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PRACTICE INSIGHTS

The efficacy of wildlife fences for keeping reindeer outside a chronic wasting disease risk area

Atle Mysterud[1,2] | Lars Rød-Eriksen[2] | Aniko Hildebrand[2] | Roger Meås[2] | Aron Freyr Gudmundsson[3] | Christer M. Rolandsen[2]

[1]Centre for Ecological and Evolutionary Synthesis (CEES), Department of Biosciences, University of Oslo, Oslo, Norway

[2]Department of terrestrial ecology, Norwegian Institute for Nature Research (NINA), Trondheim, Norway

[3]Aurland Fjellstyre, Aurland, Norway

Correspondence
Atle Mysterud, Centre for Ecological and Evolutionary Synthesis (CEES), Department of Biosciences, University of Oslo, P.O. Box 1066 Blindern, NO-0316 Oslo, Norway.
Email: atle.mysterud@ibv.uio.no

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Abstract

1. Emerging wildlife diseases often comes with negative cultural and economic impact. Limiting disease spread is a recurrent goal and challenge, but the efficacy of various mitigation measures is rarely assessed.
2. Chronic wasting disease (CWD) is a lethal disease among cervids that was discovered among alpine reindeer (*Rangifer tarandus*) in the Nordfjella mountain range of Norway in 2016. After de-population, the entire range was fallowed to avoid re-emergence from environmental pathogen reservoirs. This involved installing perimeter fences in the alpine areas in order to keep reindeer from adjacent populations outside of the CWD risk area, while other cervids (red deer *Cervus elaphus*, roe deer *Capreolus capreolus* and moose *Alces alces*) were likely to enter through the forested areas.
3. We used camera trapping and surveillance reports to assess the efficacy of the perimeter fences. All four species of cervids were documented inside the CWD risk area. For reindeer, only 12.0% of observations were inside the CWD risk area, while this was 28.7% for the other cervids. The higher proportion of observations outside of the fenced area indicate that fences provided a barrier and lowered the number of crossings also of red deer, roe deer and moose.
4. Fences do not provide complete barriers, and we discuss practical solutions for how to avoid 'intruders' entering a given area, such as maintenance at critical points (e.g. river and road crossings) and height of fences (e.g. species variation in jumping; deep snow) to uphold their desired effect.
5. We argue that two fence lines with a buffer zone would be required when re-introduction of reindeer are planned in the CWD risk area after fallowing, similar to what has been suggested for other wildlife diseases.

1 | INTRODUCTION

Notifiable emerging wildlife diseases come with negative welfare, cultural and economic consequences to humans, and how to limit transmission, spread and spillover is a recurrent challenge (Delahay et al., 2009). Mitigation efforts used to combat wildlife diseases are often based on general knowledge found in 'veterinary text books' with evidence originating from management of livestock diseases. A more evidence-based management of wildlife diseases was recently highlighted as an important goal by a broad group of experts (Vicente et al., 2019). African swine fever (ASF) in wild boar (*Sus scrofa*) and chronic wasting disease (CWD) in reindeer (*Rangifer tarandus*) have recently emerged and are spreading geographically in Europe. In both cases, perimeter fencing to limit spread has been implemented in several countries of Europe (Mysterud & Rolandsen, 2019). Yet, there is limited evidence of the efficacy of perimeter fencing to limit movements of wildlife host species in a disease containment context (European Food Safety Authority (EFSA) et al., 2018).

