Vitenskapskomiteen for mattrygghet
Norwegian Scientific Committee for Food Safety

VKM Report 2017:9

CWD in Norway – a state of emergency for the future of cervids (Phase II)

Opinion of the Panel on Biological Hazards of the Norwegian Scientific Committee for Food Safety

Report from the Norwegian Scientific Committee for Food Safety (VKM) 2017:9
CWD in Norway – a state of emergency for the future of cervids (Phase II)

Opinion of the Panel on Biological Hazards of the Norwegian Scientific Committee for Food Safety
29.03.2017

ISBN: 978-82-8259-266-6
Norwegian Scientific Committee for Food Safety (VKM)
Po 4404 Nydalen
N – 0403 Oslo
Norway

Phone: +47 21 62 28 00
Email: vkm@vkm.no

www.vkm.no
www.english.vkm.no

Suggested citation: VKM. (2017) CWD in Norway – a state of emergency for the future of cervids (Phase II). Opinion of the panel on Biological Hazards, ISBN: 978-82-8259-266-6, Oslo, Norway.

Title

CWD in Norway – a state of emergency for the future of cervids (Phase II)

Authors preparing the draft opinion

Helge Hansen, Georg Kapperud, Atle Mysterud, Erling J. Solberg, Olav Strand, Michael Tranulis, Bjørnar Ytrehus, Maria Gulbrandsen Asmyhr (VKM), Danica Grahek-Ogden (VKM)

Assessed and approved

The opinion has been assessed and approved by Panel on Biological Hazards. Members of the panel are: Yngvild Wasteson (Chair), Karl Eckner, Georg Kapperud, Jørgen Lassen, Judith Navhus, Truls Nesbakken, Lucy Robertson, Jan Thomas Rosnes, Olaug Taran Skjerdal, Eystein Skjerve, Line Vold

Acknowledgments

The Norwegian Scientific Committee for Food Safety (Vitenskapskomiteen for mattrygghet, VKM) has appointed a working group consisting of both VKM members and external experts to answer the request from the Norwegian Food Safety Authority/Norwegian Environment Agency. Project leader from the VKM secretariat has been Maria Gulbrandsen Asmyhr. The members of the working group Georg Kapperud (Panel on Biological Hazards), Bjørnar Ytrehus (Panel on Microbial Ecology), Atle Mysterud (University of Oslo), Erling J. Solberg (NINA), Olav Strand (NINA) Helge Hansen (Fylkesmannen i Sør-Trøndelag) and Michael Tranulis (NMBU) are acknowledged for their valuable work on this opinion. The Panel on Biological Hazards are acknowledged for comments and views on this opinion. VKM would like to thank Eli K. Rueness (Panel on Alien Organisms and Trade in Endangered Species (CITES)), Roar Gudding (Panel on Animal Health and welfare), Eystein Skjerve (Panel on Biological Hazards) for their valuable comments on the report. VKM would also like to thanks Line Tau Strand (NMBU) for writing Appendix I and Lucy Robertson (Panel on Biological hazards) for valuable comments on content and language.

Competence of VKM experts

Persons working for VKM, either as appointed members of the Committee or as external experts, do this by virtue of their scientific expertise, not as representatives for their employers or third party interests. The Civil Services Act instructions on legal competence apply for all work prepared by VKM.

Table of Contents

1 Literature 15
1.1 Relevance screening 15
2 Introduction 16
2.1 Background 16
2.2 Prion diseases 18
2.2.1 Transmission and species barrier 19
2.2.2 *PRNP* variation among deer and the question of silent carriers 20
2.2.3 Prion strains 23
2.3 What is currently known about CWD strains in Norway? 25
3 Transmission and environmental factors 27
3.1 The role of environmental contamination and persistence 27
3.2 The influence of soil and bedrock on environmental persistence and disease pathogenesis 29
3.3 Environmental processes that remove infective prions 30
3.4 Spread by carnivores 31
3.5 The importance of salt licks and supplemental feeding 32
4 Epidemiology of CWD in cervid populations 34
4.1 Rise in CWD prevalence 34
4.2 Age and gender associations with infection 35
4.3 Density-dependent or frequency-dependent transmission? 36
4.4 Predators, hunters, vehicles, and other modulators of CWD epidemiology 40
5 The effects of CWD on population dynamics 42
5.1 CWD, mortality and reproduction 42
5.2 Variation in dynamic effect of CWD 42
5.3 Species differences in effects of CWD 43
5.4 Assumed CWD dynamics in Norwegian cervids 44
5.5 The process and risk of spillover 47
6 Wild cervid population development and surveillance in Norway 49
6.1 General population development and performance of wild cervids in Norway 49
6.2 Migration, dispersal, and the spatial scale of population units 50
6.3 Population development and performance of reindeer in the Nordfjella area 51
6.4 Population development and performance of moose and deer in the Trøndelag region (Selbu and surrounding municipalities) 55

7 Screening for CWD in cervids in 2016 and early 2017 56
7.1 Results of the CWD screening in 2016 and early 2017 (to early March)..... 57
8 Semi-domesticated reindeer 59
8.1 Management levels 59
8.2 Risk factors with regard to herding practices 60
8.3 Herding to control and limit disease..... 60
9 Measures for prevention, control, and eradication of CWD 61
9.1 Prevention..... 62
9.2 Control..... 63
9.2.1 Removing the infectious agent 63
9.2.2 Containing the infectious agent 63
9.2.3 Removing infected animals..... 64
9.2.4 Reducing animal density 64
9.2.5 Selective targeting of males 66
9.2.6 Environmental and managerial adjustments to minimise contact rates 66
9.3 Eradication 67
10 Strategies for management of CWD in Norway..... 69
10.1 Strategies – options for management 69
10.1.1 Strategy 1a – No intervention in the case of classical CWD..... 70
10.1.2 Strategy 1b – No intervention in the case of atypical, less-contagious CWD .. 71
10.1.3 Strategy 2 – Eradicate CWD outbreaks in a confinable population by depopulation, fallowing, and restocking 72
10.1.4 Strategy 3 – Control CWD outbreak in a continuous population by spatially targeted harvest 73
10.2 Decision process - Strategies for surveillance..... 74
10.3 Management options for reindeer in Nordfjella and Filefjell..... 76
10.3.1 Assessment of management strategies for Nordfjella zone 1 76
10.3.2 Reindeer in Nordfjella zone 2..... 77
10.3.3 Semi-domesticated reindeer in Filefjell 78
10.4 Management recommendations for moose in Selbu 79
10.4.1 Assessment of management strategies for moose in Selbu..... 79
11 Uncertainties..... 80
11.1 Specifics for current management situation 80
11.1.1 The evidence and uncertainties along the timeline for reindeer in Nordfjella zone 1 80
11.1.2 The evidence and uncertainties along the timeline for moose in Selbu 81

11.2 Summary of uncertainties 81
12 Conclusions (with answers to the terms of reference) 82
13 Data gaps 94
References 95
Appendix I 109
Appendix II 115
Appendix III 121

Summary

The Norwegian Food Safety Authority (Mattilsynet, NFSA) and the Norwegian Environment Agency (Miljødirektoratet, NEA) requested the Norwegian Scientific Committee for Food Safety (Vitenskapskomiteen for mattrygghet, VKM) for a scientific opinion on Chronic wasting disease (CWD) in cervids. The project was divided into two phases, and VKM published the scientific opinion from phase I "CWD in Norway" in June 2016. The current report is the result of phase II.

VKM was asked to provide updated information on food safety, aspects important for transmission of CWD within and between populations and species, and the potential origin of the disease in Norway. Moreover, VKM was asked to highlight important risk factors with regard to disease transmission, and how these risk factors might affect choice of management strategy. Finally, VKM was asked to highlight relevant management strategies from North America or elsewhere.

VKM appointed a working group consisting of one member of the Panel on Microbial Ecology, one member of the Panel on Biological Hazards, and five external experts, as well as VKM`s secretariat to answer the questions from NEA and NFSA. One member of the Panel on Alien Organisms and Trade in Endangered Species (CITES), one member of the Panel on Animal Health and Welfare, as well as one member of the Panel on Biological Hazards commented on the draft report. The Panel on Biological Hazards assessed and approved the final report.

Background
Chronic wasting disease (CWD) is a prion disease that affects deer, moose, reindeer, and related species (cervids). Prion diseases are chronic neurodegenerative diseases that occur naturally in humans and ruminants, and are invariably fatal. Some prion diseases, such as classical scrapie in sheep and goats and chronic wasting disease (CWD) in cervids, are contagious, spreading directly between animals or via environmental contamination. In contrast, prion diseases known to affect humans are not known to be contagious.

Prions are extraordinary agents consisting of misfolded protein aggregates that are remarkably stable and can remain infectious for years in the environment. Prion proteins are present in most animals, but the misfolding makes them very hard to break down. Consequently, misfolded prion proteins accumulate in the brain and eventually in other tissues, causing damage to those tissues.

Until recently, CWD was only known from North America and South Korea. During a routine marking event in April 2016, a female reindeer (*Rangifer tarandus*) of the Nordfjella wild reindeer herd in Norway exhibited unusual behaviour, and died shortly afterwards. This unusual death was routinely investigated, and the animal was diagnosed with CWD. This was the first time CWD had been diagnosed outside North America and South Korea and the first case of natural CWD in reindeer.

In addition, two moose (*Alces alces*) in Selbu, Norway were diagnosed with CWD in May 2016. Selbu is located approximately 300 km northeast of the Nordfjella mountain range. Currently there is considerable uncertainty regarding the nature of the CWD diagnosed in the two moose. Some of the characteristics of these cases indicate consistency with atypical prion disease, as described in domestic animals, but a final conclusion depends on the results from ongoing investigations.

Following the diagnosis in reindeer, Norwegian authorities initiated a screening programme in which hunters were requested to collect tissue and the heads of dead cervids during the 2016 hunting season. Animals that had died from causes other than hunting were also tested for CWD. Since March 2016, 4629 samples of moose, 2550 samples of red deer, 627 samples of roe deer, 860 samples of reindeer, 2494 semi-domesticated reindeer, 163 farmed deer and 104 samples of unidentified species were tested for CWD.

Two additional cases of CWD were diagnosed in wild reindeer in the Nordfjella population. Together with a clinical, pathological and epidemiological picture consistent with contagious CWD, as described from North America, this indicated that there is an ongoing outbreak of CWD in the wild reindeer population of the northern part of Nordfjella wild reindeer range.

Results

An increase in the distribution and prevalence of CWD will increase exposure of other species, including domestic animals and humans, to this infectious agent. There is currently no evidence indicating transmission of CWD to domestic animals or humans, either by direct contact with cervids, cervid meat, or other products from cervids, or through the environment. VKM continues to support the conclusion from phase I concerning food safety of meat from cervids, that the zoonotic risk of CWD (transmission to humans) is **very low**. Preliminary results from characterisation of the moose cases and the agent involved indicate that important features deviate significantly from those found in the reindeer and in North American cervids, raising uncertainty with regards to the zoonotic potential. Therefore, based on the data currently available, VKM **is not able to reach an evidence-based conclusion** regarding the food safety of meat from moose and other cervids infected with this potentially new variant of CWD.

Whereas direct transmission (animal-to-animal) seems most important in the early phases of a CWD epizootic, the role of indirect transmission (from the environment) increases as the prevalence increases. Once contagious CWD is established, it is very likely that the disease will increase in prevalence *within* the affected population and spread to contact populations. The rate of increase in prevalence, the resulting impact in a given population, and the efficacy of spread will depend on a range of environmental factors, and the characteristics of the species and population in question. For example, in affected populations of a gregarious species like reindeer, CWD is likely to lead to population decline in the long-term.

Experiences from North America indicate that prions aggregate in the environment, making eradication of the disease extremely difficult once it has been allowed to develop and become endemic. It is therefore important that efficient measures are implemented at the

earliest opportunity in order to have a realistic chance of eradicating local occurrence of CWD and preventing further spread.

Contagious CWD found in a confinable population, such as many wild reindeer herds, should be managed by eradication of the host population, fallowing of the area (> 5 years), and restocking from a healthy population.

The report explains that culling of the Nordfjella reindeer herd is a necessary, immediate response to the current situation. However, as part of an adaptive management strategy, this measure should be under active review and may be revised in the event that new cases of CWD are discovered.

In contrast, in continuous populations, such as most red deer, moose, and roe deer populations, spatially targeted culling within a defined containment zone should be used to control a CWD outbreak. Confinement of CWD-infected populations should be increased where possible and contact with other populations of cervids restricted, for example by fencing, herding, enhancing natural or man-made obstacles, or decreasing the densities of the relevant cervid populations.

Potential "hotspots" for disease transmission (supplementary salt-licks, supplementary feeding sites etc.) should be eliminated in areas with CWD as well as the surrounding areas, and should further be considered for other parts of the country. Precautionary measures should be implemented to prevent anthropogenic spread of the disease.

Finally, increasing the national surveillance of CWD in cervids is essential to ensure that there is a comprehensive basis for future evidence-based management. This is required to ensure that cases and spread of disease are identified as soon as possible, as late discovery will limit the chances for successful eradication of CWD in Norway.

Key words: VKM, risk assessment, Norwegian Scientific Committee for Food Safety, Norwegian Environment Agency, Chronic Wasting Disease

Sammendrag på norsk

Vitenskapskomiteen for mattrygghet (VKM) har fått i oppdrag av Mattilsynet og Miljødirektoratet å lage en vitenskapelig vurdering av risiko forbundet med skrantesyke (Chronic Wasting Disease, CWD) hos hjortedyr i Norge. Prosjektet ble delt inn i to faser. I juni 2016 publiserte VKM rapporten fra fase I, «CWD in Norway».

I fase II ble VKM spurt om å presentere oppdatert informasjon knyttet til mattrygghet, sykdomsoverføring og sykdommens opphav. I tillegg ble VKM spurt om å belyse hvilke risikofaktorer som er viktige i forbindelse med sykdomsoverføring, samt hvordan disse risikofaktorene vil kunne påvirke valget av forvaltningsstrategi. VKM ble også bedt om å trekke frem relevante forvaltningsstrategier fra Nord-Amerika og andre steder.

VKM utnevnte en tverrfaglig prosjektgruppe bestående av ett medlem fra faggruppen for hygiene og smittestoffer, ett medlem fra faggruppen for mikrobiell økologi, fem eksterne eksperter samt VKMs sekretariat for å besvare oppdraget. Ett medlem fra faggruppen for dyrehelse og dyrevelferd, ett medlem fra faggruppen for fremmede organismer og handel med truede arter samt ett medlem fra faggruppen for hygiene og smittestoffer var referansepersoner for denne rapporten og kom med innspill underveis i arbeidet. Rapporten ble godkjent av faggruppen for hygiene og smittestoffer.

Bakgrunn
Skrantesyke er en prionsykdom som rammer hjortedyr som reinsdyr, rådyr, elg og hjort. Prionsykdommer skader nervesystemet og er dødelige. Det finnes andre prionsykdommer som rammer mennesker og drøvtyggere. Noen prionsykdommer, som for eksempel skrapesyke hos sau og geiter og skrantesyke hos hjortedyr, er smittsomme, og kan overføres direkte fra dyr til dyr eller indirekte gjennom miljøet. Prionsykdommer hos mennesker regnes derimot ikke som smittsomme.

Prionproteiner finnes naturlig i kroppen til de fleste dyr. Sykdom oppstår når disse endrer tredimensjonal form, det vil si at de blir «foldet feil», slik at kroppens celler ikke klarer å bryte dem ned. Prionene vil da hope seg opp, særlig i hjernen, og forårsake vevsskade.

Feilfoldede prioner som er skilt ut fra kroppen til et hjortedyr med skrantesjuke eller en sau med skrapesjuke, er svært stabile og kan smitte nye individer selv etter at de har ligget i miljøet i flere år.

Skrantesyken var inntil nylig kun kjent fra Nord-Amerika og Sør-Korea. Da en gruppe forskere skulle merke reinsdyr *(Rangifer tarandus*) i Nordfjella villreinområde i Norge i april 2016, fant de en døende simle. Siden dyret døde i forbindelse med at flokken var skremt av forskerne, ble det sendt inn til obduksjon. Rutinemessig prøvetaking viste da at simla hadde skrantesyke. Dette var første gang skrantesyke var påvist utenfor Nord-Amerika og Sør-Korea og aller første gang det ble påvist naturlig infeksjon hos reinsdyr.

I tillegg til dette tilfellet hos reinsdyr, ble det i mai 2016 oppdaget to elg (*Alces alces*) med skrantesyke. De to elgene ble funnet i Selbu, som er lokalisert omtrent 300 km nord-øst for Nordfjella.

Som en følge av at skrantesyke var påvist hos norske hjortedyr, iverksatte myndighetene et kartleggingsprogram. Det ble samlet inn prøver fra hjortedyr skutt under ordinær jakt, hjortedyr som var drept av andre årsaker, f.eks. i trafikken (såkalt «fallvilt») og fra tamrein og oppdrettshjort som ble slaktet. Alt i alt ble 4629 prøver av elg, 2550 prøver av hjort, 627 prøver av rådyr, 860 prøver av villrein, 2494 tamrein, 163 oppdrettshjort og 104 prøver av uidentifiserte hjortedyrarter testet for skrantesyke mellom våren 2016 og februar 2017.

I kartleggingen ble det påvist skrantesyke hos ytterligere to villrein fra Nordfjella. De kliniske, patoanatomiske og epidemiologiske beskrivelsene av tilfellene i Nordfjella, indikerer at denne sykdommen er sammenliknbar med den varianten av skrantesyke som er påvist hos hjortedyr i Nord-Amerika. Det er dermed sannsynlig at det er et utbrudd av smittsom skrantesyke i villreinbestanden i den nordlige delen av Nordfjella villreinområde.

Resultater

En økning i forekomst og utbredelse av skrantesyke innebærer at andre arter, både mennesker og dyr, blir mer eksponert for smittsomme prioner. Basert på dagens kunnskap, er det ikke noes om indikerer at skrantesyke kan overføres til husdyr og mennesker, hverken gjennom direkte kontakt med hjortedyr, gjennom kjøtt eller andre produkter, eller gjennom miljøet. I lys av dette opprettholder VKM konklusjonen fra fase I, at faren for smitte tilmennesker anses som **veldig lav**. Dette gjelder kjøtt fra hjortedyr som er infisert med smittsom skrantesyke tilsvarende den som er beskrevet I Nord-Amerika.

Når det gjelder de to elgene, indikerer de første analysene at de sykdomsfremkallende prionene har karaktertrekk som er annerledes enn de prionene som er funnet hos villrein i Nordfjella og i nordamerikanske hjortedyr. Enkelte trekk minner om atypiske former for prionsykdom hos husdyr, som regnes som mindre smittsomme. VKM kan med dagens kunnskap ikke sikkert si om dette medfører at prionsykdommen er mindre eller mer smittsom enn den sykdommen man kjenner fra Nord-Amerika. VKM kan derfor **ikke gi en endelig konklusjon** angående mattryggheten til kjøtt fra elg eller andre hjortedyr som er infisert med denne potensielt nye varianten av skrantesyke.

I de tidlige fasene av en skrantesykeepidemi ser det ut til at den viktigste smitteveien er direkte overføring fra dyr til dyr. Etter hvert som andelen smittede dyr øker, og miljøet blir mer og mer forurenset med smittestoff, blir indirekte overføring via miljøet viktigere. Det er sannsynlig at når skrantesyke først er etablert, vil forekomst av sykdommen øke innen den berørte bestanden, for deretter å spres til nabobestandene. Økningen i forekomst, hvordan en gitt populasjon påvirkes, og hvor effektivt sykdommen spres vil være avhengig av en rekke miljøfaktorer og særtrekk hos arten og bestanden det gjelder. Blant reinsdyr, som er svært sosiale, tror man sykdommen vil spre seg fort og ha ødeleggende effekt, mens det er mer usikkert hvor stor effekt sykdommen vil ha på de andre artene. Det kan for eksempel tenkes at elgen, som er lite sosial, ikke vil rammes like hardt.

Erfaringer gjort i Nord-Amerika indikerer at prioner fortsatt er smittsomme og sykdomsfremkallende selv etter flere år, noe som gjør at det er svært vanskelig å bli kvitt sykdommen. Dersom målet er å bli kvitt skrantesyke i Norge er derfor viktig at det iverksettes effektive tiltak så tidlig som mulig.

Hva som er effektive tiltak vil kunne variere fra art til art. Et effektivt tiltak i en avgrensbar bestand, som for eksempel Nordfjella, er at alle dyrene skytes ut og området legges brakk, det vil si fritt for hjortedyr, i minst fem år. «Avgrensbar» vil i denne sammenhengen si at det på grunn av naturgitte og menneskeskapte forhold er praktisk mulig og i stor grad å forhindre at hjortedyr går inn og ut av området. Dyr fra en garantert frisk bestand kan brukes til å reetablere bestanden når brakkleggingstiden er over. Dette krever prøvetaking for å være sikker på at de nye dyrene ikke har skrantesyke.

I rapporten er nedslakting av Nordfjella-flokken beskrevet som en umiddelbar respons på dagens situasjon. Denne strategien må imidlertid kunne revideres i forbindelse med en adaptiv håndtering der eventuelt nye funn av CWD tas med i betraktningen.

I bestander som ikke er mulig å avgrense, vil den beste strategien for å kontrollere et utbrudd av skrantesyke være å skyte ut hjortedyr i det lokale området hvor sykdommen ble påvist. Det gjelder for de fleste hjorte-, elg- og rådyrpopulasjoner. Man vil da ta ut flest mulig av de dyrene som har vært utsatt for smitte gjennom direkte kontakt med de påviste dyrene, slik at man senker forekomst og spredning mest mulig. Hvor stort område man skal gjennomføre et slikt tiltak i, må baseres på kunnskap om hjortedyrets områdebruk akkurat der.

Hvis det er påvist smitte i en bestand, er et viktig tiltak være å hindre at dyr derfra kommer i kontakt med andre bestander. Dette kan for eksempel gjøres ved hjelp av gjerder, gjeting, ved å forsterke naturlige eller menneskeskapte hindringer eller ved å redusere bestandstettheten i randsonene.

For at bekjempelsen skal være vellykket, er det avgjørende å hindre at det etableres steder hvor dyr kommer i hyppig kontakt med hverandre og hvor smitten overføres særlig effektivt, såkalte «hot-spots» for overføring av sykdom. Saltslikkesteiner har potensiale for å fungere som spesielt farlige hot-spots. Fôring av hjortevilt er også en aktivitet som øker risikoen for smitteoverføring. Om man skal forhindre spredning av skrantesyke i eller til et område, vil det være svært viktig å slutte å bruke saltslikkestein, gjøre salt-forurenset jord utilgjengelig for hjortedyr og slutte med fôring av hjortedyr. Føre-var-tiltak bør iverksettes for å forhindre spredning ved hjelp av mennesker.

Opptrapping av den nasjonale kartleggingen og overvåkningen av skrantesyke hos hjortedyr er avgjørende for å forsikre at det finnes tilstrekkelig grunnlag for god og målrettet fremtidig forvaltning og for å unngå at områder med skrantesyke forblir uoppdaget, da sjansen for å bli kvitt sykdommen er svært liten hvis man oppdager den for sent.

Background as provided by the Norwegian Food Safety Authority/ Norwegian Environment Agency

In April 2016 The Norwegian Veterinary Institute diagnosed Chronic Wasting Disease (CWD) in a wild reindeer from the Nordfjella population in the southwest of Norway. A moose was diagnosed with the same disease in May in Trøndelag and another in the same area in June. The disease is well known in North America. However, this is the first detection of CWD in Europe and in wild reindeer worldwide. The CWD situation is not directly comparable to that in North America. Reindeer is a nomadic species that lives in herds, while moose is a more solitary animal. Norwegian wild reindeer and moose populations are mainly regulated through harvesting. Modelling effects of different management strategies (e.g. harvesting tactics and the short- and long-term outcome of these) that take into account ecology, demography and movement of wild reindeer, including strategies of how the disease spreads, may be relevant in the future. Due to the lack of information and the lack of experience in handling this disease, the Norwegian Food Safety Authority and the Norwegian Environment Agency hereby requests VKM to provide a scientific opinion.

Terms of reference as provided by the Norwegian Food Safety Authority/ Norwegian Environment Agency

Phase 2

1. **Food safety**

Update of the assessment from phase 1 if necessary

2. **Disease transmission between animals**

Update of the assessment from phase 1 if necessary

3. **The origin of the disease**

a. What is the most likely way the disease occurred in the affected animals

(spontaneous mutation, inherited, the known type from North America or

transmission from other species in the area)?

4. **Wildlife management and reindeer herding**

a. Which risk factors relevant to disease transmission should be included in different management strategies and how do these factors affect disease transmission?

What would be beneficial and non-beneficial consequences of reducing the risk factors?

b. Which management strategies, e.g. strategies used in CWD-infected areas in North America, can be relevant to implement in Norway?

i. How does choice of strategy depend on the occurrence of CWD in a given population?

1 Literature

A literature search was performed in PubMed and ISI Web of Science Core Collection using the following search strings: (("prions"[MeSH Terms] OR "prions"[All Fields] OR "prion"[All Fields]) OR ("prion diseases"[MeSH Terms] OR ("prion"[All Fields] AND "diseases"[All Fields]) OR "prion diseases"[All Fields] OR ("prion"[All Fields] AND "disease"[All Fields]) OR "prion disease"[All Fields])) AND cervids[All Fields]. Search returned 157 results (CWD[All Fields] OR ("wasting disease, chronic"[MeSH Terms] OR ("wasting"[All Fields] AND "disease"[All Fields] AND "chronic"[All Fields]) OR "chronic wasting disease"[All Fields] OR ("chronic"[All Fields] AND "wasting"[All Fields] AND "disease"[All Fields]))) AND cervids[All Fields].

There were no restrictions on date of publication. The search in PubMed returned 153 results. Using ("chronic wasting disease" OR "CWD") and ("deer" or "cervid") in ISI returned 689 results.

1.1 Relevance screening

The titles of all hits were scanned, and, if relevant, the abstracts were also inspected. Articles were excluded if they did not relate to the terms of reference. The reference lists in selected citations were scrutinized to identify additional articles or reports that had not been identified by the PubMed or ISI search.

2 Introduction

2.1 Background

Prion diseases are chronic neurodegenerative diseases that occur naturally in humans and ruminants and are invariably fatal. Some prion diseases, such as classical scrapie in sheep and goats and chronic wasting disease (CWD) in cervids, are contagious, spreading directly between animals or via environmental contamination. Prions are unusual agents, consisting of misfolded protein aggregates that are remarkably stable and can remain infectious for years in the environment.

Prions are generally species-specific pathogens with limited ability to move between different species under normal, non-experimental conditions. However, they display some structural plasticity and may adapt during propagation in a new host, such as reindeer or moose.

With the exception of bovine spongiform encephalopathy (BSE), animal prion diseases have not been recognized as zoonotic agents. However, given the heterogeneity among different strains of prions and the limitations of available datasets, precautionary measures must be taken to avoid human exposure to prions. Widespread exposure of humans to prion agents probably increases the likelihood of an animal prion strain adapting to humans. It must be appreciated that prion diseases can have long incubation periods in humans and that experimental studies and epidemiological analysis of this possibility of adaptation are challenging.

In March 2016, CWD was unexpectedly diagnosed in a wild reindeer (*Rangifer tarandus*) from the Nordfjella mountain area in Norway. This was the first case of CWD diagnosed outside North America and the Republic of Korea, and the first case ever diagnosed in reindeer. In May, CWD was diagnosed in two moose (*Alces alces*) in Selbu in South Trøndelag County, approximately 300 km northeast from the first reindeer case in Nordfjella. All cases were diagnosed by recognized methods, and the first case was confirmed at the OIE reference laboratory for CWD in Canada.

The scientific opinion "CWD in Norway" was published by VKM in June 2016. The report was the result of phase 1 of a two-phase project assigned to VKM by the Norwegian Food Safety Authority and the Norwegian Environment Agency. Phase 1 of the project was concerned with questions related to food safety and disease transmission among animals.

The opinion concluded that the origin and time of introduction of CWD agents in Norway are unknown. Furthermore, it was concluded that it is highly unlikely that prion diseases in cattle and sheep are the origin of CWD in Norway. Although sheep scrapie has been endemic in continental Europe and in the UK for centuries, and there has been considerable habitat overlap between sheep and a variety of cervid species, no CWD has been observed. This provides robust epidemiological evidence against sheep scrapie being the origin of CWD. Transmission of CWD to sheep and cattle has proven inefficient (Greenlee et al., 2012; Hamir et al., 2006) and *in vitro* assessment/modelling of the species barrier supports this (Kurt and Sigurdson, 2016; Li et al., 2007), indicating that there is a similar species barrier to that which occurs for humans. This also argues, indirectly, against CWD originating in sheep or cattle (or humans) since re-introduction of the agent to its original host would be expected to occur more readily, even after adaptation in the new host. Finally, while the opinion points out that transmission of CWD to humans has never been recorded, the possibility cannot be excluded, and several measures to limit exposure to humans were recommended (VKM, 2016).

Phase 2 of the project is concerned with the management of cervid populations, and on how these measures can be used to prevent further spread of the disease in Norway.

Since the release of the Phase I report, two more wild reindeer from Nordfjella were diagnosed with CWD in 2016. Both animals appeared clinically healthy and were shot during regular hunting, one 7-year old buck diagnosed August 29th 2016 and one 4-year old female was diagnosed on September 19th 2016.

During the surveillance in 2016 and early 2017, 860 wild reindeer were tested, including two of the three cases from Nordfjella. No further CWD-positive cases were found. The three cases are from the Northern zone/area of Nordfjella. Tests of semi-domesticated reindeer in the Filefjell area, situated at the Northern border of Nordfjella, have all been negative (201 animals tested).

Thus, CWD is present at an estimated prevalence of around 1% in the Northern zone of Nordfjella wild reindeer area, which includes approximately 2,000 animals. There are no indications of CWD in reindeer in other areas, but substantial testing was only conducted in two populations outside Nordfjella, namely Forollhogna (105 animals) and Hardangervidda (320 animals). Although highly valuable, current surveillance data are only from a few populations, and testing of other wild and semi-domesticated reindeer populations in Norway is recommended.

The clinical, pathological, and molecular features of CWD observed in these infected reindeer are very similar to CWD observed in North America.

Investigations of the two cases diagnosed in Norwegian moose are ongoing. Preliminary findings suggest characteristics that differ substantially from that which have previously been observed in CWD – regardless of host species. Available information indicates that whereas the CWD strain observed in reindeer appears typical for CWD, the strain that affects moose is unusual or atypical, and possibly less contagious. All of the 4629 moose tested in 2016 were negative. Of these animals, 647 were from Sør-Trøndelag where the two positive cases were found.

It can be concluded that an active outbreak of contagious CWD is currently ongoing in wild reindeer in the Northern zone of Nordfjella. No cases have been observed in other cervid populations inhabiting the areas surrounding the location of this outbreak.

Current data suggest the presence of two different strains of CWD in Norway. The strain that affects moose appears unusual and might be a novel CWD strain, whereas the strain detected in reindeer appears very similar, if not identical, to that previously recognized in North America. This CWD strain and the disease it causes is therefore in this report referred to as "CWD" whereas the strain disease observed in moose will be referred to as "atypical CWD".

Transmission properties, including the zoonotic potential, of the CWD strains seen in Norway, are presently unknown and experiments in mice carrying the human prion protein gene (*PRNP*) are currently in progress.

2.2 Prion diseases

In several chronic neurodegenerative disorders such as Alzheimer's disease (AD), Parkinson's disease (PD), and the prion diseases, misfolded proteins accumulate in the brain (Jellinger, 2010). The abnormal protein aggregates consist of host-encoded proteins that have undergone profound conformational changes and changed into disease provoking aggregates. Both AD and PD are multifactorial, highly complex diseases, influenced by many genes (Jellinger, 2014; Nelson et al., 2012). Prion diseases, however, are predominantly, but not totally, controlled by a single gene that encodes the prion protein, PrP . This protein is present in many tissues and at high levels in brain tissue. The physiological function of PrP is an area of intense research (Bakkebo et al., 2015).

In prion diseases, protein aggregates contain multimeric (many PrP molecules clumped together) abnormal PrP, called PrP^{Sc} (scrapie), which has a three-dimensional conformation that is significantly different from that of normal PrP, despite the proteins being composed of identical amino acid chains (primary structure). Transgenic mice in which the gene encoding PrP (*Prnp*) has been inactivated are completely resistant to prion disease, demonstrating that endogenous PrP is obligatory for disease development and progression (Brandner et al., 1996; Bueler et al., 1993). Consequently, a line of Norwegian dairy goats which, due to a nonsense mutation, lack PrP,are also believed to be fully resistant to prion diseases (Benestad et al., 2012).

As discussed in the Phase I report from VKM (VKM 2016), the nomenclature of the prion diseases and prion agents is not stringent. In this report, misfolded and partly proteinase-resistant prion protein observed by immunohistochemistry in tissues or by western immunoblots or ELISA analysis will be called PrP^{Sc}. Although associated with the transmissible agent, PrP^{Sc} is not identical to the prion agent. The terms "prions", "infectivity", "CWD prion" or "CWD agent" is used throughout the text to denote the biological entity that causes disease and harbours the capacity to transmit CWD between animals.

Prions can direct, with molecular precision, misfolding of normal PrP and, in this way, spread this misfolding within a host and even transmit it to other animals. When disease-causing prion templates are introduced into a healthy host, the process of misfolding can start and potentially cause deadly prion disease (Prusiner, 1998).

2.2.1 Transmission and species barrier

Misfolding of the normal cellular PrP, here referred to as the "substrate", results in accurate copying of the incoming aggregated PrP structures that constitute the prion agent, referred to as the prion "template". This is the principle of prion propagation. If the PrP substrate fits readily into the abnormal PrP structure, the process of misfolding is efficient and disease progression is rapid. However, if the substrate fits poorly into the aggregated template, the process is inefficient and disease development is slow or blocked. Similarity in PrP primary structure (amino acids composition and sequence) between template and substrate is important in this regard (Prusiner et al., 1990).

Interestingly, a difference in one single amino acid residue (of 230) between substrate PrP (mature PrP) and template prion can dramatically influence the prion replication. This phenomenon is well known from classical scrapie in sheep, in which animals encoding arginine at codon 171 instead of glutamine are almost completely

resistant (Goldmann et al., 1994a; Laplanche et al., 1993). This genetic element is the main basis for breeding for resistance towards classical scrapie worldwide.

Nevertheless, similarity in primary structure does not fully explain the so-called species transmission barrier. Rather, structural features of a prion strain can profoundly influence the transmission efficiency (Bruce et al., 1994).

