The Kevitsa mine, situated in the Oraniemi reindeer herding district, the dots around the Kevitsa mine are from the years 2018 – 2020, (data: Finnish National Land Survey 2026, Finnish Environment Institute (SYKE)).

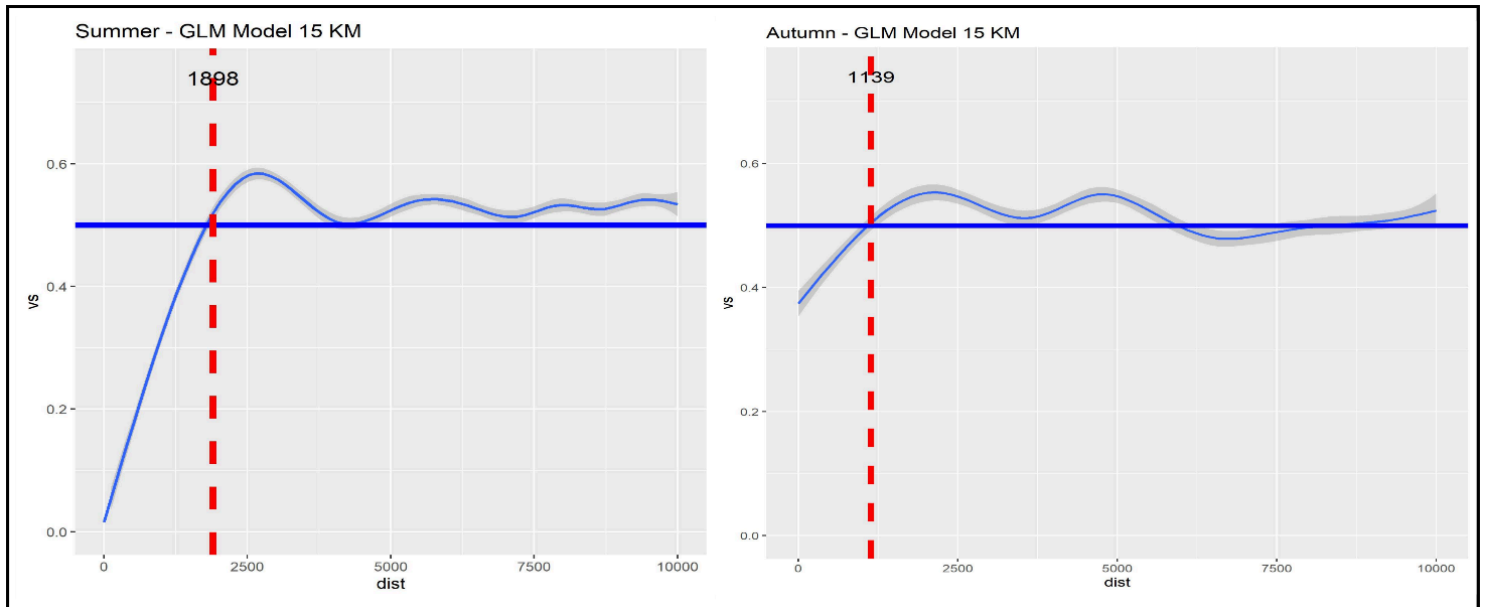


Figure 4

Predicted response of reindeer during summer and autumn season. Red dashed line shows the crossing of the 0.5-probability line, indicating the distance where the mining operations cease to affect reindeer behaviour. Note that for the autumn season the effect on reindeer is limited. X-axis is distance from fence around mine, Y-axis is probability of habitat use, 0.5 indicating normal use.