CWD is a lethal prion disease among cervids. CWD was first described in Colorado, USA, in the 1960s (Spraker et al., 1997), and it has since spread and been detected in 30 states of USA and four provinces of Canada. CWD causes deer population declines in endemic areas (DeVivo et al., 2017; Edmunds et al., 2016). The first detection of CWD in Europe was among wild reindeer in 2016 in Norway (Benestad et al., 2016). It was regarded as a major new issue for biodiversity and conservation globally (Sutherland et al., 2018), and with risk assessments being performed in both Norway (Hansen et al., 2017) and EU (EFSA Panel on Biological Hazard (BIOHAZ) et al., 2018). The whole reindeer range with more than 2000 individuals was de-populated in an attempt to eradicate the disease (Mysterud & Rolandsen, 2018). The causative agent of CWD are prions that are persistent in the environment for years (Zabel & Ortega, 2017). Therefore, to lower the risk of re-emergence from environmental reservoirs, the aim was to fallow the CWD risk area by keeping it free of reindeer in years following the de-population. Perimeter fencing was therefore erected in the alpine part of the area, that is, areas above the treeline, typically traversed by reindeer (Mysterud & Rolandsen, 2019). Other cervid species might enter from the forested areas, as it was considered impossible to fence such a vast area. Hence, rather than installing fences in these areas, moose (*Alces alces*) and red deer (*Cervus elaphus*) were targeted for population reduction to limit their presence in the region (Solberg et al., 2019).

We here report on the efficacy of the perimeter fencing for keeping wild and semi-domestic reindeer, as well as other cervids (red deer, roe deer *Capreolus capreolus*, and moose), out of the CWD risk area (Figure 1). We assessed the extent to which the area was kept free of cervids by mounting 30 wildlife cameras along the fence lines and by inspecting the surveillance logs of the Norwegian Nature Inspectorate, the Norwegian Food Safety Authority, and semi-domestic reindeer herders.

2 | MATERIAL AND METHODS

2.1 | Study area

The study area is the Nordfjella mountain range in Norway (Figure 1). CWD was detected in Nordfjella management zone 1. This area is bordered in the southwest by the road FV50 towards Nordfjella management zone 2 with a wild reindeer population of ~500 animals, and in the northeast by the road RV52 towards the Filefjell range with a semi-domestic reindeer population numbering 3000 animals.

In the forested areas to the west of this mountain range, there are dense populations of red deer and occasional visits of moose. In the forested and inland areas towards the east, there is sizeable populations of moose. There is red deer also in this eastern part, but at much lower densities than in the west. With detection of CWD in 2016, a region consisting of 15 municipalities was defined as the Nordfjella region. The aim was initially (in 2017) to reduce population densities of moose and red deer to 50% relative to 2016 levels, but the aim changed (in 2019) to have densities below 1 individual per km^2 in the Nordfjella region. Higher hunting quotas, less specific hunting quotas (allowing higher female harvest), extended hunting seasons, and helicopter support to lift carcasses out of remote areas was implemented to increase harvest efficacy. The impression is that aims have for the most part been reached in the eastern areas dominated by moose, while the reductions in population densities of red deer in the western areas have only been moderate (Solberg et al., 2019). There are low abundances of roe deer in the eastern areas, but no plans for a similar population reduction as for moose and red deer.

2.2 | The fences

The fences were raised by management with the purpose to limit movement of reindeer into Nordfjella zone 1. Reindeer in Norway are considered to be alpine, and alpine areas are by definition those above the tree line. Data from GPS-collared reindeer in Nordfjella zone 1 prior to de-population showed they used 99.4% of their time in areas above the forest (unpubl. data). In contrast, roe deer, red deer and moose mainly use forested areas, and the fences were not intended to limit their access into zone 1. If restricted to the alpine areas, there are only two ways to enter the Nordfjella zone 1, either from southwest or northeast. Historical data and local knowledge also identify these two areas as immigration routes of reindeer into zone 1. Therefore, the perimeter fencing strategically targeted these two stretches (Figure 1(b)). The perimeter fencing consists of two separate stretches. (1) One stretch of 9.4 km was close to the road Hol-Aurland (FV50) towards the neighbouring wild reindeer range in the southwest (Nordfjella zone 2). The fence covers most of the alpine habitat, and the ends of the fence were in very steep terrain considered not possible to cross even for reindeer (Figure 1(c)). This fence was erected summer