Although the prion protein gene is conserved among mammals, there is some genetic variation between and within species. Thus, human PrP is slightly different from that of sheep, and sheep PrP differs slightly from that of reindeer, and so forth. In some mammals, there is a high degree of normal genetic variation in the PrP gene, leading to several polymorphisms (gene variants). This is the case for sheep (Tranulis, 2002) and humans (Lloyd et al., 2013), in contrast to, for example, cattle (Goldmann et al., 1994b), in which PrP genetic variation is limited. Some of the PrP polymorphisms modulate disease susceptibility.

2.2.2 *PRNP* variation among deer and the question of silent carriers

Compared with sheep and humans, variation in the *PRNP* gene in deer is limited and in two species, roe deer (*Capreolus capreolus*) and fallow deer (*Dama dama*), PrP polymorphisms have not been reported to date (Peletto et al., 2009; Rhyan et al., 2011). In other species, only one single amino acid variation has been observed, such as the M132L in Rocky Mountain wapiti (*Cervus canadensis nelsoni*) (Perucchini et al., 2008). In Alaska moose (*Alces alces gigas*) and Shiras moose (*Alces alces shirasi*) a variation at codon 209 (Huson and Happ, 2006) has been observed, whereas in European moose (*Alces alces alces*) a K109Q polymorphism is observed (Wik et al., 2012). In a sample of 47 Norwegian moose, the K109 allele was present in 83% of the animals and the Q109 allele in 17%. The two CWD cases in moose were homozygous for the K109 allele (Røed et al., unpublished observations).

Analysis of European red deer (*Cervus elaphus*) revealed four polymorphisms encoding amino acids changes: G59S, T98A, P168S, and Q226E (Peletto et al., 2009). The red deer samples were from Italian and Scottish red deer. They have the same mitochondrial DNA haplotypes as those in Norway (Skog et al., 2009), but data on *PRNP* genetic variation in Norwegian red deer populations are currently not available.

In the Alaskan Caribou (*Rangifer tarandus grantii*), four polymorphisms giving rise to amino acid substitutions have been described: V2M, G129S, S138N, and V169M (Happ et al., 2007). Similar observations were made in analysis of a small sample of European reindeer (*Rangifer tarandus tarandus*), with the addition of a N176D

polymorphism (Wik et al., 2012). In a sample of 38 wild reindeer, of which some were from the CWD affected area in Norway, several of the previously documented polymorphisms were demonstrated, along with some variations not previously documented at codons 143 and 176 in addition to a repeat variation (Røed et al., unpublished). Given the small sample size, the level of polymorphism was substantial. Further studies allowing comparison of the Nordfjella population with other sub-populations would be of interest to characterize the *PRNP* genetic makeup of Norwegian reindeer populations.

From the above paragraphs it can be concluded with reasonable confidence that the majority of the Scandinavian moose population should be considered genetically susceptible to the atypical CWD agent observed in moose. The situation in reindeer is less clear because the degree of *PRNP* genetic variation in this species is considerable.

It is worth mentioning that although *PRNP* genetic variation can strongly modulate disease occurrence, particularly in classical scrapie, absolute resistance is considered unlikely. Rather, animals carrying less-susceptible genotypes normally experience prolonged incubation periods that sometimes exceed normal life expectancies.

In CWD, disease has been shown to spread from one cervid species to another, suggesting that the transmission barrier for CWD within the family of Cervidae is relatively weak (Kurt and Sigurdson, 2016). Importantly, variation in disease occurrence between species of deer might also result from variations in social, feeding, and other behavioural and physiological differences between animals, as well as the aforementioned variability between strains of the agent. Thus, occurrence and spread of CWD in deer populations will be a function of many variables in addition to any genetic modulation of disease susceptibility (see chapter 6.1).

One question of importance that remains to be clarified is whether less susceptible animals can shed infectious CWD prions into the environment without developing clinical disease themselves. Such animals could contribute to contamination of the environment and in spreading the disease, and consequently affect CWD epidemiology.

Traditionally, *PRNP* genetic modulation of disease susceptibility has been considered to correlate well with prion propagation (Watts et al., 2014). Thus, *de novo* generation of infectious prions will occur inefficiently in less susceptible animals compared with highly susceptible animals. Accordingly, the susceptible animals that develop clinical disease should be considered as the dominant source of infectivity compared with that shed by asymptomatic carriers.

Although this suggestion might be valid in most instances, Béringue and collaborators provided a striking example of facilitated prion propagation in extraneural tissues, most notably lymphoid tissues in the gastrointestinal tract and the spleen, without clinical disease (Beringue et al., 2012). This example indicates that the barrier for prion propagation can be weaker in peripheral tissues than in the brain. In line with this, an analysis of 32,441 human appendixes, revealed 16 positive samples for abnormal PrP, which is a significantly higher prevalence than the observed occurrence of variant Creutzfeldt Jakob disease (vCJD) in humans (Gill et al., 2013), suggesting that a significant proportion of humans exposed to the bovine spongiform encephalopathy (BSE) agent are in a carrier state. How many, if any, of these will develop clinical disease is unknown.

In one study utilizing the sensitive real-time quaking induced conversion (RT-QulC) methods for detection of conversion activity (prion seeding activity) in faecal samples at different time-points post infection, it was shown that two elk (*Cervus canadensis*) carrying the L132 allele, associated with lower susceptibility for CWD, shed similar amounts of prion seeding activity in faeces throughout the incubation period as the more susceptible animals (Cheng et al., 2016). The terms "seeding or conversion" activity denotes the ability of a prion isolate to, under certain conditions, initiate misfolding of PrP *in vitro.* This feature is not equivalent to the infectivity of the prion isolate, which must be determined in bioassays, but is still is a useful approximation. Given that the incubation period is longer in elk with this genotype, they could potentially shed more infectivity to the surroundings than the more susceptible animals. Another RT-QuIC experiment, performed in white-tailed deer (*Odocoileus virginianus*) and including some animals of the somewhat less susceptible 96G/S *PRNP* genotype, also failed to show significant differences in release of prion-seeding activity between animals of different *PRNP* genotypes (Henderson et al., 2015).

Selariu et al. (2015) found that whereas only three out of 19 clinically normal female elk were immunohistochemistry PrP^{Sc} positive in the retropharyngeal lymph nodes (and two of these three also in the brain stem at the level of the obex), as many as 15 were positive in several tissues when examined with the highly sensitive serial protein misfolding cyclic amplification (PMCA) method. Notably, five of these positives did not have detectable levels of PrP^{Sc} in the obex or lymphoid tissues (spleen, retropharyngeal lymph node, or rectal mucosa-associated lymphoid tissue), suggesting that in some animals the prions might replicate in peripheral tissues without reaching the brain and causing clinical disease. The investigated animals in this study were all pregnant and an additional finding was that in 12 of the 15 sPMCA-positives, the foetus also had one or more tissues that tested positive, giving rise to the idea that vertical transmission may be more important than previously

thought. However, sample sizes and the possibility of false positives means that it is premature to conclude about the relative importance of this mode of transmission.

Conclusions concerning *PRNP* genetics and carrier states:

1. None of the Norwegian CWD cases reported so far carried unusual *Prnp* genotypes.
2. Although genetic modulation of disease occurrence is likely, absolute resistance is considered extremely unlikely.
3. Although a final conclusion cannot be reached at present, all Norwegian cervid populations should be considered susceptible to CWD.
4. The importance of asymptomatic carriers in the epidemiology of CWD is not known, but is probably low. More data are needed to clarify this.

2.2.3 Prion strains

Although prion replication occurs with high fidelity, several PrP aggregates can be formed (Bessen and Marsh, 1994), some of which might differ slightly from the bulk of protein conformers. Thus, in any given prion isolate, there will likely be a structural "cloud" of variation. In subsequent serial passage in the same host, the dominant structural conformer will be propagated, which will also be the case in most instances when transmitted to new hosts. However, if by chance a minor structural component of the prion isolate should propagate more efficiently in a new host, this structural conformer would emerge as the new dominant form after passage into the new host. This structural selection process, which is known as the conformation selection model (Collinge and Clarke, 2007), provides the current understanding of strain selection and so-called "strain mutations" in prion diseases. It implies that when a prion infects a new host, which is normally a very inefficient process, the structural features of the strain might change slightly and thereby make the subsequent infection of the new host more efficient (decreasing the incubation period). In this way, prions may adapt to new hosts and give rise to new strains.

Prion strains can be studied in detail by experimental inoculation in mice and differentiated according to: a) the incubation period, b) morphological changes in defined areas of the brain (vacuoles and distribution of PrP^{Sc} aggregates, constituting a lesion profile), and c) by physiochemical characterization of PrP^{Sc} in western immune blots (PrP^{Sc} glycotype, see below). When passaged in defined hosts, these features are remarkably reproducible and provide reliable characterization of the prion strain (Bruce, 1993).

The primary characterization of a prion isolate starts, however, with studies of the diseased animal. Information collated includes the species (sheep, deer, etc.), the age and gender of the animal, and, in many instances, analysis of the *PRNP* gene. Furthermore, microscopic analysis of the brain, in which the distribution of brain damage and the pattern of PrP^{Sc} deposits are characterized, is important since these features are reproducible and characteristic for a given prion strain. In addition to the lesion distribution in the brain, the presence of PrP^{Sc} aggregates in peripheral organs is also of significance, since, in some prion diseases, like classical scrapie in sheep and CWD in deer, such aggregates are often, but not always, detectable.

Finally, some properties of the PrP^{Sc} aggregates can be revealed by electrophoresis after pre-treatment with a protease that degrades most proteins. Since the PrP^{Sc} aggregates often, but not always (see Safar et al. (1998)), contain some protein that can withstand the protease, a characteristic pattern of protein bands remains as a signature of the PrP^{Sc} isolate. This molecular signature is called the PrP^{Sc} type or PrP^{Sc} glycotype. Studies of PrP^{Sc} types have proven to be of tremendous value in discriminating between prion strains, particularly in relation to BSE and the appearance of vCJD in humans.

The PrP^{Sc} type in the Norwegian reindeer cases is indistinguishable from the pattern of CWD 1 and/or 2 (Benestad et al., 2016), whereas the pattern observed for the moose cases has not yet been published.

In summary, discrimination between prion strains can be achieved by:

1. Host species, age, gender, *PRNP* genetics
2. Distribution of brain lesions – "lesion profile"
3. Distribution and pattern of PrP^{Sc} aggregates in the brain
4. PrP^{Sc} in peripheral organs, such as lymph nodes and spleen
5. PrP^{Sc} type (glycotype)
6. Transmission properties (attack rates, incubation periods, pathology, etc.) in defined hosts, such as transgenic mice or bank voles (*Myodes glareolus*)
7. Characterization of disease properties after experimental transmission

Full characterization of a prion strain is elaborate and expensive.

2.3 What is currently known about CWD strains in Norway?

Until these cases in Norway were reported, CWD had not been diagnosed in reindeer. Furthermore, only six cases in moose had previously been observed (Baeten et al., 2007). The first case in reindeer has been thoroughly studied and a report from these investigations has been published (Benestad et al., 2016). From this, it is evident that the pathology, and pattern of brain damage of deposits of PrP^{Sc} and the presence of PrP^{Sc} lymph nodes were similar to previously-investigated, naturally occurring CWD in deer and in experimental CWD in reindeer (Mitchell et al., 2012). Furthermore, the PrP^{Sc} type characterization revealed a three-band pattern that was virtually indistinguishable from that seen in CWD in elk in North America. These observations and the subsequent finding of two more positive animals from the same population reinforce the judgement that an outbreak of CWD is ongoing in that reindeer population.

Currently, we do not have similar data published from the moose cases. However, based on personal communications (Benestad, S.) and preliminary data presented at scientific meetings, it appears that important features differ significantly from "typical CWD" in deer and that seen in moose CWD in North America. One major finding relates to the distribution of PrP^{Sc} in the brain, with large amounts of positive material within neurons and smaller amounts extracellularly. Furthermore, novel findings concerning the PrP^{Sc} type, with the presence of protein bands with lower molecular mass, have been observed, but are not yet published. From one of the moose, a single lymph node was available for testing and this was negative for PrP^{Sc}.

A relevant question is whether the moose cases found in Norway could be equivalent to atypical prion disease seen in domestic ruminants (Tranulis et al., 2011). The fact that the moose in both CWD cases were old (13 and 14 years) supports this idea, since atypical ruminant prion disease affects old animals. Close to 500 moose were tested during the autumn 2016 from the County of Sør-Trøndelag, including the Selbu area (where CWD was detected in the two moose), and all tests were negative.

Based on the limited data available, the two cases in moose appear to differ from "classical" CWD with regard to lesion profile, distribution, and pattern of PrP^{Sc} aggregates and PrP^{Sc} type. The elevated age of the two affected moose and the absence of other positive cases in the area are also consistent with the theory that this could be a form of "atypical CWD".

Further characterization of the Norwegian CWD strains awaits the results of investigations that are ongoing in several laboratories; each involves experimental

transmission followed by detailed analysis according to various criteria. Importantly, however, this will still not enable conclusions to be reached concerning the possibility of sporadic/atypical occurrence of disease in moose. This uncertainty will persist, probably for several more years, during which large numbers of moose, including old animals, should be tested.

3 Transmission and environmental factors

Transmission can either be direct animal-to-animal contact (vertical or horizontal) or indirect from contamination of the environment. Horizontal animal-to-animal contact and indirect transmission though the environment are regarded as the two main modes of transmission. Direct, vertical transmission from mother to offspring was shown in an indoor experiment in Reeve's muntjac (*Muntiacus reevesi*) (Nalls et al. 2013). Vertical transmission has not generally been regarded as an important route of infection, but this is not definitively determined (Selariu et al., 2015).

In the following, we discuss environmental contamination, and the role of soil and processes affecting prion persistence. In chapter 4.3 the assumed relative contribution of direct and indirect transmission are discussed. We also highlight the potential importance of the role of supplementary feeding sites and salt licks for both direct and indirect transmission of CWD.

3.1 The role of environmental contamination and persistence

Experimental work performed on captive mule deer (*Odocoileus hemionus*) by Miller and co-workers (2004) indicated that PrP^{Sc}-negative animals may become infected without any direct contact with infected individuals, with indirect transmission via an environment that had been previously inhabited by infected individuals 2.2 years before. Environmental transmission is also assumed in scrapie over even longer timespans (Georgsson et al., 2006; Pállson, 1979). It must be noted, however, that the scrapie agent in these reports could have persisted in locations such as barns that provide shelter from wind, rain, moisture, and sunlight. Consequently, the survival time indicated in these studies may not be illustrative of survival time for the CWD agent in an exposed, natural environment. Indeed, both Icelandic and Norwegian scrapie eradication schemes have considered home pastures as being free from scrapie agent after a fallow period of five years (Anonymous, 2007) and the risk of sheep contracting infection on mountain outfield pastures as negligible.

Infected animals shed prions in nasal secretions, saliva, urine, faeces, and antler velvet long before they show clinical signs of disease (Gough and Maddison, 2010; Tamgüney et al., 2009). A carcass from an animal that died in the late phase of the disease may contain large amounts of prions (Saunders et al., 2012). The immediate surroundings of a decomposing CWD carcass might, therefore, be heavily contaminated with infectious prions.

Since prions are persistent, they will accumulate in densely populated environments where the level of contamination exceeds the natural decay and clearance of infectivity. Hence, the amount of prions in a contaminated area will increase both with time and with increasing

density of infected animals. Consequently, it is widely believed that while direct spread between animals is most important in the phases of introduction and establishment of the disease, indirect spread through the environment may become the primary source for susceptible cervids after a certain period of time (Almberg et al., 2011).

- Epidemiological studies indicate long-term environmental persistence of the scrapie agent, but 5-years of fallowing could be sufficient for elimination from an environment.
- The CWD agent can persist in natural environments and remain infectious for more than 2 years.
- There is little information about variation in the persistence of prions in natural environments.

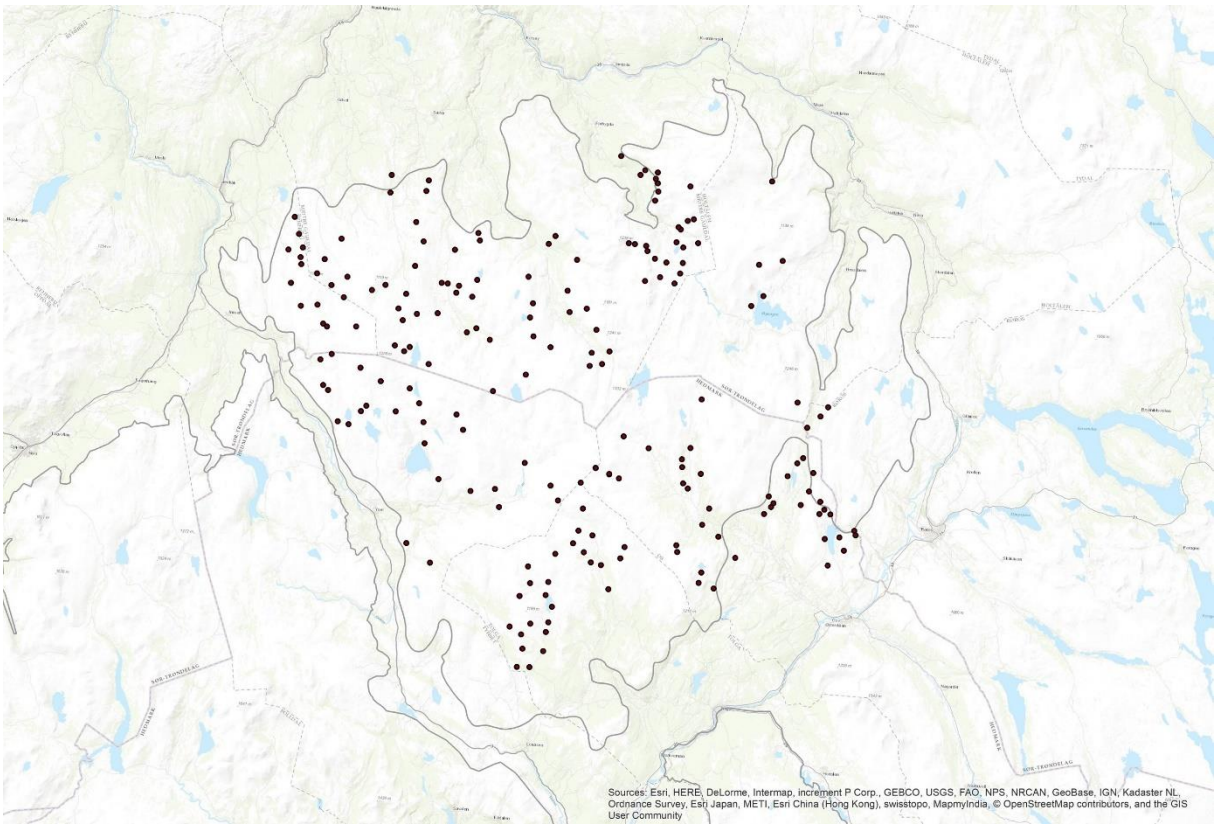

Figure 3.1-1 Map showing the locations of salt licks for sheep placed out in Forollhogna wild reindeer area. The map is based on a preliminary survey performed by the Norwegian Nature Inspectorate (SNO) and Norwegian Institute for Nature Research in late 2016. There are around 200 salt licks in the 1700 km^2 area, each of them annually supplied with around 100 kg of mineral stone. Forollhogna was surveyed because of easy access to data. Similar patterns of salt lick placement are expected in most other wild reindeer areas in Norway.

3

Figure 3.1-2 Cervids on salt licks. The moose in A, the reindeer herd in B and the red deer in C are all photographed by an automated wildlife camera on the same salt lick in Nordfjella (Courtesy of Lars Nesse), while the reindeer herd gathering on the eroded soil of a salt lick were photographed from the air in Forolhogna (Courtesy of Roy Andersen, NINA).

3.2 The influence of soil and bedrock on environmental persistence and disease pathogenesis

Prions are known to adsorb to soil and retain their infectivity for more than two years (Brown and Gajdusek, 1991; Seidel et al., 2007). Hence, many authors have hypothesized that soil could be a reservoir of prion infectivity (Johnson et al., 2006; Schramm et al., 2006; Seidel et al., 2007) though the nature of the association between prions and soil remains poorly understood (Smith et al., 2011).

When prions were bound to the common mineral clay montmorillonite, Johnson and co-workers (2007) observed that their oral infectivity was higher than that of brain-derived prions (homogenate). In line with this, transgenic mice expressing cervid PRNP developed prion disease after being exposed to CWD-contaminated soil (Wyckoff et al., 2016). An important role of clay in CWD epidemiology has also been supported by studies of CWD infection odds ratio between areas with soils with different clay content (Walter et al., 2011).

However, although much of the available data indicate that soils rich in clay could increase prion survival and uptake, the true epidemiological effect of this remains unresolved. Some studies have shown that sand-rich soils, which are common in Norway, may adsorb fewer prions and allow efficient drainage and dilution in groundwater (Bartelt-Hunt et al., 2013; Kuznetsova et al., 2014). In Norway, clay-enriched soils are restricted to only a few localities and are absent from areas in which CWD has been diagnosed. It remains to be determined whether lack of clay-enriched soils is sufficient for indirect transmission and for environmental persistence to play a less important role in the spread and perpetuation of CWD in Norway. An overview of soils in Norway is given in Appendix I.

The organic content of the soil may also retain prion protein (Giachin et al., 2014), but the interactions between organic matter in soil and prions as well as prion infectivity are incompletely understood (Kuznetsova et al., 2014; Smith et al., 2011).

Physiochemical properties, such as ion strength, pH, and metal composition might also variably influence the binding and stability of prions in soils (Smith et al., 2011). Several studies have assessed whether levels of trace elements in forage, water, and soils influence scrapie and CWD epidemiology (Davies and Brown, 2009; Gudmundsdóttir et al., 2006; Ragnarsdottir and Hawkins, 2006; Russo et al., 2009) but no consistent correlations have been observed to date (Bartelt-Hunt et al., 2013; Imrie et al., 2009). Whether trace metal imbalance is involved in prion disease pathogenesis has also been studied and some epidemiological data have indicated associations between trace metal imbalance and disease progression (Choi et al., 2006; Mitteregger et al., 2009; Nichols et al., 2016; Rana et al., 2009).

- Prions bind to soil
- Bioavailability and infectivity of prions vary with soil type – clay-rich soils bind the prions close to the soil surface, increase environmental stability, and enhance infectivity
- The clay-content of Norwegian soils is generally low
- Trace element imbalances have been suggested as important factors behind the spatial variation of prion diseases, but there is currently little consistent data on the relationship between trace element supply and disease occurrence and pathogenesis

3.3 Environmental processes that remove infective prions

Although prions are remarkably stable in the environment, over time they degrade and lose infectivity or otherwise disappear from the part of the environment where they are accessible for susceptible animals (Saunders et al., 2008). The net effects of different natural removal mechanisms and their role in CWD epidemiology are not well documented.

Repeated drying and wetting seem to degrade soil-bound (and, to a lesser degree, unbound) prions (Yuan et al., 2015). This may indicate that to a larger extent the infectivity of prions will be better preserved in a stable climate than an unstable one. Rain and surface water

may also wash away prions, either unbound or bound to soil particles, so that they become entrapped and diluted in large water bodies, such as ground water or rivers and lakes (Kuznetsova et al., 2014; Nichols et al., 2009). High run-off, for example associated high frequency and magnitude of snowfall and rainfall and high speed of snow melting in the spring, may increase prion removal from a landscape (Nichols et al., 2009). Repeated freeze-thaw cycles have also been suggested as reducing prion persistence (Smith et al., 2011).

Microbial and enzymatic degradation of prions, for example by serine proteases present in lichens, occurs (Smith et al., 2011), but seems to be most efficient at relatively high temperatures (50 – 60°C) and high pH (Bartelt-Hunt et al., 2013). A single study indicates, however, that soil proteases around buried animal carcasses can degrade recombinant PrP (Rapp et al., 2006), and several studies indicate that enzymes produced by lichens could be potential mediators of prion degradation (Bennett et al., 2012; Ducett et al., 2014; Johnson et al., 2011a; Rodriguez et al., 2012).

Presence of natural inorganic oxidants, for example manganese dioxide, is also reported to decrease prion stability and infectivity in the environment (Russo et al., 2009).

- Several natural processes degrade or remove infective prions from the accessible environment of cervids
- The impact of the different processes and how this varies spatiotemporally are not known.
- The impact of the different processes on prion persistence is important, as residence time of prions in environmental reservoirs and the efficiency of transmission via these are critical parameters in CWD epidemiology.

3.4 Spread by carnivores

Cervids infected by CWD prions are, according to some reports, killed more often by predators and more often involved in traffic accidents than non-infected animals (Edmunds et al., 2016; Wild et al., 2011). Predators and scavengers eating the carcasses of these animals will naturally be exposed to the CWD prions. In addition, animals in the late phase of the disease will die and their carcasses constitute a significant source of prions easily available to other animals.

This could contribute to spread of disease in three different ways: 1) The animals could transport pieces of infected material to new areas; 2) Prions can survive passage through the digestive system of the carnivore and, as such, be introduced to new areas through their scat; 3) The predator/scavenger can itself be infected and thereby spread the disease, but there are no direct studies on this issue.

Experiments from North America confirm that CWD prions fed to both crows (*Corvus brachyrhynchos*) and coyotes (*Canis latrans*) pass through the digestive system to some extent and have preserved their infectivity when excreted with the faeces (Nichols et al.,

2015; VerCauteren et al., 2012). It has been suggested that translocation with carnivores can be one explanation regarding how CWD has unexpectedly emerged in locations distant from, and with no obvious connection to, endemic areas (Fischer et al., 2013)

Natural cases of transmissible spongiform encephalopathies (TSE) have been observed in several feline species and in farmed American mink (*Neovison vison*), but have been associated with BSE or scrapie rather than CWD. Natural cases of TSE have never been reported in wild carnivores (Jennelle et al., 2009; Stewart et al., 2012). Ferrets (*Mustela furo*) and mink have developed disease after experimental intracerebral inoculation with CWD prions, but not after oral inoculation (Bartz et al., 1998; Harrington et al., 2008; Sigurdson, 2008). Wild carnivores generally show little genetic variation in the PrP protein. Canids, wolverines (*Gulo gulo*), and pine marten (*Martes martes*) do, however, have an aspartic acid or glutamic acid at codon 163, which is suggested to constitute a genetic basis for low susceptibility to prion infection (Stewart et al., 2012). Prion disease has not been reported in avian species.

In conclusion, although transport of CWD prions with carnivores seem possible, either as infectious material transported from a carcass or passaged through the digestive system, it does not seem likely that CWD in its current form will spillover to predators or scavengers. Compared with the risk of transmission between cervids, the risk of environmental transmission via infectious materials distributed by predators or scavengers must be considered very low.

Scavengers in Norway are mammals, such as red fox (*Vulpes vulpes*), Arctic fox (*Vulpes lagopus*), and wolverine, and birds such as corvids and birds of prey. Reducing densities of red fox and corvids are conducted many places to reduce predation on game species, but this is not an alternative for the red-listed species, Arctic fox, and wolverines. Also, it is illegal to hunt birds of prey in Norway.

3.5 The importance of salt licks and supplemental feeding

Given that CWD-infected animals can shed infectious prions via saliva, urine, and faeces, and that the infective agent persists in the environment, any natural or management factors that artificially increase direct and indirect animal contact could increase the likelihood of disease transmission. Salt licks are an obvious example of an item that increases direct and indirect contact between animals. Lavalle and co-authors summarises as follows: "Although beneficial in meeting mineral requirements, use of licks results in the congregation of animals increasing the likelihood of deposition and ingestion pathogens. Further, behaviours exhibited therein including defecation, urination, ejaculation, soil consumption, inhalation, drinking, and wallowing and bedding followed by grooming increase potential for transmission of pathogens (Lavelle et al., 2014). Also, Schramm and co-authors (2006) conclude that "since minerals from saltlicks are persistent and attract deer to their location on a regular basis for many years, they may serve as points of prion accumulation from deposited saliva, urine and faeces" (Schramm et al., 2006). VerCauteren and co-authors

(2007), who monitored elk activity suggested that mineral licks have the potential to play a role in CWD transmission (VerCauteren et al., 2007).

Supplemental feeding of cervids may have a range of both intended and unintended environmental effects (Milner et al., 2014). The use of supplemental feeding is also debated in Norway due to its long-term negative impact on habitat development and for ethical reasons (Mysterud, 2010; Mysterud, 2011).

- Salt licks and supplemental feeding sites for deer are regarded as particular hotspots for disease transmission.

4 Epidemiology of CWD in cervid populations

4.1 Rise in CWD prevalence

The basic reproduction number (R0) describes how many new individuals each infected individual will infect. Hence, a R0 value above 1 is required for CWD to increase in prevalence over time and cause an epidemic, and a rise in the prevalence of the disease will be more rapid the larger the value of R0. Management actions, environmental conditions, and the properties of the animal populations of the area will all affect the rate of rise in CWD prevalence. In mule deer, the basic reproduction numbers (R0) for CWD were determined to be 1.3 and 1.5 in two different epidemics (Miller et al., 2006). This is a very low rate of disease transmission and may partly explain why CWD prevalence can remain at a low level for prolonged periods and that the diffusion rate is slow. A substantial increase in prevalence may take decades, as documented in deer populations in Wisconsin (Wasserberg et al., 2009), Colorado, and Wyoming (Miller et al., 2000). In Colorado and Wyoming, models suggested 1% prevalence in 15-20 years, reaching 15% after 37-50 years (Miller et al., 2000). Recent empirical estimates for CWD in white-tailed deer in endemic areas of Wyoming have now reached 40% or more, and in some areas CWD has resulted in a decline in the population of white-tailed deer (Edmunds et al., 2016).

A major challenge in modelling the development and population effects of CWD, is that the quantitative importance of various transmission routes remains uncertain. It is plausible that the different mechanisms will be of different importance between locations according to variation in climate, soil, and vegetation. Most evidence suggests animal-to-animal contact (or via salt licks etc.) is the main route of infection in early stages of the disease. This means that the social behaviour of hosts is a critical issue for transmission (and salt licks a management issue), and such direct contact rates may be weakly density dependent (chapter 4.3). At later stages of disease development in a population, environmental transmission is likely to be more important and cause frequency-dependent transmission (chapter 4.3). The slow development of CWD suggests that the early stages of population-level disease development may be several years, but the exact number of years before environmental transmission becomes more effective is uncertain and dependent on many factors.

Estimated R0 values rarely reach above 2-3 in CWD-modelling studies when direct transmission is assumed, whereas they can reach considerably higher values (up to 10) when environmental transmission is also assumed (Almberg et al., 2011). Environmental transmission routes may potentially create long-lasting time lags in the system (see chapter 3.1.1). The range of model outcomes when including environmental contamination is large,

ranging from low prevalence and limited decline, to host population extinction (Almberg et al., 2011; Sharp and Pastor, 2011).

Spatial variation in CWD infection rates in North America is not fully understood. Modelling of CWD dynamics suggested it was not given that for CWD in mule deer R0 would be above 1 (which is required for an epidemic to develop) under all conditions (Miller et al., 2006). It is difficult to estimate CWD prevalence changes empirically at very low prevalences, due to the large sample sizes required to detect changes. Therefore, if CWD prevalence has remained low for a long period (Geremia et al., 2015), it is difficult to determine whether it is a stable situation, or whether there has been a slight increase or decrease, but only that the sample sizes are too low to detect changes. A formal analysis could not detect spatial variation in changes in the prevalence of CWD infection in Wisconsin (Heisey et al., 2010). It was found that changes in the rate of CWD prevalence were determined primarily by the timepoint of disease introduction, rather than variation in how rapidly CWD spreads (Heisey et al., 2010). Whether CWD prevalence can remain low in the absence of countermeasures is not supported by current analysis (Heisey et al., 2010).

Another challenge for the study of the epidemiology and spread of CWD is that several management actions aimed at restricting spread of the disease operate simultaneously. Management actions that restrict increasing the prevalence and distribution of CWD are implemented in Colorado, Wisconsin, and Illinois and the Canadian provinces of Alberta and Saskatchewan, whereas Wyoming has mainly implemented CWD surveillance with no direct actions. Differences between management actions may bias estimates of changes in CWD prevalence.

We discuss the variation in changes in the prevalence of CWD among different cervid species in chapter 5.

- CWD prevalence normally increases slowly in a population, with a basic reproduction number (R0) around 1.3 - 1.5 observed in mule deer, but can become greater if/when environmental transmission occurs.

- Rises in the prevalence of CWD in the USA have occurred despite quite significant management actions.

- There are no known CWD outbreaks in which the pathogen has died out by itself after becoming established.

4.2 Age and gender associations with infection

The prevalence of CWD in deer is approximately twice as high in males as in females (Potapov et al., 2013), but estimates vary, probably due to limitations in sample size. In Colorado mule deer, the prevalence of CWD peaked at ages 5-6 years in males, but there was no specific age pattern among adult females (Miller and Conner, 2005). The pattern was even slightly reversed between the genders for white-tailed deer in Wyoming, when the

prevalence was as high as 28.8% in males and 42% in females (Edmunds et al., 2016). In a recent analysis including large sample sizes of both female (>8,000) and male (>7,000) white-tailed deer from Illinois and Wisconsin, the prevalence of CWD was 3 times higher among males than female (Samuel and Storm, 2016). The prevalence increased with age in both genders, more so in males, and was, as expected, low in yearlings. Although the gender-biased increase in males is incompletely understood, the low levels in juveniles may reflect the long incubation period. The age at death declined from 4-6 years down to 2-3 years in captive mule deer over time (Miller and Williams, 2003).

We do not have sufficient data from Norway to estimate age or gender-specific prevalence. Estimates should be based on hunter-harvested data being more unbiased than data from fallen stock. However, there may also be bias in hunter data due to behavioural changes in CWD-infected deer or because hunters may be reluctant to shoot animals with abnormal behaviour (Conner et al., 2000). Nevertheless, these are the least-biased estimates available. So far, we currently have 1 female and 1 male reindeer with CWD infection from the hunter harvest. Therefore a gender bias towards males, as seen in North America, cannot currently be excluded or confirmed.

- CWD prevalence in cervids in North America is about twice as high in adult males than in females.
- CWD prevalence is low in young animals (yearlings and fawns).
- CWD prevalence increases with age in adult males, until a weak decline is observed at very old age.
- Age at death declined over time down to 2-3 years of age for captive mule deer.