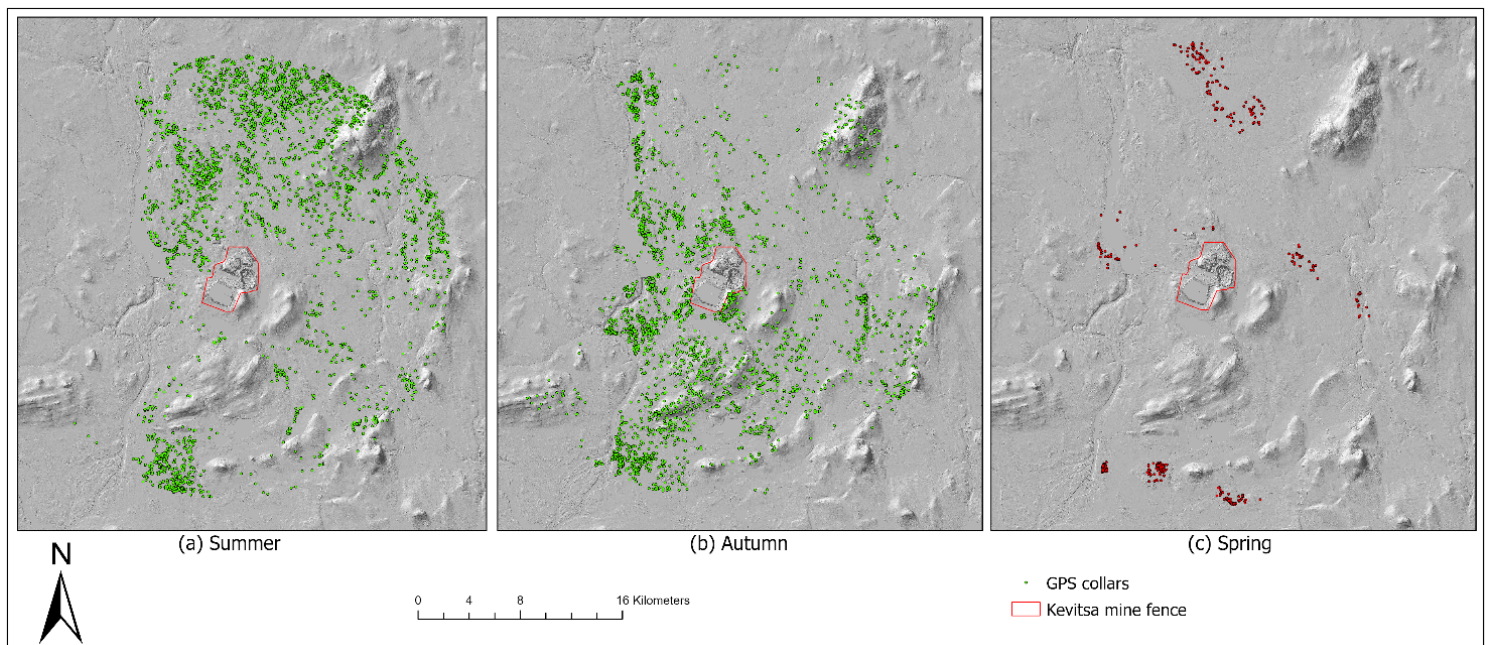


Figure 5

Hillshade elevation model and GNSS-collar locations for summer (a), autumn period (b) and winter (c), 15-kilometre zone.