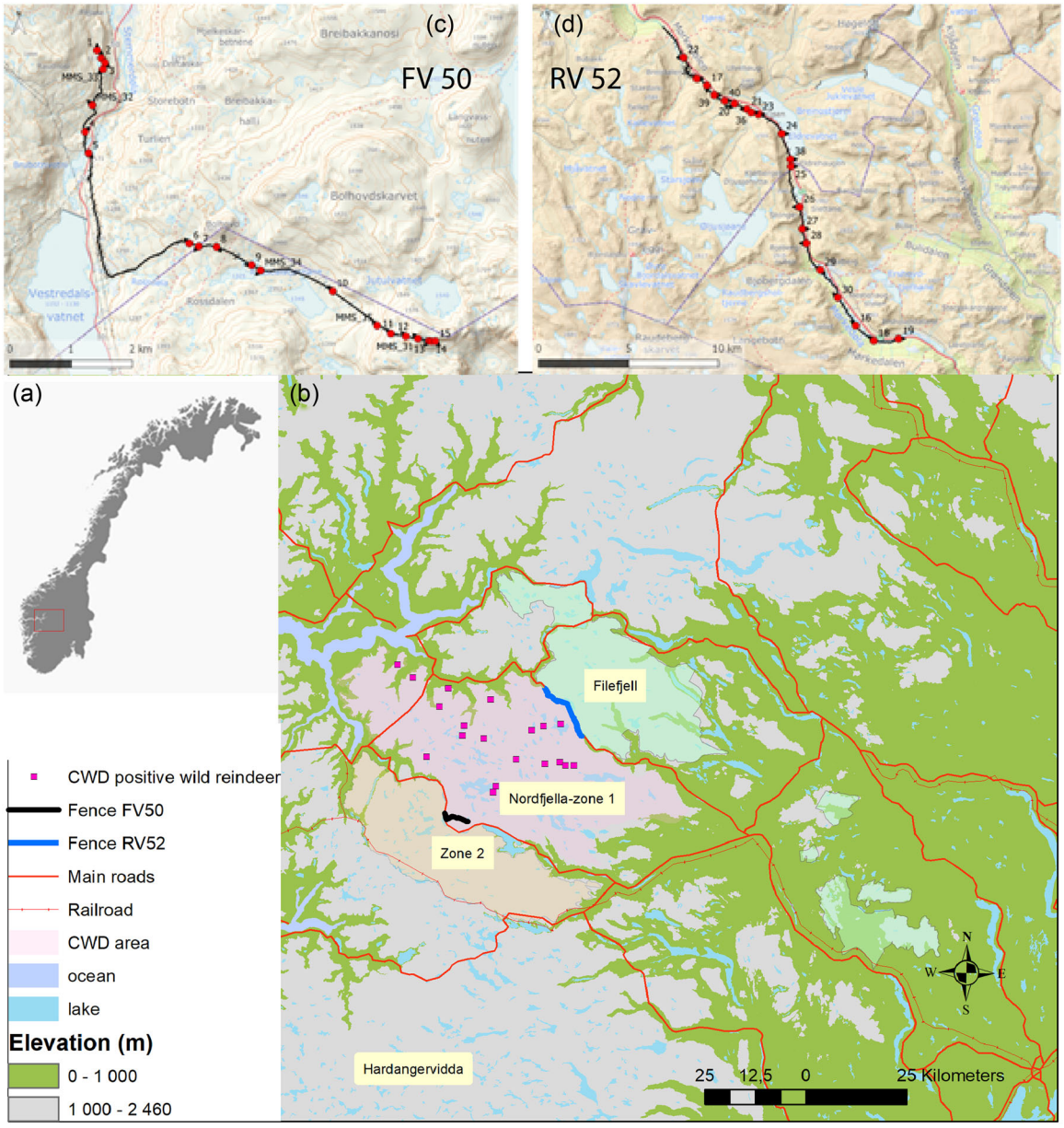

FIGURE 1 (a) The study area is situated in the southern part of Norway. (b) An overview of the CWD risk area in Nordfjella zone 1 with the position of the perimeter fences in the high elevation, alpine habitat of reindeer. The perimeter fences (c) southwest of Nordfjella along road FV50 and northeast along road RV52 towards Filefjell. Red dots indicate the placement of cameras along the fence lines

of 2017 (by the Norwegian Environment Agency). (2) The other stretch of 25.2 km was close to the road Hemsedalsfjellet (RV52) and towards a semi-domestic reindeer population in the northeast (Filefjell). In summer and fall 2017, two stretches of fences in total 14.3 km were erected (by the Director for semi-domestic reindeer herding at 'Fylkesmannen' in Trøndelag county), but with a gap of 3.8 km towards a mountain considered not passable by reindeer. In fall 2018, this gap was also fenced, and the fence was extended eastwards another 7.1 km (by the Norwegian Food Safety Authority). The fence now covers the entire alpine area from one forested valley to another (Figure 1(d)). The fences were standard cordon-wire fences of approximately 1.6 m height, with effective height varying with terrain and topography, typically used in management of semi-domestic reindeer.

