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MONOGRAPH

A quality standard for conservation of wild reindeer

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Abstract

The ongoing biodiversity crisis requires policy tools to establish baselines and assess biodiversity status. Reindeer and caribou (*Rangifer tarandus*) are iconic ungulates in the Arctic and subarctic, but populations are declining. Although the species is considered vulnerable globally in the International Union for Conservation of Nature [IUCN] Red List, more detailed policy tools at the population level would allow for targeted conservation efforts nationally. We developed an environmental quality standard (or norm) for reindeer populations to evaluate their overall status and put complex variation and change into simple status categories (poor, medium, and good) based on sets of quantitative indicators for 1) population performance, genetic diversity, and health status; 2) available lichen resources; and 3) loss of seasonal habitat and connectivity. We implemented the environmental quality standard for 10 national and 14 smaller wild reindeer areas (populations) in Norway. Except for 1 area with good status, all others ranged from medium ($n = 11$) to poor quality ($n = 12$). More than half of the populations had medium ($n = 7$) or poor ($n = 6$) status for 1 or more population performance indicators, with negative trends in calf body mass and recruitment in several populations. High loss of genetic diversity gave poor status in 4 small and isolated populations, and 2 populations with chronic wasting disease scored poor on health status. The status of lichen resources was medium ($n = 20$) or good ($n = 3$), with 1 exception. However, lichen time series data were not available to evaluate temporal trends to assess overgrazing. Loss of connectivity (poor; $n = 7$) was more problematic than loss of seasonal habitat ($n = 3$). The poor availability of high-quality empirical data, particularly on population performance, has limited the ability to fully assess the conservation status of several small populations. The environmental quality standard provides an important step towards operationalizing management and aiding in securing the long-term conservation of wild reindeer. We discuss further improvements and the potential usefulness of this approach for other large mammals.

KEYWORDS
condition, conservation genetics, early warning, fragmentation, habitat loss, indicators, lichens, policy tools, population status, *Rangifer tarandus*

Une norme de qualité pour la conservation des rennes sauvages

La crise actuelle de la biodiversité nécessite des outils politiques permettant d'établir des données de référence et d'évaluer l'état de la biodiversité. Les rennes et les caribous (*Rangifer tarandus*) sont des ongulés emblématiques de l'Arctique et du subarctique, mais leurs populations sont en déclin. Bien que l'espèce soit considérée comme vulnérable à l'échelle mondiale dans la liste rouge de l'Union internationale pour la conservation de la nature [UICN], des outils politiques plus détaillés au niveau des populations permettraient de mener des efforts de conservation ciblés à l'échelle nationale. Nous avons élaboré une norme de qualité environnementale pour les populations de rennes afin d'évaluer leur état général et de classer les variations et les changements complexes en catégories simples (mauvais, moyen ou bon) sur la base d'un ensemble d'indicateurs quantitatifs portant sur 1) les performances de la population, la diversité génétique et l'état de santé; 2) les ressources en lichens disponibles; et 3) la perte d'habitat saisonnier et de connectivité. Nous avons appliqué la norme de qualité environnementale à 10 zones nationales et à 14 zones plus petites abritant des populations de rennes sauvages en Norvège. À l'exception d'une zone présentant un bon état, toutes les autres présentaient une qualité moyenne (n = 11) ou mauvaise (n = 12). Plus de la moitié des populations présentaient un statut moyen (n = 7) ou mauvais (n = 6) pour au moins un indicateur de performance démographique, avec des tendances négatives concernant la masse corporelle des veaux et le recrutement dans plusieurs populations. La perte de diversité génétique a entraîné un mauvais état dans 4 populations petites et isolées, et deux populations atteintes de la maladie du dépérissement chronique ont obtenu de mauvais résultats pour leur état de santé. L'état des ressources en lichens était moyen (n = 20) ou bon (n = 3), à une exception près. Toutefois, l'absence de séries temporelles sur l'abondance en lichens n'a pas permis d'évaluer les tendances temporelles afin d'évaluer le surpâturage. La perte de connectivité (faible; n = 7) était plus problématique que la perte d'habitat saisonnier (n = 3). La faible disponibilité de données empiriques de haute qualité, en particulier sur les performances démographiques, a limité la capacité à évaluer entièrement l'état de conservation de plusieurs petites populations. La norme de qualité environnementale constitue une avancée importante vers l'opérationnalisation de la gestion et la mise en œuvre de mesures visant à assurer la conservation à long terme du renne sauvage. Nous discutons des améliorations supplémentaires et de l'utilité potentielle de cette approche pour d'autres grands mammifères.

En kvalitetsnorm for å bevare villrein

Biodiversitetskrisen krever forvaltningsverktøy som etablerer referanseverdier og vurderer status for biologisk mangfold. Villrein (*Rangifer tarandus*) er et ikonisk hjortedyr i Arktis og subarktiske områder, men mange bestander er i tilbakegang. Selv om arten globalt er vurdert som sårbar på den internasjonale rødlista, vil mer detaljerte forvaltningsverktøy på bestandsnivå gjøre det mulig med målrettede bevaringstiltak nasjonalt. Vi har utviklet en kvalitetsnorm for villrein for å evaluere bestandenes samlede status og forenkle komplekse variasjoner og endringer til enkle statuskategorier (dårlig, middels og god) basert på et sett av kvantitative indikatorer for 1) bestandskondisjon, genetisk mangfold og helsetilstand, 2) mengden lavressurser, og 3) tap av sesonghabitat og konnektivitet. Vi implementerte kvalitetsnormen for 10 nasjonale og 14 mindre villreinområder (bestander) i Norge. Med unntak av ett område med god status, hadde de øvrige status som middels (n = 11) eller dårlig (n = 12). Over halvparten av bestandene hadde middels (n = 7) eller dårlig (n = 6) status for én eller flere indikatorer for bestandskondisjon, med negative trender i kalvevekter og rekruttering i flere bestander. Betydelig tap av genetisk mangfold ga dårlig status i fire små og isolerte bestander, og to bestander med skrantesjuke fikk dårlig status for helsetilstand. Status for lavressurser var middels (n = 20) eller god (n = 3), med ett unntak. Tidsseriedata for lavressurser manglet, og det var derfor ikke mulig å evaluere utviklingen over flere år for å vurdere eventuell overbeiting. Tap av konnektivitet (dårlig; n = 7) var et større problem enn tap av sesonghabitat (n = 3). Begrenset tilgang på empiriske data, særlig for bestandskondisjon, reduserte muligheten til å vurdere bevaringsstatus for flere små bestander. Kvalitetsnormen for villrein representerer et viktig skritt mot operasjonalisering av forvaltningstiltak, og den bidrar til å sikre langsiktig bevaring av villrein. Vi diskuterer videre forbedringer og mulig nytte av denne tilnærmingen for andre store pattedyr.

Contents

INTRODUCTION

Global climate and land-use changes are increasingly affecting populations, species, and ecosystems (Thuiller 2007). Establishing baselines and indices of the biodiversity state are key to informing policy to enable the protection and restoration of nature (Scholes et al. 2008, Feld et al. 2009). Policy support tools in the form of state indices come at different levels of organization, from populations of species to ecosystems (Rodríguez et al. 2011), with or without being linked to environmental drivers (van Strien et al. 2009). Some indices incorporate a large number of indicators to represent major trends in biodiversity, such as the Nature Index (Certain et al. 2011) and the Living Planet Index (World Wildlife Fund 2018). The International Union for Conservation of Nature (IUCN) Red List is another important development of objective, repeatable, and transparent criteria for assessing extinction risk at the species level and is typically applied at the national or global level (IUCN 2022). For species of particular conservation concern or importance, serving as flagships, umbrellas, indicators, or keystone species, more detailed indicators of status and early warning signals in the different populations of a given species may be valuable tools for implementing policies at the national level (Labadie et al. 2024).

The IUCN Red List focuses mainly on changes in the abundance and size of the distribution area; however, these are not necessarily early warning signals. For large animals, a decline in population numbers, or even population collapse (Cerini et al. 2023), is typically preceded by a decline in more sensitive parameters, such as body mass (Clements et al. 2017). Thus, using indicators that allow for such early warning signals of a decline in population performance is important for the development of more detailed indices (Scheffer et al. 2009). Similarly, behavioral buffering of environmental changes (Stien et al. 2010) can delay or counteract the effects on the indices of conditions. Habitat loss and fragmentation can limit resource accessibility, seasonal range use, and the ability to spatially respond to novel conditions. Human infrastructure development or other disturbances can also initiate animal displacement or restrict space use (Tucker et al. 2018) but may not necessarily affect body condition, vital rates, or abundance in the short term, especially if alternative habitats are available. Nevertheless, enforced range displacement or space-use restrictions due to disturbances are likely to eventually lead to increased stress, decreased feeding rates, and overall reduced resource availability. This may also increase the risk of disease transmission, overgrazing, and pasture deterioration, with density-dependent feedback on body conditions, vital rates, and population growth (Skogland 1985). In the long term, increasingly smaller and fragmented populations are more vulnerable to stochastic events; fragmentation can also restrict gene flow, cause genetic drift and inbreeding, and reduce the overall standing genetic variation, which is important for the capacity to adapt to novel conditions (Stockwell et al. 2003).

In the Arctic and sub-Arctic, both wild and semi-domestic reindeer and caribou (*Rangifer tarandus*), hereafter referred to as reindeer, are iconic ungulates that are considered a cultural and ecological keystone (Mustonen 2022). Reindeer can function as an umbrella species for the conservation of wider biodiversity (Labadie et al. 2024), but many populations are in decline. Reindeer was first Red Listed as vulnerable globally in 2016 (Gunn 2016), but there is huge variation between different regions and populations (Hebblewhite 2017, Hebblewhite and Fortin 2017). Thus, for reindeer, more detailed state indices reflecting both the short- and long-term development of each population would be valuable policy tools to improve targeted conservation efforts. Ideally, indicators should be easily measured, should have direct and predictable links to different limiting factors (that can be managed), and should be integrative (Dale and Beyeler 2001).

Wild reindeer is a challenging species to manage. They typically occur in seasonally dynamic aggregated groups with extensive seasonal space use. Their habitats are under pressure owing to human development and

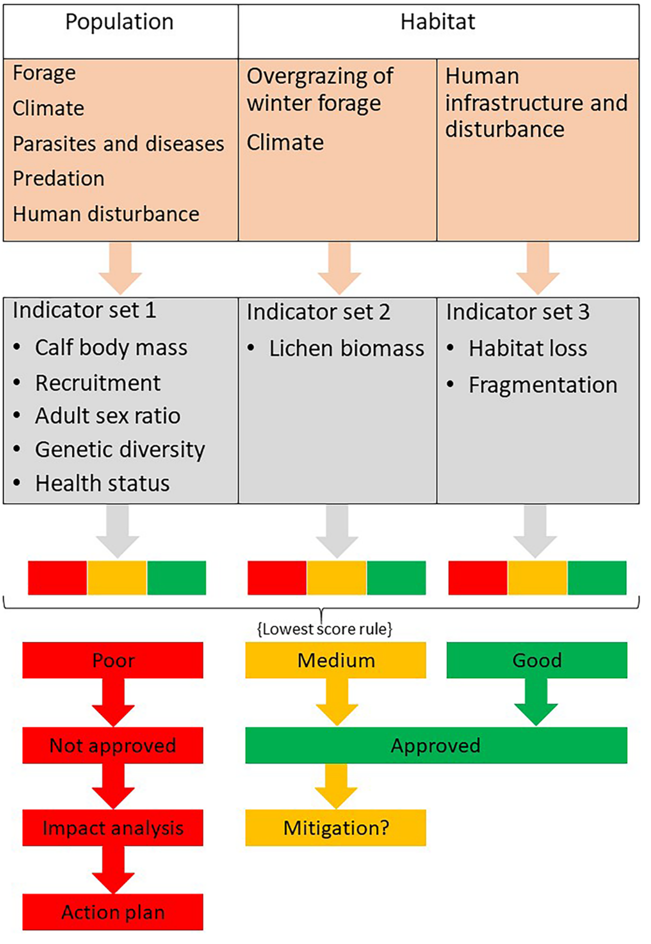


FIGURE 1 A conceptual overview of the quality standard for reindeer in Norway. The standard cover indicators for limiting factors (drivers) are linked to the population and habitat level. A score (good, medium, and poor) is given for each indicator and area. The lowest score determines the overall score for a given area. A poor score will lead to an evaluation of drivers and an action plan.

disturbances. They usually rely on vulnerable and slowly regenerating lichen resources as their main winter food, which are prone to overgrazing and are sensitive to environmental changes. Therefore, any overall status index for reindeer should include 1) the status and early signals of short- and long-term declines in population performance (body growth, recruitment, and adaptability), 2) the status and trend of lichen resources, and 3) measures of seasonal habitat availability and connectivity.

Norway is especially responsible for the conservation of wild tundra reindeer in Europe (Andersen and Hustad 2005). The Red Listing of wild reindeer on the national scale changed to near threatened in 2021 (Artsdatabanken 2021). This highlights the need for policy tools to determine the status of the 24 local populations as a basis for mitigation and restoration efforts. In 2017, an independent expert group charged with developing an environmental quality standard (or norm, hereafter referred to as the standard) for Norwegian wild reindeer was appointed by the Norwegian Environment Agency and commissioned by the Ministry of Climate and Environment. The overall objective for reindeer management is to ensure that the species and the 24 administrative reindeer areas (hereafter referred to as populations) are managed in such a way that international obligations are met, and that national objectives are reached for the conservation of viable populations within ecologically functional habitats (The Nature Diversity Act; Lov om forvaltning av naturens mangfold (naturmangfoldloven), LOV-2009-06-19-100. §5 and §13). The standard was established as an official regulation in June 2020 (Ministry of Climate and Environment 2020). A new expert group in collaboration with managers and stakeholders first implemented the standard in 2022-2023 for the 10 national reindeer areas (or populations), which are typically larger populations (Rolandsen et al. 2022), and then for the 14 smaller (termed non-national) populations (Rolandsen et al. 2023).