4.3 Density-dependent or frequency-dependent transmission?

A commonly used management tool for combating infectious animal diseases is reduction of host population densities. Such efforts will mainly be effective in cases where transmission efficiency is increased by high population densities (density-dependent transmission). Frequency-dependent transmission is considered synonymous with transmission that is independent of host population density. If CWD transmission in deer populations is frequency-dependent, CWD cannot be controlled by harvesting or culling of deer. In such cases, only complete removal of the infected population can eliminate the disease (Wasserberg et al., 2009). Considerable effort has therefore been directed towards determining whether CWD transmission is density-dependent or frequency-dependent or intermediate. Note the distinction between population density and level of sociality or group size (fig. 4.3-1).

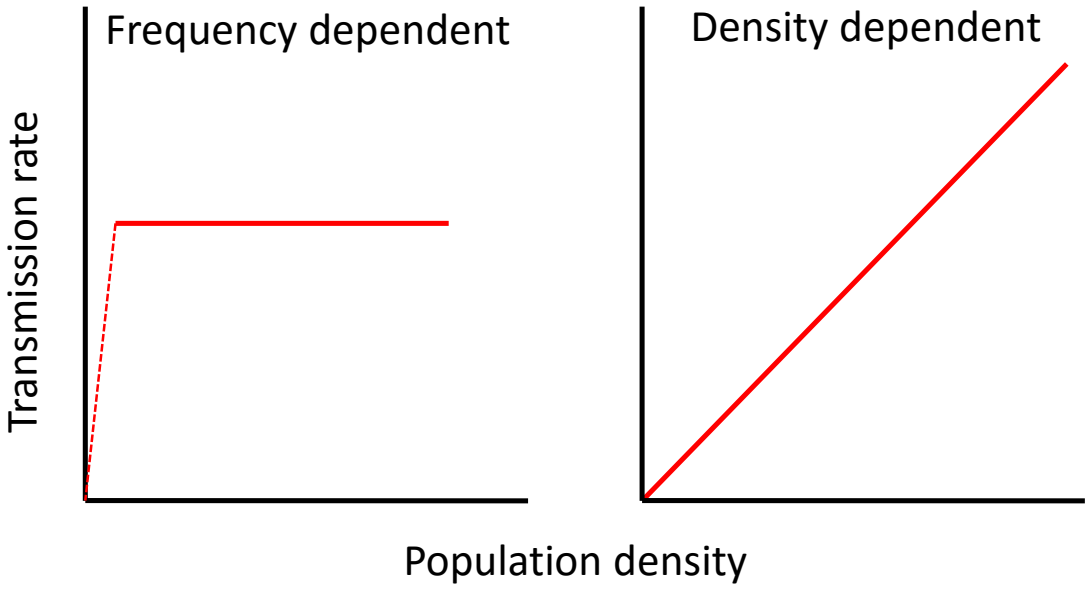

Figure 4.3-1 The transmission rate of diseases may be independent of population density ('frequency dependent') or dependent of population density ('density dependent'). CWD has close to a frequency dependent transmission. This has implications on how to combat CWD.

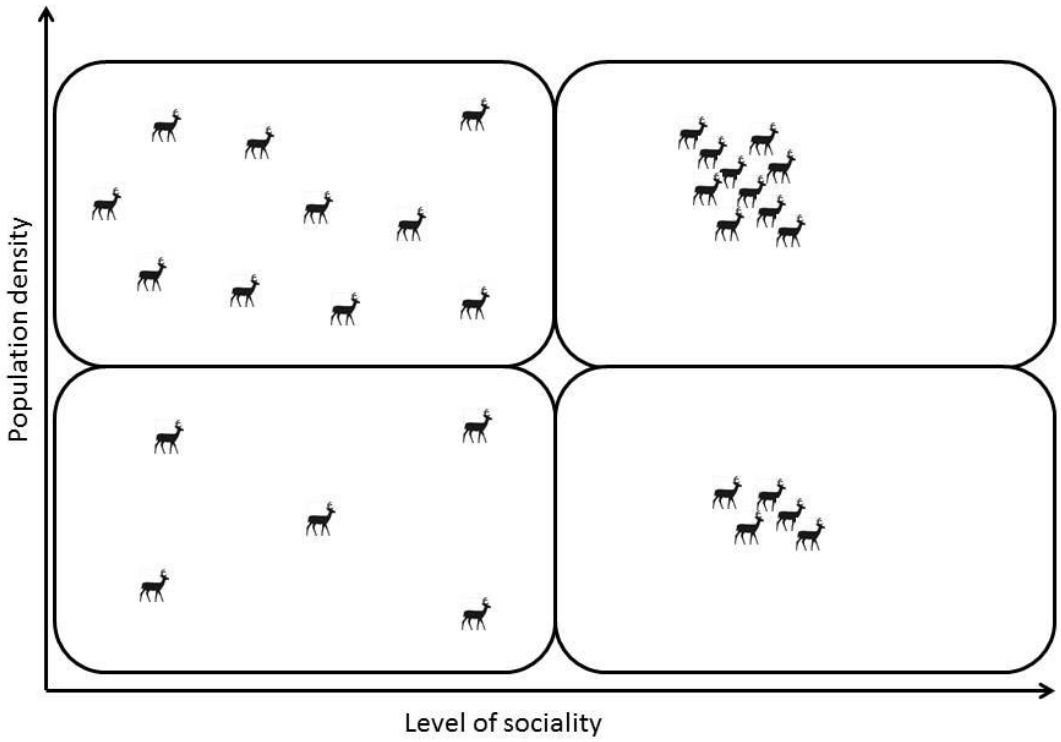

Figure 4.3-2 The term 'population density' is used for number of individuals in a given area, irrespective of their social organization. The 'level of sociality" or gregariousness refers to group sizes for a given species or population. For example reindeer may occur at low population density in a given area, but have a high level of sociality facilitating direct transmission. Reducing population density of animals may therefore not have a large effect on CWD transmission, if the remaining individuals gather in herds.

Several lines of evidence can be used to evaluate whether CWD is likely to have density-dependent or frequency-dependent transmission.

1) Different mathematical modelling approaches of transmission dynamics are used to match model outputs with empirical data on CWD prevalence (Gross and Miller, 2001; Jennelle et al., 2014; Potapov et al., 2013; Potapov et al., 2016; Wasserberg et al., 2009). A detailed overview of the different modelling approaches is given in table 2 of Uehlinger et al. (2016). Frequency-dependent transmission models give a slightly better fit overall in most cases (Wasserberg et al., 2009, Jennelle et al., 2014).

2) Empirical observations of contact rates or level of sociality (group size) for a given species can also be used to assess potential impact of population density on transmission of CWD. Direct contact between genetically related females, that typically have overlapping home ranges, is a risk factor leading to a higher prevalence of CWD infection in white-tailed deer (Grear et al., 2010) and mule deer (Cullingham et al., 2011). If contact rates or group sizes

are density-dependent, this can be extrapolated to indicate indirect evidence that CWD may also have density-dependent transmission. The critical question then is whether that specific mechanism is sufficiently important to affect the overall disease transmission. Space-use data can be used to estimate direct contact rates among animals (Habib et al., 2011; Schauber et al., 2015; Schauber et al., 2007). Direct contact is typically higher within social groups than between them (Schauber et al., 2015), suggesting that the level of sociality can be important for transmission. Empirical studies using GPS-marking in different cervids suggest that contact rates increase as a function of population density (Cross et al., 2013; Habib et al., 2011). The relationship was, however, satiated at high population density, supporting a model intermediate between (a linear) density- and frequency-dependent model of contact rates (Habib et al., 2011). Contact rates in elk also appeared to be intermediate between predictions from strict density- or frequency-dependent contact rate models (Cross et al., 2013). Further, it has been argued that frequency-dependent and density-dependent transmission of CWD may shift according to season (Oraby et al., 2014). Direct contact rates are typically higher during the rut (autumn) and lowest during summer season (Kjær et al., 2008). Hence, such indirect evidence of contact rates suggest that direct contact rates are highest during rut and at winter feeding sites, that contact rates during rut are likely to cause frequency-dependent transmission, while direct contact rates due to grouping may increase with increasing population density.

3) Empirical analysis of CWD-infection prevalence in young white-tailed deer in Wisconsin found that an intermediate model was better than simple frequency- and linear density-dependent functions (Storm et al., 2013). This provides some empirical evidence that prevalence of CWD is partly predicted by population density, but that the effect of population density is weak.

4) Culling efforts to reduce population density should limit spread of CWD if transmission is density-dependent. There is no solid documentation that culling efforts to reduce population density have reduced the rate of rise in prevalence of CWD (review in Uehlinger et al. 2016). A formal analysis comparing culling efforts found no effect (Conner et al., 2007). This is again evidence that the effect of population density is weak. It remains to be determined whether comparing a wider range of population densities or prolonging culling efforts may have an impact on CWD transmission.

5) There may be effects of population density on development of CWD, even if the transmission rate itself is frequency dependent. If there is moderate or strong density-dependence in recruitment (Potapov et al., 2012), a reduction in population density will increase reproductive output and hence more non-infected individuals will enter the population. Modelling such a possibility gave the interesting result that eradication can be achieved even with frequency-dependent transmission of CWD, if density-dependent recruitment results in faster growth of the healthy part of the population (Potapov et al., 2012). Whether this will happen will depend on how recruitment is limited in a given population. There is no empirical evidence for this potential effect.

In summary, most evidence suggests that CWD has close to frequency-dependent transmission. It is clear that CWD is not strongly density-dependent (Jennelle et al., 2014; Potapov et al., 2013; Wasserberg et al., 2009). The effect of CWD on cervids may, nevertheless, be weakly related to population density if comparing a wide range of population densities, and evidence from empirical studies of direct contact rates suggest the relationship is likely to be nonlinear, levelling off at high density.

- CWD has a close to frequency-dependent transmission mode, and this suggests that a moderate lowering of population density will not limit transmission.
- If CWD transmission is at all density-dependent, it is weak.

4.4 Predators, hunters, vehicles, and other modulators of CWD epidemiology

Any factor causing increased mortality of CWD-infected deer relative to non-infected deer may aid in limiting the rise in prevalence and distribution of CWD. Such factors can be selective predation, hunting, or slaughtering (of semi-domesticated/farmed cervids) of CWD-infected individuals. CWD-infected deer may also be more prone to accidents.

Predators vary widely in the degree to which they target weak animals, and the effect of predators on infectious disease also depends on epidemiological factors (Packer et al., 2003). Only under particular circumstances can predators keep herds healthy; these conditions are when the disease agent is highly virulent and aggregated in hosts, hosts are long-lived, and predators are selective of infected individuals (Packer et al., 2003). Modelling wolf predation on CWD-infected mule and/or white-tailed deer suggests that if predation is selective (i.e., targets CWD-infected individuals), it could cause a marked decline in CWD prevalence (Wild et al., 2011). Empirical evidence for selective predation on CWD-infected individuals is, however, not consistent. CWD-infected mule deer were more likely to be predated by mountain lions (*Puma concolor*) than non-infected mule deer (Krumm et al., 2010). In contrast, marked elk killed by cougars and hunters in South Dakota, USA, were in good physical condition and were not more frequently CWD-infected than non-infected (Sargeant et al., 2011).

A study reported increased harvest of CWD-positive white-tailed deer in Wyoming using marked individuals to estimate selection (Edmunds et al., 2016), and a similar increased harvest of CWD-infected mule deer was found in Colorado (Conner et al., 2000). In white-tailed deer in Wisconsin, male offspring with CWD-infected mothers were harvested more often than would be expected by chance (Blanchong et al., 2012). However, another study of white-tailed deer in Wisconsin found no difference in harvest rates between CWD-infected and non-infected deer (Grear et al., 2006). This latter study did not use marked individuals and evidence was based on more indirect evidence, related to the time of harvest.

Predation and selective hunting can thus, to some extent, remove a higher proportion of CWD-infected individuals than present in the population. A key issue is to determine whether the level of selectivity of predation and hunting is sufficient to result in a decrease in the prevalence of CWD. Due to the long incubation time, when animals appear healthy, but can spread disease, this is not a trivial issue. Empirical evidence from the study system of mule deer and mountain lion found that, despite selective predation, remarkably high infection rates were sustained, even in the face of intense predation (Miller et al., 2008). This suggests that even complete ecosystems offer little resistance towards CWD (Miller et al., 2008). Similarly, despite hunting, CWD has increased in prevalence in many US states, suggesting that hunting is not sufficient to limit CWD.

If production of cervids (either semi-domesticated reindeer or farmed deer) is based on slaughtering the vast majority of males and yearlings, calves that are below average condition, and females that are evaluated as poor (based on behaviour and/or condition), there is the potential that animals in the early stages of CWD will be selectively removed before being diagnosed. This has the potential to partly limit growth and delay discovery of CWD. CWD-infected individuals are sometimes more vulnerable to predators and hunters.

- Targeted slaughtering of can delay development of CWD in a population, but not hinder the spread of spread of the disease.

5 The effects of CWD on population dynamics

5.1 CWD, mortality and reproduction

Prion diseases like CWD are invariably fatal, but whether all infected animals will develop the disease is unknown. This may depend upon the route of infection, the infective dose and the genetic makeup of the host animal. Mortality is the main effect on the population dynamics. Empirical evidence does not indicate reduced reproduction rates in CWD-infected individuals in either mule deer (Dulberger et al., 2010) or white-tailed deer (Blanchong et al., 2012; Edmunds et al., 2016). In general, for large herbivores, any factor affecting adult female mortality will have the greatest impact on the population (Gaillard et al., 1998). Since CWD increases the mortality of adult females, it has the potential to modulate population dynamics at high CWD prevalence.

A difficulty in assessing the effects of CWD on population dynamics is that populations are influenced by harvesting/culling, sometimes implemented as part of the management aimed at controlling CWD. Therefore, studies of GPS-marked or otherwise marked animals and following their age-specific reproduction, cause-specific mortality, and CWD prevalence appear to be a viable approach to assess population dynamic effects (Edmunds et al., 2016). Also, determining the CWD prevalence in harvested deer may be a useful approach to estimating age-specific CWD prevalence and hence expected mortality. The estimated age and gender-specific vital rates can then be fed into standard matrix population models and used to estimate the population growth rate. In Colorado and Wyoming, population declines for deer were predicted at 5% prevalence (Miller et al., 2000), at 13% [0-35%] in elk (Monello et al., 2014), and at 26% in white-tailed deer in Wyoming (Edmunds et al. 2016). From this, it can be inferred that CWD at prevalences (5-30%) will cause population decline depending on the demography of the species and population in question. This will thus be influenced by other limiting factors such as harvesting.

- CWD affects population dynamics through an increase in adult mortality.
- CWD-infected females reproduce at close to normal rates.
- Since CWD increases adult female mortality, it may have considerable effects on population dynamics.

5.2 Variation in dynamic effect of CWD

The effect of CWD on populations is driven mainly by the balance between rate of transmission, the incubation period, and how quickly new offspring (without infection) are produced. The processes affecting transmission dynamics of CWD are discussed in chapter 4. If CWD increases in prevalence, it will limit populations and eventually cause a decline at

some point. The rise in CWD prevalence will determine mortality, but with a time lag. Genotypes of hosts associated with longer incubation periods will produce more offspring before death, and the rise in prevalence of CWD in the population will be slower. Similarly, species and populations with higher reproductive rates will also be less affected, all else being equal.

Spatial variation in the rise of CWD prevalence is discussed in chapter 4.1. Modelling shows that stable CWD prevalence is possible under some specific conditions. There is a reported case of CWD having a minimal impact on a mule deer population even with CWD present for 3 decades in the Laramie Foothills of north-central Colorado and southern Wyoming, USA (Geremia et al., 2015). However, it is unknown whether such examples represent truly stable conditions or whether it is only a matter of time before CWD will increase, as sample sizes are small.

Usually, once CWD is established, CWD prevalence will rise slowly and over decades cause a gradual population decline. It is important to realize that the situation in the USA has not stabilized. After CWD was first identified among wild deer in 1981, it is still spreading to new areas and continuing to increase in prevalence in the first endemic areas. The first report of a declining population in an endemic area was published as recently as 2016 (Edmunds et al., 2016). Due to the time aspect and slow rise in prevalence of CWD, it seems likely that more such reports of population declines will appear in coming years. The really long-term effects (century scale) are currently not known, and it is therefore unclear if it will cause local extinctions as many models predict. Over longer time scales, less-susceptible host genotypes may become more common and dampen the population effects of CWD (Williams et al., 2014). However, individuals that lack susceptibility to CWD are unlikely (chapter 2.2.2) and prolongation of the incubation period is likely to be the major effect (chapter 2.2.2).

- High host reproductive rates and long incubation periods will reduce the rise in prevalence of CWD.
- How spatial variation may affect the dynamic effect of CWD is not well understood.

5.3 Species differences in effects of CWD

A recurring pattern of CWD in USA is that mule deer populations are more affected than populations of white-tailed deer, and elk populations are least affected. In Colorado and Wyoming, the prevalence is higher in mule deer (4.9%) than white-tailed deer (2.1%) and elk (0.5%) (Miller et al., 2000).

The higher reproductive rate of white-tailed deer compared with mule deer may explain the rapid increase in prevalence of CWD in mule deer populations. However, even in white-tailed deer, CWD can lead to population decline. A detailed study, reporting a very strong population effect of CWD, comes from two populations of white-tailed deer in Wyoming, USA, with endemic and high prevalence of CWD (Edmunds et al., 2016). Here, CWD prevalence reached very high levels in both females (42%) and males (28.8%). Hunter

harvest and clinical CWD were the most common sources of mortality. CWD-positive deer were 4.5 times more likely to die annually than CWD-negative deer. There was no effect of CWD on pregnancy or recruitment rates. There was a 10.4% annual decline in population size with these vital rates (Edmunds et al., 2016). A matrix population model for this population suggested that the critical threshold for CWD-prevalence leading to population decline was 27%.

CWD develops faster, with shorter incubation periods, in deer than in elk (Race et al., 2009). This may, at least partly, explain the slower development of CWD in elk populations and the consistently lower prevalence of CWD in elk than white-tailed deer and mule deer. In elk, there is so far no population with CWD prevalence above 10%. An example is a high-density elk herd in the Rocky Mountains, USA, in which CWD has been reported for 25 years (Monello et al., 2014). The annual incidence of CWD was estimated to be 0.08 [0.05-0.12]. Annual cohort survival, excluding harvest, decreased from 0.97 [0.93-0.99] in 2008 to 0.85 [0.75-0.93] in 2010. The proportion of collared elk dying of CWD increased from 0.02 [0-0.05] (2008) to 0.11 [0.04-0.21] (2010). It was concluded that deaths from CWD can exceed natural rates of mortality, reduce survival of adult females, and decrease population growth rates. Population declines were indicated when prevalence of CWD exceeded 13% [0-35%] (Monello et al., 2014). So even in elk populations, CWD prevalence may rise sufficiently to affect the population dynamics (Monello et al., 2013).

Elk populations have consistently lower CWD prevalence despite being more social than both mule deer and white-tailed deer in the CWD-endemic region (Miller et al., 2000), suggesting that other factors than sociality contributes significantly to CWD development in populations. Thus, the role of different aspects of the social organization and species differences in susceptibility for CWD dynamics remains unclear.

- Mule deer, white-tailed deer, and elk populations are affected to different degrees by CWD, but all species have been documented to decline due to high CWD prevalence.
- The rise in prevalence, and hence effect, of CWD will depend on social organization, incubation period and susceptibility, and reproductive capacity of a given species.

5.4 Assumed CWD dynamics in Norwegian cervids

It is currently uncertain how fast CWD will spread and spillover among the Norwegian cervid species - roe deer, moose, red deer, and reindeer. The evidence of population effects of CWD is mostly derived from white-tailed deer, mule deer, and elk in North America. It is likely that differences in development of CWD are caused by variability in the hosts' reproductive rates, social organization, population densities, and physiological and genetic differences between species, causing variation in susceptibility and incubation periods.

Roe deer and, to some extent, moose have rapid reproductive rates. Moose and roe deer are generally more solitary animals than other cervids. Both these factors may limit the rise in

prevalence and distribution of CWD. However, if CWD infects roe deer in Norway, the high dispersal rate of yearling roe deer may rapidly spread the disease to new areas.

Cases of CWD in moose in North America are rare, and Baeten and co-authors (2007) suggest that the relatively solitary behaviour of moose compared with mule deer and elk may be the explanation for this. However, the population density of the North American moose is much lower than that of moose in Scandinavia. For example, when CWD was discovered in Colorado, there were only about 1,200 individuals over an area of 270,000 km^2 (Beaten et al., 2007).

The demography of elk is similar to that of red deer, but elk often occur in larger groups than red deer in Norway. Social groups of red deer are typically small in Norway with an average of only 2-3 females during summer (Bonenfant et al., 2004), but can be much larger during winter, especially when aggregating on feeding sites or agricultural pastures.

Due to the gregarious nature of reindeer, we would expect higher contact rates than for other deer species. Nevertheless, elk in USA also form large groups, but CWD prevalence is much lower in elk than in mule deer and white-tailed deer, so susceptibility is also important. A main difference of reindeer is that movement within the different reindeer areas are more or less nomadic, with complete mixing of individuals within the populations (Panzacchi et al., 2015). Similar systems do not occur in North America.

With the exception of reindeer, there is considerably more grouping in all species during the winter, which is particularly associated with agricultural fields and feeding sites. Therefore, any action that results in limiting artificial aggregation of cervids is likely to be beneficial for reducing the risk of spillover and transmission within species.

A key uncertainty is the susceptibility and incubation periods among hosts that may limit development of CWD.

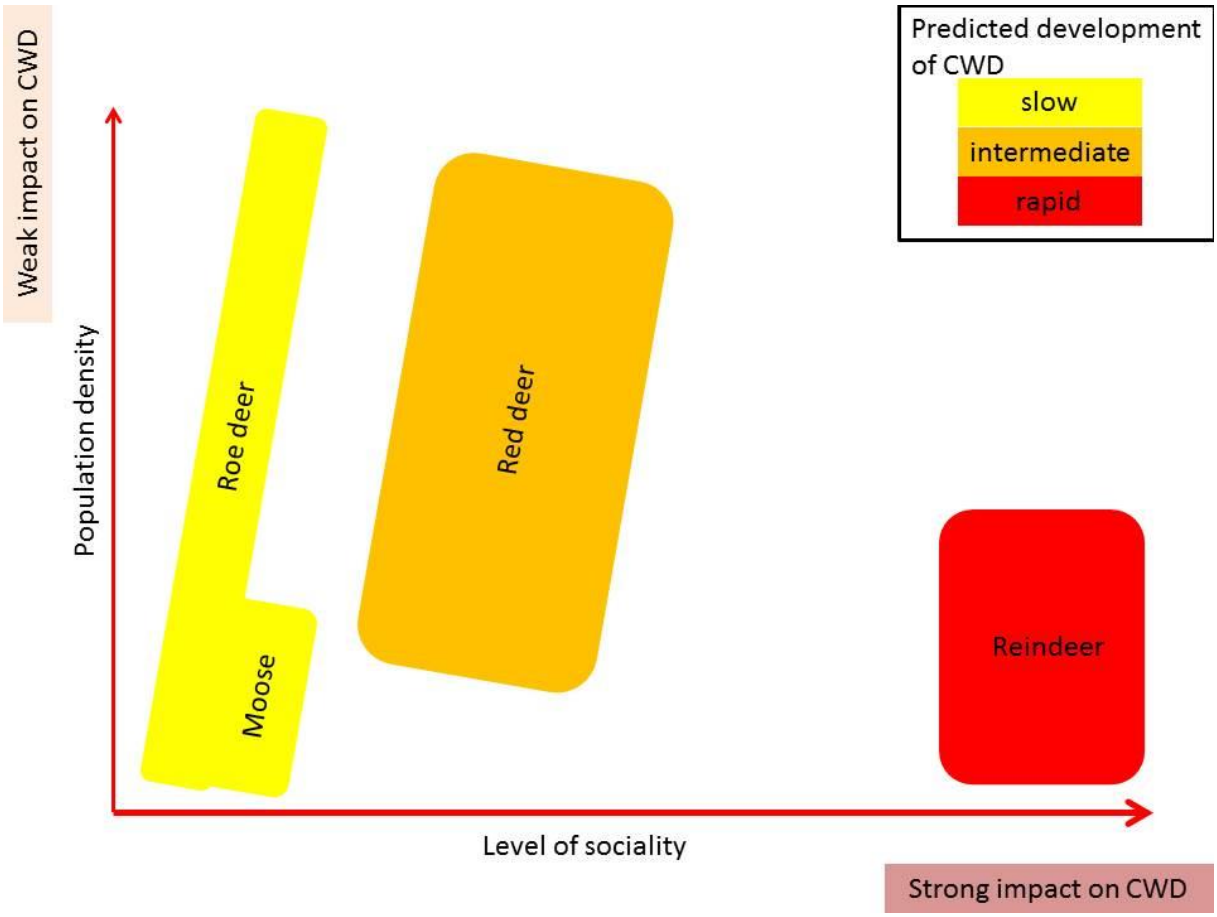

Figure 5.4-1 Level of sociality is assumed to be important for CWD transmission due to direct contact rates, and also that feeding on the same pasture may increase the risk of environmental transmission. The solitary behaviour of moose and roe deer may limit the spread of CWD compared with red deer and, in particular, reindeer. Roe deer, moose, and red deer are more social during winter and more so at high population densities. Population density has a lower impact on within-population CWD transmission, but may nevertheless be relevant for spread to non-infected populations, including spillover across species. Other aspects of differences among species, such as susceptibility, are also likely to be important for CWD transmission. These aspects are currently not known for Norwegian deer species. There is hence considerable uncertainty regarding the relative rating of the different species with the limited current information available.

- Social organization, and, to a lesser extent, population density may affect the likelihood of CWD becoming an epidemic.
- Group living and aggregation are risk factors for both direct and indirect transmission.
- Based on social organization and assumed direct contact rates the predicted order of risk can be ranked as: **reindeer > red deer > moose > roe deer.**

5.5 The process and risk of spillover

From a genetic perspective, there is a low barrier for transfer of CWD between most cervid species (see chapter 2.2.2). In North America, CWD has transferred from mule deer to white-tailed deer, elk, and moose. However, the process of spillover from one cervid species to another is not well described in the literature. It is likely that such transmission between species is indirect, as direct contact between individuals of different species is rare. Two different processes may be important for successful spillover across the species barriers: 1) whether the two species actually come into contact, so that the donor species population infects the recipient species population, and 2) whether the social organisation, susceptibility, or population density of the recipient species is favourable for CWD transmission within species. Solitary behaviour, low site fidelity, and low population density are assumed to reduce the risk of CWD spillover.

Why does spillover not always cause an epidemic in the new species? The transmission of CWD within a species is not strongly density-dependent (chapter 4.3). However, it is likely that a spillover event would be linked to: (1) population density of the recipient species, (2) the spatial overlap of the two species populations, and (3) the density of infected individuals in the donor population. Contact points attracting multiple species are likely to be risk factors, such as common salt licks and supplemental feeding sites. Similar feeding niches linked to feeding on low vegetation may be a risk factor, as this is more likely to transfer prions through ingestion of soil and prions in vegetation. There is no direct empirical evidence to support these hypotheses, so they are all inferred from general knowledge about CWD transmission. It is suggested that the lower levels of prions in lymph nodes of elk compared with white-tailed deer and mule deer reduces the risk of elk transmitting CWD to other species ((Race et al., 2007).

Due to the role of environmental contamination with prions, all deer species may be relevant for the dynamics of CWD in a given area, or it may be that the CWD dynamic is driven by one species and only occasionally crosses the species barrier. Anecdotal evidence suggests the latter may be important (Haley and Hoover, 2015). The number of reported CWD cases in moose in North America is very low (n=6) (Haley and Hoover, 2015), despite seasonal overlap of areas with high prevalence of CWD in deer and/or elk (Baeten et al., 2007). In this case, it appears that moose occasionally visit areas with endemic CWD infection in mule deer. The visiting moose may become infected with CWD, but die before transmitting the disease to more moose. Anecdotal evidence from Canada similarly suggests that the CWD dynamics are driven by mule deer, and that there is occasional spillover to white-tailed deer and elk, but not always causing an epidemic in these species.

In some cases, spillover does not seem to happen, even in captivity. Apparently, in some enclosures elk can be kept for years without becoming infected, while co-housed mule deer consistently contract CWD. In other cases the opposite occurs, with elk contracting the disease and not mule deer in other enclosures (Terry Spraker, pers. comm.). However, these

observations have not been reported in the peer-reviewed literature and there are few other studies that indicate any degree of barrier of infection between different cervid species.

- There has been spillover of CWD from mule deer to white-tailed deer, elk, and moose in North America
- The risk of spillover may be linked to: (1) population density of the recipient species, (2) the spatial and dietary overlap of the two species populations, and (3) the density of infected individuals in the donor population and the sensitivity of the recipient towards a given strain of the prion agent.
- High prevalence in one species may cause occasional spillover, without an epidemic occurring in the recipient species.

6 Wild cervid population development and surveillance in Norway

Here we provide a general overview of the distribution, population development (population size and structure), and individual performance (body growth, fecundity and survival) of wild cervids in Norway, as well as their movement patterns. We also present the populations in the Nordfjella wild reindeer area, where the first CWD-infected reindeer was found, and in the Selbu area (i.e. Selbu and surrounding municipalities), where the two CWD-infected moose were detected. A more detailed description of the recent population history and limiting factors can be found in Appendix II and in Bjørneraas (2012).

6.1 General population development and performance of wild cervids in Norway

Over the last century, the four wild cervid species in Norway have increased considerably in distribution and density. In the mid-19th century, roe deer were extinct in Norway and unrestricted hunting suppressed moose and red deer populations to small pockets of land at the very eastern or western parts of southern Norway, respectively. A similar development occurred in the mountain regions in the south, where wild reindeer were heavily harvested and partly displaced by semi-domesticated reindeer.

In the first half of the last century, the situation improved for wild cervids, mainly because of reduced harvest. In addition, the wolf was functionally eradicated and agricultural developments improved conditions for cervids. Initially, the populations increased slowly, with several setbacks, but after the Second World War, populations grew rapidly. Roe deer recolonised Norway from Sweden at the beginning of the century, and like moose, quickly increased their range (Andersen et al., 2004). Red deer spread more slowly. A particularly strong increase in the harvest of the three species, and most likely their abundances, was seen in the 1950s and early 1960s, and then again in the early 1970s. The second phase of population increase culminated in the early 1990s for moose and roe deer and well into the new millennium for red deer. Although part of the variation in population abundance can be attributed to varying food availability and predation (mostly roe deer), the recent changes in population size were mainly the result of varying hunting pressures and thus controlled by the wildlife management.

Overall, the population abundances of moose, red deer and roe deer have been high in Norway during recent decades and probably higher than in any of the previous 300-500 years (possibly longer). Rough estimates suggest that Norway had about 90,000 moose in 2014 (http://www.naturindeks.no/), which is less than the abundances in 2000 (130,000, Solberg et al., 2005), and in 2007 (100,000, Solberg et al., 2008). The estimated red deer population was roughly 130,000 in 2014 (http://www.naturindeks.no/) and 125, 000 in 2007

(Solberg et al., 2008). For roe deer, the 2014 estimate was 115,000 individuals (http://www.naturindeks.no/), but, as for moose and red deer, the estimate is highly uncertain. The current winter abundance of wild reindeer in Norway is probably somewhere between 25,000 and 35,000 individuals.

The increases in population densities has been accompanied by a significant decline in body mass and fecundity in populations of moose, red deer and reindeer (e.g. Solberg et al., 2015), and, to some extent, also in locally abundant roe deer populations. Density dependent food limitation may also have negatively affected survival, particularly in juveniles, but so far we see no substantial density-dependent increase in natural mortality rate (i.e., mortality apart from hunting). In general, density-dependent natural mortality is rare in adult cervids, whereas this is more common among juvenile individuals (Gaillard et al., 1998).

Studies of radio-collared cervids indicate that adult cervids have low natural mortality rates in most of Norway, and that mortalities due to starvation and infections constitute a minor proportion. Based on fallen stock, the most common cause of death, apart from due to hunting, is traffic accidents (Appendix II). However, it is highly unlikely that all cervids that die from other causes are found and reported. There has been no large increase in mortality during the last three decades (Appendix II).

6.2 Migration, dispersal, and the spatial scale of population units

In Norway, the spatial distribution of cervid populations is well known from marking studies: red deer (Bischof et al., 2012; Mysterud et al., 2011; Rivrud et al., 2016), moose (Bunnefeld et al., 2011; Rolandsen et al., 2010; Van Moorter et al., 2013), reindeer (Panzacchi et al., 2015), roe deer (Mysterud, 1999; Mysterud et al., 2012), and targeting efforts should be based on such data. For reindeer, the population scale is the different wild reindeer management regions or parts of regions (as for Nordfjella south and north), whereas for moose and red deer, populations are partially migratory and more difficult to demarcate. Hence, any reduction in density to combat CWD requires large areas to capture the population scales and this is particularly so for migratory populations. For roe deer, although there is some migration, populations can be managed locally and more similarly to white-tailed deer and mule deer in North America.

The proportion of migrators in red deer varies between 38% and 100%, with recorded distances averaging 27.5 km and maximum distances slightly above 100 km (Mysterud et al., 2011). Migration in red deer is more common in topographically heterogeneous landscapes; in inland areas with low population density, close to 100% are migratory. More than 50% of the moose population migrate, and migration distances are frequently above 100 km (Bunnefeld et al., 2011). Migration in moose is longer and more frequent in Central and Northern Norway than in southern areas (for Sweden see Singh et al., 2012). Around 30-40% of roe deer migrate, and they migrate over shorter distances. On average, roe deer

were found to migrate 15 km, and the longest recorded was 45.7 km (Mysterud, 1999; Mysterud et al., 2012). Genetics can also be used to infer large-scale dispersal and hence risk of CWD spread (Cullingham et al., 2011; Kelly et al., 2014; Lang and Blanchong, 2012). Reindeer are atypical among cervids as they are nomadic, and the boundaries of the area they inhabit determine their space use.

Besides migration, the dispersal patterns also have relevance for the spread and the likelihood of being able to contain CWD within a restricted area. There are few studies on the dispersal of young animals and how they settle, but this is probably relevant for long-distance spread of disease. Gender differences in the dispersal of roe deer in France were not identified (Gaillard et al., 2008). In red deer, there is male-biased dispersal (Loe et al., 2009), and, based on social organization, the same might be expected in moose. In red deer, males dispersed 21 km (median) with maximum of 147 km, but females dispersed around 6 km, with maximum 151 km (Loe et al., 2009). The proportion of dispersers varied from 30-80% in males, depending on population density, and <20 % for females. The majority of yearlings of both genders disperse in roe deer, apart from in high quality habitat areas. Dispersal distances can be very long and regularly >100 km. Hence, cases of CWD may arise quite some distance from outbreak areas if yearlings have the infection.