2.3 | Camera trapping data

We used 30 Reconyx HyperFire 2 (Reconyx, Inc., Wisconsin, USA) cameras that were operated 607 days on average (Table S1). In September 2018, eight cameras were mounted on the fence along FV50 in northern parts of the fence in Aurland municipality (Figure 1), including cameras 50 and 150 m from the fence end. In December 2018,

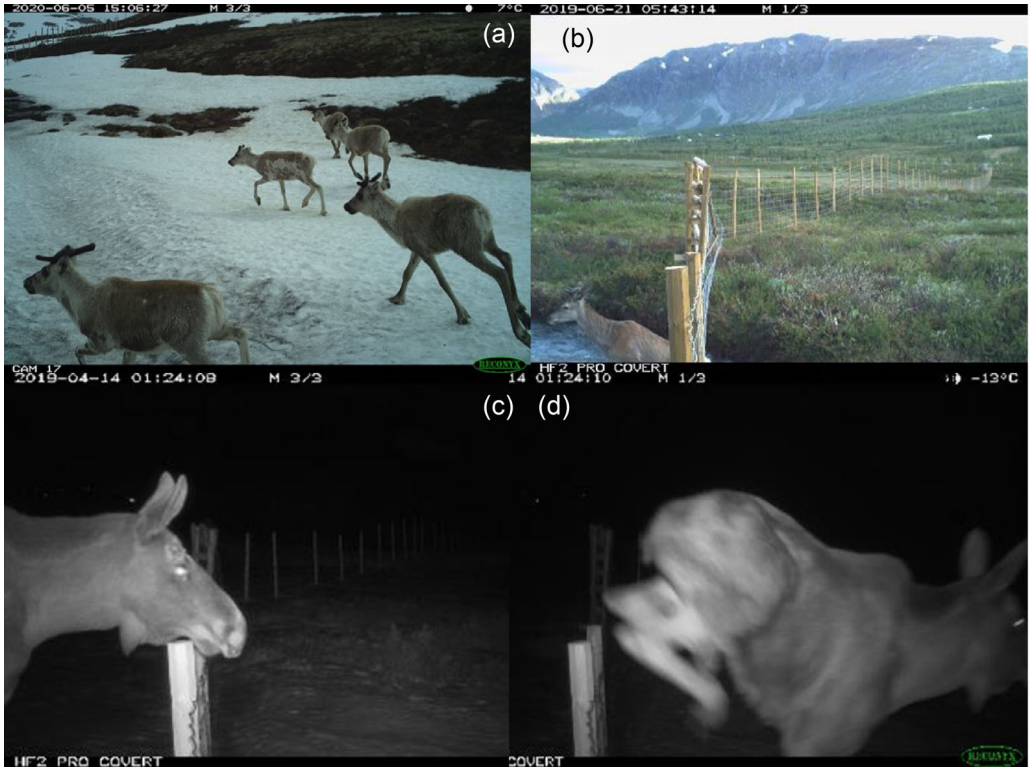

FIGURE 2 Camera traps documented (a) presence of semi-domestic reindeer inside the CWD risk area, (b) red deer crossing under the fence in a river, and (c–d) moose jumping over the fences