We present and discuss this work to develop the environmental quality standard for Norwegian wild reindeer and report results from the assessment. We describe 3 sets of indicators for 1) population performance, 2) lichen resources, and 3) human-related habitat loss and fragmentation, and their rationale (Figure 1). We then present and discuss the first evaluation results and the status of all 24 reindeer areas based on an analysis of available data.

STUDY AREA

The 24 wild reindeer areas, as defined by national management authorities, are all located in southern Norway (Figure 2). There are also some areas adjacent to these wild reindeer areas with semi-domesticated reindeer, whereas in northern Norway, there are only semi-domesticated reindeer. The sizes of the wild reindeer areas and aims for winter population size set by management authorities vary from 90 km^2 and 30 individuals in Oksenhalvøya to 8,720 km^2 and 12,000 individuals in Hardangervidda (Table 1). The 24 populations aligned along 2 main natural environmental gradients: coastal to inland and boreal to alpine.

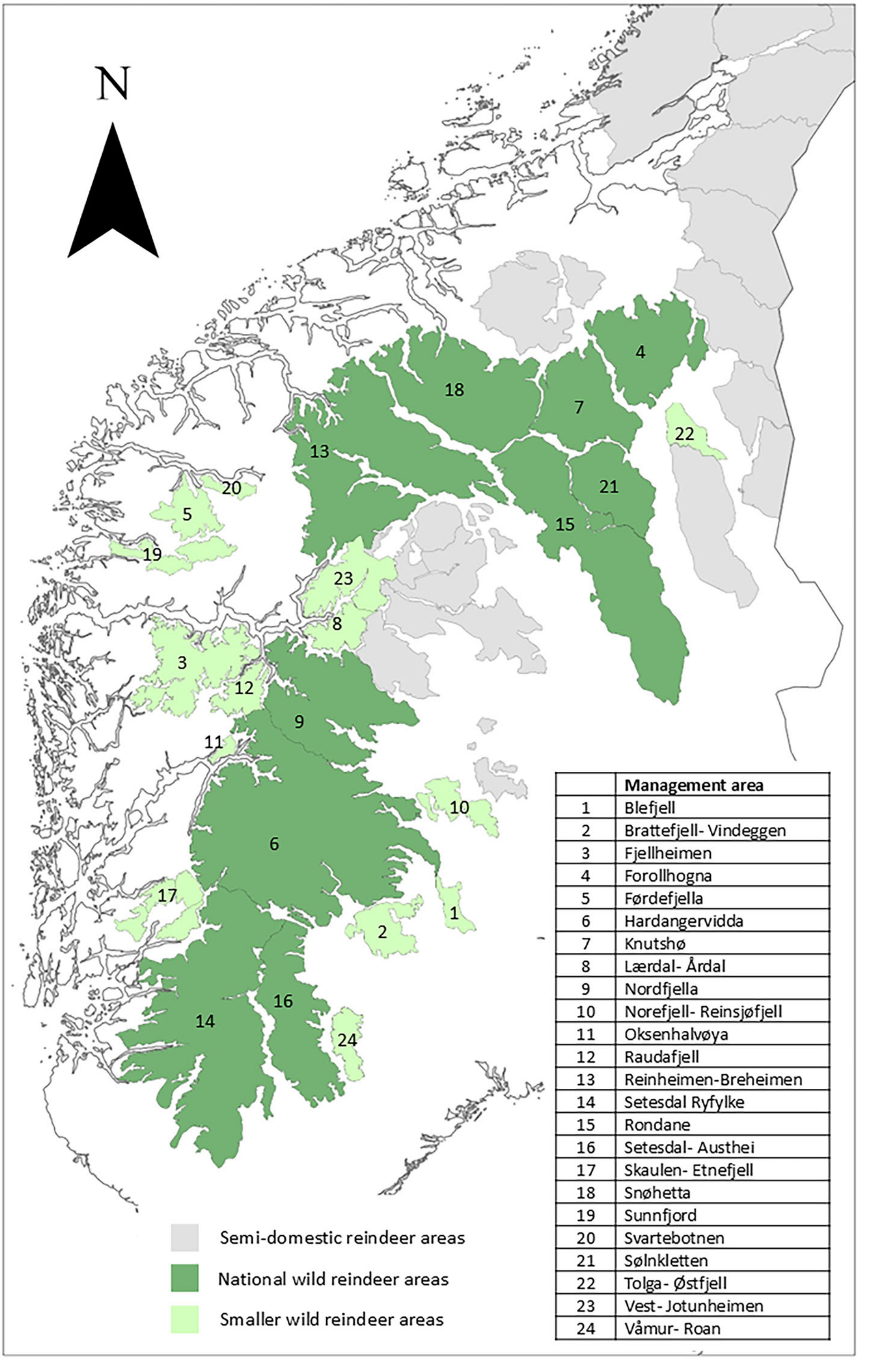
Wild reindeer ancestry based on mitochondrial genotypes reflects a historical division between a southern and a northern metapopulation with limited exchange between them (Kvie et al. 2019). Additionally, at least 9 (1 in the north, 8 in the south) of the 24 populations are feral with a sole semi-domestic origin but are nevertheless regarded as wild in a management context (i.e., they are regulated by recreational hunting; Mysterud et al. 2024). All other populations in the southern metapopulation had a high level of admixture with semi-domesticated reindeer in the 1800s to 1900s, and some are still subject to gene flow from semi-domesticated reindeer owing to the mixing of herds.

Reindeer habitats in Norway are affected to various degrees by human-related processes that can lead to permanent habitat loss and fragmentation (Panzacchi et al. 2015a, Dorber et al. 2023), such as hydropower development (the creation of large water reservoirs), construction of cabins and tourist resorts, linear infrastructure limiting connectivity (railways and highways), and factors that cause disturbance effects (tourist volume and type of activity; Panzacchi et al. 2013a, b; Gundersen et al. 2019, Dorber et al. 2023). The division into 24 populations or wild reindeer areas is partly a result of fragmentation caused by human infrastructure development and ongoing fragmentation, which further limits movement and leads to subdivision into somewhat isolated (sub)populations (Panzacchi et al. 2013a). Owing to fragmentation effects that cut previous migration routes (Panzacchi et al. 2013b), access to seasonal foraging habitats differs markedly between reindeer areas.

All wild reindeer populations in Norway are primarily regulated by recreational hunting (Strand et al. 2012). The mean annual harvest per population during 2014–2023 varied from 0 to 1,527 reindeer according to the variation in area and population size, and the quota filling varied from 16% to 94% (Table 1).

Moose (*Alces alces*), red deer (*Cervus elaphus*), and to a lesser extent, roe deer (*Capreolus capreolus*), overlap with reindeer in lower elevational ranges (Mysterud et al. 2023a). There is extensive summer grazing of domestic sheep (*Ovis aries*) in most of the alpine areas, and muskox (*Ovibos moschatus*) inhabit the Snøhetta area.

In Scandinavia, large predators were functionally exterminated by 1930 and have since recolonized only part of the former range. Currently, there are no permanent populations of large predators in the southern mountains where wild reindeer occur in Norway (Figure 2), according to distribution maps of wolves (*Canis lupus*), wolverines (*Gulo gulo*), and bears (*Ursus arctos*) in Bischof et al. (2020). The golden eagle (*Aquila chrysaetos*) has been observed preying on newborn calves and adult reindeer in some areas, but the extent of this predation is uncertain.



	Management area
1	Blefjell
2	Brattefjell- Vindeggen
3	Fjellheimen
4	Forollhogna
5	Førdefjella
6	Hardangervidda
7	Knutshø
8	Lærdal- Årdal
9	Nordfjella
10	Norefjell- Reinsjøfjell
11	Oksenhalvøya
12	Raudafjell
13	Reinheimen-Breheimen
14	Setesdal Ryfylke
15	Rondane
16	Setesdal- Austhei
17	Skaulen- Etnefjell
18	Snøhetta
19	Sunnfjord
20	Svartebotnen
21	Sølnkletten
22	Tolga- Østfjell
23	Vest- Jotunheimen
24	Våmur- Roan

FIGURE 2 Overview of 24 wild reindeer populations in Norway with adjacent semi-domestic populations marked in grey. Wild populations are classified as national reindeer areas and smaller reindeer areas.

TABLE 1 An overview of the reindeer management areas (populations) of Norway. Information about area and population size are from Helseth et al. (2023) and villrein.no (accessed 28 Feb 2024). Data on harvest and quota-filling (2014–2023) are from Statistics Norway.

Populations	Area (km^2)	Population size aim	Harvest	Quota filling (%)
National areas				
Setesdal Ryfylke	7,021	4,000	361	16
Setesdal Austhei	2,431	1,500	201	20
Hardangervidda[a]	8,720	12,000	1,527	21
Nordfjella[a]	3,225	2,400	232	42
Reinheimen-Breheimen	5,886	2,500	695	68
Knutshø	2,085	1,500	248	52
Snøhetta	3,733	3,000	601	45
Rondane	5,049	4,100	417	45
Sølnkletten	1,383	800	180	38
Forollhogna	2,354	1,750–1,850	438	76
Smaller areas				
Våmur-Roan	453	200	45	69
Vest-Jotunheimen	1,140	400	24	68
Skaulen Etnefjell	819	60	11	31
Brattefjell-Vindeggen	737	550	78	33
Blefjell	284	150	26	26
Norefjell-Reinsjøfjell	582	570	201	87
Oksenhalvøya	90	30	0	0
Fjellheimen	1,820	600	47	57
Lærdal-Årdal	544	500	15	54
Sunnfjord	611	150	9	83
Førdefjella	636	100	10	76
Svartebotnen	165	60	12	94
Tolga Østfjell	434	300	16	42
Raudafjell[b]	506	200	3	32

[a]Current numbers are substantially lower because of chronic wasting disease management.
[b]Numbers from 2020–2023

METHODS

Mandate for developing the classification system

Harvest management following biological reference points is common in many fisheries worldwide (MacNeil 2013), and the management targets for Atlantic salmon (*Salmo salar*) in Norway (Forseth et al. 2013) have informed the development of guidelines. The mandate to the expert group was that classification should be a simple category system. It was decided that the status should be given on a 3-level scale (good, medium, and poor) with a color indication and meaning following a clear traffic light analogy (green, yellow, red) to improve communication with the public.

Each set of indicators is assigned an equal weight. Based on the precautionary principle, the overall status should equal the indicator with the lowest status. In cases of insufficient or no available data, the group assigned a grey status without any influence on the overall status.

The rationale of indicator sets

A review and expert opinion of the relative roles of natural and anthropogenic drivers of the reindeer populations provided a basis for the rationale of the proposed indicator sets. Relevant quantitative parameters were divided into 3 sets of indicators (Table 2) that reflected the status of the reindeer population (indicator set 1), lichen resources (indicator set 2), and the level of human-related loss and fragmentation of seasonal habitat (indicator set 3), respectively. The sets of indicators were chosen to cover early warning signals from the shorter-term (e.g., body mass, health) to longer-term (loss of genetic diversity) population viability, overgrazing of lichens, and loss of habitat and fragmentation (Figure 1). The availability of data informed by the reindeer population and health monitoring in Norway constrained the selection of indicators, which are discussed in the selection of each indicator set.

Indicator set 1 covered population performance. A good balance between seasonal grazing areas is crucial for reindeer and other larger herbivores. However, the area and proportions of seasonal habitats available vary greatly between reindeer populations, owing to both environmental and climatic gradients and habitat loss and fragmentation (Skogland 1983). As a rule of thumb, the amount of food available in winter is assumed to determine the carrying capacity of cervid populations at northern latitudes, whereas summer conditions mainly determine the body size and condition (Klein 1965). The drivers of the different performance indicators may be season-specific (Burant et al. 2019). Winter range conditions are unlikely to be strongly reflected in calf body mass measured during the fall hunting season but may be partly captured in recruitment rates (Simmonds et al. 2025).

Indicator set 2 covered lichen resources. A unique feature of reindeer is the extensive reliance on lichens as winter forage. Both in North America and Europe, there is a history of occasional overgrazing followed by population collapses in reindeer and caribou. A large increase in population size to above the carrying capacity preceded the collapse of an introduced reindeer population relying on lichens for winter forage on St. Matthew Island in Alaska, USA (Klein 1968). The same occurred following the reintroduction of Svalbard reindeer (*R. t. platyrhynchus*) to Ny-Ålesund, Svalbard, where lichens acted as a supplementary resource, catalyzing the overshoot of the carrying capacity (Hansen et al. 2007). Overgrazing of lichen pastures can lead to long-term deterioration of range conditions (Klein and Shulski 2009). This happened in the Snøhetta and Hardangervidda reindeer populations in Norway during a period of overabundance in the 1960s and 1980s, respectively. Avoiding such overgrazing is a constant management concern. Therefore, the standard included indicators of both body condition and recruitment (indicator set 1) and the status of winter forage (lichens, indicator set 2).

Indicator set 3 covered human-related habitat loss and fragmentation, which represent major challenges to the long-term conservation of wild reindeer and their habitats in Norway (Panzacchi et al. 2015b 2022, Van Moorter et al. 2023b) and elsewhere (Hebblewhite and Fortin 2017, Morineau et al. 2023). Human development and disturbances to reindeer and their habitat have increased in recent decades (Gundersen et al. 2019, 2020). For instance, the rapidly growing economy and welfare in Norway have caused the development of private second homes in the range fringes, and there is increasing fragmentation by transportation infrastructure, hydropower, and tourism (Dorber et al. 2023). Therefore, the standard included indicators for the level of human-related loss and fragmentation of seasonal habitat (indicator set 3).