Diffusion models, including movements and habitat use, have been used to predict spread of CWD in mule deer in Utah (Garlick et al., 2014). Disease spread was linked to landscape connectivity, based on empirical analysis of GPS-data from mule deer in Canada (Nobert et al., 2016). Genetic tools have also been used to assess connectivity and risk of spread of CWD. Similar genetic structure of white-tailed deer on each side of a potential barrier (the Mississippi river), suggests that dispersing males frequently cross over and may spread CWD across the barrier (Lang and Blanchong, 2012). Also in mule deer in Saskatchewan, there was weak genetic structure and relatedness declining with distance, suggesting no barriers to spread over time (Cullingham et al., 2011).

6.3 Population development and performance of reindeer in the Nordfjella area

Nordfjella is a 3,000 km^2 mountain area in southern Norway (Fig. 6.3-1) that is strongly influenced by hydroelectricity developments, roads, and recreational cabins. As a consequence, the Nordfjella reindeer are divided into two sub-populations, one north of the road, Rv 50 Hol-Aurland (where CWD was identified) and one in the south (Hallingskarvet), where CWD has not been identified.

During the last 50 years, reindeer in Nordfjella have been strongly influenced by immigration from the neighbouring Hardangervidda wild reindeer area in the south. The last big influx occurred in the 1970s when more than 10,000 animals moved to Nordfjella during the winters. At that time, the population density and grazing pressure at Hardangervidda was particularly high, which may explain the exodus. The mountain areas between Hardangervidda and Nordfjella have a large number of archaeological sites, indicating that

this has been an important migration corridor in prehistoric times. Since the 1970s, Rv 7, one of the main roads between Oslo and Bergen, has become an increasingly stronger barrier to reindeer movements between the two wild reindeer areas.

Following the influx of reindeer from Hardangervidda in the 1970s, the local management in Nordfjella increased the harvest quota, which eventually reduced the population size (Fig. 6.3-2). In the same period, several hydroelectric installations were established and highway 7 was kept open during winter. This contributed to fragmentation of the population and a gradual disappearance of reindeer from the northernmost parts of Hardangervidda, as well as close to disappearance of reindeer in the southern part of Nordfjella. The local management has since been trying to restock the southern part of Nordfjella by reducing the harvest pressure.

The situation changed in the year 2000 when more than 1,000 reindeer crossed the Rv 50 from the north and remained in the southern part of Nordfjella. At the same time, this herd started to use the northernmost range in Hardangervidda (i.e., north of Rv 7), leaving highway 7 as the only remaining barrier for reindeer movements between Nordfjella and Hardangervidda.

The reindeer performance (body growth and reproduction) in Nordfjella has improved since the large influx in the 1970s. The body condition of calves has improved and the recruitment rate of calves is now close to the average for Norwegian wild reindeer populations. The local management has largely succeeded in keeping the population density stable at the northern part. However, reduced hunting has been implemented to increase the population size in the southern part of Nordfjella.

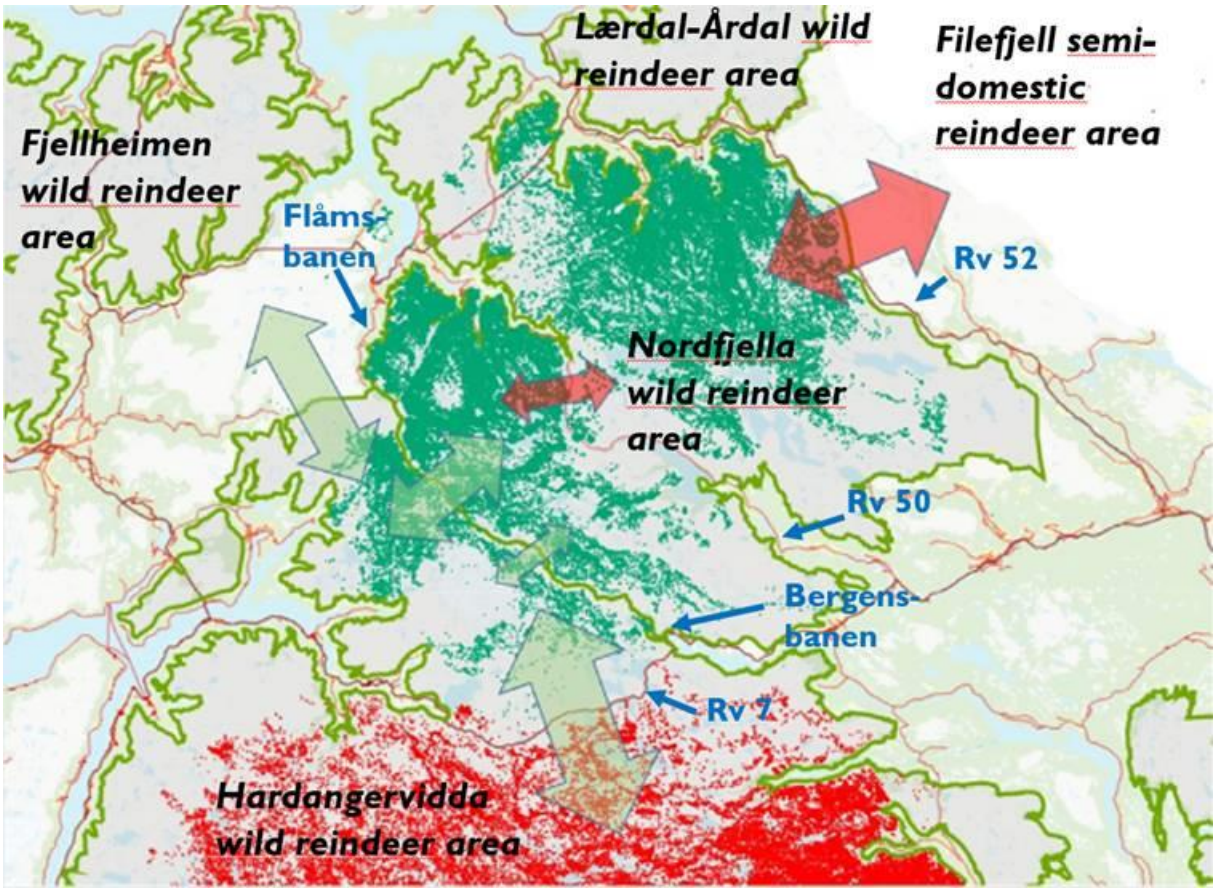

Figure 6.3-1 Main roads and railroads in and around the Nordfjella wild reindeer area, as well as GPS-locations of wild reindeer (green and red dots) and potential crossing points (big arrows) to neighbouring reindeer areas (demarcated by green borders). The Nordfjella wild reindeer area extends to highway Rv52 in the north, the tree line in southeast and the Bergensbanen railroad in the south. In the west, the area extends to Flåmsbanen railroad and the sea (Sognefjorden). The highway Rv 50 cuts through the area and acts as a semipermeable barrier for reindeer movement. Reindeer from the southern parts of Nordfjella frequently move into the northern part of Hardangervidda where they can mix with reindeer that cross Rv 7 from the southern part of Hardangervidda during winter.

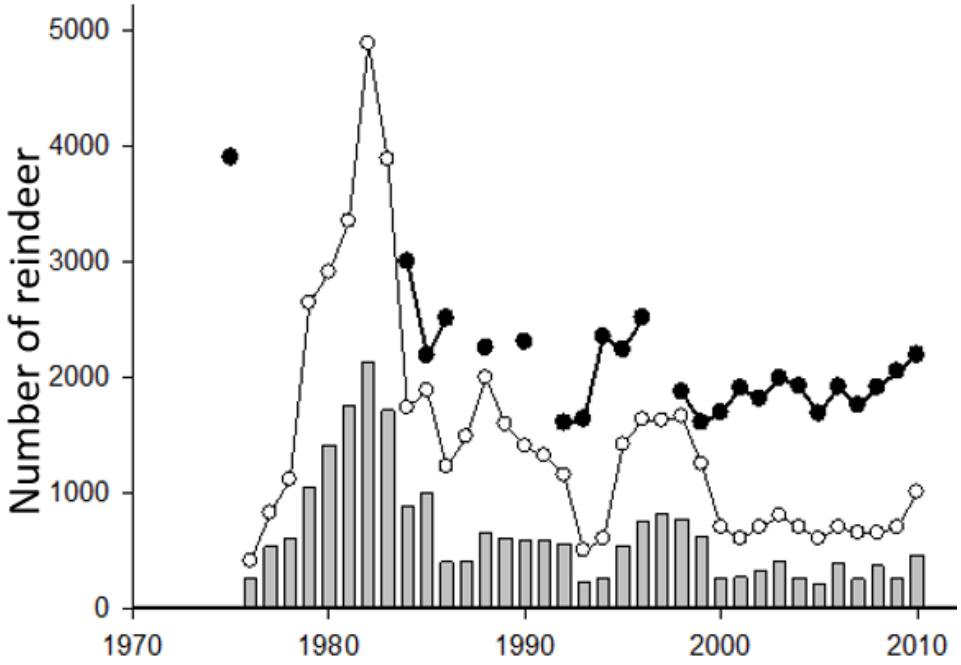

Figure 6.3-2 Annual variations in number of reindeer hunting permits (open circles), reindeer harvested (columns), and reindeer counted during summer surveys (black circles) in the Nordfjella reindeer area during 1975-2010.

Evidence from a handful of GPS-marked red deer and moose around Nordfjella suggest there is considerable contact between the reindeer population and the surrounding red deer and moose populations. Reindeer and red deer are both mixed feeders and have substantial dietary overlap (Mysterud, 2000). Moose are browsers with somewhat lower dietary overlap. Red deer using the areas into the Nordfjella, do so only during summer, and may have winter ranges 20-40 km away. Approximately 30% of the red deer population leaves the summer range before 15. September (Rivrud et al., 2016). We regard the situation for roe deer to be somewhat less critical. The population density of roe deer around Nordfjella is very low, both on the eastern and western side, although they are present. Nevertheless, roe deer are the species with the longest juvenile dispersal and also the highest dispersal rates. Therefore, should roe deer become infected with CWD, they could result in the infection being spread rapidly.

6.4 Population development and performance of moose and deer in the Trøndelag region (Selbu and surrounding municipalities)

In the Trøndelag region (7 municipalities), moose, red deer, and roe deer are typically found in the forest and lower alpine areas where they also show some habitat overlap with reindeer. Among the wild cervids, moose is the most common, followed by roe deer and red deer. During the last decade, on average 1,200 moose, 500 roe deer and 80 red deer have been harvested annually in this region (www.ssb.no), distributed throughout approximately 2,700 km^2 of forestland. According to the number of hunter kills, the density of cervids is higher in the lowland (e.g. Trondheim, Malvik, Stjørdal) than highland municipalities (Tydal, Selbu, Meråker).

As in most of Norway, the moose population abundance in the region has increased since the early 1970s and peaked just after the turn of the century. Since then, the population density has decreased in most municipalities. The current population density is about 1.0 - 1.5 animals per km^2 forestland, which is above average for Norway. Accordingly, there has also been a decrease in moose performance during the last 15 years as measured by the proportion of twin-producing females and carcass mass of calves (Solberg and Rolandsen, 2015; Solberg and Rolandsen, 2016; Solberg et al., 2015) probably due to density-dependent food limitation.

Except for the harvest records, less is known about the population development and performance of roe deer and red deer in the region. The harvest of roe deer seems to be quite stable, but is lower than in the early 1990s. The harvest of red deer has increased continuously during the last two decades to almost 140 animals in 2015. Most red deer are harvested in Stjørdal and Selbu. According to monitoring data from Stjørdal, the average carcass masses of calf and yearling red deer are still high in this region and show no trends over the last decade (Tangvik et al., 2016).

7 Screening for CWD in cervids in 2016 and early 2017

Following the discovery of CWD in Nordfjella (reindeer) and Selbu (moose) in the spring of 2016, several initiatives were launched for screening the wild cervid populations for CWD. The first initiative was to test deer killed in traffic accidents or by other incidental mortality factors (fallen stock) throughout Norway. The latter includes deer found dead by the public, killed for damage control or security reasons, or deer culled by wildlife officials because of injuries, diseases, or atypical behaviour. Each year approximately 8 000-10 000 wild cervids (all four species) are recorded dead for reasons other than hunting (www.ssb.no), of which the majority (approximately two thirds) are killed in traffic accidents. Another 1-3% are killed for damage control, safety reasons, or illegally. The remaining 30% are deer found dead or are culled due to atypical behaviour. The latter group is most likely to include individuals with CWD. Most traffic kills of deer are recorded in late autumn and winter.

The second initiative was to test a large number of cervids killed during the ordinary hunting season. Accordingly, the Norwegian Environment Agency asked the Norwegian Institute for Nature Research (NINA) to implement a CWD-survey as part of the National monitoring programme for large cervids. Because of the short notice and limited resources, the survey only included adult individuals (1 + years) from a limited number of areas. The selected areas were: 1) the two areas with recorded CWD-incidence (Nordfjella and Selbu), 2) neighbouring municipalities, 3) all monitoring areas for moose and red deer (Solberg et al., 2015), and 4) the two reindeer monitoring areas of Hardangervidda and Forollhogna (Solberg et al., 2015).

The last initiative was to test all hunter-killed deer submitted to game meat processing companies in the autumn of 2016. A game meat processing company is a small slaughterhouse that buys and butchers carcasses of deer killed by hunters, and subsequently sell the meat, either to a third-party or back to the hunter. Because these small slaughterhouses are part of the commercial meat-industry, they are subject to regular surveillance implemented by the Food Safety Authority, and provide easy access to samples for CWD analysis. In several municipalities outside the main surveillance areas, representatives from the Norwegian Food Safety Authority have also been testing a smaller number of hunter-killed cervids that are not submitted to game meat processing facilities.

In addition to wild cervids, samples of farmed red deer and semi-domesticated reindeer were tested for CWD in 2016 and early 2017. These were tested after slaughter in approved slaughter facilities, except for a few individuals that were killed in traffic (reindeer), euthanized, or found dead for other reasons.

7.1 Results of the CWD screening in 2016 and early 2017 (to early March)

Since March 2016, 8770 samples from wild cervids have been tested for CWD (moose n = 4,629, red deer n = 2,550, wild reindeer n = 860, and roe deer n = 627, unknown species n = 104), of which 5 were CWD-positive (2 moose, 0 red deer, 3 reindeer, 0 roe deer). These numbers include the single CWD-positive reindeer first found in Nordfjella in March 2016, and the two CWD-positive moose found in Selbu in May 2016. Hence, after detection of the three initial cases, only 2 more CWD-positive reindeer were found as part of the screening – both in the Nordfjella wild reindeer area.

Most samples came from hunter kills (n = 6786), followed by samples from fallen stock (n = 1984). Samples were collected in 310 municipalities and 9 wild reindeer areas (Fig. 7.1-1). Samples from fallen stock included samples from 250 (out of 323) reindeer killed by lightening in Hardangervidda in August 2016.

In the Nordfjella area, 358 reindeer were tested for CWD, of which 3 were positive (i.e., including the first case in March 2016). The remaining two CWD-positive cases were found among the 326 hunter-killed reindeer tested in the area (prevalence of 0.6%). In the Trøndelag region, samples from 647 moose, 47 red deer, and 20 roe deer were analysed for CWD. All were negative. A large proportion of the samples came from Selbu municipality (254 moose, 15 red deer, and 4 roe deer).

In total, more samples were collected from males than females (55% males), and the same was true for moose (57% males), and red deer (55% males). More samples were collected from females than males for wild reindeer (47% males) and roe deer (42% males). The two Nordfjella CWD-positive reindeer detected during the hunting season were a male and a female.

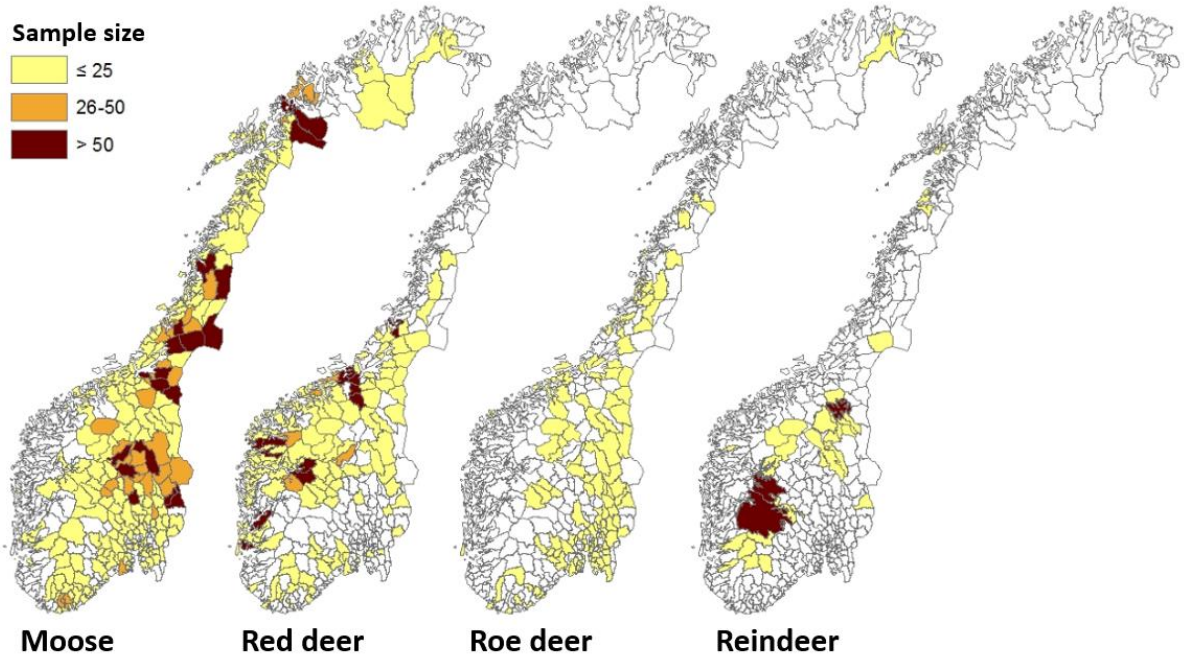

Figure 7.1-1 Geographical distribution of samples from hunter kills and fallen stock in 2016 and 2017 (until end of February 2017).

Although the surveys were extensive in selected areas, it is important to note that most areas were not covered by a full screening of hunter kills in 2016 (Fig. 7.1-1). As a consequence, CWD may still be undetected in many parts of Norway. This is particularly so for wild reindeer, which, because of their less accessible living areas, are rarely found and reported dead by the public. Hence, due to the very low number of tested animals, it is highly unlikely that CWD would be detected in wild reindeer other than in Nordfjella, Hardangervidda, and Forollhogna, which were subjected to surveillance testing.

Regarding domesticated cervids, 163 farmed red deer (57 % males) and 2494 semi-domesticated reindeer (37 % males) were tested in 2016 or early 2017. All were negative for CWD. Most were slaughtered for consumption, but a few (19 red deer, 103 reindeer) died due to other reasons. From the herd of Filefjell reinlag, i.e., the herd just north of Nordfjella wild reindeer area, 201 reindeer were tested for CWD. The remaining reindeer samples came from herds in Oppland, Central Norway, and Northern Norway. Samples from farmed red deer came from all parts of Southern and Central Norway (up to Helgeland).

8 Semi-domesticated reindeer

Nomadic-style reindeer herding in Fennoscandia can be traced back to the 1500-1600s. Wild reindeer and semi-domesticated reindeer exhibit similar behaviour. Typically, for herbivorous species inhabiting open landscape habitats, both semi-domesticated and wild reindeer exhibit well-developed herd instincts as a defence against predators (Skogland, 1994). However, semi-domesticated animals are generally more tame then their wild relatives.

For reindeer to be categorised as semi-domesticated they must be privately owned and marked accordingly, with active herding of the animals within and between seasonal pastures. Animals can be herded into fenced areas and handled without being overly stressed. Handling of the animals should follow the current guidelines provided by the authorities, and should be in line traditional knowledge of reindeer herding.

8.1 Management levels

The Sami reindeer pasture area extends from Finnmark to Hedmark and is divided into six grazing regions. With some exceptions, the borders between the grazing areas correspond to the county borders: Finnmark, Troms, Nordland, Nord-Trøndelag, Sør-Trøndelag, Hedmark and Oppland. Reindeer herding also occurs outside the Sami reindeer grazing areas in Trollheimen, Nord-Gudbrandsdalen and Valdres in Oppland. The Sami reindeer grazing areas are further divided into 80 reindeer grazing districts (Landbruksdirektoratet, 2016), which preferably should have borders that facilitate herding. A siida is a group of reindeer owners who share responsibilities and collaborate on herding. There are 99 summer-siidas and 150 winter-siidas within the Sami reindeer grazing grounds of Norway.

There are substantial differences in both topography and climate between the different reindeer grazing areas, and this leads to large variation in herding patterns. Seasonal herding of semi-domesticated reindeer between pastures is based on the ancient migration patterns of wild reindeer. In Finnmark and Sør-Trøndelag, the reindeer spend their summers close to the coast, and winters are spent in the dry and cold inland areas. More complex grazing patterns are found in the coastal areas from Troms and though to Nord-Trøndelag. In Troms, some of the herds are located on the local islands on an annual basis, whereas others are moved inland in winter. In Nordland and Nord-Trøndelag, the animals are commonly moved towards the coast in winter. Fenced areas in the vicinity of these migration routes are used when gathering or moving a herd of semi-domesticated animals (see Appendix III).

8.2 Risk factors with regard to herding practices

The use of common infrastructure provides a considerable risk for spread of diseases. Semi-domesticated reindeer are gathered together within fenced areas several times each year, which further facilitate close contact among them. Many different herds may use the same fenced reindeer facilities, thus each reindeer herd is indirectly in contact with other herds through their urine, faeces, hair, means of transportation, equipment, and people in contact with the animals. Many different herds use the same trailers, vehicles, and boats to transport reindeer. Mobile slaughterhouses are used across large areas and in many different regions.

Other risk factors are artificial feeding and use of salt licks, which is common practice during the snow-free months. Selling and purchasing live reindeer is a common practice in the start-up days for young reindeer owners. Reindeer are marked by cutting off a tiny section of their ear, using the same knife/plier for all animals.

8.3 Herding to control and limit disease

General measures limiting spread of disease in a semi-domesticated reindeer setting involve many of the same tactics as are described in chapters 9 and 10. Owners of semi-domesticated reindeer may have measures imposed upon them to prevent disease spread. Thus, it should be easier to prevent the spread of a disease in a semi-domesticated herd than in a wild herd.

Herding can be actively used to combat spread of disease. A semi-domesticated herd may be structured in such a way that animals are more or less stationary in one area, thus reducing the chance of disease transfer outside the herd. This includes removal of animals that repeatedly escape to other herds and moving herds located in the vicinity of risk areas. Barriers to prevent disease transfer, including fences, can be established in strategic places. Surveillance of the herds can further be improved if both wild and semi-domesticated reindeer are equipped with GPS-transmitters. An established routine for exchanging such data between the Norwegian Nature Inspectorate (SNO) and the reindeer herder would be beneficial.

9 Measures for prevention, control, and eradication of CWD

The management approach chosen should depend on the potential impact of the disease on the animal population, the economic and sociocultural value of this population, the available resources, the nature of the disease and its host(s), the environment, and, most notably, the extent of establishment of the disease is in the area and population of interest. In an early phase, a proactive response may facilitate eradication at a relatively low cost, whereas higher prevalence and/or a wider geographic distribution could make it impossible to prevent further spread and eradication of the disease (Fig. 9-1)

Based on experiences from North America and their applicability to the situation in Norway, we here review measures that can prevent, limit, or eradicate CWD. In the early stages, disease eradication is often the preferred goal. However, as soon as a disease has reached endemic proportions, eradication is no longer realistic (Williams et al., 2002).

There are few effective means of controlling CWD in wild populations (Uehlinger et al., 2016). Most actions against CWD have involved harvesting, either non-selectively or by different kinds of selective harvesting (Uehlinger et al., 2016). The latter means a targeted reduction of specific demographic groups, such as males that are suspected to have a higher CWD prevalence. Other targeted efforts include removal of clinically suspect animals.

In contrast to the situation in North America, where CWD is present in open, continuous deer populations, the fact that the Nordfjella reindeer population is a contained population is a major benefit regarding the likelihood of eradication of CWD. However, it should be noted that although this population is closed from a reindeer-population perspective, both red deer and moose use the same area and pose a risk of spillover and spread. If CWD spreads from Nordfjella to red deer or moose with open populations, eradication will be almost impossible and efforts to limit spread must be instigated.

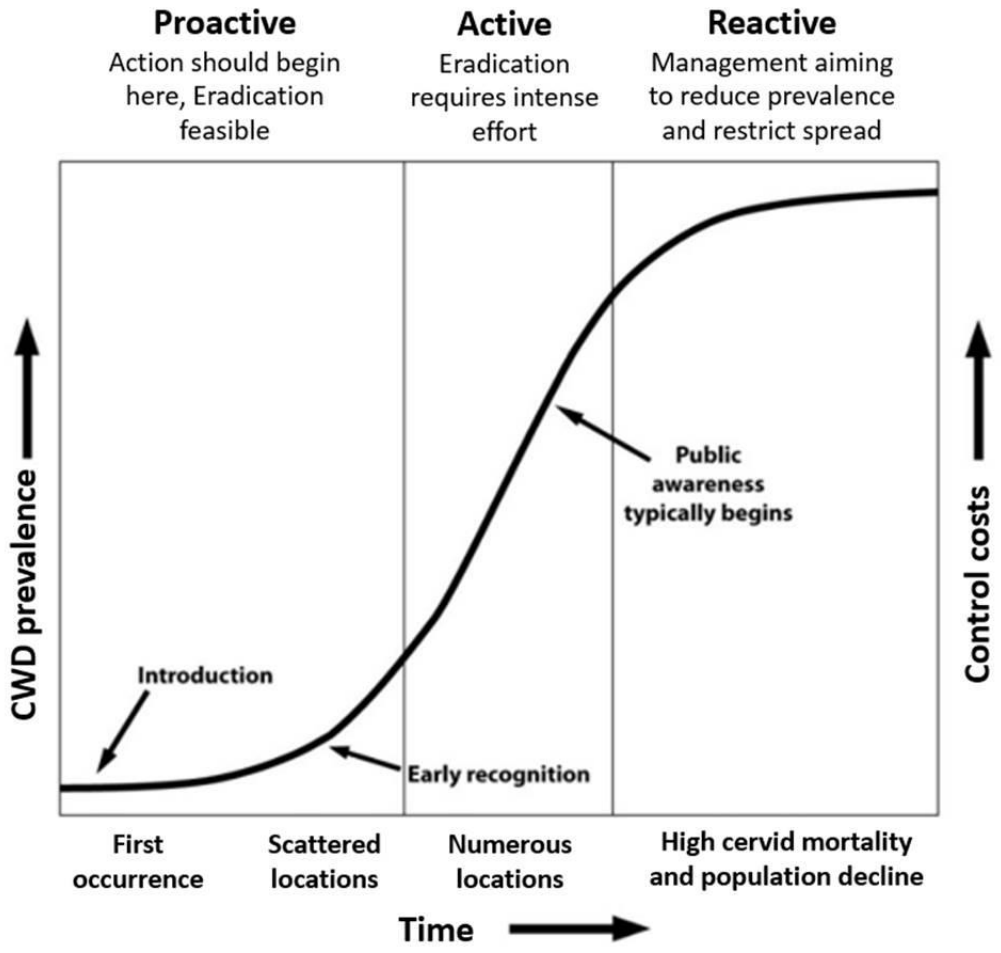

Figure 9-1 Phases of CWD introduction and control (adapted from Florida Invasive Species Partnership (FISP): http://www.floridainvasives.org/edrr.cfm). We are probably in the phase of early recognition in Norway.

9.1 Prevention

Generally, the most feasible and least expensive way of preventing spread of an infectious agent, is to keep it out of the area of interest (AoI), i.e., to prevent its introduction and establishment in a given area. Long-distance spread of CWD in North America is due to human activity, such as transport of live animals and material from hunter-harvested CWD-infected individuals. There should be restrictions on import, export, and domestic transport of live animals and any material that can carry the infectious agent from potentially infected areas. Hunters and tourists, in particular those from other countries than Norway, should be made aware of the risk of CWD-prions in cervid tissues (e.g., bones and antlers) from infected areas. Since test sensitivity for CWD is relatively low, it is likely that false negatives can occur, and hence material from all harvested deer in CWD-infected areas should be treated accordingly.

Obstacles and fences that prevent contact between the animals of the AoI and the infectious agent are highly relevant for CWD. For example, fences along roads such as RV52,

separating the CWD-infected herd in Nordfjella from semi-domestic reindeer in Filefjell, could be highly relevant.

Vaccination against prion diseases is particularly challenging since there is typically no immune response to the infective prions. Other related preventive measures tried on captive mule deer were also deemed ineffective (Uehlinger et al., 2016).

- Transport of captive deer is a risk factor.
- Transport of infective material by hunters from CWD-infested areas is a risk.
- Fences can aid in limiting connectivity and introduction of CWD
- No vaccine for CWD exists.

9.2 Control

The aim of control measures is to reduce the occurrence of an established infectious agent and/or its impact within an area to a (socially/politically/economically) tolerable level. Control measures alone may not have sufficient power to prevent the establishment of a disease or to eradicate it from an area, but can facilitate prevention or eradication when combined with other measures.

9.2.1 Removing the infectious agent

Elimination of an infectious agent from an environment can, in general, be achieved by a combination of treatment of infected animals, destruction or removal of the infectious agent in the environment, or reduction/eradication of the vectors of the infectious agent, depending on the location of the reservoir of the agent in question.

In the context of CWD, however, none of these approaches are relevant. This is because CWD infection is difficult to detect in live animals and a curative treatment is currently unavailable. Furthermore, inactivation of prions in the environment is not feasible and vectors are not involved in the transmission of CWD.

9.2.2 Containing the infectious agent

As for prevention, limiting contact between animal populations using fencing and buffer zones may be important in the context of CWD. Restricting animal movement can be achieved either by minimizing the contact rate of susceptible individuals with the infectious agent or by minimizing migration and dispersion of infected individuals. In either case, this can be accomplished by creating obstacles and/or scaring the animals away.

If CWD is confined to a limited number of clearly defined locations, it is essential to limit further spread of the agent. Reindeer populations in Norway are relatively isolated, either due to human infrastructure or naturally by intersecting valleys. They can therefore be treated as partly confined populations, and it may be important and feasible to strengthen man-made and natural barriers by fencing. In areas and situations where there is a high risk of contact between infected and susceptible reindeer populations, surveillance, herding, and

even chasing of animals that try to cross the borders may be a sensible approach. This kind of management is less likely to succeed for moose, red deer, and roe deer populations. However, fencing may also limit spread between adjacent populations of these species.

- Restricting animal movement between confinable populations of reindeer is important.
- Restriction of animal movement is difficult to achieve in more continuous populations, but can be performed where there are strong natural and/or man-made barriers. For example, roads with long stretches of fences to reduce traffic vehicle collisions often have openings that allow crossing at specific points. These should be shut to limit spread of CWD.

9.2.3 Removing infected animals

Animals shed infectious prions during most of the long incubation period. The period where the infected animals show clinical signs of disease is relatively short. Selective culling of clinical suspects has been conducted in Colorado and Wyoming for many years, but this approach has proven insufficient to reduce CWD prevalence (Williams et al., 2002). However, as the carcass of an animal that has died with, or of, CWD may contain large amounts of prions and represents a significant and long-lasting source of infection for other animals, it's removal may reduce the transmission rate.

- Culling of clinically suspicious animals will have limited effect.

9.2.4 Reducing animal density

Reducing animal population density is often an important tool to combat infectious diseases and can be done at the following scales:

i. In the infected area to: minimize contact and spread between animals, reduce the number of infected animals, and/or decrease the motivation for migration/dispersion
ii. In a zone around a defined infected area to minimize contact rate between the infected population and animals in AoI.
iii. In a large area

As discussed in chapter 4.3, CWD transmission within a population is only weakly affected by population density and actions to reduce population density are unlikely to be highly effective.

Drastic, non-selective density reductions in deer close to newly identified foci has been undertaken in many cases (Williams et al., 2002). The first detailed assessment of density reductions did not show a significant effect on CWD occurrence in mule deer in Colorado (Conner et al., 2007). Whether this was due to the short duration of the efforts or issues related to power in testing was uncertain (Conner et al., 2007).

Later empirical analysis of the management programme for white-tailed deer in Illinois indicates that continued targeted harvesting efforts seem to have been effective in reducing CWD prevalence (Manjerovic et al., 2014; Mateus-Pinilla et al., 2013). This included both hunter harvest as well as governmental sharpshooters. In Wisconsin, CWD prevalence remained stable when there was both hunter harvest and governmental hunting, but increased when governmental hunting was stopped (Manjerovic et al., 2014).

Density reductions should reflect patterns of migration and be based on functional population units, i.e., the geographical extent of infection (Williams et al., 2002). Spatial targeting of disease detection using hunter harvest during early phases of an outbreak can be critical (Rees et al., 2012). Data on habitat use by mule deer (Russell et al., 2015) and white-tailed deer (Evans et al., 2016) was used to identify the areas for targeting, and niche-based models were used to predict focal areas of CWD in white-tailed deer in Illinois and Wisconsin (O'Hara Ruiz et al., 2013). CWD prevalence was correlated at a scale of 3.6 km in white-tailed deer in Wisconsin (Joly et al., 2006). Targeting efforts are important both for measures to be effective and because other mitigation efforts may have considerable direct and indirect costs. In Colorado, the typical scale of targeted state wildlife management culling was 17 km^2 (Conner et al., 2007). Such efforts depend upon known dispersal and migration of cervids, possibly with a wide buffer zone.

A spatially targeted harvest may remove a higher proportion of CWD-infected animals compared with the overall prevalence in the population, as related females are spatially clumped and spread disease amongst each other. Thus, a targeted effort to reduce density by removing social groups in white-tailed deer in Wisconsin was regarded as being more effective for CWD control than non-selective harvest (Magle et al., 2015).

As mentioned in chapter 5, the risk of spillover from a population of one species to another may be linked to (1) population density of the recipient species, (2) the spatial and dietary overlap of the two species populations, and (3) the density of infected individuals in the donor population and the suceptibility of the recipient towards a given strain of the prion agent. Consequently, population density reduction of both a potential recipient population and a potential donor population should be considered, especially in the border areas between the population ranges, in order to minimize contact rate between infected individuals from the donor population and the susceptible individuals of the recipient population, and hence risk of spillover.