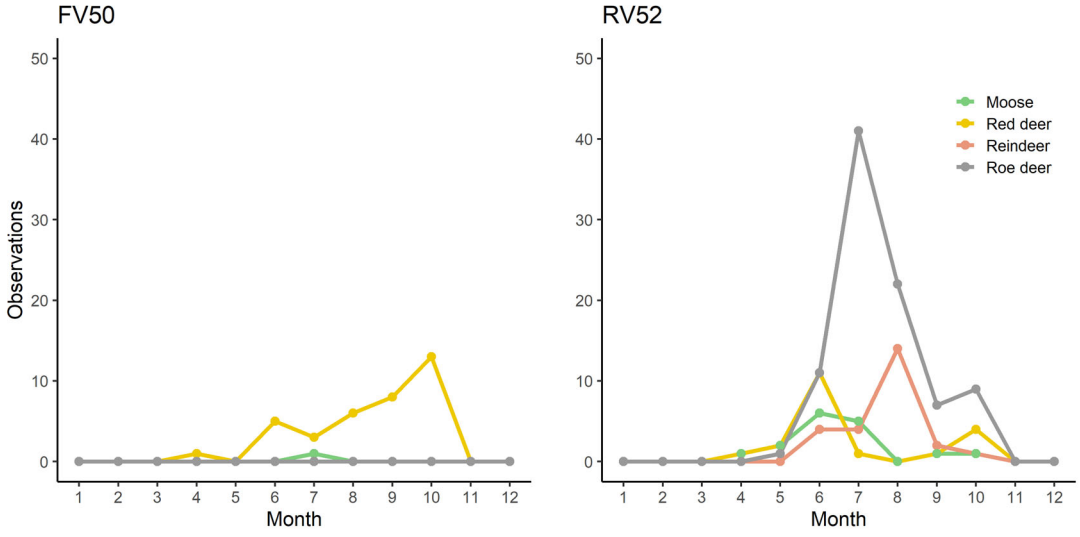

FIGURE 3 Observations of cervids was seasonal and mainly during the plant growing season. Observations of particular species differed in the northeast (RV52) and the southwest (FV50) reflecting the known species distribution in the region

seven cameras were mounted in the south-eastern part of the fence in Hol municipality. A total of 15 cameras were mounted along the RV52 January–March 2019. Placing the cameras along the fences were considered the most efficient way to monitor potential intrusions, as reindeer are alpine (see Section 2.2), and they will often follow the fence lines before finding a possible place to enter. The cameras were removed either June 2020 or January 2021. We did not consider the 52 observations of red foxes (*Vulpes vulpes*).