TABLE 2 An overview of the reindeer quality standard for the 3 set of indicators for status of the population, lichens, and human-related habitat loss and disturbance. Color-coding indicates the status as poor (dark red), medium (bright yellow), or good (medium green).

Indicator set	Indicator	Poor	Medium	Good
1. Population performance	Autumn dressed mass of calves (female, date corrected, last 5 years)	<15 kg	15–18 kg	>18 kg
	Recruitment. Calves per 100 females and yearlings (last 5 years)	<35	35–50	>50
	Proportion of adult males in the adult population (last 5 years, adult males [≥3 years], adult females [≥1 year])	<20%	20–35%	>35%
	Genetic diversity (lost variation)	>3%	3–0%	0%
	Health status – presence of serious, notifiable disease	Present	[not used]	Not present
2. Lichen conditions	Lichen biomass in ≥60% of area	<132 g/m^2	132 – 220 g/m^2	>220 g/m^2
3. Human-related habitat loss and fragmentation	Habitat loss (reduced use of space)	Large extent (>20%) and >90% reduced use	Medium extent (10–20%) and reduced use >50% or large extent (>20%) and 50–90% reduced use	Small extent (<10%) for all categories of reduced use, or medium to large extent and <50% reduced use
	Fragmentation (loss of connectivity)	>90% reduced use affecting >20% of seasonal area	50–90% reduced use affecting >10% of seasonal area, or >90% reduced use affecting 10–20% of seasonal area	<50% reduced use

We limited the choice of indicators to key ecological parameters. One could also have considered indicators of the management regime (Niemi and McDonald 2004, Singh et al. 2009). The reindeer populations in Norway are well-regulated through an annual harvest typically from 20 August to 30 September (Strand et al. 2012). On average, 15% of the pre-hunt reindeer populations are hunted, but the different reindeer areas differ in their organization, level of surveillance, and ability to regulate the population according to their aims. Quota filling is far lower and more variable in larger areas with genetically wild reindeer, compared to smaller areas with less shy feral reindeer (Table 1). Nevertheless, given the management regime, we do not consider harvest pressure as a meaningful indicator itself.

Indicator set 1: Population performance

The main factors securing the condition and performance of the population are sufficient access to resources as a basis for growth, reproduction, and survival; absence of notifiable diseases; and sufficient genetic variation for the persistence and adaptations in the longer term. For large mammals, a decline in individual performance with environmental deterioration follows a predictable pattern (Eberhardt 2002). With increasing environmental severity, mothers reduce investment in their offspring, leading to lower mass gain of offspring (Gaillard and Yoccoz 2003) and occasionally even abortion (Albon et al. 2017). This reduces the maternal costs of reproduction but increases offspring mortality or the age of maturation. In the absence of predation, the mortality of prime-aged large herbivores is generally low and increases only notably under extreme environmental conditions (Albon et al. 2017). Therefore, this standard uses calf body mass and recruitment as sensitive indicators of the environmental status and changes.

Body mass (dressed carcass weight) of calves

Body mass is a sensitive parameter of the condition and performance of a population, especially in large herbivores such as reindeer (Loison and Strand 2005, Albon et al. 2017). In Norwegian wild reindeer, body mass (dressed weight) is routinely collected by hunters in some reindeer areas (Tables S1 and S2). This was regarded as a feasible data source for standard data collection in all reindeer areas through collaboration with hunters. Calf body mass should be standardized according to hunting date and sex. The standard was established using 4 September as the standardization date and female calves as the standard sex. The standard establishes the following categories for mean calf body mass (dressed weight) over 5 years: poor (<15 kg), medium (15–18 kg), and good (>18 kg; Table 2). If we identified statistical evidence for a linear trend in calf body mass over the last 10 years in a regression model, we lowered the status classification by 1 level if it was negative and raised it by 1 level if it was positive. Minimum data requirements were set to 3 years for estimating the mean and 7 years for estimating the trend based on at least 10 samples with known sex and date. Body mass was analyzed using linear and linear mixed-effects models.

Recruitment

The proportion of females with calves at the heel in early summer can, in general, be affected by fertility and a range of factors causing early mortality, like resource limitations, severe weather, predation, and disease. Following the implementation of the standard, all populations should undergo aerial (by helicopter) calving surveys in summer, typically in June or early July. Based on these surveys (Tables S3 and S4), a proxy for calf recruitment can be estimated based on the number of calves per adult female and the yearlings counted from the pictures (Mysterud et al. 2025a). During this period, calves, females, and yearlings are generally grouped together and are normally separated from most adult males (Skogland 1989). However, male and female yearlings are not easily distinguished from adult females at a distance at this time of year. The standard established the following condition categories for the number of calves per 100 females and yearlings: poor (<35), medium (35–50), and good (>50; Table 2). As for body mass, we evaluated recruitment based on the 5-year mean and 10-year trend. We analyzed recruitment mean and trends using generalized linear models.

Adult male to female ratio

Reindeer are a polygynous species, in which an adult male can mate with many females, and highly skewed sex ratios do not normally limit female reproduction. However, a low proportion of adult males can delay rutting and, subsequently, calving (Holand et al. 2003). The proportion of males that sire offspring also affects the effective population size (N_e). The effects of skewed sex ratios can be small and are generally poorly documented. Additionally, a high proportion of males, which have a different space use compared to females (Hjermann et al. 2024), may ensure greater use of the peripheral parts of the reindeer ranges, indirectly aiding the conservation of these habitats. The aim of management to avoid a low proportion of adult males implies a precautionary principle and is also based on considerations not linked to conservation biology (e.g., positive aesthetic and recreational value). The operational adult sex ratio can be obtained from population structure counts during the rutting season in the fall (after the hunting season; Mysterud et al. 2025a), when there is no sexual segregation (Tables S5 and S6). These counts are normally performed on foot using telescopes, photographs, and video recordings. The standard establishes the following categories of percentage of adult males (≥3 years) in the adult population: poor (<20%), medium (20–35%), and good (>35%; Table 2). Similar to calf body mass and recruitment, we evaluated the adult sex ratio based on the 5-year mean and 10-year trend. We analyzed adult male-to-female ratios (number of adult males [≥3 years] per 100 females [≥1 year]) using generalized linear models with a binomial distribution.

Genetic diversity

Genetic variation is important to avoid inbreeding, maintain viable populations, and adapt to long-term environmental changes (Willi et al. 2022). Genetic tools can provide information on genetic structure, genetic diversity, and initial effects of habitat fragmentation, such as founder effects and genetic drift (Lande 1995). Since long-term population viability characteristics are not captured by population counts or vital rates alone, direct monitoring of changes in genetic variation was implemented in the standard. We estimated changes in genetic variation in terms of the percentage change in observed heterozygosity. Changes in genetic variation occur slowly. The standard establishes the following categories for loss of genetic variation over a 5-year period: poor (>3% variation lost), medium (0–3% variation lost), and good (0% variation lost; Table 2). In practice, we assigned a category of good when there was no statistically significant change, medium when there was a statistically significant change and a point estimate of <3% loss, and poor when there was a statistically significant change and a point estimate of >3% loss.

Genetic samples were collected mainly from hunted reindeer. For the 10 national areas (which we assessed first), we used microsatellites based on 18 loci to estimate genetic variation and estimated changes in genetic variation using 9 loci to enable comparison with previous analyses (Kvie et al. 2019, Mysterud et al. 2019). The 5-year estimation period established in the standard usually could not be met due to logistical (i.e., sampling) reasons, and we categorized the available samples for a given reindeer area into old and new for simplicity. New samples included year(s) in the period 2016–2019, while old samples included year(s) in the period 2003–2014. Hence, the length of the time between old and new samples varied substantially between areas (3–20 years).

Methods for measuring genetic structure and diversity are being rapidly developed. When assessing the 14 smaller reindeer areas, we used a 147,934 loci subset selection of a novel array of 625,000 single nuclear polymorphisms (SNPs; Hansen, B. B., B. Peeters, Ø. Flagstad, K. Røed, M. D. Martin, H. Jensen, H. A. Burnett, V. C. Bieker, A. Mysterud, X. Sun, S. D. Côté, C. Robert, C. M. Rolandsen, and O. Strand, unpublished manuscript). This method was developed from available libraries and reindeer whole-genome sequences (Burnett et al. 2023) and embeds 63,000 SNPs from a previously published SNP array for *Rangifer* (Carrier et al. 2022). We calculated the proportion of heterozygous SNPs per individual, and estimated the percentage change in genetic diversity between the old and new samples (as a factor variable) for a given reindeer area using a linear model. Only 9 of the 14 smaller areas had sufficient samples for such estimates.

Health status

Health status was restricted to listed transmissible diseases that are notifiable. Poor wildlife health is often not determined by the presence of a single disease (Tryland and Kutz 2019). Health can be defined as the sum of infections and parasitic infestations, together with mineral and feed status, interacting with environmental factors to result in either a favorable or unfavorable status (Wobeser 2013). Monitoring complex traits such as health is challenging and requires extensive surveillance. Therefore, the standard only included the presence (poor) or absence (good) of notifiable transmissible diseases (Table S7), and health status was based on the data gathered from the National Health Monitoring of Cervids (Våge et al. 2023, Reiten et al. 2024). Nevertheless, a poor health status can be expected to result in poor performance and can be captured in body mass and recruitment assessments, though their exact relationship remains uncertain. Currently, there is insufficient knowledge and limited health surveillance to recommend more detailed parameters, but the health status indicator can be expanded beyond the binary classification (Table 2) if later developments allow for inclusion of more indicators.

Indicator set 2: Lichen resources

A unique feature of reindeer is their ability to digest and use lichens as a maintenance feed during the winter (Falldorf et al. 2014). Lichens grow on well-drained, dry ridges, often located on acidic and poor soils, and thrive best on shallow snow ground. Lichen heaths grow slowly and can require decades to recover after overgrazing (Klein and Shulski 2009). Because of the delayed effects on conditions, lichen pasture conditions should also be monitored directly.

The standard establishes the following categories for the condition of lichen resources: poor (<132 g/m^2), medium (132–220 g/m^2), and good (>220 g/m^2), and at least 60% of the wintering area should be in the given biomass range (Table 2). Monitoring should be carried out in permanent plots, measuring lichen cover, height, and volume every 5 years. In addition, satellite-based monitoring (Landsat or Sentinel-2AB), using the relevant vegetation indices, should be conducted annually. Satellite-based data are typically presented in volume (dm^3/m^2) but can be transformed to biomass ($g/m^2 = 22 \times dm^3/m^2$; Tømmervik et al. 2012). For field-based data, each transect should have 10 fields, each with 5 randomly placed measurement points.

We used a satellite-based method to calculate the lichen biomass (Tømmervik et al. 2021, Erlandsson et al. 2022). This method uses a deep neural network trained using artificial intelligence (AI) to estimate lichen biomass based on spatially explicit empirical data of pale mat-forming terricolous lichens (achieving an R^2 of 0.57). This method uses Landsat data with a resolution of 30 × 30 m and different vegetation indices. However, owing to data processing constraints, we estimated the test area (Rondane) using grids with lower resolutions of 120 m × 120 m and 240 m × 240 m and interpolated the values between the assessed points (Erlandsson et al. 2022). There was a strong correlation between the 2 lower resolutions ($r = 0.78$), and we decided to use 240 m × 240 m in the assessment to speed up the processing.

The method was developed based on data from lichen-rich inland areas with semi-domestic reindeer (Erlandsson et al. 2022). However, several wild reindeer areas are located in coastal areas with fewer lichens and more rocky terrain. In these areas, we noticed that lichens on top of or between rocks were sometimes falsely classified as having high lichen abundance. To avoid including areas of no expected significance as lichen grazing resources for reindeer, we excluded areas previously classified as wetlands, exposed ridges, scree, bare rocks, grass and moss snow beds, extreme snow beds, glacier snow-covered areas, water bodies, built-up areas, and unclassified areas (Erlandsson et al. 2022). We used the Normalized Moisture Index (Wilson and Sader 2002) in the model, removing small moist habitat (Erlandsson et al. 2022). Lastly, we removed all areas with a slope of >25° in a digital terrain model with a 100-m resolution, as we considered them inaccessible to reindeer based on our own expert judgement.

Indicator set 3: Human-related habitat loss and fragmentation

Infrastructure and human activity affect reindeer space use and, in turn, productivity and, ultimately, their distribution (Van Moorter et al. 2023b). There are often complex relationships among different types of infrastructure, their density and spatial configuration, disturbances, and their impact on reindeer (Gundersen et al. 2019, Dorber et al. 2023, Niebuhr et al. 2023b). Static infrastructure, such as roads, railways, trails, and ski tracks, the amount and intensity of traffic, and traffic dynamics are known to strongly affect reindeer space use (Gundersen et al. 2022).

The expert group chose to base the measurement parameters on the observed reindeer space use in each area, rather than indirectly on human land use. We classified seasonal habitat loss (loss of use) and fragmentation (loss of connectivity) within focal areas. The term focal area is a well-established concept in reindeer management in Norway (Mossing et al. 2020), and refers to subsets of the wild reindeer areas where challenges and conflicts related to area intervention and human activity have been identified, based on an expert assessment of whether human-related activity has reduced use by reindeer by >50%. Both seasonal habitat loss (loss of use) and fragmentation (loss of connectivity) were based on several different data sources to document changes in reindeer presence over the last 10 years (2012/2013–2021/2022) compared with the past 50 years (1972/1973–2021/2022; Table S8). Experts and the local managers met to identify and map focal areas following an established protocol using published scientific and documented local knowledge (Table S8). Those areas (seasonal area use, connectivity) not demarcated as focal areas were, per definition, areas with good standard, and some focal areas were in the end determined to have good standard based on the evidence. Indicator set 3 comprised 2 parts: one assessing habitat loss and the other assessing fragmentation for each season.