- Spatially targeted harvesting appears to be the main tactic for limiting CWD in open populations.
- Related individuals infect each other and may live closer together.
- Reduction of population densities in the adjacent border areas of both a potential donor and a potential recipient population appears prudent to reduce the likelihood of spillover.

9.2.5 Selective targeting of males

In deer, CWD prevalence is often higher in males. Modelling has suggested that targeting all males is more effective for combating CWD than targeting more specific demographic groups, such as age classes of males (Potapov et al., 2016).

For species with male-biased yearling dispersal, one management tool may be to target such individuals (Skuldt et al., 2008). Young males have the greatest dispersal potential and adult males often have a higher prevalence of CWD (Clements et al., 2011). Red deer and most likely also moose have male-biased dispersal, while both genders disperse in roe deer (chapter 6.2)

Targeting male yearlings is broadly the approach in current population management of cervids in Norway, so there is limited possibility to increase this further.

- Males have higher infection levels, and removing them may contribute towards reducing CWD prevalence.
- Young males disperse more often, and may spread disease over greater distances.

9.2.6 Environmental and managerial adjustments to minimise contact rates

Any action that limits direct contact among individuals, reduces communal use of small areas, and decreases the likelihood of ingestion of soil on shared pastures, will probably reduce the risk of spread of CWD within and between populations.

Aggregation of deer at winter-feeding sites most probably increases disease transmission (Williams and Miller, 2003). In areas with CWD-infected animals in North-America, the use of salt licks and feeding baits are generally prohibited (Williams et al., 2002).

Salt licks are not used in wild reindeer management in Norway. However, salt licks for sheep are extensively used and are available to reindeer in most mountain ranges. Salt licks for cervids are banned. However, without prohibiting salt licks for livestock outside fenced areas this ban is unlikely to have any major effects on the CWD dynamics in wild cervids. Importantly, as salt from the licking stone runs off and is retained in the surrounding soil, cervids will visit these spots and consume the soil there (Schramm et al., 2006). As the soil surrounding a licking stone is contaminated with urine and droppings from animals, prions shed in these excretions from infected animals may persist in the soil here. Thus, removal of the mineral stone alone will not prevent disease transmission, but must include measurements that prevent the contaminated soil from being accessible for cervids.

Guide-fences, migration obstacles, road crossings, and particularly attractive food resources may also result in increased gathering of animals and thereby elevate the risk of disease transmission at the local scale.

- Salt licks constitute a major risk factor, and any ban must also include salt licks for livestock.
- Removal of contaminated soil around salt licks is necessary to ensure infective prions do not remain in these areas.
- Supplemental feeding is a significant risk factor.

9.3 Eradication

Eradication is defined as an action performed within a defined area during a limited period of time in order to reduce permanently the occurrence of a given infectious agent or disease to zero. In a wildlife context, eradication is often not feasible and/or not socially/politically acceptable, as eradication measures may be costly both in terms of economy, human resources, and animal lives and welfare. The literature indicates some success criteria for eradication programs: (adapted from Bomford and O'Brien (1995); Myers et al. (2000) og Wobeser (2006)):

Biomedical criteria:

I. It should be feasible to remove the infectious agent in question more rapidly than it reproduces/is reproduced at all densities/prevalences.
II. Reinvasion/recontamination of the eradication zone should be preventable.
III. The infectious agent should be detectable at low densities/low prevalence.
IV. It should be possible to remove all reproducing individuals.
V. The biology of the infectious agent should be so well known that the eradication actions are as targeted and as efficient as possible, i.e., the agent's ability to spread and persist in the environment, and its reproductive biology and life history must be well known.

Socio-political/economic criteria:

VI. The goal of the programme should be clearly defined and related to a predefined measurement of its efficacy. Targeted and long-term surveillance must be established relative to the goal and this efficacy parameter.
VII. The resources available should be sufficient to sustain the programme until the goal is achieved.
VIII. Lines of authority and responsibility should be clarified and implemented and monitored by a single managerial body.
IX. Cost-benefit analysis should show that eradication is a preferable solution than control.
X. The programme should have broad socio-political support.

In the next chapter, chapter 10, we discuss the possibilities for eradication of CWD from Norway, depending on whether the population is containable, as for reindeer in Nordfjella (strategy 2), or continuous, as for moose in Selbu (strategy 3).

10 Strategies for management of CWD in Norway

Reviewing the North American literature on CWD management demonstrates that control and eradication of CWD from populations of wild cervids is very challenging. Eradication of CWD in North America has, however, been successful in farmed deer (closed populations), typically involving depopulation, quarantine, and restocking. This is similar to classical scrapie in Norway, which has not been diagnosed since 2009, demonstrating that in containable populations contagious prion disease can be dramatically reduced and even eradicated. There are only two cases (New York and Minnesota) with successful eradication of CWD under free-ranging conditions (open populations). In both cases, this involved massive, spatially targeted harvesting and the implementation of intense surveillance soon after the discovery of CWD.

Achieving CWD eradication is regarded as unattainable if CWD becomes endemic in open populations, and the remaining options in such a situation are controlling and limiting the prevalence. Norway is therefore very likely to be currently positioned in a historical window of time, where there is still have the opportunity to eradicate CWD. However, this situation obviously calls for immediate action. Unnecessary delay will markedly reduce the likelihood of successful eradicating CWD, due to the risk of spread and contamination with, and persistence of, prions in the environment.

The management decisions for CWD in Norway at the current stage must be based on a high level of uncertainty at different levels, both in terms of the situation and regarding the likelihood of success. Due to this, adaptive management should be implemented. Below we evaluate the current evidence and the different kinds of uncertainties, as of March 2017, to suggest support for different management strategies, given different aims.

However, it is important that decision-makers do not delay action until further information on uncertainties is available from researchers, if this means that action may be postponed beyond the point at which meaningful intervention is possible (Milner-Gulland and Shea, 2017).

10.1 Strategies – options for management

Actions can broadly be divided into prevention and containment versus control and eradication of CWD (chapter 9). The management options for CWD depend on whether the host populations are closed and containable (as for some reindeer populations) or more open and continuous, as for most moose, red deer, and roe deer populations. We consider the following management strategies:

1. No intervention.

a. Typical contagious CWD.
b. Atypical, less contagious CWD.

2. Stamp out outbreaks by eradication of infected containable populations by depopulation, fallowing, and restocking.
3. Control outbreaks in continuous populations by spatially targeted harvesting.

The timeline and evidence concerning wild reindeer in Nordfjella and moose in Selbu are assessed. These strategies can build valuable competence in case of new emergence of CWD in Norway or elsewhere in Europe. The first strategy is divided into two, according to putative differences in contagiousness between CWD strains seen in reindeer versus moose. Strategies 2 and 3 are intended for typical contagious CWD.

10.1.1 Strategy 1a – No intervention in the case of classical CWD

Empirical evidence from North America demonstrates that CWD does not disappear by itself. On the contrary, CWD slowly increases in distribution and prevalence. It is unlikely that evolutionary adaptation in disease susceptibility will significantly influence spread of the disease. Nevertheless, knowledge about genetic susceptibility of different populations is limited and potentially valuable.

Genetics play a role in CWD dynamics in North America (Robinson et al., 2012b) and variation in the *PRNP* gene can modulate disease susceptibility. Modelling of the genetic influence on CWD occurrence in white-tailed deer (Robinson et al., 2012a) and elk (Williams et al., 2014) indicates considerable room for host selection, if there are genetic differences that affect incubation period and possibly shedding of infectivity. However, absolute resistance is unlikely (Johnson et al., 2011b). The influence of *PRNP* variation on CWD in Norway is currently unknown, but preliminary data suggest that considerable proportions of Norwegian deer populations should be considered susceptible.

Furthermore, predators are very rare in Norway (all large predators are listed as endangered or critically endangered on the Norwegian Red List of Threatened species), therefore predation is of little relevance for CWD epidemiology in Norway. A management strategy of no action with CWD would allow the disease to spread and become endemic, and virtually impossible to eradicate in the future. The infection could then spillover to other cervids and, potentially, slowly spread across Norway, and eventually into Sweden and beyond. For roe deer, disease susceptibility is currently unknown, but the *PRNP* gene in roe deer suggests that they are susceptible.

Anthropogenic spread of CWD is well known from North America and is by far the most likely mode of long-distance spread. Spread of CWD to Continental Europe from Norway is most probable through human transport, rather than through gradual spread or dispersal of animals or birds. It may take decades before CWD prevalence is high enough to affect growth rates of affected deer populations substantially. In wild reindeer, due to their social structure and herding behaviour, the rate of increase in prevalence of CWD is likely to be

higher than observed in North America for less social deer species. In continuous cervid populations in USA, some foci of high infection occur, but there are also other areas with lower rates of infection. Formal analysis suggests that this is mainly due to time of introduction of CWD (chapter 4). In the case of moose, which is a less social species, there has been repeated spillover, without eliciting an epidemic in moose. It is unknown how fast CWD will spread, and how high the prevalence will become, if unmanaged. However, for red deer and reindeer, it seems likely that it will become a major limiting factor for species success and cause population declines.

Increasing prevalence and distribution of CWD will increase the exposure of other species. This is thought to increase risk of spillover of infection, establishment in new species, and perpetuation of new strains with different host infectivity.

- Untreated classical CWD spreads and increases and does not die out by itself.
- Genetic adaptation of cervids to CWD is unlikely to have a significant influence on the epidemiology of this disease in Norway.
- High prevalence among adult females will reduce population growth rates.
- It may take decades for CWD to reach a high prevalence in a population, but it is likely to cause population declines in the long term.
- CWD will spread out of an area by animal movement and human transport.
- Future spatial patterns of prevalence are unpredictable in continuous populations in Norway.
- CWD will spillover between cervid species.
- Other species will experience increased exposure to CWD.
- Waiting before implementing decisive action now will reduce the chances of succeeding with strategies 2 or 3.

10.1.2 Strategy 1b – No intervention in the case of atypical, less-contagious CWD

The limited data available suggest that the CWD cases in the moose from Selbu might be less contagious than is typical for CWD known from North America. The CWD in moose is possibly more similar to well-known atypical forms of prion disease in livestock, such as atypical scrapie in sheep and atypical forms of BSE (chapter 2.2.3). These atypical TSEs are considered non-contagious and their occurrence appears to be sporadic. The epidemiological behaviour of these diseases has resulted in different approaches in terms of control and management. They cannot be eradicated through local depopulation, and, therefore, testing of certain age groups and fallen stock is implemented to minimize the risk of animals with atypical prion disease entering the human food chain.

If the CWD observed in moose in Norway is recognised as an atypical and non-contagious form, a similar test regime should be implemented to prevent human exposure. However, no further actions, based on today's knowledge, would be warranted.

A nation-wide comprehensive testing of moose could contribute to clarifying the distribution of this disease. This would also be of tremendous value for our understanding of the nature of CWD in moose in Norway. If the distribution of the disease is unclustered, this would suggest sporadic occurrence. However, a focal occurrence indicates a contagious nature of the disease or a hitherto unknown predisposing factor with limited geographical distribution.

- If particular CWD are characterised as atypical prion diseases, these are less contagious and should not require action.
- There is uncertainty about this strategy, as atypical CWD in cervids has never been reported previously.

10.1.3 Strategy 2 – Eradicate CWD outbreaks in a confinable population by depopulation, fallowing, and restocking

If CWD is discovered in a closed population, such as a deer farm, complete eradication of CWD is possible by: 1) complete removal of the host population (depopulation), and 2) at least 5-years fallowing, before 3) reintroduction of new stock.

The low connectivity between the different wild reindeer management areas of Norway means that such a strategy is a possible option for eradication of CWD. Also, due to the nomadic space use and gregarious behaviour of reindeer, any spatial structure of infection within the different wild reindeer areas is unlikely. Therefore, spatially targeted hunting of parts of the population (strategy 3) would not be an option. Strategy 2 will also be the most natural management strategy for semi-domesticated reindeer. More knowledge on the persistence of prions in pastures and practical experiences with eradication, fallowing, and restocking of captive herds in North America are necessary to determine the most appropriate duration of the fallowing period if this strategy is implemented, but 5 years seems to be the minimum. The strategy is also dependent on application of sensitive and reliable test methods on the population and/or individuals that are used for restocking.

The success of strategy 2 is considered uncertain, as this has never been attempted in wild, free-ranging populations of cervids. However, there appears to be no clear alternative approach for many wild reindeer populations due to lack of home range behaviour (Fig. 10.1-1). Such a dramatic strategy may be locally beneficial, even in situations where the strategy will not eradicate the disease from the country, i.e., when CWD has become established in several other locations. As long as confinement of the population is feasible, reintroduction of infected animals can be prevented, and there are disease-free animals available for restocking, the strategy is rational for reestablishment of a healthy population. The rationale will disappear when it is unrealistic to prevent reinfection or disease-free individuals of the same genetic heritage for restocking are unavailable.

Strategy 2 is a drastic measure, and the following conditions would increase feasibility and likelihood of success:

i. CWD infection is documented.
ii. Confineable population.
iii. Relatively small population over a small spatial scale.
iv. Reinfection probability low.
v. Animals for restocking are available.

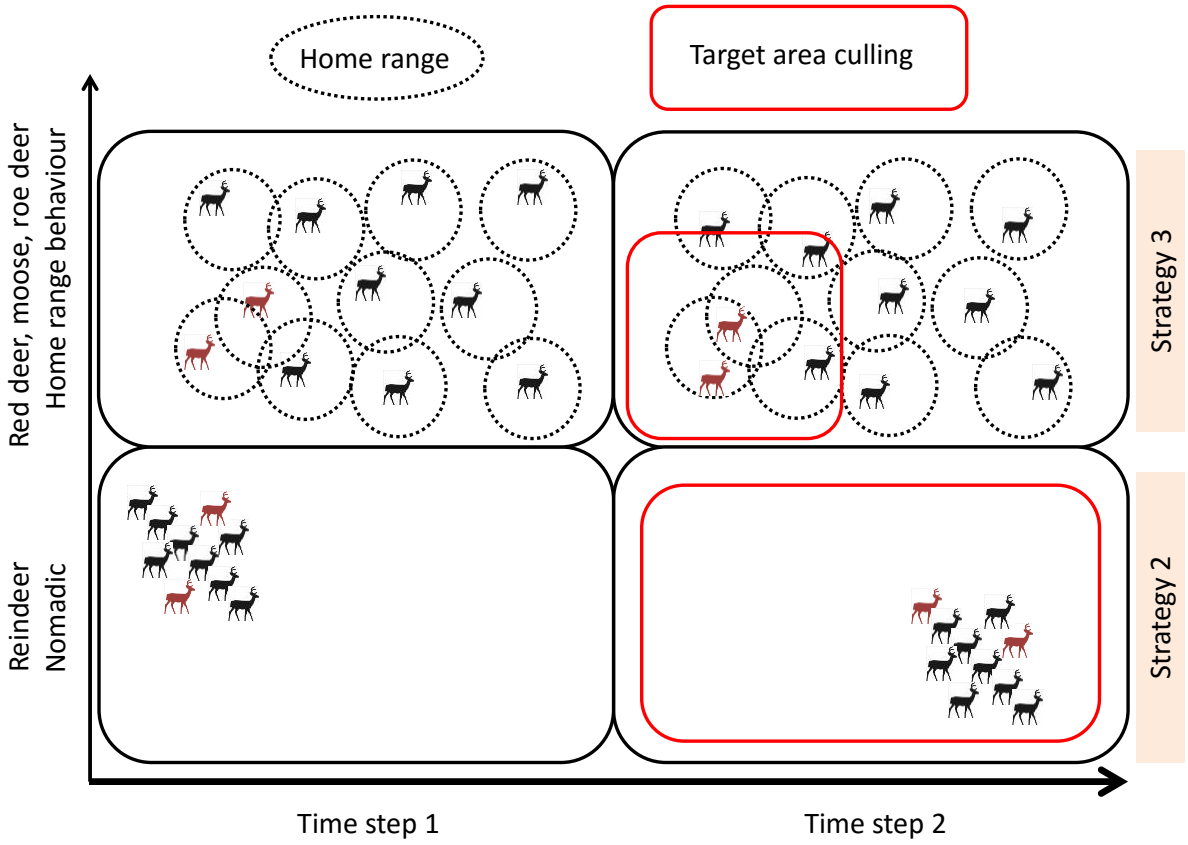

Figure 10.1-1 The selected strategy for combating CWD will differ depending on the species. Reindeer are nomadic within confinable areas and the targeted area for culling efforts is the scale of the entire reindeer area. Moose, red deer, and roe deer are more bound to home ranges, but live in continuous populations. Targeted culling in areas with CWD cases may remove a higher proportion of CWD-infected individuals than in the total population.

10.1.4 Strategy 3 – Control CWD outbreak in a continuous population by spatially targeted harvest

Spatially targeted population reduction is the method of choice in continuous populations of cervids with home range behaviour (Fig. 10.1-1). However, eradication of CWD in continuous populations appears difficult. The scientific evidence that targeted harvesting to limit prevalence of CWD is efficacious is not consistent (chapter 9.2.3). The social structure of

cervids in forest-dwelling populations means that it is likely that infected individuals are spatially aggregated. It is common for roe deer, red deer, and moose that are related (female) to live closely together, with some overlap in space use (Fig. 10.1-1). A reduction in population density in areas of CWD outbreaks can limit CWD by removing a higher proportion of infected individuals than in adjacent areas. Removing a large proportion of individuals in an area with known infection may remove all or most infected individuals. However, a marked reduction in population density does not, in itself, affect rate of transmission within a population, as CWD is not strongly density-dependent (chapter 4). This can also be a drastic measure, and the following conditions would increase the likelihood of success:

i. CWD infection is documented.
ii. There is a degree of site fidelity of individuals.
iii. The targeted area reflects knowledge about space use.

10.2 Decision process - Strategies for surveillance

A major challenge in attempts to control CWD is the data gaps regarding the distribution and prevalence of the disease. CWD can remain at low prevalence for a long time, thus making it difficult to detect. Large samples and considerable effort are required to confirm its absence. As a consequence, poor surveillance data often complicate the decision-making process and make it harder to generate the public support necessary to carry out radical measures.

The first and obvious action towards increasing knowledge about CWD distribution and prevalence is to increase the surveillance of areas adjacent to, and connected with, infected areas. However, due to the potential spread of CWD by humans and dispersing deer, surveillance should also include more distant areas.

After detection of the first CWD-infected reindeer in March 2016, 11427 wild (n = 8770) and semi-domesticated (n = 2494) cervids were tested for CWD in Norway (data as of early March 2017). However, the tested animals had a patchy distribution (Fig. 7.4-2) and samples sizes in many areas were too low to substantiate the absence of CWD with high probability. A more comprehensive survey is warranted in the years to come to define the distribution and prevalence of CWD, and to detect potential new foci of disease.

In order to achieve this we suggest that Norway is split into three zones or areas, depending on their current CWD status: 1) CWD-infection areas, 2) immediate risk areas, and 3) currently uninfected areas.

Infection areas are the Nordfjella wild reindeer area and the municipality of Selbu — where the CWD-positive reindeer and CWD-positive moose were identified. Immediate risk areas include adjacent municipalities and reindeer areas. All remaining parts of Norway are currently uninfected areas. The Nordfjella wild reindeer area is the most immediate concern due to the known contagious form of CWD.

Based on the current methodologies, surveillance will have to depend on testing samples from dead animals. That includes wild cervids killed by hunters and slaughtered semi-domestic reindeer, as well as moose and deer found dead for other reasons (fallen stock). In addition, liberal use of selective harvesting of weak and potentially diseased animals can be used to provide samples with a higher-than-average chance of being infected by CWD. In order to enhance sample sizes, we suggest that managers consider testing all adult cervids (2 years and older) killed during hunting and slaughtering, as well as all adult individuals in the fallen stock. Based on the recent age distribution in the harvest, this may include more than 30 000 wild cervids (www.ssb.no) and another 15000 semi-domestic reindeer.

Sampling intensity should be particularly high in the infection area, in order to obtain information on changes in prevalence, and in the risk area, such that the infection zone can be more accurately demarcated. In both areas, samples may also be collected from tissues other than brain, such as lymph tissue. This may require that the entire head is collected, as well as more distant lymphoid tissue and faeces. Research has shown that CWD can be detected at an earlier stage in retropharyngeal lymph nodes than in brain tissue (Sigurdson et al., 1999). CWD can also be detected in faeces (e.g. Cheng et al., 2016). So far, there have been few tests for CWD in substances other than brain tissue in Norway, and more samples and research are needed to validate the detection probability of the various methods in Norwegian cervids. Even if eradication of CWD should fail in Norway, continuous surveillance would be of considerable use for determining those areas remaining free of infection.

All samples from wild cervids killed or found dead, including those from areas considered non-infected, should be tested for CWD. Moose and deer killed in traffic are usually handled by professional wildlife officials, who can be asked to collect or extract the relevant samples (e.g., brain samples). Likewise, cervid hunters often contribute by collecting both data (gender, age, and carcass mass) and samples (e.g. lower jaws, reproductive tracts) from hunter kills. Furthermore, given appropriate instructions, they would be probably willing to provide brain tissue and other samples. Indeed, according to existing hunting legislation, wildlife authorities can also lawfully order cervid hunters to provide samples from their kills. Although rarely used (if ever), we believe such an action may now be warranted given the extraordinary circumstances.

In the years to come, both wildlife and animal health authorities will have to make multiple decisions regarding the monitoring, control, and possible eradication of CWD in Norway. In order to facilitate the decision-making process, we recommend that a comprehensive survey on the distribution and prevalence of CWD is conducted. This will reduce the uncertainty that is an unavoidable part of adaptive management, and will provide data for future monitoring of the disease in Norway.

10.3 Management options for reindeer in Nordfjella and Filefjell

10.3.1 Assessment of management strategies for Nordfjella zone 1

Our assessment is based on evidence available as of January 2017. Current evidence and timeline for Nordfjella zone 1: A female reindeer with CWD was identified March 2016 and surveillance in autumn 2016 identified two additional cases of CWD.

- Strategy 1 with classical CWD is not considered an appropriate option, as this would lead to a higher prevalence within the Nordfjella reindeer population. The risk of spread to semi-domestic reindeer in Filefjell and wild reindeer in Nordfjella zone 2, and further to Hardangervidda, may be a matter of time unless actions to decrease connectivity are taken. The risk of spillover to other species, such as red deer and moose, may also be a matter of time.
- Strategy 2 with depopulation, fallowing, and restocking is the most appropriate option if current evidence of CWD only in Nordfjella is correct and the aim is to eradicate CWD.
  Uncertainty is mainly linked to the CWD situation beyond Nordfjella, i.e., whether classical CWD is truly restricted to wild reindeer in Nordfjella. Also, such an action has never previously been conducted for a herd the size of the Nordfjella reindeer and in such a large area. The whole of Nordfjella is 2,995 km^2, of which zone 1 is approximately 2,000 km^2 (Strand et al., 2011). It is therefore uncertain whether this option will be effective. However, the likelihood of success will decrease over time due to the risk of spread and accumulation of prions in the environment.
- Strategy 3 is not considered an option here, as there is comprehensive mixing of reindeer within Nordfjella.

Delays in reaching a decision will increase the risk of spread to adjacent reindeer herds and spillover to other cervid species. If there is spillover to the red deer or moose populations surrounding Nordfjella, the risk of reinfection of the herd would be high if it is later decided to attempt strategy 2. If aiming to contain CWD within reindeer in Nordfjella, the population of red deer and possibly moose around Nordfjella should be reduced. Targeting deer at winter-feeding sites would be one option.

Identification and evaluation of risk-reduction options

Following the adaptive management strategy, current evidence as of March 2017 suggests initiating depopulation of the CWD-infected herd in Nordfjella no later than during hunting in autumn 2017 and, at the same time, significantly increasing testing for CWD in adjacent populations. If this strategy is pursued, building the capacity to enable removal of the herd the following winter (2017/18) may require action already during summer 2017. This may, for example, involve building fences to gather herds when the ground is not frozen and establishing a mobile slaughter facility to ensure proper handling of potentially infected

material and to enable sampling for research. Strategy 2 would also involve initiating a plan regarding re-establishment of an uninfected herd in Nordfjella, with wild reindeer of a similar genetic heritage. This could either be reindeer from Nordfjella zone 2, Årdal-Lærdal, or Hardangervidda. However, the health status of these populations remains to be determined.

New evidence likely to affect assessment:

Any case of CWD detected within Hardangervidda or in other cervid populations surrounding Nordfjella would complicate the situation, as the likelihood of reinfection would increase. Note, however, that detection of CWD outside Nordfjella would not change the conclusion regarding removal of the entire population and re-stocking, as this is the only available measure to re-establish a healthy population in Nordfjella, whereas any other strategy might allow CWD to become endemic in the area and would probably spread.

10.3.2 Reindeer in Nordfjella zone 2

There was considerable movement of large herds of reindeer between the zones in Nordfjella in the period from 2000 until 2007. Therefore, until 2007 they were essentially the same population. It is therefore possible that CWD is also established in zone 2, if CWD was present already prior to 2007. There is considerable (measurement) uncertainty regarding how long the CWD infection in zone 1 has been present. Assuming a CWD expansion rate of 1.5, an incubation period of 2 years, and the current estimate of slightly above 1% in adults, the first CWD-infected individual may have appeared up to 15 years ago, although this estimate is highly uncertain.

The sample from autumn 2016 in zone 2 is, in itself, too small (n = 44) to state with certainty whether an infection of the same level as found in zone 1 is also present in zone 2. Furthermore, individuals may have moved between zones without being detected, which would lead to the possibility that CWD is already established, albeit at a lower prevalence, in zone 2. Knowledge about infection status in zone 2 would also be important if later reintroduction of reindeer to Nordfjella zone 1 is planned after depopulation, as in scenario 2. Surveillance in this region is difficult due to the low population size. However, as the risk of CWD in this population is quite high, increasing the sample size should be considered. This includes lowering the population size, both to increase sample size and to reduce the risk of spread to Hardangervidda. Males pose a larger risk in terms of movement out of the region. One option is to increase the harvest of adult males, as, according to observations of deer from North America, this demographic group has a high prevalence of CWD in the early stages of an epidemic and is also the demographic segment that is most likely to move out of the area. This also has the beneficial side-effect that it will not have a large impact on the productivity of the herd, although it may result in delayed calving.

New evidence likely to affect assessment: Any case of CWD detected within Nordfjella zone 2 would result in this area being in a similar situation as discussed for zone 1 (chapter 10.3.1).

10.3.3 Semi-domesticated reindeer in Filefjell

There is a long history of interchange of semi-domesticated reindeer in Filefjell and wild reindeer in Nordfjella zone 1, as the road RV52 Hemsedalsfjellet is an incomplete barrier to movement between the herds. The sample from Filefjell during autumn 2016 is quite large (n = 200, out of 2585 female adults) and mainly from old adult females that are more likely to be infected with CWD than calves and yearlings. Thus, it currently seems most likely that the Filefjell herd is not infected at the same level of prevalence. However, it is far from certain that the herd is free of CWD if infection was introduced recently, and hence may be at a very low prevalence. If an infected individual recently entered the Filefjell population, detection would take more time. Evidence from semi-domesticated reindeer in Filefjell as of January 2017 support continued surveillance, at least at the level of autumn 2016. It is also possible to increase the strength of the barrier along RV52 Hemsedalsfjellet by patrolling and/or erecting fencing.

The sex and gender composition of the herds may affect the likelihood of CWD spread. The older males in the population constitute the highest risk of spreading CWD to other reindeer areas, as they move greater distances to search for food in the spring. Therefore, males moving out of Nordfjella zone 1 in spring appear to be the most likely threat for introducing CWD to the semi-domesticated reindeer herds at Filefjell.

Potential tactics to consider include:

- Continued surveillance.
- Decreasing and limiting contact with the infected Nordfjella zone 1 along RV52 Hemsedalsfjellet; fencing should be considered.
- Immediate removal of all wild reindeer trying to cross RV52 in an eastward direction towards the pasture areas of Filefjell.
- Continuous surveillance of the mountain areas west of RV52. Herds located in areas close to RV52 should be removed.

New evidence likely to affect assessment: Any case of CWD detected within Filefjell would shift the recommendations more in direction of strategy 2. Strategy 2 is more feasible in a herd of semi-domestic reindeer, as all animals can be gathered and restocking is achievable from other herds of semi-domestic reindeer. If CWD spreads to other cervid populations in the vicinity, the chance of reinfection would reduce the chances of successful eradication.

10.4 Management recommendations for moose in Selbu

10.4.1 Assessment of management strategies for moose in Selbu

Our assessment is based on evidence available as of January 2017.

Current evidence and timeline for moose in Selbu: The two first cases of CWD in moose identified in Selbu in May 2016 were tested as a direct consequence of the first reindeer CWD case. Reports of the CWD pathology in moose differ from that in reindeer, and the infected moose were old. No new cases of CWD were identified during the autumn 2016 surveillance (chapter 7).

- Strategy 1 with no action is currently a viable option, with most weight placed on the pathological evidence and demographic pattern that suggests that the identified cases could be atypical CWD. However, this puts less weight on the epidemiological evidence of two cases being identified in the same area at around the same time.
- Strategy 2 with depopulation, fallowing, and restocking is clearly not a realistic option in such a continuous population.
- Strategy 3 with spatially targeted harvesting is an option if the main weight is placed on the epidemiological evidence, of two cases in the same area at the same time, rather than on the pathological evidence and demographic pattern that suggests that this is an atypical form of CWD and less contagious.

If this is a novel disease with a long incubation time, it might be worth targeting adult females to increase the sample of old females and hence the likelihood of finding evidence of low-prevalence CWD in moose. This strategy would also lower the mean age of females in the population, which might be of benefit if there is long incubation period and animals spread infection during this period. Culling adult females will also lower the population density. The costs of such a strategy appear low, as reduction of the moose population has previously been suggested for other reasons, such as browsing pressure. Any spatial targeting should consider that moose are migratory, and it is essential to understand the functional connectivity of the moose population in the area.

- Increased surveillance.
- Targeting of adult females to reduce average age.
- Moderate reduction of population size.

New evidence likely to affect assessment: Any new cases of CWD among moose (or other cervid species) in the Selbu region would increase the suspicion that this is a contagious form of CWD. This would then suggest that strategy 3 is more appropriate.

11 Uncertainties

There is extensive knowledge regarding the development and spread of classical CWD from populations in North America. Due to multiple initial loci of CWD in North America, there is a level of replication in assessing what happens following introduction of CWD. The broad picture of CWD development is hence based on solid and substantial scientific evidence that is consistent. However, the species or subspecies of cervids differ between the continents, raising the issue of transferability.

The uncertainty regarding the current distribution of CWD in Norway, calls for a framework termed adaptive management (general review in Westgate et al. 2013, applied to CWD in Wasserberg et al. 2009). Adaptive management explicitly incorporates uncertainty and frame-specific predictions so that the next surveillance data or mitigation measure is used to maximize inference. Adaptive management acknowledges four different types of uncertainty: (1) process level uncertainty, (2) structural uncertainty, (3) measurement uncertainty, and (4) implementation uncertainty. There has been considerable controversy over the government cull to control CWD (Williams et al., 2002; Manjerovic et al., 2014), and a transparent framework for decision making might be important for acceptance and success of management strategies (Vaske, 2010).

11.1 Specifics for current management situation

11.1.1 The evidence and uncertainties along the timeline for reindeer in Nordfjella zone 1

Pathological evidence from the first reindeer diagnosed with CWD in March 2016 suggests that this is typical CWD (Benestad et al., 2016). The increased surveillance during autumn 2016 confirmed the outbreak of CWD in Nordfjella zone 1. That the number of CWD cases is low is not a rational argument for postponing decisions, as the exact prevalence is not critical for decision-making. Based on experience from North America, it is highly unrealistic to assume this CWD infection will die out by itself, and it is highly unlikely that all infected individuals have now been harvested. The Nordfjella zone 1 can be regarded as a semi-closed population and can, realistically, be further isolated by herding and/or fencing. The uncertainty is more towards whether CWD has spread south (towards Nordfjella zone 2 and Hardangervidda), as spread to those populations will limit the chances of successful restocking of zone 1 with reindeer of the same genetic heritage after eradication.

- Pathological evidence suggests that the CWD strain in Nordfjella is highly similar to that seen in North America, and thus typical, contagious CWD.
- Epidemiological evidence demonstrates that there is an outbreak of CWD in the Nordfjella reindeer.

- Further surveillance of wild reindeer and other cervid populations in adjacent areas is essential and must be given high priority.

11.1.2 The evidence and uncertainties along the timeline for moose in Selbu

The main uncertainty concerning CWD in moose in Selbu is whether these cases represent typical or atypical CWD, and, most importantly, whether this may be a less contagious form of prion disease. As previously discussed, there is preliminary evidence to suggest that this is atypical CWD. This evidence includes: 1) the pathology in the brain of the CWD-infected moose differing from that of classical CWD, and 2) the relatively advanced ages of the infected moose (13 and 14 years), which are close to age of reproductive senescence, and 3) the absence of PrP^{Sc} in the one retropharyngeal lymph node that was available for testing.

However, the fact that two cases were found in the same area indicates that this could still be a contagious form of CWD despite differing from typical CWD.

Further surveillance is needed to map in detail the distribution of this disease.

- Preliminary data suggest this is an atypical form of CWD.
- The demographic pattern of infection with the CWD-positive moose both being relatively old is consistent with atypical CWD.
- Epidemiological evidence, with two cases in the same area the same year, does not support the theory that these cases are an atypical and less contagious form of CWD.

11.2 Summary of uncertainties

The main uncertainty for decision-making regarding the situation for CWD in wild reindeer in Nordfjella sone 1 is whether or not CWD has already spread to other populations. An ambitious plan for surveillance during autumn 2017 is therefore recommended to reduce this uncertainty. Strategy 2 appears the only option available to eradicate CWD from this herd. However, there is uncertainty regarding the required duration of fallowing, although a 5-year period appears to be the minimum. There is also uncertainty regarding the likelihood of having healthy reindeer with the same genetic heritage available for restocking, but determining the infection status of reindeer in Nordfjella zone 2, Årdal-Lærdal, and Hardangervidda appears to be important.

The main uncertainty regarding the situation for CWD in moose in Selbu, is whether or not this is a contagious form of CWD.