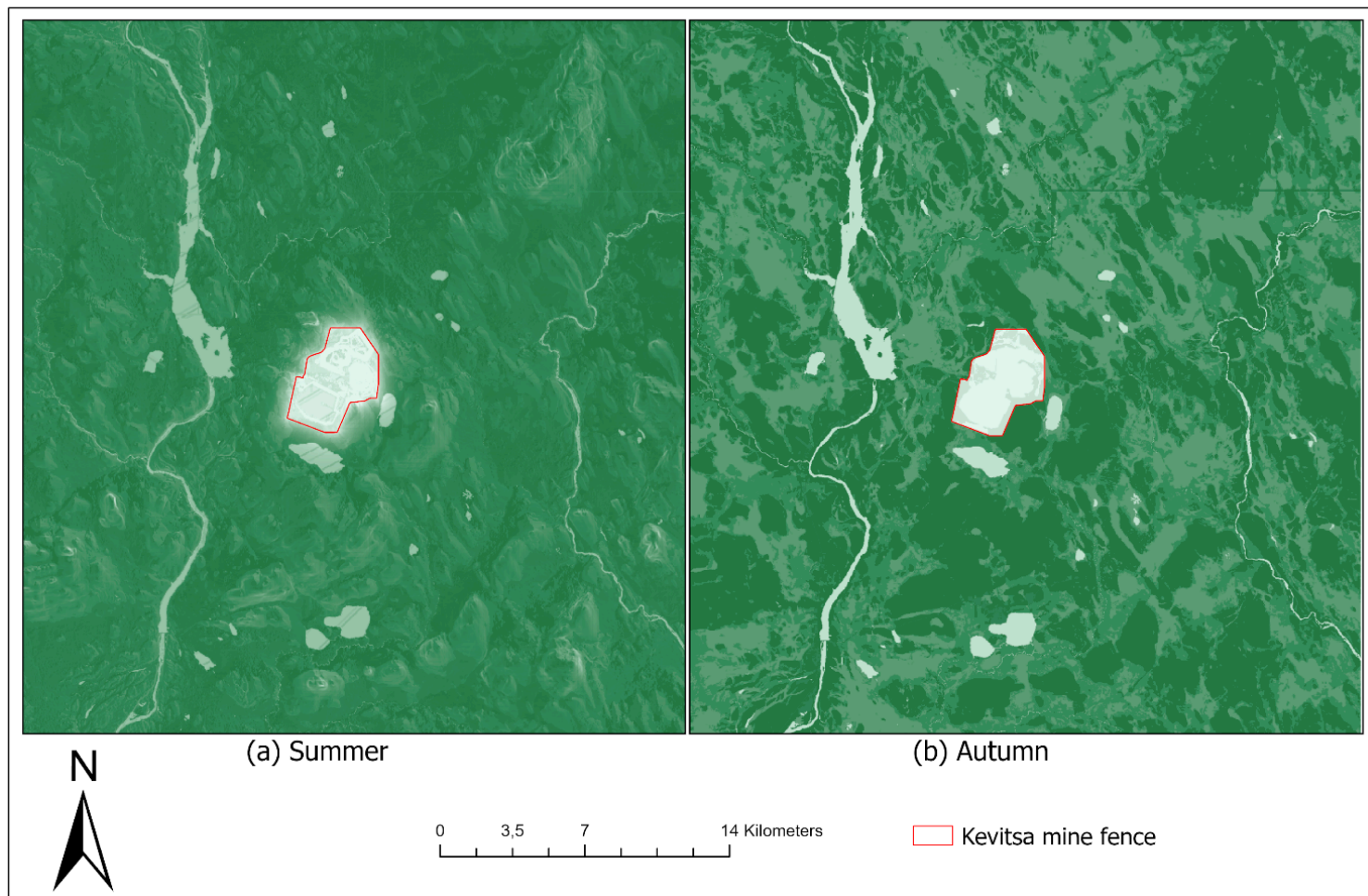


Figure 6

Predicted RSF models (Resource Section Function) summer and autumn, note the limited effect during autumn.

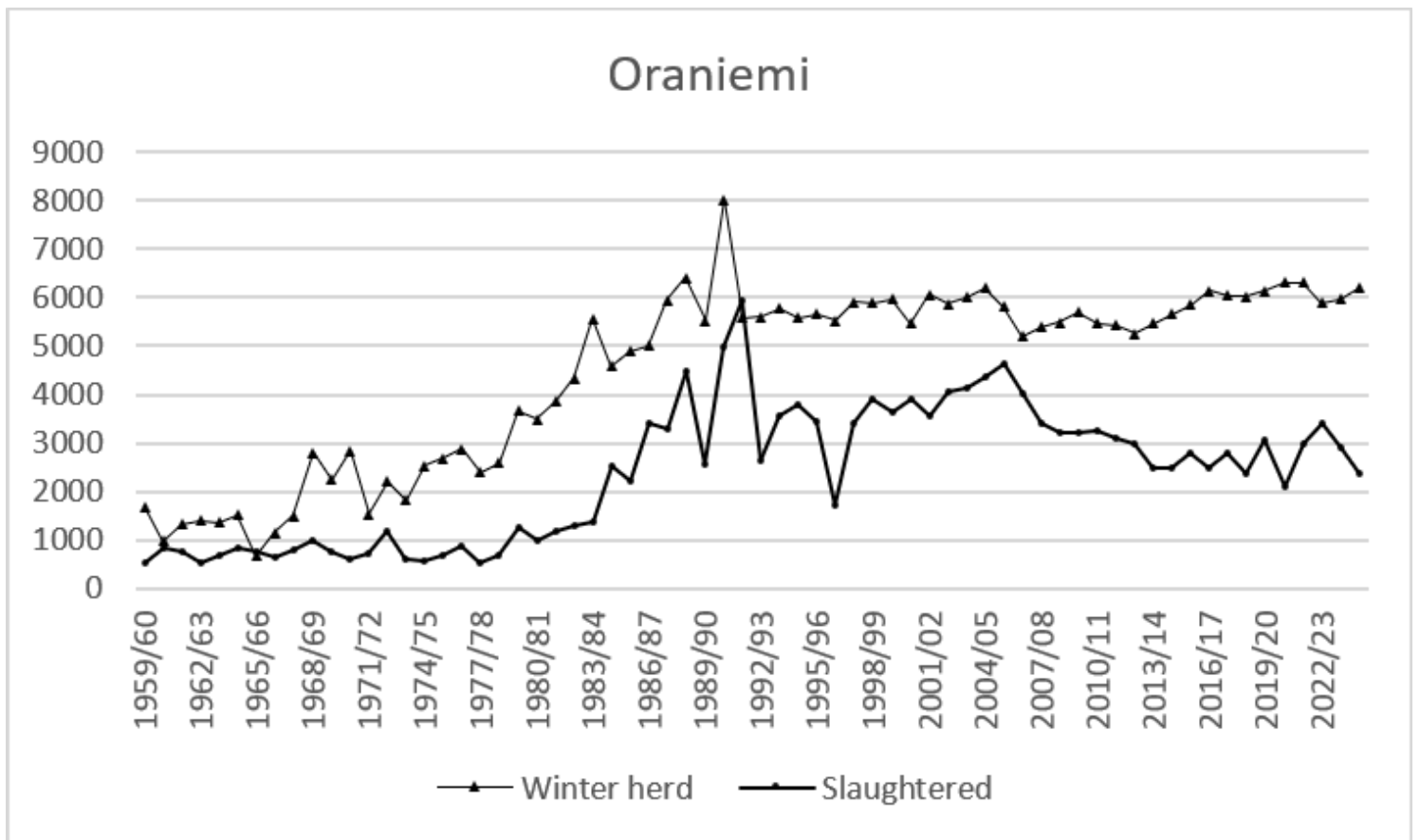


Figure 7

Development of the Oraniemi reindeer herd 1960 – 2025. Note the increase in herd between 1960 and 1990, afterwards the winter herd has been stable by adjusting the number of animals slaughtered. (Data: Poromies 1960-2025)