Habitat loss (loss of area use)

Reindeer typically shift areas during the year because of changing environmental conditions and habitat requirements: winter, calving (spring and early summer), and summer-fall areas. First, reindeer experts mapped seasonal ranges and focal areas following a previously described protocol (Mossing et al. 2020) and demarcated areas where there had been a reduction of reindeer use of these areas in the last 10 years compared to the previous 50 years based on multiple data sources (Table S8). Second, for each season (winter, calving, and summer-fall), we categorized focal areas with reduced use into whether reindeer use was reduced to a low (<50%), medium (50–90%), or high (>90%) degree. Third, for each season, we calculated whether the summed area of all of the focal areas with a high degree of reduced use (>90%) represented a small (<10%), medium (10–20%), or large (>20%) proportion (extent) of the entire seasonal habitat area (winter, calving, summer-fall). Fourth, we conducted the previous step for the reduced use focal areas with a medium status (50–90%). Finally, we used a matrix with combinations of degree of reduced use of focal areas and extent of focal areas out of total seasonal areas to categorize the habitat loss indicator as poor, medium, or good for each season (Table S9). Poor included areas with >90% reduced use of the total seasonal range and a large extent (>20%); medium included areas with >90% reduced use of the total seasonal range and a medium extent (10–20%); medium also included those with 50–90% reduced use of the total seasonal range and either a medium or large extent (>10%); and good included all other combinations (Table 2). The score of the whole reindeer area was equal to the most severe classification set in any season, following a precautionary principle.

Fragmentation (loss of connectivity)

Connectivity refers to whether reindeer have the opportunity to move between various parts of the reindeer area. Movement corridors are included as separate parameters in the standard because of their importance in connecting habitats. Both natural and anthropogenic features, such as topography, tourist or transportation infrastructure, and hydropower reservoirs, can block traditional movement corridors or constrain reindeer movement into bottlenecks that are particularly vulnerable to additional sources of disturbance (Dorber et al. 2023). The assessment relied on expert opinion using data from various sources (Table S9). First, we demarcated the most important movement corridors within each focal area. Second, we classified reduced use into >90%, 50–90%, and <50%, based on whether crossing frequency had decreased or crossing speed had increased compared to historical crossings of the past 50 years. Third, we demarcated the proportion of the area the reindeer had lost access to with >90% reduced use and summed by season (winter, calving, and summer-fall), and it was calculated whether this represented a small (<10%), medium (10–20%), or large (>20%) proportion of the entire seasonal area. Fourth, the same was repeated for the areas with 50–90% reduced use, representing a small (<10%), medium (10–20%), or large (>20%) proportion of the entire seasonal area. Finally, we used a matrix with combinations of degree of reduced use of movement corridors and proportion of seasonal ranges with lost access to set status for the whole reindeer area: poor (>90% reduced use and >20% proportion with lost access), medium (50–90% reduced use and >10% proportion with lost access, or 50–90% reduced use and 10–20% proportion with lost access), and good (reduced use <50%; Table 2). The score was set equal to the most severe classification, following a precautionary principle.

RESULTS

Half of the 24 wild reindeer areas in Norway ended up with an overall poor status (Tables 3 and 4). The overall status of the 10 national reindeer areas was poor for 6 areas and medium for 4 areas (Table 3). Six of the 14 smaller areas were scored as poor, 7 as medium, and 1 as good (Table 4). Ideally, data for all indicators should be calculated for each area (example in Figure 3), but the available data differed markedly for national and smaller reindeer areas. Indicator sets 2 and 3 were available from all populations with only 1 exception. However, sufficient data for indicator set 1 on calf body mass, recruitment, and adult sex ratio were lacking for most of the smaller reindeer areas (Figures 4 and 5). For body mass, most national areas had a medium score, while most of the smaller areas with sufficient data had a good score (Figure 4A). In contrast, there was a marked loss of genetic diversity in 4 of the smaller populations (Figure 4D). Indicator 2, lichen biomass, was comparable across national and smaller areas and, for the most part, medium or good (Tables 3 and 4). For indicator 3, fragmentation was more commonly scored as poor compared to habitat loss. Fragmentation was an issue for all national areas but for less than half of the smaller areas.

Indicator set 1: Population performance

For national areas, the lowest mean body mass (adjusted for harvest date and sex) of calves over the last 5 years was on Hardangervidda with 13.8 kg and a poor status. All other areas had medium status, either based on mean body masses of 15–18 kg or based on a declining trend (Forollhogna; Table 3). Sufficient data were available to calculate the trend in all except 2 national areas (Figure 5), resulting in poor status (declining 10-year trend) in 3 areas and medium (uncertain or no trend) in 7 areas. For example, reindeer in Snøhetta had medium body masses but a statistically negative 10-year trend that indicated a poor score (Figure 3A). For the 14 smaller reindeer areas, sufficient data to estimate the 5-year mean body mass were only available for 5 areas, 1 scored medium and 4 scored good. Only 1 area had sufficient data to calculate the 10-year trend

TABLE 3 An overview of the scoring of all 10 national reindeer areas in Norway based on data mainly collected in years 2012–2021 (Tables S1, S3, S5). We color-coded each population as poor (dark red), medium (bright yellow), or good (medium green) for each indicator and overall. Indicator set 1 displays the mean or trend (with 95% CI in brackets). The color for 10-year trend is the overall score. For lichen resources, we present the percentage of the area ranked as poor (P) or medium (M) and the remaining percentage is good. No data indicates there was insufficient data to calculate the given indicator.

	Indicator set 1								Indicator set 2	Indicator set 3		
	Calf body mass (kg)		Recruitment (%)		Adult sex ratio (%)		Genetic diversity (%)	Health status	Lichen resources	Habitat loss	Habitat fragmentation	
Population	5-yr mean	10-yr trend	5-yr mean	10-yr trend	5-yr mean	10-yr trend	ΔHobs[a]	+/−[b]	(% of area)		Degree and area (%)[c]	Overall
Forollhogna	20.2 [19.2, 21.3]	−0.075 [−0.129, −0.022]	55 [50, 60]	0.98 [0.97, 0.99]	43 [38, 47]	1.00 [0.98, 1.02]	7.8 [−15.6, 31.3]	-	32 P 15 M	Good	Medium (42)	Medium
Snøhetta	15.4 [14.6, 16.2]	−0.12 [−0.21, −0.04]	41 [39, 43]	0.98 [0.97, 0.99]	28 [22, 36]	0.98 [0.96, 1.01]	−1.1 [−22.6, 20.4]	-	34 P 14 M	Good	High (40)	Poor
Rondane	16.9 [16.0, 17.9]	0.007 [−0.02, 0.08]	44 [42, 46]	1.00 [0.99, 1.01]	27 [23-30]	1.00 [0.98, 1.02]	0.9 [−15.1, 16.9]	-	11 P 39 M	Medium	High (49)	Poor
Sølnkletten	16.8 [16.2, 17.4]	−0.11 [−0.22, 0.00]	no data	no data	28 [23-33]	1.03 [0.996, 1.06]	19.3 [−4.6, 43.3]	-	30 P 5 M	Good	Medium (37)	Medium
Knutshø	16.1 [14.9, 17.3]	−0.23 [−0.34, −0.13]	39 [38, 41]	0.99 [0.97, 1.00]	39 [30, 48]	0.96 [0.94, 0.99]	−2.3 [−20.3, 15.6]	-	25 P 11 M	Medium	Medium (95)	Poor
Hardangervidda	13.8 [12.3, 15.2]	0.04 [−0.10, 0.17]	47 [44, 50]	1.03 [1.02, 1.03]	34 [13, 64]	0.79 [0.78, 0.81]	−1.5 [−21.7, 18.6]	CWD+	32 P 17 M	Poor	Medium (51)	Poor
Setesdal Austhei	17.9 [17.0, 18.8]	no data	51 [48, 53]	0.98 [0.97, 1.00]	43 [35, 52]	no data	−0.1 [−21.7, 21.4]	-	18 P 57 M	Medium	Medium (72)	Medium
Nordfjella	16.0 [14.8, 17.1]	0.04 [−0.42, 0.51]	42 [39, 45]	0.98 [0.97, 1.00]	20 [12, 33]	0.91 [0.89, 0.94]	−5.3 [− 24.2, 13.5]	CWD+	41 P 18 M	Good	High (49)	Poor
Setesdal Ryfylke	17.0 [16.0, 17.9]	0.02 [−0.11, 0.16]	43 [38, 49]	0.99 [0.98, 1.00]	33 [23, 45]	0.94 [0.91, 0.96]	5.1 [−7.2, 17.4]	-	40 P 19 M	Medium	High (61)	Poor
Reinheimen-Breheimen	16.9 [16.2, 17.6]	no data	44 [41, 47]	1.00 [0.98, 1.02]	no data	no data	5.5 [−14.3, 27.3]	-	38 P 15 M	Good	Medium (100)	Medium

[a]Change in observed heterozygosity.

[b]Both populations with a poor health status had detections of chronic wasting disease (CWD).

[c]The reduced use of migration corridors was classified as high (>90%), medium (50–90%) or low (<50%), while numbers (%) refer to the proportion of seasonal area affected by the reduced movements.

TABLE 4 An overview of the scoring of all 14 smaller reindeer areas in Norway based on data collected in 2013–2022. We color-coded each population as poor (dark red), medium (bright yellow), or good (medium green) for each indicator and overall. Indicator set 1 displays the mean or trend (with 95% CI in brackets). For lichen resources, we present the percentage of the area ranked as poor (P) or medium (M) and the remaining percentage is good. No data indicates there was insufficient data to calculate the given indicator.

	Indicator set 1								Indicator set 2	Indicator set 3		
	Calf body mass (kg)		Recruitment (%)		Adult sex ratio (%)		Genetic diversity (%)	Health status	Lichen resources	Habitat loss	Habitat fragmentation	
Population	Mean	Trend	Mean	Trend	Mean	Trend	ΔHobs[a]	+/−	(% area)		Degree and area (%)[b]	Overall
Skaulen Etnefjell	no data	no data	no data	no data	no data	no data	−10.2 [−14.2, −6.3]	-	40 P 21 M	Poor	Low	Poor
Våmur-Roan	20.4 [18.2, 22.5]	no data	no data	no data	no data	no data	−2.3 [−5.0, 0.4]	-	51 P 19 M	Good	Low	Medium
Brattefjell-Vindeggen	no data	no data	no data	no data	no data	no data	−0.1 [−2.8, 2.6]	-	48 P 22 M	Poor	High (24)	Poor
Blefjell	17.6 [16.6, 18.7]	no data	no data	no data	no data	no data	−2.6 [−6.1, 0.9]	-	53 P 18 M	Medium	Low	Medium
Norefjell-Reinsjøfjell	21.2 [20.8, 21.7]	−0.11[−0.24, 0.02]	no data	no data	no data	no data	−0.8 [−4.1, 2.5]	-	28 P 18 M	Good	Low	Medium
Oksenhalvøya	no data	no data	no data	no data	no data	no data	no data	-	48 P 27 M	Medium	Low	Medium
Fjellheimen	18.1 [17.4, 18.7]	no data	46 [37, 55]	no data	30 [20, 42]	1.03 [0.98, 1.09]	−3.3 [−6.4, −0.2]	-	36 P 22 M	Good	High (100)	Poor
Lærdal-Årdal	no data	no data	49 [43, 55]	1.10 [1.05, 1.15]	no data	no data	no data	-	30 P 19 M	Good	Low	Medium
Vest-Jotunheimen	no data	no data	no data	no data	no data	no data	no data	-	33 P 22 M	Good	Medium (100)	Medium
Sunnfjord	no data	no data	33 [25, 43]	1.0 [0.91, 1.1]	no data	no data	−1.4 [−4.7, 1.9]	-	61 P 18 M	Medium	High (100)	Poor
Førdefjella	no data	no data	no data	no data	no data	no data	−5.1 [−10.2, 0]	-	46 P 21 M	Good	Low	Poor
Svartebotnen	18.4 [16.0, 20.7]	no data	no data	no data	no data	no data	−5.5 [−11.4, 0.4]	-	43 P 23 M	Good	Low	Poor

(Continues)

TABLE 4 (Continued)

	Indicator set 1								Indicator set 2	Indicator set 3		
	Calf body mass (kg)		Recruitment (%)		Adult sex ratio (%)		Genetic diversity (%)	Health status	Lichen resources	Habitat loss	Habitat fragmentation	
Population	Mean	Trend	Mean	Trend	Mean	Trend	ΔHobs[a]	+/−	(% area)		Degree and area (%)[b]	Overall
Tolga Østfjell	no data	no data	no data	no data	no data	no data	no data	-	8 P 4 M	Good	Low	Good
Raudafjell	no data	no data	no data	no data	21 [11, 35]	no data	no data	-	29 P 20 M	no data	no data	Medium

[a]Change in observed heterozygosity.

[b]The reduced use of migration corridors was classified as high (>90%), medium (50–90%) or low (<50%), while numbers (%) refer to the proportion of seasonal area affected by the reduced movements if high or medium reduced use.