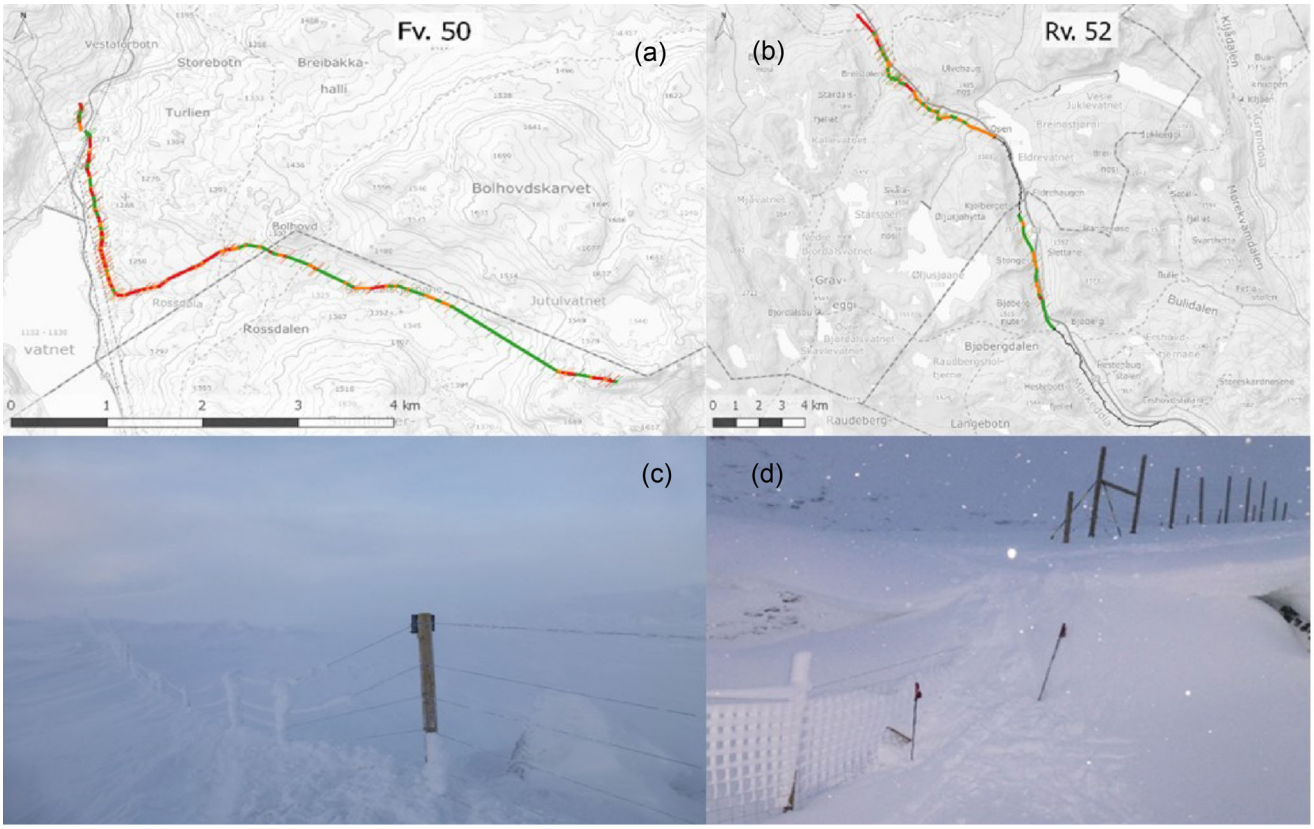

FIGURE 4 Snow conditions markedly affect the operability of the fences in this high alpine region of Nordfjella, Norway. The maps show the snow depth along the fences following (a) road FV50 and (b) road RV52 during winter of 2018. Red stretches: fence completely under snow. Orange: fence less than 1 m above snow. Green: operational fence with more than 1 m above snow. (c) Example of a camera trap placement. (d) Example of fence under snow. (Photo credit: Aron Freyr Gudmundsson)

2.4 | Surveillance and snow measurements

The fence lines were inspected with snow mobiles in late winter 2018 (April), and the amount of snow along segments of the fence was assessed. The division into segments was made sequentially based on whether the fence was, 1 = not visible, 2 = fence visible, but less than 1 m above the snow, and 3 = fence visible and over 1 m above the snow. Snow was measured along the entire fence along FV50, and along the two original sections (total of 14.3 km) for the fence along RV52. Note that these are snow measurements mentioned in another, more general paper about fencing (Mysterud & Rolandsen, 2019). We approached the Norwegian Nature Inspectorate, the Norwegian Food Safety Authority, and semi-domestic reindeer herders to get access to logs of events with reindeer moving into zone 1.

2.5 | Statistical analyses

We analysed variation in number of reindeer, red deer, moose and roe deer photographed by the cameras using the package glmmTMB (Brooks et al., 2017), in R version 4.0.3. We analysed data on a daily scale, using elevation (m above sea level), Julian date (continuous) and year (categorical) as our candidate covariates. Elevation and Julian date was standardized to facilitate model convergence. We considered also a squared term for Julian date, as observations appeared to first increase from winter to summer and then decline into autumn. The camera ID was used as a random intercept term. Due to low number of observations, we used zero inflation models, that is, a model separating the process of excess zero counts (Brooks et al., 2017). We used either binomial (moose, reindeer) or negative binomial models (roe deer, red deer) depending on frequency of multiple daily observations.