12 Conclusions (with answers to the terms of reference)

ToR1 Food safety

The phase 1 assessment concluded (VKM, 2016):

1. Taking into account uncertainties regarding the plasticity of the CWD agents and the lack of transmission data from the Norwegian isolates, this scientific opinion considers the zoonotic risk of CWD to be very low.
2. Human health risks must be continuously assessed through results from surveillance and characterisation of prion isolates. Any study or research that indicates the possibility of zoonotic transfer must be taken into consideration.
3. Since any dead cervids or any animal showing symptoms indicative of CWD should be handled by the authorities and their trained staff, the risk to hunters or slaughterhouse staff should be negligible. However, the information must be circulated widely and be available in appropriate languages.
4. As only meat from healthy animals should be considered fit for human consumption, the risk linked to consumption of CWD-infected animals should be very low. This opinion includes meat from the 2016 hunting season and previous seasons.
5. Human health risk through berries, other plant materials, or soil is considered to represent a negligible risk.

Amendments made in the present (phase 2) assessment:

Conclusions 1, 2 and 5:

- Concerning the reindeer cases, no further information relevant for assessment of the zoonotic potential or food safety issues is currently available. Hence, conclusions 1, 2 and 5 cited above are still valid.

For conclusions 3 and 4, we would emphasise the following:

- Absence of clinical illness does not preclude human *exposure*, as cervids may harbour and shed the CWD agent for several months prior to onset of their symptoms.

Amendments relevant for the moose cases:

- Preliminary results from characterisation of the moose cases and the agent involved indicate that important features deviate significantly from those found in the reindeer

and in North American cervids (section 2.3). This raises uncertainties regarding zoonotic potential, which may differ from that of typical CWD. At the present stage of knowledge, it is not possible to reach firm conclusions concerning food safety. Precautionary principle would reduce the potential risk.

Concluding remarks:

- Given the present evidence and level of uncertainty regarding the zoonotic potential, proactive and precautionary measures aimed at minimising the risk of human exposure, not only through the food chain, but also through other direct or indirect sources, are important.
- The most important measure for preventing human exposure is to reduce the prevalence of CWD among cervids, and, preferably, to eradicate the disease before it becomes enzootic.

ToR2 Disease transmission between animals

In the phase 1 assessment it was concluded that:

- CWD spreads easily among cervids, with apparently little or no species barriers. If not controlled, there is a high risk that CWD will spread among cervids both within Norway, across the border to Sweden, and further.
- Locations where animals concentrate, such as feeding places, salt licking stones, or corrals for semi-domesticated reindeer, should be considered as hotspots for disease transmission.
- Human transport of contaminated material and/or animals seems to have been important factors for spread in North America, especially over long distances.
- CWD is transmitted horizontally through direct animal contact or via environmental sources. CWD prions are found in faeces, urine, saliva, placenta and amniotic fluid, milk, and epidermal debris (skin rubbings).
- Shedding of CWD prions in urine, saliva, and faeces occurs over prolonged periods.
- Repeated exposure to materials with low-level contamination may be of relevance.
- The surface of silage and grass may be contaminated and plants may take up CWD prions from soil and hence cannot be ruled out as potential transmission vehicles.
- CWD prions bind to soil particles.

In phase 2, we add the following:

- Transmission of CWD within a population seems to be mainly frequency-dependent, due to transmission via environmental contamination. This implies that a reduction in host density will probably have little impact on transmission rate, and that only host eradication is effective in combating CWD.
- The relative importance of direct (animal-to-animal) and indirect (through the environment) transmission may vary between different environments and with time and prevalence during an epizootic.
- Direct transmission is probably most important in the early phases of an epizootic (can result in weakly density-dependent transmission), whereas indirect transmission seems to play a larger role over time and as the prevalence increases (frequency-dependent transmission). When a certain level of environmental contamination is reached in an open population, eradication will be practically unattainable due to the prolonged persistence of CWD prions in the environment. This emphasises the importance of acting early if the aim is to eradicate CWD, before environmental transmission becomes the primary mode of infection. Exactly what constitutes such an early phase in number of years is uncertain.
- The contact rate between infected animals in an infected population and susceptible animals in a non-infected population with overlapping ranges will likely increase with increasing population densities. The risk of transmission between populations (termed spillover) is likely to be density-dependent. Reducing hot population densities may therefore decrease the risk of spillover to non-infected populations.
- Supplemental salt licks create hotspots for disease transmission within and between species, as they increase direct and indirect animal contact rates. This occurs irrespective of whether the salt licks are intended for livestock or wildlife. Salt run-off from the licking stones makes consumption of soil in these areas also attractive for ruminants, but, at the same time, prion contamination of the soil may occur through saliva, urine, and faeces. Cessation of the practice of using salt licks, and clean-up or blocking of access of cervids to soil from salt lick locations are important for mitigation of disease transmission.
- The importance of environmental transmission in a given area is related to the rate of clearance of CWD prions. Soils with high clay content facilitate persistence, but clearance seems to be higher in sandy soils and soils with high organic content. We have little knowledge about the persistence of CWD prions under Norwegian environmental conditions.

ToR3: The origin of the disease

a. What is the most likely way the disease occurred in the affected animals (spontaneous mutation, inherited, the known type from North America or transmission from other species in the area)?

There is no new information regarding the origin of the CWD found in reindeer in Norway compared to the phase 1 report. The sporadic or genetic (somatic mutation) occurrence of prion disease in cervids cannot be excluded, nor can introduction from North America or other countries. Furthermore, there is so little previous surveillance for CWD in Norway that we cannot state with confidence whether CWD has, or has not, circulated at low levels in the Norwegian cervid populations for years, but has not previously been identified.

Cattle and sheep are at very low risk of developing CWD, and it is highly unlikely that prion diseases in sheep or cattle are the origin of CWD.

Preliminary investigations of the disease observed in moose indicate that it might be caused by a previously unrecognized CWD strain. The origin of this putative strain is unknown and sporadic occurrence cannot be excluded. Analysis of the coding region of the PRNP gene in the two cases in moose did not detect mutations that could explain the disease occurrence.

ToR 4: Wildlife management and reindeer herding

a. Which risk factors relevant to disease transmission should be included in different management strategies and how do these factors affect disease transmission?

Risk factor 1: Hotspots for disease transmission

- Eliminating hotspots for potential disease transmission where contagious CWD has been diagnosed and in nearby areas where spread from initial cases is plausible would reduce the risk for transmission.
- Elimination of similar practises and installations in other areas would reduce the risk of rapid and extensive spread of CWD. This is of particular importance for the reindeer husbandry industry, where current practices facilitate rapid spread over large distances.

The following hotspots have been identified:

Supplemental salt licks

- Supplemental salt licks (salt licking stones) attract deer and are likely to increase transmission of CWD. Eliminating such hotspots irrespective of whether they are intended for wildlife or livestock is likely to facilitate successful management of CWD.
- Cessation in use of supplemental salt licks should include areas where contagious CWD has been diagnosed as well as in neighbouring areas would reduce the risk.
- It is also important to prevent access to soil around salt licks in areas infected with CWD as this soil may be heavily contaminated with prions. This can be achieved by removal of soil, erecting fencing, or by covering exposed soil.
- Discouraging the use of supplemental salt licksin other parts of Norway and encouraging alternative solutionswould reduce the risk of disease transmission.

Feeding sites of cervids

- Aggregation of cervids at winter-feeding sites probably increases the risk of disease transmission. Cessation of this practice in areas infected with CWD and in neighbouring areas would reduce the transmission rate. An evaluation of the necessity and potential consequences of cessation of winter-feeding in other parts of Norway is suggested.

Reindeer corrals

- The use of common corrals in reindeer husbandry substantially increases the risk of CWD transmission and spread between reindeer herds should CWD infect semi-domesticated reindeer. Reducing the use of shared corrals will contribute to prevent rapid and extensive spread of any disease. Avoiding using shared corrals for herds

that otherwise have little contact, i.e., are separate epidemiological units, would reduce disease transmission.
- Reducing the time spent in the area if one corral is used by several consecutive herds, would reduce the exposure to any prions in the environment.

Vehicles and boats

- Use of common trucks and boats for transporting semi-domesticated reindeer may increase the risk of CWD transmission and spread between herds. Appropriate cleaning of vehicles between consecutive herds will decrease the risk.

What would be the beneficial and non-beneficial consequences of reducing the risk factors?

- A ban on use of salt licks may have negative consequences for sheep farming, as gathering and herding of sheep is made easier by this practise. A ban might also have negative consequences for hunters and other outdoor people that use wildlife cameras beside salt licking stones to survey areas for deer and other mammals.

- A ban on supplemental winter-feeding may have negative consequences if such feeding is used to encourage deer away from moving towards roads and railroads with high risk of vehicle collision, or to increase winter survival.

- A ban on the use of common corrals and vehicles is likely to have negative economic consequences for the reindeer husbandry industry.

Risk factor 2: Connectivity between populations

Landscape connectivity is likely to increase the spread of CWD between populations. , Establishing barriers would reduce the likelihood of such spread.

- Wildlife fences used to stop deer movement between populations, in particular where some natural or man-made barriers already exist, would reduce the likelihood of spread. Increased herding of semi-domesticated reindeer may prevent mixing of herds and/or contact with wild cervids.
- Where populations are connected through fauna passages across roads or railroads, closures may reduce the risk if contagious CWD is diagnosed on one side of the passage.
- If CWD becomes endemic in parts of Southern Norway, establishment of barriers may be considered along roads and railway lines to prevent spread to wild cervids and semi-domesticated reindeer in Northern Norway (and Sweden).

What would be the beneficial and non-beneficial consequences of reducing the risk-factors?

- The beneficial consequences of reduced connectivity are solely related to limiting spread of diseases.
- There are several negative impacts of reducing connectivity. Connectivity between seasonal ranges for wild cervids is important for optimal use of seasonally available resources. Hence, reducing connectivity may lead to less productive populations. Connectivity is also important for gene flow, and reduced connectivity may reduce effective population size.

Risk factor 3: Anthropogenic spread (contagious CWD)

Anthropogenic spread seems to be a major route of transmission of CWD between areas and populations in North America (chapters 5.1-5.7). Below, we indicate practises and behaviours that may constitute a risk of spread of CWD prions from an infected area to other parts of the country (ranked from high to less plausible risk of transmission):

Transport of live deer from areas where contagious CWD has been diagnosed or adjacent areas is associated with high risk of transmission.

If transport is required, testing of properly marked animals, only released onto premises that are confinable, with the most sensitive tests available for live animals, may reduce the risk of spread.

Transport of body parts (head, central nervous system (apart from the spinal cord), skin, and offal) of cervids from areas where CWD has been diagnosed is associated with high risk. Limiting such transport to only be performed according to regulations for transport of contagious material and as part of diagnostic work or research would reduce the risk.

Disposal of remains and offal from cervids at locations accessible for deer increases the risk considerably. Burying or covering the offal and other remains at the place where the deer were killed, or disposing of at an incineration plant or landfill approved by the authorities reduces the risk.

Bait feeding of predators with any remains of deer from other populations than those that reside in the area constitutes a risk of transmission, and should be avoided. The resident population should preferably be strictly defined (i.e., within a 10 kilometre from the bait site)

Transport and deposition of superficial soil from areas where CWD is diagnosed to presumed CWD-free areas will likely pose a risk of indirect transmission of prions to new areas.

Hay, grass, and lichens harvested in areas with CWD may contain or be superficially contaminated with CWD prions. Feeding cervids in other areas with such feed increases the risk of spread.

Vehicles, equipment, shoes, and clothes that have been in contact with cervids in CWD-affected areas or soil in such areas can constitute a risk of transmission. Thorough washingd of such equipment before they are used in areas inhabited or visited by cervids from other populations may reduce the risk. Washing or disinfecting shoes, clothes, equipment, and vehicles when moving from one population to another may reduce the risk of spread by reindeer herders, veterinarians, wildlife researchers and other people that come in close contact with cervids.

What would be the beneficial and non-beneficial consequences of reducing the risk factors?

- Reducing the risk factors is likely to make it more cumbersome to hunt or utilise other resources within CWD-affected areas.
- Removal of offal can aid in lowering the number of scavengers also predating on small game.
- Removal of offal may mean that predatory scavengers turn their attentions to some other source of food (prey) and that may alter the ecology of an area??

Risk factor 4: High population densities

- High population density is likely to increase contact rate between adjacent populations of the same species or different species with overlapping ranges. Reducing population density can hence reduce the risk of spread and spillover of CWD to non-infected populations and other species, respectively.
- Because transmission of CWD within populations is likely to be more frequency-dependent than density-dependent, decreasing density is less likely to limit CWD prevalence in infected populations.
- Due to higher social contact between adjacent individuals in continuous populations, selective killing of deer close to CWD-positive cases may increase the chance of removing infected individuals. Hence, density reduction from selective killing may decrease CWD prevalence.

What would be the beneficial and non-beneficial consequences of reducing the risk factors?

- Lowering population density will, in most cases, decrease income to landowners and reduce hunting opportunities.
- It may, however, also reduce the negative effects of high population density (density dependence), such as higher risk of traffic collisions, lower performance of individual deer, browsing damage on commercial forests, and damage to agricultural crops.

Risk factor 5: Spread with other animals

- CWD prions ingested by non-cervids may pass through their gastrointestinal system and still be infective when excreted with faeces.
- This mode of transmission has the potential to enable long-distance spread and may explain unpredictable occurrences of CWD.
- However, despite a lack of research, these modes of transmission constitute a minor risk for transmission relative to the risk from infected cervids and anthropogenic spread.

What would be the beneficial and non-beneficial consequences of reducing the risk factors?

Removal of scavengers may have beneficial or non-beneficial consequences, depending on several factors such as their conservation status and effects on other game species.

b. Are there any management, e.g. strategies used in CWD-infected areas in North America that can be relevant to implement in Norway (e.g. demographic composition)?

The strategy of spatially targeted culling around identified cases of CWD in continuous populations (termed strategy 3 in this report) is comparable to that which has been performed in several American states (e.g., Illinois, Wisconsin, New York) and Alberta in Canada. Although it has seemed to be successful in New York State, the efficacy is often low and not well supported by current peer-reviewed research.

The current outbreak of CWD in reindeer provides a new setting, as social groups are shifting through the seasons, the animals are nomadic, and they gather in large herds in some parts of the year. Targeted harvest of individuals surrounding identified CWD cases is not meaningful in wild reindeer populations. When a case is found within a wild reindeer population, the whole functional population must be regarded as infected.

The chosen management strategy will therefore depend on whether the population is containable (strategy 2), as for reindeer, or more continuous or open (strategy 3) as for red deer, moose, and roe deer.

Contagious CWD present in containable population (strategy 2)

- Eradication of the infected population, followed by fallowing of the area for a minimum of five years, is currently the only available method of management that has any chance of eradicating the disease within an area (chapters 9.3 and 10.1.3).
- During the fallowing period, other mitigation measures meant to minimize transmission may further contribute to eradication in the area (as elaborated in chapter 9). Reintroduction of the target cervid species should only be done from intensely surveyed areas where there is high certainty that CWD is not present.

Contagious CWD present in a continuous population (strategy 3)

- Eradication of CWD in continuous populations has only been effective if immediate action, with massive harvesting around disease foci, is undertaken (as in New York and Minnesota in North America).
- Eradication of CWD may not be feasible in continuous populations when it has become endemic.
- Management may then aim at stabilizing the prevalence at a low level and preventing further spread.

- Spatially targeted harvesting in the areas where cases have been diagnosed appears the only feasible method, but not very effective (see chapter 10.4.1). The extent of the culling zone should be determined based upon local area usage by different cervids.
- Spatially targeted harvesting, combined with other mitigation measures to minimize transmission may reduce the risk of spread (elaborated in chapter 10.4.1).
- Harvesting young males may reduce the spread of CWD as they disperse more often and over longer distances than other demographic groups. This group of animals is already heavily hunted in Norway.
- More selective hunting can be obtained by removing hunting restrictions and by rewarding hunters that shoot deer from pre-determined gender and age groups with a high CWD prevalence.
- Targeted harvesting by governmental sharpshooters has been implemented in North America and may be of relevance in Norway.
- Good and sensitive communication with local stakeholders and the general public, particularly in affected areas is imperative to ensure socio-political acceptance and co-operation.

Density reduction of deer populations overlapping with, or adjacent to, populations where contagious CWD has been diagnosed may reduce the risk of spread because the risk of transmission between neighbouring populations of different species is linked to population density.

Management actions other than harvesting

In the USA, CWD management differ between states and areas, and "containment zones" (with positive CWD) and "surveillance zones" are frequently used. Different restrictions apply in these zones, with mandatory testing of deer within containment zones and no transfer of infectious material out of the zone.

- Transport of live cervids, salt licks, and feeding of wild cervids are prohibited in large parts of North America.
- In CWD-areas, it is common to demand or recommend that hunters bone out the carcass and only bring pure meat, a cleaned hide, and cleaned antlers home. In some areas, an alternative is to bring home quarters of the carcass without the head or spine attached.
- Surveillance by conventional methods (i.e., harvest kills) is implemented in most American states with cervid populations. Testing is often free of charge and the hunters are provided with the results.
- If a deer is CWD positive, the hunters are often allowed a new permit.
- In CWD-management zones, testing of hunted cervids is often mandatory.

i. How does choice of strategy depend on the occurrence of CWD in a given population?

- Eradication of a population is only rational if it is possible to hinder reintroduction of infected animals. If CWD becomes endemic in areas adjacent to the population to be eradicated, such a strategy is unlikely to be successful.
- Targeted harvesting around positive cases will also be inefficient if the overall prevalence is so high that infected animals will soon after recolonize the area.

13 Data gaps

Measurement uncertainty.

- The top priority is to obtain more data on the likelihood of CWD infection in areas around Nordfjella. This includes reindeer on Hardangervidda, as well as red deer and moose surrounding Nordfjella; that is, the municipalities of Hol, Hemsedal, Aurland, and Lærdal. This should be regarded as an immediate priority if the intention is to have a better basis for decision-making.

Structural uncertainty.

- Data for mapping and potentially removing recognized hotspots for spread of CWD in areas close to zone 1 in Nordfjella (feeding sites, places with salt lick stones) are needed.
- The CWD situation in moose in Selbu must be monitored carefully in order to determine whether this is atypical and a less contagious form of CWD.
- Data on space use are required to assess the overlap of red deer and moose populations in relation to the reindeer population in Nordfjella, and to assess the risk of spillover.
- Data on the gene coding for the prion protein for Norwegian cervid species are needed to assess the likelihood of spillover.
- Data on space use are required to assess the functional connectivity of the moose population in the Selbu region.
- Data are required to assess whether sheep can spread prions having grazed in CWD-infected areas.

References

Aamlid D., Andreassen K., Hylen G., Clarke N., Timmermann V., Rosberg I., Solheim H., Aas W. (2006) Norwegian monitoring programme for forest damage. Annual report 2005, in: B. Langerud (Ed.), Forskning fra Skog og landskap, Norwegian forest research institute, Ås, Norway. pp. 20.

Agriculture Canada Expert Committee on Soil Survey. (1987) The Canadian system of soil classification. 2 ed. Agriculture Canada Publication 1646. 164pp.

Ali A., Esser K.B., Esser J.M. (1995) Mineral distribution in 4 podzolic soils in southern norway. Norsk Geologisk Tidsskrift 75:137-145.

Almberg E.S., Cross P.C., Johnson C.J., Heisey D.M., Richards B.J. (2011) Modeling routes of chronic wasting disease transmission: environmental prion persistence promotes deer population decline and extinction. PloS one 6:e19896.

Andersen R., Herfindel I., Sæther B.E., Linnell J.D., Oddén J., Liberg O. (2004) When range expansion rate is faster in marginal habitats. Oikos 107:210-214.

Anonymous. (2007) Retningslinjer for bekjempelse av skrapesjuke med ny bekjempelsesstrategi for NOR 98 (Instructions for mitigation of scrapie with a new mitigation strategy for NOR 98), in: M. N. F. S. Authority) (Ed.), Mattilsynet, Oslo.

Baeten L.A., Powers B.E., Jewell J.E., Spraker T.R., Miller M.W. (2007) A natural case of chronic wasting disease in a free-ranging moose (*Alces alces shirasi*). Journal of Wildlife Diseases 43:309-14. DOI: 10.7589/0090-3558-43.2.309.

Bakkebo M.K., Mouillet-Richard S., Espenes A., Goldmann W., Tatzelt J., Tranulis M.A. (2015) The Cellular Prion Protein: A Player in Immunological Quiescence. Frontiers in Immunology 6:450. DOI: 10.3389/fimmu.2015.00450.

Bartelt-Hunt S.L., Bartz J.C., Saunders S.E. (2013) Prions in the Environment, in: W.-Q. Zou and P. Gambetti (Eds.), Prions and Diseases: Volume 2, Animals, Humans and the Environment, Springer New York, New York, NY. pp. 89-101.

Bartz J.C., Marsh R.F., McKenzie D.I., Aiken J.M. (1998) The host range of chronic wasting disease is altered on passage in ferrets. Virology 251:297-301. DOI: 10.1006/viro.1998.9427.

Benestad S.L., Austbo L., Tranulis M.A., Espenes A., Olsaker I. (2012) Healthy goats naturally devoid of prion protein. Vet Res 43:87. DOI: 10.1186/1297-9716-43-87.

Benestad S.L., Mitchell G., Simmons M., Ytrehus B., Vikoren T. (2016) First case of chronic wasting disease in Europe in a Norwegian free-ranging reindeer. Veterinary Research 47:88. DOI: 10.1186/s13567-016-0375-4.

Bennett J.P., Rodriguez C.M., Johnson C.J. (2012) Prion protein degradation by lichens of the genus Cladonia. The Lichenologist 44:523-531.

Beringue V., Herzog L., Jaumain E., Reine F., Sibille P., Le Dur A., Vilotte J.L., Laude H. (2012) Facilitated cross-species transmission of prions in extraneural tissue. Science 335:472-5. DOI: 10.1126/science.1215659.

Bessen R.A., Marsh R.F. (1994) Distinct PrP properties suggest the molecular basis of strain variation in transmissible mink encephalopathy. Journal of Virology 68:7859-68.

Bischof R., Loe L.E., Meisingset E.L., Zimmermann B., Van Moorter B., Mysterud A. (2012) A migratory northern ungulate in the pursuit of spring: jumping or surfing the green wave? The American Naturalist 180:407-424.
Bjørneraas K. (2012) Klauvilt i norsk natur-helse, biologi og forvaltning. Akademia, Trondheim, Norway.
Blanchong J.A., Grear D.A., Weckworth B.V., Keane D.P., Scribner K.T., Samuel M.D. (2012) Effects of chronic wasting disease on reproduction and fawn harvest vulnerability in Wisconsin white-tailed deer. Journal of Wildlife Diseases 48:361-370.
Bomford M., O'Brien P. (1995) Eradication or Control for Vertebrate Pests? Wildlife Society Bulletin (1973-2006) 23:249-255.
Bonenfant C., Loe L.E., Mysterud A., Langvatn R., Stenseth N.C., Gaillard J.-M., Klein F. (2004) Multiple causes of sexual segregation in European red deer: enlightenments from varying breeding phenology at high and low latitude. Proceedings of the Royal Society of London, Series B: Biological Sciences 271:883-892.
Brandner S., Raeber A., Sailer A., Blattler T., Fischer M., Weissmann C., Aguzzi A. (1996) Normal host prion protein (PrPC) is required for scrapie spread within the central nervous system. Proceedings of the National Academy of Sciences U S A 93:13148-51.
Brown P., Gajdusek D.C. (1991) Survival of scrapie virus after 3 years' interment. The Lancet 337:269-270. DOI: 10.1016/0140-6736(91)90873-N.
Bruce M., Chree A., McConnell I., Foster J., Pearson G., Fraser H. (1994) Transmission of bovine spongiform encephalopathy and scrapie to mice: strain variation and the species barrier. Philospphical Transactions of the Royal Society of London: B Biological Sciences 343:405-11. DOI: 10.1098/rstb.1994.0036.
Bruce M.E. (1993) Scrapie strain variation and mutation. British Medical Bullentin 49:822-38.
Bueler H., Aguzzi A., Sailer A., Greiner R.A., Autenried P., Aguet M., Weissmann C. (1993) Mice devoid of PrP are resistant to scrapie. Cell 73:1339-47.
Bunnefeld N., Börger L., van Moorter B., Rolandsen C.M., Dettki H., Solberg E.J., Ericsson G. (2011) A model-driven approach to quantify migration patterns: individual, regional and yearly differences. Journal of Animal Ecology 80:466-476.
Cheng Y.C., Hannaoui S., John T.R., Dudas S., Czub S., Gilch S. (2016) Early and Non-Invasive Detection of Chronic Wasting Disease Prions in Elk Feces by Real-Time Quaking Induced Conversion. PLoS One 11:e0166187. DOI: 10.1371/journal.pone.0166187.
Choi C.J., Kanthasamy A., Anantharam V., Kanthasamy A.G. (2006) Interaction of metals with prion protein: Possible role of divalent cations in the pathogenesis of Prion diseases. Neurotoxicology 27:777-787. DOI: 10.1016/j.neuro.2006.06.004.
Clements G.M., Hygnstrom S.E., Gilsdorf J.M., Baasch D.M., Clements M.J., Vercauteren K.C. (2011) Movements of white-tailed deer in riparian habitat: Implications for infectious diseases. The Journal of Wildlife Management 75:1436-1442.
Collinge J., Clarke A.R. (2007) A general model of prion strains and their pathogenicity. Science 318:930-6. DOI: 10.1126/science.1138718.

Conner M.M., McCarty C.W., Miller M.W. (2000) Detection of bias in harvest-based estimates of chronic wasting disease prevalence in mule deer. Journal of Wildlife Diseases 36:691-699.

Conner M.M., Miller M.W., Ebinger M.R., Burnham K.P. (2007) A meta-baci approach for evaluating management intervention on chronic wasting disease in mule deer. Ecological Applications 17:140-153.

Cross P.C., Creech T.G., Ebinger M.R., Manlove K., Irvine K., Henningsen J., Rogerson J., Scurlock B.M., Creel S. (2013) Female elk contacts are neither frequency nor density dependent. Ecology 94:2076-2086.

Cullingham C.I., Merrill E.H., Pybus M.J., Bollinger T.K., Wilson G.A., Coltman D.W. (2011) Broad and fine-scale genetic analysis of white-tailed deer populations: estimating the relative risk of chronic wasting disease spread. Evolutionary Applications 4:116-131.

Davies P., Brown D.R. (2009) Manganese Enhances Prion Protein Survival in Model Soils and Increases Prion Infectivity to Cells. PLoS One 4:e7518. DOI: 10.1371/journal.pone.0007518.

Ducett J.K., Gonzalez R.M., Rodriguez C.M., Gibbs N.M., Heisey D.M., Bennett J.P., Johnson C.J. (2014) P. 137: Intracerebral and oral challenge studies indicate a protective role for lichens against prion infection. Prion 8:88-89.

Dulberger J., Hobbs N.T., Swanson H.M., Bishop C.J., Miller M.W. (2010) Estimating chronic wasting disease effects on mule deer recruitment and population growth. Journal of Wildlife Diseases 46:1086-1095.

Edmunds D.R., Kauffman M.J., Schumaker B.A., Lindzey F.G., Cook W.E., Kreeger T.J., Grogan R.G., Cornish T.E. (2016) Chronic Wasting Disease Drives Population Decline of White-Tailed Deer. PLoS One 11:e0161127.

Evans T.S., Kirchgessner M.S., Eyler B., Ryan C.W., Walter W.D. (2016) Habitat influences distribution of chronic wasting disease in white-tailed deer. The Journal of Wildlife Management 80:284-291.

Fischer J.W., Phillips G.E., Nichols T.A., Vercauteren K.C. (2013) Could avian scavengers translocate infectious prions to disease-free areas initiating new foci of chronic wasting disease? Prion 7:263-6. DOI: 10.4161/pri.25621.

Gaillard J.-M., Festa-Bianchet M., Yoccoz N.G. (1998) Population dynamics of large herbivores: variable recruitment with constant adult survival. Trends in Ecology & Evolution 13:58-63.

Gaillard J.-M., Hewison A., Kjellander P., Pettorelli N., Bonenfant C., Van Moorter B., Liberg O., Andren H., Van Laere G., Klein F. (2008) Population density and sex do not influence fine-scale natal dispersal in roe deer. Proceedings of the Royal Society of London B: Biological Sciences 275:2025-2030.

Garlick M.J., Powell J.A., Hooten M.B., MacFarlane L.R. (2014) Homogenization, sex, and differential motility predict spread of chronic wasting disease in mule deer in southern Utah. Journal of Mathematical Biology 69:369-399.

Georgsson G., Sigurdarson S., Brown P. (2006) Infectious agent of sheep scrapie may persist in the environment for at least 16 years. Journal of General Virology 87. DOI: 10.1099/vir.0.82011-0.

Geremia C., Miller M.W., Hoeting J.A., Antolin M.F., Hobbs N.T. (2015) Bayesian Modeling of Prion Disease Dynamics in Mule Deer Using Population Monitoring and Capture-Recapture Data. PloS One 10:e0140687.

Giachin G., Narkiewicz J., Scaini D., Ngoc A.T., Margon A., Sequi P., Leita L., Legname G. (2014) Prion protein interaction with soil humic substances: environmental implications. PLoS One 9:e100016. DOI: 10.1371/journal.pone.0100016.

Gill O.N., Spencer Y., Richard-Loendt A., Kelly C., Dabaghian R., Boyes L., Linehan J., Simmons M., Webb P., Bellerby P., Andrews N., Hilton D.A., Ironside J.W., Beck J., Poulter M., Mead S., Brandner S. (2013) Prevalent abnormal prion protein in human appendixes after bovine spongiform encephalopathy epizootic: large scale survey. BMJ 347:f5675. DOI: 10.1136/bmj.f5675.

Gjems O. (1967) Studies on Clay Minerals and Clay-mineral Formation in Soil Profiles in Scandinavia. Meddelelser fra det Norske Skogforsøksvesen 81:303-408.

Goldmann W., Hunter N., Smith G., Foster J., Hope J. (1994a) PrP genotype and agent effects in scrapie: change in allelic interaction with different isolates of agent in sheep, a natural host of scrapie. Journal of General Virology 75 (Pt 5):989-95. DOI: 10.1099/0022-1317-75-5-989.

Goldmann W., Hunter N., Smith G., Foster J., Hope J. (1994b) PrP genotypes and the Sip gene in Cheviot sheep form the basis for scrapie strain typing in sheep. Annals of the New York Academy of Sciences 724:296-9.

Gough K.C., Maddison B.C. (2010) Prion transmission: Prion excretion and occurrence in the environment. Prion 4:275-282. DOI: 10.4161/pri.4.4.13678.

Grear D.A., Samuel M.D., Langenberg J.A., Keane D. (2006) Demographic patterns and harvest vulnerability of chronic wasting disease infected white-tailed deer in Wisconsin. Journal of Wildlife Management 70:546-553.

Grear D.A., Samuel M.D., Scribner K.T., Weckworth B.V., Langenberg J.A. (2010) Influence of genetic relatedness and spatial proximity on chronic wasting disease infection among female white-tailed deer. Journal of Applied Ecology 47:532-540.

Greenlee J.J., Nicholson E.M., Smith J.D., Kunkle R.A., Hamir A.N. (2012) Susceptibility of cattle to the agent of chronic wasting disease from elk after intracranial inoculation. Journal of Veterinary Diagnostic Investigation 24:1087-93. DOI: 10.1177/1040638712461249.

Gross J.E., Miller M.W. (2001) Chronic wasting disease in mule deer: disease dynamics and control. The Journal of Wildlife Management:205-215.

Gudmundsdóttir K., Sigurdarson S., Kristinsson J., Eiríksson T., Jóhannesson T. (2006) Iron and iron/manganese ratio in forage from Icelandic sheep farms: relation to scrapie. Acta Veterinaria Scandinavica 48:16.

Habib T.J., Merrill E.H., Pybus M., Coltman D.W. (2011) Modelling landscape effects on density–contact rate relationships of deer in eastern Alberta: implications for chronic wasting disease. Ecological Modelling 222:2722-2732.

Haley N.J., Hoover E.A. (2015) Chronic wasting disease of cervids: current knowledge and future perspectives. Annual Review of Animal Biosciences 3:305-25. DOI: 10.1146/annurev-animal-022114-111001.

Hamir A.N., Kunkle R.A., Cutlip R.C., Miller J.M., Williams E.S., Richt J.A. (2006) Transmission of chronic wasting disease of mule deer to Suffolk sheep following intracerebral inoculation. Journal of Veterinary Diagnostic Investigation 18:558-565.

Happ G.M., Huson H.J., Beckmen K.B., Kennedy L.J. (2007) Prion protein genes in caribou from Alaska. Journal of Wildlife Diseases 43:224-8. DOI: 10.7589/0090-3558-43.2.224.

Harrington R.D., Baszler T.V., O'Rourke K.I., Schneider D.A., Spraker T.R., Liggitt H.D., Knowles D.P. (2008) A species barrier limits transmission of chronic wasting disease to mink (Mustela vison). Journal of General Virology 89:1086-96. DOI: 10.1099/vir.0.83422-0.

Heisey D.M., Mickelsen N.A., Schneider J.R., Johnson C.J., Johnson C.J., Langenberg J.A., Bochsler P.N., Keane D.P., Barr D.J. (2010) Chronic wasting disease (CWD) susceptibility of several North American rodents that are sympatric with cervid CWD epidemics. Journal of Virology 84:210-5. DOI: 10.1128/JVI.00560-09.

Henderson D.M., Denkers N.D., Hoover C.E., Garbino N., Mathiason C.K., Hoover E.A. (2015) Longitudinal Detection of Prion Shedding in Saliva and Urine by Chronic Wasting Disease-Infected Deer by Real-Time Quaking-Induced Conversion. Journal of Virology 89:9338-9347. DOI: 10.1128/jvi.01118-15.

Huson H.J., Happ G.M. (2006) Polymorphisms of the prion protein gene (PRNP) in Alaskan moose (*Alces alces gigas*). Animal Genetics 37:425-6. DOI: 10.1111/j.1365-2052.2006.01466.x.

Imrie C.E., Korre A., Munoz-Melendez G. (2009) Spatial correlation between the prevalence of transmissible spongiform diseases and British soil geochemistry. Environmental Geochemistry and Health 31:133-145. DOI: 10.1007/s10653-008-9172-y.

Jellinger K.A. (2010) Basic mechanisms of neurodegeneration: a critical update. Journal of Cellular and Molecular Medicine 14:457-87. DOI: 10.1111/j.1582-4934.2010.01010.x.

Jellinger K.A. (2014) The pathomechanisms underlying Parkinson's disease. Expert Review of Neurotherapeutics 14:199-215. DOI: 10.1586/14737175.2014.877842.

Jennelle C.S., Henaux V., Wasserberg G., Thiagarajan B., Rolley R.E., Samuel M.D. (2014) Transmission of chronic wasting disease in Wisconsin white-tailed deer: Implications for disease spread and management. PloS One 9:e91043.