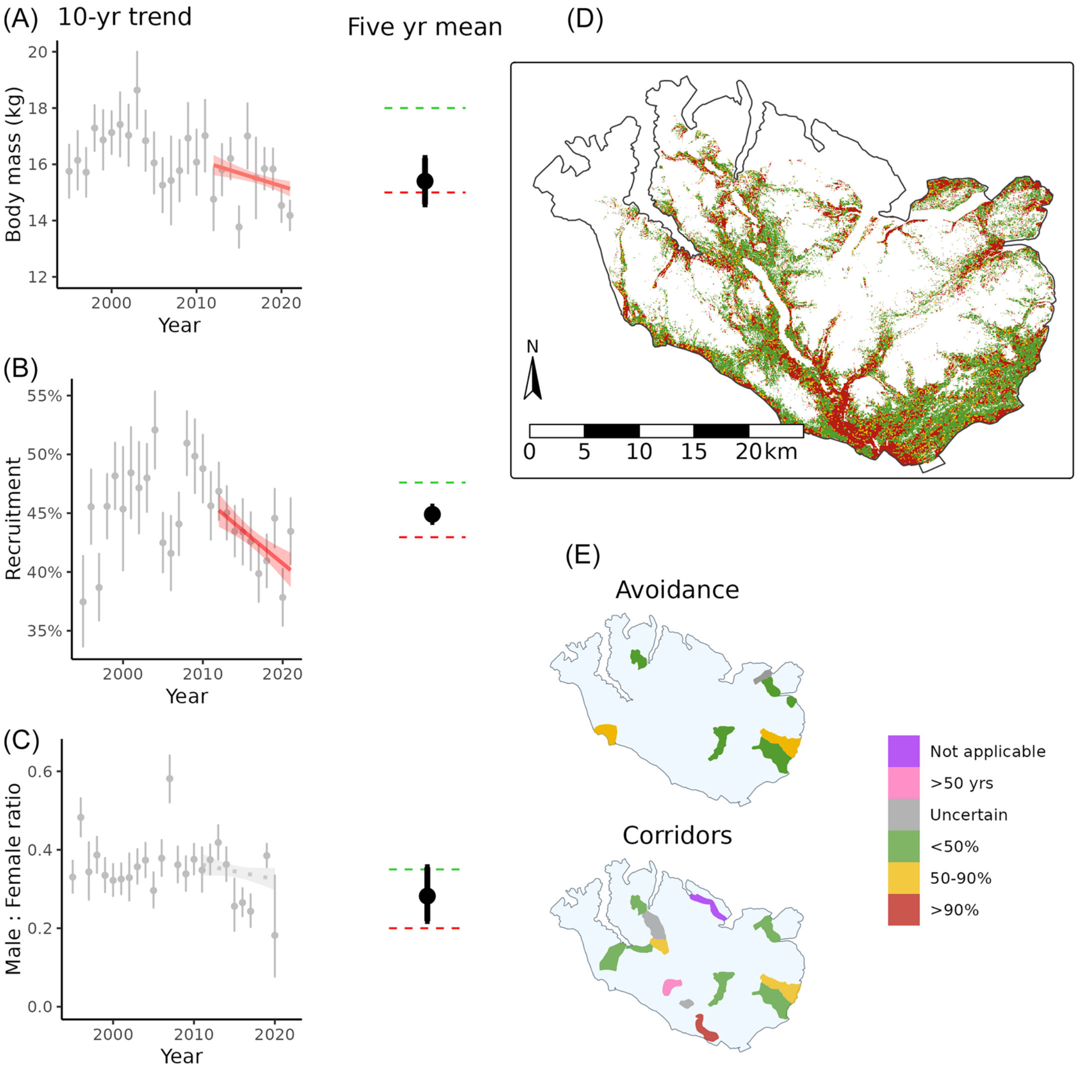


FIGURE 3 A case example of scoring A) calf body mass, B) recruitment, C) adult sex ratio (males 3 years and older: females 1 year and older), D) lichen biomass, and E) habitat loss (reduced use of area) and fragmentation (loss of connectivity) illustrated with summer as an example for the Snøhetta reindeer area in Norway based on data mainly collected in 2012–2021. The norm (A, B, C) is set relative to the 5-year mean and the 10-year trend (red: significant; grey: not significant; with 95% CI shaded). The areas with loss of use or connectivity (E, lower panel) dating back >50 years (pink) were not included in the assessment.

(Norefjell-Reinsjøfjell). This result showed no specific trend (95% CIs overlapped 0) and consequently did not affect the status classification (Table 4).

For national areas, the 5-year mean recruitment (number of calves per 100 females and yearlings of both sexes) varied between 39 (medium) in Knutshø to 55 (good) in Forollhogna (Figure 4B). A declining trend over the last 10 years in 2 populations lowered their status (Figure 6), resulting in 2 populations with good, 6 with medium, and 1 with poor as the overall status for recruitment (Table 3). For the 14 smaller areas, sufficient data for estimating mean recruitment were only available for 3 areas: 2 with medium and 1 with poor. Sufficient data for trend estimation were available for 2 of these and a positive trend raised status of one population to good (Lærdal-Årdal).

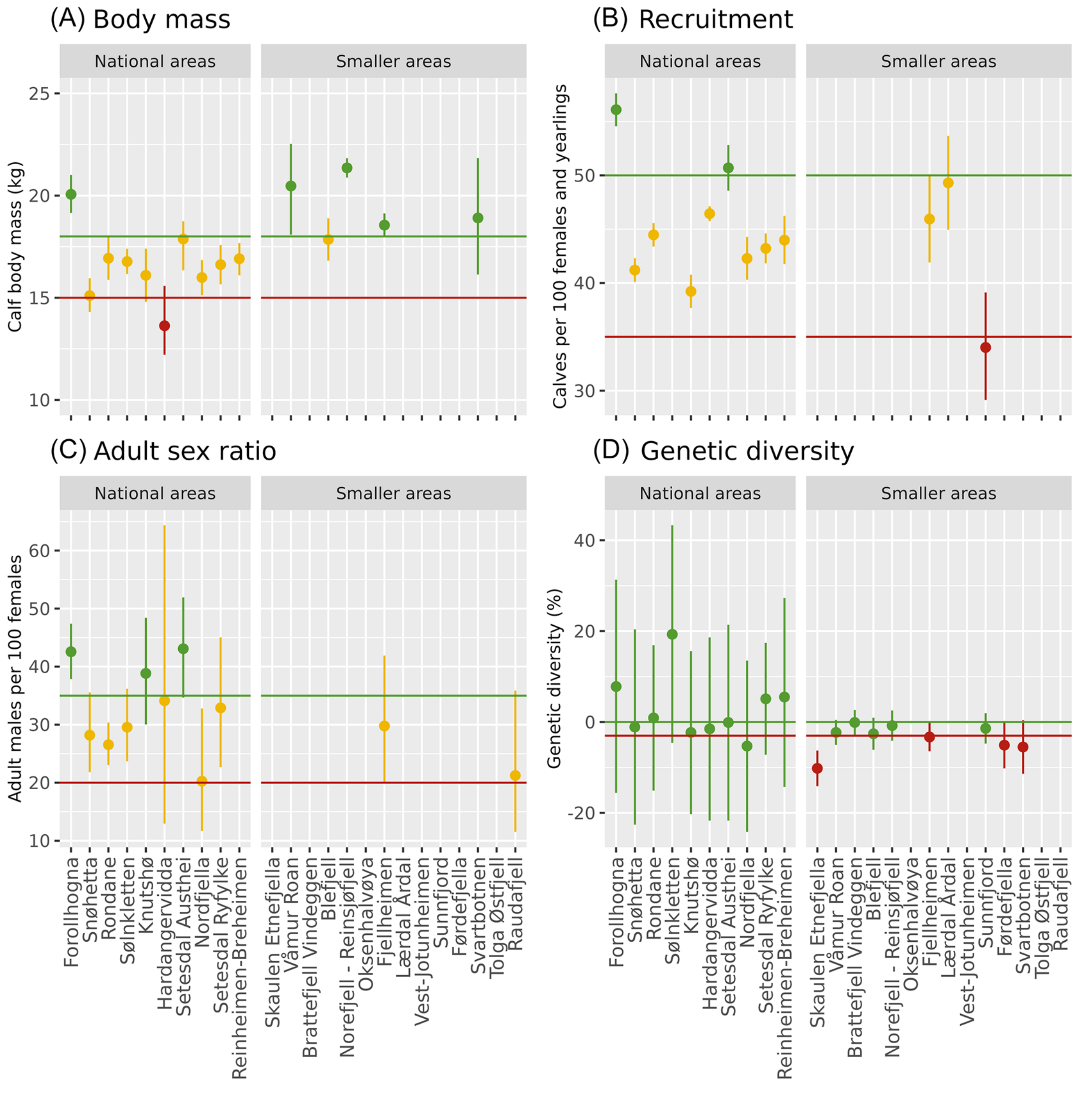


FIGURE 4 An overview of population status of national, 2017–2021, and smaller, 2018–2022, reindeer in Norway, for indicator set 1 with the 5-year mean (and 95% CI) for A) calf body mass, B) recruitment, C) adult sex ratio, and D) changes in genetic diversity for each population. For national areas, data on adult sex ratio included years 2016-2020. Note that a different method to calculate genetic diversity was used for national areas compared to smaller areas, and the year of genetic sampling differed between areas. Indicator set 1 also includes health status (not shown).

For national areas, the adult male to female ratio over the last 5 years was highly variable and ranged from 20% male and poor in Nordfjella to 43% male and good in Setesdal Austhei (Figure 4C). Six populations scored medium (20–35%) and 3 populations scored good (≥35%). A declining trend over the last 10 years in 4 populations has reduced their status, resulting in 2 national areas with good status, 4 with medium, and 3 with poor sex ratios (Figure 7; Table 3). Two of the areas with a negative trend (Hardangervidda and Nordfjella) were due to intended efforts to skew sex ratios as part of chronic wasting disease (CWD) management. For the smaller areas, sufficient data to estimate the 5-year mean sex ratio was only available for 2 areas, both scoring medium, while only one area had sufficient data for calculation of the 10-year trend.

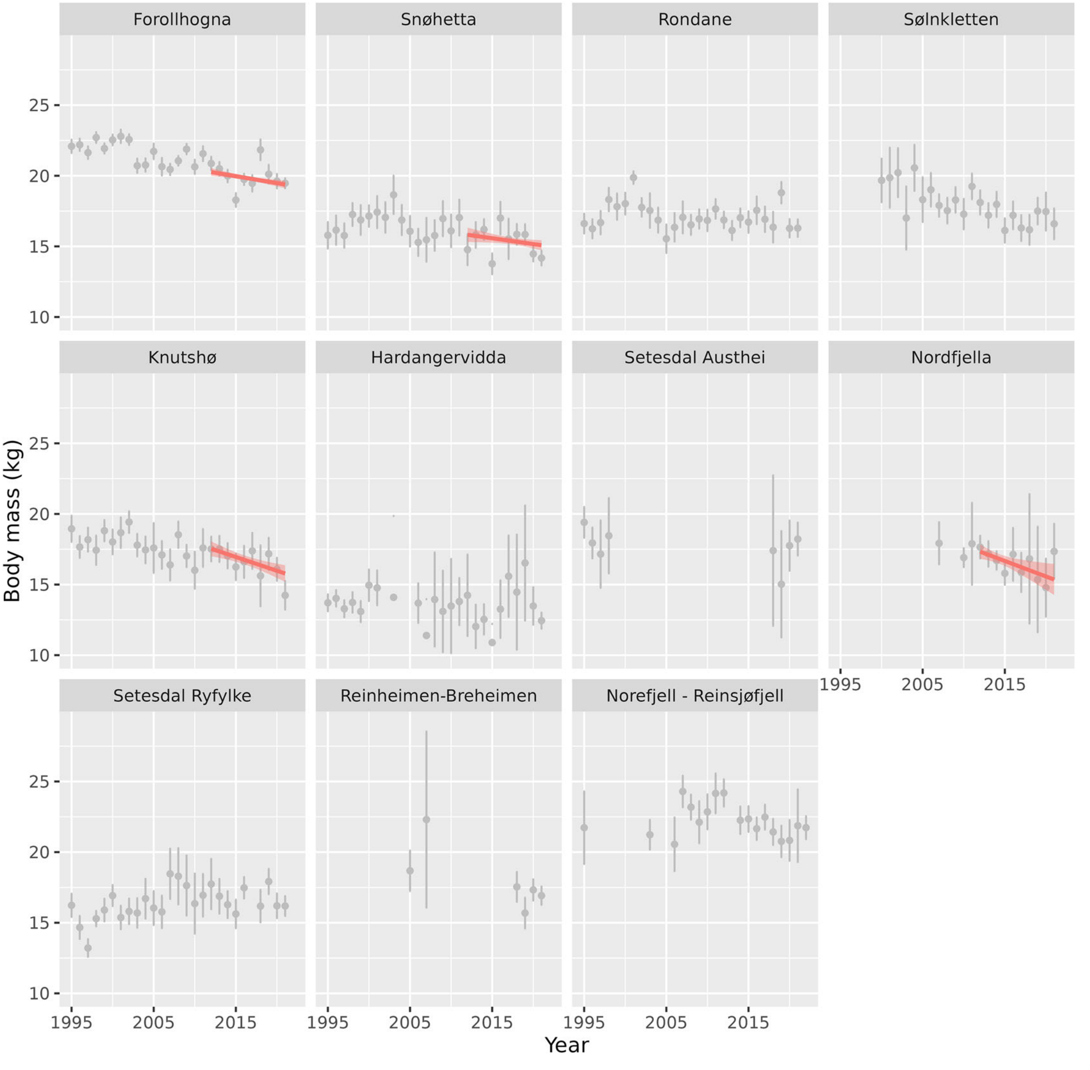


FIGURE 5 Trends in calf body mass in reindeer areas of Norway. Only populations with sufficient data available were included. Following the quality standard, the index used was a combination of 5-year mean calf body mass (grey dots with 95% CI [bars]) and 10-year trend (red line with 95% CIs [shading]); a negative trend over the last 10 years (red line with 95% CIs [shading]) in 5 populations lowered the scoring 1 level. No population had a positive trend in calf body mass over the last 10 years.

All 10 national areas scored as good for loss of genetic diversity based on the 9 analyzed microsatellites but with very large confidence intervals for estimates of percentage change in observed heterozygosity (Figure 4D). The SNP-based analysis of the smaller areas gave a poor status to 4 areas and a good status to 5 areas, while the remaining 5 areas lacked sufficient data (Table 4). All 4 poor areas showed a substantial loss of genetic variation (i.e., a point estimate of >3% reduction in observed heterozygosity) over a period of 3 to 6 years. For some of these areas, the sample sizes (i.e., the number of individuals) were small, and changes in diversity were only marginally non-significant. Across the populations analyzed with SNP data, the loss of genetic variation was strongly correlated with population size (Figure 8).