3 | RESULTS

The 30 camera traps yielded 11,814 camera-trap-days in the west (along FV50) and 6440 in the east (along RV52). For reindeer, only 12.0% of observations were inside the CWD risk area (Figure 2(a)), while this was 28.7% for the other cervids (Table 1). The higher proportion of observations outside of the fenced area indicate that fences lowered entrance also of red deer, roe deer and moose. In the west (along FV50, $n = 37$), red deer (97.3%) and moose (2.7%) was recorded, but no roe deer or reindeer. In the east (along RV52, $n = 152$), semi-domestic reindeer (16.4%), red deer (13.2%), roe deer (59.9%) and

TABLE 1 An overview of number of camera trap observations of cervids along fences west (FV50) and east (RV52) of Nordfjella zone 1. More observations were made outside than inside of the CWD risk area

Fence – side	Reindeer	Red deer	Roe deer	Moose
FV50 – inside	0	4	0	1
FV50 – outside	0	32	0	0
RV52 – inside	3	12	28	2
RV52 – outside	22	8	63	14
Number (%) inside	3 (12.0%)	16 (28.6%)	28 (30.8%)	3 (17.6%)

TABLE 2 Parameter estimates for the most parsimonious models for observations of cervids along fences surrounding Nordfjella zone 1, Norway. SE = standard error. Baseline for year is 2019

Parameter	Estimate	SE	*z*	*p*
Moose				
Intercept	−5.682	0.486	−11.697	<0.001
St(elevation)	−1.048	0.364	−2.880	0.004
St(Julian date)	2.077	0.824	2.519	0.012
St(Julian date)^2	−2.801	0.967	−2.895	0.004
Roe deer				
Intercept	−7.385	0.769	−9.606	<0.001
St(elevation)	−2.173	0.549	−3.956	<0.001
St(Julian date)	8.007	1.360	5.888	<0.001
St(Julian date)^2	−5.730	0.916	−6.259	<0.001
Year(2020)	1.752	0.613	2.860	0.004
Reindeer				
Intercept	−12.215	2.344	−5.211	<0.001
St(elevation)	−0.963	0.441	−2.184	0.029
St(Julian date)	21.060	6.203	3.395	0.001
St(Julian date)^2	−14.227	4.151	−3.428	0.001
Year(2020)	5.777	1.942	2.974	0.003
Red deer				
Intercept	−5.985	0.542	−11.042	<0.001
St(Julian date)	1.898	0.683	2.779	0.005
St(Julian date)^2	−2.800	0.760	−3.684	<0.001

moose (10.5%) were observed. Observations were made of a red deer crossing under the fence in a river (Figure 2(b)), and a moose jumping over the fence (Figures 2(c) and 2(d)).

Observations of all cervid species was limited to the plant growing season (Figure 3), and the most parsimonious models included a squared term for Julian date (Table S2). Number of observations declined with increasing elevation from 900 to 1150 m above sea level for roe deer, moose and semi-domestic reindeer along RV52, but not for red deer along FV50 (Table 2). There were more observations in 2020 compared with 2019 for roe deer and semi-domestic reindeer (Table 2).

Surveillance discovered repeated cases of 'intruding' semi-domestic reindeer herds of up to 100 individuals, but only two intrusions of wild reindeer (Table S3). A single female wild reindeer was shot inside the CWD risk area, and a herd of about 20 male wild reindeer entered the CWD risk area. Three GPS-marked individuals in the herd enabled early detection when they crossed the road into zone 1, and they were herded out before they reached the fence that was some distance from the road (Figure 1). The wildlife managers noted that fences at this time was partly out of function because of high snow depth. During winter of 2018, 35% of fences were less than 1 m above snow, and 34% was completely covered by snow (Figure 4).

4 | DISCUSSION

Management of wildlife diseases involve invasive actions and should strive towards being evidence-based (Vicente et al., 2019). Our study contributes with the first assessment of whether perimeter fencing of alpine habitat could keep a CWD risk area free of reindeer. We also document observations of other cervids, which could have entered from the forested areas without fences or crossed the fences. We documented multiple breaks from semi-domestic reindeer entering the CWD risk area (Figure 2(a)), but only 12.5% of observations were inside the CWD risk area. Seasonal presence of red deer, roe deer and moose along fences was also more common outside than inside (28.7%) the CWD risk area. Hence, fences are semi-permeable barriers to wildlife hosts, and they do not eliminate the risk of pathogen introduction or risk of re-emergence by 'intruders' as in our case. Rather, fences are likely to limit number of crossings, and placement, height and details of construction are key to their effectiveness.