Jennelle C.S., Samuel M.D., Nolden C.A., Keane D.P., Barr D.J., Johnson C., Vanderloo J.P., Aiken J.M., Hamir A.N., Hoover E.A. (2009) Surveillance for transmissible spongiform encephalopathy in scavengers of white-tailed deer carcasses in the chronic wasting disease area of Wisconsin. Journal of Toxicology and Environmental Health A 72:1018-24. DOI: 10.1080/15287390903084249.

Johnson C.J., Bennett J.P., Biro S.M., Duque-Velasquez J.C., Rodriguez C.M., Bessen R.A., Rocke T.E. (2011a) Degradation of the disease-associated prion protein by a serine protease from lichens. PLoS One 6:e19836.

Johnson C.J., Herbst A., Duque-Velasquez C., Vanderloo J.P., Bochsler P., Chappell R., McKenzie D. (2011) Prion protein polymorphisms affect chronic wasting disease progression. PLoS One 6:e17450.

Johnson C.J., Pedersen J.A., Chappell R.J., McKenzie D., Aiken J.M. (2007) Oral transmissibility of prion disease is enhanced by binding to soil particles. PLoS Pathogens 3:e93. DOI: 10.1371/journal.ppat.0030093.

Johnson C.J., Phillips K.E., Schramm P.T., McKenzie D., Aiken J.M., Pedersen J.A. (2006) Prions adhere to soil minerals and remain infectious. PLoS Pathogens 2:e32. DOI: 10.1371/journal.ppat.0020032.

Joly D.O., Samuel M.D., Langenberg J.A., Blanchong J.A., Batha C.A., Rolley R.E., Keane D.P., Ribic C.A. (2006) Spatial epidemiology of chronic wasting disease in Wisconsin white-tailed deer. Journal of Wildlife Diseases 42:578-588.

Kelly A.C., Mateus-Pinilla N.E., Brown W., Ruiz M.O., Douglas M.R., Douglas M.E., Shelton P., Beissel T., Novakofski J. (2014) Genetic assessment of environmental features that influence deer dispersal: implications for prion-infected populations. Population Ecology 56:327-340.

Kjær L.J., Schauber E.M., Nielsen C.K. (2008) Spatial and Temporal Analysis of Contact Rates in Female White-Tailed Deer. The Journal of Wildlife Management 72:1819-1825.

Krumm C.E., Conner M.M., Hobbs N.T., Hunter D.O., Miller M.W. (2010) Mountain lions prey selectively on prion-infected mule deer. Biology Letters 6:209-11. DOI: 10.1098/rsbl.2009.0742.

Kurt T.D., Sigurdson C.J. (2016) Cross-species transmission of CWD prions. Prion 10:83-91. DOI: 10.1080/19336896.2015.1118603.

Kuznetsova A., McKenzie D., Banser P., Siddique T., Aiken J.M. (2014) Potential role of soil properties in the spread of CWD in western Canada. Prion 8:92-99. DOI: 10.4161/pri.28467.

Landbruksdirektoratet. (2016) Utfordringer for selvstyre i reindriftsnæringen.

Lang K.R., Blanchong J.A. (2012) Population genetic structure of white-tailed deer: Understanding risk of chronic wasting disease spread. The Journal of Wildlife Management 76:832-840.

Laplanche J.L., Chatelain J., Westaway D., Thomas S., Dussaucy M., Brugere-Picoux J., Launay J.M. (1993) PrP polymorphisms associated with natural scrapie discovered by denaturing gradient gel electrophoresis. Genomics 15:30-7. DOI: 10.1006/geno.1993.1006.

Lavelle M.J., Phillips G.E., Fischer J.W., Burke P.W., Seward N.W., Stahl R.S., Nichols T.A., Wunder B.A., VerCauteren K.C. (2014) Mineral licks: motivational factors for visitation and accompanying disease risk at communal use sites of elk and deer. Environmental geochemistry and health 36:1049-1061.

Lenvik D. (2005) Utviklingen av bærekraft i reindriften i Trøndelag og Jotunheimen – «Rørosmodellen», Jord og gjerning, Norsk Lanbruksmuseum, Oslo, Norway.

Li L., Coulthart M.B., Balachandran A., Chakrabartty A., Cashman N.R. (2007) Species barriers for chronic wasting disease by in vitro conversion of prion protein. Biochemical and Biophysical Research Communications 364:796-800. DOI: 10.1016/j.bbrc.2007.10.087.

Lindström E.R., Andrén H., Angelstam P., Cederlund G., Hörnfeldt B., Jäderberg L., Lemnell P.A., Martinsson B., Sköld K., Swenson J.E. (1994) Disease reveals the predator: sarcoptic mange, red fox predation, and prey populations. Ecology 75:1042-1049.

Lloyd S.E., Mead S., Collinge J. (2013) Genetics of prion diseases. Current Opinions in Genetics & Development 23:345-51. DOI: 10.1016/j.gde.2013.02.012.

Loe L.E., Mysterud A., Veiberg V., Langvatn R. (2009) Negative density-dependent emigration of males in an increasing red deer population. Proceedings of the Royal Society of London B: Biological Sciences:rspb. 2009.0224.

Magle S.B., Kardash L.H., Rothrock A.O., Chamberlin J.C., Mathews N.E. (2015) Movements and habitat interactions of white-tailed deer: implications for chronic wasting disease management. The American Midland Naturalist 173:267-282.

Manjerovic M.B., Green M.L., Mateus-Pinilla N., Novakofski J. (2014) The importance of localized culling in stabilizing chronic wasting disease prevalence in white-tailed deer populations. Preventive Veterinary Medicine 113:139-145.

Martinsen V., Mulder J., Austrheim G., Mysterud A. (2011) Carbon storage in low-alpine grassland soils: effects of different grazing intensities of sheep. European Journal of Soil Science 62:822-833. DOI: 10.1111/j.1365-2389.2011.01393.x.

Mateus-Pinilla N., Weng H.-Y., Ruiz M.O., Shelton P., Novakofski J. (2013) Evaluation of a wild white-tailed deer population management program for controlling chronic wasting disease in Illinois, 2003–2008. Preventive Veterinary Medicine 110:541-548.

Miller M.W., Conner M.M. (2005) Epidemiology of chronic wasting disease in free-ranging mule deer: spatial, temporal, and demographic influences on observed prevalence patterns. Journal of Wildlife Diseases 41:275-290.

Miller M.W., Hobbs N.T., Tavener S.J. (2006) Dynamics of prion disease transmission in mule deer. Ecological Applications 16:2208-2214.

Miller M.W., Swanson H.M., Wolfe L.L., Quartarone F.G., Huwer S.L., Southwick C.H., Lukacs P.M. (2008) Lions and prions and deer demise. PLoS One 3:e4019.

Miller M.W., Williams E.S. (2003) Prion disease: horizontal prion transmission in mule deer. Nature 425:35-6. DOI: 10.1038/425035a.

Miller M.W., Williams E.S., Hobbs N.T., Wolfe L.L. (2004) Environmental sources of prion transmission in mule deer. Emerging Infectious Diseases 10. DOI: 10.3201/eid1006.040010.

Miller M.W., Williams E.S., McCarty C.W., Spraker T.R., Kreeger T.J., Larsen C.T., Thorne E.T. (2000) Epizootiology of chronic wasting disease in free-ranging cervids in Colorado and Wyoming. Journal of Wildlife Diseases 36:676-690.

Milner-Gulland E., Shea K. (2017) Embracing uncertainty in applied ecology. Journal of Applied Ecology.

Milner J.M., Van Beest F.M., Schmidt K.T., Brook R.K., Storaas T. (2014) To feed or not to feed? Evidence of the intended and unintended effects of feeding wild ungulates. The Journal of Wildlife Management 78:1322-1334.

Mitchell G.B., Sigurdson C.J., O'Rourke K.I., Algire J., Harrington N.P., Walther I., Spraker T.R., Balachandran A. (2012) Experimental oral transmission of chronic wasting disease to reindeer (*Rangifer tarandus tarandus*). PLoS One 7:e39055. DOI: 10.1371/journal.pone.0039055.

Mitteregger G., Korte S., Shakarami M., Herms J., Kretzschmar H.A. (2009) Role of copper and manganese in prion disease progression. Brain Research 1292:155-164. DOI: 10.1016/j.brainres.2009.07.051.

Monello R.J., Powers J.G., Hobbs N.T., Spraker T.R., O'Rourke K.I., Wild M.A. (2013) Efficacy of antemortem rectal biopsies to diagnose and estimate prevalence of chronic wasting disease in free-ranging cow elk (*Cervus elaphus nelsoni*). Journal of Wildlife Diseases 49:270-8. DOI: 10.7589/2011-12-362.

Monello R.J., Powers J.G., Hobbs N.T., Spraker T.R., Watry M.K., Wild M.A. (2014) Survival and population growth of a free-ranging elk population with a long history of exposure to chronic wasting disease. The Journal of Wildlife Management 78:214-223.

Myers J.H., Simberloff D., Kuris A.M., Carey J.R. (2000) Eradication revisited: dealing with exotic species. Trends in Ecology & Evolution 15:316-320. DOI: http://dx.doi.org/10.1016/S0169-5347(00)01914-5.

Mysterud A. (1999) Seasonal migration pattern and home range of roe deer (*Capreolus capreolus*) in an altitudinal gradient in southern Norway. Journal of Zoology 247:479-486.

Mysterud A. (2000) Diet overlap among ruminants in Fennoscandia. Oecologia 124:130-137.

Mysterud A. (2010) Still walking on the wild side? Management actions as steps towards 'semi-domestication'of hunted ungulates. Journal of Applied Ecology 47:920-925.

Mysterud A. (2011) Bør vi fôre hjortevilt? Jakt og Fiske 140:72-73.

Mysterud A., Bischof R., Loe L.E., Odden J., Linnell J.D. (2012) Contrasting migration tendencies of sympatric red deer and roe deer suggest multiple causes of migration in ungulates. Ecosphere 3:1-6.

Mysterud A., Loe L.E., Zimmermann B., Bischof R., Veiberg V., Meisingset E. (2011) Partial migration in expanding red deer populations at northern latitudes–a role for density dependence? Oikos 120:1817-1825.

Nelson P.T., Alafuzoff I., Bigio E.H., Bouras C., Braak H., Cairns N.J., Castellani R.J., Crain B.J., Davies P., Del Tredici K., Duyckaerts C., Frosch M.P., Haroutunian V., Hof P.R., Hulette C.M., Hyman B.T., Iwatsubo T., Jellinger K.A., Jicha G.A., Kovari E., Kukull W.A., Leverenz J.B., Love S., Mackenzie I.R., Mann D.M., Masliah E., McKee A.C., Montine T.J., Morris J.C., Schneider J.A., Sonnen J.A., Thal D.R., Trojanowski J.Q., Troncoso J.C., Wisniewski T., Woltjer R.L., Beach T.G. (2012) Correlation of Alzheimer disease neuropathologic changes with cognitive status: a review of the literature. Journal of Neuropathology & Experimental Neurology 71:362-81. DOI: 10.1097/NEN.0b013e31825018f7.

Nichols T.A., Fischer J.W., Spraker T.R., Kong Q., VerCauteren K.C. (2015) CWD prions remain infectious after passage through the digestive system of coyotes (*Canis latrans*). Prion 9:367-75. DOI: 10.1080/19336896.2015.1086061.

Nichols T.A., Pulford B., Wyckoff A.C., Meyerett C., Michel B., Gertig K., Hoover E.A., Jewell J.E., Telling G.C., Zabel M.D. (2009) Detection of protease-resistant cervid prion protein in water from a CWD-endemic area. Prion 3:171-183.

Nichols T.A., Spraker T.R., Gidlewski T., Cummings B., Hill D., Kong Q., Balachandran A., VerCauteren K.C., Zabel M.D. (2016) Dietary magnesium and copper affect survival time and neuroinflammation in chronic wasting disease. Prion 10:228-50. DOI: 10.1080/19336896.2016.1181249.

NILF. (2014) Gjennomgang av tamreinlagene og ordningene over reindriftsavtalen, Oslo, Norway.
Nobert B.R., Merrill E.H., Pybus M.J., Bollinger T.K., Hwang Y.T. (2016) Landscape connectivity predicts chronic wasting disease risk in Canada. Journal of Applied Ecology.
O'Hara Ruiz M., Kelly A.C., Brown W.M., Novakofski J.E., Mateus-Pinilla N.E. (2013) Influence of landscape factors and management decisions on spatial and temporal patterns of the transmission of chronic wasting disease transmission in white-tailed deer. Geospatial Health 8:215-27. DOI: 10.4081/gh.2013.68.
Oraby T., Vasilyeva O., Krewski D., Lutscher F. (2014) Modeling seasonal behavior changes and disease transmission with application to chronic wasting disease. Journal of Theoretical Biology 340:50-59.
Packer C., Holt R.D., Hudson P.J., Lafferty K.D., Dobson A.P. (2003) Keeping the herds healthy and alert: implications of predator control for infectious disease. Ecology Letters 6:797-802.
Pállson P.A. (1979) Rida (scrapie) in Iceland and its epidemiology., in: S. B. H. Prusiner, W.J.; (Ed.), Slow transmissible diseases of the nervous system. Academic Press, New York. pp. 357-366.
Panzacchi M., Van Moorter B., Strand O., Loe L.E., Reimers E. (2015) Searching for the fundamental niche using individual-based habitat selection modelling across populations. Ecography 38:659-669.
Peletto S., Perucchini M., Acin C., Dalgleish M.P., Reid H.W., Rasero R., Sacchi P., Stewart P., Caramelli M., Ferroglio E., Bozzetta E., Meloni D., Orusa R., Robetto S., Gennero S., Goldmann W., Acutis P.L. (2009) Genetic variability of the prion protein gene (PRNP) in wild ruminants from Italy and Scotland. Journal of Veterinary Science 10:115-20.
Perucchini M., Griffin K., Miller M.W., Goldmann W. (2008) PrP genotypes of free-ranging wapiti (Cervus elaphus nelsoni) with chronic wasting disease. Journal of General Virology 89:1324-8. DOI: 10.1099/vir.0.83424-0.
Potapov A., Merrill E., Lewis M.A. (2012) Wildlife disease elimination and density dependence. Proceedings of the Royal Society of London B: Biological Sciences 279:3139-3145.
Potapov A., Merrill E., Pybus M., Coltman D., Lewis M.A. (2013) Chronic wasting disease: Possible transmission mechanisms in deer. Ecological Modelling 250:244-257.
Potapov A., Merrill E., Pybus M., Lewis M.A. (2016) Chronic wasting disease: transmission mechanisms and the possibility of harvest management. PloS One 11:e0151039.
Prusiner S.B. (1998) Prions. Proceedings of the National Academy of Sciences U S A 95:13363-83.
Prusiner S.B., Scott M., Foster D., Pan K.M., Groth D., Mirenda C., Torchia M., Yang S.L., Serban D., Carlson G.A., et al. (1990) Transgenetic studies implicate interactions between homologous PrP isoforms in scrapie prion replication. Cell 63:673-86.
Race B., Meade-White K.D., Miller M.W., Barbian K.D., Rubenstein R., LaFauci G., Cervenakova L., Favara C., Gardner D., Long D., Parnell M., Striebel J., Priola S.A., Ward A., Williams E.S., Race R., Chesebro B. (2009) Susceptibilities of nonhuman

primates to chronic wasting disease. Emerging Infectious Diseases 15:1366-76. DOI: 10.3201/eid1509.090253.
Race B.L., Meade-White K.D., Ward A., Jewell J., Miller M.W., Williams E.S., Chesebro B., Race R.E. (2007) Levels of abnormal prion protein in deer and elk with chronic wasting disease. Emerging Infectious Diseases 13:824-30. DOI: 10.3201/eid1306.070186.
Ragnarsdottir K.V., Hawkins D.P. (2006) Bioavailable copper and manganese in soils from Iceland and their relationship with scrapie occurrence in sheep. Journal of Geochemical Exploration 88:228-234.
Rana A., Gnaneswari D., Bansal S., Kundu B. (2009) Prion metal interaction: Is prion pathogenesis a cause or a consequence of metal imbalance? Chemico-Biological Interactions 181:282-291. DOI: 10.1016/j.cbi.2009.07.021.
Rapp D., Potier P., Jocteur-Monrozier L., Richaume A. (2006) Prion degradation in soil: Possible role of microbial enzymes stimulated by the decomposition of buried carcasses. Environmental Science & Technology 40:6324-6329. DOI: 10.1021/es060943h.
Raulund-Rasmussen K., Callesen I. (1999) NORDSOIL - Nordic forest soil data base, Nordsoil -Nordic forest soil data base, Danish Forest and Landscpe Research Institute, Hørsholm, Denmark.
Rees E.E., Merrill E.H., Bollinger T.K., Ten Hwang Y., Pybus M.J., Coltman D.W. (2012) Targeting the detection of chronic wasting disease using the hunter harvest during early phases of an outbreak in Saskatchewan, Canada. Preventive Veterinary Medicine 104:149-159.
Rhyan J.C., Miller M.W., Spraker T.R., McCollum M., Nol P., Wolfe L.L., Davis T.R., Creekmore L., O'Rourke K.I. (2011) Failure of fallow deer (*Dama dama*) to develop chronic wasting disease when exposed to a contaminated environment and infected mule deer (Odocoileus hemionus). Journal of Wildlife Diseases 47:739-44. DOI: 10.7589/0090-3558-47.3.739.
Rivrud I.M., Bischof R., Meisingset E.L., Zimmermann B., Loe L.E., Mysterud A. (2016) Leave before it's too late: anthropogenic and environmental triggers of autumn migration in a hunted ungulate population. Ecology 97:1058-1068.
Robinson S.J., Samuel M.D., Johnson C.J., Adams M., McKenzie D.I. (2012a) Emerging prion disease drives host selection in a wildlife population. Ecological Applications 22:1050-1059.
Robinson S.J., Samuel M.D., O'Rourke K.I., Johnson C.J. (2012b) The role of genetics in chronic wasting disease of North American cervids. Prion 6:153-162.
Rodriguez C.M., Bennett J.P., Johnson C.J. (2012) Lichens: unexpected anti-prion agents? Prion 6:11-6. DOI: 10.4161/pri.6.1.17414.
Rolandsen C.M., Solberg E.J., Bjørneraas K., Heim K., Van Moorter B., Herfindal I., Garel M., Pedersen P.H., Sæther B.-E., Lykkja O.N. (2010) Elgundersøkelsene i Nord-Trøndelag, Bindal og Rissa 2005–2010. Sluttrapport. NINA Rapport 588:1-142.
Russell R.E., Gude J.A., Anderson N.J., Ramsey J.M. (2015) Identifying priority chronic wasting disease surveillance areas for mule deer in Montana. The Journal of Wildlife Management 79:989-997.

Russo F., Johnson C.J., Johnson C.J., McKenzie D., Aiken J.M., Pedersen J.A. (2009) Pathogenic prion protein is degraded by a manganese oxide mineral found in soils. Journal of General Virology 90:275-80. DOI: 10.1099/vir.0.003251-0.

Safar J., Wille H., Itri V., Groth D., Serban H., Torchia M., Cohen F.E., Prusiner S.B. (1998) Eight prion strains have PrP(Sc) molecules with different conformations. Nature Medicine 4:1157-65. DOI: 10.1038/2654.

Samuel M.D., Storm D.J. (2016) Chronic wasting disease in white-tailed deer: infection, mortality, and implications for heterogeneous transmission. Ecology 97:3195-3205.

Sargeant G.A., Weber D.C., Roddy D.E. (2011) Implications of chronic wasting disease, cougar predation, and reduced recruitment for elk management. The Journal of Wildlife Management 75:171-177.

Saunders S.E., Bartz J.C., Telling G.C., Bartelt-Hunt S.L. (2008) Environmentally-relevant forms of the prion protein. Environonmental Science & Technology 42:6573-9.

Saunders S.E., Bartelt-Hunt S.L., Bartz J.C. (2012) Occurrence, transmission, and zoonotic potential of chronic wasting disease. Emerging Infectious Diseases 18:369-76.

Schauber E.M., Nielsen C.K., Kjær L.J., Anderson C.W., Storm D.J. (2015) Social affiliation and contact patterns among white-tailed deer in disparate landscapes: implications for disease transmission. Journal of Mammalogy 96:16-28.

Schauber E.M., Storm D.J., Nielsen C.K. (2007) Effects of Joint Space Use and Group Membership on Contact Rates Among White-Tailed Deer. The Journal of Wildlife Management 71:155-163.

Schramm P.T., Johnson C.J., Mathews N.E., McKenzie D., Aiken J.M., Pedersen J.A. (2006) Potential Role of Soil in the Transmission of Prion Disease. Reviews in Mineralogy and Geochemistry 64:135.

Seidel B., Thomzig A., Buschmann A., Groschup M.H., Peters R., Beekes M., Terytze K. (2007) Scrapie Agent (Strain 263K) Can Transmit Disease via the Oral Route after Persistence in Soil over Years. PLoS One 2:e435. DOI: 10.1371/journal.pone.0000435.

Selariu A., Powers J.G., Nalls A., Brandhuber M., Mayfield A., Fullaway S., Wyckoff C.A., Goldmann W., Zabel M.M., Wild M.A., Hoover E.A., Mathiason C.K. (2015) In utero transmission and tissue distribution of chronic wasting disease-associated prions in free-ranging Rocky Mountain elk. The Journal of General Virology 96:3444-3455. DOI: 10.1099/jgv.0.000281.

Sharp A., Pastor J. (2011) Stable limit cycles and the paradox of enrichment in a model of chronic wasting disease. Ecological Applications 21:1024-1030.

Sigurdson C.J. (2008) A prion disease of cervids: chronic wasting disease. Veterinary Research 39:41. DOI: 10.1051/vetres:2008018.

Sigurdson C.J., Williams E.S., Miller M.W., Spraker T.R., O'Rourke K.I., Hoover E.A. (1999) Oral transmission and early lymphoid tropism of chronic wasting disease PrPres in mule deer fawns (*Odocoileus hemionus*). J Gen Virol 80 (Pt 10):2757-64. DOI: 10.1099/0022-1317-80-10-2757.

Singh N.J., Börger L., Dettki H., Bunnefeld N., Ericsson G. (2012) From migration to nomadism: movement variability in a northern ungulate across its latitudinal range. Ecological Applications 22:2007-2020.

Skjenneberg S., Slagsvold L. (1968) Reindriften og dens naturgrunnlag, Universitetsforlaget, Oslo, Norway.
Skog A., Zachos F., Rueness E., Feulner P., Mysterud A., Langvatn R., Lorenzini R., Hmwe S., Lehoczky I., Hartl G. (2009) Phylogeography of red deer (*Cervus elaphus*) in Europe. Journal of Biogeography 36:66-77.
Skogland T. (1994) Villrein Fra urinnvåner til miljøbarometer, Teknologisk forlag Drammen, Norway.
Skuldt L.H., Mathews N.E., Oyer A.M. (2008) White-Tailed Deer Movements in a Chronic Wasting Disease Area in South-Central Wisconsin. The Journal of Wildlife Management 72:1156-1160.
Smith C.B., Booth C.J., Pedersen J.A. (2011) Fate of Prions in Soil: A Review. Journal of Environmental Quality 40:449-461.
Solberg E.J., Grøtan V., Rolandsen C.M., Brøseth H., Brainerd S. (2005) Change-in-sex ratio as an estimator of population size for Norwegian moose *Alces alces*. Wildlife Biology 11:163-172.
Solberg E.J., Rolandsen C.M. (2015) Bestandsutvikling og avskytning av elg innenfor Trondheim storviltvald–Evaluering av bestandskondisjon og måloppnåelse i planperioden 2010-2014.
Solberg E.J., Rolandsen C.M. (2016) Bestandsutvikling og avskytning av elg i Malvik kommune. Evaluering av bestandskondisjon og måloppnåelse i planperioden 2013-2014.
Solberg E.J., Strand O., Veiberg V., Andersen R., Heim M., Rolandsen C.M., Solem M.I., Holmstrøm F., Jordhøy P., Nilsen E.B. (2015) Hjortevilt 2012–2014: Framdriftsrapport fra Overvåkingsprogrammet for hjortevilt.
Solberg E.J., Veiberg V., Strand O., Andersen R., Langvatn R., Heim M., Rolandsen C.M., Holmstrøm F., Solem M.I. (2008) Hjortevilt 2007. Årsrapport fra Overvåkingsprogrammet for hjortevilt, NINA rapport 380, Trondheim, Norway. pp. 65.
Stewart P., Campbell L., Skogtvedt S., Griffin K.A., Arnemo J.M., Tryland M., Girling S., Miller M.W., Tranulis M.A., Goldmann W. (2012) Genetic predictions of prion disease susceptibility in carnivore species based on variability of the prion gene coding region. PLoS One 7:e50623. DOI: 10.1371/journal.pone.0050623.
Storm D.J., Samuel M.D., Rolley R.E., Shelton P., Keuler N.S., Richards B.J., Van Deelen T.R. (2013) Deer density and disease prevalence influence transmission of chronic wasting disease in white-tailed deer. Ecosphere 4:1-14.
Strand L.T., Callesen I., Dalsgaard L., de Wit H.A. (2016) Carbon and nitrogen stocks in Norwegian forest soils — the importance of soil formation, climate, and vegetation type for organic matter accumulation. Canadian Journal of Forest Research:1-15. DOI: 10.1139/cjfr-2015-0467.
Strand L.T., Haaland S., Kaste O., Stuanes A.O. (2008) Natural variability in soil and runoff from small headwater catchments at Storgama, Norway. Ambio 37:18-28.
Strand O., Jordhøy P., Mossing A., Knudsen P.A., Nesse L., Skjerdal H., Panzacchi M., Andersen R., Gundersen V. (2011) Villreinen i Nordfjella. Status og leveområde. , Norsk Institutt for naturforskning (NINA), Tronheim, Norway. pp. 71.

Tamgüney G., Miller M.W., Wolfe L.L., Sirochman T.M., Glidden D.V., Palmer C. (2009) Asymptomatic deer excrete infectious prions in faeces. Nature 461. DOI: 10.1038/nature08289.

Tangvik A.J., Haukbø B., Solberg E.J. (2016) Bestandsvurdering av elg og hjort i Nord-Trøndelag 2016, Naturdata AS.

Tranulis M.A. (2002) Influence of the prion protein gene, Prnp, on scrapie susceptibility in sheep. APMIS 110:33-43.

Tranulis M.A., Benestad S.L., Baron T., Kretzschmar H. (2011) Atypical prion diseases in humans and animals. Topics in Current Chemistry 305:23-50. DOI: 10.1007/128_2011_161.

Uehlinger F., Johnston A., Bollinger T., Waldner C. (2016) Systematic review of management strategies to control chronic wasting disease in wild deer populations in North America. BMC Veterinary Research 12:173.

Van Moorter B., Bunnefeld N., Panzacchi M., Rolandsen C.M., Solberg E.J., Sæther B.E. (2013) Understanding scales of movement: animals ride waves and ripples of environmental change. Journal of Animal Ecology 82:770-780.

Vaske J.J. (2010) Lessons learned from human dimensions of chronic wasting disease research. Human Dimensions of Wildlife 15:165-179.

VerCauteren K.C., Burke P.W., Phillips G.E., Fischer J.W., Seward N.W., Wunder B.A., Lavelle M.J. (2007) Elk Use of Wallows and Potential Chronic Wasting Disease Transmission. Journal of Wildlife Diseases 43:784-788. DOI: 10.7589/0090-3558-43.4.784.

VerCauteren K.C., Pilon J.L., Nash P.B., Phillips G.E., Fischer J.W. (2012) Prion remains infectious after passage through digestive system of American crows (*Corvus brachyrhynchos*). PLoS One 7:e45774. DOI: 10.1371/journal.pone.0045774.

VKM. (2016) CWD in Norway. Opinion of the Panel on biological hazards, ISBN: 978-82-8259-216-1, Oslo, Norway.

Walter W.D., Walsh D.P., Farnsworth M.L., Winkelman D.L., Miller M.W. (2011) Soil clay content underlies prion infection odds. Nature Communications 2:200. DOI: 10.1038/ncomms1203 http://www.nature.com/articles/ncomms1203#supplementary-information.

Wasserberg G., Osnas E.E., Rolley R.E., Samuel M.D. (2009) Host culling as an adaptive management tool for chronic wasting disease in white-tailed deer: a modelling study. Journal of Applied Ecology 46:457-466.

Watts J.C., Giles K., Patel S., Oehler A., DeArmond S.J., Prusiner S.B. (2014) Evidence that bank vole PrP is a universal acceptor for prions. PLoS Pathogens 10:e1003990. DOI: 10.1371/journal.ppat.1003990.

Wik L., Mikko S., Klingeborn M., Steen M., Simonsson M., Linne T. (2012) Polymorphisms and variants in the prion protein sequence of European moose (Alces alces), reindeer (*Rangifer tarandus*), roe deer (*Capreolus capreolus*) and fallow deer (*Dama dama*) in Scandinavia. Prion 6:256-60. DOI: 10.4161/pri.19641.

Wild M.A., Hobbs N.T., Graham M.S., Miller M.W. (2011) The role of predation in disease control: a comparison of selective and nonselective removal on prion disease dynamics in deer. Journal of Wildlife Diseases 47:78-93.

Williams A., Kreeger T., Schumaker B. (2014) Chronic wasting disease model of genetic selection favoring prolonged survival in Rocky Mountain elk (*Cervus elaphus*). Ecosphere 5:1-10.

Williams E.S., Miller M.W. (2003) Transmissible spongiform encephalopathies in non-domestic animals: origin, transmission and risk factors. Revue Scientifique et Technique 22:145-56.

Williams E.S., Miller M.W., Kreeger T.J., Kahn R.H., Thorne E.T. (2002) Chronic wasting disease of deer and elk: a review with recommendations for management. The Journal of Wildlife Management:551-563.

Wobeser G.A. (2006) Essentials of Disease in Wild Animals Blackwell Publishing Ltd., Oxford, United Kingdom.

WRB I.W.G. (2015) World reference base for soil resources 2014, update 2015. International classification system for naming soils and creating legends forsoil maps, World Soil Resources, FAO, Rome.

Wyckoff A.C., Kane S., Lockwood K., Seligman J., Michel B., Hill D., Ortega A., Mangalea M.R., Telling G.C., Miller M.W. (2016) Clay components in soil dictate environmental stability and bioavailability of cervid prions in mice. Frontiers in Microbiology 7.

Yuan Q., Eckland T., Telling G., Bartz J., Bartelt-Hunt S. (2015) Mitigation of Prion Infectivity and Conversion Capacity by a Simulated Natural Process—Repeated Cycles of Drying and Wetting. PLOS Pathogens 11:e1004638. DOI: 10.1371/journal.ppat.1004638.

Appendix I

Soils in Norway

Only 3 % of Norway's land area is agricultural land, approximately 37% is forested, leaving large areas with non-forested heathland and mountain areas. Systematic soil mapping has only been conducted for cultivated soils, per 2016 49% of Norway's agricultural area was mapped; the areas with priority were the ones bordering to the North Sea and areas with marine deposits. The soil maps covering forest, heathland and mountain areas are few, unsystematic and there is no common register or database of these.

The soil types vary significantly depending on the land cover/land use. In Norway generally the soils in cultivated areas have a higher clay content, less stone and are deeper than the soils in forest, heathland and mountain areas. As the cultivated areas are more prevalent in valley bottoms and in areas, with marine deposits they will also be wetter and less well drained. The cultivated soils will in general also have a lower content of organic matter in the surface layer compared with surface layers in forest and heathlands due to management tillage. The connection between soils and underlying bedrock will also be less evident for cultivated soils as these often have been transported for longer distances than the forest and heathland soils.

Though there is no soil map for Norwegian forest, an existing area-representative forest soil database covering forest sites in a grid system (9 × 9 km) give an overview of the dominating soil types in Norwegian forests (Table 1). The clay content in Norwegian forest soils are generally low < 5 %. The podzolized soils cover largest areas (approximately 55%), and poorly drained soils, mineral and organic, cover 30-35 % of the forested area (Strand et al., 2016).

Table 1 Estimated area coverage for Norwegian forest soil types according to Canadian soil classification. Percentage based on total forested area for soil types present in the Norwegian soil forest database. Modified from table 9, Strand et al. 2016.

Soil type		**%**	**Area km2**
Shallow soils	< 10cm	3	3600
Gleysolic		9	10800
Podzolic	- self-drained	38	45600
	- gleyed	9	10800
Brunisolic	- self-drained	6	7200
	- eluviated	8	9600
	- gleyed	4	4800
Regosolic		9	10800
Organic	- folic	5	6000
	- wet	10	12000

No soil database covers the heathland and mountain areas equivalent to the forest soil database. Few and sporadic soils maps exist and they are difficult to access and no national database exist. In general, the Norwegian heathland and mountain areas have a patchy soil cover and the soils are shallow, rich in organic matter, with mineral soil closely related to the underlying bedrock, determining both thickness deposit, particle size distribution and nutrient status/mineralogy (Strand et al., 2008). On exposed ridges with little vegetation cover erosion processes will dominate and mineral soil will be exposed.

Clay content and mineralogy

Particle size distribution in forest soil profiles suggest that forest soils are sandy (> 60% sand) and frequently low in clay (< 5 %) (Strand et al., 2016). There are few resent studies of the clay mineralogy of Norwegian soils. However, Gjems conducted a comprehensive study of clay mineralogy of Norwegian forest soils in 1967 (Gjems, 1967). He found that the clay mineralogy is mostly determined by the mineralogy of the bedrock parent material. In most Norwegian forest soils the clay mineralogy will be dominated by illite, vermiculite and chlorite. Gjems found that some montmorillonite may form by weathering processes in the upper mineral soil horizon of podzols but still it would not dominate the clay fraction. Several later studies have not been able to confirm the presence of montmorillonite in podzols suggesting that there may be a methodical divergence Ali (Ali et al., 1995). In any case, we are talking about low amounts.

Organic matter

In natural environments (not cultivated) the upper soil layer of Norwegian soils would normally be an organic horizon, with a low pH (pH < 5) and a low nutrient status. In forest

soils this layer is in average 8-10 cm (Strand et al., 2016). However, in more nutrient rich areas, the organic material decomposes more rapidly and there is more faunal activity giving rise to a surface horizon with higher content of more clay rich mineral material. These soils would also be soils that support more nutrient rich vegetation; vegetation more attractive to herbivores/ grazing.

Soil chemical composition – metals and soil solution

Bedrock mineralogy determines the element composition of the mineral soil. A geochemical map in combination with bedrock map of Norway may suggest which elements one could expect in different areas (NGU-should have some relevant maps here). However, processes connected to water quality and quantity, to organic material and biological activity, regulate the bioavailability of the elements. Information about this is not easily available. Here there is some information to be gained from the TOV /OPS monitoring sites 6-8 places (Aamlid et al., 2006), however the components analysed for is limited.