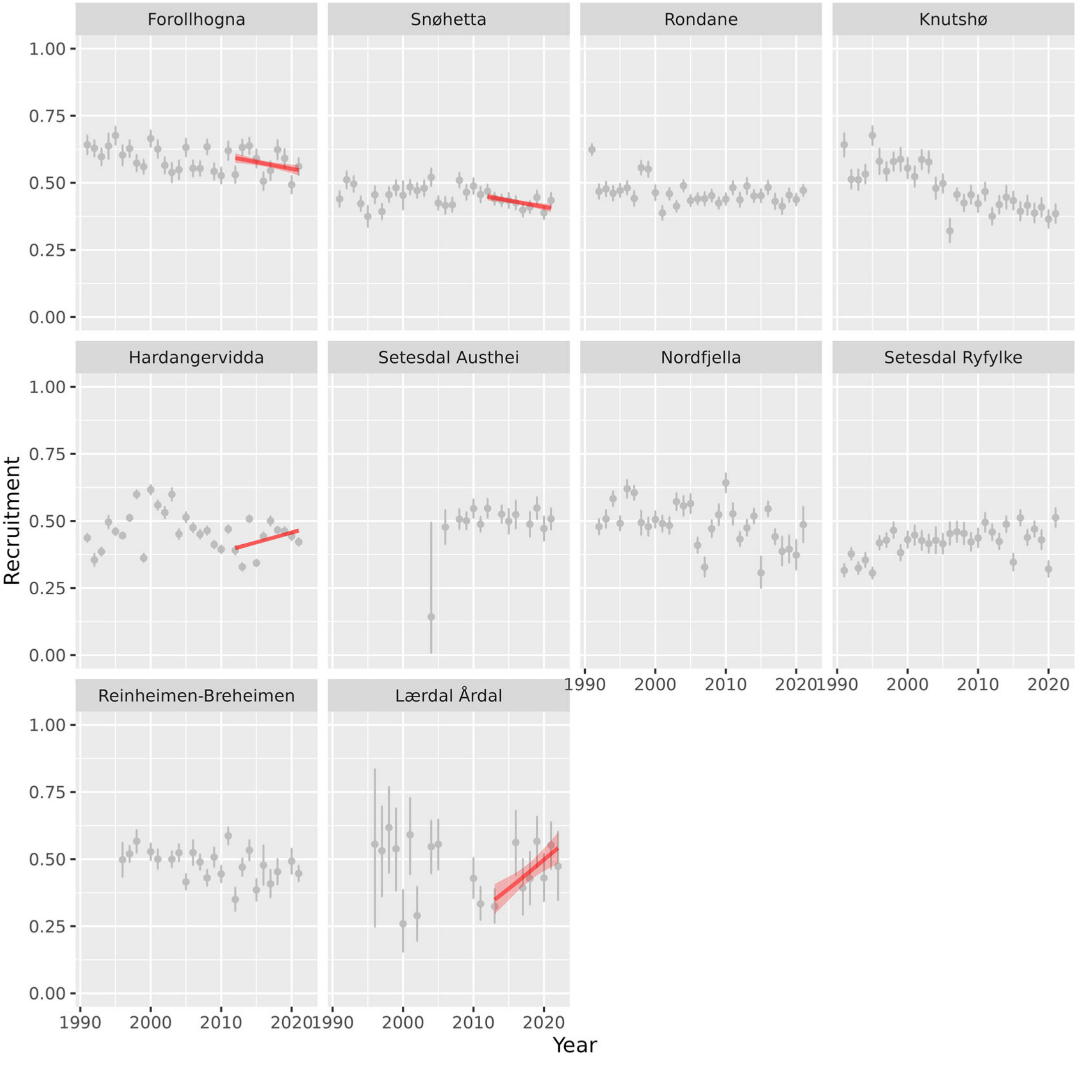


FIGURE 6 Trends in recruitment in reindeer areas of Norway. Only populations with sufficient data available were included. Following the quality standard, the index used was a combination of 5-year mean recruitment (grey dots with 95% CI [bars]) and 10-year trend (red line with 95% CIs [shading]); a trend over the last 10 years changed the scoring 1 level. There was a negative trend in recruitment over the last 10 years in 2 populations and a positive trend in 2 populations.

In regard to the presence or absence of listed transmissible diseases that are notifiable, the status was poor in both Hardangervidda and Nordfjella because of detection of CWD. Health status was good in all other national and smaller areas (Tables 3 and 4).

Indicator set 2: Lichen resources

The estimated lichen biomass status was poor in 1 area, medium in 20 areas, and good in 3 areas (Tables 3 and 4). The best lichen condition was found in Tolga Østfjell, where 88% of the winter areas were classified as good (Table 3). At the other end of the range, Sunnfjord had as much as 61% of the total winter area classified as poor (Table 4).

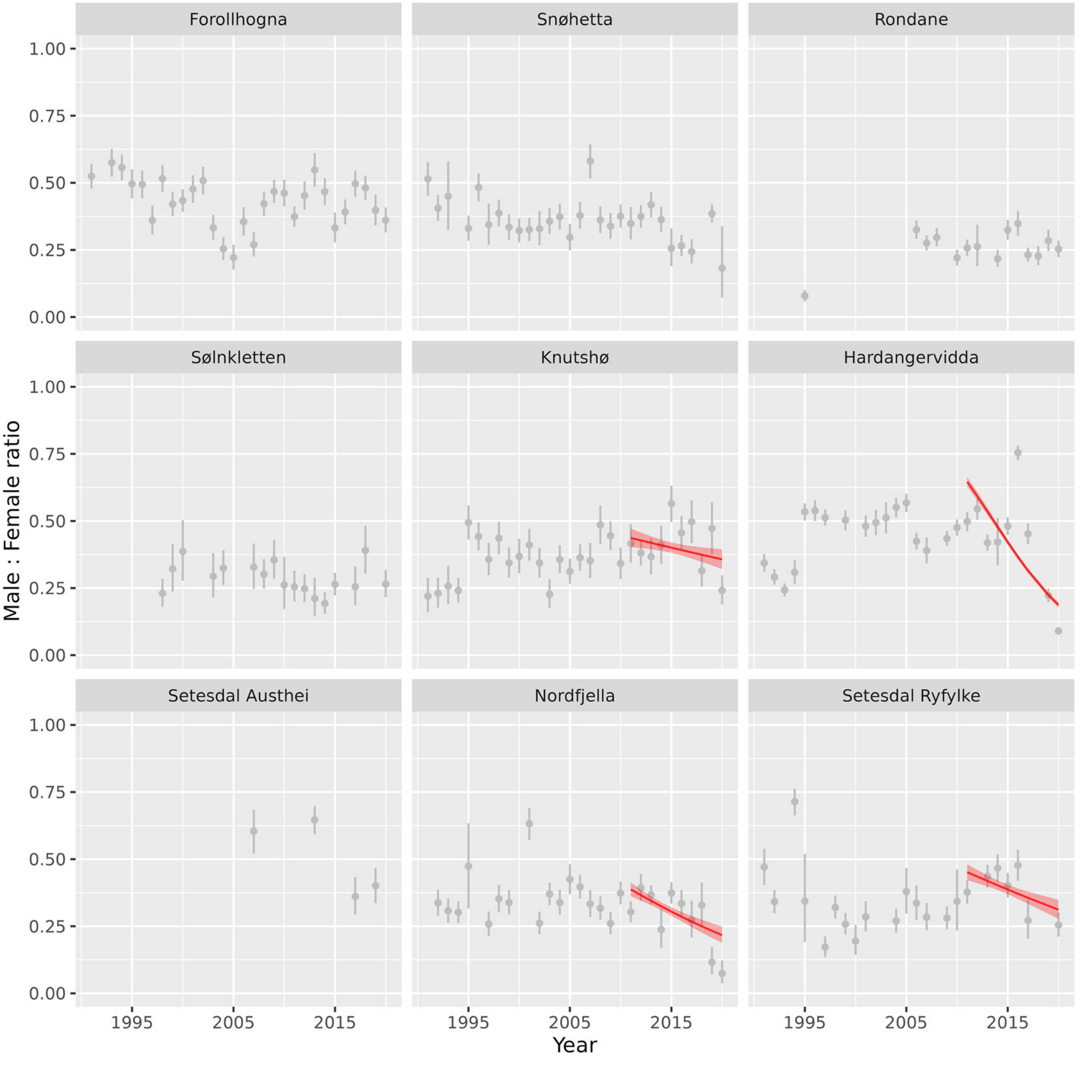


FIGURE 7 Trends in adult sex ratio (proportion of adult males) in reindeer areas of Norway. Only populations with sufficient data available were included. Following the quality standard, the index used was a combination of 5-year mean in proportion of adult males (grey dots with 95% CI [bars]) and 10-year trend (red line with 95% CIs [shading]); a negative trend over the last 10 years in 5 populations lowered the scoring 1 level. No population had a positive trend in adult sex ratio over the last 10 years.

Indicator set 3: Human-related habitat loss and fragmentation

Five national areas were classified as good, with ≤10% of their total areas included in focal areas with a medium (50–90%) or high (≥90%) reduction of use (Table 3, Table S9). Only 1 national area, Hardangervidda, scored as poor, with 38% of areas with a reduction of >90% in reindeer use of calving areas. For smaller areas, 8 scored as good, 3 scored as medium, 2 scored as poor, and 1 area could not be classified (Table 4, Table S10).

Connectivity scored as poor in 4 national areas and medium in the remaining 6 national areas. The indicator status ranged from 37% of movement corridors with a medium reduction in use in the area Sølnkletten to 61% of the movement corridors classified as poor in the most affected area of Setesdal Ryfylke. Connectivity in the smaller

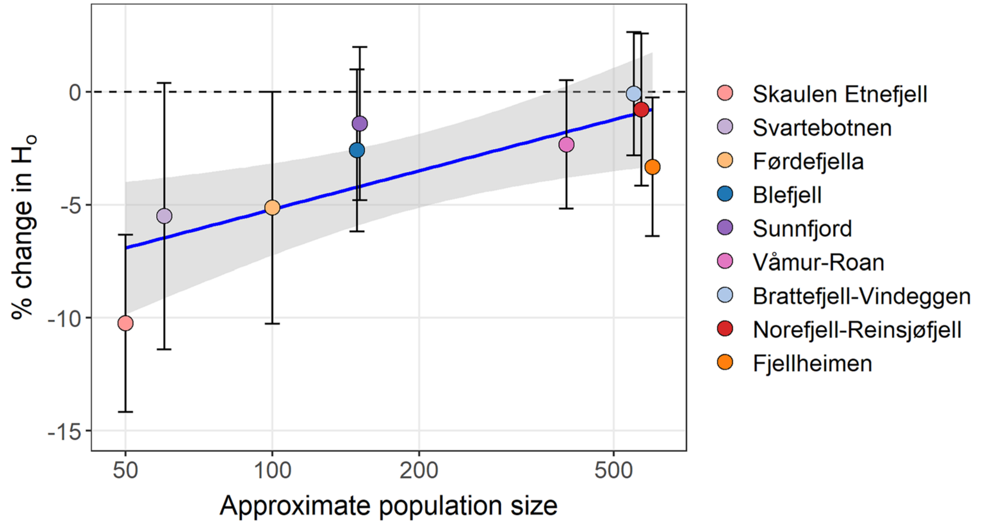


FIGURE 8 The relationship between aim for population size and loss of genetic diversity (observed heterozygosity [H_o]) for 9 of the 14 smaller reindeer populations in Norway, 2003–2019. Note that years for old versus new samples differed across populations.

areas was good in 9 areas, medium in 1 area, and poor in 3 areas. The last of the smaller areas could not be classified (Table 4).

DISCUSSION

Ecological indicators are becoming an increasingly applied tool to assess the condition of the environment and act as early-warning signals and indicators of change (Niemi and McDonald 2004). The quest for reliable indicators of biodiversity status to inform policy is urgently needed owing to rapid environmental changes, including human disturbance and infrastructure expansion. Reindeer and other wide-roaming species are particularly challenging to monitor and manage, and their populations are declining globally (Gunn 2016). Based on a mandate given by the Norwegian authorities, we developed an environmental quality standard for reindeer using 3 sets of status indicators: 1) population performance (body mass, recruitment, sex ratio, genetic diversity, and health), 2) lichen resources (biomass), and 3) human-related habitat loss and fragmentation. We then applied this standard to all 24 reindeer populations in Norway. The intention of the standard was to form a basis for action plans and restoration efforts that could improve status if needed (Figure 1). Here, we discuss the process of applying the standard, how it revealed several challenges for each set of indicators, and the potential for future development.

Indicator sets for monitoring ungulate populations

The background for management and conservation of reindeer share commonalities with other ungulate species but differs in some important details. Most ungulate populations in Europe were driven to a minimum in the nineteenth and twentieth centuries, while they have increased markedly in population size and distribution in the last century. This increase was due to a combination of changes in land use, better control of human hunting, low numbers of large predators, and direct restoration efforts by reintroductions (Apollonio et al. 2010). Subsequently, management of cervids in Europe has in the last decades mainly focused on the direct hunting management to limit populations under different aims (Gordon et al. 2004). Our indicator set 1 with body mass of calves and recruitment follows well-established standards used as ecological indicators for other cervid populations (Morellet et al. 2007), and is linked to the key role of density dependence in performance (Bonenfant et al. 2009). Owing to the potential for lagged density effects, indicators to avoid overgrazing or overbrowsing of winter forage can be critical (Mysterud 2006). For other cervids, there is a tradition to use a browsing index as an indicator for habitat status (Morellet et al. 2007). These are typically limited to trees or other woody vegetation where evidence of browsing is clearly visible during the non-growing season. Hence, indicator 2 with lichen biomass has a similar function as browsing indexes for other cervids (Morellet et al. 2007).