There were only two cases of wild reindeer entering zone 1. In contrast, repeated cases of semi-domestic reindeer, mainly smaller herds, or single individuals, have been observed along the fence and inside the infected area (Table S3). They have typically entered at the fence ends, or through holes or weaknesses in the fence. The semi-domestic reindeer have either been herded out of the infected area or killed, except for a female and calf disappearing within zone 1.

CWD is a multi-host disease with the ability to infect different species of cervids (Robinson et al., 2012), which makes management challenging. Since fences was limited to the alpine habitats typically traversed by reindeer, it was not surprising to document presence of red deer, roe deer and moose in the CWD risk area. Their use of the CWD risk area was mainly restricted to the lower elevations in the subalpine range and mainly during summer months, which was expected due to seasonal migration to even lower elevations during winter (Mysterud et al., 2012; Rolandsen et al., 2017). The lower proportion of observations inside than outside of the CWD risk area indicate an effect of fences, but most forested areas do not have fences and likely more frequent visitation of the other cervid species. This suggests that the population reduction for moose and red deer being performed is contributing to lower risk of CWD spillover (Solberg et al., 2019).

5 | FUTURE DIRECTIONS

There are lessons to be learned from our study for the specific case of CWD in reindeer, but also more in general. Construction details of fences matters for efficacy. A recent example was the provisional electric fence along the German-Polish border that proved insufficient to stop entrance of ASF from Poland to Germany. In our case, red deer crossed under the fence in a river (Figure 2(b)). Points where fences cross roads and rivers are challenging, and the latter may require frequent maintenance. We also documented a moose that jumped over the fence (Figure 2(c)). A height of 160 cm is standard for semi-domestic reindeer, but not sufficient for other cervids, and a height of 240 cm is standard along roads in Norway. Higher fences may also partly solve the issue of deep snow during winter (Figure 4).

After a minimum of 5 years of fallowing of the CWD risk area, the plan is to re-introduce wild reindeer to the area. Identifying 'intruders' was possible in our case because the CWD risk area was free of reindeer. After re-introduction of new reindeer, it will not be possible to identify 'intruders', unless they are tagged as the semi-domestic ones. Fencing along the road may lead to a higher barrier effect. However, having an open 'buffer' zone between the road and fence line facilitate spotting of potential 'intruders'. If funding is sufficient, adding a double fence line may yield both a stronger barrier effect (fence 1 close to road) and also a 'buffer' zone (fence 2 away from road) where potential 'intruders' can be identified and removed. A similar buffer zone has been proposed along the two border fences in Poland and Germany in the case of ASF (Reuters staff, 2021). We hence strongly recommend that the authorities consider having empty buffer zones to detect potential 'intruders', and active surveillance will be required to make sure fences are in operation and 'intruders' can be removed when they appear in buffer zones. All intervention measures to reduce the risk of disease should be weighed against potential adverse effects (McInturff et al., 2020), such as risk of injuries and reduced connectivity also for non-target species.

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AUTHOR CONTRIBUTIONS

Christer Moe Rolandsen and Atle Mysterud conceived the study. Christer Moe Rolandsen was PI, applied and organized the study. Roger Meås and Aron Freyr Gudmundsson did the fieldwork. Aniko Hildebrand, Roger Meås, Lars Rød-Eriksen and Christer Moe Rolandsen organized the data. Atle Mysterud did the statistical analysis, Atle Mysterud made Figure 1, LRE made Figure 3, while Christer Moe Rolandsen and Lars Rød-Eriksen prepared GIS data. Atle Mysterud drafted the paper. All authors edited and approved the final version.

CONFLICT OF INTEREST

The authors have no conflict of interest to declare.

DATA AVAILABILITY STATEMENT

Data and code are available in Zenodo: https://doi.org/10.5281/zenodo.6906378 (Mysterud, 2022).

PEER REVIEW

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ORCID

Atle Mysterud https://orcid.org/0000-0001-8993-7382
Lars Rød-Eriksen https://orcid.org/0000-0003-0482-4384
Christer M. Rolandsen https://orcid.org/0000-0002-5628-0385

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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