Soils in the Selbu and Nordfjella region.

Soil information from Selbu is scarce, table 2. Two small farm areas have been mapped and the soil types found in this connection is given in table 2, the data was extracted from the web page https://kilden.nibio.no/ . One of the permanent forest monitoring plots (OPS) was situated in Selbu and has one well described soil, this soil is described in the Nordic forest soil data base (Raulund-Rasmussen and Callesen, 1999). Eight other forest soils from Selbu are described in the Norwegian forest soil data base, table 2. No information on Heathland and mountain soil in Selbu was found at this point. The OPS soil is the soil with most data available this soil is a Gleyed Ferro-Humic Podzol formed on a lacustrine deposit with a 7 cm thick humus layer over sandy silt mineral soil. The clay content of 2.5 % in the upper mineral, varying downward between 2-12 % depending on stratification. Analysis of total chemical composition is available for the surface layer and the first underlying mineral soil horizon is available 32 elements.

Table 2 Soils of Selbu

Land use	Soil types	Comment
Agricultural areas **(WRB, 2015)**	Histic Gleysols, Sapric Histosols, Endostagnic Cambisol (Dystric), Endoleptic Cambisol (Dystric), Haplic Stagnosol Haplic GleysoEndoleptic Cambisol (Dystric), Haplic Regosol (Skeletic, Arenic), Umbric Endoleptic Stagnosol, Umbric Gleysol, Epileptic Umbrisol	Nekkåbjørga (47 ha) Selbustrand (67 ha)
Forest **(Agriculture Canada Expert Committee on Soil Survey, 1987)**	Orthic humo ferric podzol (4) Gleyed Ferro humic podzol (1 ops) Fibric/humic Organic (2) Othic regosols (1) Humic gleysol (1)	8 soil profiles in the forest soil database 1 from the intensively monitored forest sites (ops)
Heathland/mountain	No information	

For the Nordfjella area information about the soil is equally scant table 3. A few areas, probably summer farms have been mapped in the Norefjell area, these were found through the web page https://kilden.nibio.no/ . Only three soils were described in the Norwegian forest soil database. However, in connection with a grazing experiment (Sheep) in Minnestølen east of Strandavatn, Hol, the soil in the enclosures was described and sampled. See Martinsen et al. (2011) for more detailed description of the soil and area. Typically the soil varies between well drained Podzols and moister more poorly drained Brunisols see pictures below

A) Podzol(Photo Vegard Martinsen)

B) brunisol/cambisol(Photo Vegard Martinsen)

Table 3 Soils of Nordfjella

Land use	Soil types	Comments
Agricultural areas **(WRB, 2015)**	Podzols • Haplic (Skeletic) Cambisol • Endostagnic (Dystric, Skeletic) • Haplic (Dystric, Skeletic) Histosol • Fibric Umbrisol • Endostagnic • Haplic (Endoskeletic) Regosol • Haplic (Skeletic, Arenic) Fluvisol • Umbric Epigleyic	Hol –(Skurdalen0,9 ha 1050 masl, Gjerdelii 8 ha 850masl Geilo Gjerdestølane 13 ha 1075 masl, Holastølen 840 masl, Hovet 1050 masl 38 ha) (Hovda/Bakkestølen 800 masl) Aurdal_ some along Flomsdalen and along Dyrdalselvi Lærdal – the valley bottom along side the Lærdals river, sporadic Hemsedal sporadic (23 ha) (Gramstølen 940 masl)
Forest **(Agriculture Canada Expert Committee on Soil Survey, 1987)**	Eluviated dystsric brunisol (Hol, 792 masl) Orthic humo-ferric podzol (Hol 685 masl) Sombric Humo-ferric podzol (Aurland 450 masl)	3 profiles from the forest soil database
Heathland/mountain (Martinsen et al., 2011)	Podzol – well drained and more poorly drained Brunisols/Cambisols (see pictures below)	low alpine region (1050–1320 m, Minnestølen east of Strandavatn

Appendix II

Wild cervid population development in Norway

Moose

The geographical variation in moose population density and performance has changed over the last three decades. Until recently, the moose density was substantially lower in Northern and Central Norway than in Southern Norway, but is today less variable across Norway (Fig. 1). After the overall population peaks, the annual harvest (and abundance) of moose has decreased, but with considerable regional variations. The South-eastern populations of moose peaked in the early 1980s, whereas most other populations in Southern Norway peaked in the early or mid-1990s (Fig. 2). Since then, the sizes of most populations in southern Norway have decreased substantially. In Central Norway, moose populations peaked a decade later, whereas most populations in Northern Norway peaked recently or are still growing. In contrast to the present densities, the spatial variation in moose performance (body growth and reproduction) is large. Following the high moose densities in the late 1980s and early 1990s, performance decreased in parts of Southern Norway, and has yet to show any strong recovery despite substantial population reductions (Solberg et al., 2015). In Northern Norway, and parts of Central Norway, moose performance is still high but trends are negative (Solberg et al., 2015).

Red deer

Red deer have a more restricted distribution than moose (Fig. 1) and were, until recently, confined to the western and central parts of Norway. Today, red deer have also recolonized Norway east and south of the mountain range, and show a continuous increase in population abundance (Fig. 1). Conversely, red deer populations have been deliberately reduced in Western and in Central Norway during the last few years. This is mainly a management response to the substantial decline in body mass and fecundity during the last two decades (e.g. Solberg et al., 2015) — most likely due to density-dependent food limitation. No similar decline in performance has occurred in Southeastern Norway and eastern parts of Central Norway, indicating that the nutritional conditions are better there.

Roe deer

Roe deer inhabit areas below the tree line in central, eastern and southern Norway, as well as parts of the west coast and Northern Norway. Because of their smaller size, they are more vulnerable to predation and adverse weather conditions, which may explain their patchy distribution in the north, and their rather volatile population dynamics. A particular large increase in the harvest of roe deer occurred during the 1980s (Fig. 2), when sarcoptic mange

(scabies) suppressed red fox populations and thus decreased the predation rate on roe deer fawns (Lindström et al., 1994). This was followed by a steep decline in the harvest after the severe winter of 1993/94 when red fox populations had recovered, and also lynx predation had increased. In recent years, the annual harvest has been less than 70 % of the harvest in the peak year, but because of the significant impact of red fox and lynx predation, the decline in population density is probably less than indicated by the harvest record.

Wild reindeer

The extant wild reindeer are distributed in 23 different populations in Southern Norway (Fig. 3) with no, or limited, exchange of individuals due to physical barriers (valleys) or anthropogenic fragmentation (transportation infrastructure). As for the forest-dwelling species, the recovery of reindeer was caused by improved hunting regulations, but the abandonment of reindeer herding in most of southern Norway was probably equally important. Consequently, the remaining semi-domesticated populations mixed with wild reindeer, or were simply declared 'wild'. Later, there were also reintroductions of reindeer to 'empty' mountain areas, mainly from semi-domestic herds. Most wild reindeer populations in southern Norway are therefore either semi-domesticated in origin or they have experienced different levels of gene flow from semi-domesticated herds.

The population dynamics of reindeer are mainly the result of local management goals and variable goal achievements. During the last 40 years, many of the larger flocks have experienced periods of overabundance and overgrazing with subsequent declines following intensive harvesting and density-dependent food limitation. The variation in the total wild reindeer population size is mainly the result of fluctuations in the largest population, on Hardangervidda (Fig. 3), which has fluctuated more than fivefold during the last 60 years. It peaked in the late 1960s and again in the late 1970s and early 1980s, reaching more than 35,000 and 25,000 individuals, respectively. The high-density periods were followed by degraded winter pastures, females in poor body condition, low birth weights, and reduced calf survival (Skogland, 1994). The experiences in Hardangervidda, and similar experiences in the Snøhetta wild reindeer area in the 1950s and early 1960s affected reindeer management strategies. Since the 1980s, the management goal has been to limit population growth and to keep the population at stable intermediate densities. Data from the national monitoring programme for large cervids indicate that regional managements is relatively successful, and that the population in the previously high density areas are now recovering, albeit slowly (Solberg et al. 2015).

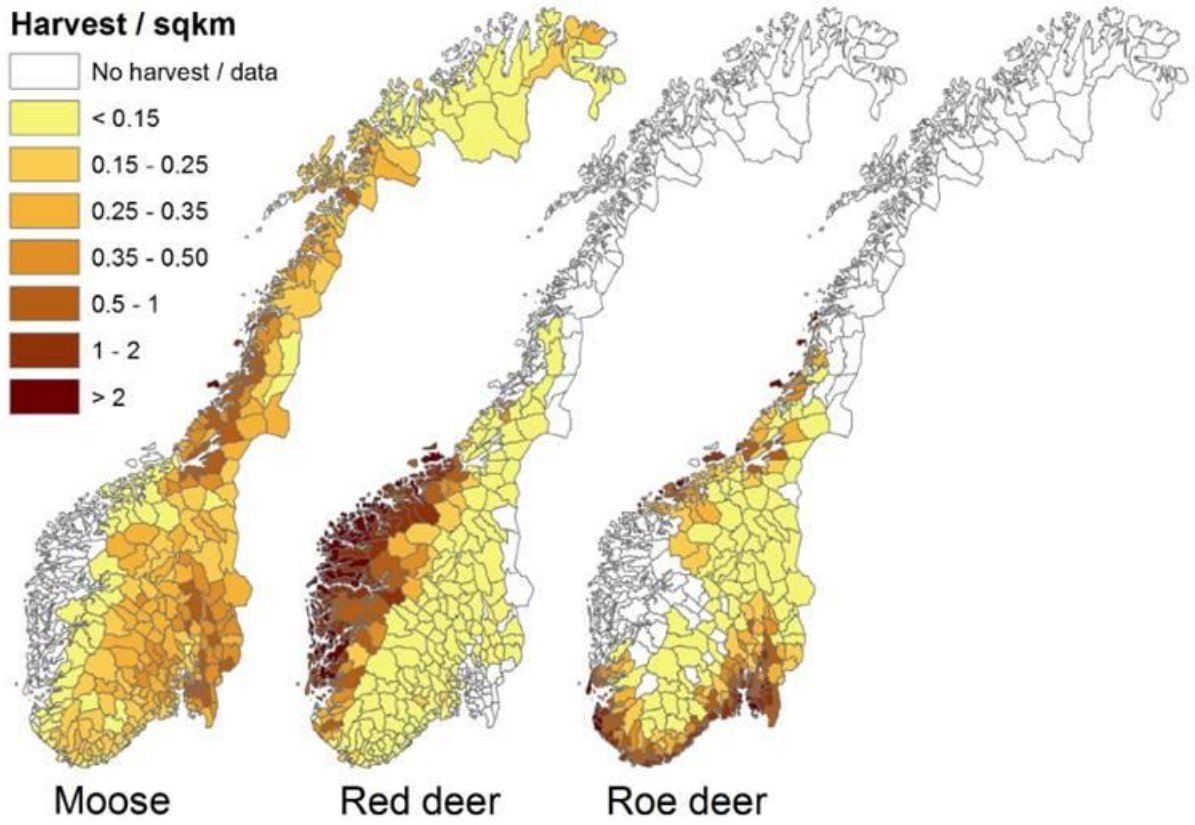

Figure 1 Number of moose, red deer, and roe deer shot per km^2 forestland and year in Norwegian municipalities in the period 2011-2015. The variation in harvest is to a large extent related to variation in deer density.

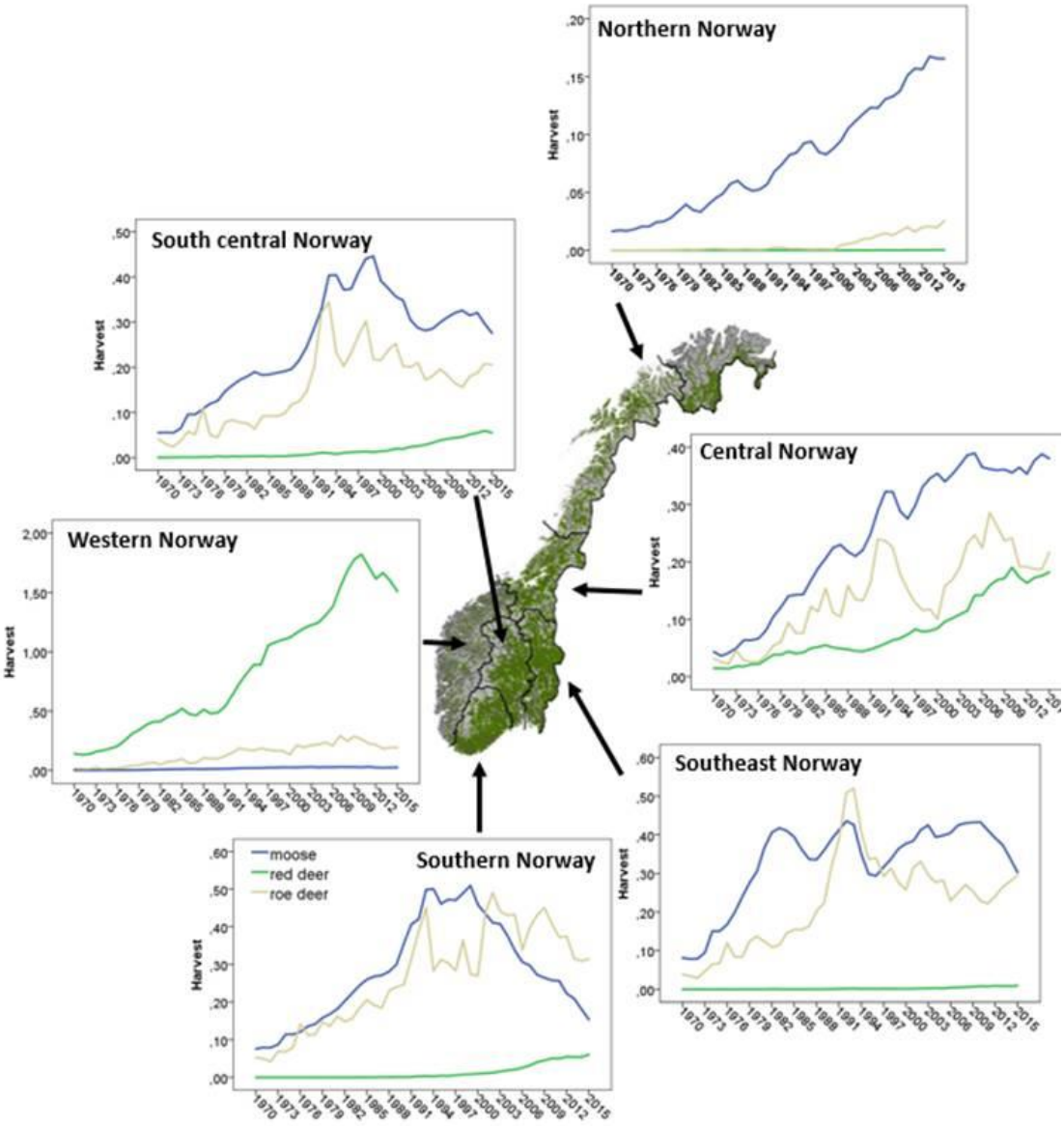

Figure 2 Annual variations in harvest (number shot) per square km of forestland for moose (blue), red deer (green) and roe deer (grey) in different parts of Norway during the last 45 years. Green shading in map indicates forestland.

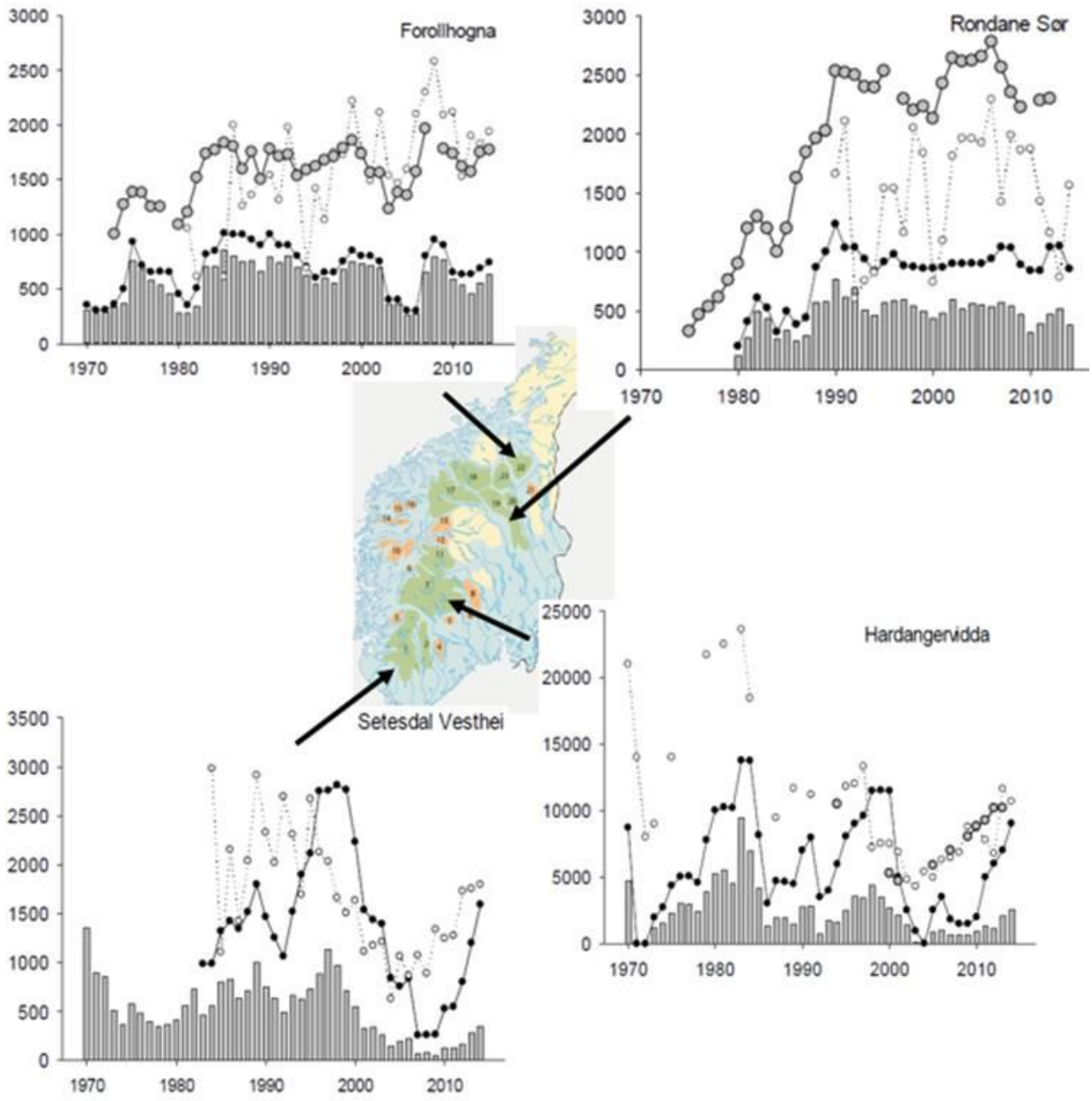

Figure 3 Annual variation in number of reindeer hunting permits (black circles), number harvested (columns), and number of reindeer counted during summer (open circles) and winter surveys (grey circles) in some important wild reindeer areas in southern Norway. Green and orange indicate wild reindeer areas, and white areas are inhabited by semi-domesticated reindeer.

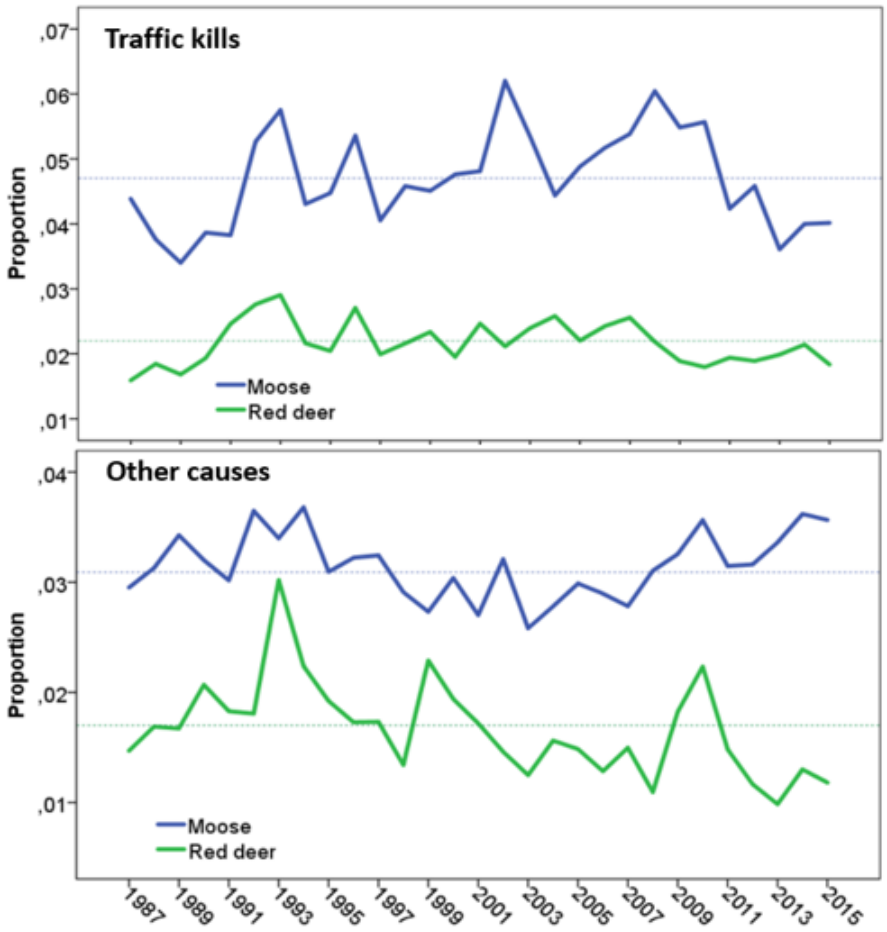

Figure 4 Annual variations in proportion (of all known mortalities) of moose and red deer reported killed in traffic and by other causes (e.g. starvation, predation, diseases, parasites, accidents, crippling (i.e. shot but not retrieved)) in Norway during 1987-2015. In addition, a smaller proportion is shot for damage control, for safety reasons, and by poaching.

Appendix III

Semi-domestic reindeerherding in Norway

Lovgivning og myndigheter:

De to mest sentrale virkemidler for å nå de reindriftspolitiske mål, er reindriftsloven av 1. juli 2007 og «reindriftsavtalen» som er et resultat av forhandlinger mellom Staten v/ Landbruk- og Matdepartementet og reindriftsnæringens organisasjon Norsk Reindriftssamers Landsforbund. (Meld. St. 9 (2011-2012). Relevant i denne sammenheng er reindriftslovens krav til bl.a. dyrevelferd i § 1, forholdet til folkeretten i § 3, men også lovgivers forutsetninger i lovens kapitel 7 om godkjente bruksregler for å oppnå økt indre sjølråderett, og krav om distriktsplaner til støtte for den offentlige forvaltning. Med distriktsplanene følger også detaljerte arealbrukskart som bl.a. viser hvordan beiteområdene brukes gjennom reindriftsåret.

Offentlige myndigheter som forvalter reindriften i Norge, er Landbruks- og Matdepartementet (LMD), Landbruksdirektoratet v/Reindriftsstyret og Fylkesmennene i de fem nordligste fylkene i Norge (Landbruksdirektoratet, 2006). Den statlige regionale fagmyndighet i den offentlige forvaltning av reindriften i Sør-Norge, herunder også tamreinlagene, er p.t. tillagt Fylkesmannen i Sør-Trøndelag v/ reindrifts-direktøren.

Offentlige myndigheter som forvalter villrein i Norge i samsvar med Naturmangfoldloven og viltloven er Klima- og miljødepartementet (KLD), Miljødirektoratet v/ lokale villrein-nemnder og lokale villreinutvalg. Villrein-nemndene (ni nemnder) er oppnevnt av Miljødirektoratet. Statens Naturoppsyn (SNO) er en del av samme direktorat.

Både villrein og tamrein er i tillegg underlagt Dyrevelferdsloven og Matloven som forvaltes av LMD v/ Mattilsynet.

I og med at det er samme lovverk med tilhørende regelverk som gjelder for all reindrift i Norge, er reindriften i prinsippet ganske lik. Forskjellene kommer til uttrykk i antall innbyggere som prøver å leve av reindrift innen de forskjellige distrikter. Blir det for mange reineiere uten en effektiv regulering, blir tettheten av rein for stor, og den økologiske bærekraft forsvinner. Særlig i Karasjok og Vest-Finnmark har et for høyt reintall over lang tid medført lave slaktevekter og en betydelig reduksjon av lavressursene på vinterbeitene.

Reindrift i Sør-Norge

Tamreinlagene (NILF, 2014) er sentrale i denne sammenheng på grunn av deres nærhet til Nordfjella villreinområde (Figur 2-4 i VKM, 2016). De er greit organisert med klare kommando-linjer, og må følgelig også være aktuelle som «smittebarrierer» mot spredning av CWD fra Nordfjella og inn i tamreindriften for øvrig.

Det kan dokumenteres reindrift i fjellområder i Sør-Norge tilbake til tidlig på 1700-tallet (NILF, 2014). Tidligere hadde reindrift i Sør-Norge langt større omfang enn i dag, både mht. antall reinlag og totalt antall tamrein. Bønder og andre bygdefolk sto i hovedsak bak, og ofte i samarbeid med samene som reinen ble kjøpt fra.

Antall tamrein i Sør-Norge var i 1910 regnet til om lag 26 600 dyr fordelt på i alt 17 reinlag. I 1949 var det 25 tamreinlag i Sør-Norge. Rundt 1960 var tallet om lag 20 000 dyr fordelt på 12–14 lag.

Det drives i dag reindrift i fire tamreinlag i Sør-Norge: Lom, Vågå, Fram og Filefjell reinlag. Alle disse er i eller rundt Jotunheimen, beliggende i fjellområder innen kommuner i Oppland, Buskerud og Sogn og Fjordane fylker. Oppland er det fylket med nest største reinkjøttproduksjonen i landet, bare i Finnmark produseres det mer. Reindriften i disse fire tamreinlagene ligger utenfor de samiske områdene, og er fra og med reindriftsloven av 1978 konsesjonsbelagt og avhengig av grunneiertillatelse iht. reindriftslovens § 8. Blir leieavtalene mellom grunneiere og respektive tamreinlag sagt opp, kan grunnlaget for konsesjon falle bort og laget må avvikles og hjorden må slaktes ut.

I tillegg til dagens fire tamreinlag har vi Rendal Renselskap i Hedmark. Renselskapet er unntatt fra merkeplikten i reindriftslovens § 41. Dette er ikke reindrift i sedvanlig forstand, da tilveksten i hjorden høstes med jakt.

Tamreinlagene i Sør-Norge er organisert som aksjeselskap/andelslag av bønder/grunneiere og andre som driver reindrift i fellesskap. Antallet eiere i hvert reinlag varierer, og er fra 5 til 225. Det er felles eierskap til reinen, og hvert reinlag har ett felles reinmerke. Reindriften drives på beitearealer leid av fjellstyrer og private grunneiere. Generelt nyttes kystnære høyfjellsområder i nordvest som barmarksbeite og mer kontinentale og lavereliggende fjell- og skogsområder i sørøst som vinterbeite. Det foretas sesongmessige flyttinger mellom beiteområdene om våren og på høsten/tidlig vinter.

Det er forskjeller mellom de fire tamreinlagene selv om produksjonen er forholdsvis lik. Filefjell og Fram har en eierstruktur sammensatt av få eiere, og de beiter stort sett på privat grunn. I Vågå og Lom er det store andelslag med over 200 andelseiere. I Vågå er en del av beiteområdene på privat grunn, mens de i Lom er hovedsakelig i statsallmenning.

Det er svært lite sammenblanding av rein mellom tamreinlagene, men rein fra Fram tamreinlag kan komme over til tamreinlagene Vågå og Lom. Lom tamreinlag et oppsamlingsområde (Veofjellet) som overlapper med beiteområde til Vågå i forbindelse med høstslakting, men ingen har felles anlegg. Filefjell har egen mobil slaktebuss som kan flyttes etter behov.

Tamreinlagene har enten fast ansatte gjetere, ellers så forestår aksje-/andelseierne selv den praktiske reindriften. Det er 3–6 gjetere i hvert tamreinlag. I noen tilfeller er gjeterne også eiere. I tillegg til tilsyn, gjeting og flytting av reinen i beiteområdene, utføres det arbeid i

reingjerdene i forbindelse med merking og slakting, bygging og vedlikehold av reindriftsanlegg, administrasjon m.m. På årsbasis utgjør dette ca. 40 årsverk.

Det totale antallet rein i tamreinlagene er ca. 12 000; ca. 5 % av det totale antallet tamrein i Norge. Slakteuttaket ligger på 6–7 000 rein, hvorav andelen kalveslakt utgjør ca. 70 %. Det totale slaktekvantumet var 214 tonn kjøtt i 2015. Produksjonen tilsvarte da 14 % av reindriftens totale produksjon av reinkjøtt i landet. Tamreinlagenes andel av den totale reinkjøttproduksjonen omsatt gjennom registrert slakteri utgjør 15–20 % av den totale årlige omsetningen i landet. Flokkstrukturen er i gjennomsnittlig 74 % simler, 22 % kalver og 3 % bukker. Produktiviteten ligger på ca. 18 kg kjøtt per livrein. Tamreinlagene følger i stor grad «Rørosstrategien» med hensyn til flokkstruktur og individmerking (https://tv.nrk.no/serie/gjetarar-i-jotunheimen)

Tamreinlagene er organisert i «*Kontaktutvalget for tamreinlagene i Sør-Norge*». Kontaktutvalget har observatørstatus i forbindelse med reindriftsavtale-forhandlingene. I likhet med reindriften innenfor de samiske reinbeiteområdene, mottar tamreinlagene forskjellige tilskudd over reindriftsavtalen.

Tamreinlagene i Sør-Norge er forvaltningsmessig og faglig underlagt Fylkesmannen i Sør-Trøndelag.

Det må fremheves at tamreindriften i Sør-Norge representerer en god og fornuftig ressursutnyttelse i marginale fjell- og utmarksområder. Den bidrar bl.a. til et næringsmessig mangfold, og til opprettholdelse og utvikling av næringslivet i distrikts – Norge. I tillegg finansierer tamreinlagene en rekke av fjellstyrenes aktiviteter gjennom betaling av beiteleie. Myndighetene ser det som viktig at det legges til rette for fortsatt god drift og en positiv utvikling av tamreinlagene (NILF, 2014).

The annual phases of reindeer herding

Wild reindeer migration routes are associated with variation in food availability throughout the year, and the same routes are also utilised for herding semi-domesticated reindeer. Thus, seasonal herding of semi-domesticated reindeer between pastures, is based on the ancient migration patterns of wild reindeer. Fenced areas in the vicinity of these migration routes are used when gathering or moving a herd of semi-domesticated animals.

December- February → Winter: The main goal of this period is to keep reindeer energy expenditure to a minimum, as the animals experience reduced metabolic rates and food is limited to lichen underneath the snow. Handling and other actions causing stress should be avoided, and additional feeding may be necessary in situations where the animals have experienced stress (Skjenneberg and Slagsvold, 1968).

February- March → Spring winter: Animals are gathered before being moved to their spring pastures. Females find their way, whereas the males are herded. The males generally remain at a discrete distance during this period as they have lost their antlers and are thus ranked at the bottom of the herd hierarchy. The females keep their antlers until after the calving season. In units with few males, the males born last season are breeding in September.

April – May → Spring: After arriving at the spring pastures, females seek up their old calving spots, and keep away from the rest of the herd. The females keep last year's calves on a distance, as these may cause a threat to the newly born calves. It is therefore essential that the spring pastures are spacious areas.

May – June → Spring summer: Most calves are born in the middle of May, but calving occurs throughout May, making it a good month for predators and scavengers. The male herd is during this period gaining access to the best grazing areas which is important after a long winter of restricted food access.

June – August → Summer: After spending the first weeks together, the females and calves join the rest of herd around midsummer. The animals gather into small flock units and will seek windy and snow filled areas to escape insects. When the temperature drops, such as in early morning and evening, the animals move back to the richest pasture areas.

During this summer period, when the ground is bare, reindeer keep together in smaller flocks and move to find the richest and most nutritious pasture grounds. They will always try to move against the wind to be able to sense potential dangers to avoid costly escapes.

As soon as the fenced grazing grounds contain a sufficient level of grass and herbs, the reindeer are gathered and the marking of the new calves begins. Calves are marked the same as their mother's with additional individual marks. To determine the ownership of the new calves, it is essential that females and calves are paired up correctly. The fenced areas

must contain sufficient food and water and the animals should be retained for a minimal time to avoid stress (https://qa.landbruksdirektoratet.no/no/).

August – September → Autumn summer: The reindeer are in good condition and numbers of insects are in decline. The reindeer are therefore less dependent on the herd protection against both insects and predators and may roam alone to feed on mountain birch and mushrooms. During this period, the reindeer may be widely spread out, posing challenges for reindeer herding.

After the Chernobyl disaster in 1986, reindeer herders received financial incentives to conduct the main part of the annual slaughtering before September (oestrous season). There were several advantages to this strategy; the meat contained lower levels of radioactivity and hence less meat was discarded. Further, animals were in good condition when slaughtered and the density of animals was reduced before the harsh winter season. Therefore, some of the semi-domesticated herders have maintained this early slaughtering strategy, even without the additional financial incentives. In herds comprising a large numbers of older males that are no longer active during the breeding season, these animals are slaughtered sometime in early September before the rutting-season starts (Lenvik, 2005).

October – November → Autumn: This is the rutting-season and the reindeer are left alone, particularly between September 15th and October 15th. The timing of the rutting-season may vary between the north and south and among wild and semi-domesticated reindeer (Skogland, 1994).

November – December → Autumn winter: The rutting-season is followed by slaughtering of calves and poorly ranked females and males. Reindeer from neighbouring areas or counties are removed and preferably slaughtered, to prevent them from returning on a regular basis. This is important, as winter comes with associated food restrictions (lichen only), and the food available at the winter pastures should, ideally, be for the local herd only. When the movement towards winter pastures starts it is essential that all handling (including slaughtering of intruding animals) is finalised before the reindeer metabolic rate falls to winter levels and they should be left alone. This has been challenging in some areas, due to overly large reindeer herds, and changing climate with unstable winters and winter rainfall causing the lichen pastures to be covered in ice.