Another feature of reindeer in Norway is their reliance mainly on alpine and sub-alpine habitat. These habitats tend to be quite restricted and less well connected; therefore, populations in these areas are smaller compared to forest-dwelling ungulates. The relationship between genetic diversity and population viability is expected to be non-linear, as framed in the small population paradigm (Caughley 1994). After reintroduction, population growth rates of alpine ibex (*Capra ibex*) in Switzerland were reduced by 71% when suffering from inbreeding (Bozzuto et al. 2019). Genetic diversity is regarded as a broadly applicable indicator across taxa (Zimmerman et al. 2022), and there is considerable empirical evidence for a positive effect of genetic diversity on adaptability (Willi et al. 2022). An unrelated challenge connected to the openness of alpine landscapes is increased vulnerability to human disturbance (Courbin et al. 2022). There is considerable evidence that reindeer avoid passing through areas with tourist trails or where cabins are placed in narrow habitat corridors (Gundersen et al. 2022). Developing reliable indicators for how loss of habitat and fragmentation affect large herbivores appears urgent.

Measurements and indicator thresholds

The rationale of the indicators is firmly established in ecological theory. However, the choice of specific measurements and setting thresholds remain a key to retaining the original intent of each indicator set (Houle et al. 2011). The use of threshold values for indicators used in conservation faces different challenges (Johnson 2013): 1) definitions of thresholds are not always clear, 2) methods are not consistent, and 3) thresholds can differ between species and populations. We faced several of these challenges when setting common thresholds for all populations as poor, medium, and good status. A threshold in ecology is ideally indicative of a nonlinear change in performance at a given level (Johnson 2013), but thresholds in the reindeer quality standard partly rely on expert judgement rather than quantitative evidence of threshold effects. There are currently several quantitative methods to identify critical thresholds (Andersen et al. 2009), and we consider long-term datasets as more of a limitation than the method itself. Most parameters for indicator sets 1 and 2 can be regarded as easy to measure, while the basis for setting the thresholds varies. The definition and measurement of fragmentation, corridors, and structural and functional connectivity remain challenging and not strictly quantitative (Tischendorf and Fahrig 2000). For indicator set 3, there were no gold standards of measurement, and setting thresholds mainly relied on expert judgement. The current approach attempts to score loss of habitat and connectivity related to increased infrastructure and disturbances by humans in recent decades. Because the scoring was based on reindeer behavioral responses in terms of lost habitat use, this is intended to capture loss of functional habitat and connectivity. We discuss details and potential for improvement for each indicator below.

Status of population condition

The indicators calf body mass and recruitment clearly captured that the status of population condition was more often medium than good in the national reindeer areas of Norway (Figure 4). Calf body mass appeared to be higher in the smaller reindeer areas, typically with feral origin, but only 5 out of 14 areas had sufficient data to allow a robust scoring. The low body mass scores and some negative trends in development are cause for concern, and the indicator appears to work as an early warning of lowered population performance. However, the limiting factors driving the declines are uncertain.

In semi-domesticated reindeer, a clear threshold in the body mass of females determines whether they ovulate in a given year (Lenvik 1988), and a similar threshold in the body mass of females exists for neonatal survival of calves (Lenvik and Aune 1988). Similarly, a quite definite late winter body mass threshold for calf production has been documented in adult female Svalbard reindeer (Albon et al. 2017) and caribou in Alaska (Cameron et al. 1993, Adams and Dale 1998). Hence, given sufficient data, one could imagine setting the upper threshold (good → medium) for reduction in reproduction (ovulation), and the lower threshold when mortality is increasing (medium → poor). However, the thresholds for body mass effects on survival or maturity may not be clear and can vary among populations (Rönnegård et al. 2002). In our study from mainland Norway, a mean body mass of calves with good status was only found in Forollhogna (though with a negative trend) and 4 of the smaller areas. The overall limits for good condition were set partly based on the extensive knowledge from semi-domesticated reindeer (Lenvik 1988, Lenvik and Aune 1988, Rönnegård et al. 2002). Local thresholds may be developed and used to inform local management for populations with sufficient time-series data and quantitative estimates of their effects on vital rates. However, this would be at the expense of simple and common scoring across populations.

Status of recruitment

For the most part, status for recruitment and calf body mass followed the same pattern for each area (Figure 4). A notable exception was Hardangervidda, which had a poor status for calf body mass and a good status for recruitment. The relationship between female body mass and age at maturity also varied over time in Hardangervidda (Skogland 1990). A smaller female body size or a younger age at the onset of reproduction may yield high recruitment but lower calf body mass.

The applicability of monitoring data for the estimation of recruitment and sex ratios has limitations because of the variation in the ability to determine sex and relevant age classes from aerial photos or ground observations throughout the annual cycle. A limitation of helicopter-based calving surveys in wild reindeer is that count data are only separated into calves and adult females or yearlings (of both sexes), which are difficult to distinguish, and hence are pooled (Reimers 2006). Therefore, the recruitment rate is only a rough proxy (i.e., number of calves per 100 adult females and yearlings). The size of the previous year's cohort and their overwinter survival determine the proportion of yearlings, which in turn can strongly affect the estimation of recruitment, especially because most females do not give birth before the age of 2 or 3 years old. A population estimation model based on counts, harvest, and a change-in-ratio approach has been developed to account for this (Nilsen and Strand 2018), but it requires long-term, high-quality data from several surveys and harvest records to perform well. This is only available for a few of the larger populations. Model-based estimates could thus be used to inform the standard in some but not in the majority of reindeer populations. Nevertheless, a model-based approach could open for clearer thresholds related to population growth estimated before harvest (i.e., related to whether the current recruitment yields a harvestable offtake).

Status for adult sex ratio

Surveys of the demographic structure during the rut, when the sexes are aggregated, allow for a representative sample of the demographic composition and, hence, an estimation of the adult sex ratio. Status for adult sex ratio varied markedly across national reindeer populations, while data were lacking for most of the smaller populations (Figure 4). The poor status for Nordfjella and Hardangervidda was due to CWD management. During surveys, it remains challenging to separate some sex and age classes (Høymork and Reimers 2002), in particular yearling males from females and 2-year-old males from older males. The ability to separate male age classes also varies between observers and areas, causing substantial noise in the data. These age categories were pooled for some of the reindeer areas, and it was therefore not possible to apply the standard in all areas. Changing the adult male category to ≥2 years in the standard would probably reduce the noise and allow scoring for these areas too.

At a proximate level, the proportion of adult males in the population is mainly driven by hunting. In Norway, the most common way to issue license cards involves categories, which include free licenses, female licenses, and calf licenses (both sexes). A free license will typically result in hunters shooting an adult male because of their larger size (more meat) and trophy. Historically, male-biased harvesting has caused highly skewed sex ratios; therefore, we did not apply an upper threshold to the male-female ratio. The degree to which a low proportion of adult males affects short- and long-term population viability is unclear, and lower thresholds for adult sex ratio were not set from the perspective of population viability alone. The only documented case of an immediate population collapse due to skewed sex comes from the saiga antelope (*Saiga tatarica*), when poaching reduced adult males to <2% (Milner-Gulland et al. 2003). This extreme sex ratio is very far from the lower limit for poor condition of 20% adult males in the standard. However, a skewed sex ratio of <20% prime-aged males may lead to delayed calving, though the effects are only about 4-5 days of delayed calving (Holand et al. 2003, Mysterud et al. 2025a). It was challenging to reach a consensus among experts for setting thresholds because of their different scientific backgrounds, and we set a lower threshold for adult sex ratio more from a precautionary principle perspective; it was not directly linked to quantified population viability criteria. A sustained high proportion of males ensures sexual selection processes over a longer period. Furthermore, having a high proportion of adult males is viewed positively by many managers, as males generate a higher income and tend to use the peripheral parts of the reindeer range, often with higher anthropogenic pressure. Retaining access to and restoring such areas may become more important under adverse (or otherwise changing) future climatic conditions.

Health status

Due to a lack of systematic surveillance data and detailed knowledge of both status and how parasites and diseases affect reindeer populations, the health status indicator currently only includes the presence or absence of listed transmissible diseases, which are notifiable (Ministry of Agriculture and Food and Ministry of Trade 2022). The Nordfjella and Hardangervidda reindeer areas had a poor health status owing to the detection of CWD. Since 2016, there has been extensive surveillance of CWD in all reindeer areas except for a few very small populations with no current harvests (Mysterud et al. 2023c). The presence of a notifiable, listed, transmissible disease with the potential for being zoonotic or with risk of spillover to livestock will mean that public health or veterinary health authorities can intervene and override ordinary population management. The detection of CWD in Nordfjella and Hardangervidda shows how outbreaks of the listed diseases can turn all other factors upside down in reindeer management. For populations with CWD detection, recommended actions to limit the disease include an overall reduction of population size and male-biased harvesting leading to female-biased sex ratios, which will also give a low status for other parts of the standard. Currently, there are no direct data for reindeer to set thresholds for population parameters to successfully limit CWD over the long term. In terms of other notifiable transmissible diseases, Norwegian wildlife health monitoring generally relies on passive surveillance (Reiten et al. 2024), and few incoming carcasses from wild reindeer.

Currently, climate change is increasing the risk of infection by many groups of parasites and pathogens (Jones et al. 2008). A footrot disease (digital necrobacillosis) was first described in wild reindeer in 2007–2008 (Handeland et al. 2010), and a massive outbreak occurred in Hardangervidda in 2019 (Mysterud et al. 2023b). Oestrid flies, both warble fly (*Hypoderma tarandi*) and nose botfly (*Cephenemyia trompe*), are known to markedly affect the foraging time of reindeer during warm weather conditions (Hagemoen and Reimers 2002) and can affect the body condition of calves (Handeland et al. 2021). Castor bean ticks (*Ixodes ricinus*), which can infect reindeer with the bacterium *Anaplasma phagocytophilum*, have increased their elevational distribution (Stuen 1996). Infection with the brainworm *Elaphostrongylus rangiferi* increases at higher temperatures, partly because of the restricted elevational niche of the intermediate gastropod host (Handeland et al. 2019). In the Knutshø area, a highly pathogenic nematode

(*Nematodirus battus*) was detected (Utaaker et al. 2023), which likely represents a spillover event from domestic sheep. Furthermore, infectious diseases are not the only health concerns for reindeer. Extensive antler gnawing before shedding has been documented in several populations (Mysterud et al. 2020). This is assumed to reflect mineral deficiencies; however, the causes remain undocumented.

We assume that both low body mass and recruitment could indicate poor health status owing to increasing parasitism or disease (Ballesteros et al. 2012), and extensive monitoring of a broader range of parasites and diseases is challenging and costly to implement as an indicator in the standard. However, monitoring a wider range of diseases and parasites in specific areas is urgently required to better understand the drivers of body conditions and recruitment in general.

Status of genetic diversity

Genetic diversity was scored as having a good status among all 10 national reindeer populations. The microsatellite method used to evaluate the areas appeared to have low sensitivity, with very wide confidence intervals for changes in heterozygosity (Figure 4). Sensitivity was markedly improved when a recently developed SNP-array was made available for the later assessment of the 14 smaller areas (Hansen, B. B., B. Peeters, Ø. Flagstad, K. Røed, M. D. Martin, H. Jensen, H. A. Burnett, V. C. Bieker, A. Mysterud, X. Sun, S. D. Côté, C. Robert, C. M. Rolandsen, and O. Strand, unpublished manuscript). Four of the smaller populations were classified as poor because of excessive loss of genetic diversity (Figure 4), even though changes in diversity were marginally insignificant owing to small sample sizes. This classification was justified by expert opinion combined with additional analyses showing very high levels of inbreeding or very small or declining effective population size (N_e), ranging between only 6–41 for these 4 reindeer areas. Three other small populations had indications of high levels of genetic loss, but with weak statistical support. Because of the original definition of the indicator in the standard, they were rated as having a good genetic status, likely owing to very low power in statistical analysis, which is hence misleading.

Genetic load and inbreeding problems can be critical for small populations (Dussex et al. 2023). Genetic variation and inbreeding levels are linked to N_e, a key parameter that influences genetic drift (Wright 1931). Effective population size depends on the individuals who have conceived and given birth (Wang et al. 2016) and for a polygynous species like reindeer can be as low as only a fifth or less of the actual population size (Kvalnes et al. 2024), depending on the demographic composition and genetic relatedness of the reproducing individuals. The immigration of individuals from neighboring populations increases N_e, whereas fragmentation within a given area may decrease N_e (England et al. 2010). Therefore, we suggest including changes in N_e and an inbreeding coefficient as indicators in the standard, representing a potential early warning indicator of the likely future loss of genetic diversity, before this can be measured directly as changes in observed heterozygosity.

Conservation genetics and genomics are rapidly advancing fields (Willi et al. 2022), as illustrated by the changes in methodology applied in the standard for national versus the later assessment of the smaller reindeer areas. Falling costs of whole-genome sequencing may also soon allow for even more detailed surveys, and we recommend that the methods used in the standard be adjusted when new technology becomes available and affordable.

Status of lichen resources

The only 2 national wild reindeer areas with a good status for the lichen condition index are dry inland areas, while all other areas had a medium status. This likely reflects the natural variation in the suitability of habitats for lichens, as lichens are typically outcompeted by mosses and vascular plant groups in moist habitats (Wielgolaski 1975). Therefore, the lichen biomass did not necessarily reflect changes related to reindeer overgrazing, as was the intention of the index. Rather than using lichen biomass per se, one may consider using trends in the status of lichen resources over time in each area, which account for spatial habitat variation. However, lichen may also decline because of ongoing climate change (Tømmervik et al. 2004). Therefore, analysis of drivers will be a key part to inform decision making (see Conservation Implications).

The method we used does not capture darker lichens with a different spectral signature, such as the snowbed Iceland lichen (*Cetrariella delisei*), gray witch's hair (*Alectoria nigricans*), and Iceland moss (*Cetraria islandica*; Brodo et al. 2001). These lichens provide good grazing for reindeer, and methods should be developed to include these resources. Furthermore, reindeer in many areas likely rely heavily on food resources other than lichens during the winter, especially with decreasing lichen availability (Skogland 1984). Vegetation indices such as normalized difference vegetation index (NDVI) can be used as a proxy for the content of edible vascular plants in winter grazing areas. This also involves seeking refuge in birch forests at lower elevations to forage under adverse conditions. Further insight into the diet of reindeer in different areas, now within the reach with methods such as metabarcoding approaches, appears to be the next step in developing a more complete set of indices for forage conditions.

Status on human-related habitat loss and fragmentation

Today, the loss of connectivity is a more common concern than the loss of seasonal habitat (Tables 3 and 4). A notable exception was the largest area in Hardangervidda, with considerable displacement from the presumed best summer foraging habitat observed over the last 3–4 decades. A large part of this area has the status of a National Park that attracts more tourists (Gundersen et al. 2020). The national authorities are currently developing indirect (e.g., restriction by law) and direct (e.g., removal of infrastructure) measures to improve habitat use by reindeer in unapproved ranges, and trend indicators may be more important than the current status to evaluate the effects of such interventions.

Combining monitoring and model-based information with expert-based judgment is ideally required to overcome data limitations (Certain et al. 2011), which was the case for conservation programs for caribou in Canada (McLellan et al. 2023, Lelotte et al. 2025). The benefit of the current approach was the participatory process with meetings between practitioners, local management, and researchers in all 24 reindeer areas, with the common task to map focal areas (i.e., areas where human-related activity has reduced reindeer use). This approach yields a high level of trust from the local communities in the results and thus provides a good basis for the implementation of actions with the aim of improving habitat connectivity and migration because such actions are mainly about people management. However, the current habitat approach is challenging to implement in updated assessments with its comparison to the status 50 years ago, and hence, difficult to operationalize in management. A comprehensive statistical framework has been developed to assess cumulative anthropogenic impact on functionally connected habitats to assess simultaneously habitat loss and fragmentation in reindeer (Panzacchi et al. 2015a, b; Van Moorter et al. 2023a, b). This framework builds upon new methods, such as ConScape (Van Moorter et al. 2023a, Niebuhr et al. 2023b), that appear powerful for identifying functional areas and corridors important to reindeer. These approaches are also used to predict how new infrastructure or mitigation measures are expected to affect reindeer in each given area, as a basis for operational management (Dorber et al. 2023, Niebuhr et al. 2023a, Panzacchi et al. 2022, 2024).

Integration of indicators

Our sets of indicators are together integrative to capture the complexity of the conservation situation for reindeer, but how to assess this diverse evidence to inform decision-making is challenging. Novel methods are arising that may improve the balance between the strength of support and weight of evidence (Christie et al. 2023), and there are several approaches for weighting and aggregating ecological indicators (Gan et al. 2017). The general status in the standard was set as the poorest score for all indicators in the set, which was done from a precautionary principle perspective and for consistency with other classifications, such as that for wild salmon (Forseth et al. 2013). This was part of the mandate given to the scientists, and retrospectively there are clearly limitations to following these principles in practice.

First, this yields low overall scores even for populations differing quite markedly in their mean score (Table S11). If using values for categories (good = 1, medium = 2, poor = 3), a status of medium had a variation in mean score across all indicators from 1.2 to 1.6, while values for the poor status ranged from 1.5 to 2.3 (Table S11). Hence, a poor status may occasionally have a better mean score across indicators than a medium status, and reindeer areas with a similar score can face considerable variation in conservation situation. The mean scores calculated across all indicators and between indicator sets were similar ($r = 0.959$; Table S11). Second, improvements in some scores in future reassessments may be hidden by a single poor score.

Also, in retrospect, how to integrate scores could have been considered more carefully. Finding a scoring system that integrates information in a more nuanced manner can motivate local managers to make further efforts if they immediately see the results of actions taken. Equal weighting was part of the mandate for the reindeer quality standard, but this is only advised when all indicators are considered equally important (Gan et al. 2017). There has been a heated debate related to the Living Planet Index (LPI) regarding aggregation and weighting of data in analysis (Leung et al. 2022, Loreau et al. 2022), and arguments that global status assessments can exaggerate the effects of local decline (Leung et al. 2020). Similarly, the precautionary principle with the lowest score setting the overall score will tend to exaggerate effects. Other options could be presenting the proportion of indices with a low status per area, or visualized scoring using multiple correspondence analysis.

Following this first assessment, we see clear arguments for refinement on how to meaningfully integrate indicators in the standard for reindeer. However, such technical details should not divert from the real issue, which is a considerable biodiversity loss documented in the case of LPI (Loreau et al. 2022), and the critical conservation situation for reindeer in this study. Clearly, despite some limitations of the environmental quality standard, it clearly conveys the threats facing reindeer conservation.

CONSERVATION IMPLICATIONS

Although the specifics of the environmental quality standards are outlined for application to reindeer, we see considerable promise for similar approaches for the management of other large mammals. This is not limited to species of conservation concern. Overabundance of ungulates is often a challenge, resulting in a reduction in performance indicators and raising concerns for biodiversity conservation and societal interests related to forestry, agriculture, and traffic accidents (Côté et al. 2004). Developing aims and standards for management would provide clearer guidance to managers facing contrasting perspectives. Nevertheless, the application of this standard revealed some limitations and possibilities for improvement.

Analysis of drivers and data gaps

Overall, despite some data limitations and uncertainties regarding the chosen indicators and thresholds, we regard this standard as a major step forward in the conservation and sustainable management of wild reindeer populations in Norway. The establishment of quality standards has important conservation implications. The aim of the Ministry of Climate and Environment in Norway is now to halt the negative trends by 2030, have a medium status of all national areas by 2050, and a good status by 2100 (Ministry of Climate and Environment 2024). In the standard, it was explicitly stated in the mandate that, when sets of indicators are assigned the poor status, an evaluation of the potential causes of negative trends should be conducted before implementation of an action plan (Figure 9). Owing to a lack of resources and time, we conducted only a qualitative assessment proposing hypotheses for the observed patterns. We strongly recommend that quantitative studies of drivers based on analysis of long-term time series are implemented for indicators where available, which will enable more targeted mitigation measures. There are several potential limiting factors, and the cause of a poor status can differ from population to population. Climate

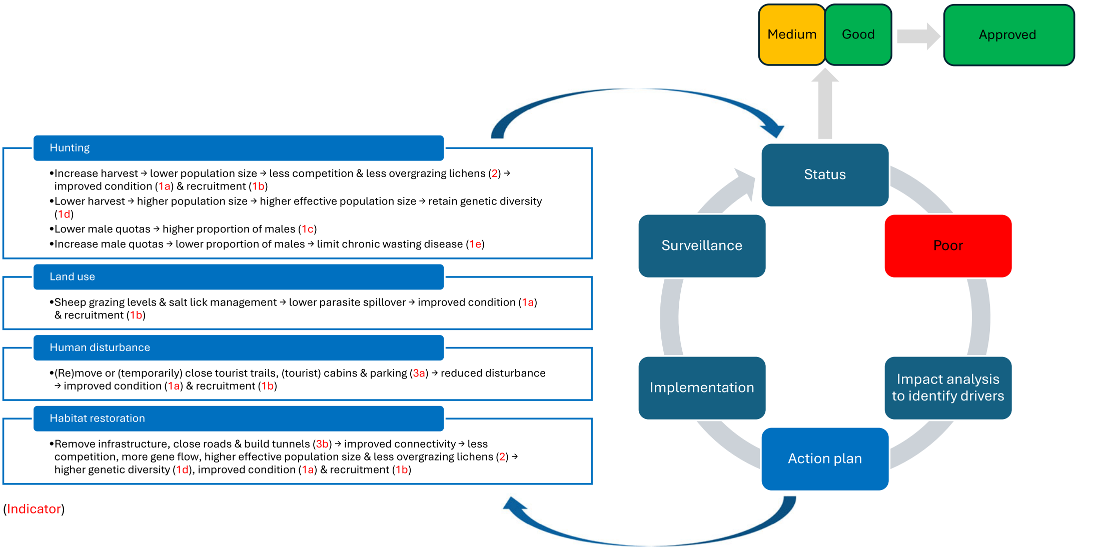


FIGURE 9 An overview of the operationalization of the quality standard for reindeer in Norway. A poor score should elicit an impact analysis and identification of underlying drivers to serve as a basis for action plans. These action plans should target limiting factors (drivers) at the population or habitat level linked to specific indicators (in red) in each case. The list of possible actions offers some concrete examples of assumed functional relationships but is not intended to be exhaustive. Surveillance and updated indicators will assess whether the implemented actions have had the desired effect. A medium or good score results in an approved status for the given reindeer area, which represent the long-term aim for all reindeer areas.

change is currently affecting alpine populations of many vertebrates globally, and if the main driver, it will be challenging to reverse declines. However, if declines are linked to human disturbance, management would be a feasible option. An understanding of limiting factors for the current poor status of reindeer is in many cases lacking, and there is a risk that national and local governments could implement costly action plans that may not work, or that the most proper actions are overlooked.

The lack of high-quality empirical data typically limits efforts to reliably assess conservation status in detail (Post et al. 2022, Dove et al. 2023). Long-term data were a limitation in the first evaluation of 24 reindeer populations in Norway, in particular for indicator set 1 for the smaller reindeer areas (Figure 4). This is likely to improve with established data protocols in future assessments but will remain a challenge for some of the smaller populations with very limited harvests and, hence, a lack of incoming data on calf body masses and samples for genetic analysis. Ecological surveillance works best in combination with research and the continued use of data (Lindenmayer and Likens 2010). Much of the data from this first classification were scattered on the computers of local experts and never reached the national database of wild ungulates. There is always a risk that monitoring data are not well organized and are lost (Lindenmayer and Likens 2010). A scientific board that oversees annual gatherings, data collection, and the quality control of incoming data, and secure data storage, would be a marked improvement.

Scale, population size, genetics, and conservation value

Following the mandate from the government, we relied on the current demarcation of 24 reindeer populations. We assumed equal conservation value irrespective of their genetic origin or wild genetic integrity (Anderson et al. 2017), population size (Table 1), or status as a national reindeer area (Figure 2). Historically, wild reindeer in

Norway consisted of southern and northern populations, with considerable seasonal movement between summer and winter grazing areas (Andersen and Hustad 2005). National management authorities first demarcated wild reindeer ranges in the 1970s, with Raudafjell added as late as 2019, and their boundaries were partly defined by human fragmentation.

Population viability is clearly related to population size (Beissinger and McCullough 2002). Population size itself was not implemented as an indicator in the standard, partly because of the substantial logistical challenge to obtain accurate population size estimates for all populations. Hunting management is the main factor limiting (or even regulating) population size (Strand et al. 2012). Population sizes should ideally be balanced (not too high, not too low) to avoid overgrazing of lichens at high densities and to avoid reduced population viability and adaptability through low genetic diversity, effective population size, and inbreeding (Poirier et al. 2019). Keeping the population at a population size goal (typically winter numbers) or within an upper and lower boundary is thus often a local management aim. Currently, there is limited knowledge to inform the setting of such density thresholds, and because of variable carrying capacities, they would differ for each area. A viable alternative for the quality standard could be the inclusion of an indicator with a threshold for a lower effective population size (see Status of genetic diversity).

Ideally, one should restore connectivity to allow gene flow between populations. In reality, fragmentation is ongoing, and some of the populations now consist of 2 or more smaller and isolated sub-populations (Panzacchi et al. 2013b). This highlights the need for more detailed data, like the spatial coordinates of tissue samples used in genetic analysis. It also questions the whole basis for valuation. The different origins and levels of mixing with semi-domestic reindeer (Kvie et al. 2019) are contentious issues that have been neglected in the current wild reindeer management (Mysterud et al. 2024). If the aim is to follow a conservation biology principle aligned with the Norwegian Biodiversity Law and the IUCN Red List criteria, further mixing of semi-domestic or feral herds with those of mainly wild origin should be strictly avoided. Establishing an indicator of wild genetic integrity in the standard is one option.

How to distribute limited resources across 10 national areas and 14 smaller areas is likely to become an issue of debate before future reassessments. Several of the smaller 14 reindeer ranges in Norway probably cannot sustain increased population sizes owing to the limited habitat available. Hence, the situation with a low effective population size and resulting severe loss of genetic diversity is likely to remain and develop further (Figure 8). Translocation of males was effective in countering bottleneck effects in an isolated bighorn sheep (*Ovis canadensis*) population (Poirier et al. 2019). This partly relates to the single large or several small (SLOSS) debate for optimal conservation of biodiversity through spatial configuration (Diamond 1975). Some of the smaller populations are isolated (Figure 2) and may serve as a refuge for healthy reindeer if CWD continues to spread across the larger populations. For caribou in Canada, it was argued that it will be too expensive and difficult to implement conservation action across all ranges (McLellan et al. 2023), and that priority should be given to populations with the greatest potential for recovery. Overall, the environmental quality standard provides a transparent and robust framework to enable conservation of reindeer, but it remains uncertain whether implementation of action plans can restore a good standard in both national and smaller reindeer areas.

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CONFLICT OF INTEREST STATEMENT

The authors have no competing interests to declare.

DATA AVAILABILITY STATEMENT

The data and scripts are available in Zenodo (Mysterud et al. 2025b).

ETHICS STATEMENT

No animals were marked or shot for the purpose of this study, and thus no ethical approval was required for this study.

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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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